PRODUCT AND PROCESS INNOVATIONS BY MEANS OF RAPID TECHNOLOGIES

D. DIMITROV, N. DE BEER and T. CENTNER
Laboratory for Rapid Product Development, Department of Industrial Engineering, University of Stellenbosch, Stellenbosch, South Africa

ABSTRACT
Over the past few years, methods of layered manufacturing (LM) have advanced substantially to the point where they now provide vital strategic benefits to various organisations. One area of application where LM technologies have begun to reach a critical mass is in the development and production of high-performance tooling in different forming processes. With these tooling capabilities now available, the next challenge becomes the development of optimal process chains to minimise lead times and production costs, while still ensuring high quality of castings. The relevant issues that influence where a break-even point will be between different process chains and thereby also the point of selection between such optimal process chains according to different situations include among others:

- the size of production runs,
- part size and complexity, and
- the cast materials involved.

This paper reflects some of the experiences gained from an investigation towards developing a set of generic rules (guidelines) for the design of optimal process chains for sand casting prototypes of automotive components using LM methods, and more specifically the 3D Printing process.

Keywords:
Rapid Prototyping, Rapid Tooling, 3D Printing

1. INTRODUCTION

Rapid Prototyping (RP) technologies have over 15 years of history [1], in which time they have expanded vastly. Some of them, like the Strereolithography, continue to keep their market leadership, while others, like the Selective Ground Curing (SGC) or the Laminated Object Manufacturing (LOM), disappeared from the market. In their place new technologies are emerging, bringing new advantages and covering different application areas. One of these technologies is the Three Dimensional Printing (3DP) based on MIT's (Massachusetts Institute of Technology) ink jet principle and utilised by Z-Corporation in a variety of printers. It is considered to be one of the most future oriented rapid prototyping systems. Classified as a typical "concept modeller", a low-end system, it is spreading rapidly worldwide and within only three years it has become the third most widely used layered manufacturing (LM) equipment [2]. The selective use of different materials in combination with the high building speed and suitable post treatment techniques opened a wide field of application for this technology - far beyond the original idea of generating design iterations. These applications include pattern making for investment, sand and vacuum casting as well as for bridge tooling, design aids for tooling equipment, reconstructive surgery aids and others.

With the advent of each new avenue of application, it is however critical to understand exactly what the range of its capabilities are, in order to compare current processes and techniques, or even future improvements. As its abilities become apparent, a set of process chains is spawned. Based on its inherent advantages and drawbacks, each process chain will have specific situations where it will be more suitable than the other.

One such avenue of application that is considered in this paper is the production of high-performance tooling in different forming processes. Several process chains have been developed [3] that utilise different combinations of materials and techniques.

This paper deals with current research towards the building a set of generic rules (guidelines) for the design of optimal process chains for sand casting prototypes of automotive components using LM methods, and more specifically the 3D Printing process.

2. DECIDING FACTORS FOR THE CHOICE OF PROCESS CHAIN

The key indicators that determine which process chain is more suitable for a given situation usually become apparent with time and experience. But with the growing international competition and shortened product lifetimes, companies are pressurised to develop new abilities and process chains much sooner in order to be at the market earlier with their innovative products than their competitors. In this regard, the development, maintenance and expansion of prototyping capability are very important.

It still remains a challenging task to identify optimal process chains for specific applications, and therefore a framework or model for selecting the most suitable process chain needs to be developed. This model is to be based on a comparative benchmarking study of capabilities of each process chain.

The execution of benchmarking tests is a traditional practice and necessary for all kinds of high productive and capital-intensive equipment. The objective of the benchmarking can however, differ substantially from case to case. In our case a benchmarking procedure was developed with the sole purpose to evaluate the performance capabilities of process chains for sand casting prototypes of automotive components. From the results of the benchmarking study, the individual abilities of each process will indicate its suitability and scope of application.

