THE 22ND ANNUAL INTERNATIONAL RAPDASA CONFERENCE

RAPID PRODUCT DEVELOPMENT ASSOCIATION OF SOUTH AFRICA

2021
RAPID PRODUCT DEVELOPMENT ASSOCIATION OF SOUTH AFRICA - ROBOTICS AND MECHATRONICS - PATTERN RECOGNITION ASSOCIATION OF SOUTH AFRICA

(RAPDASA-RobMech-PRASA)

DIGITAL MANUFACTURING: INDUSTRIALISING AFRICA

3 - 5 NOVEMBER 2021

AT THE
INTERNATIONAL CONVENTION CENTRE
CSIR
PRETORIA

Hosted by the CSIR National Laser Centre
2021 CONFERENCE HOST

CSIR National Laser Centre
https://www.csir.co.za/
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RAPDASA Editor and Chairperson of Technical Committee

Dr Kobus van der Walt
(Track director for pre-conference seminar on Design and additive manufacturing of titanium parts)

Dr Thywill Dzogbewu
(Track director for additive manufacturing material development)

Prof Elisha Markus
(Track director for robotics and mechatronics)

Dr Ritesh Ajoodha
(Track director for pattern recognition)

Prof Thorsten Becker
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Dr Lerato Tshabalala
(Track director for additive manufacturing part characterisation)

Dr Ntombi Mathe
(Track director for additive manufacturing post processing and qualification)

Mr Francois Du Rand
(Track director for product development)

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(Track director for rapid sand casting)
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FOREWORD AND WELCOME

Message by the Chairperson of the RAPDASA 2021 Conference
Mr Marius Vermeulen

The first RAPDASA international conference was held here at the CSIR in November 2000, and today, we are celebrating our 22nd annual conference. Being back here, where we started, allows a glance into history to see how the world around us has been changing and adapting over two decades.

During the last two years we have been faced by many challenges and digital solutions have become an everyday solution. This impacted in many ways, from the way we interact in the workplace, to the way we do our shopping. This step-change in our realm, however, seems to reflect what has been happening in industry over the last two decades.

In a world where manufacturing is moving into a digital realm, rapid product development is now the norm, rather than the exception. To keep up with an ever-changing world, product development is not just about the physical object anymore, but on how the product relates, communicates and interacts with its user and environment. The designer is, more than ever, faced with a multi-disciplinary environment and solutions require collaborative approaches. As always, it is the responsibility of our scientists, engineers and captains of industry to not only adapt to this change, but to drive innovation for tomorrow.

The Rapid Product Development Association of South Africa (RAPDASA) have a proud history of fostering product development in the country. By bringing stakeholders together, we have been creating a platform for collaborative innovation for over two decades. This year, we are honoured to take hands with IEEE and to be joined by RobMech for their 14th conference on ‘Robotics and Mechatronics’, as well as PRASA for the 32nd ‘Pattern Recognition Association of South Africa’ conference.
I’m excited about the new possibilities when we bring together our gurus in Additive Manufacturing, Robotics, Mechatronics, Pattern Recognition and Artificial Intelligence. Collaboration, across disciplines, is one of the essential tools we need to adopt when carving our future. Our conference theme for the year ‘Digital Manufacturing: Industrialising Africa’ is about us taking charge of our own future in a world where the pace of innovation is increasing. This is only possible by taking hands and innovating together.
I would like to take this opportunity to congratulate the organisers of the RAPDASA/RobMech/PRASA conference of 2021! You have risen to the challenges and created a conference within a set of unprecedented limitations. Not only have you succeeded but you excelled.

I want to thank our sponsors who continually support us and make RAPDASA possible, with a special thanks to the CSIR, our conference host. I also wish to thank our exhibitors who trust in us and adds tremendous value to the conference and to our delegates. We also appreciate the involvement of our speakers and international guests and thank you for sharing your experience.

To our delegates: the students, scientists, makers, engineers, policy makers, funders, innovators and industrialists of Africa and abroad. We thank you for your contribution and I challenge you to reach out, network, take hands and develop the solutions of our future together. I’m excited to be able to look back again a decade from now and to see how you changed our world again.

Mr Marius Vermeulen
SUBMISSION FOR REVIEW PROCESS

A formal “Call for papers” for the 2021 Rapid Product Development Association of South Africa - Robotics and Mechatronics - Pattern Recognition Association of South Africa (RAPDASA-RobMech-PRASA) Conference was issued in May 2021 to submit an ‘Extended Abstract’ within the identified conference themes. Extended Abstract submissions were subjected to an internal reviewing process, whereby successful submissions were notified and invited for presentation to the conference. Authors were subsequently invited to submit an optional ‘Full Paper’, which was intended for publication in the conference proceedings. Both the Extended Abstracts and Full Papers were submitted online through the EasyChair conferencing system whereafter acknowledgement of receipt was sent to authors through the system. Authors were informed that a double-blind review process would be applied to Full Paper submissions.

The following dates were set by the Technical Committee:

- Deadline for submission of abstracts: 4 June 2021
- Extended deadline for submission of abstracts: 30 June 2021
- Notification of acceptance of abstracts: 26 July 2021
- Deadline for submission of full papers: 16 August 2021
- Feedback on paper reviews: 27 September 2021
- Deadline for final revised paper submission: 8 October 2021

Extended Abstracts were required to be a maximum length of 2 pages. Full Papers were required to comply with the Author Guidelines and template provided on the conference website.

A double-blind peer review process was used for the Full Paper submissions. The authors’ identities were concealed from the reviewers and the reviewers’ identities were concealed from the authors, throughout the review process. Each Full Paper submission was sent to a minimum of two reviewers, with a third reviewer being requested in case of lack of consensus between the first two reviewers. The reviews were performed by national and international academics, and other experts in the respective fields, listed on the Technical Committee page.

For this conference 62 papers were submitted for review and more than 90 local and international reviewers participated in the review process. Reviewers were asked to review submissions according to the following criteria and were encouraged to provide recommendations and suggestions.

- Does the title reflect the contents of the paper?
- Does the paper relate to what has already been written in the field?
- Do you deem the paper to be proof of thorough research and knowledge of
the most recent literature in the field of study?

- Is the paper clearly structured, easy to read and with a logical flow of thought?
- Are the arguments employed valid and supported by the evidence presented?
- Are the conclusions clear and valid?
- Does the paper conform to accepted standards of language and style?
- Any other recommendation(s)?
- Select reviewer recommendation: ‘Accept Submission’, ‘Revision Required’, or ‘Decline Submission’.

Reviewer feedback was saved on the EasyChair submission system, from where acceptance emails together with review comments were sent to the authors, allowing them to revise the submission. The authors were given about 2 weeks to incorporate changes, after which the final document was submitted for approval and publication in the conference proceedings.

Based on the outcome of the double-blind peer review process and the recommendations of the reviewers, eight papers were selected from the papers submitted to the conference and were submitted to the South African Journal of Industrial Engineering (SAJIE) to be considered for publication as journal articles. The editor of SAJIE accepted six of the submitted papers for publication in the journal. These papers were not included in the conference proceedings and were subjected to SAJIE’s editorial process.
KEYNOTE AND INVITED SPEAKERS

Prof Ian Campbell
Emeritus Professor at Loughborough University

Prof Paulo Bartolo
Executive Director, Singapore Centre for 3D Printing

Markus Glasser
Senior Vice President EMEA, EOS GmbH

Dr Karsten Heuser
VP Additive Manufacturing, Siemens Digital Industries

Prof Alessandro Fortunato
Associate Professor at the University of Bologna

Prof Med Dr Mashudu Tshifularo
ENT specialist, University of Pretoria, Steve Biko academic Hospital

Dr Terry Wohlers
Dr Terry Wohlers, President of Wohlers Associates, Inc., U.S.A

Johan Pretorius
Aerosud Group IT Leader, Leader and Strategist at OCTi Agile Consulting and MWorx™

Prof Olaf Diegel
Professor of Additive Manufacturing, University of Auckland, New Zealand

Prof Joel Vasco
Polytechnic of Leiria, Institute for Polymers and Composites, Portugal

Stefan Ritt
SPEE3D GmbH
After graduating from the Special Engineering Programme at Brunel University in 1985, Ian Campbell worked as a design engineer, first in Ford Motor Company, and later in the Rover Group. In 1989, he was appointed as a Senior Teaching Fellow for CAD/CAM at the University of Warwick. This gave him the opportunity to raise his awareness of CAD/CAM technology and practices. He remained in this position for four years, during which time, he undertook a part-time MSc degree by research. In 1993, he obtained a lectureship at the University of Nottingham and gained his PhD, again through part-time study, in 1998. He moved to Loughborough University in October 2000, where he was appointed as a senior lecturer and then promoted to reader in 2006. He became Professor of Computer Aided Product Design in the School of Design and Creative Arts in 2017. He is currently supervising several research projects, mainly in the area of design interaction and 3D printing technologies. Prof Campbell is a Fellow of the Institution of Mechanical Engineers and was Editor-in-Chief of the Rapid Prototyping Journal from 1995 to 2020. He is now an Emeritus Professor at Loughborough University.

**ABSTRACT**

*How a Collaborative International Partnership is Driving the DiCoMI Project Forward*

Many research projects require an interdisciplinary approach that brings together the best minds and best facilities from different subject areas. Finding the appropriate combination of partners within a single institution, or even a single country, is often difficult and sometimes impossible. The European Commission’s programme entitled Research and Innovation Staff Exchange Evaluations (RISE) is designed to overcome these issues. This presentation describes Loughborough University’s experience in developing, submitting and running the DiCoMI project under the auspices of the RISE programme. It explains the importance of finding the right partners, writing a strong bid,
and managing a project effectively. The results of the DiCoMI project are presented, both in terms of technological advancements, but also the human development aspect. Important lessons that have been learned will be shared to help future applicants to this and other programmes. The outcomes should be of particular interest to South African researchers since the Vaal University of Technology is a DiCoMI partner.
Paulo Bartolo holds a PhD from the University of Reading (2001), an MSC in Mechanical Engineering (1996) and a first degree (Licenciatura – five year programme) in Mechanical Engineering (1993) both from the University of Lisbon (Portugal). Since August 2021, Paulo Bartolo is Professor at the School of Mechanical and Aerospace Engineering (MAE), Nanyang Technological University (NTU), Executive Director of Singapore Centre for 3D Printing (SC3DP) and Director of the National Additive Manufacturing Innovation Cluster (NAMIC) hub at NTU. Since 2014 he served the University of Manchester as Chair Professor on Advanced Manufacturing. At the University of Manchester, he was the Head of the Manufacturing Group, the Industry 4.0 Academic Lead; member of the Advanced Manufacturing Strategic Oversight Group; member of the Management Board of the EPSRC & MRC Centre for Doctoral Training in Regenerative Medicine; and theme leader of the “Industry 5.0” Societal Challenge area within the Digital Futures. Between 1994 and 2014, Paulo Bartolo served the Polytechnic Institute of Leiria (Portugal) as Lecturer, Assistant Professor and Coordinator Professor. At the Polytechnic Institute of Leiria, he was the founder and Director of the Centre for Rapid and Sustainable Product Development (2007-2013); Head of the Mechanical Engineering Department (2001-2009); President of the Research Assessment Commission (2009-2013); President of the Scientific Council for Research, Development and Advanced Studies (2009-2013); and Member of the Academic Council and Senate of the Polytechnic Institute of Leiria (2009-2013).

Paulo Bartolo authored/co-authored more than 600 publications in journal papers, book chapters and conference proceedings, co-edited 22 books and holds 16 patents. He has been engaged in around 100 research projects funded by EPSRC, Innovate UK, Bill and Melinda Gates Foundation, the Royal Society, the Portuguese Foundation for Science and Technology, the Portuguese Agency for Innovation, the European Commission, and Industry representing around £45 million.

Public recognition for outstanding contributions: Commendation and public recognition from the Portuguese Government, published in the Portuguese Government’s Law
Journal (Diário da Republica), for the outstanding work as advisor of the Portuguese Government in the area of Research and Innovation; Commendation from the Polytechnic Institute of Leiria, published in the Portuguese Government Journal, for the outstanding work carried out (2014); Council award Afonso Lopes Vieira in the area of Innovation, Leiria Town Council, Portugal (2009). Microsoft Academic ranked Paulo Bartolo as the most salient author worldwide on the biomanufacturing field and among the top 100 most salient author worldwide on the field of tissue engineering.

**ABSTRACT**

Advances in Additive Manufacturing: a journey from Manchester to Singapore

Additive manufacturing is a disruptive technology being one of the key technological pillars of the fourth industrial revolution allowing to increase labour and resource productivity, strengthening supply chains and creating new value streams, reduce cost of quality and inventory, enabling manufacturing close to point of use. Through the last two decades we have contributed to the development of this field in multiple ways. This keynote summarises our most recent contributions in terms of advanced materials and novel fabrication strategies. Examples related to the construction, marine, agriculture and medical sectors will be provided.
As the Senior Vice President EMEA since January 2020, Markus is responsible for EOS’s business in Europe, Middle East, Africa and also South America. Since joining EOS in 1998, Markus has held various sales-related roles in the export region. Over the years, he established EOS subsidiaries in UK and Nordics, introduced distribution partners in many other countries in his region and significantly grew the business by expanding into new markets and industries.

Prior to joining EOS, Markus was the Area Manager for Europe and Asia at Kettner, an equipment manufacturer in the packaging industry. Markus has a Dipl. Ing. degree in Production Engineering.

**ABSTRACT**

**BRINGING INDUSTRIAL 3D PRINTING OF SERIAL PRODUCTION PARTS TOGETHER WITH RESPONSIBLE MANUFACTURING**

EOS provides responsible manufacturing solutions via industrial 3D printing technology to manufacturers around the world. We are deeply committed to fulfilling customer needs while acting responsibly for the planet. To emphasize our commitment, EOS is introducing a holistic sustainability approach that extends the boundaries of industrial 3D printing to ensure that future production is less harmful for the planet. What that means in detail and how this supports the success of our customers, I will present in my presentation.
Dr Karsten Heuser  
VP Additive Manufacturing, Siemens Digital Industries

Dr Heuser has been with Siemens for nearly 20 years in various management positions within Siemens businesses including Corporate Technology, Energy and is now the VP of Additive Manufacturing and is located in Erlangen next to the AMEC which is one of the AM Competence Center in Siemens.

Dr Heuser has a Ph.D. in solid state physics from the University Augsburg, as well as a Postgraduate Diploma in Advanced Management from ESMT.

ABSTRACT

MANUFACTURING REINVENTED WITH ROBOT-BASED ADDITIVE MANUFACTURING

Additive Manufacturing transforms the everyday with unlimited opportunities. May it be performance improved designs, enabling personalized products, supporting more efficient and flexible manufacturing,

or unleashing new business models like spare parts on demand. However, the technology is still at the verge of being industrialized for serial production. It’s all about efficiency, reliability and affordability while scaling 3D printing.

Within my keynote at this years RAPDASA hybrid conference, I would like to take the chance to present out of our Additive Manufacturing Experience Center in Germany. We will dive into the technology of transforming a robot system into a high precision, free-form Additive Manufacturing machine. Based on our CAD-CAM integrated software solutions and the Sinumerik controller nearly unlimited opportunities become possible, may it be composite or metal free form printing.
Allessandro Fortunato is an Associate Professor in Manufacturing Technologies at the University of Bologna. He obtained his PhD in Mechanics of Materials and Production Technologies at the same university in 2006 with a thesis on numerical modelling of laser processes.

**ABSTRACT**

**SELECTIVE LASER MELTING IN ENDOPROSTHESES FABRICATION: OPPORTUNITIES AND CHALLENGES**

Joint replacement is the surgical treatment that allows to preserve joint motion in case of osteoarthritis and the use of patient-specific prostheses is a current challenge. The present research aims at investigating the use of Laser Powder-Bed Fusion to produce innovative CoCrMo endoprostheses. This process allows geometrical customization of prosthesis design to fit the patient anatomy and it enables the production of functionally graded (FG) bone-to-implant surface for failure reduction. This study involves process optimization, mechanical and kinematic characterization of both full density and FG structures and biological tests for the validation of innovative prostheses.
The road from herdsman to ground-breaking ear, nose and throat (ENT) surgeon is one that Professor Mashudu Tshifularo has walked with determination, skill and dignity. Born in poverty in Thohoyandou to a large family, Prof Tshifularo tended his family’s livestock as a boy and attended school under a tree. He knew, however, from a young age that his future lay in medicine and his career has been one of many firsts: he was the first black ENT specialist in South Africa and one of the youngest appointed to Meduns’s Department of Otorhinolaryngology. More importantly, he made world headlines earlier this year when he performed the first transplant surgery of the hammer, anvil, stirrup and the ossicles – that make up the middle ear – using 3-dimensional printed inner ear bones.

Today, Prof Tshifularo is Head of the Department of Otorhinolaryngology at the University of Pretoria and Steve Biko Academic Hospital. Like many black children at the time, Tshifularo was affected by financial challenges in furthering his education after he passed matric. But today he has several degrees to his name. He is currently busy with his second PhD degree at the University of Pretoria. He holds a number of patents for middle ear implants and has published extensively in a number of leading peer-reviewed journals. He has dedicated himself to the training of students from disadvantaged groups and has been instrumental in training more black ENT specialists than any other institution.
ABSTRACT

The role of 3D technology in medicine prosthesis (personal experience)

The 4IR technology has changed the way we practice medicine. The advances in 3D technology have allowed us to do prosthesis as a possible to normal part which is defective, because of advances.

I will present my experience on 3D middle total ossicle replacement and the outcome. The case report of this technique brings about possibility of middle ear transplant pioneering idea research.
Terry Wohlers is principal consultant and president of Wohlers Associates, Inc., an independent consulting firm he founded 35 years ago. Through Wohlers Associates, he has provided consulting assistance to more than 280 organizations in 27 countries, as well as to nearly 200 companies in the investment community. He has authored 440 books, articles, and technical papers and has given 170 keynote presentations on six continents. Wohlers served as a featured speaker in events at the White House in 2012 and 2014 and has appeared on many television and radio news programs. He is a principal author of the Wohlers Report, the undisputed industry-leading report on additive manufacturing and 3D printing worldwide for 26 consecutive years. Many refer to it as the “bible” of 3D printing. In 2004, Wohlers received an Honorary Doctoral Degree of Mechanical Engineering from Central University of Technology in Bloemfontein, South Africa.

**ABSTRACT**

A Maturing Industry Advancing to the Next Level

The additive manufacturing industry is 32 years of age. Many AM applications are nothing short of astounding, both from technical and business points of view. Investment in the development and adoption of AM is at a pace not seen in the past. This activity is helping companies to scale and focus on complete end-to-end solutions. Sales of machines, materials, software, and services are strong, even in a pandemic. The industry faces a myriad of challenges and obstacles, yet it is on track to exceed $100 billion in less than 10 years. This will be supported by strong returns on investment, coupled with countless stakeholders determined to take AM to the next level.
Johan Pretorius is the Aerosud Group IT Leader and Business Strategist with 25+ years of information and communication technology experience. He has an in-depth understanding of Business and Digital Transformation in the manufacturing industry and the approach needed to unlock business value. He is a committed change agent and business agility coach.

ABSTRACT

Stabilise, Automate, Innovate and Accelerate:

Speed and agility in a rapidly changing world have become the new benchmark for businesses. Any business successfully achieving this will gain the competitive edge. This is the journey of how we re-imagined and transformed the legacy Aerosud business and how it shaped our current and future business strategies.
Olaf is both an educator and a practitioner of additive manufacturing (AM) and product development with an excellent track record of developing innovative solutions to engineering problems. In his role as professor of additive manufacturing, at the University of Auckland, in New Zealand, he is involved in all aspects of AM and is one of the principal authors of the annual Wohlers Report, considered by many to be the bible of AM. His current main area of research expertise is in design for AM. In his consulting practice he develops a wide range of products for companies around the world. Over the past three decades he has developed over 100 commercialized new products including innovative new theatre lighting products, security and marine products and several home health monitoring products and, for this work, has received numerous product development awards.

Over the last 30 years, Olaf has become a passionate follower of AM. He believes it is one of the technologies that has been a real godsend to innovation as it allows designers and inventors to instantly test out ideas to see if they work. It also removes the traditional manufacturing constraints that have become a barrier to creativity and allows us to get real products to market without the normally high costs that can become a barrier to innovation. In 2012, Olaf started manufacturing a range of 3D printed guitars that has developed into a successful little side-business.
ABSTRACT

Design for additive manufacturing and design automation: A perfect synergy

Many industries approach additive manufacturing (AM) as a drop-in replacement for conventional manufacturing technologies. This approach, however, does not fully utilize the unique possibilities that additive processes offer and their potential to be a catalyst for innovation. For over thirty years, AM has been extensively used as a rapid prototyping technology. When using the technologies for manufacturing, however, it should be noted that AM does not remove all manufacturing restrictions. It, instead, replaces them with a different set of design considerations that designers must take into account if they wish to successfully use the technologies to add value to their products. Otherwise AM can easily become a slow and uneconomical way of manufacturing products or parts.

The recent advent of automated design software technologies has also allowed the ability to almost completely automate the design of complex products that are perfectly suited to the complexity that AM offers. If these software technologies are combined with good design for AM practices, it can become a tremendous catalyst for increased innovation. This talk attempts to impart some practical guidance on how to design parts and use automated design software to gain the maximum benefit from what AM can offer.
Joel Vasco has been lecturing at the School of Technology and Management in Leiria since November 2001, as a member of the Mechanical Engineering Department, lecturing classes in areas such as Industrial Production Processes, Mould Design, Advanced Manufacturing Processes, Direct Digital Manufacturing Technologies, among others. He is currently the coordinator of the Master of Engineering for Direct Digital Manufacturing since December 2018 for the Polytechnic of Leiria and the vice-director of the PhD in Direct Digital Manufacturing for the polymers and moulds industries for the University of Minho, recently approved.

He also performs research at the Institute of Polymers and Composites at the University of Minho, focusing his areas of interest on subtractive, formative and additive manufacturing processes, micro technologies and direct digital manufacturing. The results of the research have been published in international indexed scientific journals, book chapters and in renowned international conferences, with scientific peer review.
ABSTRACT

Presentation Title: The adoption of AM by the Automotive industry

Automotive industry is a very competitive industry, where new market and design trends emerge continuously, requiring new manufacturing approaches to comply with the market requests. Additive manufacturing (AM) rises up in this context as a key-enabling technology to provide flexibility on production and bringing an important competitive edge to this industrial domain.

The use of AM on soft assembly tools or specialized tools to produce vehicle components is powered by the freeform of design that AM has to offer. It enables the design and direct production of optimized automotive components, incorporating lightweight structures, focused on vehicle’s performance as well as customised assembly tools to enhance productivity. Finally, AM is the key-enabling technology for mass customization, providing the means for collaborative development of products between designers, engineers, regulators and end-users to co-create new products within the AM ecosystem.
After earning his engineering degree in technical physics from the University of Applied Science in Lübeck, Germany, Stefan Ritt started his career in RP/AM in 1985 when running a prototype lab in the R&D arm of a coffee and vending machine company. After that, he held positions in QA and product management for mid-sized Dutch and Danish companies. In 1998, Stefan took on international sales and marketing of RP tooling products for a UK/German joint venture. In this capacity, he was successful in international markets with the development and support of the transition of RPT and metal AM equipment into production equipment. Stefan has also worked for SLM Solutions where he continued his efforts to grow the metal AM market internationally. There he managed to bring the first powder-bed Laser metal printer on display at an AMUG-conference to the US. He now works for SPEE3D from Melbourne-Australia, which brings another new metal AM technology for production into the market, as their European managing director. He is a part-time lecturer for supply chain management at the technical university of Lübeck and guest lecturer for international business communication in marketing at the Technical University in Hamburg. He was also head of the DIN standardization group “additive manufacturing in aerospace” for 4 years and helped to develop the first international AM-standards for certification in that industry. In 2011, he was appointed as the European liaison officer and global ambassador for AMUG. As he travels around the world, he spreads the news about AMUG activities to expand the awareness of the users group in global markets. In 2015 he was awarded the AMUG-DINO for his continuous support and involvement for the user group and industry. Every year he brings the latest news, trends and future outlooks of the AM industry from around the world to the audience at the AMUG conference. Stefan is also part of the EPMA AM-steering committee to help our association to focus on the additive manufacturing industry for our members.
ABSTRACT

Additive manufacturing for metals is now established in more and more industries

Due to the high flexibility and just-in-time as well as on-demand manufacturing possibilities, this technology is also predestined for expeditionary and defense applications. However, many systems on the market are technically very sensitive and complex and therefore stand in the way of use “in the wild”.

Several field tests have already been successfully carried out with cold spray technology. The presentation will report on this and thus also show possible future application concepts such as offshore wind farms, oil and gas industry applications and expeditionary environments such as in Central Africa or Asia.

Because cold spray technology does not completely melt the material, the process is tens of orders of magnitude faster and handling much easier. The number of usable metal powders is constantly increasing, opening up more and more areas of application.

The Australian Defence Force has already been using the technology for several years to support field repair and spare parts procurement problems. Other industrial applications such as mould making and the production of unavailable spare parts have also been developed.

These attributes make the potential use of cold spray technology in the environmental conditions of the African continent particularly interesting and the presentation is intended to stimulate discussion on this.
PROGRAMME

PRE-CONFERENCE SEMINAR

Tuesday, 02 November 2021
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<tr>
<td>08:30</td>
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<tr>
<td>09:00</td>
<td>Welcoming Address - Dr Kobus van der Walt, CUT</td>
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<tr>
<td>09:10</td>
<td>Opening Address - Ms Mmamose Seloane, Director: Technology Localisation, DSI</td>
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<tr>
<td>09:30</td>
<td>Direct metal laser sintering production of Ti6Al4V parts from a purely elemental powder blend - LA Ramosena, TC Dzogbewu and WB du Preez</td>
</tr>
<tr>
<td>09:50</td>
<td>Surface morphology of LPBF manufactured Ti6Al4V processed by centrifugal barrel finishing - NW Makoana, I Mathoho, L Tshabalala and I Yadroistev</td>
</tr>
<tr>
<td>10:10</td>
<td>Examining various mixing techniques and their effect on the uniform dispersion of carbon nanotubes within a Ti6Al4V (ELI) matrix - M Mashabela, M Maringa and TC Dzogbewu</td>
</tr>
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<td>TEA</td>
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<tr>
<td>11:00</td>
<td>Investigation of acoustic emission signal during laser powder bed fusion at different operating modes - Dr D Kouprianoff</td>
</tr>
<tr>
<td>11:20</td>
<td>Comparative analysis of the high velocity impact behaviour of wrought and stress relieved DMLS Ti6Al4V (ELI) - TC Moleko, M Maringa and WB du Preez</td>
</tr>
<tr>
<td>11:40</td>
<td>Effect of varying energy density on the microstructure of TIC/TI-6AL-4V metal composite - P. Ramasobane, P. Lekoadi, PM Mashinini and B Masina</td>
</tr>
<tr>
<td>12:00</td>
<td>Additive Manufacturing: Looking Beyond Prototyping - I Adam</td>
</tr>
<tr>
<td>12:20</td>
<td>Closure - Dr Kobus van der Walt</td>
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<td>12:30</td>
<td>Lunch</td>
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Hosted by Central University of Technology, Free State (CUT)
Supported by the Department of Science and Innovation (DSI)
PROGRAMME

DAY 1

Wednesday, 03 November 2021
The 22nd Annual International RAPDASA Conference
Digital Manufacturing: Industrialising Africa

Breakaway Sessions

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Links and passwords to the online Zoom sessions will be distributed via email to registered conference attendees. For additional information, visit: https://rapdasa.org/annual-conference/

Wednesday, 03 November 2021

09:00 Opening and Welcome: Chairperson RAPDASA 2020 conference organizing committee - Dr Hencharl Strauss

09:15 Welcoming by CSIR management: Dr Thulani Dlamini, President and CEO of CSIR

09:30 Opening Address: Mr Beeuwen Gerryts, Chief Director: Technology localisation, beneficiation and advanced manufacturing, Department of Science and Innovation

Plenary Sessions

Chair: Prof Deon de Beer

10:00 Keynote Address: Prof Ian Campbell, Emeritus Professor at Loughborough University: How a Collaborative International Partnership is Driving the DiCoMI Project Forward

10:30 Tea/Coffee Break

10:50 Prof Paulo Bartolo, Executive Director, Singapore Centre for 3D Printing: Advances in Additive Manufacturing: a journey from Manchester to Singapore

11:20 Questions and answers
## TECHNICAL PRESENTATIONS

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<td>Session Chair: Hardus Greyling</td>
<td>Session Chair: Prof Elisha Markus</td>
<td>Session Chair: Imdaadulah Adam</td>
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</table>

### Theme: AM Material Development

- **11:30**
  - Influence of powder characteristics on the spreadability of pre-alloyed WC-CO
  - Preyin Govender (1)

### Theme: Robotics and Mechatronics

- **11:30**
  - Development of a multipurpose, outdoor autonomous ground vehicle for agricultural inspection
  - Willis de Ronde (12)

### Theme: Pattern Recognition

- **11:30**
  - Digital Twinning of Lap-Based Marathon Infrastructure
  - André Broekman (24)

### Theme: AM Material Development

- **11:50**
  - Characterization of polypropylene powder produced by precipitation for powder bed fusion additive manufacturing
  - Joseph Nsengimana (2)

### Theme: Robotics and Mechatronics

- **11:50**
  - VLOS and BVLOS RPAS Operators Certificate: Case Study for Inspection Requirements
  - Riaan Stopforth (13)

### Theme: Pattern Recognition

- **11:50**
  - Model-Based Design of Additive Manufacturing Operations for Improved Management, Control and Compliance
  - Duncan William Gibbons (25)

