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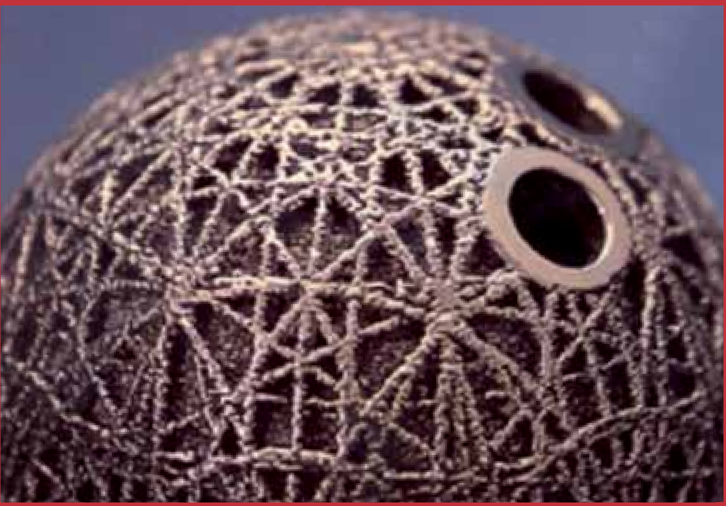
RAPID MANUFACTURING
Techniques and Applications for the Australian Manufacturing Industry



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ISS Institute/TAFE Fellowship

Fellowship funded by Skills Victoria,
Department of Innovation,
Industry and Regional Development,
Victorian Government

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Executive Summary

Rapid Manufacturing (RM) is the latest approach for the manufacture of small quantities or complex individual items such as prostheses and hip replacement components. RM is a process that employs additive fabrication technology to produce end-use items, directly from Computer Aided Design (CAD) data. Components are manufactured without moulding, casting or machining. The impact of RM is far-reaching and the opportunities and advantages are extensive. Implications are significant for the medical field which is ready to take advantage of developments in the use of RM.

The Fellowship provided a valuable opportunity to undertake a comprehensive investigation of skills and processes required to maximise the potential of RM within the Australian context. Key areas of study included:

- RM processes used for specific products by specific industry sectors including aspects of design, innovation and quality, from concept to prototyping and manufacture.
- The implementation of basic to post apprenticeship options for high level specialisations into vocational education and training programs. Learning pathways for gaining knowledge regarding the use of RM processing skills to produce parts suitable for immediate use to be a key area of investigation.
- Possibilities for producing tailored and individualised components to accommodate individual requirements.

The Fellowship enabled the Fellow to attend the 'Third International Rapid Manufacturing Conference' at Loughborough University, followed by participation in a master class offered as part of the conference program. A number of industry visits to discuss operational processes associated with RM were also arranged.

Barnett believes that RM is one of the most exciting emerging technologies available to global industry today and that it will be regarded by many as the next industrial revolution.

RM uses 3D CAD data to directly 'print' or 'grow' parts in a variety of polymeric, metallic, ceramic and organic materials. RM allows companies to manufacture ever more complex and optimised components at very low unit volumes.

The Fellow suggests that with the ability of designers in Australia to be innovative, RM could enable a change for manufacturers that will ultimately result in manufacturing being maintained in high wage economies with high level of sophistication. Production would be given to the countries of lowest manufacturing cost (suggested by Barnett, based on observations arising from this Fellowship).

The advantages that RM brings are already being commercially exploited by organisations such as Holden, Ford, Boeing, Cochlear, Royal Perth Hospital, Rolls Royce and many others are seeking to gain commercial advantage in today's markets.

Following an overview of the international experience, a series of findings are made regarding a range of initiatives and activities that the Fellow identifies as central to knowledge transfer and furthering opportunities for the RM industry. The report concludes with a series of recommendations for government bodies, professional associations, education and training providers, industry, and the community.

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Abbreviations and Acronyms

3D	Three dimensional
3DP	3D Printing
AMRC	Advanced Manufacturing Research Centre with Boeing
CAD	Computer Aided Design/Drafting
CAM	Computer Aided Machining
CAMTEC	Centre for the Computer Aided Manufacturing Technology
CECA	Centre of Excellence of Customised Assembles
CAT or CT	Computerised Axial Tomography
CNC	Computer Numerical Control
DMLS	Direct Metal Laser Sintering
DMLM	Direct Metal Laser Melting
EBM	Electron Beam Melting
EDM	Electrical Discharge Machining
FDM	Fused Deposition Modelling
FEA	Finite Element Analysis
IMMPETUS	The Institute for Microstructural and Mechanical Process Engineering: The University of Sheffield
IMPC	Innovative Metals Processing Centre
LOM	Laminated Object Manufacturing
MJM	Multi Jet Modelling
MRI	Magnetic Resonance Imaging
MSA	Manufacturing Skills Australia
OH&S	Occupational Health and Safety
OPM	Object Polyjet Modelling
RM	Rapid Manufacturing
RMRG	Rapid Manufacturing Research Group
RP	Rapid Prototyping

Abbreviations and Acronyms

SAE	Society of Automotive Engineers
SLA	Sterolithography
SLM	Selective Laser Melting
SLS	Selective Lasing Sintering
STL	Stereolithography file format
TAFE	Technical and Further Education
TIG	Tungsten Inert Gas
VET	Vocational Education and Training system
WMIT	Western Metropolitan Institute of TAFE
WYSIWYG	What you see is what you get

Acknowledgments

Kenneth Barnett would like to thank the following individuals and organisations who gave generously of their time and their expertise to assist, advise and guide him throughout the Fellowship program.

Awarding Body - International Specialised Skills Institute (ISS Institute)

We know that Australia's economic future is reliant upon high level skills and knowledge, underpinned by design and innovation.

The International Specialised Skills Institute Inc (ISS Institute) is an independent, national organisation, which has a record of nearly twenty years of working with Australian industry and commerce to gain best-in-the-world skills and experience in traditional and leading-edge technology, design, innovation and management. The Institute has worked extensively with Government and non-Government organisations, firms, industry bodies, professional associations and education and training institutions.

The Patron in Chief is Sir James Gobbo AC, CVO. The ISS Institute Board of Management is Chaired by Noel Waite AO. The Board comprises Franco Fiorentini, John Iacovangelo, Lady Primrose Potter AC and David Wittner.

Through its CEO, Carolynne Bourne AM, the ISS Institute identifies and researches skill deficiencies and then meets the deficiency needs through its *Overseas Skill Acquisition Plan (Fellowship Program),* its education and training activities, professional development events and consultancy services.

Under the Overseas Skill Acquisition Plan (Fellowship Program) Australians travel overseas or international experts travel to Australia. Participants then pass on what they have learnt through reports, education and training activities such as workshops, conferences, lectures, forums, seminars and events, therein ensuring that for each Fellowship undertaken many benefit.

As an outcome of its work, ISS Institute has gained a deep understanding of the nature and scope of a number of issues. Four clearly defined economic forces have emerged out of our nearly twenty years of research. The drivers have arisen out of research that has been induced rather than deduced and innovative, practical solutions created - it is about thinking and working differently.

A Global Perspective. 'Skills Deficiencies' + 'Skills Shortages'

Skill deficiencies address future needs. Skill shortages replicate the past and are focused on immediate needs.

Skill deficiency is where a demand for labour has not been recognised and where accredited courses are not available through Australian higher education institutions. This demand is met where skills and knowledge are acquired on-the-job, gleaned from published material, or from working and/or study overseas. This is the focus of the work of ISS Institute.

There may be individuals or firms that have these capabilities. However, individuals in the main do not share their capabilities, but rather keep the IP to themselves; and over time they retire and pass way. Firms likewise come and go. If Australia is to create, build and sustain Industries, knowledge/skills/understandings must be accessible trans-generationally through nationally accredited courses and not be reliant on individuals.

Our international competitors have these capabilities as well as the education and training infrastructure to underpin them.

Addressing skill shortages, however, is merely delivering more of what we already know and can do to meet current market demands. Australia needs to address the ***dual*** challenge – skill deficiencies and skill shortages.

Acknowledgments

Identifying and closing skills deficiencies is vital to long-term economic prospects in order to sustain sectors that are at risk of disappearing, not being developed or leaving our shores to be taken up by our competitors. The only prudent option is to achieve a high skill, high value-added economy in order to build a significant future in the local and international marketplace.

The Trades

The ISS Institute views the trades as the backbone of our economy. Yet, they are often unseen and, in the main, have no direct voice as to issues which are in their domain of expertise. The trades are equal, but different to professions.

The ISS Institute has the way forward through its 'Master Artisan Framework for Excellence. A New Model for Skilling the Trades', December 2004. The Federal Government, DEEWR commissioned ISS Institute to write an Australian Master Artisan School, Feasibility Plan.

In 2006, ISS Institute Inc. set up a new ISS advisory body, the **Trades Advisory Council.** Members are Ivan Deveson AO; Martin Ferguson AM, MP, Federal Labor Member for Batman; Geoff Masters, CEO, Australian Council of Educational Research; Simon McKeon, Executive Chairman, Macquarie Bank, Melbourne Office; Richard Pratt, Chairman, Visy Industries and Julius Roe, National President Australian Manufacturing Workers' Union.

Think and Work in an Holistic Approach along the Supply Chain - Collaboration and Communication

Our experience has shown that most perceive that lack of skills is the principal factor related to quality and productivity. We believe that attitudes are often the constraint to turning ideas into product and a successful business; the ability to think laterally, to work and communicate across disciplines and industry sectors, to be able to take risks and think outside the familiar, to share – to turn competitors into partners.

Australia needs to change to thinking and working holistically along the entire Supply Chain; to collaborate and communicate across industries and occupations - designers with master artisans, trades men and women, Government agencies, manufacturers, engineers, farmers, retailers, suppliers to name a few in the Chain.

'Design' has to be seen as more than 'Art' discipline – it is a fundamental economic and business tool for the 21st Century

Design is crucial to the economic future of our nation. Australia needs to understand and learn the value of design, the benefits of good design and for it to become part of everyday language, decision making and choice.

Design is as important to the child exploring the possibilities of the world, as it is to the architect developing new concepts, and as it is to the electrician placing power points or the furniture designer working with a cabinet-maker and manufacturer. As such, design is vested in every member of our community and touches every aspect of our lives.

Our holistic approach takes us to working across occupations and industry sectors and building bridges along the way. The result has been highly effective in the creation of new business, the development of existing business and the return of lost skills and knowledge to our workforce, thus creating jobs - whereby individuals gain; industry and business gain; the Australian community gains economically, educationally and culturally.

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Fellowship Sponsor

The Victorian Government, Skills Victoria is responsible for the administration and coordination of programs for the provision of training and further education, adult community education and employment services in Victoria and is a valued sponsor of the ISS Institute. Barnett would like to thank them for providing funding support for this Fellowship.

Supporters

In Australia

- John Cawley, Associate Director, Victoria University
- Coralie Morrisey, Executive Director, Victoria University
- Daniel Thompson, Sales Manager, ARRK Australia & New Zealand, Melbourne
- Fred Campion, Sales Director, Camplex Pty Ltd, NSW
- Ben Draffin, Machining Department Co-ordinator, Drew Price Engineering Pty Ltd
- Peter Schriener, Teacher, Swinburne University
- Arnold Rowntree, '05 ISS Institute/Italy (Veneto) Overseas Fellow, and ATTCA Project Officer, Swinburne University[1]
- Nick Juniper, MEM05 Training Package Developer, Manufacturing Skills Australia
- Paul Kennett, Manufacturing and Engineering Skills Advisory Council

In the United Kingdom

- Dr Phil Reeves, Managing Director, Econolyst Ltd, Derbyshire
- Dr Chris Sutcliffe, Rapid and Micro Manufacturing Research, Department of Engineering, The University of Liverpool, Liverpool
- Dr Robin Weston, Sales Engineer, MCP Tooling Technologies Limited, Stone, Staffordshire
- Professor Richard Hague, Rapid Manufacturing Research Group, Wolfson School of Mechanical and Manufacturing Engineering, Loughborough University, Loughborough
- Dr Gregg Gibbon, Senior Research Fellow, WMG Innovative Solutions, International Automotive Research Centre, The University of Warwick, Warwick
- Dr Trevor Illston and Dr Gordon Green, Materials Solutions, Rapid Development to Meet Environmental Challenges, University of Birmingham, Birmingham
- Dr Max Ruffo, Additive Manufacturing and IMPC Manager, The University of Sheffield, Sheffield
- Daniel Eyers BEng (Hons) MPhil MIET, Research Associate, Innovative Manufacturing Research Centre, Cardiff Business School, Cardiff University, Wales

[1] Arnold Rowntree is an '05 ISS Institute/Italy (Veneto) Overseas Fellow who was sponsored by the International Division, Victorian Government. He is employed at Swinburne University, TAFE. His Fellowship program was undertaken in the Veneto Region, then he travelled from Italy to Germany and the USA. Rowntree's Fellowship focus was on skill deficiencies related to engineering, design, advanced manufacturing and the skills training associated with Powder Injection Moulding (PIM), materials selection and quality assurance. Contact ISS Institute for a copy of his report.

