Rapid Prototyping and Tooling in the manufacture of mould elements for large parts

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ABSTRACT: In the last two decades the advances in rapid prototyping and tooling (RPT) technologies made possible the use of materials alternative to steel in some mould components. They also have allowed novel fabrication strategies and new ways of thinking on the production of injection moulds for short series of plastics parts. These technologies induced a new generation of toolmaking techniques. In the scope of the development project Hybridmould 21 the *pros* and *cons* of some RPT technologies were studied to fabricate moulding blocks and inserts for hybrid injection moulds for large plastics parts. Essentially, the studies aimed at finding the best solution for quick production and compliance with specific product requirements, such as complex features, complex cooling layout and large size (around 1 m^2) in short production series. This paper discusses the main advantages and disadvantages associated to a number of different RPT technologies for the manufacture of moulding element.

1 INTRODUCTION

In the context of the development project *Hybridmould 21*, rapid prototyping and tooling (RPT) technologies have been studied to produce moulding elements for hybrid moulds. The *Hybridmould 21* project is destined to industries that produce large parts, such as automotive, aeronautics, urban furniture, among others. It is being developed by a consortium consisting of 3DTech as the promoter, Moliporex as co-promoter, and the University of Minho and Centimfe. They aim at consolidating the knowledge developed during the last decade in the field of hybrid moulds (Pontes et al. 2005) as well as acquiring new knowledge to improve the competitiveness of the companies involved.

Hybrid injection moulds are being increasingly considered as an alternative for prototype series or short production runs of large dimension parts. In this solution for injection moulds the moulding elements (blocks or other inserts) are manufactured in alternative metallic materials or in synthetic materials typically using rapid prototyping techniques (RP) (Pouzada 2009).

In this project the following additive manufacturing technologies are being explored: stereolithography (SL), selective laser sintering (SLS), fused deposition modeling (FDM), and the polymer jetting technology (PolyJet).

In SL three-dimensional models are built from a photosensitive liquid polymer that polymerizes when exposed to ultraviolet (UV) light, or other source of light, such as Infrared Radiation (IR) or even visible radiation can also be used (e.g., (Chen et al. 1992; Jardini et al. 2004)). The model is built on a movable platform situated just below the surface in a container of liquid resin (epoxy or acrylate). A UV laser traces out the first layer, materializing the model cross section. The surface layer of the resin is cured selectively by the laser beam following the path defined in the slicing model. After this layer has been created, and the movable platform is lowered into the container, a new thin layer of liquid monomer floods the model and the process is repeated (Rosochowski and Matuszak 2000). The SL resins available for use in the stereolithography process are essentially variants of epoxy and acrylic (Harris et al. 2003).

SLS uses a high-power laser to selectively heat powder material just beyond its melting point (Dimov et al. 2001). The laser traces the shape of each cross-section of the model to be built, sintering the powder into a thin layer. Various materials, such as polyamide (PA), polystyrene (PS), polycarbonate (PC), acrylonitrile butadiene styrene (ABS), metals, ceramics and composites can be used in laser sintering applications.

In the FDM technique, filaments of heated thermoplastics are extruded from a tip that moves in the x-y plane. Like a baker decorating a cake, the controlled extrusion head deposits very thin beads of material onto the build platform to form the first layer. The platform is maintained at a lower temperature, so that the thermoplastics quickly hardens. After the platform lowers, the extrusion head deposits a second layer upon the first. Supports are built along the way, fastened to the part either with a second, weaker material or with a perforated junction (e.g. (Chryssolouris et al. 2001)). Materials that are processable by SL include ABS, PC, polyphenilsulfone (PPS) or investment casting wax (Foggiatto et al. 2004).

PolyJet is a process where a jetting head slides back and forth along the X-axis, similar to a line printer, depositing a single super thin layer of photopolymer onto the build tray. Immediately after building each layer, UV bulbs alongside the jetting bridge emit UV light, curing and hardening each layer. This step eliminates the additional post curing required by other technologies (Singh 2009). The internal jetting tray moves down with extreme precision and the jet heads continue building, layer by layer, until the model is complete (Drstvensek et al. 2008; Singh 2011). Two different photopolymer materials are used for building, one for the actual model and another gel-like material for supporting (Singh et al. 2010).