### Theme: AM Material Development

- **12:10**
  - Parameters affecting the mixing of powders for additive manufacturing and the results of mixing SiC and Ti6Al4V powders
  - Mamphutlane Seleso (3)

### Theme: Robotics and Mechatronics

- **12:10**
  - An Octomap-based 3D costmap
  - Daniel Withey (14)

### Theme: Pattern Recognition

- **12:10**
  - Development of a graphical user interface as a learning tool for artificial intelligence
  - Natasha Botha (26)

### Theme: AM Material Development

- **12:30**
  - Laser metal deposition of TiB2/TiC/Ti6Al4V composites
  - Athernia Thunyiswa (4)

### Theme: Robotics and Mechatronics

- **12:30**
  - Ground Robot Path Planning on 3D Mesh Surfaces Using Local Regions
  - Cebisile Mthabela (15)

### Theme: Pattern Recognition

- **12:30**
  - A comparative study towards particle identification employing semi-automated image processing in experimental SEM images
  - Beatrice van Eden (27)

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13:00 LUNCH BREAK
### Breakaway Sessions

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<td>Session Chair: Prof Sisa Pityana</td>
<td>Session Chair: Duwan Bester</td>
<td>Session Chair: Dr Lethu Chikosha</td>
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</table>

#### Theme: AM Material Development

14:00
- Development of novel bioinks for bioprinting and tissue engineering
  - Jaundrie Fourie (5)

14:20
- Risk based classification of powder bed defects
  - Francois Du Rand (6)

14:40
- Effect of particle size distribution on the resulting part density and mechanical properties in selectively laser melted cobalt chrome
  - Stuart Papworth (8)

15:00
- Validation and investigation of deformation prediction and deformation compensation for additive manufacturing
  - Benic van Wyk (9)

#### Theme: Robotics and Mechatronics

14:00
- Evaluation of visual odometry method in 3D LIDAR based mapping
  - Samuel Ogunniyi (16)

14:20
- Manufacturing and Evaluation of the Open-Source AR3 Robot Arm for Educational Uses
  - Kyla Purdon (17)

14:40
- Development of a platform for the freeform extrusion of a continuous glass fiber reinforced photopolymer
  - Daniel Kirkman (18)

15:00
- Core functional MES with machine monitoring using open-source software
  - Kshir Ramruthan (19)

15:20
- PID Control for a collaborative humanoid robot
  - Teboho Ntsinyi (20)

#### Theme: Pattern Recognition

14:00
- One-Class Support Vector Machines for Boat Detection using Fully Polarimetric Radar
  - Thabang Matladi (28)

14:20
- Framework for cemented tungsten carbide drill bit prototype fabrication using laser engineered net shaping
  - Natasha Sacks (29)

14:40
- Direct energy deposition of a cemented tungsten carbide rotary burr prototype
  - Emma Molobi (30)

15:00
- The role of AM polymers to improve the OEE of operations
  - Henk Harmse (31)

15:20
- Combined implicit and explicit techniques to create a bespoke optimized 3D printed lattice socket for a prosthetic hand
  - Jode Fourie (32)
### 15:40 TEA/COFFEE BREAK

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<td>Additive Manufacturing</td>
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<tr>
<td>Session Chair:</td>
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<tr>
<td>Dr Wayne Koen</td>
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</table>

### Theme: AM Process Development
- **16:00**
  - Effect of Stress-relief anneal time on residual stress of Co-Cr-Mo parts manufactured with selective laser melting
    - Genevieve Rousseau (10)
  - Design and manufacturing of an aggregate abrasion test device for testing in high acceleration field
    - Sipho Xungu (21)

### Theme: Robotics and Mechatronics
- **16:20**
  - Prediction of inter-layer adhesion in polymer additive manufacturing
    - Tobias Ott (11)
  - Elimination of shrinkage porosity in low alloy steel using MAGMASOFT simulation software
    - Jonathan Kabasele (22)

### Theme: Product Development
- **16:40**
  - Medical product development for animals using AM and digital manufacturing
    - Philip van der Walt (34)

### Theme: Rapid Sand Casting
- **16:40**
  - Assessment of the financial feasibility of rapid sand-casting process using the payback period method
    - Anazo Msani (23)

*17:00 CLOSURE*
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PROGRAMME

DAY 2

Thursday, 04 November 2021
### Thursday, 04 November 2021

**08:00** Opening and Welcome: Chairperson RAPDASA 2020 conference organizing committee - Dr Hencharl Strauss

#### PLENARY SESSIONS

**Chair: Dr Ntombi Mathe**

**08:10** Markus Glasser, EOS: Bringing industrial 3D printing of serial production parts together with responsible manufacturing

**08:40** Dr Karsten Heuser, VP Additive Manufacturing, Siemens Digital Industries: Manufacturing reinvented with robot-based additive manufacturing

**09:10** Prof Alessandro Fortunato, Selective laser melting in endoprostheses fabrication: opportunities and challenges

**09:40** Prof Mashudu Tshifularo, ENT specialist, University of Pretoria, Steve Biko academic Hospital: The role of 3D technology in medicine prosthesis (personal experience)

**10:10** Questions and answers

**10:20** TEA/COFFEE BREAK
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>10:40</td>
<td><strong>Theme: AM Process Development</strong></td>
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<tr>
<td></td>
<td>Cold spray technology for metal 3D printing in rough environments and offshore applications</td>
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<td>Invited speaker: Stefan Ritt (35)</td>
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<td>11:00</td>
<td><strong>Theme: Rapid Sand Casting</strong></td>
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<tr>
<td></td>
<td>Characterization of waste sand generated during the Voxeljet rapid sand casting process</td>
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<td>Accolade Motlhabane (46)</td>
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<td></td>
<td>Topology Optimisation for Mass Reduction in Additively Manufactured Rocket Engine Propellant Pumps</td>
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<td>Byron Blakey-Milner (56)</td>
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<td>11:20</td>
<td><strong>Theme: Product Development</strong></td>
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<tr>
<td></td>
<td>Pre-optimisation of a resin coated chromite sand for rapid sand casting applications</td>
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<td>Neo Tshabalalana (47)</td>
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<td>Geographical education of the visually impaired using Braille system on physical models</td>
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<td>Sanat Agrawal (57)</td>
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<tr>
<td>11:40</td>
<td>Assessment of Consol silica sand for three dimensional printing applications</td>
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<td>Oyombo Dady (49)</td>
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<tr>
<td>11:20</td>
<td>Laser optimized process parameters for suppressing columnar phase and Nb segregation in IN718 clad Bathusile Masina (37)</td>
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<tr>
<td>11:40</td>
<td>Suitability of Local Chromite Sand for use in Rapid sand casting</td>
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<td>Julieth Langutani Chauke (48)</td>
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<td>An AM solution to a golfing predicament – a bespoke golf putter head and hosel with multiple configuration options for personalized club fitment</td>
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<td>Wian van Aswegen (58)</td>
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<td></td>
<td>Heat Treatment Development for Residual Stress Reduction in SLM Manufactured CoCr Components</td>
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<td></td>
<td>Juan Du Plessis (36)</td>
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<tr>
<td>11:20</td>
<td>Geographical education of the visually impaired using Braille system on physical models</td>
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<tr>
<td>Theme: AM Part Characterisation</td>
<td>Theme: AM Post Processing and Qualification</td>
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<td>Qualitative measurement rubric for internal cranial prostheses STL evaluation&lt;br&gt;Henra Muller (38)</td>
<td>Dimensional error testing of 3D printed samples and sterilisation techniques for orthopedic surgery&lt;br&gt;Leon Kotze (50)</td>
</tr>
<tr>
<td><strong>12:20</strong></td>
<td><strong>12:20</strong></td>
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<tr>
<td>Investigation of the properties of direct energy deposition additive manufactured 304 stainless steel&lt;br&gt;Shaik Ebrahim Hoosain (39)</td>
<td>High cycle fatigue performance of Ti6Al4V (ELI) parts produced with inherent direct metal laser sintering surface roughness&lt;br&gt;Hlakae Miya (51)</td>
</tr>
<tr>
<td><strong>12:40</strong></td>
<td><strong>13:00 LUNCH BREAK</strong></td>
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<tr>
<td>Influence of Ti and Cu on the Corrosion Properties of Laser-Deposited High Entropy Alloys in NaOH solution&lt;br&gt;Modupeola Dada (40)</td>
<td>Understanding the effect of characterising variability for batch production using laser powder bed fusion&lt;br&gt;Cindy Sithole (52)</td>
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<td><strong>14:00</strong></td>
<td><strong>14:00</strong></td>
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<tr>
<td>An overview of the latest additive manufacturing research in the 3D Innovation group at Stellenbosch University&lt;br&gt;Anton Du Plessis (41)</td>
<td>The effect of sandblasting and bead blasting on material removal rate of SLM parts using dry electrolyte polishing&lt;br&gt;Daniel Taljaard (53)</td>
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<tr>
<td>14:20</td>
<td>Using the Vickers indentation method to measure surface residual stress in SLM IN718 specimens by Barend Coetsee Stander (42)</td>
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<td>Industry taking up on-demand Additive Manufacturing of spare parts by Duwan Bester (54)</td>
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<tr>
<td>14:40</td>
<td>Fractography of polypropylene laser sintered tensile test specimens by Fredrick Mwania (43)</td>
</tr>
<tr>
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<td>Qualification and certification for fatigue life in additive manufacturing by Nic Macallister (55)</td>
</tr>
<tr>
<td>15:00</td>
<td>Residual stress, porosity and surface roughness measurements for laser powder bed fusion manufactured Ti6Al4V at high laser powers by Nkutwane Washington Makoana (44)</td>
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<tr>
<td>15:20</td>
<td>The efficacy of the inherent strain method in determining residual stress in IN718 SLM specimen by Herculaas Botha (45)</td>
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<td>15:40</td>
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**PLENARY SESSION**

Chair: Prof Ian Campbell

16:00 **Keynote Address:** Dr Terry Wohlers, President of Wohlers Associates, Inc.: A Maturing Industry Advancing to the Next Level

16:30 Questions and answers

16:40 **CLOSURE**

17:00 **RAPDASA ANNUAL GENERAL MEETING**

19:00 **GALA DINNER**
The 22nd Annual International RAPDASA Conference

Digital Manufacturing: Industrialising Africa

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PROGRAMME

DAY 3

Friday, 05 November 2021
Friday, 05 November 2021

08:00 Opening and Welcome: Chairperson RAPDASA 2020 conference organizing committee - Dr Hencharl Strauss

PLENARY SESSIONS

Chair: Prof André van der Merwe

08:15 Mr Johan Pretorius, Aerosud Group IT Leader, Leader and Strategist at OCTi Agile Consulting and MWorx™: Stabilise, Automate, Innovate and Accelerate

08:45 Prof Olaf Diegel, Professor of Additive Manufacturing, University of Auckland, New Zealand: Design for additive manufacturing and design automation: A perfect synergy

09:15 Prof Joel Vasco, Polytechnic of Leiria, Institute for Polymers and Composites, Portugal: The adoption of AM by the Automotive industry

09:45 Questions and answers

10:30 TEA BREAK – Sponsors live sessions
## TECHNICAL PRESENTATIONS

### BREAKAWAY SESSIONS

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<td><strong>Session Chair:</strong> Dr Monnamme Tlotleng</td>
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### Theme: AM Part Characterisation

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<tr>
<td>10:50</td>
<td>An overview of the latest Analysis of corrosion and mechanical properties of DMLS manufactured Ti6Al4V parts Kabelo Raselabe (59)</td>
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<tr>
<td>11:10</td>
<td>Investigation of microstructure and hardness properties of in-situ TiB/Ti6Al4V ELI composite manufactured by laser metal deposition Paul Lekoadi (60)</td>
</tr>
<tr>
<td>11:30</td>
<td>Microstructure and tensile properties of 3D printed Ti-48Al-2Nb-2Cr alloy manufactured by direct laser metal deposition Sisa Pityana (61)</td>
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11:50 ACKNOWLEDGEMENTS: Chairperson of RAPDASA 2021 - Mr Marius Vermeulen
12:00 CLOSING
12:00 LUNCH
Dimitri Dimitrov Scholarship
In honour of Dimitri Dimitrov

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ABSTRACTS
Pre-Conference Seminar

Tuesday, 02 November 2021
DIRECT METAL LASER SINTERING PRODUCTION OF Ti6Al4V PARTS FROM A PURELY ELEMENTAL POWDER BLEND

L.A. Ramosena¹ & T.C. Dzogbewu² & W.B Du Preez³

¹,² Department of Mechanical and Mechatronics Engineering, Faculty of Engineering, Built Environment and Information Technology, Central University of Technology, Free State, South Africa, ¹lramosena@cut.ac.za, ²tdzogbewu@cut.ac.za
³ Centre for Rapid Prototyping and Manufacturing, Faculty of Engineering, Built Environment and Information Technology, Central University of Technology Free State, Bloemfontein, South Africa, wdupreez@cut.ac.za

ABSTRACT

Additive manufacturing processes have been successfully used to produce Ti6Al4V alloy parts from pre-alloyed powders of Ti6Al4V. Although the efficacy of this method has been scientifically proven, the high-cost production of the pre-alloyed powders results in a high-cost alloy, which warrants the development of new, more cost-effective additive manufacturing materials and methods. The purpose of this paper is to demonstrate the results obtained from an attempt to produce the Ti6Al4V alloy from an elemental powder blend using the Direct Metal Laser Sintering process. Single tracks, followed by multiple layers and three-dimensional parts were produced and analysed. Since single tracks are considered as the building blocks of sintered parts, process parameters that produced optimum single tracks were identified and used to produce the subsequent layers and three-dimensional parts.

INTRODUCTION

The Direct Metal Laser Sintering (DMLS) process is an additive manufacturing (AM) process that has been reliably used to produce Ti6Al4V alloy parts from pre-alloyed (PA) powders [1]. To date, Ti6Al4V has only had application in certain crucial industries due to the costly parts produced from this process [2]. The high cost of these parts can be largely attributed to the cost of the starting PA powder feedstock. The production of these PA powders involves alloying and atomisation processes, which essentially result in an expensive feedstock material for the DMLS process [2,3]. A new approach to the production of Ti6Al4V parts needs to be explored, not only for cost implications, but to further explore the advantages of this process by increasing the variety of materials that can be employed as feedstock in this process [4]. In this study, a powder blend consisting of elemental Ti, Al and V was employed as the
starting feedstock in the DMLS process. A series of experimental results starting from single track formation to three-dimensional (3D) part development, is presented and analysed.

METHODOLOGY AND RESULTS

A powder blend consisting of commercially pure (CP) Ti (grade 1), Al and V was used in the EOSINT M280 machine to firstly produce single tracks from which the optimum primary process parameters (laser power and scanning speed) were identified. These process parameters were then used to produce single and double layers from which the optimum hatch distance was determined. Ultimately, 3D components were produced using the optimum process parameters. The preparation and analysis of the samples were conducted according to generally accepted methods.

Only the single track analysis has been completed to date. The optimum primary process parameters were found at laser powers of 150 and 200 W and a scanning speed of 0.6 m/s. These are the process parameters that are being used in the subsequent experiments to produce single and double layers. A full set of experimental data will be made available in the final paper.

CONCLUSION

Primary process parameters were identified for the production of optimum single tracks. It is expected that these will be successfully applied to produce single and double layers and 3D parts.

REFERENCES


SURFACE MORPHOLOGY OF LPBF MANUFACTURED Ti6Al4V PROCESSED BY CENTRIFUGAL BARREL FINISHING

N.W. Makoana¹,², I. Mathoho¹, L. Tshabalala¹ & I. Yadroiste⁰²

¹ National Laser Centre, Council for Scientific and Industrial Research, South Africa, nmakoana@csir.co.za

² Department of Mechanical and Mechatronic Engineering, Central University of Technology, South Africa, iyadroitsau@cut.ac.za

ABSTRACT
The poor surface quality of LPBF parts obtainable in the as-built condition impairs the mechanical performance, especially for components subjected to high mechanical loads. This work aims to investigate the effect of barrel finishing, specifically rotational speed and processing time, on the surface quality of LPBF manufactured Ti6Al4V. The surface morphology and its evolution during barrel finishing have been characterised via stylus technique and scanning electron microscopy. Initial results showed a significant reduction of the average roughness with increasing rotation speed and time, respectively.

INTRODUCTION
The surface quality of LPBF parts is one of the concerning issues that inhibit the application of this technology as the final manufacturing technique, especially for the manufacturing of parts that are regularly subjected to high mechanical loads during their service life, Pegues et al. [1]. Often some kind of post-processing is required to improve the surface integrity of the LPBF manufactured parts, as it affects the mechanical properties such as the fatigue strength. Moreover, material strength and corrosion resistance were proved sensitive to the surface quality. Notwithstanding its slow process, barrel finishing is vastly used for conditioning the part’s surface because it is a versatile and cost-effective method. Accordingly, this study aims to investigate the effect of barrel finishing on the surface morphology of Ti6Al4V manufactured by LPBF.

METHODOLOGY AND RESULTS
Methodology
Ti6Al4V test pieces previously manufactured were processed using an industrial equipment CB320 CBF machine by varying the rotational speed and polishing time. The tumbling barrel was filled to almost 50 percent volume capacity with angle cut triangle ceramic media, water, and a small amount of
LC-13 polishing liquid. The rotational speed was varied between 45 – 85 rpm, while the processing time varied between 1 - 5 hours at five intervals. The surface roughness was measured using a MarSurf PS1 portable surface roughness tester and further characterised using a scanning electron microscope to reveal the surface morphology.

**Results**

Preliminary results are illustrated in Figure 1, showing the effect of rotational speed and processing time on the average surface roughness; and the surface morphology of the non-processed sample and the sample processed at 85 rpm for 5 hours.

![Figure 1: (a) Variation of surface roughness, and different surface morphologies (b & c)](image)

**CONCLUSION**

The current study investigates the effect of barrel finishing on the surface integrity of Ti6Al4V test pieces manufactured via LPBF by varying the rotational speed and processing time. In the non-processed condition, the surface morphology is mostly dominated by sintered powder particles caused by partial melting of the particles on the periphery of the part. The rotational speed is found to have a stronger effect on the surface roughness compared to the processing time. The lowest surface roughness was obtained at the highest speed of 85 rpm for a processing time of 5 hours, with some small cavities still present on the surface of the sample.

**REFERENCES**

EXAMINING VARIOUS MIXING TECHNIQUES AND THEIR EFFECT ON THE UNIFORM DISPERSION OF CARBON NANOTUBES WITHIN A Ti6Al4V (ELI) MATRIX

M. Mashabela¹ & M. Maringa² & T.C. Dzogbewu³

¹Department of Mechanical and Mechatronics Engineering, Central University of Technology, Free State, South Africa, mphosiek@gmail.com
²Department of Mechanical and Mechatronics Engineering, Central University of Technology, Free State, South Africa, mmaringa@cut.ac.za
³Department of Mechanical and Mechatronics Engineering, Central University of Technology, Free State, South Africa, tdzogbewu@cut.ac.za

ABSTRACT

Carbon nanotubes offer the possibility to improve the mechanical properties of Ti6Al4V. Their low density, high strength, and high Young’s modulus make them a preferred choice for reinforcement. However, their small size and tendency to agglomerate pose a challenge to achieving homogeneous dispersion in a matrix. To examine the effect the mixing process has on achieving a homogenous mixture between carbon nanotubes and Ti6Al4, three different techniques were investigated experimentally in the present study and shown to have differing outcomes.

INTRODUCTION

Carbon nanotubes (CNTs) have exceptional physical and mechanical properties and their use as reinforcement material has increased over the last ten years especially for use with metal matrices [1]. Although CNTs have desired properties for use as reinforcement material, their agglomeration poses a challenge in the formulation of composites. To achieve uniform dispersion various methods of blending and dispersion are available which include colloidal mixing, magnetic stirring, molecular-level mixing, nanoscale dispersion processing, particle composite system mixing, friction stir processing, layer stacking, ball milling, and roller mixing. Of the aforementioned processes, the most commonly used methods include molecular-level mixing, ball milling, and colloidal mixing [2].
A process control agent is utilised in all these commonly used processes. In the case of ball milling, ethanol is used to prevent cold welding of the matrix and to prevent agglomeration of powder particles during ball milling. In molecular-level mixing the CNTs are first treated in an acid then dispersed in a solvent using ultrasonic agitation. Colloidal mixing makes use of dimethylformamide or ethylene glycol to achieve a stable dispersion of CNTs [3].

A number of distinguished works are available on high energy and low energy ball milling to mix CNTs and metal matrices. However, little literature exists for the remaining processes, which is the focus of the present study. In this study, molecular-level mixing, colloidal mixing, and magnetic stirring are examined.

METHODOLOGY AND RESULTS

The experimental work was conducted using spherical gas atomized Ti6Al4V powder and aligned multi walled carbon nanotubes, purity: > 96%, outside diameter: 8-18 nm, surface area 30-300 m²/g. The CNTs were mixed into the Ti6Al4V matrix at a weight fraction of 8%. Magnetic stirring was first used without a process agent. Secondly, magnetic stirring was used followed by the addition of ethanol into the mixture, and and then an ultrasonic cleaner from SCIENTECH model 704 employed to agitate the particles for 10min, and at a frequency of 35Hz. The mixture was then oven-dried at 50°C for 20 minutes to evaporate the ethanol, leaving behind the powder mixture. Finally, acetone was added to the mixture, which was then stirred magnetically and thereafter oven-dried at 70°C for 15 minutes.

Based on literature it was expected that the mixture containing ethanol would produce a more homogenous mixture than the mixtures containing acetone and the one that was only stirred magnetically [2,4].

CONCLUSION

The various mixing techniques used here yielded different degrees of homogeneity of mixing, neither of which was perfect. The ethanol mixture yielded a better dispersion of CNTs in the Ti6Al4V matrix compared to the acetone, and magnetically stirred mixtures. Agglomeration of CNTs was present in all three mixtures. However, the highest degree of severity of agglomeration was observed in the magnetically stirred mixture, followed by the acetone mixture and lastly the ethanol mixture.

The possibility of adding a polymer binder to the Ti6Al4V matrix in order to reduce surface tension to assist in the uniform dispersion of carbon nanotubes
within the matrix is a subject for future investigation. Using a processing agent proved to aid in the dispersion of the particles but this was not sufficient and hence methods to enhance its efficacy are recommended for future investigations.

REFERENCES


INVESTIGATION OF ACOUSTIC EMISSION SIGNAL DURING LASER POWDER BED FUSION AT DIFFERENT OPERATING MODES

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ABSTRACT

The increasing use of metal additive manufacturing (AM) in production components make quality control more necessary. Performance of LPBF parts depends on optimal process-parameters and careful selection of scanning and building strategies of complex parts. In-situ acoustic emission provides a suitable solution for monitoring of LPBF process directly during manufacturing. A defective powder layer is one of the main concerns due to the anisotropic nature of LPBF. This paper shows the effect of different keyhole mode forming process parameters on the sound pressure and frequency content during LPBF processing. Acoustic emission is correlated to track morphology. Results present valuable information for online monitoring development.

INTRODUCTION

Metal AM has shown great application in industry. The metal AM market has grown more than 40% in the last 5 years [1]. The complex nature of LPBF process makes slight variation in process variables detrimental to the quality of the parts. This led to the development and much needed process monitoring for quality control. Gas-borne acoustic emission (AE) has been reported to be a possible method for online monitoring of laser welding [2] and for laser powder bed fusion [3, 4, 5]. For acoustic emission some systems monitor the sound waves through the substrate [5]. This work sets out to show the characteristic acoustic emission of single tracks at different keyhole process parameters using EOSINT M280 system.

METHODOLOGY

Ti6Al4V (ELI) powder were used with single track experiments. The equivalent diameters (by volume) of the powder particles were d10 = 12.03 μm, d50 = 21.38 μm and d90 = 31.15 μm. Experiments were done with an EOSINT M280; a microphone was placed inside the building chamber 240mm above the substrate. To produce keyhole welding the laser power was varied at between 100W, 170 W and 340W and scanning speed kept at 0.6 m/s. Tracks were produced at different layer thicknesses of 1, 2, 4, 5 and 10 layers with layer thickness set to 30 μm. Each track’s corresponding sound waveform was extracted from the recording and analyzed with Fast Fourier Transform (FFT) and the sound pressure level (SPL) calculated. For microscopy top and cross-sectional images were taken. The data was used to correlate the track morphology to the frequency content for the specific layer thickness.

RESULTS AND DISCUSSION
For current system, at laser a power of 100W conduction mode welding resulted (Figure 1). From the top view it can be observed that the track width for all laser powers is uniform throughout the length of the track. The depth of the tracks increased greatly with increase in laser power.

![Figure 1: Top-view and cross-sections of single tracks without powder at 100W, 170W and 340W laser power and 0.6 m/s scanning speed.](image)

The frequencies emitted at the two different keyhole parameters (170W & 340W at 0.6m/s) are very similar (Figure 2). This suggests that at these two parameters, the melt pool dynamics are very stable and similar. The same shape is present in both 170W and 340W (Figure 1), but 340W having deeper penetration.

![Figure 2: FFT spectrum of single tracks without powder at 100 W, 170 W and 340 W laser powers and 0.6 m/s scanning speed](image)

**CONCLUSION**

Gas borne acoustic emission results are reported for keyhole mode LPBF. The sound pressure level decreases with an increase of layer thickness and showed a relationship with the contact zone measurements. From this data it is clear that track morphology cannot be used alone to correlate to acoustic emission, but one should consider the different combinations of process parameters.

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COMPARATIVE ANALYSIS OF THE HIGH VELOCITY IMPACT BEHAVIOUR OF WROUGHT AND STRESS RELIEVED DMLS Ti6Al4V (ELI)

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ABSTRACT
The comparison presented here is based on the minimum thickness required to prevent through penetration, and further, fractography of the fracture surfaces and microstructural changes around and radially away from the penetration hole. The high velocity ballistic impact tests conducted on both types of Ti6Al4V alloys revealed a minimum thickness to prevent through penetration that was just above 14 mm. Fractographic analysis revealed both alloys exhibited brittle behaviour and ductile behaviour at the entry point and exit point of the penetration holes, respectively. Microstructural analysis further revealed changes that are consistent with the effects of high temperature.

INTRODUCTION
In previous work, testing was conducted on wrought Ti6Al4V as an alternative to aluminium alloy AA 5083 and Rolled Homogeneous Armour steel for high velocity impact applications [1]. In this paper, a comparative analysis is conducted on the results obtained from this testing and further unpublished work done on as-built and stress relieved Direct Metal Laser Sintering (DMLS) Ti6Al4V (ELI) [2].

In high velocity ballistic impact applications, one of the criteria used to rate the performance of a metal is its resistance to penetration [1]. The resistance to penetration is normally quantified through an optimum thickness to prevent through penetration of a projectile [1]. Additively manufactured Ti6Al4V (ELI) with its higher value of hardness (326 BHN) compared to the wrought alloy (300 BHN) is expected to perform better by providing more effective blunting of the projectiles and hence achieving better resistance to penetration [3][4]. Furthermore, its higher value of yield strength (1089 MPa) compared to that of wrought Ti6Al4V (948 MPa) implies a higher capacity to absorb energy during
elastic deformation and therefore a higher capacity to stop the penetration of projectiles [4][5].

The transient high strain rates prevalent during high velocity impact are known to lead to adiabatic temperature rises of target materials [6]. Therefore, it is important to understand whether the temperature rise during impact is significant enough to bring about microstructural change of the target material [6]. Depending on the temperatures attained during high velocity impact of Ti6Al4V, the hexagonal close packed α phase of the alloy existing at room temperature can undergo an α to β transformation [7][8].

The projectile holes in targets impacted by high velocity projectiles display features of fracture, that speak of the type of deformation prevalent at particular points in them [9][10]. Determination of the mode of failure, ductile or brittle fracture, from the features of the surfaces of projectile holes, is important for gaining insight into the behaviour of target materials under high velocity impact [9][10]. Adiabatic shear bands are common in cases of high strain rate and are likely to occur in cases of ballistic impact failure, due to the prevailing high strain rates and the attendant thermosoftening [11].

RESULTS AND DISCUSSION
The high velocity ballistic impact tests conducted on both types of Ti6Al4V alloys revealed a minimum thickness to prevent through penetration that is just above 14 mm.

The projectile penetration hole exhibited brittle fracture smeared surface and ductile failure at the entry, mid-depth and exit sides, respectively, with microstructural changes occurring within a limited distance radially from the surface of penetration. The average size of the α laths in wrought Ti6Al4V fell within the range of 2.17 μm and 2.33 μm at distances of 25 – 40 mm the edge of the penetration holes, with signs of globular α grains. Microstructural analysis of the stress relieved DMLS Ti6Al4V (ELI), revealed a microstructure comprised of a combination of lamellae and Widmanstätten microstructure within elongated prior β columnar grains near the edge of the projectile holes with increasing content of α phase with increasing distance from the edge of the penetration hole.

CONCLUSIONS
Although wrought Ti6Al4V is classified as a ductile metal under normal low strain rate conditions of loading, the tests conducted here showed that under conditions of high velocity impact, both alloys exhibit brittle and ductile behaviour, at various points through the thickness of projectile, penetration holes.

The high strain rate and attendant high rise in temperature arising from high velocity impact led to the formation of adiabatic shear bands (ASBs) that served as sights in which cracks propagated thus forming paths for failure of
the materials, and whose incidence reduced with distance away from the edge of the projectile hole.

Contrary to expectations the higher hardness and strength of the as-built and stress relieved DMLS Ti6Al4V (ELI), this does not translate to a better resistance to penetration or more absorption of energy before failure of the target material.