Acknowledgments

In Germany

- Andreas Tulaj Hofman, Regional Sales Manager, Concept Laser GmbH, Innovation Group Germany
- Keith Murry, Sales and Marketing Manager (EMEA), Powders Group Sandvik, Osprey Limited

In Belgium

- Johan Puawels, Director of Sales, Materialise Software Group

In Spain

- Pol Palouzie, ASCAMM Foundation Technology Centre, Barcelona

Australian Organisations Impacted by the Fellowship Program

The following industry, government and education sectors have been identified by the Fellow as potentially benefiting from the introduction of RM technology.

Aerospace Engineering

1. Aerospace landing gear components
2. Gas turbine combustion chamber
3. Gas turbine blades

Manufacturing Engineering

1. Tool making for the injection moulding industry
2. Tools for jigs and fixtures
3. Internal coolant flow design for injection moulding tools
4. Surface coating of injection moulding tools
5. Prototypes for mobile phones
6. Gear design
7. Nozzle design for water jets
8. Fuel pump designs to save weight
9. Impeller design pumps
10. Pipe and/or wire clamps
11. Metal sieves for filtering microscopic particles
12. Fan housing design
13. Back of LCD monitors and electrical appliances
14. Completed assembled parts of one material
15. Planetary gear design
16. Honeycomb crumple zone manufacture
17. Manufacture of cores for castings

Art and Design

1. Individually designed sports shoes with special compression sole
2. One-off jewellery
3. Model ships

Acknowledgments

4. Action figures
5. Models for the film industry such as dinosaurs
6. Trophies
7. Figurine design
8. Chess set pieces
9. Pendants
10. Garments and accessories such as buttons and buckles
11. Musical instrument manufacture
12. Bottle and can opener manufacture
13. Prototype design games controllers
14. Corporate gifts
15. Packaging design and prototyping
16. Homewares such as vases and bowls

Manufacture of the Following Automotive Components

1. Motor vehicle bumper bars
2. Race car gear boxes
3. Exhaust manifold
4. Water pump design
5. Thermostat housing
6. Motorcycle dash board and supports
7. Prototypes of door handles
8. Special name plates
9. Air ducting inside the vehicle
10. Wheel design

Building and Construction

1. Reverse engineering and manufacture of decorative ceiling roses
2. Reconstruction of decorative columns
3. Prototypes for items such as handles and taps
4. Door handle design

Furniture

1. Functional and decorative items such as tables and chairs, lamp shades and bases, closing and hinging devices

Education and Training

1. Research into heat exchanger shapes
2. Research in design for industry
3. Research into materials design
4. In the TAFE sector, training of operators for industry. In the university sector, educating industrial and product designers in this technology and engineering for researching developments.

Acknowledgments

Medical

1. Hip replacement implant manufacture in titanium or stainless steel
2. Knee replacements
3. Skull part replacements
4. Ear implants
5. Denture caps
6. Jaw bone replacement
7. Using CT scan replicate bone parts
8. Disassemble body parts for training

Government

Manufacturing Skills Australia has identified some of the benefits of RM and is now proposing to develop new competencies for the MEM07 Engineering Training Package. This will involve the creation of skills and knowledge competencies that would be directly related to:

1. The creation of drawings in Computer Aided Drafting (CAD) using solid models
2. The transfer of this solid model into an STL file that can be interpreted by the RM machinery
3. The funding through grants to training organisations for:
   a) The creation of the physical model using RM machinery
   b) The preparation of the model for display and use in the expected environment.

Industry

The manufacturing engineering organisations involved in research and development have just begun to look at RM as a manufacturing tool, rather than as a rapid method to manufacture a prototype. Organisations that will benefit from RM technology will only be limited by a lack of individual innovation and imagination.

1. Car manufacturers currently use the traditional process for the manufacture and production of their vehicles. For research and development these companies have taken up plastic RM process for rapid prototyping of a component for size and shape comparisons. In the car racing industry where the quantities are small and the changes are large, RM is used regularly to efficiently develop a new part. This has the effect of making the car lighter and, therefore, more competitive.
2. Drew Price Engineering Pty Ltd, in Noble Park, Victoria, uses the RM process to make parts for prototype racing go-carts. If the design is successful it is then generally manufactured using traditional methods, because of the cost difference in large quantity manufacturing.
3. Cochlear Limited, manufacturer of hearing implants, have been making parts using RM technology for a number of years, but still have difficulty with the this process due to a lack of experienced designers. This difficulty is further exacerbated by limitations to availability and type of powders used in the manufacturing process, such as nano powder.
4. Camplex Pty Ltd is a supplier of CAD/CAM equipment and software. It has been suggested that they would like to be partners with Vocational Education and Training (VET), in the forming of a company that would be a commercial business and a learning establishment for the manufacture of parts using RM.

Acknowledgments

Professional Associations

The VET senate has registered its interest in RM with support for the Fellow to undertake this study into RM.

Engineers Australia will be consulted as to how the RM material will be introduced into the training environment and into the engineering industries.

TAFE

Educational institutions have been slow to take up RM. It was noted during the visits to organisations in the United Kingdom that their main aim in the use of RM was for research and development, not training on the equipment.

The University of Liverpool was teaching the concepts of RM to the Bachelor of Engineering students and applying this to the manufacture of parts for the Society of Automotive engineers (SAE) race car. The University of Liverpool's entry contained a number of parts made with the RM process and was a good learning experience.

Community

The savings that can be made when RM is employed will be significant. Production of fully functional units will allow testing and modification to be completed much quicker. Passing on savings to the consumer will be easier with lower costs for research and development.

Other

RM allows the part to be made without creating expensive tools and dies. This could be particularly appealing to the Art and Design Industries particularly related to industrial and product design such as jewellery.

Modifications to the design in the CAD model and then a creation of a completely new design will be possible, especially in the use of precious metals such as gold and silver. Whilst it will be relatively expensive to manufacture jewellery in the RM mode, the waste is anticipated to be minimal and the after-work on a finished part limited only to surface polishing.

About the Fellow

Name: Kenneth Barnett

Employment: Teacher/Program Manager, Victoria University

Qualifications

- Fitter and Turner, Technicians Certificate, Education Department, 1977
- Higher National Certificate in Engineering, Preston Polytechnic, Lancashire, UK, 1982
- Teacher's Certificate, University of Manchester, UK, 1983
- Certificate in Workplace Leadership, Western Melbourne Institute of TAFE, 1998
- Certificate IV in Workplace Assessor and Training, Western Melbourne Institute of TAFE, 1998
- Graduate Certificate in Leadership Development of Education and Training Managers, The Chair Academy, 1999
- Graduate Certificate in Tertiary Education, Victoria University, 2000

Professional Associations/Memberships

- Victorian VET Senate

Barnett has been the Program Manager at Victoria University, Sunshine Campus since 2003. He has operated and trained teachers and students on three dimensional (3D) Computer Aided design (CAD) drafting, 3D scanning, 3D printing, and virtual reality presentations. The Fellow has a vision to ensure that the introduction of RM into the curriculum for the training of designers and operators occurs as soon as possible.

Recent activities include:

- The implementation of Occupational Health and Safety (OH&S) systems for machine operation, handling of materials in the workshop and supervision of the OH&S representative. Barnett project managed a four week program for Computer Numerical Control (CNC) teachers from Chongqing Industry Polytechnic College in China, covering how to teach competency based training of CNC.
- The Fellow is also the Project Manager for International Training Australia. Barnett has developed an equipment specification list for the new Malaysian Institute of Marine Engineering Technology, and the creation of layout plans using AutoCAD of the entire site to show process planning and access for the delivery of materials and the water, power requirements in the buildings.

Earlier experience was gained in management and industry responsibilities:

- Program Manager, Victoria University of Technology, Melbourne/Training Co-ordinator, Vehicle Industry Certificate, General Motors Holden
- Western Melbourne Institute of TAFE (WMIT) Teacher, Sunshine Campus – teaching Vehicle Industry Certificate at Toyota Australia
- Philips Australia – Major Domestic Appliances, Maintenance Engineer
- Food Machinery Corporation Australia, Apprentice Fitter and Turner.

About the Fellow

Previous overseas experience:

- British Aerospace, Contract Design Draftsman
- WMIT (formally Footscray College of TAFE), Teacher
- Blackpool and Fylde College of Further and Higher Education, Lancashire, England, Lecturer Mechanical Engineering Craft Studies
- Solid Waste Engineering Ltd, Lancashire, England, Design Draftsman
- Jonas Woodhead Ltd, Lancashire, England, Design Draftsman

Barnett believes that it is essential to instil into the designers and engineers of today an enthusiasm and a passion for design; an enthusiasm that enables innovative designs to be developed. One way to encourage this is to start with students in courses such as the Bachelor and Advanced Diploma of Engineering. These students have already decided on a career direction and by initiating design problems that can be seen to be improved with the use of RM (either as a prototype or as an immediate use item), the future of RM within the Australian Manufacturing Industry will provide an important skill set to the industry.

Aim of the Fellowship

The aim of this Fellowship was to undertake a comprehensive investigation of skills and processes required to maximise the potential of RM within the Australian context as result of identifying the skills deficiencies existing in Australia.

Key areas of study included:

- Identification of RM processes used for specific products by specific industry sectors including aspects of design, innovation and quality, from concept to prototyping and manufacture.
- Implementation of basic to post apprenticeship options for high level specialisations into vocational education and training programs. Learning pathways for gaining the skills and knowledge regarding the use of RM processing skills to produce parts suitable for immediate use to be a key area of investigation.
- Identification of possibilities for producing tailored and individualised components to accommodate individual requirements. Particularly useful in the medical field where a part is to be designed and manufactured to match an individual's CTC scan data where deformation has occurred due to accident or birth defect.
- Introduction into the Australian Metal and Engineering Training Package (MEM05) of competencies that reflect the skills and knowledge required for successful operation of RM machines.
- Introduction into the Victorian qualification of Advanced Diploma of Engineering Technology (Mechanical) of competencies that reflect the skills and knowledge required for successful design using RM components.

The Australian Context

A Brief Description of the Industry

The Fellow's early career and experience was through the apprenticeship system and he identifies with the traditional approach to tool making. Once a part is designed the tool maker is required to make it. Depending on the size of the tool (anywhere from one kilogram to several hundred kilograms), the complexity and size will directly affect the number of tool makers involved and the time it will take to manufacture. The complexity will also determine if it will be necessary to manufacture jigs and fixtures to hold the tool while machining to the required size.

Rapid Prototyping (RP) manufacture has been around since the late 1980s and has been used in fabrication, usually stereo lithography, utilising a weaker material than is required for the final actual part. The part produced has been very brittle and is only a model or prototype. RP takes virtual designs from Computer Aided Design (CAD) modelling software, transforms them into thin, horizontal cross-sections and then creates each cross-section in physical space, one after the other until the model is finished. It is a 'what you see is what you get' (WYSIWYG) process where the virtual model and the physical model are almost identical; a similar approach is used with a Computer Axial Tomography (CAT or CT) scan of the human body to produce an image on a computer.

RM parts are starting to be used for a much wider range of applications and are also used to manufacture production quality parts in relatively small numbers. Designers are producing designs of parts and testing the part prior to production.

Since the earliest days of RP, experts have envisioned the application of the technology in the manufacturing process, with the focus of this vision on the initial cost and time savings that are realised when tooling is eliminated. Slashing hundreds of thousands of dollars and months from a product launch are significant benefits to manufacturers in all RM related industries. However, the relative impact pales in comparison to the wide-ranging advantages that exist when RM is implemented. A reason for the slow take up of RM is the material and laser development.

