TALENT DRIVEN INNOVATION

15th ANNUAL INTERNATIONAL CONFERENCE
6 -7 NOVEMBER, 2014
STELLENBOSCH, SOUTH AFRICA

FINAL PROGRAMME

Organised by:
Institute for Advanced Tooling in Association with
The Rapid Product Development Laboratory,
Department of Industrial Engineering
Stellenbosch University

Endorsed by:
Global Alliance of Rapid Prototyping Associations
(GARPA)
Acknowledgements

Sincere thanks to our distinguished supporters and sponsors, whose generosity made the success of this conference possible.
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Programme and Organising Committees

Conference Chair
Dimitrov, D., Stellenbosch University, South Africa

Co-Chair
Becker, T.H., Stellenbosch University, South Africa
Goniwe, N., IAT, South Africa
Oosthuizen, G.A., Stellenbosch University, South Africa

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Barnard, L., Central University of Technology, South Africa
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Booysen, G., Central University of Technology, South Africa
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Cain, V., Cape Peninsula University of Technology, South Africa
Campbell, I., Loughborough University, United Kingdom
Chikwanda, H.K., CSIR, South Africa
Damm, O.F.R.A., Stellenbosch University, South Africa
De Beer, D.J., North West University, South Africa
Du Plessis, A., Stellenbosch University, South Africa
Du Preez, W.B., Central University of Technology, South Africa
Gibson, I., National University of Singapore, Singapore
George, S., University of Cape Town, South Africa
Greyling, H., CSIR-NLC, South Africa
Kochan, D., APT-Ing Büro, Germany
Matope, S., Stellenbosch University, South Africa
Mendonidis, P., Vaal University of Technology, South Africa
Molteno, M., Stellenbosch University, South Africa
Müller, B., Fraunhofer IWU, Germany
Oosthuizen, G.A., Stellenbosch University, South Africa
Schmidt, M., Friedrich Alexander Universität Erlangen-Nürnberg, Germany
Schreve, K., Stellenbosch University, South Africa
Sciammarella, F., Northern Illinois University, United States
Tait, R., University of Cape Town, South Africa
Truscott, M., Central University of Technology, South Africa
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Van der Merwe, A., Stellenbosch University, South Africa
Van der Walt, K., Central University of Technology, South Africa
Vermeulen, M., Aerosud Innovation & Training Centre, South Africa
Vicatos, G., University of Cape Town, South Africa
Yadroitsev, I., Central University of Technology, South Africa

Organizing Committee
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Conradie, F.W., Stellenbosch University, South Africa
Conradie, P.J.T., Stellenbosch University, South Africa
Hugo, P.A., Stellenbosch University, South Africa
Pndela, N., IAT, South Africa
Saxer, M., IAT, South Africa
Preface

Rationale

Additive Manufacturing (AM) technologies have expanded vastly over the more than 20 years of its history. Originally seen as mostly suitable for Rapid Prototyping (RP), these processes are not exclusively used for that purpose any longer. Intensive research efforts in recent years focused primarily on the technologies for processing metallic powders and showed their huge potential for delivery of end-use components, or to be an adequate complementary to machining. With its more than 1000 systems currently in use, South Africa is swiftly following this general trend.

The Annual International RAPDASA Conference is taking place for the fifteenth time. Over the years it grew constantly in importance both from academic and industrial perspective, as well as in international significance. Having a fully peer reviewed conference and keeping at the same time its industrial relevance, this anniversary signifies a milestone in its own right. In this way it meets its main objective to be a generator of innovative ideas and fruitful collaboration both locally and abroad. The theme of the conference captures this objective, expressing the precondition of engineering education and skills development for industrial growth.

Topics

Papers are invited in the following areas relevant to the conference theme:


**New Techniques and Systems**: Multi-material systems, Material Removal and Additive Technologies, Laser Systems for AM, Process Monitoring and Control Technologies, Quality Systems and Management, Hybrid Manufacturing, Large Scale AM, Biofabrication, Post-processing Techniques

**Applications and Industries**: Aerospace, Automotive, Architecture, Medical and Biomedical, Tooling, Sport & Leisure, Fashion, Jewellery and Art, Foundry, Model-making, Power Generation, Marine
Conference Registration

WEDNESDAY, November 5, 2014

15:30 - 18:00  Registration
Wallenberg Centre
(Stellenbosch Institute for Advanced Study, STIAS), Marais Street

18:00 - 20:00  Conference Reception
Wallenberg Centre (STIAS)

Wallenberg Centre (STIAS)
Opening Session

THURSDAY, November 6, 2014

07:30 - 08:30 Registration
Wallenberg Centre

Plenary Session 1
Auditorium 1
Opening Address
Session Chair: Prof D. Dimitrov

08:30 Introduction
Prof D. Dimitrov, Conference Chair
Stellenbosch University, Stellenbosch, South Africa

08:35 Welcome of Guests
Prof T.E. Cloete, Vice Rector Research and Innovation
Stellenbosch University, Stellenbosch, South Africa

08:45 Welcoming Address
Mr B. Gerrys, Chief Director: Technology Localisation and Advanced Manufacturing
Department of Science and Technology, South Africa

Prof D. Dimitrov
Prof T.E. Cloete
B. Gerrys
### Plenary Session 1  
**Auditorium 1**

**Additive Manufacturing – State of the Industry**  
Session Chair: Prof D. Dimitrov

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
<th>Speaker</th>
<th>Location</th>
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<tbody>
<tr>
<td>09:00</td>
<td>Additive Manufacturing State of the Industry</td>
<td>T. Wohlers</td>
<td>Wohlers Associates, Inc., Colorado, United States</td>
</tr>
<tr>
<td>pp 26</td>
<td></td>
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<tr>
<td>09:40</td>
<td>Bioengineering – an Additive Manufacturing Perspective</td>
<td>P. Bartolo</td>
<td>The University of Manchester, Manchester, United Kingdom</td>
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<td>pp 27</td>
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<tr>
<td>10:20</td>
<td>“Walk Again”, and Other ways 3D Printing is Helping Enable the Disabled</td>
<td>D.A. Prawel</td>
<td>Colorado State University, Colorado, United States</td>
</tr>
<tr>
<td>pp 28</td>
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**11:00 – 11:30**  
**TEA/COFFEE BREAK**
Terry Wohlers earned a master's degree in industrial sciences from Colorado State University in 1982. He is president of Wohlers Associates, Inc., an independent consulting firm he founded 27 years ago. The company provides technical and strategic consulting on the new developments and trends in rapid product development, additive manufacturing, and 3D printing. Through this company, Wohlers has provided consulting assistance to more than 240 organizations in 24 countries. Also, he has provided advice to more than 150 companies in the investment community, most being institutional investors that represent mutual funds, hedge funds, and private equity valued at billions of dollars. For 30 years, Wohlers has focused his education, research, and practice on design and manufacturing. Over this time, he has authored nearly 400 books, magazine articles, and technical papers on engineering and manufacturing automation. In 2007, more than 1,000 industry professionals from around the world selected Wohlers as the #1 most influential person in rapid product development and additive manufacturing. He is constantly invited to serve as a plenary speaker on major events around the world. In May 2004, Wohlers received an Honorary Doctoral Degree of Mechanical Engineering from Central University of Technology, Free State (Bloemfontein, South Africa).

Paulo Bartolo holds a PhD degree in Polymer Physics from the University of Reading (UK, 2001), a Master of Science in Mechanical Engineering (1996) and a Licenciatura in Mechanical Engineering (1993), both from the Technical University of Lisbon (Portugal). He is Professor of Advanced Manufacturing Processes at the Polytechnic Institute of Leiria (Portugal), Adjunct Professor at Queensland University of Technology (Australia), Visiting Professor at Nanyang University (Singapore), and Professor of Biomaterials (Catedra UNESCO) at the University of Habana (Cuba). In 2014 he was appointed Professor of Advanced Manufacturing at the University of Manchester and Director of the Manchester Bio-manufacturing Research Centre. Professor Bartolo is a CIRP (The International Academy of Production Engineering) fellow, Vice-Chairman of the CIRP Scientific Technical Committee on Electro-Physical and Chemical Processes, and Member of the Direction Board of the International Society of Bio-manufacturing, Scientific advisor of the Research Institute in Biofabrication (BIOFABRIS) funded by the Brazilian Government and regional coordinator of the working group of Rapid Manufacturing Platform. Paulo Bartolo served on a number of panels in various countries in advisory capacity including on the evaluation panel of the South African National Research Foundation.

David Prawel has a BS and MS from University of Buffalo, an MS from Rutgers University, and a Ph.D. from Colorado State University in Biomedical Engineering, Department of Mechanical Engineering. David Prawel has been thoroughly consumed by 3D technology for over three decades. As a serial entrepreneur, speaker, author and consultant in 3D technology and product development, he has helped build 5 startup companies and consulted for dozens of large manufacturers and technology vendors. Most recently, he founded the Idea-2-Product 3D Printing Laboratory at Colorado State University, a public-access center for 3D printing, scanning and personal fabrication. He also currently co-directs the Biomaterials Research & Engineering Laboratory in Mechanical Engineering at CSU, where he researches orthopedic and cardiovascular biomaterials. He is founder and chair of the International 3D Collaboration & Interoperability Congress, now in its twelfth year.
**Session **RPD 1  
Product and Process Development and Realisation
Session Chair: Prof D.J. de Beer

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
<th>Title</th>
<th>Authors/Institutions</th>
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</thead>
<tbody>
<tr>
<td>11:30</td>
<td>Session Keynote</td>
<td>Fifteen Years of Metal AM Research at CUT – A Glance Back and Future Outlook</td>
<td>G. Booyse, Centre for Rapid Prototyping and Manufacturing, Central University of Technology, Bloemfontein, South Africa</td>
</tr>
<tr>
<td>12:00</td>
<td></td>
<td>State of the Art and Review of Advanced Experiences in Rapid Tooling</td>
<td>J. Dietrich, D. Kochan &amp; L. Lachmann, University of Applied Sciences, Dresden, Germany</td>
</tr>
<tr>
<td>12:40</td>
<td></td>
<td>Exploring Opportunities for Improvement in Selective Laser Melting</td>
<td>L. Mugwagwa, D. Dimitrov &amp; S. Matope, Stellenbosch University, Stellenbosch, South Africa</td>
</tr>
</tbody>
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**13:00 – 14:00  **LUNCH BREAK
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<thead>
<tr>
<th>Time</th>
<th>Session Title</th>
<th>Speaker(s)</th>
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<tbody>
<tr>
<td></td>
<td><em>Friedrich-Alexander Universität Erlangen-Nürnberg, Erlangen, Germany</em></td>
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<tr>
<td>12:00</td>
<td><strong>On the Heat Treatment of LaserCUSING Produced Ti-6AL-4V Components</strong></td>
<td>M. van Rooyen, T. Becker &amp; D. Dimitrov</td>
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<td><em>Stellenbosch University, Stellenbosch, South Africa</em></td>
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<td><em>Central University of Technology, Bloemfontein, South Africa</em></td>
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<td><em>Tupy Superior Institute, Joinville, Brazil</em></td>
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<td><em>National Engineering School of Saint-Etienne, Saint-Etienne, France</em></td>
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<td><em>Federal University of Santa Catarina, Florianópolis, Brazil</em></td>
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<tr>
<td>12:40</td>
<td><strong>Peculiarities of Single Track Formation from Ti-6AL-4V Alloy at Different Laser Power Densities by SLM</strong></td>
<td>I. Yadroitsava, J. Els, G. Booysen &amp; I. Yadroitsev</td>
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<td><em>Central University of Technology, Bloemfontein, South Africa</em></td>
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<td>13:00</td>
<td><strong>LUNCH BREAK</strong></td>
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*Session Chair: Dr G.A. Oosthuizen*
## Session NT&S 1