REFERENCES


EFFECT OF VARYING ENERGY DENSITY ON THE MICROSTRUCTURE OF TIC/TI-6AL-4V METAL COMPOSITE

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ABSTRACT

Titanium-based alloys are reported to offer up to 50% strength to weight ratio. These lands titanium-based alloys as a preferred material over steel and nickel-base super-alloys, where strength and stiffness are required. The loss of strength and stiffness of titanium-based alloys at high temperatures prompt a need for a matrix of titanium to be braced with a material with superior properties, such as a ceramic. The reinforced particulate may be continuous or discontinuous particulates. In-situ synthesis with laser metal deposition (LMD) of Ti-6Al-4V-ELI braced with discontinuous particulates of TiC is expected to yield improved wear resistance and strength. Various fabrication methods and properties of titanium are well documented in the literature. This paper focuses on the effect of energy density on the microstructure of TiC/Ti-6Al-4V-ELI.

INTRODUCTION

Additive Manufacturing (AM) is based on incremental layer by layer manufacturing; this contrasts conventional, subtractive manufacturing methods (Emmelmann, et al., 2013). AM technologies commonly use powder or wire as a feedstock selectively melted by a focused heat source and consolidated in subsequent cooling to form a part (Carroll, et al., 2015). One of the most studied AM technologies is the powder blow system that incorporates the Laser Metal Deposition (LMD). AM has attracted attention over the past decades due to its inherent advantages, such as unrivaled design freedom and short lead times (Kranz, et al., 2015). LMD is a complicated technique influenced by numerous process factors, such as powder feed rate, laser power, and scanning speed. The four significant parameters, such as laser power P (W), scanning velocity v (mm .s⁻¹), and layer thickness d (mm), can be combined in the Laser EnergyDensity (LED), also known as volume energy, using the formula LED = P/(vd) (J.mm⁻²).

The relation between the process, microstructure, and properties of AM technology still need to be explored. To argue the effectiveness of AM is
justified, the material's microstructure and mechanical properties are studied and equated with those of a conventionally manufactured. Titanium (Ti) alloys have low hardness values, poor resistance to wear, and oxidation at elevated temperatures (Polmear, 1981).

Ti-6Al-4V (Ti-64) alloy is the workhorse titanium alloy in the aerospace industry because of its excellent corrosion resistance and toughness (Tabrizi, et al., 2015) (Lu, et al., 2012). The low surface hardness and wear resistance of Ti-6Al-4V restricts its application (Xing, et al., 2011). The introduction of ceramic particulate reinforced TMC is confirmed to be an efficient way to enhance the hardness and tensile properties of Ti-6Al-4V (Xing, et al., 2013). TiC is studied as a favorite particulate reinforcement for the Ti-6Al-4V matrix composite predicted on its high thermal stability, high hardness, and harmony with titanium alloy (Qi, et al., 2012) (Wang, et al., 2014).

In this study, a TiC/Ti-6Al-4V-ELI metal matrix composite will be fabricated by LMD processes using Ti-6Al-4V-ELI and TiC powders to get a 3.85% TiC volume fraction. The formation mechanism of primary and eutectic TiC will be studied together with the microstructure and microhardness of the TiC/Ti-6Al-4V-ELI metal matrix composite. In addition, the influence of direct and eutectic TiC on the microhardness of TiC/Ti-6Al-4V-ELI will be discussed.

**METHODOLOGY AND RESULTS**

A Ti-6Al-4V plate with the following dimensions 72x72x5 mm³ was used as a substrate. The materials were used in this study were TiC powder with an average particle size ranging from 129 to 206 µm and Ti-6Al-4V-ELI powder with an average particle distribution of 182 to 241 µm with a purity of 99%. A 3 kW IPG multi-mode Ytterbium fiber laser (1073 nm) was used to manufacture the TiC/Ti-6Al-4V-ELI MMC horizontal multitrack onto the Ti-6Al-4V plate. Two hoppers were utilized for both powders. During the laser metal deposition process, as described in the figure. 1, the coaxial nozzle moved 193 mm distance paralleling to the substrate for single-layer deposition. The powder feed rate was kept constant at 0.2 rpm TiC and 5.0 rpm Ti64-ELI. The argon gas was used as the carrier and shielding gas, the flow of which was maintained at 1.5 l/min and in the range of 15 l/min, respectively. The laser scanning speed and laser spot size were maintained at 0.5 m/min and 2 mm all the time during the laser metal deposition process. The laser power was controlled manually to produce a set of 5 overlapping tracks by 50%, between 1800 W, 1900 Wand 2000 W, for each group, respectively.

Micro-hardness
CONCLUSION

Increasing the energy density affects the morphology of the TMC matrix and TiC. There is a significant size reduction in the partially or unmelted particles of TiC. The hardness value remains unchanged in the range of 400 HV0.3 with a tolerance of ±50 HV0.3.

REFERENCES


Edward Arnold.


ABSTRACTS

DAY 1

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INFLUENCE OF POWDER CHARACTERISTICS ON THE SPREADABILITY OF PRE-ALLOYED WC-CO

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ABSTRACT

With rising interest in additive manufacturing (AM) techniques, there is increased focus on research that evaluates critical parameters that guide the selection of powders suitable for AM. One such parameter is the spreadability of a powder, described by metrics such as spread density and percentage coverage. This study focuses on spray-dried WC-Co powders (12 and 17 wt% Co) and evaluates the influence of typical powder characteristics, such as particle size and shape, apparent density and flow rate, on their spreadability.

INTRODUCTION

Cemented carbides are metal matrix composites where metallic carbides, such as WC, TiC, or TaC, act as reinforcing particles inside a metallic matrix, typically Co- or Ni-based; they are traditionally produced via the press-and-sinter powder metallurgy (PM) technique [1],[2]. The WC-Co composite is a common cemented carbide that is traditionally used for cutting inserts or high wear tool parts due to its excellent combination of thermal stability, and high hardness and toughness [1],[3]. Laser powder bed fusion (LPBF), an additive manufacturing (AM) technique, provides a potential alternative to conventional production methods, by offering advantages in the reduction of production time and feasibility of manufacturing complex geometries [2],[3]. High quality LPBF products depend on the use of powder that has suitable spreadability characteristics.

The aim of this study is to determine the link between typical powder characteristics and powder spreadability metrics, specifically for spray-dried WC-Co powders, at Co contents of 12 and 17 wt%, respectively. Single tracks,
produced using LPBF, are evaluated to link spreadability results with LPBF performance.

**METHODOLOGY AND RESULTS**

Three different spray-dried WC-Co powders, two with 12 wt% Co and one with 17 wt% Co, were evaluated. Powder characteristics of particle size distribution by light scattering, powder particle morphology by SEM, crystal structure by powder XRD, apparent density and flow rate according to ASTM standards B212, B213 and B417 were evaluated for all powders. Additionally, spreadability metrics of spread density and percentage coverage were determined for the powders [4],[5].

**CONCLUSION**

Links between typical powder characteristics and spreadability parameters for spray-dried WC-Co powders were identified.

**ACKNOWLEDGEMENTS**

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**REFERENCES**


CHARACTERIZATION OF POLYPROPYLENE POWDER PRODUCED BY PRECIPITATION FOR POWDER BED FUSION ADDITIVE MANUFACTURING

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ABSTRACT

Laser sinter additive manufacturing is a technology that uses a laser to selectively melt powder to manufacture fully dense parts for medical and many engineering applications. The limited selection of polymeric materials for the production of powder suitable for laser sintering (LS) remains a challenge to overcome. Polypropylene is a polymeric material with a potential to increase the selection of polymers for the LS process. Precipitating a mixture of HNR100 and HTV145 polypropylene grades from SASOL in xylene with talc added, powder with particle size suitable for LS was obtained. Carbon black was added to the dried powder to enhance the flowability and laser energy absorption.

INTRODUCTION

Goodridge et al. [1] reported that although LS can process a wide range of materials, 95% of LS production processes of prototypes and functional parts that are based on polymers, involves only nylon polyamides PA11 or PA12.

Cryogenic grinding is one of the techniques through which polymeric granules or pellets can be converted into powder particles of average size ranging from 50 to 125 µm [2]. However, particles obtained through comminution grinding are characterized by irregular shapes, leading to poor flowability of the powder during the LS process [3, 4, & 5]. Liquid-Liquid Phase Separation (LLPS) is a
physico-chemical technique whereby a polymer in the form of granules or pellets is heated in a solvent such as xylene while continuously stirring until complete dissolution is obtained [6]. Under quiescent conditions, the cooling and precipitation of such a solution results in the formation of spherical particles that can be used as a polymeric powder for the LS process. This study aims to characterize powder obtained through precipitation of polypropylene pellets from SASOL to determine its suitability for laser sinter additive manufacturing.

METHODOLOGY AND RESULTS

A mixture of two polypropylene grades, namely HNR100 (70 wt%) and HTV145 (20 wt%) from SASOL were dissolved under heat in xylene together with talc (10 wt%). After precipitation, the powder was dried, ground and sieved up to 90 µm. One gram of carbon black was added to every batch of 400 g of the dry mixture to enhance the laser absorption on the Sintratec S1 machine that was used in the study and to improve the flowability of the powder. Tests performed on the powder for characterization included flowability, packing density, differential scanning calorimetry, thermogravimetric analysis and scanning electron microscopy.

Results and discussions from the research will be presented in the full RAPDASA 2021 paper.

CONCLUSION

It proved possible to produce polypropylene powder with particles with the correct morphology, powder size distribution and physical properties for the laser sinter additive manufacturing process through the precipitation process.

REFERENCES


PARAMETERS AFFECTING THE MIXING OF POWDERS FOR ADDITIVE MANUFACTURING AND THE RESULTS OF MIXING SiC AND Ti6Al4V POWDERS

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ABSTRACT

Segregation and agglomeration are major problems in the mixing of powder intended for use in additive manufacturing and the prevention and limitation of these phenomena are very important in powder-mixing. The particle size distribution of the constituents used in a powder mixture is one of the key factors that determine the homogeneity of the mixture, though differences in particles density and shape are also known to cause segregation in mixtures. This paper provides a review of existing methods of sampling and mixing powders, and specifically addresses the mixing of SiC/Ti6Al4V powders for additive manufacturing. The parameters affecting the quality of mixture that are considered in this paper include powder homogeneity and heterogeneity, size distribution, particle shape, and methods of mixing.

INTRODUCTION

Powder mixing is an important process in blending of components as it combines different powders into single products that must meet specifications and standards based on the homogeneity of mixes [1]. Powder mixing is widely used in areas such as pharmaceuticals, powder metallurgy, as well as processing of food and cement.

Additive Manufacturing (AM) is a technique which uses 3D model data to build parts in a process of layer by layer fashion until a complete component is produced. Additively manufactured parts are affected by powder segregation and agglomeration during production. Powder segregation is defined as the separation of portions of particles from one another [2]. Segregation is caused by differences in the physical properties of particles such as particle size, shape
and density [3,4]. Agglomeration is defined as the sticking of individual particles to one another because of forces between them.

There are two broad categories of the methods of mixing powder, namely batch and continuous methods. Continuous methods involve the mixing of different powders which are fed continuously to a mixer and an equal amount of powder is discharged continuously on the other side of the mixer as the mixing continues [1]. In batch mixing methods, the constituent powders are loaded into a mixer, mixed until the powder is homogenous then discharged as a single batch.

This paper presents a review of mixing methods and further, sampling methods suitable for determining the uniformity of powder mixtures. The results of batch automated mixing of silicon carbide (SiC) and Ti6Al4V at different volume fractions of SiC particles are presented and discussed based on the results of scanning electron microscopy (SEM) of the mixed powders. The SEM scans of the individual powders are also presented and discussed.

**METHODOLOGY**

Silicon carbide and Ti6Al4V powders were mixed using a multi-tube rotary batch mixer. The mixer has five tubes, into each of which was inserted sealed containers with SiC and Ti6Al4V powders for mixing. As there were six containers, each bearing a different volume fraction of mixture, only four containers were used for mixing during the first round and the last two in the second round of mixing. The tubes had a diameter of 45 mm and length of 160 mm. The powder was mixed for thirty minutes and then analyzed using the SEM.

**RESULTS AND DISCUSSION**

For 5% -10% volume fractions, the SiC particles were dispersed randomly amongst the Ti6Al4V (ELI) particles, without clustering or agglomeration. Clustering or agglomeration of particles was seen to occur at a volume fraction of SiC of 15% and higher. Reduced segregation was observed after mixing of the powders in the multi-tube rotary batch mixer. Satellites and small particles of SiC on the surfaces of large Ti6Al4V particles were observed to increase with the addition of SiC particles and subsequent mixing. This implies that small particles of Ti6Al4V (ELI) and SiC were broken off the larger pieces during mixing.

**CONCLUSION**

- Batch mixing methods are suitable for small products and do not require large quantities of constituent powders to be mixed unlike continuous mixing methods.
• Similar properties of different samples of a mixture obtained during sampling indicate the homogeneity of the mixture.
• Increase in the difference of the size of particles increases segregation.
• Increase in volume fraction of SiC particles led to an increase of agglomeration of both SiC and Ti6Al4V particles.
• Satellite particles on the surfaces of large Ti6Al4V particles increased in number with the addition of and mixing of small SiC particles.

REFERENCES


LASER METAL DEPOSITION OF TiB$_2$/TiC/Ti6Al4V COMPOSITES

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ABSTRACT

Ti6Al4V alloy is used in aerospace, marine and automotive industries due to its excellent properties such as superior strength, high stiffness, and exceptional corrosion resistance. However, its application is limited due to poor high-temperature mechanical properties, while titanium matrix composites offer good high-temperature mechanical properties. In this study, TiB$_2$ and TiC reinforcements were added in Ti6Al4V ELI bulk matrix to produce titanium matrix composites, TiB$_w$/TiC/Ti6Al4V ELI. The effect of laser reinforcement material on the microstructure and hardness properties of the TiB$_2$/TiC/Ti6Al4V ELI composites were investigated.
Figure 1: Microstructure of TiB\textsubscript{2}/TiC/Ti6Al4V ELI that was produced by varying the volume ratio of TiB\textsubscript{2} and TiC.

Figure 2: Hardness profile of the TiB\textsubscript{2}/TiC/Ti6Al4V ELI at different volume ratios.
Development of novel bioinks for bioprinting and tissue engineering

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ABSTRACT

The unmet demand for tissue and organs shortages in the medical industry has led to research focussed on developing alternative treatment options. To overcome this tissue engineering approaches along with bioprinting has been fields of research receiving a lot of attention in recent years. One of the main challenges that hinder the utilization of bioprinting in tissue engineering is the development of novel bioinks. In bioprinting a successful scaffold is not only determined by structural properties, but also through the survival and function of cells post-fabrication. This together with designing a printable bioink is a daunting task. This review will focus on the development of novel bioinks and will provide a road map for optimization of process parameters.

INTRODUCTION

Additive manufacturing has been adopted in various fields of industry to overcome the limitations of traditional manufacturing. The ability of AM to fabricate objects with complex and intricate geometries made it particularly attractive for the medical industry. Additive manufacturing is currently widely used in personalized medicine to fabricate dental parts, medical implants and orthopedic medical devices [1]. The limited supply of donor organs and tissues remains a major challenge in the medical industry. This demand created the opportunity in the field of tissue engineering to develop substitutes for organs and tissue [2]. With these public health challenges bioprinting an additive manufacturing technology has been instrumental in ongoing research in regenerative medicine and tissue engineering field [3]. Although the main aim of tissue engineering is to design tissue and organs to replace or repair original tissue, successful bioprinting of functional and reliable tissue models for in vitro models that can be used for testing the efficacy and toxicity of drugs is also very promising. In light of this, a lot of research has been dedicated to tissue engineering and bioprinting in recent years [4].
The general approach of tissue engineering is to combine living cells and a matrix or scaffold and/or bioactive molecules in order to establish an engineered construct that is inserted into a defect site to promote the regeneration or repair of tissue [5]. Regenerative medicine combines tissue engineering with other strategies which include cell-based therapy, gene therapy and immunomodulation to induce in vivo tissue or organ regeneration [6]. Bioprinting is used to fabricate the matrix or scaffold using a bioink which contain biomaterials and living cells. In principle, bioprinting is the process of simultaneous and controlled patterning of living cells and biomaterials (bioinks) in a predefined structure while preserving cell viability [7],[8]. The development of bioinks that can be used in bioprinting methods has gained a great deal of attention in recent years.

One of the major challenges in bioprinting is the development of the biomaterial. With various parameters dictating the success of the print. In bioprinting a successful print is not determined only by structural properties but also the survival and function of cells after printing [4]. This study will review the process of developing a bioink and provide a road map for optimizing process parameters for novel bioinks

REFERENCES


RISK BASED CLASSIFICATION OF POWDER BED DEFECTS

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ABSTRACT

The detection and classification of surface defects that occur during powder bed additive manufacturing processes, is currently receiving of attention from various researchers. Most research studies focus on the detection and classification of defects to make the technology more reliable. However, it is very important to determine the risks that these defects pose to the outcome of the build and final part. This study aims to develop a risk-based defect classification method. The results will be used to develop a defect decision matrix that could be used to determine the appropriate course of action during a build for the different types of defects.

INTRODUCTION

With the steady adoption of AM technologies in industry, part of the drive to make AM technologies more stable, repeatable, certifiable and increase industry adoption has given rise to new quality control methods. An area of research that has grown steadily has been the detection and classification of powder bed surface defects that occur during the printing process [1],[2]. Most of these studies focused on the detection of defects [1],[2], with some studies looking to classify defects according to type using machine learning algorithms [3]. Since AM machines do not use closed loop feedback systems, repairing defects during the build process is very difficult and requires an operator to physically monitor the build process. In order to autonomously monitor the build, the detection and classification of defects must be performed automatically without any user intervention. To develop a closed loop feedback system, it is necessary to be able to first determine what risk the defect poses to the build and the part. Once the defect risk can be determined, decisions can be made as to what the appropriate action should be to rectify the defect.

PROPOSED RISK ASSESSMENT METHOD

This study aims to develop a risk classification method that could be used to define the effects a defect has on the final part and the outcome of the build. This method will be developed using existing methodologies that are used by both the Medical AM [4] and Civil engineering industry [5]. Although the types of defects analysed by these studies are not relevant to this study, the methods used to classify these defects according to
risk are of significant value to this study. The risk can be measured using qualitative parameters, and where possible, quantified.

It is of great importance to perform a detailed risk assessment on each of the defects that has been encountered in literature. However, literature mostly outlines the effect that each type of defect has on the final part, but not the risk that each defect would have on the outcome of the final built part. Thus, it would be important to consult with experts in the AM field to determine what types of defects has been observed, the effect these defects had on the outcome of the build, as well as how they would rate the severity, likelihood and detectability of the defect. This information could be used to develop a defect decision matrix, the appropriate course of action during a build for the different types of defects.

REFERENCES


EFFICIENCY EVALUATION OF A HIGH-TEMPERATURE PREHEATING SYSTEM FOR ADDITIVE MANUFACTURING

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ABSTRACT

Additive Manufacturing (AM) of titanium using selective laser melting (SLM) may generate significant residual stresses, which can cause premature component failure. The Aeroswift platform is a large volume machine using high-temperature baseplate preheating to mitigate high thermal gradients. The preheating system currently cannot reach the target temperature of 600°C. This study focuses on evaluating the performance of the preheating system using Finite Element Analysis (FEA) to determine the cause of its inefficiency. FEA achieved 395°C maximum temperature due to the thin thermal insulation applied, mechanical components, and heater power. Findings will inform design modifications of the preheating system.

INTRODUCTION

AM creates 3D components layer-by-layer from computer-aided drafting (CAD) models [1]. Aeroswift is an AM machine that uses SLM technology to build complex titanium parts using a 5kW fibre laser. SLM processing creates large thermal stresses due to high temperatures, laser melting and fast cooling, resulting in part cracking or warping [2]. Ali et al. demonstrated significant stress reduction by applying high-temperature preheating [3]. Saewe et al. preheated the baseplate at 500°C and achieved dense and crack-free specimens of high speed steel with an improved microstructure and mean hardness [4]. Based on a performance test, the Aeroswift’s preheating system could not reach the target temperature of 600°C at the base plate, thus limiting its ability to reduce residual stresses during processing. This study evaluates the preheater performance to determine the cause of its inefficiency to make recommendations on design upgrades that will improve the preheating system’s performance.
METHODOLOGY AND RESULTS

Thermal analysis was performed using Siemens NX (Simcenter Thermal/Flow). The preheating system was modelled in 3D which included the stainless steel walls, titanium buildplates, mild steel baseplate, thermal insulation material, ceramic heaters, and stainless steel support structures. The heaters were modelled according to the manufacturer output specification of 3kW where convection and radiation losses to the environment were considered with an ambient temperature of 30°C. Perfect contact resistances were assumed to all surfaces that were in contact.

Modeled results show that the base plate temperature is 383.14°C, which is in-line with an experimental reference. It is observed that 86% of the heat is transferred through the 5mm insulation material. The simulated heater reached a maximum temperature of 395°C with 3 kW, which is lower than expected. The temperatures of the lower portion of the insulation, the heater holder, and pillar were 341°C, 327°C, and 200°C respectively.

CONCLUSION

The preheating system only achieves 63.8% of the required baseplate temperature. Early modelling reveals that the 5 mm of insulation material is an ineffective solution as 86% of heat managed to pass through the insulation material, and therefore requires a design upgrade to accommodate thicker insulation. Recommendations include: a reduced number of components, and a critical evaluation of the required insulation layer thickness. Experimental testing is planned to validate the model, provide further insight into the problem, and formulate a solution.

REFERENCES

ABSTRACT

Powder characterisation is an important issue to understand, as manufactured parts with reliable results are desired. In this study, the metal powders used in Selective Laser Melting (SLM) will be investigated regarding particle size distribution and morphology. Correlations between the powder properties being investigated and the final part properties will be made. The interaction of SLM powders is dependent on the machine and process parameters, thus the ramifications of varying particle size distributions will be evaluated.

INTRODUCTION

The process of Selective Laser Melting (SLM) employs the use of powder as the feedstock to manufacture a desired geometry, hence forming part of the powder bed fusion division of Additive Manufacturing (AM). Within SLM there are multiple process parameters that interact with the powder such as the layer height, laser power and scan speed. In turn the final part properties are a function of the complex relationship between powder and processing parameters.

When analysing powder for SLM the main extrinsic characteristics are the particle size distribution (PSD) and particle morphology. The process of generating each consecutive layer in SLM utilises a scraper arm that deposits a new layer of powder over the previous layer. Therefore, having a powder that is spherical with a good flowability is key to ensure no agglomeration occurs on
the build platform and a clean layer of powder is deposited. Powders with a wide distribution tend to have increased packing efficiency whereas narrow powder granulations exhibit increased flowability. The interaction between the laser beam and the powder generates a melt pool with the scan speed determining the interaction time between the powder particles and the laser [1]. Ideally, the interaction time must instigate a molten pool for a long enough period of time to allow the powder particles to reshape from its initial random packing and form a single track. The denser the powder bed generated on the build platform, the smaller the voids present between particles are, hence requiring less reshaping of particles within the molten pool. With less reshaping required, higher scan speeds are possible without compromising on part quality [1,2]. Ultimately the particle size distribution and particle morphology influence the powder bed density.

In additive manufacturing a part with a smooth surface finish, high dimensional accuracy, and a near 100% relative density is desired; particle size distribution and morphology directly impact these final part properties. SLM manufactured parts tend to warp due to residual stresses, literature has shown that a high powder bed density reduces the residual stress and porosities present [3]. A particle size distribution that is biased towards finer particles increases the powder bed density [4–7], however too many fine particles tend to create inter-particle friction and agglomeration occurs [8]. With a finer particle size distribution present, a lower energy density is required to achieve complete melting as compared to a coarser granulation [9]. Literature has shown that a fine narrow powder granulation increases hardness and ultimate tensile strength [7] whilst coarser powder granulations increase elongation in manufactured parts [10].

The quality and repeatability of SLM components is hindered by the presence of porosity; the shape and distribution of the porosity being influenced by the relationship between the powder characteristics and processing parameters used within SLM. The optimisation of processing parameters to improve part quality and minimise process variability has been thoroughly investigated. However, there is a lack of knowledge on understanding the effect of the powder characteristics, particularly the PSD and the processing parameters on the resulting part properties of selective laser melted CoCr parts.

**METHODOLOGY**

The study is still yet to yield results; thus, the following methodology will be followed to produce results:

1. Determine the powder characteristics of the CoCr powder:
   a. Determine the PSD and powder morphology using laser light diffraction.
b. Determine the apparent and tapped density of the CoCr powder.

2. Manufacture 10x10x10 mm cubic specimens to determine the part density:
   a. Manufacture twelve cubic specimens over two layer thicknesses at different positions on the build plate.
   b. Make use of Archimedes principle to determine the part density.
   c. Section the cubic specimens and evaluate the porosity present within the cube via optical imaging and correlate the porosity present to the Archimedes density results.
   d. Determine the effect layer thickness and the build position on the build plate has on the part density.

3. Manufacture capsule specimens at varying layer thicknesses to determine the powder bed density:
   a. Manufacture three capsules at different positions on the build plate to determine the powder bed density.
   b. Determine whether the PSD changes at the different build plate positions.

4. Apply methodology steps 1 – 3 with both CoCr powder granulations to determine the correlation between the PSD and layer thickness on the powder bed density and resulting part density. Compare the two powder granulations and develop a model representing the micro-macro relationship between the PSD, layer thickness and the resulting part density.
Figure 1: Flow Diagram of Research
CONCLUSION

The results of the study will broaden the knowledge we have on powder characteristics influence on SLM manufactured parts – specifically the influence of particle size distribution and morphology on part density. Through the comprehensive study of two powder granulations, comparisons will be made to determine the extent to which the particle size distribution and morphology influences the powder bed density, part density and mechanical properties.

REFERENCES


VALIDATION AND INVESTIGATION OF DEFORMATION PREDICTION AND DEFORMATION COMPENSATION FOR ADDITIVE MANUFACTURING

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ABSTRACT.

In specialized fields such as engineering and medicine, the dimensional accuracy of components is important. The selective laser melting process induces a series of heating and cooling cycles with high thermal gradients. These cycles can lead to the development of residual stress in the component which can result in deformation of the component. Accurate calibration with the help of mathematical models and computer software such as Simufact Additive makes it possible to calculate, predict and compensate for the deformation that will occur in the component during fabrication. With the use of mathematical models and computer software such as Simufact Additive makes it possible to calculate, predict and compensate for the deformation that will occur in the component during fabrication. A detailed calibration of the machine and numerical methods, using Simufact Additive, will be completed to investigate and validate the accuracy of deformation prediction and deformation compensation for selective laser melting.

INTRODUCTION

During the SLM process, a high-power density laser melts the powder particles to produce an approximate net-shape part with near full density of up to 99.5%. [1]. As the laser is highly localized, the steep heating and cooling gradient during the SLM process can produce non-uniform thermal expansion and contraction in the manufactured part also known as thermal strain. The effect of thermal strain is a complicated distribution of residual stresses in affected zones of the component. As a result, the internal stress caused by thermal strain can lead to distortion, fatigue, and fracture of components during manufacturing [2]. AM is
mostly used for prototyping and manufacturing custom components ranging from aerospace to medical applications. As AM is a relatively new manufacturing technology defects and failed parts are a common occurrence. Defects such as delamination, deformation and insufficient dimensional tolerance will lead to failure of the component.

With each failed component the running cost of part manufacturing will exponentially increase and the operation runs the risk of damage to the machine[3]. Instead of using a trial-and-error approach to find parameters for the AM machine that will yield a high success rate of fabrication, more sophisticated methods can be used. Methods such as computer simulations, can be used to find compatible fabrication parameters to increase component success, decrease defects, and minimizing losses due to failure. Computer software can enable the possibility to calculate, predict and compensate for defects such as deformation and minimizing residual stress in manufactured components [4]. By predicting and compensating for many of the defects that can occur during the AM process, the cost can be decreased while increasing the dimensional accuracy. Before any prediction and compensations can be made to increase the success rate of fabrication, the machine and simulation software must be calibrated to ensure the simulated values and the experimental value correlate. By calibrating the parameters of the machine to the variables of the software all prototyping can be done in a virtual manner to ensure the fabricated component is as close to its digital twin a possible, saving cost on material, energy, and time.

METHODOLOGY AND RESULTS.

Methodology

This study is divided into 3 main phases, the calibration phase, verification phase, and deformation compensation phase. For the calibration phase of this study, cantilever beams were fabricated using an Orlas creator using cobalt chrome as a feed stock material. After fabrication, the cantilevers were sectioned to measure the tip deformation on various points. The deformation was used as experimental data inputs for the software package, Simufact Additive, to calibrate the machine and software parameters. After the parameters were set the strain tensor values were calculated in the xx and yy direction.

The verification phase consists of a complex geometry component that was fabricated and measured. A simulation with the experimental strain tensors was solved and the measured points used as a reference comparison between the experimental data points and predicted data points. This phase was implemented to validate the accuracy of the prediction methods used in Simufact Additive.
The deformation compensation phase consists of the same complex geometry component simulated with the addition of the deformation compensation algorithm. The reference points of were used to measure and investigate the maximum deformation, dimensional accuracy, and to compare the geometry of the component with the original design validating this method.

REFERENCES


EFFECT OF STRESS-RELIEF ANNEAL TIME ON RESIDUAL STRESS OF CO-CR-MO PARTS MANUFACTURED WITH SELECTIVE LASER MELTING

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ABSTRACT

Additive manufacturing (AM) is a 3D manufacturing technique which allows the user to create designs with complex geometries faster than ever before. Dental prosthetic devices however require tolerances of at least 25 micrometers and therefore AM is not fully utilized for the manufacturing of these parts. Thermal residual stress inherent in the metal melting and solidification process is the main cause of part deformation and cracking in metal AM. To ensure build quality against residual stress, post-process heat treatment is required. Limited knowledge is available on the impact the stress-relief anneal time has on the residual stress in AM parts. This study will numerically and empirically demonstrate the effect of stress-relief anneal time on residual stress with variations within this time profile.