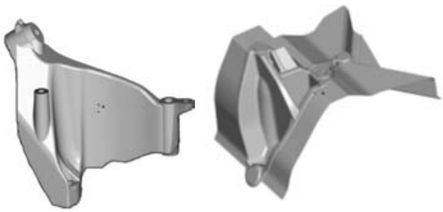
3. RESEARCH APPROACH AND EXPERIMENTAL BASE

3.1 Benchmarking approach and procedure

Benchmark development

The benchmarking procedure involved the comparison between three different process chains. The component (Figure 1) that was used for this comparison is a typical automotive component with robust features suitable for the sand casting process.

Figure 1: CAD image of component used in benchmarking study



(a) (b)

Figure 2: Benchmarking part indicating (a) split line and (b) split surface

With at least one undercut, the choice of positioning the split line was done with careful consideration of the constraints associated with the sand casting procedures.

The process chains that were compared during the benchmarking study were the following:

- ZCast™ Direct Pour (Shell Method)
- Production Intent Casting, and
- Fibreglass Tooling

A short description of each process chain is given below.

ZCast™ Direct Pour (Shell Method)

In late 2002, Z Corporation introduced a new technology to address the prototyping needs of the metal casting industry as well as end users seeking to rapidly produce metal prototype parts. This new technology, ZCast™ Direct Metal Casting, consists of materials and processes that allow designers and engineers to 3D print moulds and/or cores. These printed parts can then be used directly as a mould for pouring metal. The ZCast™ process is revolutionary because it eliminates the pattern creation phase of the traditional sand casting process. As a result, the ZCast™ process drastically reduces the time it takes to produce a casting from weeks to days [4]. The Shell Method was developed to reduce the cost of ZCast™ Direct Pour method and to increase the size of the casting envelope [5]. The process involves the design of basic parting lines and coring. A 3D mould shell approximately 25 mm thick using ZCast 500 plaster-ceramic composite material is printed. If necessary, the shell is created with ribbing and backfilled with traditional foundry sand to facilitate added strength while minimising material cost. During this study, Z Corporation's ZPrinter 310 System was used to create the printed components.

Production Intent Casting

This method is a combination of the zp102 plaster material for creating patterns, and ZCast 500 material for creating cores. The process first involves designing foundry tooling as it would be designed for the production foundry process, including coreprints, offset partings, and clearances [5]. The pattern equipment is then printed with the zp102 material, infiltrated with epoxy, and if necessary backfilled with a rigid plastic filler for added strength. If cores are required, they are produced using the ZCast 500 material.

Fibreglass Tooling

This process chain, like the previous two, begins from a CAD design with chosen split line and core designs. As with the Shell Method, the Fibreglass Tooling method requires the development of the negative CAD image from its positive in order to obtain the CAD designs of the two mould halves. The pattern halves are then printed using zp102 plaster material. Fibreglass material is applied to the split surface and sides of the mould. The positive fibreglass geometry is mounted to a wooden frame, and is used to create the subsequent sand moulds necessary for sand casting. Where cores are involved, patterns of the core geometry are printed using zp102 material and are used to create core boxes.

4. DISCUSSION OF RESULTS

Figure 3 below shows some of the results that were obtained during selected stages of each of the process chains. As with all LM technologies, each process chain begins with a CAD image of the components that are to be printed using the ZPrinter 310.