A benchmarking three-dimensional geometry was designed with features that represent challenges to these technologies to evaluate the capacities of each additive technology. This geometry was experimentally evaluated with the selected RP processes.

Based on the benchmarking and the most important desired characteristics SLS was selected to produce the master (Fig. 1). This master will serve to produce a moulding block in epoxy based composite for preliminary studies.

Figure 1 – Technology used to produce the master (Sinterstation 2500 from 3D Systems)

The main *pros* and *cons* of the RPT technologies are briefly outlined in Table 1.

The moulding blocks were manufactured by vacuum casting of an epoxy composite. The vacuum casting is a process of RPT that allows manufacturing soft tools using epoxy composites materials. The resins are poured, in vacuum, over the master to reproduce a moulding block with accuracy and good surface finishing (Dunne et al. 2004).

Table 1 – Properties of the epoxy based composite

Technology	Pros	Cons
SLA	Variety of materials. Good surface finish.	Slower process. Difficult post-processing.
FDM	Variety of materials. Thin parts produced fast. Good strength.	Slower process. Difficult finishing.
SLS	Fast, accurate, and functional parts. Easy finishing with sand paper. Good strength.	Low surface finish quality. Porosity makes it more difficult to paint.
PolyJet	Good surface finish; Fast production. High flexibility.	Low thermal and mechanical resistance.

The main advantage of the vacuum casting process is the short time to obtain freeform moulding blocks comparatively with conventional machining. In this way, it is possible to reduce the cost by around 40% in comparison to conventional tools with lead time of 2 to 5 weeks (Martinho et al. 2005; Pontes et al. 2010; Ramos et al. 2003). Generally, epoxy resins filled with metallic powder (usually aluminium) are used to improve thermal and mechanical properties (Martinho et al. 2009; Michaeli and Lindner 2001; Sabino-Netto et al. 2008). Thus, the vacuum casting is ideal for quick manufacturing of the moulding blocks used in the hybrid moulds (Bareta et al. 2006).

2 EXPERIMENTAL

2.1 Part design

The shape of the plastics part is shown in Fig. 2. This part has main dimensions approximately 400 mm in base diameter, 195 mm in height and 8 mm of thickness.

Figure 2 – Conceptual design of the plastics part.

It was thought for production in injection moulding using structural foams using hybrid moulds, this mainly resulting from its relatively large size.

2.2 *Hybrid mould*

The hybrid mould consists of a steel structure and moulding blocks manufactured by vacuum casting and assembled in the two mould sides. Figure 3 shows the structure of the hybrid mould.

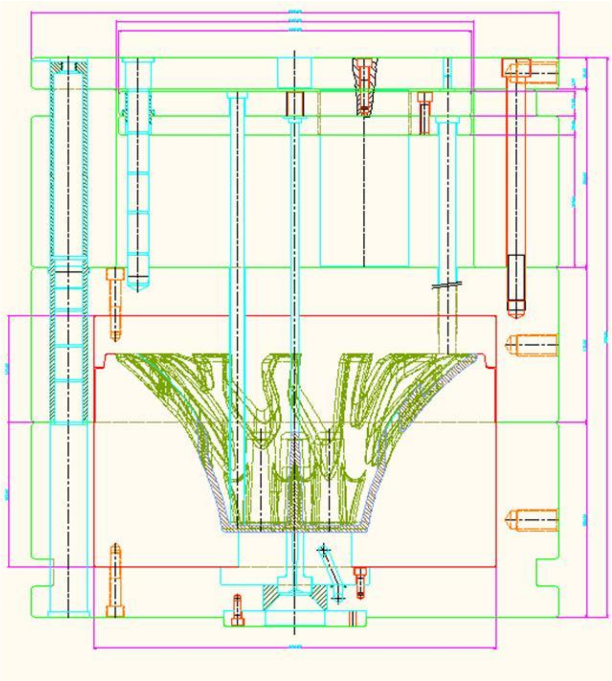

Figure 3 – Scheme of the hybrid mould

The moulding blocks were produced in a composite of epoxy resin (Biresin L74) filled with 60 wt% of aluminium powder. The thermal and mechanical properties of epoxy composite are shown in the Table 2.