INTRODUCTION

Additive manufacturing (AM) is a three-dimensional (3D) manufacturing technique which allows the user to create designs with complex geometries. Various materials have been added to the AM database including dental materials such as dental polymers and dental metal alloys [1–3]. Selective Laser Melting (SLM) is an AM process that has improved significantly over years of research and offers the possibility to produce parts with near 100% density. One of the disadvantages is residual stress within the printed parts due to thermal gradients during the manufacturing process. The heat treatment used to minimize the residual stress is known as stress-relief anneal [4].

Several studies have investigated the effect of stress-relief annealing on the microstructure and mechanical properties of additively manufactured metal
components. The research shows that stress-relief annealing significantly improves the microstructure and mechanical properties of printed parts [5–7]. The studies that measured the residual stress before and after stress-relief heat treatment concluded that the residual stress significantly decreased after the heat treatment was performed. These studies used varying annealing times ranging from 15 minutes up to 6 hours. More research is therefore required to fully understand the influence of stress-relief annealing time on the residual stress.

METHODOLOGY AND RESULTS

Literature review

The following subjects were researched comprehensively to obtain the relevant information:

Table 1: Literature review topics.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residual stress in SLM manufactured parts</td>
<td>Residual stress in SLM manufactured parts occurs due to thermal inconsistencies. Studies that investigated the effects of residual stress in SLM were researched.</td>
</tr>
<tr>
<td>Stress-relief heat treatment</td>
<td>Several studies have researched the effect that post-process heat treatment has on the residual stress in SLM manufactured parts. These studies were researched extensively to ensure all necessary consideration were made when determining the heat treatment strategy.</td>
</tr>
<tr>
<td>Neutron diffraction</td>
<td>Neutron diffraction is a method used to determine inherent strain in materials. The inherent strain is then used to determine the residual stress. The method was researched to ensure that this method consistently measures accurately.</td>
</tr>
</tbody>
</table>

Research method

- Manufacture Co-Cr samples on ORLAS Creator.
- Perform stress-relief annealing for four time-variations: 15min, 30min, 1 hour, 2 hours. The heating strategy is presented in Figure 1 below.
- Use Neutron Diffraction to determine residual stress.
- Analyse results to determine the effect that stress-relief annealing time has on residual stress.
Perform analysis with Simufact Additive software to validate results.

Results
The Neutron Diffraction and Simufact Additive simulations are yet to be completed.

CONCLUSION
Conclusion will be drawn based on the results that are yet to be attained.

REFERENCES


PREDICTION OF THE INTER-LAYER ADHESION IN POLYMER ADDITIVE MANUFACTURING

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ABSTRACT

Based on the computed thermal history of the material, Digimat-AM (a process simulation software dedicated to FFF and SLS) now integrates inter-layer adhesion indicators relying on polymer healing theory. In this presentation, we will highlight how this capability enables the Engineer to anticipate the risk of printing issues such as layer delamination and optimize the design performance.

INTRODUCTION

Additive Manufacturing (AM) is about manufacturing a new material from raw feedstock (powder, filament, pellets, …) under given process conditions (printer temperature, build direction, toolpath, …) that directly impact the material properties. In AM, even homogeneous materials (polymer or metal) may exhibit an anisotropic behavior, typically showing different material properties (stiffness, strength) in the layers stacking direction. AM materials are thus strongly dependent on the process, constraining the high-end industries (such as aerospace) to certify an ensemble material+printer+process+part.

In material extrusion processes (FFF, FDM, BAAM, …) in particular, the inter-layer adhesion has been the focus of many researches. A 3D printed part is indeed intrinsically made of a succession of layers that can be seen as welding areas – thus driven by thermal processes leading to microstructural/phase changes and defining the inter-layer bonding quality.

METHODOLOGY AND RESULTS

Thermal history

One challenge in AM of plastics and composites is accurately predicting the temperature gradients during the build process. Digimat-AM is able to simulate the thermal history, taking into account the extrusion of molten material, the latent heat of phase change, conduction, radiation and convection from the environment.
Layer adhesion

It is assumed that intimate contact is already achieved at onset of healing. Therefore, we only focus on the development of the adhesion indicator $D_h$ (value between 0 and 1), or degree of healing, which is an indication of how much stress the interface between two layers can sustain:

$$D_h(t) = \frac{\sigma}{\sigma_\infty}$$

where $\sigma$ is the tensile strength of the layer interface and $\sigma_\infty$ is the tensile strength of the bulk material. When $D_h = 1$, the layer adhesion is perfectly achieved. Two such models have been implemented and investigated in this study:

2. Akkerman [2] model, more suited to semi-crystalline materials according to its authors.

![Figure 1: Layer adhesion prediction based on the thermal history.](image)

CONCLUSION

In this presentation, we demonstrate how simulating the layer adhesion in function of the material and process setup will give a significant advantage to the Engineer to optimize the material performance, and ultimately the overall design performance.

REFERENCES

DEVELOPMENT OF A MULTIPURPOSE, OUTDOOR AUTONOMOUS GROUND VEHICLE FOR AGRICULTURAL INSPECTION

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ABSTRACT

The Dassie robot platform is a rugged outdoor autonomous vehicle, capable of moving through rough terrain whilst carrying a heavy payload and operating for long periods of time. It is designed to autonomously perform inspections of rows of grape vines in a vineyard. The design and testing of this system are covered in this paper.

INTRODUCTION

The aim of the “Dassie” platform was to be a locally designed and built, multi-purpose robotic platform, with the initial application in agricultural inspection. For the agricultural inspection application, the platform carries a sensor payload consisting of a lidar, temperature sensors and gimbal stabilised cameras. Multiple iterations of the “Dassie” platform have been designed and built, implementing learnings from each iteration.
The platform needed to conform to the following requirements:

- Navigate and turn within an average width vineyard row.
- Autonomously navigate through vineyard rows, whilst avoiding obstacles.
- Provide a modular payload mount with power and communications.
- Provide a long operating time in a rugged outdoor environment.
- Provide cliff and active sensing bumpers for self-preservation.

This paper focuses on the development and testing of the Mk II version of the platform.

**METHODOLOGY AND RESULTS**

The development started with identification of the major issues in the previous iteration, e.g. ground clearance, chain tensioning and battery management. These learnings and the system requirements informed the platform design. After the platform design, the automation algorithms were developed and refined in simulation concurrently with the manufacture of the platform. The use of the simulated development environment was invaluable but could not account for real-world sensor issues such as IMU interference and sub-par GPS accuracy. The design of the platform did address the drawbacks of the Mk I version but introduced several new challenges arising from the increased weight of the platform.

**CONCLUSION**

Inputs from the previous version were used together with the system requirements to inform the platform design. The platform was simulated using ROS [1] and Gazebo [2] allowing the automation algorithms to be developed while the platform was being constructed. The platform met the requirements for an outdoor agricultural inspection vehicle and has been successfully deployed. Future work will focus on addressing the challenges introduced by the platform size as well as improving the sensing and navigation robustness.

**REFERENCES**


VLOS AND BVLOS RPAS OPERATORS CERTIFICATE: CASE STUDY FOR INSPECTION REQUIREMENTS

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ABSTRACT

With the recent regulations for remote piloted licenses, implemented by the civil aviation authority (CAA), the procedures and steps required to have all paperwork, documentation and approvals for commercial remote piloted aircraft systems (RPAS) flights of with many uncertainties. This paper looks at the different tasks, documentation and approvals that will be required to obtain a RPAS operator’s certificate (ROC). A case study of tests that were conducted for the CAA are analysed, and the possible ways to decrease the delay for commercial flight income is given. The case study includes RPAS in Visual Line of Sight (VLOS), Beyond Visual Line of Sight (BVLOS), flights in controlled airspace, and night flights.

INTRODUCTION

The requirement for a remote piloted license (RPL) are important for the safe operation of a drone, remote piloted aircraft system (RPAS), or unmanned aerial vehicle (UAV) [1]. A visual line of sight (VLOS) RPAS Operators Certificate (ROC) is the next step required for a company to be able to have a drone to fly commercially as per part 101 regulations [2]. Further details for beyond line of sight (BVLOS), flights in controlled airspace, and night flights are added to the ROC once it is implemented.

The reason for the ROC, is to make sure that the correct procedures are followed as per the Remote Operator’s Manual (ROM), to make sure aviation safety, not only for people, buildings, and property are taken into account, but also for other aircraft using the airspace, as there is a chance for collision and threats [3]. An example of a reported collision of an RPAS with a manned aircraft, was in April 2015 in the USA [4].

The case study documented here is a collaboration with Starlite Aviation Group and Aerospace 3D, to show the visual line of sight (VLOS) flight operations that would be performed with an RPAS, within 10 km of an aerodrome.
Contributions of this paper are:
• Steps to follow and duration to prepare for the ROC.
• Hurdles experienced in the case study.
• Procedures to follow at the field testing inspection.

CONCLUSION

Obtaining an ROC for a company, requires numerous documentation to be created, approved, and assessed, which can take a time period of approximately 24 months. This estimated duration is if all documentation and applications have all the required information that is required for approval. The documentation that is approved is consider vital, as they all link up to allow for safe operations to be performed, by pursuing to decrease the possibility of injury, and damage to property.

Therefore, it is advised that once a RPL holder wants to fly a RPAS commercially, that they rather pursue with an agreement with an aviation company that has a ROC, which will allow for the person’s registered RPAS to be added to the current ROC. The duration for the additional aircraft to be added to the ROC by the CAA, is estimated to be approximately 3 months, if all documentation is as per the CAA requirements.

As seen in the case study, there are many steps that are required to be followed to prepare for the ROC. The hurdles experienced and the procedures that were to be considered for the field testing and demonstration, were shown. It was found that the initial approval of the ROC was best to pursue with a system that has shown reliability, such as the DJI RPAS, and once obtained, to have additional RPAS added. Furthermore, as it was described in this paper, it is better to have the ROC obtained for commercial flights, and have BVLOS, night flights and flights in controlled airspace added later on, to prevent a failure in the ROC due to a partial aspect that was not possible to be demonstrated, which might be unforeseen or not in control of the ROC holder or pilots.

REFERENCES


AN OCTOMAP-BASED 3D COSTMAP

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ABSTRACT

The development of OctoMap created an efficient, discrete, three-dimensional (3D) mapping framework that has been very useful in autonomous robotics for representing occupied and free space in the robot’s environment. This paper presents an OctoMap-based CostMap, with cell classifications to represent obstacle safety zones, exploration frontiers, and WiFi status, by rebranding free space with this information. The CostMap inherits OctoMap features, including efficient memory usage, and parent cells retain the set of cell types for all child cells, allowing efficient searching. Applications include aerial vehicle path planning. CostMap formation and an example in 3D motion planning are given.

INTRODUCTION

Motion planning in 3D space requires knowledge of occupied and unoccupied regions in the environment, and other information such as exploration frontiers and areas exhibiting communication problems can also be helpful. A CostMap can be used to retain and update this information. OctoMap [1] is an open-source mapping framework for 3D space, an occupancy grid that recursively divides a cube-shaped space into octants, and represents occupied and free space in the robot’s environment. The CostMap described here inherits from OctoMap and allows cells to be classified into specific types, including Drivable, Obstacle, Unsafe, Frontier, and WiFiLoss. The CostMap retains OctoMap features, including efficient memory usage, where compression can be applied to octants in which all child cells have the same cell type. Parent cells in the CostMap octree hierarchy retain the set of cell types for all child cells, which allows efficient searching for specific cell types. The CostMap is then useful for motion planning in 3D environments, and can also be used in visualization.
METHODOLOGY AND RESULTS

Figure 1 shows the inheritance diagram for the CostMap. Code is in C++ and inherits from classes in the existing, open-source, OctoMap software. New classes are marked with grey. The CostMapCellData status variable contains one bit per cell type, allowing cells in the CostMap to indicate all child types.

Figure 1: CostMap inheritance diagram.

Figure 2: Path planning in the 3D CostMap.

Figure 2 shows a point cloud environment with a WiFiLoss region shown in yellow. The blue arrow is the goal pose, and the robot is visible in grey. The green line is the computed path to the goal. Path planning is done in the CostMap and is constrained to lie within Drivable cells, avoiding other regions.

CONCLUSION

An OctoMap-based CostMap representation of a 3D environment allows a useful discretization of the environment, representing spatial constraints and permitting operations such as 3D path planning.

REFERENCES

GROUND ROBOT PATH PLANNING ON 3D MESH SURFACES USING LOCAL REGIONS

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ABSTRACT

The increasing application of ground robots requires efficient path planning algorithms in three-dimensional (3D) environments with nonspherical topology. Path planning on surface meshes is possible; however, expensive computation of geodesics is required. To reduce the length and, hence, cost of the geodesics, a growing submesh based on local regions is used. Rapidly-exploring random trees (RRT) with local regions are simulated and compared with the bi-directional variant, based on RRT-connect. Results show that RRT-connect with local regions reduces the computational burden for mesh-based path planning.

INTRODUCTION

Mesh surfaces enable direct representation of 3D environments and can model nonspherical topology, such as tunnels and bridges, encountered by ground robots in the real world. RRT and its bidirectional variant, RRT-connect [1] have been used to solve path planning problems in continuous spaces. Direct implementation of RRT on a mesh surface is computationally expensive due to the need to compute geodesics, the shortest paths on the mesh. New RRT points are sampled anywhere on the mesh so that potentially long geodesics must be computed. A local region is the mesh area of a specified radius around a tree node. By selecting new tree nodes from the union of local regions, the length and number of geodesics computed, and the computational cost, are reduced [2]. In RRT-connect, two trees grow toward each other to a point where the trees connect, and may further reduce the computation time. This study introduces RRT-connect with local regions for mesh-based path planning.
PLANNING ON A MESH WITH LOCAL REGIONS

RRT on a mesh surface with local regions (RRT-ML) [2] and RRT-connect on a mesh surface with local regions (RRT-CML) are simulated using the same synthetic mesh. The mesh consists of nonspherical topology, a tunnel and a bridge. Any mesh face having a normal vector orientation with angle of 30 degrees or above from the vertical is considered as an obstacle. The results of RRT-ML and RRT-CML are given in Table 1 for two experiment cases, each with different starting and goal position pairs. The number of iterations and time required to find the path are given, averaged over five trials.

Table 1: Comparison results of RRT-ML and RRT-CML.

<table>
<thead>
<tr>
<th></th>
<th>Case #</th>
<th>Avg. Iterations</th>
<th>Avg. Time(s)</th>
<th>Avg. Time/iter.(s)</th>
<th>Avg. Path length</th>
</tr>
</thead>
<tbody>
<tr>
<td>RRT-ML</td>
<td>1</td>
<td>61</td>
<td>8.61</td>
<td>0.14</td>
<td>9.64</td>
</tr>
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<td>66.53</td>
<td>0.12</td>
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<tr>
<td>RRT-CML</td>
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<td>2.53</td>
<td>0.07</td>
<td>11.13</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>211</td>
<td>32.85</td>
<td>0.16</td>
<td>19.35</td>
</tr>
</tbody>
</table>

CONCLUSION

The RRT-ML method uses local regions to reduce the length of computed geodesics, leading to faster convergence to a feasible path. RRT-CML, which employs RRT-connect [1] with local regions, grows two trees on the mesh, one from the starting position and one from the goal position, and further improves the computation time, compared to RRT-ML.

REFERENCES

EVALUATION OF VISUAL ODOMETRY METHOD IN 3D LIDAR BASED MAPPING

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ABSTRACT

As the 4th industrial revolution emerges at the forefront of South Africa’s national strategy, the mining industry is a potential beneficiary of these technological changes. In a typical mining environment, it is necessary to keep track of environmental changes in GPS-denied areas, e.g., the recession of a mining stope during operation. Mapping and Localisation algorithms using Simultaneous Localization and Mapping (SLAM) can map similar environments. While these SLAM-based algorithms are highly effective at mapping, they can be susceptible to registration and drift issues if provided with no external odometry. This study investigates the use of a visual odometry solution.

INTRODUCTION

The 3D mapping algorithm used in this study is an implementation of the Ethz-asl ICP Mapper [1] which uses SLAM and the Iterative Closest Point (ICP) algorithm to combine subsequent point cloud scans to form a map and simultaneously provides position estimates of the mapping sensor (typically Light Detection and Ranging (LiDAR)) while mapping is taking place. While the position estimates produced by the Ethz-asl ICP Mapper are very accurate, the computational complexity of the SLAM and the ICP algorithms slow down the frequency at which the position estimates can be produced. This allows for registration issues and drift of the position estimates if the scanning sensor is moving faster than the CPU can produce the pose estimates. In this case, there is a need for an external source of odometry to provide approximate position estimates in the interim time periods, between position estimates from the Ethz-asl ICP Mapper.
METHODOLOGY AND RESULTS

In this study the Ethz-asl ICP Mapper was integrated with the LiDAR Inertial Odometry (LIO) Mapping software package [2], which provides the external odometry needed. This combined mapper software implementation was installed on a LiDAR based sensor pack and is used to provide regular interim position estimates, as the sensor pack is moved through GPS-denied environments. The results show that although the estimates from the Ethz-asl ICP Mapper can be published at a frequency of 0.5Hz, when coupled with the LIO-Mapping software package, position estimates can be published at a frequency of 3.3Hz. A 3rd Gen. Core i7 CPU with 8GB memory was used in the sensor pack as its processor.

CONCLUSION

The intermediate position estimates published from the combined mapper implementation have been shown to eliminate drift and registration issues when pushing the LiDAR-based sensor pack on a trolley at velocities of up to 2.4 metres per second (m/s). The publishing rate of the position estimates is affected by the computation load of the Ethz-asl ICP Mapper and the LIO-Mapping software running on the same CPU.

REFERENCES


MANUFACTURING AND EVALUATION OF THE OPEN-SOURCE AR3 ROBOT ARM FOR EDUCATIONAL USES

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ABSTRACT

At the CSIR, a Learning Factory has been established to teach about the fundamentals of robotics and other Industry 4.0 disciplines. In the Learning Factory, the robotics practical station makes use of the Annin Robotics AR3 robot arm: a low-cost robot designed for small automation processes, ideal for educational purposes. The AR3 robot was chosen based on its low cost and its open-plan implementation. The robot was built at the CSIR mainly from machined aluminium parts and 3D printed covers. To test the functionality of the robot, the AR3 open-source user interface was used. It was determined that the robot can be used to teach learners about the fundamentals of robotics.

INTRODUCTION

As part of the Learning Factory at the CSIR, which represents a realistic manufacturing environment for education, training, and research [1], the Robotics Practical Workstation was used to teach learners the basics of robotics, the various applications of robotics and the use of different grippers. The Annin Robotics AR3 robot arm [2], open-source, low-cost robot, comes with a manual explaining the mechanics and the electronics and how to assemble the robot and wire the robot and the control box [3].

METHODOLOGY AND RESULTS

Mechanical

- The robot parts can be 3D printed or machined from aluminum. The robot that was built was built from about 75% aluminum parts and 25% 3D printed parts and covers. The parts were machined in the workshop using the computer-aided design models. Modifications to the mechanics. The robot is depicted in Figure 1.

Electrical

- The electric manual is very descriptive and gives clear details on all the wiring needed. Modifications to the electronics were made.

Software

- The robot software comes with a graphical user interface with video tutorials available online. Modifications to the graphical user interface
were made. The modified graphical user interface is depicted in Figure 2.

![Figure 1: Annin Robotics AR3 robot arm](image1)

![Figure 2: Modified AR3 graphical user interface](image2)

CONCLUSION

In conclusion, the robot can be used to teach learners about robots and the basics of programming. The robot did not preform as well as the suggested specifications and the accuracy and repeatability was not achieved. However, the accuracy and repeatability can be overcome by using larger a gripper that is able to pick up larger items, yet still accounting for the inaccuracies.

REFERENCES


[3] Annin, C. AR3 Robot Manual [https://drive.google.com/file/d/1T_u_RsGdRljlm2Luju5j7sy7eQUTs7K-/view](https://drive.google.com/file/d/1T_u_RsGdRljlm2Luju5j7sy7eQUTs7K-/view)
DEVELOPMENT OF A PLATFORM FOR THE FREEFORM EXTRUSION OF A CONTINUOUS GLASS-FIBER REINFORCED PHOTOPOLYMER

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ABSTRACT

The development of a system capable of continuous fiber freeform additive manufacturing is presented. Objectives of the paper are to review existing methods of continuous fiber additive manufacturing, to present hardware and process developments to the extrusion system, and to discuss tests performed to validate the functionality of the system. Developments include the implementation of a nozzle for inline impregnation of continuous glass fibers, as well as the design of a fiber-cutting mechanism. Preliminary tests indicated the viability of the system for the manufacture of simple geometries, while further tests are planned to determine suitable values of critical variables such as fiber volume ratio and extrusion speed.

INTRODUCTION

Lately, several studies have dealt with the development of algorithms for topology optimization with continuous fiber reinforcement [1], [2], [3]. In most cases, these studies provide a theoretical solution to a design problem and stop short of the manufacturing step due to limitations in existing manufacturing methods.

Composite manufacturing methods such as continuous fiber additive manufacturing and tailored fiber placement are capable of manufacturing continuous fiber reinforced designs with optimized fiber orientations [4], [5]. However, due to process and material limitations, these methods are often unsuitable except for the manufacture of shell structures or components with simple 2D stress distributions [6], [7]. The manufacture of truly 3D topology
optimized components with stress-optimized continuous fiber reinforcement has yet to be demonstrated [1], [8].

The aim of this paper is to present the early development of a method of continuous fiber freeform additive manufacturing for use in the production of topology optimized, fiber reinforced designs. Objectives of the paper are as follows:

1. Review existing methods of continuous fiber additive manufacturing.
2. Present hardware and process developments of the extrusion system.
3. Discuss tests performed to explore the capabilities and limitations of the system.

METHODOLOGY AND EXPECTED RESULTS

The system presented here is a development of the freeform photopolymer extrusion system presented in [9] and [10]. The development methodology is discussed below in terms of mechanical developments, process developments, and validation.

Mechanical and Process Developments

Initially, the photopolymer extruder developed in [10] was modified to accommodate continuous fibers by means of in-situ impregnation. A 16 gauge needle was used for the insertion of glass fibers into the nozzle used for photopolymer extrusion. The photopolymer was extruded using a syringe-and-actuator mechanism as before. Preliminary testing highlighted two major shortcomings with the in-situ impregnation approach. Firstly, the achievable fiber volume ratios were very low (about 2 per cent) due to the low inner diameter of the 16G needle used for fiber inclusion. In addition, warpage of the extrusions occurred, presumably due to shrinkage of the resin and tendency of the fibers to not stay centered in the extruded matrix. As a result of these short-comings, the in-situ impregnation approach was rejected and a prototype nozzle facilitating inline impregnation was manufactured. The redesigned nozzle enabled fiber volume ratios of 25 per cent to be achieved, with significant improvements in geometry retention.

In addition to the nozzle modifications, a fiber cutting mechanism was designed for the automated cutting of fibers at the nozzle exit. The robotic setup and toolpath generation approaches in [9], [10] were used with minor modification to toolpath generation logic to facilitate the initiation and termination of continuous fiber reinforced extrusions.
Validation and Expected Results

Preliminary testing has demonstrated the viability of producing single-segment 1D, 2D and 3D extrusions, as well as simple components consisting of “bundled” segments with joins between each bundle. In addition, mechanical tests on tensile and compressive straight-line specimens have been carried out to confirm the compatibility of glass fibers with the photopolymer matrix and to determine the relationship between fiber volume ratio and mechanical properties. Results have suggested a ten-fold increase in tensile strength for a fiber volume ratio of 25 per cent, while the corresponding increase in compressive strength was seven-fold.

The relationship between critical variables such as fiber volume ratio and extrusion speed and output parameters such as geometry retention will be determined, and a process parameter map will be formulated using the results. It is expected that lower fiber volume ratios will result in lower fiber-nozzle friction and thus in improved geometry retention, while a higher extrusion speed will result in poorer geometry retention due to incomplete curing of the photopolymer matrix.

CONCLUSION AND FUTURE WORK

A system for the freeform extrusion of continuous fiber composites is under development. Preliminary testing has shown promising results, with further testing planned to identify the capabilities and limitations of the system. Further work is under way to apply the manufacturing method for the fabrication of topology optimized components with continuous reinforcing fibers with optimized orientations based on principal stress trajectories.

REFERENCES


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[9] Removed for blind peer review

[10] Removed for blind peer review
CORE FUNCTIONAL MES WITH MACHINE MONITORING USING OPEN-SOURCE SOFTWARE

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ABSTRACT

The Fourth Industrial Revolution (4IR) has highlighted the need to digitise the manufacturing environment. In line with this, the CSIR is developing a low-cost Manufacturing Execution System (MES) based on open-source software, intended to support SMME’s in South Africa. It leverages Node-RED for the core of the system, supported by other open-source software such as InfluxDB, MongoDB, and Tasmota. The development of this system is guided by the international standards and definitions presented by the Manufacturing Enterprise Solutions Association (MESA). The developed MES solution provides several functions such as product creation, machine monitoring, and dash-boarding to name a few, and proves that a MES solution can be created using open-source software.

INTRODUCTION

The idea of a Manufacturing Execution System (MES) has been around since the 90s [1][2] and it has grown in popularity over the years due to the demand for large scale manufacturing and advances in technologies such as digitisation, the Internet of Things (IoT), and the Fourth Industrial Revolution (4IR). The Manufacturing Enterprise Solutions Association (MESA) International defines a MES as follows: “Manufacturing Execution Systems (MES) deliver information that enables the optimization of production activities from order launch to finished goods. Using current and accurate data, MES guides, initiates, responds to, and reports on plant activities as they occur” [1].

Today, many companies such as Siemens, Epicor, and SAP offer their own MES solutions, but these systems usually require licensing fees which can be expensive. Proprietary software solutions can also limit consumers to only one brand/company and not allow them to add or change functionality of the software at will. It is for these reasons that it would be beneficial to develop a local and open-source MES solution, which this paper sets out to describe.
METHODOLOGY AND RESULTS

Methodology

Investigate the various open-source code platforms available to develop a MES. Identify different database types available and investigate which database has a structure that is well suited to the needs of the proposed system. Investigate current standards and functionalities that define a MES. Implement the core functions of a MES using the resources and tools identified by the various investigations.

Results

Node-RED, an open-source, low code, flow-based programming tool was selected for the development of the core of the MES. InfluxDB was selected for the capturing of all real-time data while MongoDB was selected for the storage of all data required by the MES to produce different products. The standards and definitions from the MESA International “white paper 6” were used as guidelines for the development of our MES. Our MES provides the following functionality: product creation for production, adding and tracking operators and machines, scheduling and notification, machine monitoring, dash-boarding, and report generation.

CONCLUSION

This paper has shown that it is possible to develop a MES solution that is low code and open-source by using the software Node-RED as the core, supported by other open-source software such as InfluxDB, MongoDB, and Tasmota. Since all the software used for the functioning of the MES are open source, users can customise the system to suit their needs and they can add or change any functionality. This system has been deployed and future work will entail adding more of the required functionality of an MES, such as data analytics of current data and predictive maintenance for machines.

REFERENCES

PID CONTROL FOR A COLLABORATIVE HUMANOID ROBOT

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ABSTRACT

Hydraulic actuators are known to have more power than electrical motors at the same time having less weight than an electric motor of the same size. Control of these systems is however difficult to achieve as hydraulics come with their own complications such as the overall system complexity. A control system is thus necessary to manage and control the behaviour of the system in order for it to be usable. This study focuses on designing a control system that can allow a robot that uses hydraulic components to mimic a human being in real-time. Miniature hydraulic components connected in a closed-loop configuration are used to design a robot arm that can track human motion. The ability of the robot to be mimic allows for easy and more agile control of humanoid robots. This knowledge could be used further in teaching robots how to perform tasks easily without the need for complex reprogramming.

INTRODUCTION

The debate between hydraulic and electrical actuators in robotics is still on going with researchers trying to find the best method of actuation for their robots. Though hydraulics are only trending now, they have been around even longer than electrical systems. Many research efforts have shown the effectiveness of hydraulic actuation in robots. This is because hydraulic actuators have a high power to weight ratio [1], [2].

RESULTS

the control of the system was tested to check the controllability of the miniature hydraulic actuators using a PID controller. Figure 1 shows the results of the hydraulic motor at high speeds. It can be seen that the output reacts violently and is not stable at any point. This is due to the PID controller trying to correct the error.
CONCLUSION

In this study, the design of an electro-hydraulic control system for collaborative humanoid robot was presented. The findings show that various research efforts are being made in improving hydraulics for robotic applications. In this study, miniature hydraulic components were used to construct a mimicking robot arm. The results show that hydraulics can be controlled using PID control though the output of the system will not be as accurate. Furthermore, as research in this field gains popularity, newer control methods will be found that will increase the accuracy on hydraulic actuators.

REFERENCES


DESIGN AND MANUFACTURING OF AN AGGREGATE ABRASION TEST DEVICE FOR TESTING IN HIGH ACCELERATION FIELD

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ABSTRACT

This paper describes the design, manufacturing, testing and the findings of a mechanical system, the Aggregate Abrasion Test Device (AATD), which comprises of a rolling model drum, with the purpose of obtaining experimental data that is subsequently used to quantify the abrasion behaviour of aggregate particles. The study of the abrasion behaviour of geomaterials is complex due to among other factors, non-linear mechanical properties that depend on stress levels and stress history. In this case the aggregate assemblage is subjected to different stress levels by operating the system within the geotechnical centrifuge environment.

INTRODUCTION

The aggregate used for road construction must be durable to perform well within pavement layers, particularly upper layers, base-course or sub-base [1]. A variety of test methods are used to quantify the durability of aggregates, one of them being resistance to abrasion. Aggregates, which do not have adequate toughness and abrasion resistance, may cause long-term performance problems, such as excessive deformation in roads, instability of rail tracks as the size and shape of ballast aggregates are altered by particle breakage.