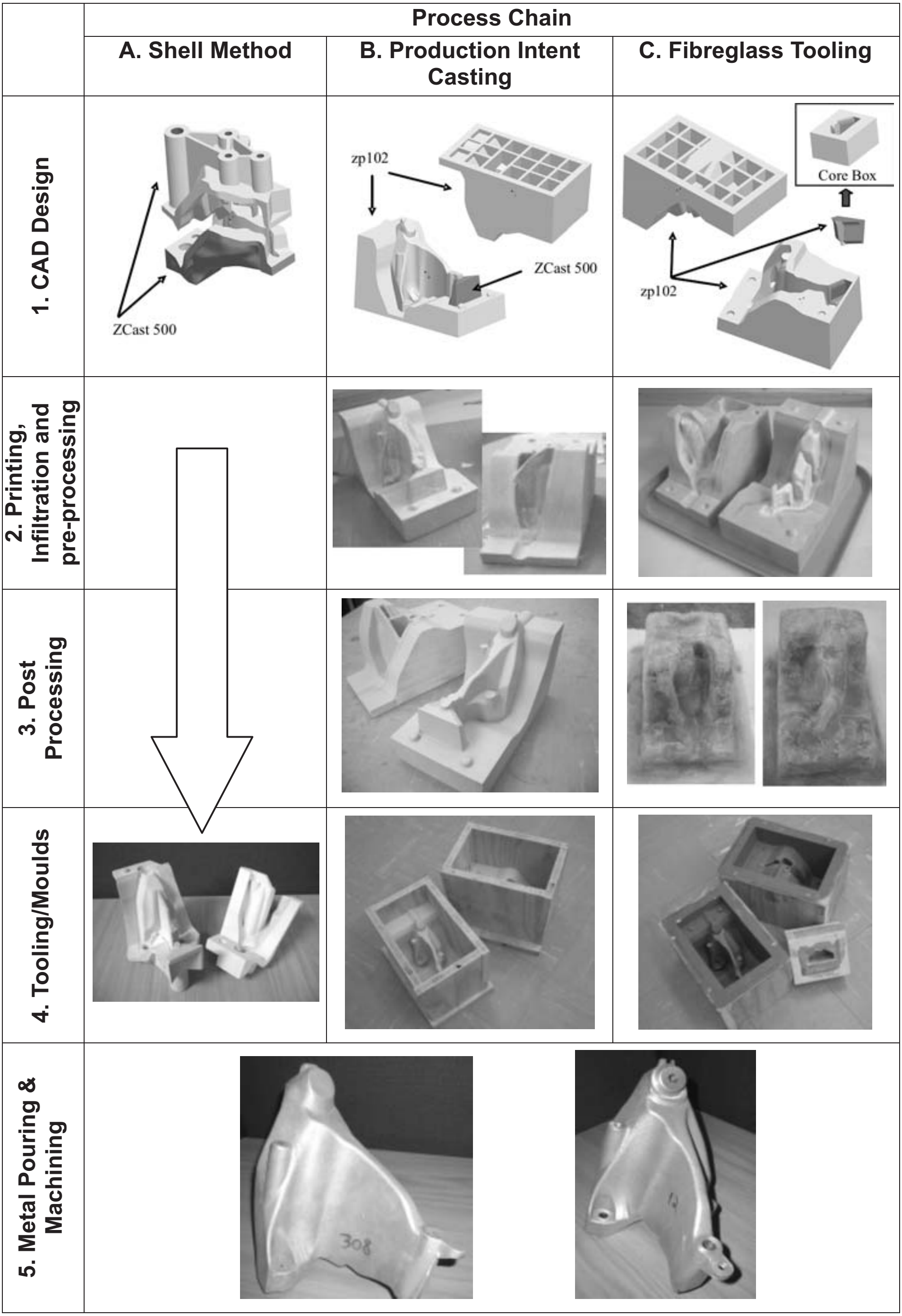


Figure 3: Selected results from steps in process chains

The steps for creating negative CAD images from the positive designs turned out to be more arduous than initially anticipated. Using ProEngineer, there are different ways to create a mould from a model. One way to create the mould is with using the ProCast module of ProEngineer. A second approach is to define a split line manually and copy the surfaces from the original model to get the negative prints of the inner and outer part geometry. After that, the split surface has to be created and the surfaces have to be merged and filled to get a solid.

The first method is quicker if the model has a simple split line, but as soon as the split line contour becomes intricate, it becomes tedious to use the ProCast module of ProEngineer, and the second, manual procedure is followed. This is why, also in this case, it became necessary to use the second method in this study.