**Advanced Techniques and Systems I**

**Session Chair:** H. Greyling

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<th>Time</th>
<th>Session Title</th>
<th>Authors</th>
<th>Institution</th>
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</thead>
<tbody>
<tr>
<td>14:00</td>
<td><strong>Session Keynote:</strong> Experimental and Numerical Analysis for Process Control and Quality Assurance in Additive Manufacturing</td>
<td>F. Sciammarella</td>
<td>Northern Illinois University, Illinois, United States</td>
</tr>
<tr>
<td>14:30</td>
<td><strong>Determination of Cooling Rates During Laser Beam Melting of Aluminium Alloy EN AW 7075 Using High Speed Pyrometry</strong></td>
<td>M.C.H. Karg, O. Hentschel, B. Ahuja &amp; M. Schmidt</td>
<td>Friedrich-Alexander Universität Erlangen-Nürnberg, Erlangen, Germany</td>
</tr>
<tr>
<td>14:50</td>
<td><strong>Development of a More “Rugged” Printing Head System</strong></td>
<td>P.J.M. van Tonder, D.J. de Beer &amp; H.C.vZ. Pienaar</td>
<td>Vaal University of Technology, Vanderbijlpark, South Africa</td>
</tr>
<tr>
<td>15:10</td>
<td><strong>Expert System for 3D Printing Technology</strong></td>
<td>K. Osowski, A. Kęsy &amp; Z. Kęsy</td>
<td>Kazimierz Pułaski University of Technology and Humanities in Radom, Radom, Poland</td>
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</table>

**15:30 – 16:00** TEA/COFFEE BREAK
THURSDAY, November 6, 2014

Session A&I 1
Innovative Approaches
Session Chair: G. Booysen

14:00  
Session Keynote: The Use of AM to Support Strategies for Regional Innovation and Sustainable Development  
D.J. De Beer  
North West University, Potchefstroom, South Africa

14:30  
Development of a 3D Printed Radio-Controlled Plane by Denel Dynamics  
P.H. Cronje  
Denel Dynamics, Pretoria, South Africa

14:50  
Designing Bespoke Adjustable Sockets for Prosthetics Using CAD Software and 3D Printing  
P. van der Walt, N. van der Merwe & D.J. de Beer  
Vaal University of Technology, Vanderbijlpark South Africa

15:10  
Entry Level FDM 3D Printer Produced Parts Satisfying Niche Market in Industry  
J. La Grange, L. Becker & D.J. de Beer  
Vaal University of Technology, South Africa  
North West University, Potchefstroom, South Africa

15:30 – 16:00  
TEA/COFFEE BREAK
### Session A&I 2
**Advanced Applications**
Session Chair: Prof D. Kochan

<table>
<thead>
<tr>
<th>Time</th>
<th>Presentation</th>
<th>Authors</th>
<th>Institution(s)</th>
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<tr>
<td>16:00</td>
<td><strong>The Role of Additive Manufacturing in Bio-Prosthetic Heart Valve Engineering</strong></td>
<td>D.A. Prawel, M. Forleo, S. James &amp; L.P. Dasi</td>
<td>Colorado State University, United States</td>
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<td>pp 72</td>
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<td>16:20</td>
<td><strong>Effect of Milling Strategy and Tool Geometry on Cutting Performance of Titanium Alloys</strong></td>
<td>P.J.T. Conradie, D. Dimitrov, G.A. Oosthuizen &amp; M. Saxer</td>
<td>Stellenbosch University, Stellenbosch, South Africa Institute for Advanced Tooling, Stellenbosch, South Africa</td>
</tr>
<tr>
<td>pp 73</td>
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<tr>
<td>16:40</td>
<td><strong>Voxeljet: 1st Year of Rapid Casting Solutions in South Africa</strong></td>
<td>J. Kowen</td>
<td>Voxeljet AG, Friedberg, Germany</td>
</tr>
<tr>
<td>Time</td>
<td>Title</td>
<td>Authors</td>
<td>Affiliation</td>
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<tr>
<td>16:00</td>
<td><strong>3D Printing Multi-Functionality: Aerospace Structures with Electronics</strong></td>
<td>M.A. Perez, E.W. MacDonald, D. Espalin &amp; R.B. Wicker</td>
<td>University of Texas at El Paso, Texas, United States</td>
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<td>16:20</td>
<td><strong>Laser Metal Deposition Thermal Analysis Using Finite Element Method</strong></td>
<td>M. Shukla &amp; V. Verma</td>
<td>Motilal Nehru National Institute of Technology, Teliarganj, India</td>
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<td>University of Johannesburg, Johannesburg, South Africa</td>
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<tr>
<td>16:40</td>
<td><strong>Porosity In Ti-6AL-4V Manufactured By High-Speed (30 Cubic Millimeters per Second) Laser Powder Bed Fusion</strong></td>
<td>D.F. Louw</td>
<td>CSIR, Pretoria, South Africa</td>
</tr>
</tbody>
</table>
17:00 - 18:00  **Annual General Meeting**  
Wallenberg Centre  
(Stellenbosch Institute for Advanced Study, STIAS), Marais Street

19:00 - 00:00  **Conference Gala Dinner**  
Overture Restaurant on Hidden Valley  
Restaurant details on the inside of the back cover page.

**Guest Speaker:**  **Prof T.E. Cloete**

**Important Information:** The bus for the Gala Dinner leaves at 18:45 from the location indicated on the map on the back cover of the programme booklet.
Gala Dinner

Overture
AT HIDDEN VALLEY

MENU

Canapés
Onion tart, smoked feta
Sago chips, spiced peanut paste
Fresh Breads & Hidden Valley Olives

Starter
Sautéed gnocchi and mushrooms, parmesan spoom, thyme and garlic

Main Courses
Line fish, tomato, chorizo, crisp squid and basil

or

Confit duck leg and breast, braised cabbage and figs, onion puree

Side services
Maple roast sweet potato
Pecan nuts
Broccoli Almandine

Dessert
Pliable chocolate, chocolate crumble, strawberry, vanilla ice cream
Coffee, tea & financiers
**FRIDAY, November 7, 2014**

**Plenary Session 2**

**Auditorium 1**

**Industrial Applications - Opportunities and Challenges**

Session Chair: Prof O.F.R.A. Damm

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<th>Time</th>
<th>Title</th>
<th>Speaker</th>
<th>Institute, Location</th>
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<tbody>
<tr>
<td>08:00</td>
<td>Additive Manufacturing at Fraunhofer – How to Develop “3D Printing” Technologies into Industrial Application</td>
<td>B. Müller</td>
<td>Fraunhofer Additive Manufacturing Alliance, Fraunhofer Institute for Machine Tools and Forming Technology (IWU), Chemnitz, Germany</td>
</tr>
<tr>
<td>08:40</td>
<td>Additive Manufacturing in Aviation</td>
<td>P. Potgieter</td>
<td>Aerosud, Pretoria, South Africa</td>
</tr>
<tr>
<td>09:20</td>
<td>Form Follows Function – Legal Aspects of Collaborative R&amp;D</td>
<td>A. Kurz</td>
<td>Fraunhofer Gesellschaft for Promotion of Applied Research Munich, Germany</td>
</tr>
</tbody>
</table>

**10:00 – 10:30 TEA/COFFEE BREAK**
Bernhard Müller studied Mechanical Engineering at the Dresden University of Technology and prepared his Master Thesis at the California State University. After his graduation he undertook leading positions in research and development in various production companies in Germany. In 2001 he obtained his PhD degree in Production Engineering again from the Dresden University of Technology. In 2008 he joined the Fraunhofer Institute for Machine Tools and Forming Technology (IWU). Here he established the Additive Manufacturing Technologies as a new research field, which he is still leading. Dr Müller is currently the spokesman for the Fraunhofer Additive Manufacturing Alliance, which brings together the activities of eleven institutes of the Fraunhofer-Gesellschaft researching in the field of additive manufacturing. He is also an active member of the Technical Committee Rapid Prototyping/Rapid Manufacturing in the Association of the German Engineers VDI and co-author of various additive manufacturing related documents. Dr Mueller also manages the German Industrial Beam Melting Network.

Paul Potgieter received his MSc Eng in 1978 and a PhD in engineering sciences in 1983 from the University of Pretoria. During his postgraduate studies he was employed by the CSIR’s Institute for Defense Research, participating in and leading various research and development programmes. In 1984 he joined the Atlas Aircraft Corporation (now Denel Aviation) where he became Programme Manager for the Rooivalk Helicopter Development Programme and since 1988 Assistant General Manager responsible for the Helicopter Division. In 1990 he was appointed Aerosud Group MD, merging hereby life-long interest in aviation with business interests and pioneering already for 20 years a paradigm shift from engineering bureau to globally recognised, sustainable and growing aviation industry supplier.

Alexander Kurz studied law at the Universities of Regensburg and Tubingen, Germany. In 1993 he obtained his Doctoral degree in administrative science (Dr.rer.publ.) from the German University of Administrative Science in Speyer. Thereafter he took various management positions in public companies in Germany and Switzerland. In 2007 he moved to the Research Centre Karlsruhe to be its business affairs director and deputy chairman. Following the formation of the Karlsruhe Institute of Technology, Alexander Kurz became Vice President for Finance and Business Affairs as well as Acting Vice President for Human Resources. Since June 2011 Dr Kurz is Senior Vice President Human Resources, Legal Affairs and IP Management at the Fraunhofer Gesellschaft Munich. Dr Kurz serves in honorary capacity in the management of various associations. Among others he is Honorary Professor at the German University of Administrative Science in Speyer, as well as Vice Chairman of the Board of the Centre for Science & Research Management in Speyer.
### Plenary Session 3

**Auditorium 1**

**The Way Forward**

Session Chair: Dr W.B. du Preez

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<th>Time</th>
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<th>Speaker</th>
<th>Institution</th>
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<tr>
<td>10:30</td>
<td>Talent Driven Innovation in Support of the SA Manufacturing Strategy</td>
<td>D. van Dyk</td>
<td>National Tooling Initiative Programme, Centurion, South Africa</td>
</tr>
<tr>
<td>11:10</td>
<td>A South African Additive Manufacturing Technology Roadmap</td>
<td>H. Greyling</td>
<td>National Laser Centre, CSIR, Pretoria, South Africa</td>
</tr>
</tbody>
</table>

**12:20 – 13:00** LUNCH BREAK
Dirk van Dyk obtained his B.Sc. degree in Mechanical Engineering from the University of Pretoria in 1982. Thereafter he went into industry and became involved in tooling design and manufacture. Later he founded Ngena - Mouldnet (Pty) Ltd based in Centurion becoming its director and main shareholder. The company provides consulting services to the manufacturing industry focusing on product design, development and industrialisation, tool, die and mould design and manufacture. Later he focused mainly on the establishment of collaborative network structures, locally and internationally to facilitate larger tooling acquisition projects, especially for the automotive and packaging industry. In 2005 he was appointed National Programme Manager of the National Tooling Initiative (NTI), a partnership between Industry and Government to Rehabilitate the Tool, Die and Mould Manufacturing sector in SA. In 2009 Mr Van Dyk became CEO of the NTI. His main tasks and responsibilities are the development and execution of strategic plans for the turnaround of a complete Industry sector that involves the implementation of 5 core programs focusing on skills development, SMME capacity expansion, technology recapitalisation and competitiveness improvement for the tooling industry sector as a whole. Dirk van Dyk look back at 30 years of experience in Tooling Design and Manufacturing Industries.