In an attempt to explore and improve an abrasion test that induces wear by rotating a single drum filled with aggregates without the use of steel balls the Council for Scientific and Industrial Research (CSIR) has developed an experimental system for determining the aggregate abrasion behaviour, solely dominated by particle-to-particle interaction mechanism by testing in high acceleration environment. The system consists of the geotechnical centrifuge and an aggregate abrasion test device (AATD)
METHODOLOGY AND RESULTS

Methodology

Several factors guided the design of the system. The first requirement was that the experimental system fulfils the principles of granular material flow in rotating drums, in the absence of radial baffles and steel ball charge to induce wear of the particles. Secondly, that all the components of the system will endure the increased self-weight due to high gravitational forces as a result of testing in the high acceleration field in the geotechnical centrifuge. The third consideration was the weight and the portability of the system.

Results

The operation and functionality of the system has been demonstrated. Several tests have been conducted successfully to determine the influence of the level of acceleration on aggregate degradation through abrasion.

The materials and components were manufactured to withstand 50-g force. The static calculations and simulations indicated minor drum wall deflections; thus the deflection of the drum was neglected. The strength of the materials used to construct the AATD could withstand 50-g. The simulation results indicated 9e-05 mm as the maximum deflection of the wall thickness of the drum.

CONCLUSION

The AATD was tested and the maximum gravitational acceleration that the device can withstand without stalling is 25-g. The design requirement of testing the aggregate at above 25-g was not met but the AATD was able to perform the tests at 25-g and below. However, tests at 25-g induce more than adequate stress levels on the aggregate assemblage to induce wear through abrasion.

REFERENCES

ELIMINATION OF SHRINKAGE POROSITY IN LOW ALLOY STEEL USING MAGMASOFT SIMULATION SOFTWARE

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ABSTRACT
The presence of porosity is a frequent defect occurrence in most solidification products. This includes castings, welds, and 3D printed components. In this investigation Magmasoft, a casting simulation software, will be used to predict shrinkage porosity in steel alloys and reduce the severity of the defects.

INTRODUCTION
Progress in computer technology has allowed the advancements in numerical simulation methods and digital manufacturing software. This progress has allowed that the development times of producing component on the market has shortened from several months and years to weeks and even days. Engineers and designers are now able to develop products and verify their performance and integrity at a very fast rate with little investment. Simulation software address the following products related issues: quality and performance upgrade, weight and design optimization, reduction in implementation and validation time, cost reduction [1]. Additionally simulation methods are used to optimise the newly developped rapid sand casting process which combined rapid prototyping (computer aided design software) and traditional casting practices [2].

The Niyama criterion is a local thermal parameter in Magmasoft and a common output of casting simulation software packages. It is frequently used to predict shrinkage porosity defects in steel castings. Niyama is a robust parameter that not only predicts macro shrinkage that is visible on radiographs, but also smaller micro-porosity that is usually not detectable using standard radiographic techniques [3]. Porosity is less likely to occur in alloys with a Niyama value above $3.87(C^0S)^{1/2}$ mm and a shrinkage percentage below 4%. Severe case of porosity is expected for niyama values below $0.129(C^0S)^{1/2}$ mm. [4]
This investigation aims to predict and optimise shrinkage porosity in ferrous alloys using the Niyama criterion.

**METHODOLOGY**

According to the procedure described in Figure 1, the data of a porous low alloy steel casting displayed in Table 1 will be used in simulation. Critical parameters will be altered throughout the simulation namely sand mould, melt temperature, in gate geometry and pouring time. Finally, revision will be made on the parameters to improve the niyama criterion and shrinkage percentage of casting.

<table>
<thead>
<tr>
<th>Table 1 casting dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Feeder’s Dimensions</strong></td>
</tr>
<tr>
<td><strong>Casting’s Dimensions</strong></td>
</tr>
<tr>
<td><strong>Total weight (feeder+ casting)</strong></td>
</tr>
<tr>
<td><strong>Chemical composition</strong></td>
</tr>
<tr>
<td><strong>Moulding sand</strong></td>
</tr>
<tr>
<td><strong>CAD design in SOLIDWORKS</strong></td>
</tr>
</tbody>
</table>

**RESULTS**
Table 2 gives a record of the parameters used in the preliminary test. Pouring time is the sole variable parameter.

Table 2 Parameters of simulation

<table>
<thead>
<tr>
<th>Alloy</th>
<th>thickness</th>
<th>Pouring temperature</th>
<th>Pouring time</th>
<th>Sand mould</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>51 cm</td>
<td>1600°C</td>
<td>10 seconds</td>
<td>silica</td>
</tr>
<tr>
<td>2</td>
<td>51 cm</td>
<td>1600°C</td>
<td>20 seconds</td>
<td>silica</td>
</tr>
<tr>
<td>3</td>
<td>51 cm</td>
<td>1600°C</td>
<td>30 seconds</td>
<td>silica</td>
</tr>
</tbody>
</table>

Figure 2 shows that by increasing the pouring time substantial improvement is achieved on the Niyama value of the low alloy steel. The shrinkage percentage is dropped from 4,97% to 4,69%.

CONCLUSION

Even under the constraint of considering pouring time as the sole variable parameter during simulation, substantial improvement was made regarding the shrinkage percentage of the alloy. The remaining simulation tests will include three more parameters namely in-gate geometry, pouring temperature and moulding sand. The study is a practical example of how digital manufacturing could be applied to the industrial foundry industry in South Africa.

REFERENCES


ASSESSMENT OF THE FINANCIAL FEASIBILITY OF RAPID SAND-CASTING PROCESS USING THE PAYBACK PERIOD METHOD.

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ABSTRACT

The Additive Manufacturing of sand moulds and cores for foundry applications is referred to as Rapid Sand Casting. Additive manufacturing is not yet adopted by the local foundry industry in South Africa, due to resistance to skepticism as it is a relatively new technology and expensive. The existing literature on additive manufacturing points out that rapid sand-casting process is more beneficial in terms of cost savings and reduced lead times compared to traditional manufacturing processes. However, it does not demonstrate whether it will be financially feasible for foundry industry to adopt this technology. This paper presents a literature review on applicable capital budgeting technique specifically payback period applied to additive manufacturing for rapid sand casting. The paper aims to investigate the payback period of acquiring an additive manufacturing equipment in a foundry. From the results obtained from several scenarios, the foundries could give an indication of the value of investment in rapid sand casting.

INTRODUCTION

Additive manufacturing (AM) is one of the modern technologies considered to be part of the Fourth-Industrial Revolution (4IR) [1] applied to foundry processes. AM produces a component layer by layer basis until the part is complete [2]. AM is applied by different industries to produce different products for different purposes and applications. Foundry is one of the industries that can adopt this technology in production of moulds and cores. This technology utilizes three-dimensional design (3D) to create and build
products [2]. Compared to traditional methods of mould making, rapid sand casting is more beneficial because no pattern is required for mould production, which is very expensive, production time and lead time are reduced because few steps are involved when making moulds and cores, complex parts are easily produced than traditional methods of mould making.

Figure 1: Voltexjet Process

Figure 1 illustrates a typical AM process during rapid sand casting.

METHODOLOGY

Payback Period

Payback period is one of the capital budgeting techniques that calculates the numbers of years it will take for a project to recover its initial investment from cash flows generated annually by the project [3]. It considers initial investment of a project and annual cash inflows from the investment. Initial investment is the cost of buying rapid sand-casting equipment. In this investigation, the AM machines available in South Africa for rapid sand-casting applications are considered including, Voxeljet and EOS machines. Cash flow is the money that is generated and consumed by a firm over a certain period. On the other hand, cash inflow is the amount of money that is generated and received from the operational activities of the firm after investing in a project.

\[
\text{Payback period} = \frac{\text{Initial investment}}{\text{Annual cash flow}}
\]

The parameters to consider when calculating the payback period is the price of the machine (initial investment), the set cutoff date expected to recover the initial investment and the cash inflows expected to be generated over a certain period.
CONCLUSION

The Payback Period is one of the capital budgeting techniques that is used by firms to evaluate the project by looking at how long will the initial investment be recovered. These techniques can be applied in purchasing and selecting an investment. Rapid sand casting is said to be the most effective method for production of moulds and cores and payback period can be used to calculate how long will the firm recover its initial investment if the machine for this process is purchased. Projects with less payback periods than a specified cutoff period are accepted. Payback period is easy to calculate and understand and can be applied by local foundry industry as first step in evaluating additive manufacturing for rapid sand casting.

REFERENCES

DIGITAL TWINNING OF LAP-BASED MARATHON INFRASTRUCTURE

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ABSTRACT
State-of-the-art sensor technologies provide unparalleled accuracy for creating digital twins of infrastructure. A new generation of low-power sensor platforms and distributed, Long-Range Wide Area Network (LoRaWAN) communications provide monitoring of the impact of the built environment. The deployment of these technologies stands to benefit sporting events. This paper demonstrates quantitative micro- and macroclimatic measurements over the course of a 42.2 km lap-based marathon hosted at the University of Pretoria, including digitisation of the marathon route using RTK GNSS and LiDAR sensing capabilities. This intersection of disciplines and technology illustrates the realisation of smart cities in a 4IR evolutionary society.

INTRODUCTION
The built environment remains inextricably linked to sports engineering applications, notably marathons. A digital twin is defined [1] as an “integrated multi-physics, multiscale, and probabilistic simulation of a complex product and uses the best available physical models, sensor updates, etc., to mirror the life of its corresponding twin”. Cyber-physical systems and Big Data implementations [2] are increasingly common to continuously improve the lifecycle management of assets and infrastructure. The Department of Civil Engineering and the University of Pretoria engaged with the organisers of the 2020 Sanlam Cape Town Marathon (Africa’s only World Athletics Gold Label Status marathon), which took place on 18 October 2020 (06:00 to 09:30) at the University’s Hillcrest campus [3]. This unique collaboration served to test and showcase real-time environmental monitoring and tracking of the marathon using state-of-the-art digital technologies.

METHODOLOGY AND RESULTS
Four key technologies were tested and demonstrated before and during the marathon:
• Customised, wireless sensor platforms, named SNOET, which measured environmental variables over the duration of the marathon. A total of four SNOET sensor platforms were commissioned, originally intended for offline functionality.

• Integration of Long-Range Wide-Area Network (LoRaWAN) infrastructure at the Engineering 4.0 laboratory. The SNOET sensor platforms were reconfigured with the new LoRaWAN microcontroller to take full advantage of the wireless sensor capabilities.

• RTK GNSS survey of the marathon route. A low-cost RTK GNSS solution was developed within the Department of Civil Engineering to provide centimetre-accuracy geolocation abilities, consisting of both a base station and rover [4].

• Emesent Hovermap LiDAR for creating an accurate, digital replica of the marathon route and the surrounding environment. The aggregated point cloud is composed of 211 million points (1.511 Gb).

CONCLUSION (HEADING 1 ALL CAPS)

This Technical Note demonstrated the implementation of state-of-the-art sensor platforms and instrumentation, traditionally isolated to applications and research of the built environment, in the context of a lap-based marathon. Based on these measurements (both online and offline), a digital twin of the infrastructure used for the event was created.

REFERENCES


MODEL-BASED DESIGN OF ADDITIVE MANUFACTURING OPERATIONS FOR IMPROVED MANAGEMENT, CONTROL AND COMPLIANCE

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ABSTRACT

In highly regulated industries production processes need to be well defined and standardised to ensure repeatable and reproducible quality in the process outputs. With the increase in smart and advanced manufacturing processes and methods being implemented in modern manufacturing systems this need is heightened due to the inherently complex nature of such manufacturing processes and methods. This paper investigates the application of a model-based systems engineering approach to designing and developing manufacturing operations allowing for improved management, control and compliance. The approach is applied to a powder feedstock reuse process and the system is modelled with a focus on defining processes, component interfaces and requirements traceability.

INTRODUCTION

As the manufacturing industry moves towards the fourth industrial revolution and the increased digitization of production processes there is a need to efficiently characterise and control these processes to reduce failures, improve efficiency, improve traceability and allow for improved compliance auditing. Highly regulated industries such as aerospace, oil and gas, and medical require production processes to be thoroughly characterised, documented and controlled. With the increase in complexity of modern advanced manufacturing processes such as additive manufacturing, the traditional document-centric approach is inefficient at ensuring such processes and their encompassing manufacturing systems are designed and managed. Utilizing model-based systems engineering (MBSE) techniques and applying a systems engineering methodology provides an approach to ensure such processes are unambiguously designed, managed and configuration controlled.

METHODOLOGY AND RESULTS

The methodology applied in this research is defined in Figure 1 and follows a systems engineering approach and utilizes MBSE techniques. INCOSE identifies benefits of utilizing a model-based approach to systems engineering...
including improved communication, management of system complexity and improved quality [1]. This methodology focuses on system functions whereby the functional architecture is the central system architecture for performing decomposition, allocation and integration of the system and its components. This approach is analogous to the traditional systems engineering methodology [1][2]. Additional focus points specific to manufacturing type systems are incorporating the human operator as a component within the system design and integration of physical machinery capabilities with the functional architecture and HMIs.

A case study was performed to demonstrate this approach. For the case study, a powder processing system was modelled using the Vitech Genesys 2021 Collaboration Edition MBSE software. Figure 2 presents the system context of the powder processing system as an IDEF0 diagram on the left-hand side, defining external entity functions and the SoI as a black-box. The reclaimed powder is received from the LPBF machine and a manufacturing plan is received from production planning. These items trigger the SoI mission function to process the powder for reuse. The system mission function, FN.0, is defined in the IDEF0 A-0 diagram on the right-hand side. The system context is decomposed and the system architecture for a powder processing system is defined including the human as a system component.
CONCLUSION

The application of Model-Based Systems Engineering has been investigated for the design of manufacturing operations. A candidate system used for metal laser powder bed fusion operations was selected for demonstrating the approach. This system was modelled using SysML, IDEF0 and EFFBD notations, which allowed for creating different views of the system model for different objectives. This approached focused on defining the human aspect of the system and how a model-based approach aids in modelling the performance of manufacturing operations, operating and interfacing with machines, identifying risks in the system and improving compliance.

REFERENCES

MODEL-BASED DESIGN OF ADDITIVE MANUFACTURING OPERATIONS FOR IMPROVED MANAGEMENT, CONTROL AND COMPLIANCE

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ABSTRACT

In highly regulated industries production processes need to be well defined and standardised to ensure repeatable and reproducible quality in the process outputs. With the increase in smart and advanced manufacturing processes and methods being implemented in modern manufacturing systems this need is heightened due to the inherently complex nature of such manufacturing processes and methods. This paper investigates the application of a model-based systems engineering approach to designing and developing manufacturing operations allowing for improved management, control and compliance. The approach is applied to a powder feedstock reuse process and the system is modelled with a focus on defining processes, component interfaces and requirements traceability.

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including improved communication, management of system complexity and improved quality [1]. This methodology focuses on system functions whereby the functional architecture is the central system architecture for performing decomposition, allocation and integration of the system and its components. This approach is analogous to the traditional systems engineering methodology [1][2]. Additional focus points specific to manufacturing type systems are incorporating the human operator as a component within the system design and integration of physical machinery capabilities with the functional architecture and HMI.

**Figure 1: System modelling methodology.**

A case study was performed to demonstrate this approach. For the case study, a powder processing system was modelled using the Vitech Genesys 2021 Collaboration Edition MBSE software. Figure 2 presents the system context of the powder processing system as an IDEF0 diagram on the left-hand side, defining external entity functions and the SoI as a black-box. The reclaimed powder is received from the LPBF machine and a manufacturing plan is received from production planning. These items trigger the SoI mission function to process the powder for reuse. The system mission function, FN.0, is defined in the IDEF0 A-0 diagram on the right-hand side. The system context is decomposed and the system architecture for a powder processing system is defined including the human as a system component.
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REFERENCES


DEVELOPMENT OF A GRAPHICAL USER INTERFACE AS A LEARNING TOOL FOR ARTIFICIAL INTELLIGENCE

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ABSTRACT

This study aimed to develop a Graphical User Interface (GUI) aimed at teaching the concepts of Machine Learning (ML) algorithms which form the backbone of Artificial Intelligence (AI). This is done by means of tutorial videos and allowing the student to interact with example datasets through a dashboard within the GUI before completing an assessment. This GUI is referred to as a practical station and is but one of ten other Industry 4.0 technology stations within the MerSeta funded CSIR Learning Factory.

INTRODUCTION

This study forms part of the CSIR Learning Factory project in partnership with MerSeta (Manufacturing, Engineering and Related Services SETA). The aim of the Learning Factory project is to develop a centralised programme and facility where students or the work force can learn more about the different technologies required in Industry 4.0. One of these technologies is Artificial Intelligence (AI) which aims to create a machine that mimics or simulates human intelligence by implementing Machine Learning (ML) algorithms. This study aimed to develop a Graphical User Interface (GUI) which provides a learning platform for three introductory ML algorithms, namely linear regression, logistic regression and k-means clustering.

METHODOLOGY AND RESULTS

An intuitive design for learning was considered in the development of the learning tool. The learner is first exposed to overview videos discussing the concepts of AI and ML. For each of the three ML algorithms discussed the learner first views a tutorial video which is followed by an example dashboard (c.f. Figure 1) allowing the learner to interact with the algorithm through an example. Finally, the learner completes an assessment at the end of each section with the results being given at the end of the practical. The learner also
has access to the accompanying guideline which takes them through the interface step-by-step, providing details surrounding the different example datasets and how to interpret the results.

![K-Means clustering example dashboard for the Artificial Intelligence learning tool.](image)

**Figure 1: K-Means clustering example dashboard for the Artificial Intelligence learning tool.**

**CONCLUSION**

An intuitive interface to teach three ML algorithms at an introductory learning level has been successfully developed in this study. The learning tool has been deployed within the MerSeta funded CSIR Learning Factory where stakeholders can interact with it.

**REFERENCES**

A COMPARATIVE STUDY TOWARDS PARTICLE IDENTIFICATION EMPLOYING SEMI-AUTOMATED IMAGE PROCESSING IN EXPERIMENTAL SEM IMAGES

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ABSTRACT

Manually characterising particles in scanning electron microscopy (SEM) images is very time consuming and costly, often requiring an expert. In previous work we developed a method which has the potential to automate the particle analysis process with limited user interaction. In this study we compare the previously developed method with other automated machine learning approaches on experimentally obtained SEM images.

INTRODUCTION

Scanning Electron Microscopy (SEM) assists the user in obtaining crucial information regarding (nano)particle morphology, size and density which provides further insights. Traditionally this is done by manually characterising the particles either using an expert or more recently with the assistance of general image processing software. The disadvantage is that only one image can be analysed at a time and a lot of user interaction is required making it costly and time-consuming. To address this issue we proposed a method for counting synthetic particles in a previous study [1] requiring user input for only one SEM image in a dataset before automatically batch processing the remaining images. In this paper we aim to apply the developed method on real SEM images and compare our method to different machine learning approaches, which are commonly employed to automate the analysis of larger datasets.

METHODOLOGY AND RESULTS

The proposed method uses contours and bounding boxes to count particles after filtering and smoothing was conducted using average intensity, a median filter and LULU transforms. We compare this method with machine learning approaches, such as Yolo. From Figure 1 it is clear that our method is able to
better count particles, compared to Yolo, with an accuracy of (4/137) 2.9\% and (228/137)166\% respectively (compared to the manual count of 137 particles).

This illustrates the developed method’s potential to be used as an automated particle analysis tool. The larger (166\%) count is due to the method picking up even the fine detail in the image and thus can be rectified by categorising the identified particles into different size bands.

![Figure 1: Comparison between (a) Yolo (2.9\% particles counted) and (b) LULU particle identification (166\% particles counted).](image)

**CONCLUSION**

The flexibility in the discussed method makes it possible to implement it on a wide range of images for the purposes of identifying particles with minimal need for user intervention. While machine learning and deep learning methods have proven effective, in this study the DL method did not perform optimally. The drawback of using ML and DL methods for a study such as this, is the need for training data which requires the annotation of many images which can be very labour intensive, while the proposed IP method needs only tuning on one image before batch processing can be conducted.

**REFERENCES**

One-Class Support Vector Machines for Boat Detection using Fully Polarimetric Radar

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ABSTRACT

This study explores the use of one-class support vector machines (OC-SVM) to improve ship detection performance. The study focuses on how the OC-SVM may be implemented in real-time and how much detection performance may be gained by utilizing full polarimetric data. Using the simulated boat inserted in measured full polarimetric sea clutter the detection performance of the OC-SVM is compared to that of the cell-averaging constant false alarm rate (CA-CFAR) detector. The detection performance is evaluated by computing the probability of detection at a given probability of false alarm for different target-to-clutter ratios. The overall detection performance of OC-SVM is superior to that of CA-CFAR, thus showing the potential use of OC-SVM for target detection applications.

INTRODUCTION

Fully polarimetric radar systems have been shown to outperform both the dual and single polarisation radar systems [1]. Furthermore, investigations into the use of machine learning (ML) for radar target detection has shown promise and has grown in interest [2–4]. Even though many studies show the potential of ML algorithms in radar detection, most does not compare the ML learning detection performance to traditional radar detectors. Thus is unclear whether there are advantages of using ML over traditional detectors. Additionally, most studies use only single polarisation.
In this study fully polarimetric data is used and also the detection performance of ML is compared to that of CA-CFAR. Since OC-SVM performance will be evaluated for real-time applications, CA-CFAR was chosen because is one of the detectors that are generally used in real-time detection radars.

**METHODOLOGY AND RESULTS**

Simulated and measure data will be used for the detection performance evaluation. The OC-SVM will be trained using the same samples the CA-CFAR uses to compute its adaptive threshold. That is the samples surrounding the cell under test for each time instance.

Figure 1 shows the results of simulated data with the target-to-clutter ratio (TCR) varying from -30 to 40 dB. The plot shows the probability of detection against SNR with the OC-SVM trained with all the polarisations channels (|HH|, |HV|, |VV|) and dual (|HH|,|HV|;|HH|,|HV|;|HV|,|VV|) while CA-CFAR utilises averaged polarisation channels, PN and the single polarisations. The $P_{FA}$ used was in the order of $10^{-1}$, which is the best $P_{FA}$ achieved by OC-SVM with the parameters used in this paper. The OC-SVM has overall superior detection performance compared to all the CA-CFAR configurations.

Figure 1: OCSVM compared to CA-CFAR – OCSVM has a higher probability detection than CA-CFAR for the same probability of false alarm.
CONCLUSION

The research explores the use of OC-SVM in real-time detection scenarios. The results show that using fully polarimetric data and OC-SVM has the potential of improving detection performance compared to conventional radar detection algorithms. However, more robust investigation is still needed.

REFERENCES


FRAMEWORK FOR CEMENTED TUNGSTEN CARBIDE DRILL BIT PROTOTYPE FABRICATION USING LASER ENGINEERED NET SHAPING

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ABSTRACT

A multiphase parameter refinement framework was designed to develop and produce a cemented tungsten carbide drill bit using laser engineered net shaping. The circularity, depth and diameter of drilled holes were benchmarked against a commercially available drill bit, and von Mises simulations were performed to illuminate regions of high stress and indicate possible fracture zones. The hole circularity was found to be consistent for the respective drill bits except when drill tip failure resulted in torn material. The hole depth and diameter varied across tests. Lack-of-fusion porosity was found to be the main cause of drill tip fracture.

INTRODUCTION

To produce successful prototypes an optimized additive manufacturing framework is required. When deposition parameters are readily available for the desired material, such as titanium-based alloys \cite{cite1}, then the prototyping can be easily performed. However, for cemented tungsten carbides there are limited publications in the field of direct energy deposition. Hence a framework which allows for rapid parameter optimization is required for these materials. Various frameworks have been developed for additive manufacturing with a focus on design aspects \cite{cite2} and computational models \cite{cite3} but not iterative parameter enhancement. Thus, the aim of the current study was to design a simple framework to determine an optimal deposition parameter set which could be used for the deposition of a functional prototype.
METHODOLOGY AND RESULTS

A framework using thin walls, cubes and the final prototype is proposed based on a full factorial design of experiments, and continual improvement measures through iterative parameter adjustments based on the deposition density. Validation was done through multiple depositions and analyses, which culminated in the deposition of a cemented tungsten carbide drill bit, as shown in Figure 1. Benchmark drilling tests were done against a commercial drill bit. The drill bits failed mainly due to tip fracture or shank failure due to lack-of-fusion defects within the depositions and the torsional forces inducing stress which exceeded the mechanical properties of the depositions.

Figure 1: As deposited cemented carbide drill bit prototype.

CONCLUSION

An iterative, multi-phase parameter optimization manufacturing framework was successfully developed and applied to a cemented tungsten carbide alloy yielding reproducible functional drill bit prototypes after 23.5 hours of active laser time. The results indicate that with a second iteration of refinement or by changing the geometry the prototype’s performance may be improved.

REFERENCES


DIRECT ENERGY DEPOSITION OF A CEMENTED TUNGSTEN CARBIDE ROTARY BURR PROTOTYPE

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ABSTRACT

In this study a cemented tungsten carbide rotary burr prototype was fabricated using direct energy deposition based on an optimal parameter set which was derived from a full factorial design of experiments matrix approach. Finite element analysis under static conditions was carried out on the burr to understand the possible geometrical stress raisers and stresses during assimilated operation. Initial field tests were done to assess the functional performance of the prototype, and comparisons were made against a conventionally manufactured burr.

INTRODUCTION

Laser engineered net shaping (LENS®) is a direct energy deposition (DED) process which has been successfully used in the fabrication of a range of materials such as stainless steels, nickel alloys, composites and graded materials [1]. There is limited research into the application of this process to fabricate cemented tungsten carbide alloys [2]. Thus, in this study a cemented tungsten carbide rotary burr functional prototype was fabricated using DED and subjected to initial field testing to assess its performance characteristics.

METHODOLOGY AND RESULTS

A LENS® 850-R system with a 1kW IPG fiber laser having a spot size of 1.4 mm was used to deposit cemented tungsten carbide rotary burr prototypes
onto a shot blasted mild steel substrate under atmospheric conditions. Finite element analyses showed that the highest stress concentration is in the fillet junction area as shown in Figure 1. This indicates where initial failure should occur during operation. Field testing was based on the removal of weld deposits, with the burr failing after machining off 0.22 mm of weld material in 2 minutes.

![Figure 1: Von Mises stress distribution due to imposed load.](image)

**CONCLUSION**

A cemented tungsten carbide rotary burr functional prototype was developed and manufactured using the LENS® process. During initial field testing the burr experienced three-point brittle fracture, which initiated at the fillet junction as predicted by FEA analysis.

**REFERENCES**


THE ROLE OF AM POLYMERS TO IMPROVE THE OEE OF OPERATIONS

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ABSTRACT

Overall equipment effectiveness or OEE is a measurement of manufacturing productivity of production facilities. OEE is a systemic measurement focusing on the reduction of the three key losses in a plant. The three losses can be defined as equipment availability loss, performance loss and quality loss. The use of AM polymers for spare part provisioning can have a positive impact on the improvement of OEE and the reduction of the three losses due to a reduction in weight, corrosion and chemical resistance and improved heat tolerance in harsh environments. High end engineering polymers are also used for metal replacement of spare parts.
COMBINED IMPLICIT AND EXPLICIT TECHNIQUES TO CREATE A BESPOKE OPTIMIZED 3D PRINTED LATTICE SOCKET FOR A PROSTHETIC HAND

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ABSTRACT

A challenge for upper limb amputees is the expense, fitment, weight and useability issues of contemporary prostheses which often sees the abandonment of the prosthesis in day-to-day use and reliance on the remaining part of the limb to carry out basic tasks. This paper includes the research, design, manufacture and testing of a bespoke Additively Manufactured prosthetic socket and protective arm sleeve for lower arm amputations. The objective was to achieve an affordable solution to the challenging parameters of long-length residual arms in prosthetic socket design.

The research problem was to address the above challenges whilst also minimizing the space between the amputation and the end device as well as to develop a new fastening method that would allow continuous adjustment of the socket throughout the day, as the residual limb shrinks and expands due to temperature changes.

The solution for this research was an additively manufactured, Nylon PA650 socket with lattice optimization and a ratchet-style adjustable fastening method. The socket design utilized a combination of explicit and implicit techniques with a reusable workflow to allow customization to fit any arm shape and size. Possible materials used for the protective sleeve were investigated and it was found through physical testing with an amputee, that basic neoprene sleeves resulted in sweat build-up and skin irritation over time, causing the amputee to abandon the prosthetic.
The advanced implicit latticing technique utilized allowed a weight reduction of 80% compared to other contemporary options on the market while maintaining full structural integrity and increasing flexibility.

Heat dissipation analyses were conducted, as well as thermal plots generated to dictate the optimal lattice density allowing maximum breathability while maintaining stiffness in the structure. The fastening mechanism was additively manufactured and tested using short-fibre carbon-impregnated nylon material to take advantage of the material’s strength and wear resistance properties.

Simulation studies were conducted in conjunction with strength and fatigue calculations to ensure the design meets safety requirements for routine use. The amputee was able to handle a 20 kg load using the socket and any compatible end device. The moving parts of the adjustable fastening system were rated to last a period of over a year in daily operating conditions, after which they are easily replaced. The cost of the socket is US$350, which is less than 10% of other typical entry-level options available on the market.
A MOBILE & PORTABLE PRE-ICU AM-PRODUCED BI-PAP VENTILATOR SYSTEM IN RESPONSE TO COVID19 CHALLENGES

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ABSTRACT

An early challenge for first-responders was the availability of both CPAP and Bi-PAP mobile or portable & easy to implement ventilators en-route to ICU. In response to the shortage of ventilators in the early stages of the coronavirus pandemic, the need for the design of a low-cost, portable ventilator that automatically inflates and deflates an Ambu-Bag, as per individual requirements, was initiated.