Table 2 – Properties of the epoxy based composite

Properties	**Biresin L74 + 60% Al**
Specific gravity [$Mg.m^{-3}$]	1.65
Specific heat [$J.kg^{-1}K^{-1}$]	1279.19
Thermal conductivity [$W.m^{-1}.K^{-1}$]	0.61
Thermal diffusivity [$m^2.s^{-1}$]	0.29×10^{-6}
Coefficient of thermal expansion [K-1]	6.00×10^{-5}
Flexural modulus (20ºC) [GPa]	5.00-6.00

The aluminium powder has an average particle size of 50 µm and a specific gravity of 2.43 $Mg.m^{-3}$ (Martinho et al. 2009).

2.3 *Master fabrication*

The technology used for the production of the master was SLS. The construction was divided in three main steps: pre-processing, processing and post-processing. The first stage consisted on the preparation and validation of the *stl* file. The material used was powder polyamide DuraForm from 3D Systems Inc. The design of the master is shown in Figure 4.

Figure 4 – Design of the master

The parts were constructed with the moulding face downwards for a better surface finish. After construction, the parts were submited to finishing: gluing the parts, application of primer intercalated with polishing, therefore improving the finish quality of the part. At last, the prototype was painted with acrylic paint to get the surface quality adequate to the final goal: the production of a master for silicone moulds.

3 RESULTS

3.1 *Master*

The construction platform of the SLS equipment has maximum volume of 320×240×300 mm. Given the large geometry dimensions of the part there was the need to cut it into sections that were glued together after production and finishing (Fig. 5). Due to the intricate part geometry, the finishing was better in the external side than in the interior of the prototype.

Figure 5 – Master being assembled in parts

The dimensional control of the prototype was made using CMM technology. It was verified that the larger dimentional deviations occurred in the *x* and *y* axes, those being more notorious in the external diameter of the base of the part (near 3 mm). This resulted mainly from the application of glue and paint in the post-processing stage. The deviations at other locations of the part were in the range 0.04-0.2 mm. After the aplication of the final finishing painting process, the surface quality was very good.

4 CONCLUSIONS

The development project *Hybridmould 21* aims at developing a hybrid mould solution to produce small batches of large plastics parts by injection moulding and analysing aspects related with the process performance. The results shown in this paper illustrate aspects related with the application of SL, SLS, FDM and PolyJet, as potential RPT techniques to the production of the moulding blocks.

A benchmarking study on potential layer additive manufacturing technologies was developed for the selection of the best option for the moulding blocks.

A major issue on the use of the selected techniques is the dimensional deviations and the finishing in the interior of the part (stair-step effect).

Selective laser sintering, SLS, is seen as the adequate Rapid Prototyping technique for the production of masters with large dimensions.

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6 REFERENCES

Bareta, D. R., Zeilmann, R. P., Costa, C. A. & Pouzada, A. S. 2006. Application of alternative materials in hybrid mould cores. In *RPD 2006 - Building the future by innovation*; *Proc. Int. Conf., Marinha Grande, Portugal, November*.

Chen, H., Corbel, S., Allanic, A. L. & Andre, J. C. 1992. Solid fabrication induced by thermal IR lasers. In *3rd Int. Conf. on Rapid Prototyping*; *Proc. Int. Conf., Ohio, USA*.

Chryssolouris, G., Zannis, S., Derdas, C. & Tsirbas, K. 2001. Dimensional accuracy of FDM parts. In *34th Int. CIRP Seminar on Manufacturing Systems*; *Proc. Int. Conf., Athens, Greece*.

Dimov, S. S., Pham, D. T., Lacan, F. & Dotchev, K. D. 2001. Rapid tooling applications of the selective laser sintering process. *Assembly Automation* **21**: 296-297.