Hardus Greyling is at present the Research Implementation Manager at the National Laser Centre, a National Research Centre at the CSIR. Mr. Greyling completed a degree in Physics at the Rand Afrikaans University in Johannesburg in 1985. He joined the CSIR National Physical Research Laboratory (NPRL) in May 1986 as scientist in the Optical Sciences group. Mr. Greyling is the CSIR project coordinator for the Aeroswift project. He is also the coordinator for the Additive Manufacturing Technology Implementation Roadmap project commissioned by the DST. Mr. Greyling is a member of RAPDASA (The Rapid Product Development Association of South Africa) and has been serving as the Chairperson on this industry association since October 2012.
## FRIDAY, November 7, 2014

### Session Mat 2

**Process Characterisation**  
Session Chair: Dr T.H. Becker

<table>
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<th>Time</th>
<th>Title</th>
<th>Authors</th>
<th>Institutions</th>
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| 13:00 | Microstructure of SLM Manufactured 316L and 420 Grades Stainless Steels | P. Krakhmalev, I. Yadroitsava, G. Frederiksson & I. Yadroitsev          | Karlstad University, Sweden  
Central University of Technology, Bloemfontein, South Africa                |
| 13:20 | Part Finishing on Entry Level FDM Models                              | S. P. Havenga, D.J. de Beer & P.J.M. van Tonder                        | Vaal University of Technology, Vanderbijlpark, South Africa                  |
| 13:40 | An Investigation into the Variation in Porosity of a Direct Metal Laser Sintered Artifact Manufactured with the EOSINT M250 Machine System Using Direct Metal 20 Powder | A. Olwagen & J. Markgraaff                                             | Central University of Technology, Bloemfontein, South Africa                  |
| 14:00 | Materialise: Innovators You Can Count On                              | J. Goossens & P. Peeters                                              | Materialise, Leuven, Belgium                                                 |

### 14:30 – 14:50 TEA/COFFEE BREAK
<table>
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Stellenbosch University, Stellenbosch, South Africa  
Institute for Advanced Tooling, Stellenbosch, South Africa |
| 13:20 | Laser Sintered Components Used as a Primary Contributor to Versatile Hybrid Prototypes: a Case Study | L. Becker, R.I. Campbell & D.J. de Beer  
Vaal University of Technology, Vanderbijlpark, South Africa  
North West University, Potchefstroom, South Africa |
| 13:40 | 3D Printing Dimensional Calibration Shape: Clebsch Cubic              | A.F. van der Merwe, J. Boehm & M.S. Marais  
Stellenbosch University, Stellenbosch, South Africa  
University of Pretoria, Pretoria, South Africa  
University of Kaiserslautern, Kaiserslautern, Germany |
| 14:00 | Laser Cladding Process Development for High Carbon Steel Substrates | T. Lengopeng, A. Botes & A.P.I. Popoola  
Tshwane University of Technology, Pretoria, South Africa  
CSIR, Pretoria, South Africa |

14:30 – 14:50 TEA/COFFEE BREAK
### Session A&I 3  
**Innovative Strategies and Applications**  
**Session Chair: M. Vermeulen**

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| 14:50 | Implementing the South African Additive Manufacturing Technology Roadmap – The Role of an Additive Manufacturing Centre of Competence | W. B. du Preez & D.J. de Beer  
*Central University of Technology, Bloemfontein, South Africa*  
*North West University, Potchefstroom, South Africa* |
| 15:10 | The Quality Management System Required to Manage “The Advanced Manufacturing Precinct” at VUT | H.L. van der Merwe, D.J. de Beer & A. El Mohamadi  
*Vaal University of Technology, Vanderbijlpark, South Africa* |
| 15:30 | Additive Manufacturing of Parts for a South African Prototype Aircraft | D. Jansen  
*Aerosud Innovation and Training Centre, Centurion, South Africa* |
| 15:50 | Future Scenarios to 2025 Plus for the Western Cape Tool, Die and Mould Industry | N. Pindela, N. Goniwe & L. Ncetani  
*Institute for Advanced Tooling, Stellenbosch, South Africa* |

**16:15 CLOSING REMARKS**  
Prof D. Dimitrov

T. Mathebula, M. Tlotleng, K. Malabi, S. Pityana & S. Camagu  
*CSIR, Pretoria, South Africa*

**14:50 pp 54**

### Comparative Study of Microstructural, Electrochemical, and Tribo-Mechanical Properties of Electrodeposited Zn-Al₂O₃/Cr₂O₃/SiO₂ Nanocomposite Coatings

N. Malatji & A.P.I. Popoola  
*Tshwane University of Technology, Pretoria, South Africa*

**15:10 pp 55**

### Characterisation of Steel Blade Microstructure Produced Using Laser Engineering Net Shape Process

L. Chauke, K. Mutombo & T. Mathebula  
*CSIR, Pretoria, South Africa*

**15:30 pp 56**

### Bioceramic Hydroxyapatite Coating Fabricated on Ti-6Al-4V Using Nd:YAG Laser

M. Tlotleng  
*CSIR, Pretoria, South Africa*

**15:50 pp 57**

### 16:15 CLOSING REMARKS

Prof. D. Dimitrov
Plenary Paper Abstracts

**Plenary Sessions**

**PLENARY SESSION 1: ADDITIVE MANUFACTURING - STATE OF THE INDUSTRY**

Additive Manufacturing State of the Industry

Bioengineering - An Additive Manufacturing Perspective

“Walk Again”, and Other Ways 3D Printing is Helping Enable the Disabled

**PLENARY SESSION 2: INDUSTRIAL APPLICATIONS - OPPORTUNITIES AND CHALLENGES**

Additive Manufacturing at Fraunhofer - How to Develop “3D Printing” Technologies into Industrial Application

Additive Manufacturing in Aviation

Form Follows Function - Legal Aspects of Collaborative R&D

**PLENARY SESSION 3: THE WAY FORWARD**

Talent Driven Innovation in Support of the SA Manufacturing Strategy

South African Additive Manufacturing Technology Roadmap
ADDITIVE MANUFACTURING STATE OF THE INDUSTRY

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ABSTRACT

Additive manufacturing is finally receiving the attention and respect it deserves. Countless corporations, government agencies, researchers, and others are investing in the technology in ways that have not been seen in the past. Some of the biggest companies and brands in the world, such as Adobe, Amazon, Autodesk, Google, HP, and UPS, have made some level of commitment to AM. What’s more, top management and boards at large corporations are putting pressure on employees to investigate AM and understand how they may fit in.

Product development and manufacturing organizations that ignore AM could find themselves at a disadvantage if their competitors embrace it successfully. Meanwhile, many companies are at work qualifying machines and materials for the direct manufacture of parts that go into final products. Aerospace companies such as Airbus, Boeing, Honeywell Aerospace, Lockheed Martin, and Pratt & Whitney are qualifying AM processes and materials and certifying new designs for flight.

The number of myths and misconceptions associated with AM has never been greater, especially among people relatively new to the technology. Also, a surprising amount of misinformation is being shared among people and groups that should know better. Only through the communication of accurate information, coupled with good quality educational programs, such as RAPDASA, can we set realistic and achievable expectations.
BIOENGINEERING - AN ADDITIVE MANUFACTURING PERSPECTIVE

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“WALK AGAIN”, AND OTHER WAYS 3D PRINTING IS HELPING ENABLE THE DISABLED

D.A. Prawel, K. Johnson & A.S. Rudolph

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ABSTRACT

Countless “amazing” technologies come and go. A select few have the potential to truly change our lives, marking the times when humanity is at its finest. Something miraculous occurred during the opening ceremonies of the 2014 FIFA World Cup. A paraplegic Brazilian teenager, aided only by a prosthetic exoskeleton that he controlled with his own brain waves, stood out of his wheelchair, walked a few steps and kicked the first ball to open the contest. In this successful live demonstration in front of a huge world audience, the Walk Again Project marked the first time a paralyzed person walked on his own, using a non-invasive device he directed by himself using only his thoughts and hopes. This presentation will highlight some of the details of this monumental achievement and the role 3D printing played in the project. We will also discuss other recent advances where additive manufacturing is making real positive impact in our lives.
ADDITIVE MANUFACTURING AT FRAUNHOFER - HOW TO DEVELOP “3D PRINTING” TECHNOLOGIES INTO INDUSTRIAL APPLICATION

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ABSTRACT

Fraunhofer is one of the world’s largest organizations for applied research with a total research budget beyond 2 billion Euros, employing about 23,000 people, most of them educated in the natural sciences and engineering, in 67 different institutes in more than 80 locations worldwide, most of them located in Germany as Fraunhofer’s home country. A major portion of Fraunhofer’s research budget gets collected from the industry through contract research, giving the Fraunhofer research approach a unique, very much industry-driven and application-oriented color. Fraunhofer research spans across a wide field of areas of expertise – ICT, Life Sciences, Light & Surfaces, Microelectronics, Production, Materials, Defence and Security – and has led to popular products and technologies like the MP3 file format, white LED or high-resolution thermo-cameras.

Fraunhofer research has allowed a breakthrough in additive manufacturing (AM) of metal materials, making it possible to fully melt standard metal material selectively for metallic parts with fully dense microstructure and mechanical properties similar to conventional manufacturing routes. A whole new horizon of possible industrial applications had been opened. Today, introduction of additive manufacturing into real industrial environments is becoming more and more into focus, allowing to establish AM as a widely accepted production technology as real industrial “3D printing” (how AM technology is very often referred to, also in an industrial context). In additive manufacturing, Fraunhofer joins its forces within the Fraunhofer Additive Manufacturing Alliance, combining all its institutes who are heavily active in AM research. The alliance is a platform to bring together all of Fraunhofer’s AM expertise with the aim to provide expert advice and appropriate solutions on AM application, structuring its activities in four research areas: Engineering, Materials, Technologies and Quality. The plenary speech will show a more detailed look into these research areas and illustrate that with a variety of examples from current research. These examples include RFID embedding into metal AM components, topological optimization of structures for additive manufacturing, a multi-component SLS process, new powder deposition methods for DLS, new FLM printers to process flexible materials including endless fibers, new developments
ADDITIVE MANUFACTURING IN AVIATION

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ABSTRACT

The reduction of time-to-market in the development of new aircraft is crucial to competitiveness in an increasingly contested aerospace environment. Whereas numerical tools have brought about huge improvements in the efficiency of design and analysis, additive manufacture is in the forefront of ensuring similar gains in the manufacturing cycle.

To date the commercial viability of additive manufacture in the aviation environment has been constrained by size and forming speed, but the latest developments, amongst others the cooperative venture between Aerosud and the National Laser Centre which is in the final stages of commissioning of a Pilot Plant, can be expected to be changing these limitations in the near future.

The presentation will focus on design and manufacturing concepts, as applied in the development of the new AHRLAC reconnaissance aircraft, and aimed at gaining the best advantage from new manufacturing technologies such as additive manufacture.
FORM FOLLOWS FUNCTION - LEGAL ASPECTS OF COLLABORATIVE R&D

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ABSTRACT

Given the complexity and inter-disciplinarity of technology development, innovations are regularly exploited in collaborative frameworks between different partners working on strategic issues of research and development. Stakeholders of such processes are in particular Universities, research organizations such as Fraunhofer in Germany and industry. There exists a wide variety of legal and contractual models of how to address such types of collaboration. The legal span reaches from pure contract-research and collaborative models of joint research to joint structures, such as joint project-centers or even companies. The presentation focuses on the legal framework for these types of collaboration or institutional research, in particular addressing the question of contract-design in major areas of legal interest. In addition the presentation will give a short overview of possible structures for legal models such as joint ventures or subsidiaries and joint project-centers.