The ventilator is derived from the open-source MIT Bag Valve Mask platform that meets international clinical requirements for a medical respiratory device. Automating the procedure of compression appeared to be the simplest strategy to satisfy the need for low-cost mechanical ventilation, with the ability to be rapidly manufactured at scale, and deployed quickly for first responders. Producing this via available Additive manufacturing (AM) resources would also be substantially cheaper than the conventional ventilator currently imported into the country at significant cost.

The focus of this paper is to present the research, design, manufacturing, and testing of a mechanical ventilator using state of the art additive manufacturing techniques and technologies, which presented an affordable solution and rapid and easily updatable manufacturing of the various components. The ventilator parts were printed using Onyx as the print material as this would provide a significant increase in strength and fatigue-resistance than standard FDM materials typically used. All components have been designed with the standards CE0085 and CE0086 in mind, to complete and pass the certification process.

The additive manufacturing industry is growing rapidly, and new markets are constantly presenting new application opportunities for this technology.
Specifically, the medical sector presents a huge potential for local additive manufacturing applications and solutions in resolving exorbitant cost demands of importing international equivalents. The cost of the ventilator as it stands is US$850 whereas an equivalent machine costs a minimum of US$2,500.

Various computational analyses were performed on the major components including dynamic motion simulations, fatigue simulations and FEA verification simulations, to confirm that each component functions in a manner which represents the goals of the project without resulting in failure due to yielding, fatigue loading and static loading.

This design lays the foundation for future development projects relating to the optimization of the ventilator.
MEDICAL PRODUCT DEVELOPMENT FOR ANIMALS USING AM AND DIGITAL MANUFACTURING

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ABSTRACT

Using Additive Manufacturing (AM) as part of the medical product development process has become common practice. Working on both human and animal medical products, we noticed that the animal side has fewer product options available, even while there are various species and sizes to cater for. Human medical products are used where they can be applied, but in many cases, they need to be edited to fit the patient. Crude bespoke tools and products are created to help where no other option exists, but by using AM we can help to narrow that gap to turn those bespoke ideas into proper medical tools and products with possible commercial outcomes.

AM IN THE PRODUCT DEVELOPMENT PROCESS

Collaboration is a key element in developing sustainable medical products. Ideas come from veterinary doctors who had to face certain challenges in cases where they either needed specific products that was either unavailable, hard to find or don’t exist, as a result they use what they can and create bespoke solutions when possible. Some have tried to develop their ideas but due to various reasons hit a dead end and abandoned them. We try to fill those gaps where possible and, in many cases, digital design and AM plays a vital role in making the idea a reality/. The fact that we can print prototypes for testing & moulds, and that some of the material options can be used for end products, allows us to create bespoke products as well as run small batch production units.

THE DESIGN PROCESS

The process starts with a conversation about an idea for a product, sometimes there is already a crude prototype, or it could be an existing product that's needs to be improved or adapted for smaller creatures.
Each vet we work with usually have multiple ideas, so we lay them out on a table looking at what is the most crucial as well as achievable regarding our resources. We then discuss the type of collaborative partnership and once the decision has been made, on all subjects we can start the development process:

1. Research
2. Design Brief
3. Conceptual Design
4. Prototypes
5. Final Design

Below is a case study of a Bird Collar product that was developed where the process was used, using AM produced products at first until we could afford to move over to injection moulding.

Figure 1: Concepts   Figure 2: Final Product

CONCLUSION

As AM develops, and more materials become available, combined with cost dropping, it is becoming easier and faster to create quality bespoke and standardised products that can eventually be mass produced by using AM. We are intent to explore this and integrate these new options as they become available as well as make this service available to veterinary doctors internationally where we can support idea driven development remotely using digital design and AM production centres worldwide.
ABSTRACTS

DAY 2
Thursday, 04 November 2021
ADDITIVE MANUFACTURING FOR METALS IS NOW ESTABLISHED IN MORE AND MORE INDUSTRIES

Stefan Ritt
SPEE3D, Melbourne, Australia

ABSTRACT

Due to the high flexibility and just-in-time as well as on-demand manufacturing possibilities, this technology is also predestined for expeditionary and defense applications. However, many systems on the market are technically very sensitive and complex and therefore stand in the way of use "in the wild".

Several field tests have already been successfully carried out with cold spray technology. The presentation will report on this and thus also show possible future application concepts such as offshore wind farms, oil and gas industry applications and expeditionary environments such as in Central Africa or Asia.

Because cold spray technology does not completely melt the material, the process is tens of orders of magnitude faster and handling much easier. The number of usable metal powders is constantly increasing, opening up more and more areas of application.

The Australian Defence Force has already been using the technology for several years to support field repair and spare parts procurement problems. Other industrial applications such as mould making and the production of unavailable spare parts have also been developed.

These attributes make the potential use of cold spray technology in the environmental conditions of the African continent particularly interesting and the presentation is intended to stimulate discussion on this.
HEAT TREATMENT DEVELOPMENT FOR RESIDUAL STRESS REDUCTION IN SLM MANUFACTURED COCR COMPONENTS

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ABSTRACT

Additive manufacturing methods that can fabricate metallic components such as the Selective Laser Melting method, has potential applications in a variety of industries. Recent studies performed on Selective Laser Melting of cobalt-chrome alloys shows promise in medical industries for instruments, implants and dental use, due to the mechanical properties of these components. However, owing to the way in which components are manufactured, defects can occur within components leading to the development of residual stress formation, resulting in possible component failure. To remove said residual stresses and improve component mechanical properties, post processing such as heat treatments have proven to be beneficial. The focus of this study is to determine adequate heat treatment processes to achieve residual stress mitigation.

INTRODUCTION

Advantages of the Selective Laser Melting additive manufacturing method displayed potential in medical applications as components can be customized for individual client needs, requiring minimal loss of functionality. Studies found that biomedical implants such as jaw and facial implants, dental bridges and crowns, as well as dental prostheses can benefit from this manufacturing method [1][2][3][4]. Further studies found that most materials used for the manufacturing of these implants include titanium, steel, and nickel-based alloys. Some other alloys however, such as copper, aluminium and cobalt-chrome, are not as renowned for their applications in the medical and dental fields [1]. Cobalt-chrome alloys have shown promise as an alternative material for dental
applications, as it possesses the required mechanical properties, corrosion resistance and fatigue resistance for dental components [2][3].

The Selective Laser Melting method melts metal powder particles in a successive layering manner. The laser heats the particles to over their melting temperatures creating melting pools that subsequently cool down. During this process rapid solidification occurs in component layers. This rapid solidification leads to phenomena such as distorted melting pool formation and thermal gradients within components; inducing high internal residual stress formation that can cause component distortion, crack formation and component failure [1]–[3], [5]–[8].

Applying post processing such as heat treatment to components after manufacturing, has been found to significantly reduce the residual stresses present in components [1][2]. Studies found that heat treatments homogenizes a material’s microstructures, relieving residual stresses by approximately 70% through annealing [7][8].

CONCLUSION

Numerous studies have been conducted on heat treatments for relieving residual stresses within components manufactured by the Selective Laser Melting method for various other alloys, such as titanium, nickel and steel. However, the amount of studies available on components manufactured from cobalt-chrome alloys are limited. Thus, in order to adequately reduce residual stresses within additive manufactured cobalt-chrome components, further research must be conducted on the influence of heat treatments on residual stress mitigation within such components.

REFERENCES


LASER OPTIMISED PROCESS PARAMETERS FOR SUPPRESSING COLUMNAR PHASE AND Nb SEGREGATION IN IN718 CLAD

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ABSTRACT

Several IN718 clads were produced with a laser cladding technique that used 1073 nm, high power continuous wave (CW), IPG Ytterbium fibre laser while varying laser power and scanning speed. The quality of IN718 clad was determined in terms of dilution, aspect ratio and metallurgical defects. Optical microscope analyses concluded a finer and coarse dendritic with inter-dendritic Laves phase microstructure from the middle to the top of the quality IN718 clad. Columnar dendritic microstructure with inter-dendritic Laves phase were found as segregates and concentrated at the edges and interface of the quality IN718 clad. SEM-EDS analyses concluded that the overall quality IN718 clad microstructure was achieved with $\leq 12.14$ wt.% Nb in the formed Laves phase particles. For structural engineering $\leq 20$ wt.% Nb, in the Laves-phase particles is required otherwise crack nucleation in the columnar phase occur thereby compromising the overall built structure.

RESULTS

Generally, the microstructure of the IN718 clad consists of whitish/greyish precipitates which are called Laves phase particles and darkish matrix which is called $\gamma$ phase\textsuperscript{[1]} as shown in Figs. 1(a) and 2(a). Figs. 1 and 2 depict typical SEM-EDS elemental mapping of Laves phase particles in the inter-dendritic region of finer and columnar microstructures of IN718 clad. These typical SEM-EDS elemental mapping show that the Laves phase particles are rich in Nb, Mo and a trace amount of Ti and they always segregate at the inter-dendritic region. These typical SEM-EDS elemental mapping of Laves phase particles were
conducted on the IN718 clad that was produced in this study. This was expected [2].

![Figure 1](image1.png)

**Figure 1:** SEM micrograph of the laser cladded IN718 presents the SEM-EDS elemental mapping of the Laves phase in the inter-dendritic region of cellular microstructures: (a1) Mo, and (a2) Nb.

![Figure 2](image2.png)

**Figure 2:** SEM micrograph of the laser cladded IN718 presents the SEM-EDS elemental mapping of the Laves phase in the inter-dendritic region of columnar microstructures: (a1) Mo, and (a2) Nb.

**REFERENCES**


Qualitative measurement rubric for internal cranial prostheses STL evaluation

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Introduction

Facial deformities and disfigurements may have a profound psychosocial impact on an individual. The visibility of disfigurement and being perceived as 'abnormal' by society can present various challenges. People with disfigurements often experience rejection by society, which treats them as outcasts, resulting in anxiety, severe depression and poor self-esteem. Various diseases and accidents cause facial deformities and the improvement of such deformities may require cranial reconstructive surgery and placement of implants or prostheses. Manufacturing of internal facial prostheses requires 3D imaging techniques, which include computed tomography (CT) imaging and magnetic resonance imaging (MRI). CT imaging is often the preferred method when such prostheses have to be designed for the cranial region. Because CT image quality plays a major role in cranial prosthesis design, poor quality images could result in incorrect sizing of the printed device, which may require repeat imaging and refitting, which could cause patient distress. The Centre for Rapid Prototyping and Manufacturing (CRPM) at the Central University of Technology (CUT) is responsible for the design and manufacturing of many cranial prostheses in South Africa. Currently, the CRPM does not have an optimised CT protocol for use by medical practitioners when acquiring CT images from patients. The first step in developing such a protocol requires an understanding of what constitutes a good quality CT scan. When using CT scan data the CT segmentation data is converted into stereolithography (STL) file format for computer-aided design in additive manufacturing machines. Therefore, this retrospective study was undertaken to develop a qualitative measurement rubric for the analysis of the quality of internal cranial prostheses STLs.

Materials and methods

At CRPM, there exists a collection of STL files that were used in the design and manufacturing of cranial prostheses. This collection of STL files was thus scrutinised to determine their suitability for inclusion in this study. After scrutiny, 35 of the STL files were deemed suitable for this study. These files were of adults 15 years or older and included metadata of the DICOM file of the original CT scan attached. For the qualitative evaluation of the STL files, a qualitative measurement rubric (QMR) had to be developed. Firstly, for the development of the rubric several evaluation variables had to be identified. Eight of these variables were different critical anatomical reference points (CARPs) that were identified with the assistance of an expert team.

Additionally to the CARPs, concentric rings on an STL and an overall designer impression score were also used to evaluate the image quality of the STLs. For each CARP, a visual acuity rating scale of three categories was devised,
where poor visual acuity scored 1, intermediate a 2, and good a 3. Similarly, rating scales were also devised for the
presence of concentric rings and the overall impression score awarded by the two designers involved in the design and
manufacturing of the prostheses. For the testing of the QMR, three evaluators, including the two designers, applied the
rubric to the 35 STLs. The evaluator QMR scores of the STLs were then captured on Excel spreadsheets and summary
statistics calculated. Also, ANOVAs and t-tests were performed to compare the evaluators QMR scoring of the STLs.

**Results**

The mean scores of the individual CARPs grouped around the central rating of partial visual acuity, ranging from 1.7 to
2.1. The mean total CARP scores of the three evaluators ranged from approximately 54% (13.1) of the maximum
possible score of 24 to 60% (14.4). In contrast, the mean total CARP+ring scores ranged from approximately 58% (15.8)
to approximately 64% (17.1) of a maximum possible score of 27. Ring artefacts were visible in only a few of the STLs.
The eight ANOVA tests performed on the STL image quality scores of the three evaluators revealed no significant
differences amongst evaluators. Similarly, for Total CARP and Total CARP+ring scores, the differences in evaluators’
scores were non-significant. In contrast, the t-test performed on the overall impression scores of two designers were
significantly different.

**Discussion and conclusion**

Through the application of the QMR, the quality of the 35 internal cranial prostheses STLs successfully evaluated.
Through the application of the QMR, the STLs could be distinguished from one another in terms of their image quality
and classified into three broadly defined categories; high, medium and low.

**Significance of the study**

The successful development and application of this QMR have the potential to be applied for quality evaluation of STLs
of CT scans of other anatomical regions.
INVESTIGATION OF THE PROPERTIES OF DIRECT ENERGY DEPOSITION ADDITIVE MANUFACTURED 304 STAINLESS STEEL

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ABSTRACT

One of the main considerations of the adoption of the additive manufacturing (AM) technology is whether the material properties of the AM produced part is comparable to the wrought material. This study looks at the comparison of the properties of the AM produced 304 stainless steel via the direct energy deposition AM process against the wrought 304 stainless steel. Both samples were studied in the as-built or as-received condition, heat treatment at 600°C, and at 1000°C for comparison. Methods for characterisation include, microstructural evaluation, spectroscopy, hardness tests, charpy impact testing, and x-ray diffraction. The results of this comparison are presented in this paper.

INTRODUCTION

Additive manufacturing Additive Manufacturing (AM) is a process of building 3D parts and components directly based on digital models by adding material layer by layer [1]. AM is specifically suited for low volume and complex part production as AM has significantly less manufacturing constraints than traditional CNC manufacturing processes [2]. This has resulted in design engineers being able optimize the geometry of a part according to its service environment without the traditional manufacturing restrictions. One of the key considerations for adoption of the technology is the material properties of the AM produced part compared to the wrought material. 304 stainless steel has exceptional corrosion resistance, mechanical properties, and oxidation resistance, and is used in almost every major industry [2-3]. A key factor in the 304 stainless steel final properties is the microstructural evolution during processing of which AM produces unique microstructures due to the rapid
heating and cooling rates of the laser process and layer by layer build method. This study focuses on the comparative properties of the wrought 304 stainless steel and the AM produced 304 stainless steel. Both materials are compared in the as-received and as-built conditions respectively and subject to heat treatments at 600°C and a 1000°C for further comparison. Methods for characterisation and comparison include, microstructural evaluation, spectroscopy, hardness tests, charpy impact testing, and x-ray diffraction.

METHODOLOGY AND RESULTS

Method

A 130mm x 120mm x 12mm block of 304 stainless steel was manufactured on a 3kW IPG laser coupled to a 5 axis kuka robot via the direct energy deposition process using commercial stainless steel 304 powder. The power used was 1kW, a robot translational speed of 1.5m/min, spot size of 2mm, and a 12mm stand-off distance. The samples were then sectioned for charpy impact testing according to ASTM standard E23. Samples were then heat treated at 600°C and 1000°C for microstructural evaluation, hardness testing, and XRD analysis for comparison to the as-built sample using standard metallurgical processes.

For the wrought material comparison, a 2mm 304 stainless steel plate was sectioned for microstructural analysis, hardness testing, XRD analysis, and heat treatment at the temperatures mentioned above for comparison to the AM produced 304 stainless steel.

Results

Figure 1 shows the microstructure of the as-built AM produced samples showing a columnar type microstructure inherent in the AM process due to the repeated rapid heating and cooling cycles. Wrought 304 stainless steel has an equiaxed microstructure.
Table 1 shows the results of the charpy impact testing of the as-built AM samples.

**Table 1: Charpy impact results taken at 20°C**

<table>
<thead>
<tr>
<th>Sample</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>J</td>
<td>108.60</td>
<td>92.05</td>
<td>102.45</td>
<td>101.03</td>
</tr>
</tbody>
</table>

**CONCLUSION**

Preliminary results show the elongated columnar microstructure of the as-built stainless-steel samples typical of the AM process due to the repeated high heating and cooling rates. Charpy impact results shows a reduction in toughness compared to wrought 304 stainless steel data in reference [4].

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INFLUENCE OF TI AND CU ON THE CORROSION PROPERTIES OF LASER-DEPOSITED HIGH ENTROPY ALLOYS IN NAOH SOLUTION

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ABSTRACT
In this study, AlCoCrFeNiCu (Cu-based) and AlCoCrFeNiTi (Ti-based) high entropy alloys were fabricated using laser additive manufacturing. The influence of the alloying elements and the laser processing parameters, the laser power and scanning speed on the corrosion behaviour of high entropy alloys for improved corrosion resistance were examined. The corrosion resistance in 1 mol/L sodium hydroxide solution was investigated using potentiodynamic polarization in experimental conditions at ambient temperature. Results indicate that the scan speed and laser power are two interactive factors that influence the corrosion rates, however, the laser power had more influence. Optimization occurred at 1400 W laser power and a scan speed of 10 mm/s. The Cu-based alloy with a corrosion rate of 0.00197 mm/yr was more resistant to corrosion than the Ti-based alloy with corrosion rates of 0.002635 mm/yr under optimum conditions.
AN OVERVIEW OF THE LATEST ADDITIVE MANUFACTURING RESEARCH IN THE 3D INNOVATION GROUP AT STELLENBOSCH UNIVERSITY
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ABSTRACT
The latest research of the group 3D Innovation is presented in this talk. An overview of the group’s research is presented including additive manufacturing (AM) research highlights from the last two years. This is followed by an introduction to two new projects within the Collaborative Program for Additive Manufacturing (CPAM). The first project falls within the metal AM category and is entitled “Structural integrity for mission-critical parts built by laser powder bed fusion”. The second falls in the Design for AM category and is entitled “Lattice structures and biomimetic design for AM”. These are presented in the context of possible collaborations and student opportunities.

INTRODUCTION
The research group 3D Innovation has established itself as a leading research group within Stellenbosch University, with interests ranging from Additive manufacturing to X-ray tomography and Biomimicry. This talk focusses on the additive manufacturing aspects and in particular research work funded through the CPAM program. One particular highlight is a recent book published in collaboration with > 50 experts from all over the world, entitled “Fundamentals of Laser Powder Bed Fusion of Metals” [1]. This book is set to become a reference text for students and engineers utilizing L-PBF and even working in other process categories, as many of the chapters have broader relevance also.

Particular highlights include review papers covering topics from the use of X-ray tomography in additive manufacturing [2], to biomimetic design for additive manufacturing [3], the effect of defects on mechanical properties in metal AM [4] and fatigue performance of lattice structures manufactured by AM [5]. Focused research studies in collaboration with local researchers, which are particularly noteworthy include the study of roughness and near-surface porosity in the Aeroswift high speed L-PBF system [6], the influence of porosity on bending behaviour of beams [7] and the characterization of porosity in AlSi10Mg [8]. International collaborations have been highly productive, including work involving fatigue failures studied as a function of surface roughness and build orientation [9], static and cyclic loading studies of gyroid lattice structures [10] as two good examples.
CONCLUSION
This talk is meant to share information on ongoing and successful research, for stimulating new collaborations, ideas and presenting opportunities for fruitful collaboration.

REFERENCES
USING THE VICKERS INDENTATION METHOD TO MEASURE SURFACE RESIDUAL STRESS IN SLM IN718 SPECIMENS

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ABSTRACT

Selective laser melting of Inconel 718 powder (a nickel-based superalloy) is regularly used to manufacture gas turbine parts for the aerospace industry. Residual stresses that remain in components after manufacturing are known to be detrimental, often resulting in geometric distortion and reduced mechanical properties. It is therefore important to be able to measure these residual stresses. Many non-destructive residual stress measuring techniques are used in the industry and the Vickers indentation method has been proposed as a less expensive, rapid evaluation technique of residual stresses. The efficacy of the Vickers indentation method as a residual stress measurement technique will be evaluated in the current study.

INTRODUCTION

Since selective laser melting is dominating the additive manufacturing industry, it is important to counteract the shortcomings of the process. In particular, the formation of residual stresses in selective laser melted components has obstructed the widespread adoption of this additive manufacturing technique in the industry [1]. To understand the formation of these stresses during the selective laser melting process, rapid residual stress evaluation techniques are first necessary. Many techniques are currently used in the industry, however, they are usually expensive, time consuming and generally inaccessible [2, 3]. The estimation of residual stresses using the Vickers indentation technique was first proposed by Carlsson et al. [3] in 2001, when it was observed that residual stresses can be experimentally measured using the surface area of the indentation [3]. Based on theoretical and numerical analyses, as well as experimental investigations, Carlsson et al. [3, 4] found that residual strain fields can be accurately correlated with the hardness value of sharp (Vickers) indentation tests, while the size of the contact area can be related to the residual stresses in the component [3].
METHODOLOGY

During this study, a COHERENT Creator SLM machine was used to manufacture specimens from Inconel 718 powder (acquired from Praxair). Cuboid specimens (10x10x10mm) were manufactured using process parameters obtained from the original equipment manufacturer. To ensure validation of the Vickers indentation method as a residual stress measuring technique across a range of different conditions, cuboids were manufactured with three different hatch distances. Four specimens in each hatch distance were evaluated in the as-built condition and four specimens in the stress-relieved condition. The specimens were manufactured according to Table 1.

Table 1 – Layout of manufactured specimens

<table>
<thead>
<tr>
<th>Parameter varied</th>
<th>Condition</th>
<th>Total per hatch distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hatch distance [mm]</td>
<td>As-built</td>
<td>Stress-relieved</td>
</tr>
<tr>
<td>0.120</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>0.114</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>0.108</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Total per condition</td>
<td>9</td>
<td>9</td>
</tr>
</tbody>
</table>

Stress-relief heat treatments were done according to industry standards. Each face was electrochemically polished to ensure accuracy of indentation tests.

Vickers indentation tests were done on nine locations in a 3x3 grid on the X-Z and Y-Z faces of the cuboids. The inherent strain method was used (through means of Simufact Additive simulation software) to simulate the expected residual stress values near the surfaces of the cuboid specimens at the locations mentioned above.

Results obtained from these tests will provide valuable insight into the accuracy of the Vickers indentation method as a residual stress measurement technique across a range of different conditions.

CONCLUSIONS

Since results are yet to be obtained, no conclusion can be drawn at this stage. It is expected, however, that the Vickers indentation method will be accurate enough for observing residual stress trends across the faces of the cuboid specimens.
REFERENCES


FRACTOGRAPHY OF POLYPROPYLENE LASER SINTERED TENSILE TEST SPECIMENS
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ABSTRACT

The failure edges of polymer laser sintered tensile specimens of two grades of commercial polypropylene powder (Laser PP CP 60 and Laser PP CP 75) were investigated in this study. It was concluded that parts printed using Laser PP CP 60 exhibits a ductile fracture, whereas Laser PP CP 75 was more brittle. Laser PP CP 60 manifested notable jagged and fibrous fracture, while Laser PP CP 75 fracture appeared less jagged and fibrous. Lastly, Laser PP CP 75 polymer exhibited a reduction of strength with re-use, which can be explained by the increase in the number of pores evident in the micrographs.

INTRODUCTION

Considerable research has focused on assessing the processing parameters, as well as the mechanical properties of printed parts to determine the applicability of new polymers in L-PBF. Different process parameters affect the density and mechanical characteristics of components developed using L-PBF. Some of these factors include energy density/laser power, scan spacing, laser beam speed, and part orientation (Dizon et al. 2018). The impact of aging of powder on the mechanical properties of the printed parts has also attracted considerable attention from researchers, but the arising conclusions are inconsistent. Yao et al. (2020) found that the tensile strength of parts produced using PA 12 increases and then decreases with the re-use cycles. Zarringhalam et al. (2006) found no considerable change in tensile strength of printed parts but increasing percentage of elongation at break with re-use.
cycles. Wudy et al. (2014) found that aged PA 12 powder lowers the tensile strength of the printed components.

Preliminary research focused on analysing the tensile fracture of printed parts. In this regard, the study investigated the failure edges of parts printed using two grades of commercial PP powder, Laser PP CP 60 and Laser PP CP 75 from Diamond Plastics GmbH. Further research analysed the effects of powder aging on the mechanical properties of printed components using fractography of the failed test specimens.

METHODOLOGY

In the first part of the analysis, samples were printed using Laser PP CP 60 material, then subjected to tensile testing till fracture, and finally analysed using scanning electron microscopy (SEM). Fracture samples of parts printed using virgin and aged Laser PP CP 75 were also investigated using SEM in the second part of analysis.

RESULTS AND CONCLUSION

In the preliminary investigation, it was concluded that parts printed using Laser PP CP 60 exhibited ductile fracture and failed through the formation of jagged and fibril fracture surfaces. In the further investigation, tensile fracture analysis of parts printed using virgin and used Laser PP CP 75 led to the conclusion that more pores were formed with increasing powder re-use. This was thought to have been responsible for the observed decrease of tensile strength from 7.1 MPa to 6.6 MPa for the second and fourth re-use cycles, respectively.

REFERENCES


RESIDUAL STRESS, POROSITY AND SURFACE ROUGHNESS MEASUREMENTS FOR LASER POWDER BED FUSION MANUFACTURED Ti6Al4V AT HIGH LASER POWERS

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ABSTRACT

The need for reduced manufacturing times for LPBF has propelled machine manufacturers and researchers to implement different strategies towards improved build rates and productivity. Using high-powered lasers with a larger beam focal spot size is one of the promising methods for improving LPBF build rates. In this study, we present residual stress, porosity, and surface roughness of Ti6Al4V manufactured at high laser powers.

INTRODUCTION

In LPBF, the main research thrust has been to identify and tune the effect of process parameters on the end part structure and resulting properties. In recent years, machine manufacturers and researchers are focusing on expanding the capabilities of their machines by increasing the build rates and build volumes. Thus, the main aim of this study is to characterise residual stress, porosity, and surface roughness of LPBF manufactured Ti6Al4V using high laser powers and enlarged focal beam spot size towards improved productivity of the LPBF process.

METHODOLOGY AND RESULTS

Methodology

Nine cuboid samples (12 mm x 12 mm) were manufactured using a custom-built LPBF system equipped with 5kW IPG YLS 5000 Ytterbium fiber laser at different laser powers (600 – 2000 W) and build rates. Residual stress was characterised by x-ray diffraction at Nelson Mandela University, with the x-ray emitter targeted at the center of the coupon top surface; porosity and surface roughness were measured using x-ray tomography at Stellenbosch University following methods described by du Plessis et al. [1 &2].
Results
Figure 1 shows the measurement results obtained in terms of residual stress, surface roughness, and porosity.

![Figure 1: Principal stresses (a), (b), porosity measurements and (c) surface roughness.](image)

CONCLUSION
The use of high-powered lasers equipped with a larger beam focal spot size is one of the promising methods for improving the LPBF productivity since larger volumes of metal powder can be melted in a shorter time. A thorough investigation was carried out using XRD and micro-CT to quantify residual stress, porosity, and top surface roughness. A trend in decreasing residual stress with decreasing hatch spacing and scanning speed was observed, and this is mainly due to heat accumulation at smaller hatch spacing, and increased interaction time at lower scanning speeds. The top surface roughness of the samples produced at a high build rate was also shown to be smoother compared to the other samples produced at lower build rates. However, the vertical surface was not characterized in this study and will be the focus of a future study. Nevertheless, this study is the first to reveal the potential benefits of using high powered laser to increase the build rate, while obtaining lower residual porosity, residual stress, and top surface roughness, which is positive for improving the LPBF productivity.

REFERENCES

THE EFFICACY OF THE INHERENT STRAIN METHOD IN DETERMINING RESIDUAL STRESS IN IN718 SLM SPECIMEN

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ABSTRACT

This paper presents a study showing the efficacy of the inherent strain method and modifications thereof to predict residual stresses within selective laser melted components. Cubic specimens with variations in hatch rotations were produced and the residual stress state simulated and measured by employing the neutron diffraction technique. Variances in simulated and observed values of stress in the samples were investigated to show the efficacy of the isotropic, orthotropic and thermo-mechanical simulation methods.

INTRODUCTION

The widespread adoption of the selective laser melted (SLM) additive manufacturing method is only viable if components can be manufactured that are crack free and exhibits minimum distortion. In order to realize this, distortion compensation or design alterations may be incorporated to inhibit the formation of residual stresses that may lead to cracking. This may be done by simulating the stress states at various production stages and optimizing the design accordingly.

METHODOLOGY AND RESULTS

Simulation

This study employed orthotropic and isotropic variations of the inherent strain method as well as a thermo-mechanically coupled technique as implemented in Simufact Additive [1] to determine the residual stress states within SLM cubic Inconel 718 samples. Specimens of 15x15x15 mm³ with 0°, 67° and 90° bi-directional hatch rotations were simulated using all three simulation methods to investigate the effect of hatch rotation on the residual stress state within components.
Manufacturing and measurement
Samples based on the simulated models were manufactured with the ORLAS Creator [2] SLM machine as shown in Figure 1 and the tri-axial stresses at positions on a central plane measured with the MPISI neutron diffractometer [3]. The results for the 67° and 90° samples were comparable with the 0° sample exhibiting generally less stress.