Drstvensek, I., Hren, N. I., Strojnik, T., Brajlih, T., Valentan, B., Pogacar, V. & Hartner, T. Z. 2008. Applications of Rapid Prototyping in Cranio-Maxilofacial Surgery Procedures. *International Journal of Biology and Biomedical Engineering* **1** (2): 29-38.

Dunne, P., Soe, S. P., Byrne, G., Venus, A. & Wheatley, A. R. 2004. Some demands on rapid prototypes used as master patterns in rapid tooling for injection moulding. *Journal of Materials Processing Technology* **150** (3): 201-207.

Foggiatto, J., Salmoria, G. V. & Ahrens, C. H. 2004. Behavior of injection molds manufactured in ABS, PC and PPSF by the Fused Deposition Modeling process. In *PPS Americas Reg. Meeting*; *Proc. Int. Conf., Florianópolis, Brazil, June*

Harris, R. A., Hague, R. J. M. & Dickens, P. M. 2003. Crystallinity control in parts produced from stereolithography injection mould tooling. *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials Design and Applications* **217** (4): 269-276.

Jardini, A. L., Filho, R. M., Scarparo, M. A. F., Andrade, S. R. & Moura, L. F. M. 2004. Infrared laser stereolithography: prototype construction using special combination of compounds and laser parameters in localised curing process. *International Journal of Materials and Product Technology* **21** (4): 241-254.

Martinho, P., Bártolo, P. J., Queirós, M. P., Pontes, A. J. & Pouzada, A. S. 2005. Hybrid Moulds: the Use of Combined Techniques for the Rapid Manufacturing of Injection Moulds. In P. J. Bártolo (ed.), *Virtual Modelling and Rapid Manufacturing - Advanced Research in Virtual and Rapid Prototyping*: 421, London: Taylor and Francis.

Martinho, P. G., Bartolo, P. J. & Pouzada, A. S. 2009. Hybrid moulds: effect of the moulding blocks on the morphology and dimensional properties. *Rapid Prototyping Journal* **15** (1): 71 - 82.

Michaeli, W. & Lindner, F. 2001. Influence of Mould Materials on the Morphological and Mechanical Properties of Injection-Moulded Prototypes. *Macromolecular Materials and Engineering* **286** (4): 232-236.

Pontes, A., Queirós, M., Martinho, P., Bártolo, P. & Pouzada, A. 2010. Experimental assessment of hybrid mould performance. *The International Journal of Advanced Manufacturing Technology* **50** (5): 441-448.

Pontes, A. J., Gago, P., Bártolo, P., Soares, R. & Pouzada, A. S. 2005. Hibridmolde - A project towards the new mould generation. *O Molde* **66**: 16-20.

Pouzada, A. S. 2009. Hybrid moulds: a case of integration of alternative materials and rapid prototyping for tooling. *Virtual and Physical Prototyping* **4** (4): 195 - 202

Ramos, A. M., Relvas, C. & Simões, J. A. 2003. Vacuum casting with room temperature vulcanising rubber and aluminium moulds for rapid manufacturing of quality parts: a comparative study. *Rapid Prototyping Journal* **9** (2): 111 - 115.

Rosochowski, A. & Matuszak, A. 2000. Rapid tooling: the state of the art. *Journal of Materials Processing Technology* **106** (1-3): 191-198.

Sabino-Netto, A. C., Salmoria, G. V., Ahrens, C. H. & Pouzada, A. S. 2008. Mechanical Properties of Epoxy Composites Filled with Short Steel Fibres for Hybrid Injection Moulds. *Advanced Materials Forum IV* **587-588**: 222-226.

Singh, R. 2009. Three Dimensional Printing for Casting Applications: A State of Art Review and Future Perspectives. *Advanced Materials Research* **83 - 86**: 342-349.

Singh, R. 2011. Process capability study of polyjet printing for plastic components. *Journal of Mechanical Science and Technology* **25** (4): 1011-1015.

Singh, R., Singh, V. & Saini, M. S. 2010. Experimental Investigations for Statistically Controlled Rapid Moulding Solution of Plastics Using Polyjet Printing. *ASME Conference Proceedings* **2010** (44274): 1049-1053.