

Polyjet technology applications for rapid tooling

Razvan Udroui*, and Ion Cristian Braga

Transilvania University of Brasov, Department of Manufacturing Engineering, Mihai Viteazu No.5, Brasov, Romania

Abstract. Polymer Jetting (PolyJet) has proved to be one of the most accurate additive manufacturing technologies, in order to manufacture rapid tools. Rapid Tooling (RT) is different from conventional tooling as follow: manufacturing time is shorter, the cost is much less, but the tool life is shorter and tolerances are wider. The purpose of this paper is to make a comparative study between the soft tools (silicon moulds) and hard tools (acrylic thermoplastic moulds) based on the Polymer Jetting technology. Thus, two types of moulds have been made in order to manufacture a test part. Reaction injection moulding (RIM) and casting techniques were used to fill these moulds with resins that simulate the plastic injection materials. Rapid tooling applications, such as indirect tooling and direct tooling, based on PolyJet technology were experimentally investigated.

1 Introduction

Rapid X [1] is a generic term based on additive manufacturing, which includes: Rapid Prototyping (RP), Rapid Tooling (RT), Rapid Manufacturing (RM) and so on. Rapid prototyping allows making, in an additive way, of physical objects, directly from computer. Rapid Tooling, based on RP techniques, allows to build tools and moulds in a rapid way. RT technologies are classified in soft tooling (silicon rubber, epoxy resins, low-melting-point alloys) and hard tooling (hard plastic, metal alloys). In indirect tooling a mould, die or tool is manufactured using a master model made by RP. In direct tooling, the tool, mould or die is created directly on the additive manufacturing system.

Different approaches for RT applications [1-5] are found in the literature. Chua presents [3] a comparison of rapid tooling technologies based on tool life, tool development time and cost. In [4] applications of vacuum forming tooling using Fused Deposition Modelling (FDM) technology were presented. Singh [5] investigated and compared PolyJet printing and silicon moulding using Alchemix VC3340 material. The companies that provide additive manufacturing systems also develop RT application based on their AM techniques. Thus, Stratasys Ltd proposes some solutions for manufacturing tools [6] based on fused deposition modelling (FDM) and polymer jetting (PolyJet) technology.

Indirect rapid tooling applications based on PolyJet technology are: silicon moulding, investment casting, sand casting and vacuum forming. All of these required a master model made by 3D printing. Direct rapid tooling with PolyJet technology requires 3D printed master mould or tool, and comprise the following applications: blow moulding, jigs and fixtures,

* Corresponding author: udroui.r@unitbv.ro

reaction injection moulding (RIM), thermoplastic injection moulding, thermoforming, composite tooling, liquid silicon casting and investment casting mould. All of these applications focused on manufacturing tooling, are under development and needs improvements based on experimental researches.

The purpose of this paper is to explain how are made the tools or moulds based on the Polymer Jetting (PolyJet) technology. Quite a few researches have studied the problem of manufacturing of tools and mould by direct and indirect methods using PolyJet technology. For a small series production, 3D printing offers an effective cost compared with milled mould by computer numerical control (CNC).

In the first part of the paper are investigated the rapid tooling techniques based on a master model made by PolyJet 3D printing. The second part presents direct rapid tooling techniques focused on PolyJet 3D printing of moulds. These rapid tooling techniques have applications for resins casting, RIM, wax pressing in a mould and vacuum casting.

2 PolyJet 3D printing technology and materials

The first Polyjet 3D printing system was launched by Objet Geometries Ltd. in 2000. Stratasys has acquired Objet Geometries Ltd. in 2012. The Polyjet 3D printing technique [6] consists in building of parts, layer by layer, combining inkjet technology with photopolymerization process. The main steps are the following: pre-processing, processing and post-processing. In the pre-processing step, the part orientation on the build tray is optimized using Objet Studio software. In the next step, droplets of resin are deposited, in 16 micron layers, onto a built tray via an inkjet print head (Fig. 1), each layer being cured by UV light. The building tray moves down and the process continues, layer by layer, until the part is complete. Two different photopolymer materials are used, model and support. In the last step, using a water jet recycling station the support material is removed. The accuracy of parts obtained by PolyJet technique is 0,1mm [6].

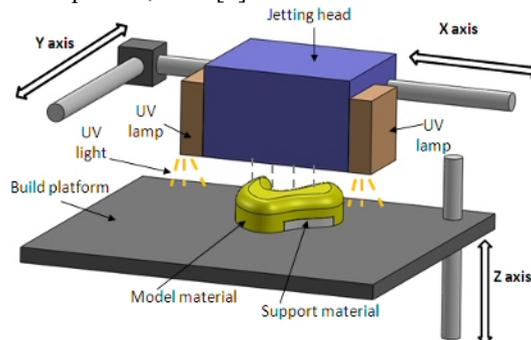


Fig. 1. Schematic representation of PolyJet printing process.