From a legal point of view the pre-contract-phase already requires particular attention. Therefore the meaning and the importance, and also the limitations, of non-disclosure agreements will be mentioned. For the design of contracts, the definition of scope already is of particular importance, because the whole contract, including (later) disputes and the joint understanding of the tasks and duties of the parties is determined by the scope. Another area of particular importance lies in the proper definition of liabilities and responsibilities of the parties. Practical cases often show deficits in these fields, leading to disputes at a later stage. Another area of very careful contractual drafting involves the whole field of intellectual property rights. Here, the crucial question of the “rights to the results problem” has to be solved. This requires firstly a proper analysis of existing background-IP and secondly of the potential for new foreground-IP to be generated under the contract. The different interests of the contractual parties, full property of title due to payment-obligation of the contract on the one hand and foreground licensing-models without property of title by the other contractual party on the other hand have to be solved in the contract. Benefits for one solution turn out to be also obstacles from time to time: A transfer of title of IP for instance, might lead to a cooling down of further developments in the field of the transferred IP by the transferring party.

For joint undertakings that go beyond bilateral contractual cooperation, a proper assessment of the purposes and the intended structure has to be made. From a legal point of view, different models have proven practicability so far. Here, joint platforms.
such as spin-ins, joint project-centers and joint ventures could be considered, especially in international collaborations.

Finally, and this is true for all types of collaboration: The legal design, be it contractually or even by creating joint legal structures, may follow the intended purpose and structure, hence “form follows function”.
TALENT DRIVEN INNOVATION IN SUPPORT OF THE SA MANUFACTURING STRATEGY

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ABSTRACT

South Africa, through the Industrial Policy Action Plan (IPAP), seeks to grow the capacity of the South African manufacturing sector through increased localisation and exports to drive economic growth and job creation.

Similar to the leading 10 manufacturing economies of the world, Talent Driven Innovation will be a main focus component of this strategy. As Tooling remains a key part of any manufacturing strategy, the South African Tool, Die and Mould Manufacturing sector (TDM), adopted this same focus area as a core strategy to re-develop the technical skills delivery system of the TDM sector. This paper will demonstrate the success of this sector in addressing the Talent sourcing, Skills Development and Skills deployment capacity developed in support of the Manufacturing sector.
A SOUTH AFRICAN ADDITIVE MANUFACTURING TECHNOLOGY ROADMAP

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ABSTRACT

The Department of Science and Technology has commissioned the development of an Additive Manufacturing Technology Roadmap for South Africa. The purpose of this Roadmap is to identify future addressable market opportunities and products in which Additive Manufacturing technology development is required to position South Africa as a competitor in the global market. In this Roadmap prioritised focus areas are identified, and programs defined that can guide public and private sector investment in AM research, development and innovation (RDI) in South Africa for the period 2014-2023. This Roadmap was developed through a combination of desk research, international market research, facilitated stakeholder workshops, a survey of local capabilities through meetings and questionnaires, and deliberations within the project core team comprising local experts in Additive Manufacturing and Technology Roadmapping approaches.
Technical Paper Abstracts

Rapid Product Development

RPD 1: PRODUCT AND PROCESS DEVELOPMENT AND REALISATION

Session Keynote - Fifteen Years of Metal AM Research at Cut - A Glance Back and Future Outlook

State of the Art and Review of Advanced Experiences in Rapid Tooling

Rapid Development of Paper-Based Fluidic Diagnostic Devices

Exploring Opportunities for Improvement in Selective Laser Melting

RPD 2: PROCESS AND RESOURCE EFFICIENCY

Resource Efficiency Assessment of Combining Selective Laser Melting and Five Axis Milling for Titanium Alloys

Laser Sintered Components Used as a Primary Contributor to Versatile Hybrid Prototypes: A Case Study

3D Printing Dimensional Calibration Shape: Clebsch Cubic

Laser Cladding Process Development for High Carbon Steel Substrates
FIFTEEN YEARS OF METAL AM RESEARCH AT CUT - A GLANCE BACK AND FUTURE OUTLOOK

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ABSTRACT

The CRPM and CUT’s research team were instrumental in developing Metal Additive Manufacturing (MAM) in South Africa to support Rapid Tooling (RT) and patient-specific implant cases.

This MAM development showcased the advantages this technology offered to both the tooling industry and the medical fraternity. Looking at medical applications of AM, the challenge was not only to supply the doctors with a digital model or design but to actually manufacture the final implant to assist them in completing these extremely difficult patient-specific cases.

The paper will discuss successful developments in the fields of RT as well as patient-specific implants which paved the way in the development of a complete process chain from design to manufacturing with both time and cost savings as a further result. The EOS M250, M270 and M280 Direct Metal Laser Sintering (DMLS) systems were instrumental in achieving these results, and the case studies presented will be supplemented by related process development, improvements as well as the certification process embarked on. The case studies will also focus on patient-specific maxillofacial implants and illustrate how these implants improve the quality of life of SA patients.

Furthermore, the proposed paper will focus on the use of Laser Sintering Technology Platforms to prove the viability of DMLS in titanium (Ti), and highlight CUT’s role in the development of an SA Ti AM initiative.
STATE OF THE ART AND REVIEW OF ADVANCED EXPERIENCES IN RAPID TOOLING

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ABSTRACT

The paper gives a short overview of the “state of the art” and a review of advanced experiences in rapid tooling. Starting in the early 90th first investigations of rapid tooling using LOM (Laminated-Object Manufacturing), HSC (High Speed Cutting), SLS (Selective Laser Sintering) and metal sheet laminating technologies like MELATO (Metal Laminating Tooling) will be reviewed. The field of application is wide from injection molding, sheet metal forming up to pressure die casting. Developments of the Incremental Sheet Forming (ISF) concept in connection with homogeneous heating tooling for GRP (Glass Reinforced Plastics) applications will be demonstrated too. For the optimization of the entire process chain from tool design with conformal cooling channels and the determined process realization are thermography and simulation applications necessary and useful methods. Some theoretical and practical experiences will be given. The well-known SLM (Selective Laser Melting) principle “LaserCUSING” from the company Concept Laser is quite suitable for injection molding but for high temperature requirements of the pressure-die casting processes the material quality leads to restrictions concerning tool life. Some experiences in this AM (Additive Manufacturing) technology will be demonstrated. In any case for further progress new principles are necessary. Some first experiences with the so called MPA (Metal Powder Application) procedure from the company Hermle will be included in the presentation. Another new approach for the improved heating/cooling procedure is possible with newly developed ceramic heating elements. Some first experiences - related to a new research project - will be demonstrated.
RAPID DEVELOPMENT OF PAPER-BASED FLUIDIC DIAGNOSTIC DEVICES

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ABSTRACT

We present a method for rapid and low-cost development of microfluidic diagnostic devices using paper-based techniques. Specifically, the implementation of fluidic flow paths and electronics on paper are demonstrated, with the goal of producing an integrated functional diagnostic device manufactured on paper.

There is an increasing demand to provide portable, robust and rapid diagnostics at the point of care, especially in poorly resourced areas where factors such as cost, power and lack of skills are major issues. Paper-based microfluidics offers solutions to address these challenges, largely as a result of the low-cost and straightforward manufacturing techniques. Printed electronics is a growing field, poised to significantly contribute to accessible diagnostics. Combining microfluidics and electronics on paper enables novel devices to be realized, since components such as diagnostic result readout can be integrated on a disposable, low-cost and readily available platform.

We explore two important components for realizing a functional paper diagnostic device: 1) fluidic flow functionality using wax barriers, and 2) detection methods via the implementation of electronics. We illustrate that these components can be realized either by using very simple, low-cost and manual methods or through sophisticated fabrication techniques utilizing specialized printing equipment for depositing various functional fluid materials such as wax and conductive inks with fine resolution. The results show that both techniques can create functional paper-based components, including multiplexed fluidic flow paths, as well as electronics on paper, and show that these can be integrated into a functional device.

The use of accessible materials to create functional devices makes this technology ideal for rapid prototyping of design ideas and for educational purposes. This also serves to create an awareness of the possibilities of this technology to spur interest and innovation in the field of paper-based diagnostics. Existing facilities in South Africa, such as the FabLabs (www.fablab.co.za), are ideal for the manufacture of paper prototypes and small-scale production of the devices and provide a ready source of device testers. For mass production, existing roll-to-roll manufacturing techniques could be employed to print the paper devices.
EXPLORING OPPORTUNITIES FOR IMPROVEMENT IN SELECTIVE LASER MELTING

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ABSTRACT

Selective Laser Melting (SLM) is a powder based process that offers significant flexibility in the manufacture of near net metallic parts. This additive manufacturing process has been adopted widely for tooling applications and is slowly making in-roads into aerospace component and medical implants manufacturing applications. However, achievable part quality shortcomings still exist that could render SLM undesirable. Some common quality problems are surface roughness, cracking, delaminations and dimensional distortions - most of which can be traced to residual stresses. The challenges are explored by classifying the SLM critical process parameters into three broad categories namely materials, process and product. The sub-parameters in each category are studied alongside their influence to part quality. This study explores, through literature, the current interventions in addressing the shortcomings of the SLM process. This exploratory research presents opportunities for further research in SLM process improvement and suggests how improved scanning strategies and expert systems can be adopted to improve and predict final part quality.
ABSTRACT

Reducing machining time and cost in manufacturing operations remain a key factor for improving the cost effectiveness of producing titanium parts. Due to the unique characteristics of titanium alloys it is classified as a difficult-to-machine material. In a country where titanium cannot be reprocessed at this stage, the potential of material saving plays a significant role in pursuing resource efficient manufacturing processes. Therefore, a reduction in the amount of stock material will have a significant effect on the production costs of the part. The use of Selective Laser Melting (SLM) is investigated as an avenue for reducing the amount of stock material as an alternative to machining a part from a solid billet. The objectives of this research study were to reduce the machining time and the amount of work piece material wasted. An aerospace component was manufactured from a solid billet using only 5-axis milling strategies. Thereafter, the same part was manufactured using a combination of SLM and machining. A resource efficiency assessment of the process combination is presented with the focus on costs, form accuracy and surface integrity, tool wear and work piece material wastage.
LASER SINTERED COMPONENTS USED AS A PRIMARY CONTRIBUTOR TO VERSATILE HYBRID PROTOTYPES: A CASE STUDY

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ABSTRACT

Designers at the Vaal University of Technology were set the task of designing a means of integrating a Samsung 10” Tablet with a biometric scanner. Other Tablets models also had to fit into the design as the final end user could not be forced to use only Samsung Tablets. There was a requirement for a rapid turn-around and so a combination of technologies was used to create “Hybrid Prototypes”. The Additive Manufacturing (AM) process known as Laser Sintering (LS) was used to produce components to be used as patterns, since it facilitated a good surface finish and good release angles for tooling. High quality Polyurethane (PU) composite tooling was then produced to curb component costs whilst maintaining the ability to cope with the stresses and temperatures seen during manufacturing. The Hybrid Prototypes consisted of several LS parts, PU composite castings, “off-the-shelf” components such as brass inserts (used as fasteners) and the feature that allowed these prototypes to become versatile, the laser cut holding struts. These holding struts fitted perfectly into predetermined grooves in the prototype base. The struts could be cut according to the contour and height of the different Tablet models. Post-process finishes, wet spray painted after sanding, made the products appear as if they had been injection moulded, as this would be the preferred route to mass production. This paper covers the strategical planning of the project, critical design criteria addressed and the pros and cons of process followed to complete twenty units for market sampling by means of field tests in several locations. The paper also discusses how the design was influenced by the rapid turnover of new tablets in the market place and how the parameters shifted over time. Finally, conclusions are drawn as to how the combination of AM with other technologies can increase the flexibility of the prototyping process.
3D PRINTING DIMENSIONAL CALIBRATION SHAPE: CLEBSCH CUBIC