The Department of Medical Engineering and Physics at Royal Perth Hospital is a leader in the medical field with custom manufacture of acetabular cages for hip replacement. The cages are designed using the information gathered from the CT scan and Magnetic Resonance Imaging (MRI) images of the patient. The image can be manipulated and a 3D CAD model is developed. The model is then used directly in the RM technique of Selective Laser Melting (SLM) to make the prosthesis.

Case Study: ARRK Australia

Head Office – Melbourne, 5 Lynch Street, Hawthorn VIC 3122 Australia

'Impellers' are used in a pump for mixing or stirring highly corrosive chemical or to move liquid or powders along a pipe. They are made to rotate with very little clearance on the outside. The majority of impellers are made from cast iron or die cast aluminium or bronze. However in the chemical and process industries impellers are often made of ceramic material. Ceramic material has the advantage of not reacting with the solution being processed and not affecting the finished product.

Right – ceramic impeller designed and manufactured by ARRK Australia

SWOT Analysis

The following SWOT analysis (strengths, weaknesses, opportunities and threats) provides a useful summary the current situation and the implications of addressing, or not addressing, the need for ongoing skills associated with the development of RM processes within Australia.

Strengths

- High level of technology already available worldwide
- Highly motivated designers in Australia that do not know of RM
- Low competition as not many people understand RM in Australia
- Educational system is already available for training; it just requires the addition of RM equipment
- Economy of Australia is relatively stable compared to many other countries
- Industry is very keen to implement new technology for plant and equipment when savings are shown to be available
- Progressive management allows the introduction of new processes
- Durable long lasting product
- Visually satisfying product
- Healthy and safe product
- MSA (Manufacturing Skills Australia) interested in adding RM to Training Package
- Capable manufacturing base willing to invest in new RM technology
- Capability to export
- Course design for universities and TAFE will allow necessary changes to be made

Weaknesses

- Limited operatives (very specialised equipment for handling metal powder) for production
- Limited tradespeople capable to design product
- Limited operatives for the operation of equipment
- No training for tradespeople in the TAFE system in RM
- Training Package currently has no RM skills component
- Some powders may be carcinogenic
- 3D printing not known
- Very limited clean room knowledge
- Surgical grade materials unknown
- Handling of titanium powder, stainless steel powder and nano powders unknown
- Sintered laser process unknown
- Powder freeze drying to kill bacteria before or after sintering
- There is no research into freeze drying at this stage for the sterilisation of parts
- Identification as to what type of process is best suited to RM of the part (SLS, EDM or DMLS)
- Need to get more industry interest for MSA to write new competencies for RM

The Australian Context

Opportunities

- Up-skill existing tradespeople
- Design in Australia and made locally – no transport requirements and no time lost. Alternatively the equipment does not have to be manufactured in the same country as it is designed (eg could be designed in Germany and built in Australia)
- Resources manufacture of powder materials for production of parts
- Partnerships with industry:
  - Cochlear Limited
  - Swinburne TAFE
  - School of Biomedical and Health Sciences, Victoria University
  - Others
- Parts produced for commercial sales
- Designs made by training organisations can be used to approve a part for industry before actual production
- Students study RM with the aim to be able to immediately apply their skills and knowledge to industry
- Build capabilities of the Victoria University engineering department, to gain recognition within the marketplace as a leader in this field
- New designs for products such as spectacle frames can be made quickly, ready for use
- Train prosthetists/orthotists to use scans, eg scans of the leg, to determine the inside dimension of the bone for a special prosthesis[2]
- Research into freeze drying of powder sintered materials and parts to kill bacteria.

These are specific:

- The design and manufacture of tools for operating on people and animals
- Designing of tools and parts for the Building Industry
- Design and manufacture models for the Australian Film Industry eg dinosaurs
- Design and manufacture of parts for the Australian Marine Industry
- Consumer choice of RM prototype or manufacture
- Need to identify further skill deficiencies that cannot be learnt in Australia.

Threats

- Asian competitors supply lower product standard and price
- Possibility of price reduction due to world economy and markets
- Cost:
  - of initial machine
  - to buy powder
  - of CAD design
  - to produce parts
  - to store powder
  - of manufacture

[2] A prosthetist/orthotist is an Allied Health Professional who designs, measures, fabricates and fits prostheses and orthoses.

- Waste of material while learning
- Lack of marketing to students about the opportunities arising from undertaking courses which include RM
- Difficulty of sterilisation may be greater when an infection occurs because of porosity in the implanted RM part
- Size of component limited to machine capacity
- Industry is slow to recognise new technology
- Change in government's policy on trade and manufacturing

Identifying the Skills Deficiencies

Definition – Skill Deficiencies

As already established, skill deficiencies address future needs. Skill shortages replicate the past and are focused on immediate needs.

Skill deficiency is where a demand for labour has not been recognised and where accredited courses are not available through Australian higher education institutions. This demand is met where skills and knowledge are acquired on-the-job, gleaned from published material, or from working and/or study overseas.

Identifying and Defining the Skill Deficiencies

As part of the process of researching skills required to produce components using RM, it became apparent to Barnett that there have been a significant advances in both skills and knowledge. RM skills requirements are constantly evolving at both a macro and micro level and new techniques are uncovered. In this scenario, it is essential that Australia maximises opportunities within this sector of the manufacturing industry. The information below provides a general overview of skills deficiencies followed by a more specific breakdown of areas identified for investigation.

Central to any analysis regarding skills and RM processes are macro issues including:

- Knowledge of the different materials that are available, the most suitable method of producing a component with the desired properties and the limitations of the parts that are made using the layer manufacturing process.
- The ability to sterilise a part before, during and after manufacture; and what is the effect of autoclaving a plastic part?
- Skills required for operating RM machines in a learning environment.
- OH&S issues in storing aluminium and titanium powders in an education environment.
- The skill to select the desired process, whether it be SLA, SLS, LOM or EBM.
- The ongoing research into transfer files, or software, that can handle the CAD data direct and not convert to an STL file type.

As established previously, the range of potential applications for RM technology is diverse. Opportunities are cross-sectoral as evidenced below, with the images in the next chapter demonstrating medical and aero applications.

Skill deficiencies at a micro level were addressed as part of the international experience. The following issues and deficiencies were identified for specific investigation.

- International usage of the process is growing. There seems to be a lot of interest worldwide with particular pockets of expertise in North America, and in Europe with Germany and the United Kingdom being leaders in the research of both materials and processes.
- The design of parts, taking into account the different manufacturing process, where there is no need to make a part big and heavy due to the manufacturing operation.
- The removal of the part from the build platform and the necessary heat treatment and other process to finish the part.

Identifying the Skills Deficiencies

- The selection of a material that meets all the specifications, metals, precious metals, plastics and ceramic powders.
- Identification of the types of plastic that are suitable for use in RM (thermosetting plastics) and whether the material can be sterilised (further investigation required with freeze drying).
- The use of Sintered Laser System (SLS) for RM to enable various materials to be sintered.
- Nano powders handling, storage and use processes are unknown. Are there OH&S problems with this type of material? Are they absorbed through gloves and then the skin? What fire risk is created when using nano powders? Are all powders flammable when in a nano state?
- The selection of RM processes that fulfil the current requirements is a difficult choice, as the equipment is expensive and specialised as the list at the end of the micro level skills deficiencies shows, eg which is the preferred process, Electrical Beam Machining (EBM) or Selected Laser Sintering (SLS)?
- The Fellow believes that new designers will have a better success rate creating a 3D model in CAD, as they will not have pre-conceived manufacturing ideas and, therefore, will not make parts stronger than is absolutely necessary.

  What are the limits of manufacture that usually relate to the design of the machine, and what are factors to be considered beyond physical size? How small can a part be made using the nano powders and the CAD system? How small can the laser beam be directed at nano powder to effectively sinter the part.
- Creating STL files, which the RM machines utilise.
- What is a better file format that will allow the creation of a curved surface without the creating flat spots that might have to be finished by polishing the surface after removal from the RM machine?
- Reverse engineering, ie scanning a 3D image of an object and then using that data to modify and create new shapes and objects using data from a CT or CAT.
- Converting the STL file into a 3D CAD object, modifying the object and then creating a new STL file for use by the RM process.
- Operation of the RM machine for the manufacture of a specific design.

  Victoria University has at present two SD300 3D printers from Solidimensional Limited in the UK, that use the solid sheet material. The shape is cut out at each layer and then another layer is glued on to that in order to build up the part. There are fewer OH&S issues with this equipment for educational purposes, but there is also less detail of part that can be produced.
- The skill to identify the appropriate process of manufacture. From current research it has been found that while SLS is very good, it is costly and dangerous. A better method could be the use of EBM.

- Some of the various processes to be considered are listed below:

Prototyping Technologies	**Base Materials**
Selective Laser Sintering (SLS)	Thermoplastics
Selective Laser Melting (SLM)	Thermoplastics, ceramics, metals and titanium and aluminium alloys
Fused Deposition Modelling (FDM)	Thermoplastics, eutectic metals
Stereo Lithography (SLA)	Photopolymer
Multi Jet Modelling (MJM)	Photopolymer
Laminated Object Manufacturing (LOM)	Paper
Electron Beam Melting (EBM)	Titanium alloys, carbon steels, aluminium
3D Printing (3DP)	Various materials
Object Polyjet Modelling (OPM)	Photopolymer
Electrical Discharge Machining (EDM)	Carbon steels

The International Experience

The overseas Fellowship program comprised three main activities, outlined as follows.

Rapid Manufacturing Conference

Loughborough University, UK

This conference on RM included an exhibition of RM machine manufacturing companies, material suppliers and RM service organisations. The conference proved to be most worthwhile in terms of addressing the aims and objectives of the Fellowship. It was particularly useful to attend the conference prior to undertaking industry visits as the opportunity to mix with delegates allowed the Fellow to organise additional industry visits to local manufacturing sites within the United Kingdom.

Key Findings

1) The advantages identified by Barnett before the overseas program were for the surgical replacement industry, where a patient would be able to receive a prosthetic that was designed and customised to meet each patient's anatomical requirements. This could take into account the density of the bone structure and or brittleness of the bones.

This to some extent has been put aside with recommendations from Dr Chris Sutcliff from the University of Liverpool and Paolo Gennaro from ProtoCast Sri Novara, Italy. They both stated in their respective presentations at the conference that the process is still too new and that it is not a cost effective way to make standard items. In addition, there is no agreed documentation for the material and/or the RM process for the manufacture of prosthetics.

This leaves the decision to the surgeon with the difficulty of implanting a prosthesis with a material that cannot be confirmed with guaranteed certainty that it will not break or be defective. At present the material, nor the process can be guaranteed.

However, Barnett believes given the current research and development, it will happen in the not too distant future. There is a considerable amount of research being undertaken by various organisations such as the Royal Perth Hospital, the University of Liverpool and the ProtoCast Sri Novara, Italy into the materials and the processes.

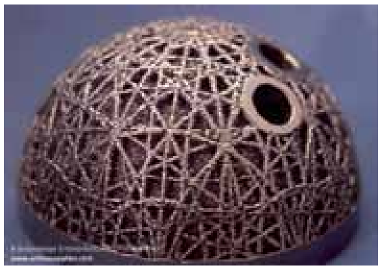
The Royal Perth Hospital is a leader in the research and use of implanting RM prosthetics. This hospital was the first in the world to perform an operation to implant a new hip into a patient using this technology. They are closely watched by the RM engineers at the University of Liverpool, Liverpool Hospital and the rest of the world.

A hip replacement requires the implanting of two main parts into the body of the recipient. The acetabular shell is implanted into the hip and the stem is implanted into the leg.

In the design of acetabular shell, the latest trend is to make a honeycomb on the surface to facilitate bone growth to support the socket. An example of this is a solid acetabular cup using EBM process.

The International Experience

Special design of acetabular cup to suit a damaged hip. Parts displayed by Dr Phil Reeves, Managing Director Econolyst Ltd, Derbyshire, UK.