![Figure 1: (a) Manufactured sample with (b) measurement plane and (c) hydrostatic stresses.](image)

Comparison
By comparing the spatial dependant tri-axial stresses of the measured results with the three simulations, trends in differences as shown in Figure 2 for the specimen with no hatch rotation were observed. Results indicated that the orthotropic inherent strain simulation predicted the residual stresses with the highest accuracy when no hatch rotation was used, however with application of rotation the thermomechanical simulation type proved more adept. All simulations generally had the higher differences with the simulated stresses towards central regions of the cubes. The $\sigma_{zz}$ stresses were also noted as having the highest difference between the simulated and measured values, especially towards the top and bottom regions of the specimens.
CONCLUSION

The residual stress prediction for the IN718 samples showed to be the least accurate for the isotropic and orthotropic inherent strain simulation types with the thermomechanical method the most accurate. It was also seen that the introduction of rotation of the hatching parameters caused the components to have less variation in the $\sigma_{xx}$ and $\sigma_{yy}$ directional stresses, with the lowest variation seen by the 90° rotation specimen. From this it could be noted that for all simulation types, applying 90° hatch rotation yielded predicted stress differences of less than 100 MPa; as the material yield strength was taken as
770 MPa this is a relatively low difference. Accordingly making use of the thermomechanical simulation type with 90° rotation would yield the best simulated results, allowing for the most accurate distortion compensation and ability to predict yielding and warping.

REFERENCES

CHARACTERISATION OF WASTE SAND GENERATED DURING THE VOXELJET RAPID SAND CASTING PROCESS

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ABSTRACT

Appreciable quantity of waste sand is generated during the manufacturing of sand parts by additive manufacturing processes. In line with environmental regulations and considering the increasing value of sand, the reuse of waste sand has become an imperative aspect to consider implementing in the rapid sand-casting process. This paper investigates the properties of waste sand generated from additive manufacturing process of sand parts using the Voxeljet process. The characterisation results suggest that the waste sand could be recycled in the production of sand cores and moulds using both the traditional method and the modern method of additive manufacturing.

INTRODUCTION

Additive manufacturing is a production of physical three-dimensional computer-aided design model, usually layer by layer. Three-dimensional printing technologies for rapid sand casting include ZCast, EXOne and Voxeljet; these are just some of the most visible examples on the market that are used to produce sand moulds and cores using a binder jetting technology.

During the printing of the furan bonded sand cores using the Voxeljet VX 1000 printer, waste sand is produced. The process uses pre-coated sand which is fed into the system. Layers of precoated sand which are 3 microns thick are applied to print out the desired geometry. If the build is bigger than the desired part, the excess sand will not be activated and will remain as normal pre-
coated sand that is not bind together. Therefore, it will be considered as waste.

The Vaal University of Technology (VUT) currently stores the waste foundry sand for a maximum of one month. This is because a longer storage period may lead to moisture pick up in the sand, which will affect the strength of the furan bonded sand parts when reused. Up to 40% of the waste sand generated can be reused but that amount can be less if the strength of the sand parts is not within the required specifications.

METHODOLOGY

Three types of sand samples were collected from the Vaal University of Technology, namely; Waste sand 1, Waste sand 2 and Virgin silica. The tests performed included sieve analysis, scanning electron microscopy analysis, moisture content, loss on ignition and pH.

RESULTS & DISCUSSION

The sand distribution of Waste sand 2 was also spread more widely than that of the virgin sand and Waste sand 1 which were both spread narrowly. Due to the higher AFS in the virgin silica sand as well as in Waste sand 1, a denser and smoother surface finish with a lower permeability was anticipated in the cores made from these sands than from the cores produced from Waste sand 2.

![SAND DISTRIBUTION: VIRGIN SAND](image)

![SAND DISTRIBUTION: WASTE SAND 1](image)

![SAND DISTRIBUTION: WASTE SAND 2](image)

Figure 1: Grain size distribution, (A) Virgin sand, (B) Waste sand 1, (C) Waste sand 2
The pH of virgin sand was found to be 2.86, indicating the presence of sulphonic acid with no contaminants. The pH of both Waste sands 1 and 2 was found to be 3.03 and 3.29 respectively. This suggests that the sulphonic acid with which they had been coated had been utilized. Waste sand 1 and virgin silica sand had a loss on ignition content of 0.54% and 0.57% respectively, which was higher than that of Waste sand 2 which was found to be 0.33%. These results suggest that Waste sand 1 and virgin silica sand were from the same source.

![Grain morphology](image)

**Figure 2: Grain morphology, (A) Virgin sand, (B) Waste sand 1, (C) Waste sand 2**

The scanning electron optical microscope revealed some morphological features of the sand samples. Virgin silica sand grains were observed to be angular to sub-angular with a medium to low sphericity, therefore the flowability and packing of the sand grains was expected to be low. Waste sand 2 grains were observed to be sub-rounded with a medium sphericity with Waste sand 1 being angular to sub-angular with a medium sphericity. The results indicate that the printing process abrades the grains to a more rounded shape.

**CONCLUSION**

This paper is aimed at investigating the properties of waste sand generated from additive manufacturing process of sand parts using the Voxeljet process and reviews the potential reuse of waste sand with the objective of reducing costs to purchase new sand, storage and transport to the landfills. From the results obtained and discussed; the reuse of waste sand for the production of sand cores and moulds using the traditional method as well as the modern method of additive manufacturing is a possibility. Furthermore, it is
recommended to treat the recovered waste sand through processes such as thermal and mechanical reclamation, to allow the reduction of residual binder content without largely affecting the physical state of the sand.

REFERENCES


PRE-OPTIMISATION OF A RESIN COATED CHROMITE SAND FOR RAPID SAND CASTING APPLICATIONS.

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ABSTRACT

Applications of three-dimensional printing (3DP) to sand casting have been well-established in the last two decades. The preferred raw material is silica (quartz) sand as it is the most readily available and cost effective sand. However, silica sand as a refractory material has some technical limitations including high thermal linear expansion, low refactoriness and thermal conductivity, therefore, it is not suitable for all castings. Other refractory sand types are available including chromite sand which is one such refractory material abundantly available in South Africa. Analysis of the coating optimisation of locally sourced chromite sand with a furan resin sand binder system was investigated in this study. Foundry tests in the laboratory that give understanding of the quality and suitability of the use of chromite sand as a potential substitute for silica material for rapid sand-casting applications were carried out. The results of this study will inform on the optimisation of parameters for the manufacturing of a resin coated chromite sand and its use in additive manufacturing using a Voxeljet VX 1000 printer.

INTRODUCTION

Additive Manufacturing (AM) is a manufacturing technique that refers to a process by which digital 3D design data is used to build up a component in layers by depositing material [1]. Applications of three-dimensional printing (3DP) to sand casting have been well-established in the last two decades [2]. One of the major benefits of using 3D printing is that it allows for the gating system (down sprue, runners, risers) to be designed into sand mould
produced, pattern-less less moulding is another advantage, this reduces costs the as production of sand patterns is costly and takes a long time. It decreases costs on resources weight up to 33% as the machine utilizes the required material for the part only.

Commercial technologies used in rapid sand casting include ZCorp, EXOne and Voxeljet which are becoming more prominent in the AM Industry, these AM based technologies use Selective Laser Meting, Fused Deposition Modelling, Selective Laser Sintering, Laminated Object Manufacturing, Stereo lithography as well as 3DP which is used to make moulds and cores [5]. 3DP, also known as binder jetting technology is being used in different sectors and industries, namely: visual aids and artistic aesthetics, presentation and functional models, short run and series productions, mould, core and pattern making predominantly in the foundry industry, spare and custom parts, device covers and research and educational purposes [6].

The 3DP process used in binder jetting additive manufacturing can be categorized into three major categories: sand mixing, sand layering as well as sand printing. Sand mixing is achieved by means of homogenizing a predetermined amount of arylsulfonic acid catalyst with a certain amount of sand. It is then put into the sand hopper, the sand is then piled up into layers via the re-coater and the print head then deposits the furan resin according to the pre-programmed furfuryl alcohol settings [7], this process is repeated until the final part is completely formed.

Silica sand is the most widely used refractory moulding material for both foundry sand moulding and AM applications because of it is the most readily available and cost effective moulding material as compared to the other sand types [8]. However, it has its own shortcomings such as a high thermal expansion and low refactoriness [9]. Other sands are used for superior applications where high refactoriness is required, Chromite sand is one such material abundantly available in South Africa, as we hold roughly three-quarters of the world’s feasible chromite reserves [10].

Chromite sand has improved metal penetration resistance, excellent chilling ability: which stems from it having elevated thermal conductivity and superior dimensional strength stems from its low thermal expansion, allowing improved final product features [11], [3]. Previous studies have been undertaken on South African silica sand as well as ceramic sand and their suitability for AM Rapid Sand Casting Applications [11], [12]. They revealed that not all local Silica sands are suitable for AM applications and as such chromite sand will be considered in this investigative work.

Optimization of the sand was carried out in this investigative work in order to give an indication of the quality as well as the suitability of use of the chromite
sand refractory material in 3DP via the binder jetting technology for rapid sand casting applications using the VX1000 printer. This will be achieved by firstly looking at the Flow ability of the acid coated sand: which is determined by the angle of repose that ideally has to be below 45° in order to be passable thereby prevent clogging of printer during sand layering [3]. Angularity of the sand grains will thus be a key factor as it will mostly affect the layering of the sand during 3D printing.

Secondly the Bend Strength of the specimens: the minimum required bend strength of 220N/cm² so that printed part can support itself and thirdly the Loss-On-Ignition: which has to be below the 3% threshold to prevent any defects during casting.

There is very little use of Chromite sand for Rapid Sand Casting applications. This research project aims to present how chromite sand can be used as an alternative in the application of 3D printing for sand mould and core making. The assessment of a local chromite sand for the suitability of its application to Rapid Sand Casting will thus be carried out.

**METHODOLOGY AND RESULTS**

In this study, the mechanical properties of sand testing samples were determined by producing bend strength samples whilst using conventional hand ramming method in a foundry laboratory according to American Foundry Society (AFS) standard [4]. The raw materials used were locally sourced chromite sand as well as imported furfuryl alcohol (binder) and aryl-sulfonic acid (catalyst) from Voxeljet.
CONCLUSION

The purpose of this investigation was to optimize the addition of furfuryl alcohol and sulfonic acid catalyst that produced optimal bend strength, flowability and LOI.

REFERENCES


SUITABILITY OF LOCAL CHROMITE SAND FOR USE IN RAPID SAND CASTING

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ABSTRACT

Rapid sand casting is a Three Dimensional printing technique which is direct fabrication of sand moulds without patterns. Pattern making is a very complex and time consuming process, eliminating such improves casting process. Silica sand is a widely used moulding material but is associated with quality problems. Its high thermal expansion causes defects mainly with heavy duty castings. Chromite sand as an alternative has excellent refractory properties and good thermal conductivity. The use of chromite sand coupled with Rapid Sand Casting could enhance production of best quality castings. This study analyses the behavior of local various chromite sand in Rapid Sand Casting.

Key words: Rapid sand casting, chromite sand, Three Dimensional Printing

INTRODUCTION

Three dimensional printing is a process of fabricating physical objects from a 3D model data by binding granulated material layer by layer whereby each layer represents a thin horizontal cross sectional area of the final object [6]. There are numerous applications of Three dimensional printing in all sectors, in foundry industry, the process is known as Rapid sand casting. Rapid sand casting is the mould fabrication process without utilizing patterns and is used as an alternative traditional mould production process. Pattern making is one of the slowest and costly casting processes because it requires extremely high quality [6].

South Africa is the world’s largest source of chromite, historically it has
accounted for approximately 72% of global reserves [3]. Chromite sand is the iron chromium moulding material mostly used in high duty castings such as impellers and mill liners. These castings require moulds with high thermal conductivity, refractory properties, and low thermal expansion. Its high thermal conductivity offers fast cooling minimizing the casting chilling effect [1]. Chromite sand is found to be advantageous over silica. The quality of castings is highly dependent on the quality of mould which also depends on the quality of the sand used. 3D printing offers very excellent advantages on manufacturing such as costs, design freedom and rapid turnaround time.

Rapid sand casting typically applies Furfuryl alcohol resin bonded sand hardened with Sulfonic acid acting as a catalyst [2]. The curing characteristics of sand mixtures are mainly affected by Acid Demand value, moisture, and resin reactivity as well as addition proportions. During rapid sand casting sand falls freely on the printing bed through gravitational force. Therefore bulk density and Flowability is one of the vital properties for rapid for good and uniform generation of strength. There is a limited literature on the utilizing of chromite sand in both traditional moulding and Rapid Sand Casting

METHODOLOGY AND RESULTS

Methodology

The raw materials used include four locally sourced chromite sand samples from different mines, Furfuryl alcohol (Binder: VX-2C Type B) and Arylsulfonic acid (Activator: VX-2C Type A)

![Flowchart of the Experimental procedure]

**Figure 1** Flowchart of the Experimental procedure

Different characterization techniques were performed in all four sand samples namely: Grain size distribution, Grain shape, Flowability, Chemical analysis, and Acid demand Value.
Results and Discussion

Sand Characterisation

Flowability measures the ability of the sand grains to flow freely expressed by the angle of repose of free flowing powders. Different chromite sand samples were first coated with 0.1% catalyst of sand %wt. and left for 48 hours. Figure 2 shows that there was an improvement of flowability of the coated sand from fair (between 36 and 40 degrees angle of repose) to Good flowability (between 31 to 35 degrees) after 48 hours of storage. Leaving coated sand for 48 hours before printing allows for acid evaporation hence better flowability. Flowability plays a crucial role in the uniformity of the deposited layers during printing as well as least variation possible in the mechanical motion during recoating of each layer.

Figure 2: Flowability measurements of the tested chromite sand samples

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<th>B</th>
<th>C</th>
<th>D</th>
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<tr>
<td>Immediatley</td>
<td>37.58</td>
<td>38.66</td>
<td>36.8</td>
<td>37.98</td>
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<tr>
<td>after 24 hrs</td>
<td>31.17</td>
<td>35.91</td>
<td>34.33</td>
<td>34.33</td>
</tr>
<tr>
<td>after 48 hrs</td>
<td>31.74</td>
<td>33.81</td>
<td>32.37</td>
<td>32.37</td>
</tr>
</tbody>
</table>

Flowability: 0 to 10 = poor, 11 to 20 = fair, 21 to 30 = good, 31 to 50 = excellent.
CONCLUSION

REFERENCES


ASSESSMENT OF CONSOL SILICA SAND FOR THREE-DIMENSIONAL PRINTING APPLICATIONS

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ABSTRACT
Silica is extensively used as a refractory material due to its properties such as its low thermal expansion, low cost, and higher temperatures resistance. The fast moving of manufacturing technology has forced the implementation of the three-dimensional printing (3DP) into the metal casting industry to improve the product quality and to satisfy customer needs. Unfortunately, this 3DP technology for sand parts production can be successfully accomplished only with the use of specially imported sand. This situation makes the sand production expensive. Previous study was already initiated with the purpose of substituting the imported sand with the Atlantis silica sand which is mined in South Africa. The outcomes have proven that the Atlantis local sand could be successfully used as a substitute and led to the economic production of moulds. This paper is an extension of the previous study aiming to use Console sand as an alternative material to substitute both the imported and Atlantis sands. Preliminary trials, with Consol sand, have already proven its performances and the outcomes show that these data are comparable to those of Atlantis sand in applications other than the 3DP. The new Consol sand will be first characterized, thereafter its characteristics will be compared to those of Atlantis sand and further determine its use for eventual 3DP application.

Keywords: Silica sand, three-dimensional printing.

INTRODUCTION
Three-Dimensional Printing (3DP) in the metal casting refers to the application of additive manufacturing (AM) for the production of sand moulds and cores used for metal casting. This technology has become very popular in the 21\textsuperscript{st} century with sophisticated three-dimensional printing (3DP) equipment for metal casting applications. These equipment are used in the production of sand parts such as moulds and cores. This application offers several benefits to foundrymen that include the elimination of tooling in the form of sand pattern and core boxes, the reduction of lead design time in the casting process and topology optimisation of complex parts \cite{1}. The 3DP methods used in the mould productions are centred on the resin bonded sand casting process such as the alkaline phenolic, croning and furan processes. Silica sand is locally mined and is one of the widely used refractory sands in metal casting applications. This is due to its large availability worldwide and low price compared to other specialized foundry sands such as chromite, olivine, and zircon sands. Silica sand foundry characteristics include size distribution, grain shape, chemical purity, refactoriness, and acidity level. The characteristics of silica sand ensure that the resin usage is diminished, the mould strength is adequate and the final castings are well built and without defect \cite{2}.

The AM processes are free of sand dampening and mould jolting and squeezing. In particular, during the layer by layer construction of sand components, sand particles size distribution needs to be narrowed and the fabrication of strong objects are supported by the intrinsic features of silica sand with regard to tighter distribution, finer and spherical shape sand particles.

Besides the above-mentioned properties being important, the variety in the sand choice is also a crucial factor in ensuring a cost-effective production of sand parts. For the same reason, the running cost of AM processes was found to be expensive because of the import of silica sand from oversea. In the quest for solving this problem, various studies and experiments have been conducted to prove that local sand could be considered for AM of sand moulds and cores using a 3DP in place of the expensive imported silica sand \cite{2}. In the aim of addressing the above issue, this research expands
its scope to find another local sand with better moulding properties besides the sand that was already identified in the previous research as an alternative material to the imported sand [3].

EXPERIMENTAL PROCEDURES
Two types of silica sands were assessed in this research. The first one, identified as Atlantis sand, was sourced from Vaal University of technology-Technology Transfer and Innovation (VUT-TTI) centre. Atlantis is the sand initially proven to be an alternative to the imported sand. The second sand is named Consol sand, also sourced from the same technology centre and was selected because of its good reputation among other sands that were recently tested at the University of Johannesburg as part of a survey commissioned by the National Foundry Network (NFTN) agency [4]. And, this sand has proven to show good response during AM trials using a 3DP technology available at VUT-TTI centre.

The experimental work was carried out in the characterization of refractory sands. Test procedures recommended in the American Foundry Society (AFS) handbook were followed during sand testing [5].

Characterisation of refractory sands
The two selected foundry sands were tested for the following properties:
- AFS Grain Fineness
- Loss on ignition
- Acid demand value (ADV)

RESULTS AND DISCUSSION

<table>
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<tr>
<th>Sand Properties</th>
<th>Consol sand</th>
<th>Atlantis</th>
</tr>
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<tbody>
<tr>
<td>Acid Demand Value [ml]</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>AFS Grain Fineness</td>
<td>55</td>
<td>67</td>
</tr>
<tr>
<td>Loss on Ignition [%]</td>
<td>0.60</td>
<td>0.40</td>
</tr>
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</table>

Table 1 shows the properties of the two local silica sands. Noticeable and appreciable differences between the two silica sands can be observed regarding the Acid Demand Value, AFS grain fineness, Loss on Ignition and total clay content:

- ADV measure the level of acidity or basicity in the sand. The two sands show equal value of ADV which is zero. An increase in ADV suggests that the sand contains a higher amount of alkaline impurities which will react with the catalyst of cold-setting, acid-catalysed binders. Moulding aggregate with higher ADV is preferable in the alkaline resin binder system. In the acid binder system such as furan, a lower ADV is therefore adequate. An improper combination between ADV and the pH of the sand leads to a neutralisation reaction hence bonding of sand will not be achieved [4].

- The AFS fineness is an indication of sand particles size. The data show that the AFS of 55 was obtained from the Consol sand and the AFS 67 from the Atlantis sand. The higher the AFS number the finer the sand and lower the number the coarser the sand. Mould permeability and surface smoothness are the properties the most affected by the PSD. In relation to this, sand yielding lower values with respect to this property will provide a good mould permeability but not an ideal mould surface finish. The opposite is completely true for the moulding aggregate with higher PSD which implies low permeability, but good surface smoothness property will be obtained [5]. In the case of 3D printing of sand moulds and cores sand with finer crystals is highly preferred to prevent jamming of the 3D printer re-coater.

- The loss on ignition results show that the Atlantis has lower value which is 0.4% compared to Console sand with 0.60%. This property is ideal when sand yields a low value of LOI preventing excess gas generation during casting that could cause gas-related defects which will affect the quality of the final casting [6].

CONCLUSION
The initial sand classification results show that the Consol sand has yielded foundry properties close to the Atlantis sand. A comprehensive sand characterisation is therefore is required to determine the properties of Consol sand that could be superior to those of the Atlantis sand.

REFERENCES
DIMENSIONAL ERROR TESTING OF 3D PRINTED SAMPLES AND STERILIZATION TECHNIQUES FOR ORTHOPEDIC SURGERY

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ABSTRACT

The purpose of this study was to investigate the dimensional accuracy of 3D printed samples after ethylene oxide (EtO) or autoclave sterilization to show material and sterilization compatibility for 3D anatomical models used as intraoperative references in a public healthcare system. Samples were 3D printed in acrylonitrile butadiene styrene (ABS), nylon, and polylactic acid (PLA), and sterilized using low-pressure EtO and autoclave sterilization. Afterward, samples were measured with a digital vernier caliper for dimensional accuracy testing. Low-pressure EtO sterilization had a minimal effect on nylon (0.151%) as opposed to PLA (-1.478%) and ABS (-1.500%), which both shrunk in size (cm³). PLA (-3.751%) was the most affected by low-pressure autoclave sterilization whereas ABS (-1.648%) and nylon (-1.124%) showed less shrinkage. Therefore, nylon may be a suitable material to use in both EtO and autoclave sterilization techniques as opposed to ABS and PLA materials.

Keywords: additive manufacturing; dimensional accuracy testing; ethylene oxide; autoclave; intraoperative references.

INTRODUCTION

Motivation

Orthopedic surgeons may require sterilized 3D anatomical models for use as intraoperative references to guide surgeons during surgery. 3D printed anatomical models are used in orthopedic surgery to improve precise implant or prosthesis placement [1] and better surgical outcomes [2]. For use in the theatre, 3D printed anatomical models needs to be adequately sterilized. However, various sterilization techniques affect and transform the 3D geometrical shape of these models [3]. Therefore, this study investigated different material and sterilization compatibility techniques to find the most suitable option to sterilize 3D anatomical models for use as intraoperative references.
Aims and Objectives

- This study aimed to investigate the dimensional accuracy of samples 3D printed in ABS, nylon, and PLA, after EtO or autoclave sterilization to show material and sterilization compatibility for 3D anatomical models used as intraoperative references during orthopedic surgery.

METHODOLOGY

Dimensional Accuracy Testing Apparatus and Technique

Samples, solid cube, open 6x cube, solid ellipse, and hollow ellipse, were 3D printed in ABS, nylon, and PLA, each with their associated AM technology: Zortrax M200 (ZM200), Zortrax M300 (ZM300) Dual, and Leapfrog Bolt Pro, respectively. Dimensional accuracy testing was performed by using a digital vernier caliper to measure each sample along its x-, y- and z-axis to estimate the volume in cubic centimeters (cm$^3$). After the first set of dimensional measurements, each 3D printed sample with its associated material was sent to the Central Sterilization Service Department (CSSD) of Tygerberg Hospital to be sterilized separately using low-pressure EtO and autoclave sterilization. Afterward, the 3D printed samples were retrieved and dimensional measurements were repeated with a digital vernier caliper.

RESULTS

Ethylene Oxide (EtO) and Autoclave Dimensional Accuracy Testing
The mean difference between the ZM200 ABS EtO sterilization and the post-printing group was -0.085cm³ (-1.500%) with a standard error of measurement (SEM) of 0.017cm³ (0.395%), shown in Figure 1. For the ZM300 Dual nylon EtO sterilization and post-printing group, the mean difference and SEM were 0.012cm³ (0.151%) and 0.010cm³ (0.130%), respectively. A comparison between the Leapfrog Bolt Pro PLA EtO sterilization and the post-printing group showed that the mean difference was -0.089cm³ (-1.478%) and the SEM was 0.021cm³ (0.319%). The mean difference between the ZM200 ABS autoclave sterilization and post-printing group was -0.081cm³ (-1.648%) with an SEM of 0.064cm³ (1.294%), shown in Figure 1. For the ZM300 Dual nylon autoclave sterilization and post-printing group, the mean difference and SEM were -0.055cm³ (-1.124%) and 0.029cm³ (0.649%), respectively. Finally, a comparison between the Leapfrog Bolt Pro PLA autoclave sterilization and the post-printing group showed that the mean difference was -0.219cm³ (-3.751%) and the SEM was 0.067cm³ (1.116%).

Fig. 1. Percentage Error (%) of Post-printing vs. EtO and Autoclave Sterilization Volume Measurements (cm³)

CONCLUSION

Low-pressure EtO sterilization had a minimal effect on nylon (0.151%) as opposed to PLA (-1.478%) and ABS (-1.500%), which both shrunk in size (cm³), shown in Figure 1. PLA (-3.751%) was the most affected by low-pressure autoclave sterilization whereas ABS (-1.648%) and nylon (-1.124%) showed less shrinkage, shown in Figure 1. Therefore, nylon may be a suitable material to use for both EtO (preferably) and autoclave sterilization, as opposed to ABS and PLA materials, for 3D printed anatomical models used during surgery.
REFERENCES


HIGH CYCLE FATIGUE PERFORMANCE OF Ti6Al4V (ELI) PARTS PRODUCED WITH INHERENT DIRECT METAL LASER SINTERING SURFACE ROUGHNESS.

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ABSTRACT

This study investigated how surface defects affect the fatigue performance of direct metal laser sintering (DMLS) Ti6Al4V (ELI) test specimens in as-built and heat-treated conditions. Tensile and fatigue specimens were built in three orthogonal directions for testing. Fatigue testing was carried out to determine the maximum stress at which a run-out number of 5 million cycles to failure could be achieved. Fractured specimens were analysed and compared for crack initiation and propagation characteristics using scanning electron microscopy. Conclusions were drawn on the possibility to produce Ti6Al4V (ELI) aircraft components through DMLS.

INTRODUCTION

The DMLS process has gained acceptance in the aerospace industry because it has the advantage of producing complex-shaped parts with little wastage. The parts produced by this process may contain defects that can reduce their fatigue life [1,2]. The effects of defects resulting from the DMLS process, such as residual stresses, lack of fusion, and porosity, on the high cycle fatigue (HCF) properties of Ti6Al4V parts have already been investigated [1,3]. However, the effects of surface roughness on HCF performance still need to be explored, since DMLS complex-shaped parts contain rough surface areas. These uneven surface areas imply additional costs, because they need to be machined or polished. This should be avoided to retain the advantage of utilizing DMLS [4]. The purpose of this study was to investigate the fatigue performance of net-shape Ti6Al4V (ELI) test specimens produced with the inherent DMLS surface roughness.
METHODOLOGY AND RESULTS

A total of 21 HCF test specimens were built in three orthogonal directions (X, Y and Z), with 7 in each direction. All specimens were built in the net-shape geometry as per ASTM standard E466, and were subjected to stress relieving heat treatment at a temperature of 650°C for 3h, followed by high-temperature annealing at 950°C for 3h. To confirm the quality of the building process, triplicate tensile specimens were also built in the three orthogonal directions and heat-treated in a similar way to the fatigue specimens. Tensile testing was performed according to ASTM E8 using an Instron 1342 servo-hydraulic testing machine. The tensile test data was used to determine the fatigue testing regime according to the ASTM E466 standard.

Fractography and surface roughness measurements were used to explain the fatigue performance of the DMLS Ti6Al4V (ELI) specimens. The fatigue cracks of as-built specimens initiated at the grooves where support structures were removed on the X- and Y-direction specimens, but the Z-direction specimens failed within the gauge length as expected. This resulted in the Z-direction built specimens having better fatigue life as compared to the X- and Y-built specimens that showed similar fatigue properties to each other.

CONCLUSION

The study confirmed that the inherent DMLS surface roughness has an impact on the HCF performance properties of Ti6Al4V test specimens. This implies that surface treatment would be needed to improve the fatigue performance for applications such as structural aerospace components.

REFERENCES


UNDERSTANDING THE EFFECT OF CHARACTERISING VARIABILITY FOR BATCH PRODUCTION USING LASER POWDER BED FUSION

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ABSTRACT

Additive Manufacturing (AM) of metals is passing the research stage and finding application in the industrial environment as a manufacturing technology of choice. However, the quality of products fabricated using metal AM technology can be inferior when used in a batch manufacturing situation, also known as high-volume, low-mix production. Quality is generally defined as conformance to specification and is inversely proportional to process variation. The amount of variation in a process signifies the number of defects produced in a given production. This gives rise to the need to characterise process variation to improve quality. This paper explores the characterisation of variability in laser powder bed fusion (LPBF) AM of metals in order to improve quality of part production. It summarises the factors that influence the variation, and discusses the tools used to improve part quality.

INTRODUCTION

Laser powder bed fusion (LPBF) is an additive manufacturing (AM) technology being increasingly adopted in highly regulated manufacturing sectors for metal fabrication[1]. LPBF for metal part production presents many benefits and opportunities among which is high-volume, low-mix manufacturing also known as batch production of customized or highly complex shapes without the need for additional tooling or assembly. Components produced using LPBF are expected to have increased quality from the production stage due to the capability of the technology to produce near-net shape products[2]. However, due to the current limitations of LPBF, which are influenced by the complexity of the production systems and the involved physics, parts are often produced with unacceptable amounts of variability. Though the technology is proficient to manufacture products with high accuracy and the process parameters can be
optimized to improve the consistency and quality of the resultant products, it is still difficult to produce components without any form of disparity in them[3,4].

**METHODOLOGY AND RESULTS**

This paper presents a theoretical research on the importance of characterising variability to improve quality by identifying and eliminating factors that affect quality in AM. This work studies the effect of characterizing process variability for quality improvement in LPBF technology. It reviews works that explore the sources of variability in AM, strategies employed to measure the variability and deviations in the technology and then outlines the quality tools to demonstrate how variability can be characterized to improve product quality. It also aims to describe the nature of variation in AM by understanding the sources of variation and to explain how to measure and quantify them to enhance product quality and process reliability. The paper is divided into three sections. The first section describes LPBF and the key process factors and their effects. The second section looks into discrepancies in LPBF products and factors that contribute to these discrepancies. Lastly, we list and explain the tools that can be applied to improve part quality from the technology. it proposes the used of traditional quality management tools for data collection and process visualisation.Figure1 shows the proposed process steps for characterising the process variation. Outlines the process in order to distinguish its critical quality elements and list different measurements tools applicable for process data collection and analysis.