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ABSTRACT

3D printing and other layer manufacturing processes are challenged by dimensional accuracy. Several techniques are used to validate and calibrate dimensional accuracy through the complete building envelope. The validation process involves the growing and measuring of a shape with known parameters. The measured result is compared with the intended digital model. Processes with the risk of deformation after time or post processing may find this technique beneficial. We propose to use objects from algebraic geometry as test shapes. A cubic surface is given as the zero set of a 3rd degree polynomial with 3 variables. A class of cubics in real 3D space contains exactly 27 real lines. We provide a library for the computer algebra system Singular which, from 6 given points in the plane, constructs a cubic and the lines on it. A surface shape derived from a cubic offers simplicity to the dimensional comparison process, in that the straight lines and many other features can be analytically determined and easily measured using non-digital equipment. For example, the surface contains so-called Eckhard points, in each of which three of the lines intersect, and also other intersection points of pairs of lines. Distances between these intersection points can easily be measured, since the points are connected by straight lines. At all intersection points of lines, angles can be verified. Hence, many features distributed over the build volume are known analytically, and can be used for the validation process. Due to the thin shape geometry the material required to produce an algebraic surface is minimal. This paper is the first in a series that proposes the process chain to first define a cubic with a configuration of lines in a given print volume and then to develop the point cloud for the final manufacturing. Simple measuring techniques are recommended.
LASER CLADDING PROCESS DEVELOPMENT FOR HIGH CARBON STEEL SUBSTRATES

T. Lengopeng\textsuperscript{1}, A. Botes\textsuperscript{2} & A.P.I. Popoola\textsuperscript{1}

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ABSTRACT

This paper evaluates the effect of process parameters (laser power and scanning velocity) on clad layer height, heat affected zone (HAZ) width, metallurgical bonding to base metal and Vickers microhardness profiles of clad layers of various composition. A 3 kW IPG Fiber laser was used to clad St1.7339 powder on a high carbon steel substrate (EN9). The laser power and scanning velocity were varied between 2 kW to 2.5 kW and 0.5 m/min to 1.2 m/min respectively. The carrier gas flow rate, laser beam spot diameter and powder feed rate were kept constant throughout the experiment. The effect of multiple layers (up to a total of six clad layers built-up) and post-weld heat treatment by a defocussed laser beam on the HAZ width and hardness were investigated respectively. The produced clads were prepared for metallurgical evaluation and were analysed for microstructure using optical microscopopy and microhardness traverse were done using a Vickers microhardness tester.

The clad height, HAZ width and its metallurgical bonding were observed and measured with an optical microscope equipped with image analysis software. All the samples that were evaluated showed sound metallurgical bonding with the substrate. A decrease in porosity was observed with an increase in laser power at constant scan speed. The hardness values taken on the HAZ showed a decrease with the increase in the number of clad layers during build-up. Meanwhile, four clad layer build up samples showed similar hardness trend independent of the laser power used. The width of the HAZ did not increase with an increase in the number of clad layers built-up. Laser post-weld heat treatment on the clad proved to be feasible as results indicated HAZ hardness was significantly decreased. Using AISI 316L as a butter layer did not lead to the formation of hard brittle chromium carbides even though the chromium content is high enough for the formation of these stable carbides. It was however observed that the use of an AISI 316L butter layer did result in a wider HAZ compared to the pure iron and medium carbon steel butter layers.


**Materials**

**MAT 1: LASER BEAM MELTING AND MATERIAL CHARACTERISATION**

Session Keynote - A Round Robin Study for Laser Beam Melting in Metal Powder Bed: Comparing Mechanical Characteristics with System Technology Variation

On the Heat Treatment of LaserCUSING Produced Ti-6Al-4V Components

Strategy Toward the Manufacturing of Fully Dense Parts From AISI 420 Stainless Steel by Selective Laser Melting

Peculiarities of Single Track Formation from Ti6Al4V Alloy at Different Laser Power Densities by SLM

**MAT 2: PROCESS CHARACTERISATION**

Microstructure of SLM Manufactured 316L and 420 Grades Stainless Steel

Part Finishing on Entry Level FDM Models

An Investigation into the Variation in Porosity of a Direct Metal Laser Sintered Artifact Manufactured with the EOSINT M250 Machine System Using Direct Metal 20 Powder

Materialise: Innovators You can Count on

**MAT 3: ALTERNATIVE PROCESSES**


Characterisation of Steel Blade Microstructure Produced Using Laser Engineering Net Shape Process

Bioceramic Hydroxyapatite Coating Fabricated on Ti-6Al-4V Using Nd:YAG Laser
A ROUND ROBIN STUDY FOR LASER BEAM MELTING IN METAL POWDER BED: COMPARING MECHANICAL CHARACTERISTICS WITH SYSTEM TECHNOLOGY VARIATION

B. Ahuja¹, A. Schaub¹, D. Junker², M. Karg¹, F. Tenner¹, R. Plettke², M. Merklein² & M. Schmidt¹

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ABSTRACT

With recent developments in additive manufacturing, there has been a keen interest in understanding its possibilities and limitations specifically with respect to the conventional engineering and manufacturing standards. Although coined as a prototyping technology at the time of its inception, Additive manufacturing with its characteristic layer by layer fabrication methodology is now the focus of end product manufacturing for many niche applications. One of the key additive manufacturing processes leading this evolution is the process of Laser Beam Melting in metal powder bed. With its ability to fabricate fully dense 3-dimensional structures by selectively melting micro-sized metal powder, Laser Beam Melting is being considered by many as a significant complimentary technology to the conventional forming and subtractive manufacturing processes. In order to completely understand the abilities and limitations of the Laser Beam Melting process, a detailed analysis of the system technology, process and user induced variations in relation to the characteristics of the resultant part needs to be performed. With the above motivations in mind, an initiative at the Collaborative Working Group, Lasers in production at the International Academy of Production Engineering (CIRP) was undertaken to conduct a comparative study in the form of a Round Robin test by analyzing the mechanical characteristics of samples fabricated by various users of the Laser Beam Melting technology from volunteers within the members of the academy. The presented paper illustrates the design and methodology of the round robin test in addition to some preliminary results and makes an attempt to connect these results with the various phenomena occurring in the Laser Beam Melting process. Authors of the paper gratefully acknowledge the contributions from the various members of the Collaborative Working Group, Lasers in production at the International Academy of Production Engineering (CIRP) who volunteered for providing the samples for the conducted round robin test.
ON THE HEAT TREATMENT OF LASERCUSING PRODUCED Ti-6AL-4V COMPONENTS

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ABSTRACT

LaserCUSING is a Selective Laser Melting (SLM) process capable of manufacturing parts by melting powder with heat input from a laser beam. The LaserCUSING process demonstrates potential for producing intricate geometries, specifically required for biomedical implants and aerospace applications. One main limitation to this form of rapid prototyping is the lack of published studies on the material performance of the resulting material. Studies on the material performance are often complicated by the dependence on several factors including starting powder properties, laser parameters and post-processing heat treatments. This study aims to investigate the heat-treatment of LaserCUSING produced Ti6Al4V. A combination of conventional and LaserCUSING-tailored heat treatments are performed. The resulting microstructures are studied and linked to the properties obtained from hardness tests.

The findings highlight that LaserCused Ti6Al4V is competitive with traditional materials provided optimal parameters are chosen and parts are subject to tailored post-processing. In the as-built condition, LaserCused Ti6Al4V displays superior hardness as a result of a martensitic microstructure and a poorer performance in ductility. However, the material performance can be improved by means of tailored heat treatments. Careful consideration must be given to suitable post-processing before the application in critical components in the aerospace or biomedical industry can occur.
STRATEGY TOWARD THE MANUFACTURING OF FULLY DENSE PARTS FROM AISI 420 STAINLESS STEEL BY SELECTIVE LASER MELTING

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ABSTRACT

Selective laser melting (SLM) is an additive manufacturing technique that produces functional parts from metal powders. SLM is a powerful technology for automotive, medical, chemical, aerospace and other hi-tech industries. SLM is a well-suited technology for the mould industry: it can considerably reduce the time for engineering and fabrication of moulds. SLM provides extraordinary freedom to validate design of moulds and to develop new materials. The extension of applications requires different materials with specific properties. To show the potential and features of SLM for mould manufacturing applications, fully-dense samples from AISI 420 stainless steel powder were fabricated. AISI 420 stainless steel is a material widely used in the plastics-moulding industry where high hardness and wear resistance is required. The study discusses the influence of laser power, scanning speed, layer thickness and hatch distance on the formation of single tracks and layers. Algorithm for finding optimal process parameters is indicated with respect to features of single tracks, layers and 3D objects. Width of the single track determines the hatch-distance to form a single layer. Height of the tracks and scanning strategy define the morphology of the synthesized layer. Morphology of the layer has a significant impact on the variation of the thickness of the next delivered powder layer. This should be considered when choosing the optimal process parameters. An energy input should be adequate to melt powder layer and to achieve remelted depth providing good cohesion between the layers. The pore analysis (shapes and sizes) can also contribute to the identification of optimal process parameters. To produce non-porous objects from AISI 420 (<32 µm) stainless steel powder, 60 W laser power, 70 µm spot diameter, 0.12 m/s scanning speed, 120 µm hatch-distance and 40 µm thickness of powder layer and two-zone scanning strategy with following 90° turning for each next layer were applied. Microhardness of the SLM samples was 513±19.5 HV\textsubscript{0.3} for inner regions; upper layers had 700-750 HV\textsubscript{0.3}. 
PECULIARITIES OF SINGLE TRACK FORMATION FROM Ti6Al4V ALLOY AT DIFFERENT LASER POWER DENSITIES BY SLM

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ABSTRACT

Modern industry requires searching for new methods of producing complex parts with the desired internal structure from modern materials. The rapid development of additive manufacturing (AM) in recent years is a reflection of these requirements. Selective laser melting (SLM) is very suitable technology for the fabrication of complex objects with well-developed structure in one working cycle. Selective laser melting sometimes even is called “3D printing of metal powders”, emphasizing the simplicity and elegance of the idea of adding powder material during manufacturing process. In fact, selective laser melting of powders is a very complex and costly process. SLM is found to be a multi-disciplinary field, as a number of different physical phenomena play a role in producing the final result. The properties of an object produced by this technology depend strongly on the quality of each single track, each layer and their superposition. Temperature distribution during SLM is important because temperature fields determine the morphology of tracks and layers, microstructure and finally mechanical properties of the SLM part. The most of published works with Ti6Al4V alloy are devoted to the study of the properties of SLM objects retrieved as a whole, without an analysis of single tracks. The analysis of single track provides information about the causes of porosity, pore shapes or their chains in 3D part. Also knowledge of the shape and geometry of single tracks produced by different process parameters allows selecting an optimal strategy for manufacturing of full dense objects or lattice structures. Analysis of temperature fields opens opportunities to build parts with desired properties by SLM. This work describes the shapes and geometrical characteristics of SLM single tracks manufactured with different laser powers (20-170 W) and scanning speeds (0.1-2.0 m/s). Simulation of temperature distribution during processing was conducted. Conclusion regarding optimal process parameters and peculiarities of selective laser melting of Ti6Al4V alloy at low and high laser powers and scanning speeds was done.
ABSTRACT