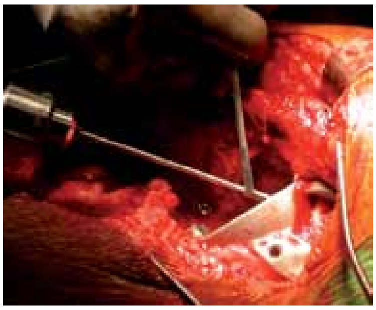


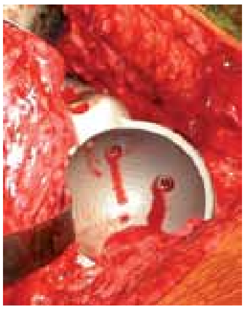
Controlled porosity lattice acetabular cup (Arcam EBM system manufactured by Medical Modelling LLC, Denver)

Another acetabular cup in place in the hip, showing correct alignment (Bioengineering Bulletin Department of Medical Engineering and Physics, Royal Perth Hospital)

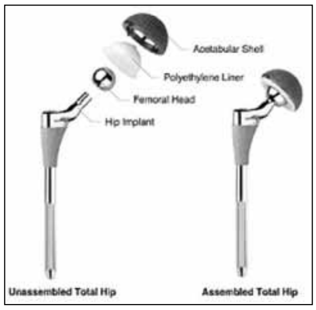
Close up showing how neat a fit can be achieved using the CT scan data to help in the design phase (Bulletin Department of Medical Engineering and Physics, Royal Perth Hospital)

There is a very small market for the design and manufacture of implants and it was suggested that the traditional methods be used for the common parts in hip or knee replacements. RM should only be used when a specific design is required to suit extenuating circumstances. As shown in the example below, the significant damage to the pelvic bone meant that this operation would not have been possible without the unique design of the acetabular cup.





Example of special design of hip Implant designed to suit an individual with a crushed pelvis (Royal Perth Hospital)

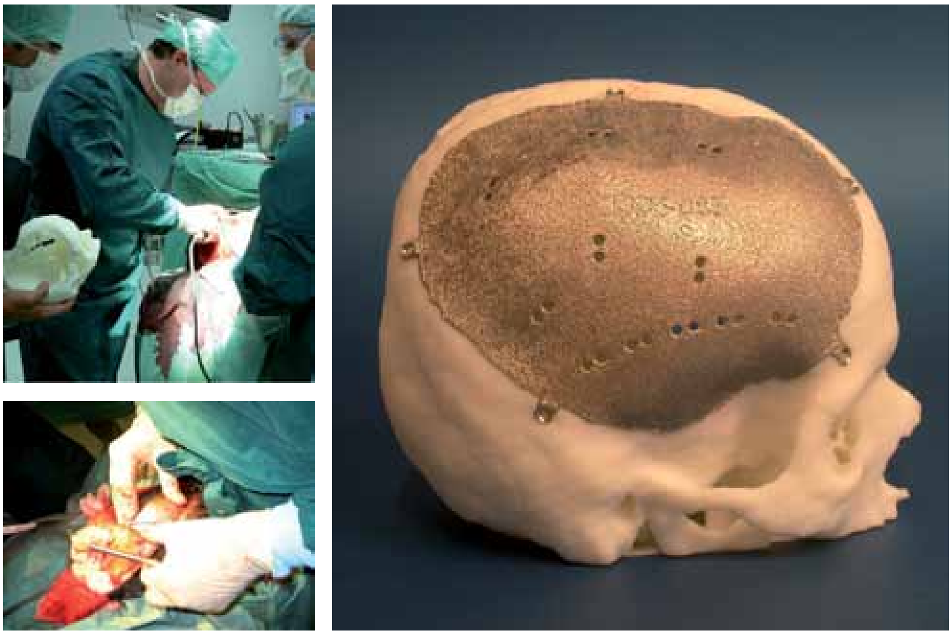


The parts required for a full hip replacement

The International Experience

For an implant to be effective it is required to maintain the strength and integrity of its material after implanting into the body and not to exude unwanted material or absorb material from the body.

The EBM process produces a claimed 100% dense material (Arcam EBM system presentation, 12/07/2007) and this would make the material suitable for medical implants. The example below is a shaped titanium plate for skull reconstruction surgery.



Skull reconstruction using Arcam EBM Rapid Manufacturing to fabricate an implant. The implant size is 180x130x5 mm, and it was designed by Instrument Development Engineering & Evaluation (IDEE) at Maastricht University in the Netherlands. The implant was built by Fruth Innovative Technologien. Build time: 12 hours.

2) RM processes used for specific products by specific industry sectors including aspects of design, innovation and quality, from concept to prototyping and manufacture.

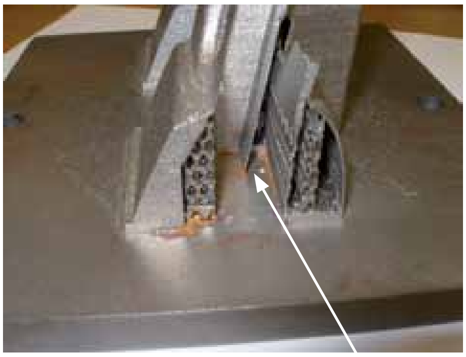
As part of the industry display at the Loughborough conference centre, Stuart Jackson from EOS Systems confirmed the notion that the most important aspect of RM is the process of design. A concept idea needs to be formed and from the concept, the required material needs to be identified. A solution can then be designed to satisfy all the criteria defining the problem using one of the many RM processes.

The left hand picture on the following page shows the product as it was removed from the RM machine and then washed to remove excess powder. The white plastic component is complete and ready for its designed use (note the very fine detail that is achievable with RM as the part is not put under any load during manufacture).

The metal part in the picture on the right on the following page shows how a (support) structure has to be made inside the designed part to support overhanging shapes. This support needs to be removed by machining or by mechanical methods.

The International Experience

A plastic part with support (Magics software)



A metal part welded to the base plate showing the internal support material produced using Magics software

Once the part has been built it is left to cool for approximately the same time as it took to build before it can be removed from the machine. It is then heat treated to normalise the part and remove internal stress before it is cut from the base plate; all the support material is now removed by cutting, breaking or machining. A metal part has very large internal stress and if heat treatment to normalise the part is not carried out then it will distort completely out of shape once it has been cut from the base plate build platform.

3) Further design issues were discussed in a paper presented by Dr Neil Hopkinson, Dr Chris Sutcliff and Paolo Gennaro

Dr Neil Hopkinson from Loughborough University presented a paper about high speed sintering (a process of linking atoms to retain desired shape). Dr Hopkinson's proposal is that an entire layer of the build platform could be processed at the same time. This would yield a component in a very short time compared to the spot melting that is used now. A much larger laser would be needed and a method of directing the melting beam developed to only pick up on the desired shape for that layer.

This will greatly reduce the time required to make a part. Paolo Gennaro presented a paper on the cost of RM which confirmed Dr Hopkinson's research. An acetabular cup for human implant with the American Society for Testing and Materials (ASTM) has an F75 standard specificaton for a cobalt, chrome and molybdenun (CoCrM7) material with a net structure on the surface to facilitate bone growth. This process should not take more than 15 hours, but at present takes 38 hours. This time taken to produce the part makes the RM process non-competitive with conventional process. The only way RM will be competitive is for custom, or prototype parts to be made which will sell at a higher price.

The manufacture of standard implantable devices by RM was discussed by Dr Chris Sutcliff from the University of Liverpool.

Dr Sutcliff stated that in order to produce parts for a prosthesis it is a requirement to be able to confirm the particle size of the powder that was used. This is just one of the requirements for the implanting of medical devices. The production of a very fine mesh on the surface of the component is produced by a software program that was developed by the University of Liverpool to enable them to compete with traditional methods.

They started to make a mesh using the standard CAD software. 'Pro Engineer' (the CAD software recommended), is available for education use and up to 500 licences are available for £2,000 per year. It was found that the file became very large because of the data required for each entity, and there are a lot of entities when the scale of elements is in the order of 100micron.

Dr Sutcliff stated in his presentation that it was not financially viable to produce parts for prosthetics with RM and that traditional methods are more than capable of making the standard parts for the medical industry. Using the system from MCP Tooling Technologies Limited in the UK, the manufacture of parts using medical grade titanium is achieved. The machine operates in an enclosed argon gas environment to prevent the ingress of foreign material, and this also prevents the spontaneous combustion of the aluminium and titanium powders. The design of the surface of the implant is made porous to encourage bone growth into the implant and secure the implant to the bone structure. The University of Liverpool developed their own software program to develop the algorithm to produce a mesh on the surface.

Over a period of 10 years or more bone tends to recede away from metal parts and this allows the implant to become loose. Other materials such as plastic and ceramics have been considered and are currently the subject of ongoing research to determine their suitability for use as implants.

There is an exception for individual parts where a person has been in an accident or has a deformity. The part can be grown in the machine from the scan data generated in CT scans. This data is input to the CAD software and then a part designed to solve the particular medical problem. This would be a custom designed result eg a person able to walk rather than face a lifetime in a wheelchair.

The training that takes place at the University of Liverpool is for all Bachelor of Engineering students to take a CAD unit and pass it before progressing to second year. All staff have been trained in Pro Engineer and for a full week the students undertake to learn the software. The student is marked on the CAD file that is produced and on the work done in the week long session. The assessment is based on the CAD file, the CNC program that is run by an operator and the production of an STL file.

4) The use of RM as a means of manufacture for the jewellery industry was explored by one of the presenters and shown to have a lot of promise in that each item designed could be made slightly different from the previous one with only a small change in the design and all made in the one build.

The Conference Master Class

This master class was was facilitated by Dr Phil Reeves, Managing Director, Econolyst Ltd, UK. This provided an excellent opportunity to address some of the specific skills deficiencies in terms of design of parts and the necessity for special handling of the powdered materials.

Basic principles of RM were addressed, followed by an exploration of current and emerging technologies and real-life RM case studies. Design benefits of RM were discussed along with material considerations of the technology, business implications and Supply Chain issues surrounding RM. Opportunities were provided to apply the skills learnt in a workshop session that required participants to resolve a specific design problem for Bentley (car manufacturers).

The International Experience

Key Findings

The master class was held on the third day of the Rapid Manufacturing Conference and was well facilitated by Dr Reeves. Specific RM skills required in the design of parts and the necessity for special handling of the powdered materials were explained to participants.

The RM master class covered the basic principles of RM before introducing current and emerging technologies and real-life RM case studies. The class looked at the design benefits of RM and the material considerations of the technology, before considering the business implications and Supply Chain issues surrounding RM. Master class participants applied the skills learnt in the workshop session and then applied the newfound knowledge back into the workplace with a specific design problem from Bentley.

It is difficult to find a course in the UK that includes RM as a feature of the course. There is mention of Computer Aided Engineering in many courses, particularly in the post graduate, Bachelor or Master of Engineering. This will involve research into the manufacturing processes and the various materials that might be developed. There is no specific training in the design and use of the current technology. The Fellow proposes this training should be in place in Australia.

There are tremendous opportunities for the design of organic shapes to solve a variety of problems. The design process is completely different to conventional design. The necessity to include work-holding structures into the design and the need to have straight holes is not a requirement.

Metal parts are built on a base plate and the support material is also built on the base plate and in any large holes. This support material is removed after heat treatment.

Plastic parts are lifted out of the cake of powder after the build and the support material is washed off with chemicals or high pressure. The part is finished and ready for use. The material left in the machine can be recycled once or twice before disposal. As the plastic part is sintered, heat is generated and the material in close proximity to the laser beam is also partially sintered. The material will not be able to make fine product when it is partially sintered.

One of the participants of the master class brought up the problem of one of the cooling radiators for the Bentley car. The cooling radiator needed to fit into the wheel arch above the wheel and to take into account the curve of the bonnet. Many suggestions were given and a number of RM design ideas would be trialled to see which was the most effective. The cost of manufacture for the Bentley was considered and it was pointed out that the Bentley is made for an individual, one does not go and buy one of the shelf; it is made to suit the requirements of the customer.

Industry and Site Visits

A number of industry and site visits were arranged to address specific operational processes including skills deficiencies associated with RM.