The Shell Method has the least amount of steps in its process chain and is therefore the quickest of the three. It is most suitable for low run mould production. Figure 3 shows the resulting moulds that were obtained after printing the CAD models with ZCast 500 material. The mould on the left has already been baked at 180ºC for approximately 6 hours, and is ready for metal pouring.

The step that took the longest for Production Intent Casting was the post processing required after printing the models. The models were printed over a period of two days, while post processing took at least three days. It was a challenge to create a good surface finish in the deep pockets of the tool geometry, and this became the cause behind the extended post processing time. The tooling was finally created by enclosing the infiltrated and surface-prepared models with wood. These tools for sand casting are not as durable as conventional tooling – but with necessary care, and depending on the tool geometry, they should be able to produce several sand moulds suitable for medium run mould production.

The Fibreglass Tooling method on the other hand, provided sand cast tooling in line with the quality of conventional tooling. The trade-off for obtaining this extended tool life was the time it took to create the tooling. Although this method, in comparison to the other two methods, took the longest to produce, it can still be stated with confidence that printing the model before overlaying with fibreglass considerably reduces the time for creating the tooling when still compared to conventional pattern and tool making.

5. CONCLUSIONS AND OUTLOOK

Based on the technological characteristics of the process chains as illustrated above, following evaluation remarks emphasising their applicability for making functional parts in end use materials (or close equivalents) in the shortest time can be made:

- The accuracy of the tooling produced is well within the required tolerances for the sand casting process.
- Design (complex shapes) – in general greater ability to handle complex shapes and design features. Creating the CAD negatives should however not be underestimated when the geometry and split line becomes more complex.
- Materials – ZCast 500 material is at this stage restricted to use for casting only non-ferrous metals. Zp102 provides a sufficiently durable alternative for tooling of medium batch sizes. Gel-coated fibreglass meets the industry standard in terms of quality and tool life.

- Part size – Size of tools is not restricted to only the build volume of the printer, since partitions can be assembled to create larger moulds and tools. The assembly process should however be planned carefully, and noted that extra time is spent on post processing.
- Batch size – The Shell Method is suitable in general for small production runs, but ideal for one-offs. Production Intent Casting is suitable, depending on part geometry, for batch sizes in the region of 10-30 parts. Fibreglass Tooling batch sizes are in line with batch sizes available from conventional tooling.
- Time saving – is substantial for Shell Method, since moulds are produced directly from CAD data. The other two processes also provide substantial time saving compared to conventional tooling methods.
- Cost issues – not necessarily prime objective due to many additional, non-monetary advantages such as quality assurance, risk management and others.

This summary as well as the case study data and analysis, presented in this paper, prove that the developed process chains have achieved the objective for a niche application in the production of sand casting prototypes of automotive components using LM methods, and more specifically the 3D Printing process.

6. REFERENCES

[1] Levy, G.N., Schindel, R., Kruth, J.P., 2003, Rapid Manufacturing and Rapid Tooling with Layer Manufacturing (LM) Technologies, State of the Art and Future Perspectives, Keynote Paper from the Annals of the CIRP Vol 52/2/2003, pp.1-23.

[2] Wohlers, T., 2004, Wohlers Report - Rapid Prototyping and Tooling: State of the Industry, Worldwide Progress Report, Fort Collins, Colorado.

[3] Wohlers, T., 2002, New Developments and Trends in Rapid and High Performance Tooling, Proceedings from International Conference: Worldwide Advances in Rapid and High-Performance Tooling, EuroMold 2002, Frankfurt, Germany.

[4] Website: www.zcorp.com, ZCast Technology Overview.

[5] Krouth, T.J., 2002, Foundry Tooling and Metal Castings in Days, Proceedings from International Conference: Worldwide Advances in Rapid and High-Performance Tooling, EuroMold 2002, Frankfurt, Germany.