Selective laser melting (SLM) is an additive manufacturing process, involving track-by-track powder material melting on the previous fabricated layer. Because of the complete remelting, SLM objects have a cast microstructure and as a result of high cooling rates the microstructure itself is fine. During manufacturing, each next track heats up already solidified materials beneath the surface. Therefore, inner layers are subjected to multiple heating-cooling cycles. In this investigation, microstructural characterization of SLM parts made of AISI 316L and 420 stainless steel grades were performed in order to understand the influence of the SLM process parameters on the final steel microstructure. It was shown that rapid solidification after track melting resulted in the formation of colonies grown epitaxially from the fusion boundary surface. Each colony consists of very fine cells with submicron cell spacing, coherent and grown in the same direction. In AISI 316L steel, this structure remains unchanged since austenite is stable and is not transformed at cooling down to room temperature. In AISI 420 steel, martensite is formed with rapid cooling and undergoes in-situ heat-treatment at further thermal cycling. The effect of thermal cycling on the final microstructure of the built part, i.e. the depth of the heat-affected zone of each next single track, is dependent on the material properties and the SLM process parameters. In the case of AISI 420 martensitic stainless steel, thermal cycling initiated a partitioning heat treatment process, which resulted in high amounts of austenite in the microstructure. The in-situ heat treatment conditions in the solidified inner parts were numerically simulated using a time-dependent “Heat transfer in solids” Comsol module, and a comparison of modeled isotherms with experimentally observed microstructures showed a good agreement between simulation and experiment. Since the model demonstrated a good agreement with experimental results, it was used to evaluate the influence of laser power and laser scanning speed on the in-situ heat treatment. This gives useful background to predict the microstructure of SLM products at manufacturing.
PART FINISHING ON ENTRY LEVEL FDM MODELS

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ABSTRACT

The Idea 2 Product lab (I2P), which was implemented at the Vaal University of Technology, is a self-help laboratory with the objective of empowering students, staff and the community to develop their ideas into a physical product or prototype using entry level Fused Deposition Modeling (FDM) printers. Since the startup of the I2P lab in 2011, a need arose to determine different part finishing techniques on entry level models. The aspects that need to be addressed to improve the appearance of the entry level models are the visible layer step traces, color and bonding/binding/fusing different pieces together. Due to the print size restrictions on entry level FDM printers, multiple parts often need to be bonded-fused together in order to form an aesthetic or functional part. The aim of the study is to determine different surface finishing and bonding/binding/fusing techniques, which can be used on entry level FDM printed ABS models in order to improve their appearance, performance and quality.
AN INVESTIGATION INTO THE VARIATION IN POROSITY OF A DIRECT METAL LASER SINTERED ARTIFACT MANUFACTURED WITH THE EOSINT M250 MACHINE SYSTEM USING DIRECT METAL 20 POWDER

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ABSTRACT

Direct Metal Laser Sintering (DMLS) is a rapid prototyping technique that allows for direct and rapid manufacturing of complex components. DMLS is however an intricate process and the quality of the final product is influenced by multiple manufacturing parameters (or DMLS settings) and powder characteristics. The effect which each of these manufacturing parameters and powder characteristics has on the final parts is not well understood and the success of process manufacturing mainly relies on empirical knowledge. Consequently high dimensional deformation and relatively poor mechanical properties are obtained in many DMLS products, in particular in Direct Metal 20 copper-based laser sintered parts produced with an EOSINT M250 system in use at the Centre for Rapid Prototyping at the Central University of Technology. A need therefore existed to systematically examine the effect of process parameters on the density of final parts in order to determine the most appropriate manufacturing parameters for specific applications of copper-based laser sintered parts at this institution.

This paper summarises the effect of different process parameters and sintering strategies on the quality of Direct Metal 20 laser sintered parts produced with an EOSINT M250 Xtended laser sintering machine from powder consisting of Ni5Cu, Cu15Sn - Cu5Sn and Cu8P - Cu2P material grains - where quality in this paper is measured as porosity which was indirectly measured via Image Analysis. The effects of three different geometric sintering strategies currently in standard use namely Solid Skin, Skin Stripes and Skin Chess were examined. This paper reports on porosity of parts sintered to these strategies by liquid phase sintering, in order to find final appropriate associated process parameters. Porosities as low as 7% only were obtained in parts sintered according to the Skin Stripes sintering strategy.
Headquartered in Leuven, Belgium and with branches worldwide, Materialise has been playing an active role in the field of Additive Manufacturing (AM) since 1990. We are a leading provider of AM software and of sophisticated 3D Printing services with customers active in a wide variety of industries, including healthcare, automotive, aerospace, art and design, and consumer products.

Since starting almost 25 years ago, Materialise has grown into the market leader for Digital CAD and 3D printing software. With our intimate knowledge of the technologies, and the bottlenecks in RP and AM, our software development staff stays ahead of the trends with revolutionary solutions that drive down costs and increase efficiency. Materialise software offers a wide range of software solutions, which boost efficiency and reduce lead-times, resulting in increased productivity throughout the entire AM process.

Most people here will probably know that when you have a final design, you will need to edit this design in a specific way to make that model printable. That’s the part where Magics RP comes in handy; it helps you to optimize the process of editing and fixing data for data preparation. But what about all the steps that are needed before and after data preparation; how can you improve your model or design before making it printable and then how do you make sure that the print data is generated and send to the machines effectively and correctly? This is what I would like to talk to you about today. I would like to use this opportunity to present our software solution that can help you to further optimize those parts of the AM process. In this presentation we will present our 3-matic\textsuperscript{STL} software and our Build Processor solutions. The first can help you to redesign better models on an STL level whereas the other one will help you to send correct data directly to your printer without having to switch interfaces.

\textbf{3-matic\textsuperscript{STL}} offers design modification, design simplification, 3D texturing, remeshing, forward engineering, and much more, and all on an STL level. With the 3-matic\textsuperscript{STL} functions you can, for example: efficiently change your design for wind tunnel testing; prepare your data for a quick and efficient FEA; investigate the look and feel of new 3D textures; design or repair missing or badly scanned components, have the ability to produce lightweight components. In short, 3-matic\textsuperscript{STL} can help to drastically reduce product development cycles. The possibilities are endless.

\textbf{Build Processors} On top of that we have developed Build Processors that can significantly simplify the 3D printing machine communication process while working towards a more standardized and user-friendly man-machine interface which reduces complexity and makes Additive Manufacturing technology accessible to a wider range of users.
EVALUATION OF MICROSTRUCTURE AND MICRO-HARDNESS OF 410L SS COATINGS FABRICATED USING LASER ASSISTED COLD SPRAYING: PROCESS DEVELOPMENT

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ABSTRACT

Automotive, marine, power generation, petrochemical and mining industries experience problems which results in huge financial constraints due to damage of the engineering components. Sometimes the components are exposed to aggressive, corrosive, contaminating and erosive environments which accelerate the degradation of these components. Surface coatings are generally used to protect and prolong the lifetime of the parts. Laser Assisted Cold Spray (LACS) is a relatively new surface coating process which can be used to protect surfaces of engineering components against these aggressive environments.

LACS is a hybrid process that combines the supersonic powder stream with laser heating of the deposition zone. In this process, the deposited particles and the substrate are not melted by the laser beam, but heated to just below the melting. Since no melting is involved, it is referred to “Laser Assisted Cold Spraying”.

LACS technique is an emerging mainstream process; which means there are gaps in the knowledge base relating to LACS-dependent applications. This paper will focus on the microstructural evolution, mechanical deformation, the correlation between functional properties and process parameters necessary for the development of required LACS coatings. This paper will provide the basis on which research will follow-on-research that will lead to the development of high-productivity LACS coatings for identified industrial applications. The investigation of the effect of varying experimental parameters such as laser power, laser travel speed and powder feed rate on coating deposition efficiency, microstructure evolution and micro-hardness of the deposited coatings, will be discussed.
COMPARATIVE STUDY OF MICROSTRUCTURAL, ELECTROCHEMICAL AND TRIBOMECHANICAL PROPERTIES OF ELECTRODEPOSITED ZN-AL₂O₃/Cr₂O₃/SiO₂ NANOCOMPOSITE COATINGS

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ABSTRACT

Nano-sized particle incorporation into metal matrix for fabrication of advance surface coatings find variety of applications in surface protection techniques. Al₂O₃, Cr₂O₃ and SiO₂ nanoparticles have been codeposited with Zn using electrodeposition process to produce Zn nanocomposite coatings. The fabricated coatings were characterized using Scanning Electron Microscope affixed with Energy Dispersive Spectroscopy and X-ray diffractometer. The mechanical and tribological properties of the coatings were investigated using diamond microhardness indenter and dry abrasive wear tester. Zn-10g/L Cr₂O₃ nanocomposite exhibited the highest microhardness of 228 HV and Zn-5g/L Al₂O₃ nanocomposite possessed the highest corrosion resistance and lowest wear loss. Zn-5g/L SiO₂ nanocomposite showed good stability as compared to other composite coatings. The incorporation of the nanoparticles of Al₂O₃, Cr₂O₃ and SiO₂ induce grain refinement and modify crystallographic orientation of Zn matrix. Zn-5g/L Al₂O₃ and Zn-5g/L SiO₂ proved to be better coatings which can find variety of industrial applications where both mechanical and electrochemical properties are required.
CHARACTERISATION OF STEEL BLADE MICROSTRUCTURE PRODUCED USING LASER ENGINEERING NET SHAPE PROCESS

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Abstract

Laser rapid forming is a recently developed method for the production of metal parts. Several laser based method such as selective laser sintering (SLS), direct metal laser sintering (DMLS), and laser engineering net shaping (LENS) are available. Of the laser based techniques, the LENS process the LENS process was employed to produce steel blades. The advantages of the technique are the fast processing speed, the elimination of tooling requirements, the ability to fabricate intricate shapes at lower cost and the retention of the metastable microstructure. The LENS process has been concentrated on producing titanium metal parts. Suitability and possible defects of components produced by the LENS process on steel material has not yet been fully studied according to the author’s knowledge. The microstructure homogeneity plays an important role in producing uniform mechanical properties of 316L stainless steel during production. It has been found that the microstructure is very dependent on the heating profile during the laser heating process.