Meetings were held in the UK with the following individuals who are actively involved in the RM industry:

- **Professor Richard Hague**, Rapid Manufacturing Research Group
  Wolfson School of Mechanical and Manufacturing Engineering, Loughborough University
- **Dr Robin Weston**, MCP Tooling Technologies Limited
  Whitebridge Park, UK
- **Dr Chris J Sutcliffe**, Rapid and Micro Manufacturing Research
  Department of Engineering, University of Liverpool
- **Dr Trevor Illston and Dr Gordon Green**, Materials Solutions
  University of Birmingham Campus, Edgebaston
- **Dr Gregg Gibbon**, WMG Innovative Solutions.
  International Automotive Research Centre, University of Warwick
- **Dr Max Ruffo**, Additive Manufacturing and IMPC Manager
  University of Sheffield

Key Findings

Loughborough University

The Rapid Manufacturing Conference was run by Professor Richard Hague, Rapid Manufacturing Research Group (RMRG) within the Wolfson School of Mechanical and Manufacturing Engineering at Loughborough University.

Research is based around a family of technologies collectively known as Rapid Prototyping (RP). All RP processes work by adding layers of material to build up three dimensional objects. Loughborough University has been conducting research into a number of aspects of the technology and has successfully run an international conference for the previous two years (2006 and 2007) with global knowledge transfer. Some examples of their innovative design ideas and concepts are shown in the following pictures.

- A dress design and material construction
- State of the art design and manufacture overnight of material and part together.

The concept of clothes being made using RM, Designed and manufactured at Loughborough University as a research project.

The International Experience

- The multiple gear component showing the ability of RM to make complex assembled engineering components requiring no further work after removal from the machine.
- The design of energy absorbing compression pads and applying that to the design of body armour.

An Impossible design that cannot easily be made in a traditional method. If one gear is rotated, they all rotate. Designed and manufactured at Loughborough University as a research project.

Simulated body armour with spring loaded panels. Designed and manufactured at Loughborough University as a research project.

The design of parts for the automotive industry as in these examples of air ducting and dash boards. The process would not be economical for the production of hundreds of parts, however, it is utilised by the more expensive car manufactures, such as Bentley, to customise each car for the individual owner.

The design of portable radios and action figures. The parts can be made in a couple of hours. If the design is not right, it can be changed and another made.

The University of Liverpool

Dr Chris Sutcliff from the University of Liverpool reported that in order to produce parts for prostheses it is a requirement to be able to confirm the particle size of the powder that is used. This is just one of the requirements for the implanting of medical devices. The production of a very fine mesh on the surface of the component is produced by a software program that was developed by the University of Liverpool to enable them to compete with traditional methods.

Dr Sutcliff stated that it was not financially viable to produce parts with RM and that traditional methods were more than capable of making the prosthesis parts.

The one exception is for individual parts where there has been an accident or a deformity and the part can be grown in the machine from the scan data generated in CT scans. This data is then input to the CAD software and then a part designed to solve the problem.

The Fellow feels that the designer needs to think outside the box and disregard the traditional approaches to design applied by current manufacturing. These traditional approaches make allowance for holding the component while machining, drilling round straight holes or for casting allowances. In the design of an RM part none of these considerations are necessary. With the lifting of restrictions in the design process a RM component can be made much lighter and still have the required mechanical properties as a traditional manufactured part. The internal structure can follow the desired shape, not the shape of a cutting tool, and it does not need to have material for holding or great machining allowances. Some clean up might be necessary as the surface finish is quite rough, depending on the RM process and the axis to be considered. For most components a polished surface finish is not required, leaving the RM part in its native form.

The University of Birmingham
Dr Trevor Illston and Dr Gordon Green, Materials Solutions

Materials Solutions is a commercial enterprise, initially set up by the University of Birmingham. The academic side of the University has not taken the opportunity to use the equipment or the extensive expertise of the Materials Solutions staff. Materials Solutions make RM products for the Aerospace Industry, with cobalt chrome, stainless steel and titanium being the three main metals used.

Dr Illston stated that the properties that they are able to achieve are better than a cast material, but not as good as a forged part. After the heat treatment process the material exhibits a better ultimate tensile strength, but lower elongation.

The materials are required to withstand high temperature creep, and to have a part that can be tested often to destruction to prove that the design is appropriate, or that it can be improved with additional CAD work. Once a design is completed manufacturing would start, often in a traditional manufacturing method as the RM process is still not fully accepted by the Aerospace Industry.

The equipment suppliers sometimes supply a support building software that they feel best suits their RM equipment. Magics Rapid Prototyping software (from Materialise UK) will give excellent solutions to the support of overhanging parts of the design. There are limitations to the automatic process and with experience modifications can be made to improve the design.

The International Experience

Most of the powdered materials used have some form of element that will be harmful to the health of operators in the manufacturing room, and the use of all the recommended OH&S safety equipment should be mandated. The use of airborne testing for particles of harmful material and the testing of oxygen levels in the room as the RM equipment operates in an inert atmosphere (usually of argon), should also be mandated. If there is not enough oxygen in the room it is unsafe for the operators.

The operators are issued with a gravimetric meter that measures the intake of particles over an eight-hour period.

A full risk assessment needs to be completed for the handling of powder material. Systems need to be put in place and checks made on a monthly basis. The use of un-powdered nitrile gloves is to be used whenever handling powdered material.

In a commercial enterprise, as in the case of Materials Solutions, they will not jeopardise the build of one customer with that of another customer, so all builds are for one customer and parts are nested only if the customer agrees or asks to nest parts to reduce cost.

When setting up a room for RM, the room needs to be within the acceptable temperature range for the equipment and a system is required that incorporates a down draft to remove any dust that is flushed into the atmosphere. The current set ups in most of the organisations do not include down draft systems.

RM has only been in operation since 2006 and developments to handling and use are continuously being updated.

A view of an EOS machine as it sinters the powder at Materials Solutions, the University of Birmingham

As a component is being built the laser can be seen as the bright area in the picture on the previous page. The laser is melting a spot of metal powder on a layer. Each layer takes up to three minutes to complete, depending on complexity. It takes a large number of layers to be processed to make a component of any significant size as each layer is approximately 40 micrometres thick. The build phase for each component can take many hours, followed by the same length of time for the cool down phase. To heat treat and finally remove the metal part from the build platform will also take time.

Typical build platform of an EOS SLS RM machine, Materials Solutions, the University of Birmingham

The centre build platform moves down the 'Z' axis with each layer being spread over the surface. The laser melts the powder in the shape of the part, and the process is repeated until the part is fully grown.

Metal powders have special requirements in that titanium and aluminium have a very low flash point and may spontaneously combust if the conditions are not controlled carefully. The use of an RM machine with a capacity to operate within a vacuum is recommended.

The surface finish on metal parts is rough and needs to be finished for most applications. This is achieved during the machining process, or by polishing. The surface finish required for medical purposes is a rough finish to allow for the growth of bone into the cavities to hold the prosthesis in place.

When the component part is created in the RM machine the entire build platform is covered in powder to a depth at least equal to the depth of the component. Additional powder that forms each layer and has not been sintered makes the shape of a rectangular block.

The International Experience

In a RM machine for plastic, the component is lifted out of the excess powder and then high pressure washed to remove the small particles from crevices and internal cavities. The part is then ready for use.

In a metal forming RM machine the entire build platform is removed, all loose powder is removed by brush and then by washing. The part and the build platform are then heat treated to remove internal stress then the part is mechanically removed from the platform. Further processing by machining or polishing is then performed as required

All metal parts need to be heat treated after cooling down within the RM machine in order to remove the internal stresses built up during the sintering process.

A typical heat treatment furnace as used by the University of Birmingham

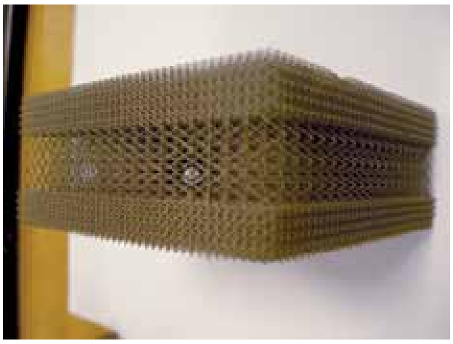
MCP Tooling Technologies
Industry visit and meeting with Dr Robin Weston

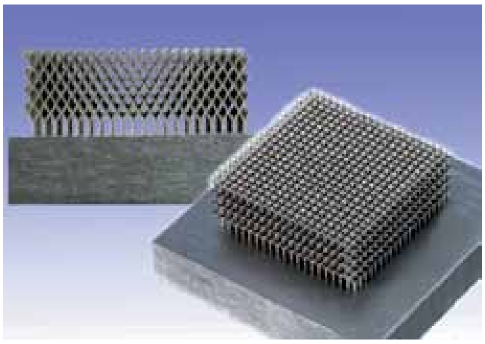
A series of questions were drafted before leaving Australia. After the conference the specific nature of some of the questions were answered by the presenters at the conference or at the one day master class with Dr Reeves.

Dr Weston stated at the conference that there are approximately 150 different plastic materials already available for use in the RM process. He believes that two of the most useful materials are nylon 6, and 8040 soft polypropylene. Research is required to determine the appropriate sterilising method for a particular material, eg whether thermo setting or thermo plastic can be safely sterilised, and the applicability of freeze drying, autoclaving and/or UV sterilisation.

The process of sterilisation of titanium and stainless steel powders is no different to the sterilisation of normal metal parts that are used in operations on the human body. These are autoclaved, a common process for the material to be heated to elevated temperatures over a predetermined period of time to ensure appropriate sterilisation. Another method is to use gamma ray treatment.

Using RM it is possible to design and manufacture shapes that are near impossible to machine, as in the mesh (shown in the following photograph) that is being tested for its absorbency of energy for use in a bullet proof vest.





Mesh designed and manufactured at MCP Tooling Technologies Ltd

The mesh can be made any shape to suit the contours of the part being protected. A CT or CAT scan would provide the actual shape for an individual fit. Each rectangle has a mesh supporting it underneath.

The process of laser sintering completely melts the grains of powder at the point of application of the laser. This leaves the particles as a whole unit and the joining will only occur on the small contact areas that are made with other atoms. With laser melting the grains of powder are completely melted to form an approximately 99.6% dense solid. The small percentage remaining is caused by foreign material that is normally present in any melting and solidification process.

One of the confusions with this process is that the naming of the process – 'Selected Laser Sintering' (SLS) is not correct, as the process is actually melting – the metal parts are fully melted in the normal process. It should actually be called Selective Laser Melting (SLM).

Boeing and The University of Sheffield Consortium Research Group

The Innovative Metals Processing Centre (IMPC) is a joint venture between the Advanced Manufacturing Research Centre with Boeing (AMRC) and the Institute for Microstructural and Mechanical Process Engineering: The University of Sheffield (IMMPETUS).

In 2001 Boeing and the University of Sheffield started a combined research group for materials and CNC processes. They started with five people and gradually a reputation was gained in being able to reduce the machining process by up to 90%. This reduction was noted by other industries who then asked to join the group. Rolls Royce joined and became a full partner. Today original equipment manufacturers of CNC machinery have been keen to place their machines in the Boeing and Sheffield research group to allow for the development of specifications for new or updated machines.

The International Experience

There were three companies formed from this consortium: Centre of Excellence of Customised Assembles (CECA), Centre for the Computer Aided Manufacturing Technology (CAMTEC) and IMPC. The business model is now more of a consultative section rather than an educational facility. The Board consists of tier one partners who contribute £100,000.00 per year and tier two partners who contribute £30,000.00 per year. The results gained enable the partners to utilise new materials and to enhance the RM manufacturing and CNC machining capabilities.

The part that achieved such a dramatic reduction in CNC machining time was a titanium part for the throat mechanism that holds the turbine blades for the jet engine. The development of a new tool to facilitate the machining was completed and tested.

IMPC is the additive layer manufacturing part of the company. This includes the CNC, RM and Tungsten Inert Gas (TIG) welding as a RM process. The addition of a TIG welder on a robot arm in an argon chamber allows the robot to weld onto itself and builds parts on a metal base. Ian Todd is the metallurgist who set up IMPC to add value to the materials research for Boeing and Rolls Royce and has perfected the use of TIG welding to make parts ready for final machining without the use of jigs and fixtures.

The equipment used for RM includes an EOS 270, which is used for building stainless steel, bronze alloys and cobalt chrome parts, and any other metal other than titanium. The build is completed in an argon atmosphere, but at room temperature. Apart from the laser melted area which cools quickly and builds high stress in the part, heat treatment needs to be completed before the part can be removed from the build plate

In the opinion of Dr Max Ruffo, Additive Manufacturing and IMPC Manager, University of Sheffield, design by itself does not deliver the final product as the material and the process of manufacture must also be taken into account. The different processes have very different characteristics.