**CONCLUSION**

This paper presented a theoretical literature work focusing on the effect of characterizing variability in LPBF AM technology. It described the common discrepancies in LPBF as a result of variability and the impact of adequate selection of process parameters in the technology. The characterization and some of the tools that can be applied in LPBF were also discussed. Variability in LPBF should be kept to a minimum to ensure adequate quality of resultant parts. Although this paper listed some of the tools used to characterise the microstructural and mechanical properties, future work will focus on characterising geometrical and dimensional accuracy of product in LPBF due to the ease of in-process measurement.

**REFERENCES**


THE EFFECT OF SANDBLASTING AND BEAD BLASTING ON MATERIAL REMOVAL RATE OF SLM PARTS USING DRY ELECTROLYTE POLISHING

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ABSTRACT

Within the medical industry, additive manufacturing has in recent times become the preferred method for producing intricate and highly patient specific implants and prostheses. This is due to numerous advantages over traditional manufacturing. Selective laser melting is an additive manufacturing process used to produce medical devices; however, current printing methods leave a rough surface finish. This is undesirable for many applications and post processing of these devices are necessary to ensure dimensional accuracy and patient comfort. For the purpose of this study dry electro-chemical polishing will be evaluated and the effect that the different pre-treatment has on the polishing time and surface finish.

INTRODUCTION

In the dental industry, surface finish and dimensional accuracy are very important when it comes to patient comfort and hygiene, thus in the case of removable partial dentures, special care must be taken to ensure the correct fit and finish. Due to the nature of Selective laser melting additive manufacturing, dentures manufactured in this way have a rough surface finish and this needs to be addressed because a surface roughness higher that 0.2 micron has a higher risk of causing hygiene problems and discomfort [1, 2]. Dry electropolishing provides a possible solution to this problem. Considering each part is patient-specific with variations in size and geometry, the influence of sandblasting and bead blasting on the material removal rate needs to be evaluated to accurately finish each part to the desired surface roughness.

This study aims to answer the following research questions:
Research aim
This study aims to determine which pre-treatment process is more beneficial for the current specific polishing process parameters, based on model surface area and mass, to achieve a predetermined surface roughness value and dimensional accuracy.

METHODOLOGY AND RESULTS

Methodology
1) Test samples will be manufactured to evaluate the following:
   a) The effect sandblasting has on the polishing time required to achieve the predetermined surface roughness measurement using the current program settings.
   b) The effect bead blasting has on the polishing time required to achieve the predetermined surface roughness measurement.

Two samples of each of the chosen will be printed
2) Surface roughness measurements will be taken at every stage of the post-processing to determine the surface finish.
3) Samples will also be accurately measured to determine the dimensional accuracy at the various stages of the post-processing process.
4) Results will be recorded, and graphs will be used to visually interpret the data.
5) Change in the humidity and other parameters will be noted as the polishing media ages.

CONCLUSION
This research study is still in its early stages and does not as of yet have results or conclusions to make on the topic.

REFERENCES

INDUSTRY TAKING UP ON-DEMAND ADDITIVE MANUFACTURING OF SPARE PARTS

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ABSTRACT

The adoption of Additive manufacturing (AM) in South Africa has grown significantly with more industries investing and investigating the possibility of adoption to their operations. Some of these industries are the railway and mining industries following the wider demands in the aerospace markets. This paper demonstrates some of the developments that has happened recently, what these industries are investigating, and how they can possibly benefit from adopting the technology.

INTRODUCTION

The early adopters of additive manufacturing technology have been the medical and aerospace industries sector. Centres such as the CRPM at Central University of Technology in Free State, began commercializing medical prototypes in plastics and metals. The focus is finally starting to shift from research to implementation in other industries such as the railway and mining industries (1-4). These industries are enormous and their adoption of the technology could begin to revolutionize the demand and manufacturing capabilities of South Africa. Industries are looking at a different approach in using AM, to minimize maintenance costs, down-time and to increase efficiency. AM has also proved to be beneficial in the produce spare parts, with opportunities for increasing localization of production and consumption goods to create employment. This reasoning is not necessarily to produce the parts at a cheaper price, but rather to for instance possibly empower and benefit the communities around the mines.

METHODOLOGY

This research studies case geometries, which are typically used in mass produced products in the rail and mining industries. The multiple case study
was used to generate the framework for implementation of AM for on-demand manufacturing of spare parts, especially those in metallic materials such as stainless steels. The approach is to cover some of the opportunities and barriers towards the implementation of AM to South African industries. Two different ways to approach the two case studies were used. The one was to do a complete redesign using Design for Additive Manufacturing (DfAM) tools of an identified component and the other was to do data collection and analysis before candidates were identified and taken through the DfAM process. The DfAM process was done to obtain CAD models of the components, which was then used to determine cost and the correct method to additively manufacture.

RESULTS

Figure 1: Process flow of case study 1

Figure 2: Process flow for case study 2

Seeing as the projects are still ongoing and some results are outstanding, it will be discussed and presented in the full conference paper. However, initial results show promise.

CONCLUSION

It is great to see that other industries are starting to investigate the benefits that AM offers and to prove it to them is even better. From the initial results it can be concluded that both industries can achieve the goals that was set at the start of the journey. Some additional work is still required to refine the approach to implement the technology, which will be done in another phase.

ACKNOWLEDGEMENTS

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REFERENCES


QUALIFICATION AND CERTIFICATION FOR FATIGUE LIFE IN ADDITIVE MANUFACTURING

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ABSTRACT

Reliability of fracture mechanics approaches for qualifying fatigue life of Additively Manufactured components hinges on adequate description of fatigue initiation sites, model parameters and underlying mechanics. Sensitivity of predictions to build-up of crack closure, fatigue thresholds and Paris parameters is presented. Furthermore, impact of multiple crack initiations including extreme value statistics on reliability of predictions is discussed. Overall, this study addresses the challenges and forms the critical aspects to consider when using a fatigue life prediction based off a NASGRO formulation and defect schema to model fatigue life of LPBF produced Ti-6Al-4V.

INTRODUCTION

Qualification and certification of Additive Manufacturing (AM) produced components is necessary to ensure safety, consistency and reliability in high performance aerospace and biomedical application. Furthermore, standardised testing is not well suited in realising the inherent material and time saving advantages of AM. Fatigue characterization of Ti-6Al-4V within the context of Laser Powder Bed Fusion (LPBF), one of the more advanced avenues of AM; remains a prevalent topic as many of the LPBF produced components are intended for cyclic loading applications [1]. The relation between fatigue and inherent defects such as surface asperities and void type defects requires careful consideration for certification of LPBF produced Ti-6Al-4V parts in highly critical aerospace and biomedical applications [2].

Approaching fatigue certification from a ‘damage tolerant’ perspective and modelling the fatigue characteristics from a fracture mechanics description of crack growth, rather assumes the presence of defects as a certainty rather than something to be completely mitigated. This type of approach may aid in circumnavigating the problem of inherent defects and allow for utilization of LPBF produced parts effectively and safely without further thermo-mechanical
processing [3]. While many fracture mechanics approaches have been attempted, Madia et al. [4] expresses their short fallings in oversimplifying the model, two of which are the use of purely linear elastic fracture mechanics (LEFM) to describe the crack driving force; and secondly non-accountancy of multiple crack initiation phenomena [4]. To effectively portray fatigue life in terms of fracture mechanics instead of traditional approaches such as stress life (S-N) requires altering the fracture mechanics description to consider rather the total lifetime instead of the residual [5]. Three challenges are highlighted in this regard: non-destructive testing (NDT) methods capable of capturing representative initial crack sizes, describing the short crack propagation regime sufficiently and finally modelling multiple crack growth and initiation [5].

A common model for fatigue prediction is the NASGRO formulation [6], which utilises stress intensity values at the advancing fatigue crack growth tip to estimate the life to failure. From a meso- and microstructural perspective the effects of different microstructures and mesostructural features such as prior-β grains are well described in the NASGRO constants for LPBF produced Ti-6Al-4V [6]. However, macrostructural features such as porosities and surface asperities should be incorporated in the description of stress intensity range (ΔK) as a driving force for the crack to propagate through the material. This work sets out to address the challenges and form the critical aspects to consider using a fatigue life prediction based off a NASGRO formulation and defect schema to model fatigue life of LPBF produced Ti-6Al-4V.

METHODOLOGY AND RESULTS

The approach optimizes for the cyclic stress values (∆σ) required to achieve a specification target cycle number at failure from the NASGRO formulation using a numerical implementation in a MATLAB environment. A simplified form of the NASGRO solution is used with parameters \(C_1, p \) and \(m\) established for LPBF produced Ti-6Al-4V in as fabricated (AF) and stress relieved (SR) material state by Macallister et al. [6]; A reformulation, as suggested in work by Maierhof et al. [7], incorporates the build-up of contact shielding/ crack closure phenomena, and inclusion of a plasticity term attached to the Murakami parameter (\(\sqrt{area}\)) for defining crack sizes from defect projected area. Selected ∆σ values are compared to S-N results of LPBF produced Ti-6Al-4V fatigue specimens built at the Central University of Technology (CUT) and tested at Stellenbosch University. From which sensitivity study on role fatigue threshold (\(\Delta K_{th,lc} \& \Delta K_{th,eff}\)) and Paris values impact the predictions.

Multiple defects are introduced incorporating extreme value statistics to describe and select sizes from defect distributions obtained by computed tomography (μ-CT.) The defects are described to populate a circular cross
section similar to the physical test specimens and grown independently with contact representing a coalescence phenomenon. The resulting $\Delta\sigma$ for failure at $10^7$ cycles considering increasing number of initiation defects is presented using a Monte-carlo type simulation approach.

**CONCLUSION**

The importance in considering correctly describing void type defects as when using prediction models is highlighted in the following points:

1.) Considering the short crack growth regime changes the predicted stress for target fatigue life. Including build-up of crack closure and plasticity influences the high-cycle and low cycle regimes respectively.

2.) Fracture mechanics-based models are sensitive to $\Delta K_{th,lc}$ & $\Delta K_{th,eff}$ in the high cycle regime, these values should be carefully determined for such models.

3.) Multiple initiation of defects increases fatigue scatter.

**REFERENCES**


TOPOLOGY OPTIMISATION FOR MASS REDUCTION IN ADDITIVELY MANUFACTURED ROCKET ENGINE PROPELLANT PUMPS

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ABSTRACT

Additively manufactured rocket components are gaining popularity in the space industry due to the associated commercial and performance benefits. The primary opportunities for additive manufacturing in the space industry include: significant cost reductions and lead time reductions, unique design solutions, mass reduction, novel materials, and consolidation of components by eliminating joining processes. As part of the South African First Integrated Rocket Engine, this project demonstrates performance improvements and cost reduction for rocket engine propellant pumps by leveraging additive manufacturing technologies and optimization techniques.

INTRODUCTION

The Aerospace Systems Research Group (ASReG) located at the University of KwaZulu-Natal was formed in 2009 with the purpose of designing, manufacturing and testing rocket propulsion systems. The South African First Integrated Rocket Engine (SAFFIRE) project at ASReG aims to develop small satellite infrastructure for launch vehicles to deliver payloads to orbit from South Africa. With ongoing development into liquid rocket engines, test vehicles and infrastructure, the project is developing the local skills and knowledge necessary for an orbital-class vehicle programme.

Liquid fuel rocket engines are one of the essential components abroad orbital launch vehicles with the vast majority of launch providers using this engine technology. These engines have traditionally been extremely complex and expensive to develop, manufacture and test. Additive Manufacturing (AM) techniques present a wide variety of benefits such as light-weighting, part consolidation, cost reduction, complex design, and reduced lead times all
when compared to traditional manufacturing techniques for liquid rocket engine components [1]. AM technology has developed rapidly over the last decade and currently, the majority of orbital launch providers are either developing or using AM for their launch vehicle components.

Topology Optimization (TO), when combined with AM techniques, has been shown to reduce the mass of components and therefore improve performance in aerospace applications [2]–[4]. In particular, turbopump components built using AM techniques have seen much research and development in recent years [5]. Lattice-based structures and lattice structure topology optimization has also seen recent development due to the complexity achievable through AM techniques. These lattice structures can be applied to turbopump components, as demonstrated by [6], to improve the performance of impeller components by reducing weight and improving spin-up characteristics all while improving the AM build process substantially.

This project relates to the design, manufacture and testing of a single volute and impeller with the objectives of weight reduction, cost reduction and part consolidation to improve the overall efficiency of the rocket engine. The particular focus will be on designing the impeller and volute utilizing the advanced tools of topology optimization and additive manufacturing which could lead to complex designs improving the thermal, structural and dynamic performance of the impeller and volute. The impeller and volute will then be manufactured through additive manufacturing technologies, post-process machined and tested.

The design of the impeller and volute will require the implementation of novel liquid oxygen (LOX) compatible materials that demonstrate high specific strength capabilities that can endure the thermal and structural loading. Computer-aided design (CAD) tools will be used to generate the structural design. Computational fluid dynamics (CFD) and finite element analysis (FEA) software will be used to model thermal loading and structural response, in order to evaluate the structural integrity of the impeller and volute. Topology optimization (TO) software will be used to optimize the structures weight and thermal responses while maintaining design performance characteristics. Build preparation software will be used to adequately prepare the designs for additive manufacture.
REFERENCES


GEOGRAPHICAL EDUCATION OF THE VISUALLY IMPAIRED USING BRAILLE SYSTEM ON PHYSICAL MODELS
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ABSTRACT

Education of the visually impaired has been a challenge. The visually impaired persons, whether complete or partial impairment, require education for their social, economic and day-to-day activities. There is a good amount of study material available for them in the Braille system. However, a very limited work has been done on representing maps, particularly 3D maps, for their education. In this work, additive fabrication of physical models of some South African landscapes is done using GIS data. Legends in Braille on the models of regions such as the Table Mountain and the Amphitheatre are provided for geographical education of the visually impaired.

Keywords: Additive Manufacturing, Braille, visually challenged persons, GIS data, STL file format, physical maps.

INTRODUCTION

Embossed braille is used in the institutions for the visually challenged persons. Shirsekar (2017) discussed the dimensions of braille alphabet. Several researchers have attempted to create a terrain model using DEM data by additive fabrication (Jacobs & Mcgeen, 2003; Agrawal et al. (2006). There used to be a loss of data involved with conversion to intermediate file formats as there was no direct method to STL file conversion. Agrawal et al. (2014) have created a method for converting DEM data directly to a 3D STL file thus eliminating data loss. They had developed their own program in C language. Pantazis & Priavolou (2017) have explained the importance of additive manufacturing for education of individuals with visual disabilities. They have described the tactile study of geo-cultural components for visually challenged individual.
METHODOLOGY AND RESULTS

The DEM ASCII XYZ data of some terrains were directly converted into solid STL file. This conversion was done with the help of the code written in C language. The DEM data have elevation data in the form of matrix. Matrix having elevation data of the Table Mountain contains 400 columns and 475 rows. The solid STL file of the Table Mountain is displayed in the Fig. 1.

Fig. 1: Solid STL file of Table Mountain

Fig. 2: 3d printed physical map of the Table Mountain with Braille legends

STL file manipulation software is used to emboss legends on the terrain model. There are several freeware available for STL file manipulation such as FreeCAD, SketchUp, Blender, MeshMixer, MeshLab, 3DSlash, SculptGL, etc. The present work is carried out using FreeCAD and MeshLab freeware packages.

The STL file of the Table Mountain with legends in Braille was obtained by using a sequence of processes described above. This STL file of the Table Mountain was converted into G-codes by using CURA software. The G-codes was then downloaded to the FDM system to build the model of the 3D maps of some selected geographical regions. The 3D printed physical map of the Table Mountain with Braille legends is shown in Fig. 2. The top surface of the Table Mountain is almost flat. The Table Mountain is overlooking the city of Cape Town in South Africa. The Braille legends namely, Table Mountain, Cape Town, Wynberg, Green Point and Claremont are embossed on the surface of the Table Mountain. Wynberg, Green Point and Claremont are the suburbs of the city of Cape Town.

The physical model of the Amphitheatre with Braille legends is similarly created.

CONCLUSION

The GIS data of the Table Mountain was directly converted into 3D STL file for additive fabrication. Braille legends were embossed on 3D STL file for geographical education of visually challenged persons. This serves as a 3D
physical map for geographical education of the visually impaired. A partially or fully visually impaired person can learn about the relief of a terrain, relative location of the peaks, basins, glaciers, forests, etc. This 3D map provides a tactile tool for learning to the visually impaired. Such a 3D map can help a visually impaired person in travelling and exploring a region as well. This improves the social interaction and the employability of the visually impaired also.

REFERENCES
AN AM SOLUTION TO A GOLFING PREDICAMENT - A BESPOKE GOLF PUTTER HEAD AND HOSEL WITH MULTIPLE CONFIGURATION OPTIONS FOR PERSONALIZED CLUB FITMENT

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ABSTRACT

The rapid & continuing evolution of Additive Manufacturing has straddled multiple sectors from hobbyist, industry, arts, homeware, wearables and sports equipment. The adaptability of printed outputs allow for enhanced options in terms of customizability and personal preference, and this is particularly applicable in the higher end user group in sporting codes.

Golfers annually spend thousands of dollars on their golf clubs, having them perfectly fitted and tweaked, yet tend to ignore the very club that they use most frequently, their humble putter. This study's intent is to provide a unique & custom designed putter head and hosel for both serious amateurs and professional golfers, which allows the golfer to hone the putter head and hosel to their specific aesthetic and feel preferences.

In particular, the serious golfer is concerned with the following variables iro club design that will impact on their style and capability - alignment aids, face loft, hosel lie angle, face balance, putter head weight, centre of gravity, impact sound and ‘feel’ as well as the all-important aesthetics that all competitors hold in high regard.

Considering this range of variables which dictate possible output configurations, the aesthetically-pleasing stainless-steel 3D-Printed product has been designed to ensure elimination of support material while printing, reducing costly material wastage and also reducing costs. The material used is similar to that of other contemporary putters, which allows the product to remain competitive in this specialized market, with the added attraction of being designed exactly to customer specification based on a base design. The user is able to request any additional features or shapes they prefer, and this is quickly achievable by making small adaptations to the design before printing. To complement this, various replaceable weights have been incorporated that can easily be interchanged to achieve the desired weight distribution in terms of moment of inertia and centre of gravity.

Any adaptations in the hosel design will allow the user to specify their preferred lie angle and offset, and improve fitment to a common or very specific shaft. With all the customizability available, it still adheres & conforms to the Royal and Ancient Rules of golf, ensuring that it would be eligible for competition use.

In the development of the final output, various simulation studies have been employed as well as physical testing to ensure compatibility with currently available putter’s frequency and impact behaviours of the additively manufactured putter.
ABSTRACTS

DAY 3
Friday, 05 November 2021
ANALYSIS OF CORROSION AND MECHANICAL PROPERTIES OF DMLS MANUFACTURED Ti6Al4V PARTS

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ABSTRACT

The aim of this study was to evaluate the corrosion and mechanical properties of direct metal laser sintering (DMLS) produced Ti6Al4V as fully solid and porous state. EOS M280 was used to manufactured the samples. The samples were post treated by vacuum heat treatment for 2 hours at 950°C below the beta-transus temperature. Vacuum heat treated samples were then evaluated for mechanical and corrosion properties. The findings demonstrated that the mechanical properties of porous and fully solid Ti6Al4V differed significantly, and that build orientation has no impact on mechanical properties. While both material’s corrosion rate was comparable.

1. INTRODUCTION

Various studies have shown that mechanical behaviour of Ti6Al4V both fully solid (FS) and porous structure (PS) play a vital role in the biomedical field when compared to other alloys (Co-Cr and stainless steels) [1]. The use of fully solid Ti6Al4V is due to high strength, while porous Ti6Al4V contains lower elastic modulus and better osseointegration [2][3]. Another area of importance is the corrosion behaviour of additively manufactured (AM) Ti6Al4V. Studies have shown that as-built of both fully solid and porous Ti6Al4V contains α’ martensite and this phase initiate corrosion [4][5]. Therefore, vacuum heat treatment of Ti6Al4V, promotes the formation of α+β phase, which show improvement of corrosion resistant especially of AM Ti6Al4V [5]. The present work aimed to study the corrosion and mechanical behaviour of DMLS manufactured fully solid and porous Ti6Al4V. Both fully solid and porous Ti6Al4V were vacuum heat-treated and manufactured at different build direction (Vertical and Horizontal).
2. METHODOLOGY AND RESULTS

The samples were produced fully solid and porous Ti6Al4V by EOS M280 Direct metal laser sintering (DMLS) system. Post manufacturing the samples were vacuum heat treated for 2 hours below the β-transus temperature at 950°C. Characterisation of mechanical and corrosion behaviour done post vacuum heat treatment. For mechanical testing; porous Ti6Al4V were compressed under ISO 13314:2011 standard, while the fully solid Ti6Al4V were tensile tested under ASTM E8 standard. Furthermore, the corrosion was tested through electrochemical test using a three-electrode cell connected to a DY2300 potentiostat. The working electrode being the fully solid and porous Ti6Al4V samples, reference electrode of Ag/AgCl and lastly the counter electrode being Platinum wire. The samples were immersed in the solution containing 10 wt% NaCl with a scan rate of 0,005 V/s at a range between -1 to +0,5.

<table>
<thead>
<tr>
<th>Mechanical Properties</th>
<th>Fully solid</th>
<th>Porous structure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Horizontal</td>
<td>Vertical</td>
</tr>
<tr>
<td>UTS (MPa)</td>
<td>969,16</td>
<td>960,1</td>
</tr>
<tr>
<td>Elastic Modulus (GPa)</td>
<td>119</td>
<td>115,7</td>
</tr>
<tr>
<td>Yield strength (MPa)</td>
<td>892,55</td>
<td>852,26</td>
</tr>
<tr>
<td>% Elongation</td>
<td>16,05</td>
<td>15,95</td>
</tr>
</tbody>
</table>

Table 1. Mechanical properties of fully solid and porous Ti6Al4V

Table 1 shows the mechanical properties of the manufactured Ti6Al4V. The results are comparable with a marginal difference. The vertical build seems to be lower values on all reported data.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Build orientation</th>
<th>Ecorr (V)</th>
<th>Corrosion resistance (mm/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fully solid</td>
<td>Horizontal</td>
<td>-0,367</td>
<td>0,0006848</td>
</tr>
<tr>
<td></td>
<td>Vertical</td>
<td>-0,391</td>
<td>0,0007802</td>
</tr>
<tr>
<td>Porous structure</td>
<td>Horizontal</td>
<td>-0,368</td>
<td>0,0008432</td>
</tr>
<tr>
<td></td>
<td>Vertical</td>
<td>-0,365</td>
<td>0,0001342</td>
</tr>
</tbody>
</table>

Table 2. Corrosion behaviour of fully solid and porous Ti6Al4V

Whereas with porous Ti6Al4V, the mechanical properties are vice versa; were the horizontally build is showing higher values, except for elastic modulus results. The corrosion potential ($E_{corr}$) gives data on the tendency of corrosion in the solution; therefore, $E_{corr}$ and the corrosion resistance show a slight difference for both fully solid and porous Ti6Al4V, regardless of the build orientation.
3. CONCLUSION

The purpose of this research was to investigate the corrosion and mechanical properties of Vacuum heat treated Additive manufactured fully solid and porous Ti6Al4V produced in various build orientations. The results revealed that the mechanical characteristics of porous and fully solid Ti6Al4V varied considerably, and that the build orientation has no significant effect on mechanical characteristics. While the corrosion potential of these material was comparable.

4. REFERENCES


INVESTIGATION OF MICROSTRUCTURE AND HARDNESS PROPERTIES OF IN-SITU TiB/Ti6Al4V COMPOSITE MANUFACTURED BY LASER METAL DEPOSITION

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ABSTRACT
This study investigated the microstructural formation and hardness properties of TiB/Ti6Al4V ELI composites produced with in-situ laser metal deposition technique. The TiB/Ti6Al4V composite samples were produced with varying the volume flow rate of TiB\textsubscript{2} in the range 1.0-2.0 rpm on a Ti6Al4V base plate pre-heated at 400°C. It was found that the in-situ reaction resulted in the formation of two types of whiskers, and size increase with increasing TiB\textsubscript{2} volume. Furthermore, the hardness increased linearly from 570 ± 18 HV to 736 ± 30 HV with increasing TiB\textsubscript{2} volume.

INTRODUCTION
The manufacturing of titanium and its alloys with additive manufacturing (AM) technology has attracted a great deal of attention in various industries such as aerospace and automotive [1,2]. AM is a three-dimensional (3D) printing technology that enables the production of parts in a layer-by-layer way guided by computer aided design (CAD) models [3,4]. The advantage and uniqueness of AM lies in its ability to produce complex geometries that are impossible to manufacture with conventional manufacturing methods, which provide opportunities in terms of productivity and competitiveness. There are various types of AM techniques for the fabrication of metallic components and are classified according to; (a) powder deposition method, (b) laser-powder interaction, and (c) metallurgical consolidation mechanism [5]. Laser metal deposition (LMD) is a type of AM technique that uses a laser beam as an energy source to form a melt pool on the surface of a metallic substrate into which the metal powder is injected by a gas stream and melted [6]. A schematic diagram of LMD process is shown in Figure 1.
METHODOLOGY AND DISCUSSION

All samples were manufactured on an (Ire-Polar-Group) IPG fibre laser (1073 nm wavelength) processing system which was integrated with a KUKA robot and a three-way nozzle. A GTV powder system (D-57629), equipped with two powder feed hoppers was used to deliver the Ti6Al4V and TiB2 powders through the carrier gas during deposition. The volume flow rate for Ti6Al4V was fixed at 5 rpm, while TiB2 was varied between 1.0 rpm, 1.2 rpm, 1.4 rpm, 1.6 rpm, 1.8 rpm and 2.0 rpm, respectively. The powder carrier gas was blown at 1.5 l/min during the deposition process. Argon gas was used as a shielding gas to prevent oxidation on the manufactured samples. Laser power of 1500 W, scanning speed of 0.5 m/min, and beam diameter of 0.5 m were used as the processing parameters during deposition for all the samples.

Figure 1: A schematic diagram of LMD [7].

Figure 2: Optical micrographs of the samples, (a) 1.0 rpm, (b) 1.2 rpm, (c) 1.4 rpm, (d) 1.6 rpm, (e) 1.8 rpm and (f) 2.0 rpm.
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MICROSTRUCTURE AND TENSILE PROPERTIES OF 3D PRINTED Ti-48Al-2Nb-2Cr ALLOY MANUFACTURED BY DIRECT LASER METAL DEPOSITION

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ABSTRACT

Ti-48Al-2Cr-2Nb (Ti-48-2-2) have attracted industrial interest for aerospace and automotive applications owing to their specific strength and high temperature corrosion resistance. This study interrogate the tensile behaviour of laser additively manufactured (LAM) specimens at both room and high temperature behaviour as well as the mode and mechanical failure. The microstructural and micro-hardness analyses after high temperature oxidation tensile testing were evaluate to determine the oxidation resistance and performance of the LAM printed (Ti-48-2-2). Fine laths and colony lamellar microstructure are revealed, and a brittle behaviour was observed at room temperature while a ductile behaviour is prominent between 600 and 900°C.

INTRODUCTION

Intermetallic gamma-TiAl alloys have low density, high specific strength, and excellent high-temperature properties, which makes them one of the most promising candidates for replacing nickel-based super alloys in low-pressure turbines of aircraft jet engines [1]. However, their manufacturing through conventional processing route is full of difficulties, a challenge that can be overcome by a direct additive manufacturing process such as powder Directed Energy Deposition (DED)[4]. This process is already implemented by industries making parts with Ti6Al4V and Nickel based super-alloys [2-3].
METHODOLOGY AND RESULTS

Methodology

Additive manufacturing was carried out using 3 kW IPG fiber laser, a powder feeding system, and a heating stage. Both the fiber laser and the powder feeding system were mounted on a KUKA robot. The laser beam and the powder stream were co-incident on the substrate and traversed in the same direction. The laser spot size was kept constant at 4mm, the scan speed at 2.5 m/min, whereas the laser beam power was varied from 1 kW to 2.5 kW. In this study we report results for 2.5 kW which was the optimum laser power for printing a crack free Ti-48-2-2 built from which tensile specimens were cut using wire cutting. In order to evaluate the mechanical properties, tensile tests were performed, according to the ASTM standard E8/E8M-09. An Instron™ machine equipped with FASTTRACK2™ software was used to axially stress specimens at a cross-head speed of 0.25 mm/min at temperature of 600 and 900°C. The standard metallurgical techniques were used to determine microstructures and hardness properties.

Results

Figure 1 shows the hardness profile along the length of the deposited sample.

Figure 1: Vicker Hardness along the height of the 3D printed specimen.

The average hardness is in the region of 430 HV. Figure 2 shows the variation of yielding stress (0.2%) (YS), ultimate tensile strength (UTS) and percentage elongation (EL. %) as a function of testing temperature.
Figure 2. Tensile properties of the laser deposited Ti-48-2-2 samples.

It can be seen that the YS and UTS decreased as the testing temperature increased, however, the percentage elongation increased with the temperature from 600 °C.

CONCLUSION

This study demonstrated that it feasible to use the DED process to manufacture components from the “crack prone” TiAl alloys, free of defects. The manufactured components exhibit extremely good tensile properties both at room and elevated temperatures. The harness results also show acceptable range.

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