410L stainless steel powder was used to produce blades using the LENS process. The microstructure characterisation was performed using optical and scanning electron microscopes. Fully martensitic microstructure was observed. The hardness profile of the blade is high on the middle section of the blade than it is on the round and sharp edges of the blade. The aim of the study was to evaluate the microstructure and hardness of the steel blade produced by the LENS process.
BIOCERAMIC HYDROXYAPATITE COATING FABRICATED ON Ti-6Al-4V USING Nd:YAG LASER

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ABSTRACT

A method of synthesising a biocompatible HAP coating is presented. In the current study, Nd:YAG laser was used to directly melt pre-place HAP powder beds on Ti-6Al-4V. The processing parameters used were 750 W laser power, 5 mm/s scanning speed and 27° inclined beam plane. The coating was studied under white light and scanning electron microscope where it was possible to characterise the microstructures. The produced coating was characterised of mixed morphologies of HAP, short and elongated titanium needles at the surface while in the middle of the coating dendrite trunks without arms were observed. This observation is related to the heat inputs, dilution and melting of the substrate and powder during processing. The absence of the arms growing from the trunks indicated low heat inputs. In addition, the microstructure of the HAP after soaking in Hanks’ solution indicated octagonal and hexagonal crystals of HAP. The hardness values indicated good metallurgical bonding at the interface. In conclusion, this study was successful in fabricating a desirable coating of HAP on Ti-6Al-4V for biomedical applications. This work highlights that even though laser power and scanning speed are predominantly influential parameter settings, it is also necessary to consider the angle at which the laser beam is scanned across the material.
New Techniques and Systems

NT&S 1: ADVANCED TECHNIQUES AND SYSTEMS I

Session Keynote - Experimental and Numerical Analysis for Process Control and Quality Assurance in Additive Manufacturing

Determination of Cooling Rates During Laser Beam Melting of Aluminium Alloy En Aw 7075 Using High Speed Pyrometry

Development of A More “Rugged” Printing Head System

Expert System for 3D Printing Technology

NT&S 2: ADVANCED TECHNIQUES AND SYSTEMS II

3D Printing Multi-Functionality: Aerospace Structures with Electronics

Laser Metal Deposition Thermal Analysis using Finite Element Method

Porosity in (3D Printed) Ti6Al4V Manufactured by High-Speed (30 Cubic Millimeters per Second) Laser Powder Bed Fusion
EXPERIMENTAL AND NUMERICAL ANALYSIS FOR PROCESS CONTROL AND QUALITY ASSURANCE IN ADDITIVE MANUFACTURING

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ABSTRACT

The potential to revolutionize the manufacturing industry is very high thanks, in part, to additive manufacturing technology. This technology can create functionally complex parts with custom tailored materials properties. Major commercialization obstacles at this time are quantitative demonstration of repeatability and reliability of the process across platforms. While the technology has been around for several decades most advances have been done in an empirical fashion creating point wise solutions. While statistical correlations exist for different Additive Manufacturing systems, there is no physics-based mechanistic understanding among the fundamental process parameters, microstructure, and mechanical properties for these different systems. This presentation will highlight accomplishments being made in this effort through the integration of a comprehensive suite of in-situ experimental tools (i.e. calorimetry, laser ultrasound) that will enhance our knowledge of the Additive Manufacturing process and enable us to understand the sensitivity of different process parameters. This will be coupled with predictive tools to virtually develop precision process planning to enhance component repeatability and reliability.
DETERMINATION OF COOLING RATES DURING LASER BEAM MELTING OF ALUMINIUM ALLOY EN AW 7075 USING HIGH SPEED PYROMETRY

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ABSTRACT

Additive Manufacturing of Aluminium cast alloys via Laser Beam Melting in powder bed (LBM) is now industrially used for functional prototypes and small series production. The choice of processable alloys is currently limited to silicon based Aluminium cast alloys such as AlSi10Mg. Geometric Freedom of Laser Beam Melting offers future potential for topology optimized lightweight structures which could be produced with less design compromises compared to other manufacturing technologies. The Mechanical properties depend on the microstructure, which is formed during melt solidification under key influence of the cooling rate. In LBM the cooling rates are several orders of magnitudes higher than in conventional production processes such as die casting. They have so far been estimated a posteriori by analysis of resulting microstructures or by numeric simulations that could not be validated directly. In this paper a high-speed pyrometer with a sampling rate of 100 kHz is used in a lateral setup to measure radiation emitted by a stationary spot, through which the laser focus passes. Signals were obtained from simplified geometries such as thin walls and cubical blocks in different vertical build heights made from Aluminium wrought alloy EN AW 7075 under variation of scan speed and laser power. Furthermore the findings were related to metallographic microsections of the generated test structures. The results improve the fundamental understanding of solidification phenomena and their dependencies on part geometry and scanning speed for Aluminium wrought alloys such as EN AW 7075, which is a challenge to be processed using Laser Beam Melting because of their characteristic poor weldability.
DEVELOPMENT OF A MORE “RUGGED” PRINTING HEAD SYSTEM

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ABSTRACT

Printing with current commercially available 3D printers is limited to the specific printing materials supplied by the original equipment manufacturer (OEM). Thus, if a prototype is printed with a commercial 3D printer it can only be printed with the material supplied by the OEM, and not with the desired engineering material. The objective of this research is to develop a more “rugged” printing head system, which will be able to print with different fluid properties, including different viscosity, surface tension and density combinations. The more “rugged” print head system can then be used as a base to develop new binder-power combinations, as the printable fluid is not limited to that of the print head manufacturer.
EXPERT SYSTEM FOR 3D PRINTING TECHNOLOGY

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ABSTRACT

The design of the expert system to support solving problems connected with using 3D printing technology has been presented. The system has been created with typical modules such as knowledge base, user interface and inference engine.

Actual publications (books, reports, research papers) have mostly been used to create the knowledge base. Methods of knowledge engineering have been applied to make the analysis of data included in actual publications where the emphasis has been put on the type, quality and reliability of the data as well as on the way of the knowledge record. The data has been recorded in the form acceptable by the expert system inference engine. The main attention has been paid to the possibility of modification and supplementation of the data included in the knowledge base.

The system operation has been shown on the basis of the selection of a 3D printer for the machine part production. The selection has included: technical parameters of a 3D printer, 3D printer operating parameters, materials, geometry, dimensions and mechanical requirements for the manufactured part.

It has been shown that, on the basis of actual publications the knowledge base for the expert system concerning 3D printing technology can be created.
3D PRINTING MULTI-FUNCTIONALITY: AEROSPACE STRUCTURES WITH ELECTRONICS

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ABSTRACT

Recently, significant research and press has focused on the fabrication freedom of Additive Manufacturing (AM) to create conceptual models as well as final end-use products. AM allows modifications in designs to be reflected almost immediately in fabricated structures and thus democratizes the manufacturing process, in which products will inevitably be fabricated locally and with unit-level customization based on unique mission requirements. However, AM is currently relegated to create mechanical devices such as wrenches or enclosures, and for the technology to find profound utility, the processes will be required to be enhanced to incorporate additional features in the fabricated structures such as electronics, actuation, and electromagnetics where thermodynamic, optical, biological, chemical and pharmacological features can be enabled. In the last decade, research has been reported of embedding electronic components and electrical interconnect into 3D printed structures by interrupting the 3D printing process. However, only until recently has a plan been reported in which fabrication will include an automated and enhanced 3D printing, non-assembly process - specifically targeting 3D electronics in arbitrary form. Furthermore, no reports have included the additional enhancement of active 3D thermal management of these 3D devices. This paper describes the status of a novel fabrication system - Multi3D manufacturing - that was recently funded by the presidential initiative for revitalizing manufacturing in the USA with 3D printing - America Makes. Other projects with embedded electronics will also be described - further informing the possible design space brought to bear by this novel technology.
LASER METAL DEPOSITION THERMAL ANALYSIS USING FINITE ELEMENT METHOD

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ABSTRACT

Laser Metal Deposition (LMD) uses a laser beam to form a melt pool of the fed metal powder to be deposited on a metal substrate. The powder melts to form a deposit that is fusion bonded to the substrate and the required geometry is built up by layer by layer deposition. In this work a three-dimensional finite element model has been developed to numerically simulate the heat transfer phenomenon in Laser Metal Deposition of both pure nickel and stainless steel. Temperature dependent physical properties have been accounted for. The commercially available finite element software ANSYS (Version 14) was used and codes were generated in Ansys Parametric Design Language (APDL) to analyse the influence of various LMD parameters on the thermal history. Thermal cycles experienced at different locations of the deposit were also validated, exhibiting similar trends as published in literature.
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POROSITY IN Ti6Al4V MANUFACTURED BY HIGH-SPEED (30 CUBIC MILLIMETERS PER SECOND) LASER POWDER BED FUSION

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ABSTRACT

Laser powder bed fusion machines available on the market utilize laser powers of 1 kW or less. This results in a relatively slow building rate which limits the technology to producing only relatively small parts. The current paper shows that high power (3 kW and higher), high scan speed (3m/s and higher) powder bed fusion is feasible. Rectangular blocks of Ti6Al4V with dimensions 70x20x3.5mm were printed. Part porosity of less than 0.15% (as measured with Archimedes method) at a building rate of 24mm$^3$/s and part porosity of 0.5% at a building rate of 60mm$^3$/s is demonstrated.
Applications and Industry

A&I 1: INNOVATIVE APPROACHES

Session Keynote - The Use of AM to Support Strategies for Regional Innovation and Sustainable Development

Development of a 3D Printed Radio-Controlled Plane by Denel Dynamics

Designing Bespoke Adjustable Sockets for Prosthetics using CAD Software and 3D Printing

Entry Level FDM 3D Printer Produced Parts can Satisfy Certain Niche Markets in Industry

A&I 2: ADVANCED APPLICATIONS

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Additive Manufacturing of Parts for a South African Prototype Aircraft

Future Scenarios to 2025 Plus for the Western Cape Tool, Die and Mould Industry
THE USE OF AM TO SUPPORT STRATEGIES FOR REGIONAL INNOVATION AND SUSTAINABLE DEVELOPMENT

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ABSTRACT

The paper and presentation focuses on the use of Additive Manufacturing (AM) platforms to develop an innovation support strategy for the Vaal Region, following an industry cluster approach. As part of the impact review, several successful industrial development case studies and the related outcomes, based on the use of AM technologies to create cluster-focused innovation support platforms will be discussed. Importantly, the early results also indicate that the local / regional approached taken, are equally applicable towards establishing national support strategies / platforms. In addition, both the impact on the host institution, as well as the region will form part of the review (following Porter’s theses). Of special importance, is the way in which the activities also created a foundation to develop a rural science and technology park development strategy, which may have significant impact on the future of science park development strategies for developing economies? Interestingly, the results also show that whilst incubation and new venture creation are important aspects of successful local and regional economic development strategies and obvious areas where the use of AM can play a significant role, it is as important to find support strategies for existing / conventional industries to maintain job opportunities and as such, help to “save” existing industries. The paper also discusses the impact of AM on last-mentioned, as part of an industry renewal strategy to refocus existing industries on competitive product development with the aim to counter expensive (and often inferior) imports, whilst in parallel, using AM platforms to improve on efficiency, cleaner production and waste minimisation. In addition, the contribution made to AM development in SA by using a focused, industry supported cluster approach, will be highlighted.
DEVELOPMENT OF A 3D PRINTED RADIO-CONTROLLED PLANE BY DENEL DYNAMICS

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ABSTRACT

During the establishment of the Three-dimensional (3D) Printing Facility at Denel Dynamics, various obstacles had to be overcome. One of these obstacles was the general perception by designers that 3D printing produces parts that are brittle, not very strong and can only be used for mock-ups. This led to an in-house development project to develop and manufacture a 3D-printed radio-controlled plane. The project proved that 3D printing can be used for functional parts and is capable of far more than perceived.