Further research has produced the following findings:

Arcam Industries is a Sweden-based manufacturer of EBM. The Arcam machine is used for the building of titanium parts because it is operated inside a vacuum. The vacuum is needed for the explosive nature of titanium powder.

Another advantage of the Arcam process is that the part does not need to be heat treated before it can be used. The Arcam chamber is heated to a high temperature and the build process is completed at this high temperature. When finished the part is allowed to cool slowly and, therefore, stresses reduce as it cools. The time taken to cool is similar to the build time.

The Arcam RM process, which is EBM, is seen as a more manufacturing-ready process. The EOS machine needs to be heat treated before removal from the build plate or the built up internal stresses will distort the shape. The internal stress is such that the part can pull itself away from the build plate before completion of build, which often causes the wiper blade to crash into the bent part and damage the surface.

Both machines have considerable ongoing costs, with the Arcam machine requiring a new electron element every 40 hours of operation, and the EOS machine requiring regular changing of filters and wiper blades. The other machine is from Concept, which is ‘manufacturing ready’ and proven in the design and manufacture of tooling.

The manufacturing of parts for the Aerospace Industry is a very exacting process and all details of the material and the process need to be documented. When a part is produced from laser powdered material the composition of the material will be slightly different depending on the position on the build platform.

The rocket engine impeller (in the photo below) made using stainless steel powder would be used for testing purposes only.

Rocket engine impeller made from Ti6Al4V ELI, weighing 2.5kg. Build time was 16 hours plus machining.

Photo of an aircraft landing gear component (courtesy of Camplex and the Arcam EBM system)

The design of the landing gear component above would be made for testing purposes using the RM Arcam system. The design would eventually be used for production parts.

The Aerospace Industry is not yet ready to put the RM component into a production aircraft. However, the use of RM parts for testing of design is a rapidly growing business as it saves a considerable amount of time compared to using conventional processes. It was suggested by Dr Trevor Illston that the ongoing cost of £7.00 per hour is not unrealistic for the machining of metal parts. This is to allow for the filters to be replaced and the wiper blades that need replacing on a regular basis.

Boeing have not taken to the idea of using a RM mesh in the structural parts as there is no data to show the properties of the structure are repeatable. There is also no technical data to allow calculations for the size of parts as is a normal part of the design process.

The University of Warwick

'Spherical Growth Manufacture' – a new technique being trialled at the University of Warwick by Adam T Clare and Carl Brancher.

Metal printing is possible with this technique, which will have major ramifications for the Electronics Industry with the direct printing of printed circuit boards (PCBs) including flexible PCBs, flat panel displays and 3D printed antennas, to name a few of the applications. The process uses direct deposition of molten conductive metals onto a suitable substrate, where the droplets are in the order of 0.005mm diameter and form metal conductive tracks on solidification.

The process involves the use of three print heads that are able to deposit UV curable materials, selectively next to each other on a moving substrate at a frequency of between 10 and 140 kHz. The stage moves at a speed up to 6m/s and the printing volume achieved can be in the range 0.5 to 4.0 ml/min.

This technique involves rotating the table at 30 RPM and then firing a jet of ink at the platen and layer by layer build up the part. This is very much in its infancy and patent applications have been submitted. The process is applicable to plastics and some ceramics and relies on the ambient heat to sinter the material.

The surface finish on metal parts is rough and needs to be finished for most applications. This is achieved in the machining process or by polishing. For example, the surface finish required for medical purposes is a rough finish to allow for the growth of bone into the cavities to hold the prosthesis in place. When the part is removed from the RM machine it is as a block with the X and Y dimensions as per the build plate. The height is determined by the height of the part.

All metal parts are built using an inert gas such as argon to prevent the powder from spontaneously combusting and to keep the oxygen away from the melting process and to not alter the material composition.

This adds another dimension to the operation of this equipment as to how much argon is in the atmosphere in the room and the oxygen level that is required for safety purposes. Gauges are used to warn of an unsafe atmosphere.

Manifold storage of inert gas for use in RM machine for metal parts at Material Solutions, the University of Birmingham

Bin hoist as used by the University of Warwick

The powder from which the part will be made is handled in the types of containers as shown in the above right photo.

The size of container is determined by the size capacity of the RM machine. The container shown in the photo is a large plastic powder bin.

When handling the powder, care must be taken to use all the OH&S equipment to prevent ingesting or powder absorbing through the skin. Care needs to be taken to keep the dust from entering the atmosphere.

A plastic part is removed from the build platform and placed in a sealed box called a glove box. A high pressure washer is used to remove the excess powder. The water is filtered and the powder is recycled once only. Care must be taken when using recycled material because in the process of melting the powder with a laser, the powder adjacent to the melt zone is also affected and starts to join together. This gives a larger powder size and so the surface finish and accuracy will not be as good as with new powder.

A glove box for high pressure washing of parts after removal from the RM Machine, used at the University of Warwick

The finished component is then shipped back to the designer. Analysis of the part can be undertaken to ascertain the effectiveness of the design. Is the part strong enough? Did the finite element analysis completed at the design stage show all the forces on the part? Did the designer choose the best material that would be suited to the requirements in use?

General Comments from Industry Visits

The following points were noted during the conference at Loughborough University, the master class in Rapid Manufacturing, and the industry visits.

1. Not every build is successful. This is particularly prevalent with metal parts as the spot melting of the component allows for internal stresses to build up. This can be powerful enough to lift the part away from the build platform and into the path of the wiper that is trying to lay down the next layer of powder. If this happens, the wiper (which is made of ceramic) is usually damaged. The process is then stopped as the subsequent layers will have a ridge of powder thicker than the rest of the layer and the component will not be made to the same accuracy as the previous layers. The whole build is ruined and all parts scrapped as each part is only partly made. It was stated by Dr Trevor Illston that the cost of consumables in the UK for a RM machine is in the order of £7.00 per hour.

2. Most powdered materials, whether metals or plastics, are dangerous to the health and safety of any person that comes in contact with them. The powdered material is very fine, usually in the order of 40 to 80 microns, and can be absorbed through the skin as well as inhaled. Some of the powders are carcinogenic and care needs to be taken to apply all the OH&S processes in handling these materials and reduce the incidence of dust in the atmosphere.

3. The handling of titanium materials is a concern to operators. The material by its nature of being fine powder is in a volatile state. Metal powders of titanium and aluminium have a low flash point and if not handled and stored correctly can spontaneously combust. The titanium powder should not be handled with bare skin as exposure to chromium and nickel fumes could cause dermatitis in some individuals. Columbium (niobium) has been reported to be a skin irritant and all powders should be treated as potentially hazardous and carcinogenic. The type of gloves to be used at all times should be nitrile gloves to prevent contamination of the RM powder being used.

4. Both the design of the part and the orientation of the CAD model in the RM machine have a strong influence on the stress build up that will take place and also on the resulting ultimate strength.

5. Stainless steel and cobalt chrome steels do not have the same dangers of spontaneously combusting, however the health issues are very similar as the powder is very small and can be inhaled or absorbed through the skin.

   A direct metal laser sintering machine for titanium and aluminium is built with double safety devices to prevent the powder from igniting in the machine. The entire build platform needs to be operated in an inert gas environment such as argon gas. This adds a considerable amount to the cost of a RM machine. In terms of operator safety, sensors need to be used in the room to make sure there is a healthy environment with an appropriate level of oxygen.

6. The RM process of laser sintering an area using one fixed layer, leaves the component in a variable state over the build platform. The laser beam is directed at a spot on the build platform. The position on the platform determines whether the spot is a circle or at the edges of the platform an ellipse. The ellipse will give different heat characteristics to the spot being melted compared to a circle and so the parts that are built have different strength characteristics in the X and Y directions than those in the Z direction. The Z direction is usually weaker than the X and Y directions.

Also the areas across the build platform, within each layer, have different characteristics. This is caused by the laser being centrally mounted and the beam is directed by using a combination of mirrors to aim the beam onto the different parts of the build platform. The further away from the middle of the laser means the beam striking the platform is in the shape of an ellipse. The ellipse shape means the heat in the ellipse is not consistent and not the same as in the circle that is formed towards the centre of the build. For larger build platforms two or more lasers are employed.

All the above points need to be considered when developing and delivering the RM training of technicians. Particular attention should be given to the OH&S issues of handling powdered materials.

New advances in technology are happening all the time, and RM processes are taking advantage of these changes to improve the production times and increase the available materials. This makes it quite difficult to amortise the cost of a RM machine over a reasonable production time as the RM machine may be made redundant by new processes and materials requiring different techniques to sinter or melt the powder.

One area where the RM process is achieving success is in the reconstruction of human or animal bones after they have been shattered. A replacement part is generated from data supplied by a CT scan and manipulated to achieve the desired result.

http://www.alternative-doctor.com/anti-ageing/heavy_metal.html
The above website, the 'Alternative Doctor Anti-Ageing Pages' explain the dangers of heavy metal poisoning. It is pointed out that most metals are toxic and require special transport and handling mechanisms within the body to keep them from harming the recipient. This needs to be considered when deciding whether to have a metal implant or not.

At the start of a RM installation it should be noted that all metal parts will need to be heat treated to normalise the part before removal from the build plate. The next process is to remove the part and the support structure from the build plate using wire cut or regular machining. The consumables in the process are filters and the wipers which come out at £7.00 per hour; this needs to be allowed for in the costing of the part. Wipers last approximately 40-60 hours of operation provided no crash takes place.

The Fellow found it interesting to note that in the UK there are no specific skill units for RM within the education and training system. This makes it hard to identify where training can be applied for technicians. In the research establishments there is no need for specific skill units be identified.

It is a firm belief of the Fellow that training needs to happen at the technician level, and that the traditional tool maker trade be exposed to RM in both prototyping and manufacturing modes.

Discussion with Dr Chris Sutcliff of the University of Liverpool showed that educational institutions have been slow to take up RM. Those institutions the Fellow visited had taken on RM and turned it into a consultancy business to help cover the running costs. However, the University of Liverpool was also teaching the concepts of RM to the Bachelor of Engineering students and applying this to the manufacture of parts for the SAE race car. The University of Liverpool's entry contained a number of parts made with the RM process. The entry was a good learning experience for those involved. It was noted during the visits to organisations in the United Kingdom that their main aim in the use of RM was for research and development, not training on the equipment.

Specific RM Issues Addressed Through the Fellowship

As established previously in the 'Identifying the Skills Deficiencies' chapter, specific skills deficiencies were identified for exploration at a micro level that were to be addressed as part of the international experience.

Types of plastics suitable for RM

During the conference it was stated that there are approximately 150 different plastic materials already available for use in the RM process. Dr Robin Weston believes that two of the most useful ones are nylon 6 and 8040 soft polypropylene.

Processes associated with the sterilisation of titanium and stainless steel powders

The process of sterilisation is no different to the sterilisation of normal metal parts that are used in operations on the human body. These undergo autoclave and gamma ray treatments. It is not uncommon for the material to be heated to elevated temperatures to sterilise the material.

If the process was sintering, then the particles are left as a whole unit and the joining will only occur on the small contact areas that are made with other atoms leaving cavities for contamination. With laser melting the grains of powder are completely melted to form an approximately 99.6% dense solid, the small percentage of waste is caused by foreign material that is normally present in any material.

One of the confusions with this process is naming the processes Selected Laser Sintering (SLS). This is not the correct term – the process should be called Selective Laser Melting (SLM) as the metal parts are fully melted in the normal process. Plastic parts are sintered as they do not require to be fully melted to allow cross linking of atoms to take place.

There is some research into the growing of new parts instead of trying to add foreign body into the area.

1. The design of parts, taking into account the different manufacturing processes.

Dr Chris Sutcliff stated in his presentation at the Rapid Manufacturing Conference at Loughborough in 2008 that Royal Perth Hospital has completed a number of RM prosthesis implants very successfully. Royal Perth Hospital had an acetabular cup specially made to suit a patient with a damaged pelvis. Hip replacement has become a very popular procedure, enabling people with advanced growth of arthritis to walk normally. The main benefit of RM comes in the speed with which a prosthesis can be designed and manufactured.

With the implanting of a prosthesis into bone within the human body, bone growth is encouraged to grow into special mesh structures designed into the surface, enabling the mesh to help lock the prosthesis into the correct position. In collaboration with Liverpool Hospital, Dr Sutcliff has been involved in the design of software that will generate the type of mesh that is most suitable for bone growth.

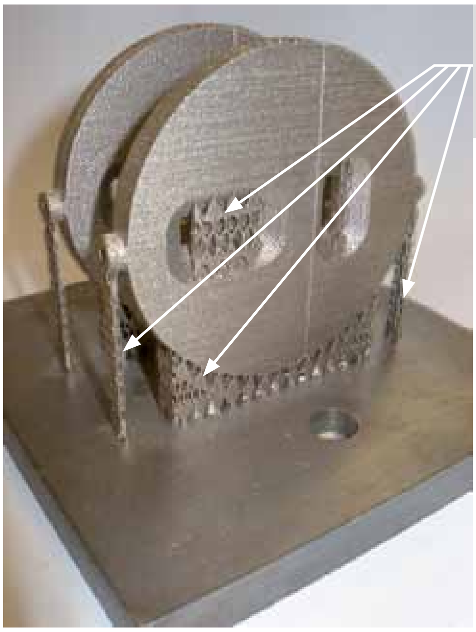
The procedure has approximately a ten (10) year serviceable period. Over this period of time bone recedes away from any metal part. The shrinking back of the bone loosens the prosthesis, and therefore the implant has to be replaced.

2. The characteristics of materials available for use in RM.

The mechanical properties are not as good as a wrought material, however the material is generally better than cast. Stainless steel is regarded as a soft material with limited mechanical properties and high corrosion resistance. Cobalt chrome is a superior material for mechanical properties and is used extensively in the RM process. Titanium has excellent strength for weight characteristics, hence its use in aircraft and medical implants.

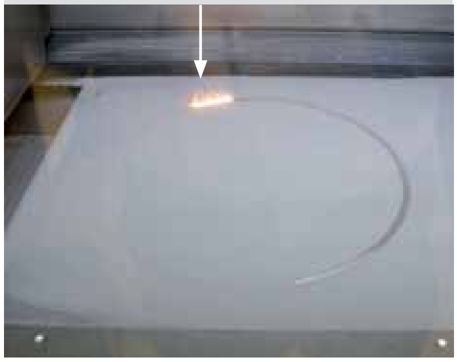
3. The factors related to the use of SLS for RM to enable various materials to be sintered.

As mentioned previously, with the processing of metal it is not a laser sintering, but laser melting as in Direct Metal Laser Melting (DMLM). This process will produce as near a 100% dense material as is possible. The design of the part has to include the build up of support material to support the building of overhanging shapes.



Support structure for overhanging elements fixed to base plate

Laser melting a circular build

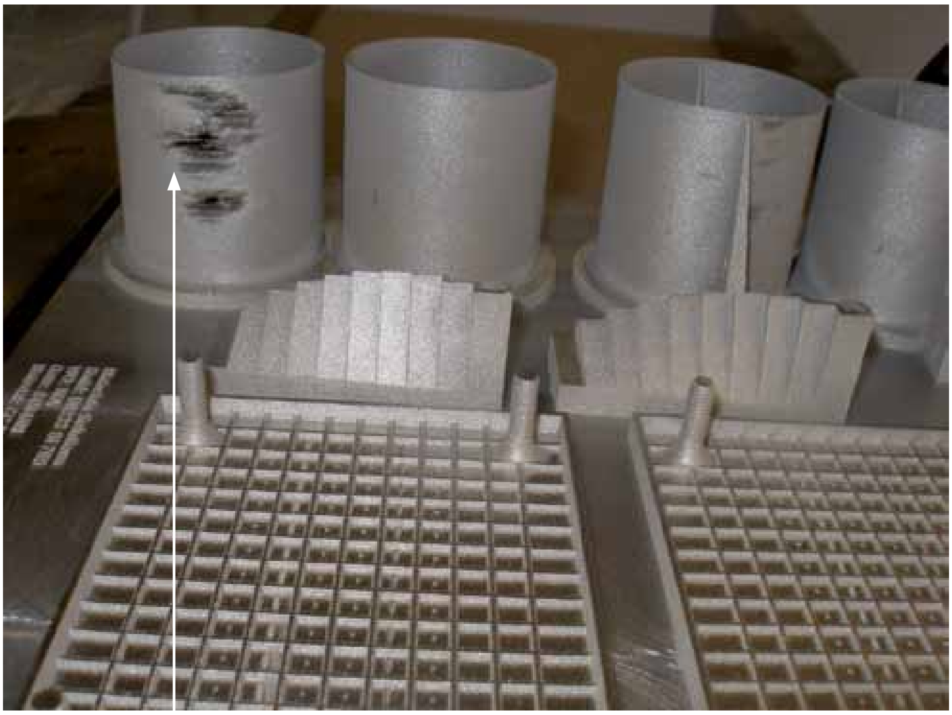


The part is not finished after the build has been completed as all metal parts need to be put through a heat treatment process to normalise the material to remove internal stresses. This is essential as the high energy RM process puts internal stresses that will try to lift the part off the build platform, caused by the spot heating onto points of each layer. Unfortunately, this normal movement of material during expansion and contraction can be too much for the RM equipment to handle.

The length of time and the temperature of the heat treatment process will depend on the material used, the geometrical shape and physical size of the part.

If the material is very thin and large, then the stresses can be greater than the support material can tolerate. This will cause the part to lift off the base plate requiring that the process be stopped before damaging the wiper blade used to add a fresh layer of material. The distance between the wiper blade and the product is approximately 20 micrometres, hence very little movement in the material from the base plate will cause a breakdown.

A similar effect can occur when building very thin walled sections. It is not difficult for the wiper to bend the thin wall and render the product useless.



Damage caused by wiper blade when placing the next layer (produced by an EOS machine at Materials Solutions)

When building a very fine structure like mesh some machines are better than others. An EOS style machine with a ceramic wiper will tend to break or bend the strands and so the build will not continue. This gives the EOS machine very high accuracy, but it is not able to build very fine parts. The MCP machine has a polymer wiper and so will be a bit more forgiving in the build. However, the spread of powder over the build platform is not as consistent as with a ceramic wiper, resulting in a compromise in accuracy. However, this compromise is still a very small figure as the build layer is between 20-40 micrometres thick.

The process of making a component is to complete a design in CAD and then use the propriety software, or one like Magics, to add in the support material where necessary so that the designed part can then be completely built.

All metal parts are made within an inert gas shield such as argon gas. This is to prevent the material becoming saturated with oxygen and reducing the material properties. The handling of the powder when sifting should also be done in an inert atmosphere to prevent the ingress of oxygen.

All the metal powders will have some form of harmful particles, eg nickel, aluminium or titanium. These powders need to be handled using all the recommended OH&S equipment, including powder free gloves and finally washing one's hands before eating. Washing of hands should be done even after handling the finished part as there might be a slight residue of powder left on the part.

4. EBM the desired method of melting powdered materials.

The problem with lasers is the time between usage. Lasers do not like long periods of inactivity; the more that a laser is used the better it will perform.

EBM is another method of melting the metal but this is done in a vacuum. This reduces the chance of explosion, but also makes the process less suitable to the melting of plastic materials.

The EBM process requires the replacement of the electron generator element after approximately 40 hours. With build times for average components of 15-20 hours, only two parts are produced before replacement is required.

A laser machine that is suitable for the melting of metals such as titanium could in theory melt and sinter plastic materials, however the power required would not easily be controlled at such a low level with a high powered laser.

5. Creating a 3D model in CAD and the limits of manufacture.

The shape of a part has to be considered in an entirely different manner than for conventional manufacture. The usual process is to start with a block of material, or possibly a casting, and then remove material until the desired component has been revealed. Machining allowances and allowances for straight round holes need to be applied.

However, with an additive process like RM the shape of the part should be as organic as possible to make the weight savings and to reduce stress. The part should be designed with enough material to withstand the forces whilst in operation and carry no more. All the internal cavities are designed with an area in mind and then the detailed shape is designed. It is much easier to produce a triangle in the shape of a pyramid, as the pyramid shape will generally not require any support material.

However, a cavity will require support material which needs to be removed after manufacture. The hole does not need to go in a straight line as it can easily conform to the shape of the component, as in an injection moulding die. The closer to the plastic injection moulded surface, the better the cooling and, therefore, the longer the life.

The initial step is to determine what process will be used to make the part. Once the process and the material is known then the design can be made. If the part is very complex and costly then a part may be made using RP to ascertain that the design requirements have been met.

6. Creating Stereolithography (STL) file format files and possible alternatives

The STL file is very good for this process and to some extent can be manipulated to improve the outcome. The STL file is a series of triangles that make up the surface – the smaller the triangle, the finer the detail available. The larger the file size, the larger the triangle, the flatter or smoother the surface. A large part with very fine detail will have a very large file size for processing.

There is some research into RM machines using the file direct from the CAD package, however with the need for support material in metal, further processing by other software packages needs to be performed.

7. Converting the STL file into a CAD 3D object.

Most CAD packages will allow the importing of the STL file and then additions to the surface can be made. However, no subtractions from the solid are allowed, as the STL file is only a picture, not a solid.

8. Best methodology for creating an STL file for use by the RM process.

Most CAD packages and some graphic animation packages create STL files as a means of exporting the data. There are graphic animation packages being used to create solid models of the characters that individuals make, eg in the games such as World of Warcraft. The design of the character is sent to an RM centre where the character is produced in either plastic or metal. This process can also be used for other games. The person playing the game can then get a model of their character (in either plastic or metal) to sit on their computer whilst playing.

9. Reverse Engineering - scanning an object into a 3D image.

The requirement is for the software package to be able to import a point cloud that has been produced using a digital 3D laser scanner and allow the creation of a 3D solid from that point cloud. Computer software such as Rapid Form enables this process to occur.

10. Potential difficulties with the design and manufacture of prosthesis.

It would be difficult to produce parts for the medical industry as they require validation that the material and processes conform to the standard required. Design of parts is not an issue; the requirement for a mesh to be on the surface will entail the use of additional software packages that develop meshes of various sizes and shapes.

Based on data received from a number of sources, the surgeon determines the shape of the implant, then instructs the prosthetist/orthotist/CAD designer as to the item to be produced. The final part can be made using conventional or RM methods. Once a mesh has been applied to a solid then Finite Element Analysis (FEA) would be difficult to apply.

11. Surgical grade material requirements for prosthesis manufacturing.

Titanium 67 and titanium 64, stainless steel 174 and surgical grade cobalt chrome are the main materials used. There is an increasing demand for one off tooling such as jigs and fixtures to enable the surgeon to use a drilling guide (this needs to be sterilised, but not left in the body after surgery). This ensures that the implant holes will line up with the prosthesis. This critical positioning requires great attention to detail when performing the operation. Fixtures are also required to hold bones in position whilst they set and grow together. These fixtures are removed from the body when the bones are able to support themselves.

12. Sterilisation requirements.

There are no additional sterilisation requirements as most parts are made of metal and can be sterilised in a conventional manner. The machine is best operated in a room that is of consistent temperature at around 25° centigrade. The laser will operate within a range from 0° centigrade up to a maximum of 40° centigrade. Once over 40° centigrade the system will stop until such time the temperature falls below 40° centigrade.

Both the EOS and the MCP machines supply an inert gas environment to the build area to eliminate as far as possible the oxygen content in the machine. It is advisable (required) to install sensors in the room to monitor the level of oxygen in the room.

13. Storage and handling of nano powders

There is a specific problem with the dust in the atmosphere and the material should only be used in a closed environment. This is the case with the MCP machine that operates with a glove box type handling system. The EOS machine requires the material to be scooped by the operator into the holding tray ready for use. The particles can become easily airborne and therein, full breathing apparatus may be required. All the materials should be handled in accordance with the material safety data sheet recommendations.

14. Limits of the 3D printing process – not just size, but fine detail

The laser beam is fixed in one position and mirrors are used to direct the beam over the build area. With machines up to 250mmx250mm there is a change in spot size of the laser from approximately 30 micron circle possibly up to 70 micron ellipse at the extremes of the build plate.

The EOS machine will build a more accurate part due to the ceramic wiper blade and the MCP machine will build a finer part due to its polymer wiper. The small MCP machine would be able to build a feature of around 80 micrometres in size.