After the conceptual design, layout and aerodynamic design were completed, the Computer-aided Design (CAD) model was modelled. The detailed design was approved in a design review and 3D printed on a Fortus 250mc 3D printer. The hardware was integrated with the electronics and tests were done to verify the performance of the subsystems. To test the system, a test flight was conducted, during which successes and failures were experienced. It was decided to make some changes to the design according to lessons learnt, and to conduct a second flight test. The design was changed and some of the components were reprinted and integrated. The second flight test was more successful than the first, and it was concluded that the goal of the project had been achieved.
DESIGNING BESPOKE ADJUSTABLE SOCKETS FOR PROSTHETICS USING CAD SOFTWARE AND 3D PRINTING

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ABSTRACT

A prosthetic limb is only effective to a patient if it fits properly. The socket part of a prosthetic is the part that interacts with the human body and is subsequently the key element between the human body and the prosthesis. The human body is not a static organism: Most amputees experience some level of volume change - ranging from subtle to drastic - during the course of a day. Various factors that affect the volume of the limb include reduction of postoperative oedema, changes in body weight, muscle atrophy, swelling and the temporary reduction of fluids in the limb caused by the normal pumping action of walking in prosthesis. This creates problems with the fit of the prosthesis as the sockets are normally a static component and patients can experience extreme discomfort. Our focus is creating a 3D printed socket that can be adjusted by the patient accordingly as the stump changes during the course of a day. A 3D scan is used to generate a perfect copy of the stump and then a socket is designed around the scan. Various slits are incorporated into the socket to allow flexibility and we use an off-the-shelf tightening system that is easily incorporated into the socket. This allows the patient to have control over the fit and can be easily adjusted to their specific needs by themselves.
ENTRY LEVEL FDM 3D PRINTER PRODUCED PARTS CAN SATISFY CERTAIN NICHE MARKETS IN INDUSTRY

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ABSTRACT

With the establishment of the Idea to Product Laboratories® (I2P Labs®) at the Vaal University of Technology, a number of entry-level additive manufacturing machines were acquired. Some of the latest additive manufacturing machines have produced parts, which after finishing, have the same look and feel as parts produced by high end equivalent technology.

If the visual quality of finished parts produced on low end additive manufacturing machines prove to be of the same or similar quality than parts produced by high end additive manufacturing machines, it should be possible to utilize entry-level machines for production runs of parts where volumes do not make it economically viable to use conventional technologies, such as injection moulding machines. This will be limited to a certain size though but will work well on parts with a low stress level in terms of structural integrity, where batches can be produced over an extended time-line, or even by running multiple machines in a production set-up.

This will open the doors to design complex parts with undercuts or internal or hidden structures/geometries to be manufactured on economical viable scales. Currently, these parts are produced on high end machines, where both cost of ownership and associated running costs are too expensive for most SME’s.
THE ROLE OF ADDITIVE MANUFACTURING IN BIO-PROSTHETIC HEART VALVE ENGINEERING

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ABSTRACT

Currently, over 290,000 HV procedures are performed annually worldwide and that number is estimated to triple to over 850,000 by 2050. Thus, the demand for artificial HVs is expanding at a rate of 10-12% per year. Additive manufacturing is playing a key role in all three main types of prosthetic heart valves. This presentation will provide a brief summary of the major activities in this area of research, with specific focus on the work ongoing at Colorado State University in Colorado, USA.
EFFECT OF MILLING STRATEGY AND TOOL GEOMETRY ON CUTTING PERFORMANCE OF TITANIUM ALLOYS

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ABSTRACT

The growing demands on aerospace manufacturers to cut more difficult-to-machine materials require manufacturers to increase their machining capability. This involves a better understanding of the effects of milling strategies and tool geometries on cutting performance. Ti6Al4V is the most widely used titanium alloy in the aerospace industry due to its unique combination of properties. These properties are also responsible for making the alloy very challenging to machine. Therefore, its machining processes are generally associated with high manufacturing costs. The complex geometries of aerospace parts necessitate that a very large amount of the original material should be machined away. The continual demand to also increase the material removal rates in combination with the milling challenges of titanium alloys creates the need to improve the performance of the cutting process. Recent studies have shown that milling strategies and cutting geometries can have a significant effect on the resource efficiency and performance of the cutting process. These research experiments were divided into two phases. Firstly, the new constant engagement milling strategy was compared with a conventional approach. Thereafter, a component was milled with different cutting tool geometries. Cost savings of more than 40\% was realised by using a constant engagement angle milling strategy. A reduction of 38\% in machining time was achieved by utilizing tools with a land on the rake side of the cutting edge. These incremental improvements made it possible to enhance the overall performance of the cutting process.
VOXELJET: 1ST YEAR OF RAPID CASTING SOLUTIONS IN SOUTHAFRICA

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ABSTRACT

In 2013 Vaal University of Technology invested in two Voxeljet industrial additive manufacturing systems. The systems run on PMMA and silica sand powders, both well suited for investment and sand casting applications.

During the first year of operation, successful case studies with local foundries showed benefits ranging from tool-less, cost and time efficient production, improved accuracy / mould assembly and others.

Design for manufacturing allows foundries a totally new approach of new mould designs resulting in improved casting quality using this technology.
IMPLEMENTING THE SOUTH AFRICAN ADDITIVE MANUFACTURING TECHNOLOGY ROADMAP - THE ROLE OF AN ADDITIVE MANUFACTURING CENTRE OF COMPETENCE

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ABSTRACT

Following on a resolution of the Annual General Meeting of RAPDASA in 2012 expressing the need for a national Additive Manufacturing Roadmap, the South African Department of Science and Technology commissioned the development of a South African Additive Manufacturing Technology Roadmap in the second half of 2013. Such a technology development route was intended to guide South African players in identifying economic opportunities, addressing technology gaps, focusing development programmes and informing investment decisions that would eventually enable local companies and industry sectors to become global leaders in selected areas of additive manufacturing. With this technology roadmap available, the challenge remains for South Africa to decide on the most efficient implementation approach towards ensuring maximum impact in the shortest possible time. This paper introduces the concept of a national Additive Manufacturing Centre of Competence as primary implementation vehicle for the South African Additive Manufacturing Technology Roadmap. The support of the current leading players in additive manufacturing in the country for such a centre of competence is shared and their key roles are indicated. A summary of the investments that the leading players have already made in the focus areas of the Additive Manufacturing Centre of Competence over the past two decades is given as confirmation of their commitment towards the advancement of the additive manufacturing technology. An exposition is given of how the Additive Manufacturing Centre of Competence could indeed become the primary initiative for achieving the agreed national goals on additive manufacturing. Consequently, this leads to the conclusion that investment by public and private institutions in an Additive Manufacturing Centre of Competence would be the next step towards ensuring South Africa’s continued progress in the field.
THE QUALITY MANAGEMENT SYSTEM REQUIRED TO MANAGE “THE ADVANCED MANUFACTURING PRECINCT” AT VUT

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ABSTRACT

The Advanced Manufacturing Precinct’s (AMP’s) scope at VUT is driven by Innovation, Engineering, Technology Development and Commercialisation. As managed within the VUT, it spans the complete value chain starting with market research, concept formulation, product development, design and optimisation, and ending with manufacturing, testing and commercialisation. Everything starts and is governed by the simple philosophy of a high-level design input, followed by a fast-tracked product development approach, by means of Direct Digital Manufacturing methods (also known as Rapid Prototyping, 3D Printing or Additive Manufacturing), with unique product development technology platforms available – some developed by the VUT team.

Current AMP strategies are focused on Innovation, IP Protection, Technology Transfer, Commercialisation, Incubation and Enterprise Development. A good Quality Management System (QMS) is required to be able to clearly communicate the services of the Precinct as a whole that are accurate, economic and cost effective and conforms to the needs of all the different groups of customers. Implementation of a QMS takes time and resources and needs commitment from all staff members involved. It was decided to model a developmental integrated QMS to ensure buy-in and to address current and future needs of the Precinct. The QMS incorporates the ISO 9001:2008 requirements for commercial customers to be able to show predictable outcomes of processes that will feed into industrial product production lines. However the system also takes into account other conditions from public funders and Academia. Although this process is still underway two major lessons learnt has already been identified that are being addressed.

This paper will concentrate on the process followed to date and how the two problems:  
\(^1\)What should become a collection of business processes for AMP?  
\(^2\)Identifying the Customers of the AMP, are being addressed.
ADDITIVE MANUFACTURING OF PARTS FOR A SOUTH AFRICAN PROTOTYPE AIRCRAFT

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ABSTRACT

Aerosud is in the process of developing a new tandem aircraft which will be produced locally. This aircraft will be certified and used for military purposes. Even though additive manufacturing is still relatively new to the aviation industry, it was decided to use this process to create parts not only for the Environmental Control System, but also for a number of other applications in the aircraft. Parts included structural and non-structural parts and needed to conform to fire smoke and toxicity standards for interior aircraft parts. Additive manufacturing is ideal because it gives the designer the opportunity to design one complex part instead of a combination of simple parts. In the end this is more compact, it saves weight, reduces design time and costs which are all critical for aircraft design. Fused deposition modeling (FDM) was the process of choice after it was compared to selective laser sintering (SLS). Due to the setup of the project, parts were manufactured as soon as the design was complete. With SLS, the only way to manufacture parts cost-effectively is to do so in large batches. FDM on the other hand allows parts to be manufactured individually, at no extra cost. Ultem 9085 is a material which is already aviation certified and was the selected material for the project. In total there were 88 parts manufactured, of which 61 are currently on the aircraft. Some parts were scrapped mostly due to design changes and not due to defect. Some of the problems encountered during this process were: Support material that had to be removed in hard to reach places; the implications of the machine stopping in the middle of a build; vibrations on tall, narrow parts and holes in the parts creating unnecessary support material. Other challenges were how to produce accurate cylinders, countersink holes and to rivet FDM parts to other structures. To minimize these problems and challenges a new “design mind set” had to be developed. To further develop this mind set, a better understanding of the process and mechanical properties are required. Manufacture orientation and mechanical property tests will be one way to gain a better understanding.
FUTURE SCENARIOS TO 2025 PLUS FOR THE WESTERN CAPE TOOL, DIE AND MOULD INDUSTRY

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ABSTRACT

The Tool, Die and Mould industry plays a major role in the growth and existence of the manufacturing sector. In South Africa, the manufacturing sector is essential for economic growth of the country as it is the second biggest Gross Domestic Product contributor. Unfortunately, the enabler of the manufacturing sector, the Tool, Die and Mould industry was seen to be gradually dying with close to retirement toolmakers, outdated technologies and unskilled young toolmakers.

As the declining Tool, Die and Mould industry largely negatively affected the economic growth of South Africa, the government saw an urgent need to intervene. For the past ten years, government played a huge role in skills development, technology transfer through national and international collaborations and SMME development especially aimed at the Tool, Die and Mould making industry. These interventions aimed at developing the TDM industry and making it globally competitive.

The purpose of this paper is to assess the growth of the Tool, Die and Mould industry in the past ten years, mainly in the Western Cape and shape its future by using strategic dialogues which will lead to different possible scenarios of the industry to 2025. The scenario development gives the Western Cape Tool, Die and Mould industry an opportunity to see different possible growth paths. This will also identify contingency plans to respond purposefully to global changes in the Tool, Die and Mould industry; reveal its opportunities in the Western Cape aiming at global competitiveness.
FROM STELLENBOSCH
Exit STIAS and turn left into Marais Road, followed by an immediate right into Van Riebeeck Road. Take a left in Drostdy Road and a right at the second intersection into Dorp Street. Left at the traffic light of the R44 crossing and follow the road for 8 km. Turn left into Annandale Road and follow this road until you reach the turn off to your right for Hidden Valley Wines, approximately 1km from the R44. Follow the road pass Ernie Else Wines to the end where you’ll find the main entrance to Hidden Valley Wines. The path is marked with directions to Hidden Valley Wines.

PHYSICAL ADDRESS
Overture at Hidden Valley Wines, T4 Route, Off Annandale Road, R44, Stellenbosch

GPS COORDINATES
34.02° 07’ 55” S, 18.85° 39’ 28” E

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