15. The international usage of the process of RM

There is a growing trend towards RM across the world with the USA and the UK leading the way. Germany and Europe in general have some equipment, South East Asia have two machines and Australia and New Zealand have a growing RM requirement.

Not everything can, or should be manufactured in the RM process; most parts would be far more economical to produce in the conventional processes of manufacture.

16. Level of teaching where RM is introduced

In the UK it would appear that teaching at the vocational level is limited to awareness only, and that the research students learn and apply new techniques to both materials and processes. New techniques of melting the powder and the handling of the powder is a major research area for students at the universities in the UK.

17. Introduction of RM into the Diploma and Bachelor of Engineering

Students going through trade or diploma level qualifications receive at least some training into RM technology.

The process should always start with the brainstorming of ideas and then the selection of the various appropriate processes. If RM is one of the processes, then the design can be completed with this in mind and an organic shape be developed to solve the problem. The selection of the material at the start of the design process will enable a better design, as support structure needs to be allowed for in the metal design and is not required in plastic models.

18. New units of competency to be created to enable the teaching of RM

The implementation of RM into the UK training system has been slow. The implementation into the Australian training system will require collaboration with industry and other TAFE and university stakeholders. The RM technology is in its first stage of development. The research that is undertaken by the universities and industry is adding new manufacturing methods and materials (both metal and plastic) that can be used in the RM process on a regular basis.

It is difficult to find a course in the UK that includes RM as a feature of the course, as the two examples show. There is mention of Computer Aided Engineering in a lot of courses, particularly in the post graduate, Bachelor or Master of Engineering. This involves research into the manufacturing processes and the various materials that might be developed. There is no specific training in the design and use of the current RM technology in Australia at this time.

There are tremendous opportunities for the design of organic shapes to solve a variety of problems. The design process is completely different to conventional design as the requirements to include work holding parts into the design and the need to have straight holes is not a requirement.

Metal parts are built on a base plate and the support material is also built on the base plate and in any large holes, this support material is removed after heat treatment.

Plastic parts are lifted out of the cake of powder after the build and the support material is washed off with chemicals or high pressure. The part is finished and ready for use. The material left in the machine can be recycled once or twice before disposal. As the plastic part is sintered heat is generated and the material in close proximity to the laser beam is also partially sintered. The material will not be able to make fine product when it is partially sintered.

The manufacturing industry would be able to absorb people from Victorian universities and TAFE institutes trained in the process of RM, from design of parts through to complete manufacture.

The change for the trades is to realise and accept that there will be no need (or very little need) for tool makers' traditional skills, as the skills required in the future will be in the form of CAD designers and RM machine operators.

The Fellow and Swinburne University have had discussions with Manufacturing Skills Australia. Through their representative, Nick Juniper, they have expresses a strong interest in having the RM skills written up and included in the Training Package MEM05. There is insufficient time to have any units written/re-written and approved by industry before the next review is due, but this should be the aim prior to the following review date.

When this is achieved, then we can begin the training of tradespeople with skills that will meet the demands of the immediate future.

Knowledge Transfer: Applying the Outcomes

This Fellowship has provided the Fellow with an opportunity to study the emerging RM technology on an international level.

Driving the RM revolution is a technique that marries computerised design with laser shaping and melting – a process known as Selective Laser Melting (SLM). Instead of being cut from milled steel, components made using SLM are built by a process using layers of powdered polymers made from a variety of plastics and metals. The powder is melted at each layer with laser tools, to bond with the previous layer. Using SLM, designer-operators can draw and build new components from concept to final product in a few days, cutting out four steps and months of production time.

The tool-designer and the tool-maker trades will be the ones most affected by the new technology. The current trend is for a designer (not the tool-designer) to design the part on a CAD system, and the drawings are then approved by engineering, marketing and sales as the product required. The CAD design is emailed off to a company that produces parts using the RM process, either as an STL file, or the raw CAD data for further modifications. If a metal part is to be made then a support structure needs to be added to the design in order to form the shape while the part is being grown.

"The future of industrial design and manufacturing is limited only by our imagination," Barnett says; *"It means that processes that once took months can now be completed in hours. It's not only saving huge amounts of time, it also means we will end up with longer-lasting components because of design improvements."*

In order to optimise the outcomes of this Fellowship and optimise opportunities within the RM sector, the Fellow recognises the importance of ensuring that the knowledge obtained as a result of the Fellowship is shared with others.

Barnett has been actively engaged in knowledge transfer activities following his return to Australia. Key activities include the following.

- A seminar was held at Swinburne University to present the findings of two Fellows to university and TAFE staff and students, on 9th April 2008 from 12.45-1.30pm in room TB210 of the Hawthorn Campus.

PROGRAM

Speaker: Ken Barnett, ISS Institute/TAFE Fellow from Victoria University (TAFE)

Topic: Rapid Manufacturing

This technology is developing quickly; eventually every home will have a 3D printer able to make consumer goods from designs purchased over the internet. Ken has studied the technology around the world and has up-to-date experience of the latest developments in the field.

Speaker: Arnold Rowntree, '05 ISS Institute/Italy (Veneto) Overseas Fellow from Swinburne University (TAFE)

Topic: Powder Injection Moulding

An intriguing blend of materials science and injection moulding technology, this manufacturing process delivers complex, high performance parts for a variety of uses in a wide range of metals, ceramics and even blends of metals and ceramics. The processing steps will be outlined and a number of applications listed.

Knowledge Transfer: Applying the Outcomes

Speaker: Carolynne Bourne AM, CEO, International Specialised Skills Institute
Topic: Overseas Fellowships: Skill Deficiencies

TAFE teachers can apply for an Overseas Fellowship that involves overseas travel, a report and dissemination of acquired knowledge and skills. Carolynne will speak on the organisation and the available Fellowships, particularly those funded by the Victorian Government.

- Presentation at a two day conference to program managers and heads of department of Victoria University (held at Ballarat in August 2008)
- A presentation of the RM processes at the Manufacturing Skills Australia conference held in Sydney in October 2008
- The inclusion of RM into the Advanced Diploma of Engineering technology course as part of the regular subject to supplement the CAD/CAM and CNC subjects
- A special course for the fourth-year Bachelor of Engineering mechanical students to apply the technology of RM into design and manufacture of parts for the Society of Automotive Engineers Australasia (SAE-A) race car project. The students have designed and built a new formula-style racing car to compete in a national event for student members of the SAE-A. Known as Formula SAE-A, the event brings together teams from universities across Australia and the winner will compete in an international event. This is not a Grand Prix-style race to see which car makes it first across the finish line. Formula SAE-A is based on the premise that each team has been engaged by a car manufacturer to build a car for the non-professional weekend autocross racer. The car must have high performance acceleration, braking and handling, combined with low cost, ease of maintenance, reliability, good looks, comfort and use parts that are readily available, and comply within specified rules.
- A 'Design Masterclass: a Different Way of Thinking, Creating and Working' was presented by Matteo Ingaramo PhD, '08 ISS Institute/OTTE (Design) Fellow, sponsored by OTTE, Victorian Government.[3]

  This workshop examined generating new ideas using analogical references to build the functions and the efficiency of a product and the analogy to communicate, ie using the analogy to set a design vision able to be interpreted by clients and consumers supplemented by the manufacture of the individual designs. A presentation on RM was given to share the findings through a Powerpoint presentation and a live demonstration followed by questions and answers.

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[3] International Fellow, Matteo Ingaramo (Milan, Italy) was awarded an '08 ISS Institute/OTTE (Design) Fellowship sponsored by OTTE, Victorian Government.

Hosted at Swinburne University, Matteo conducted the 'Design Masterclass: a Different Way of Thinking, Creating and Working', – one Masterclass with students, one with designers, trades/technical and educationalists • 'Made in Italy. How Italian design and education are adapting to a changing marketplace'. Further activities were 'Milano in Melbourne' seminar @ the DIA • Speaker at the 'Really Creative Really Fast. Automotive Industry Think Bank', hosted by DIIRD, Victoria Government.

Recommendations

Government

- This report will be sent to Manufacturing Skills Australia for potential inclusion in a National Training Package.
- The report will likewise be sent key departments within Department of Innovation, Industry and Regional Development (DIIRD), Victorian Government such as Skills Victoria, Automotive Victoria, Aerospace Victoria and Nanotechnology Victoria.
- Approve and supply funds for the purchase of equipment that will be used to manufacture metal RM parts into training organisations, particularly TAFE. TAFE can then train the tradespersons with current skills in RM.
- Actively encourage industry to take up RM technology, so that it can be internationally competitive.
- Set up a series of small cells to show examples to industry where they can view the technology and find trained staff to run their own equipment when they purchase it.
- The cost of the metal powders makes it very expensive for a training organisation to maintain a RM facility without government funding or encourage a design bureau service that TAFE could offer under subsidy to industry.
- Assist hospitals to undertake research into RM for the manufacture of body parts for human and animal implant. This will involve the development of new materials and new techniques for setting the material instead of the use of laser or EBM.
- When the new competencies have been developed into a Training Package then the skills can be directly applied to a trade qualification or into a technician level qualification where design would be the main skill required, not the operation of the equipment.

Industry

- Invest in RM technology, particularly with DMLM to enable international competitiveness.
- Invest in research into RM aimed at getting the cost per part to a competitive situation.
- Invest into the design of parts for RM, as the existing constraints of manufacture are not inherent in RM.
- Research into the development of powdered materials that will benefit the manufacture of machines and equipment.
- Research into the use of powder metallurgy using laser fusing, where the powder is compressed into a cavity and the part removed to be heated in a furnace.
- Research into different methods of fusing the powder into a solid form, on a layer by layer basis rather than a spot on a layer. This would greatly reduce the time taken for the manufacture of a part.
- Apply this new technology into new fields where fine, delicate parts are required (eg hearing aid parts, design of jewellery for the fashion industry, industrial design applications for whole objects, and component parts such as electrical appliances).
- Work with the educational establishments to investigate the use of the RM techniques that are available. This would help provide equipment for education and research and to train personnel ready for industry.

Recommendations

- Industry and TAFE institutes need to work together so that the training that takes place at the TAFE institutes is relevant to the requirements of industry.
- Set up partnerships with suitable training organisations where research and training can take place using equipment that was supplying industry with parts designed and made by students.
- Application of the RM process to the manufacture of production components where a variation in size or shape would improve the overall mechanism.

Professional Associations

- Develop a pro-active approach into RM technology. The Victorian VET senate is planning to have a theme of RM and RP at its annual conference in 2009.
- Encourage industry and Local, State and Federal Governments into taking up the challenge of RM technology.
- Assist when the Training Packages are up for amendment and require RM technology to be written into the package as competency units.

ISS Institute

It is recommended that the ISS Institute further the uptake of RM technology into government agencies, educational institutions and industry by providing opportunities for Fellowships to support and extend Barnett's findings.

References

- Professor Richard Hague, Rapid Manufacturing Research Group, Wolfson School of Mechanical and Manufacturing Engineering, Loughborough University, UK

- Dr Phil Reeves, Econolyst Ltd, Derbyshire, UK

- Donna Cope, Sir Dennis Rooke Conference Centre, Holywell Park, Loughborough University, UK

- Dr Chris Sutcliff, The Department of Engineering, University of Liverpool, UK

- Dr Trevor Illston, Materials Solutions, Rapid Development to meet Environmental Challenges, University of Birmingham, UK

- Dr Gordon Green, Materials Solutions, Rapid development to meet Environmental Challenges, University of Birmingham, UK

- Dr Gregg Gibbon, Senior Research Fellow, WMG Innovative Solutions, International Automotive Research Centre, University of Warwick, UK

- Dr Max Ruffo, Additive Manufacturing and IMPC Manager, University of Sheffield, UK

- Bob Bennett, Wellingborough, Northants, UK

- Pol Palouzie, ASCAMM Centre Technologic, Barcelona, Spain

- Daniel Thompson, Sales Manager, ARRK Australia, Melbourne, Australia

- Fred Campion, Sales Director, Camplex, Rydalmere, Australia

- Dr Robin Weston, Sales Engineer, MCP Tooling Technologies Limited, Stone, Staffordshire, UK

- SME Resource Centre at service@sme.org
  http://www.alternative-doctor.com/anti-ageing/heavy_metal.html

- Keith Murry, Sales and Marketing Manager (EMEA), Powders Group Sandvik, Osprey Limited