The test parts, including the master model and the master mould, were made by Polyjet 3D printing technology on the Objet Eden 350 machine, from FullCure™720 material by Objet Geometries (Stratasys). FullCure materials family is an acrylic-based photopolymer.

3 Resins that simulate the injection plastic materials

The resins from Sika, having similar properties with the injection plastic materials are presented in Fig.2 and Fig. 3. Some of these resins are experimentally investigated in this paper.

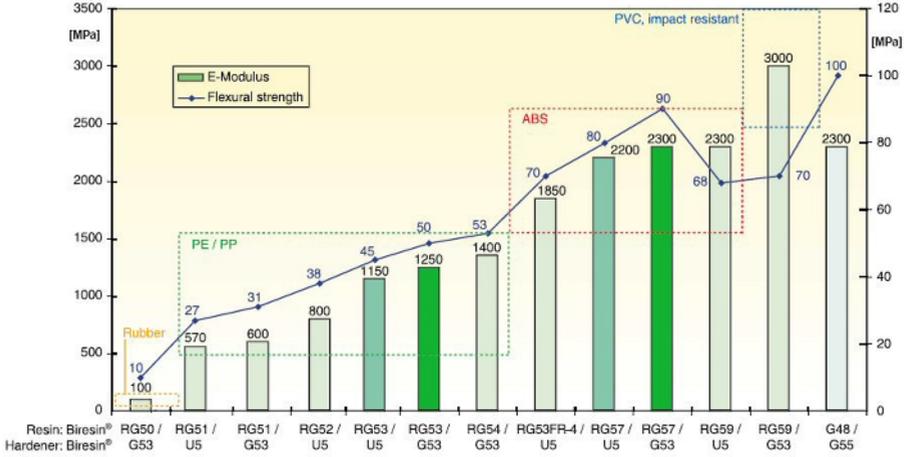


Fig. 2. RIM resins properties from Sika. [7]

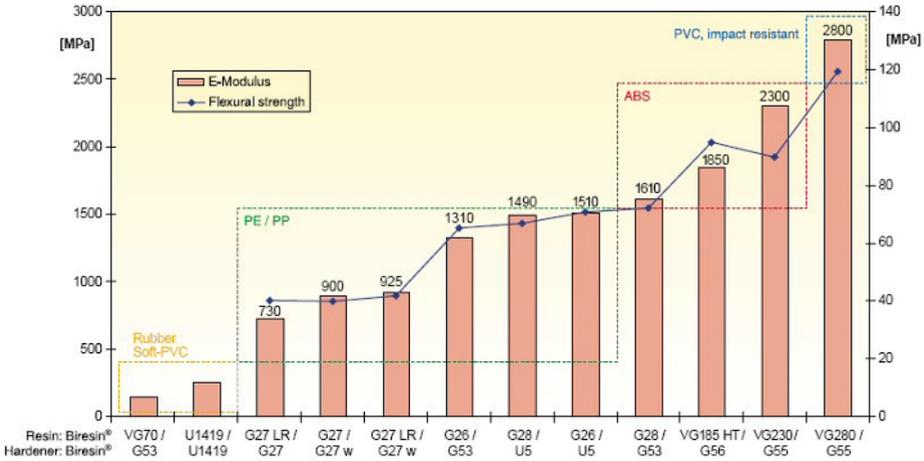


Fig. 3. Cast resin properties from Sika. [7]

The mechanical characteristics of the RIM resins (Fig. 2) and casting resins (Fig. 3), indicated on the horizontal axis, are presented on the left vertical axis (E-modulus), the right axis (flexural strength) and the dotted rectangles show the equivalent injection plastic materials used in serial production.

4 Indirect rapid tooling based on PolyJet technology

In the first case study, the development of silicon mould is investigated. The test parts (Fig. 4b) are manufactured by casting or reaction injection moulding (RIM) from a thermoset resin, into the silicon mould (Fig. 4a).

4.1 Silicon moulding for casting

Silicon rubber moulding is an indirect rapid soft tooling technique that consists in the following main steps: master model manufacturing, mould making, part casting and part finishing. A master model built by rapid prototyping reduces significantly the manufacturing

time and allows making complex shape. The master pattern needs to be prepared for the next step, by marking the parting lines and shut-offs. The silicon mould is built following the steps:

- Make a rigid box from plastic (or wood);
- Suspend the master pattern into the mould box and add gates and vents;
- Prepare the model master by marking the parting lines and shut-offs and then apply a mould release on its surface;
- Prepare the silicon by mixing the two components of the silicon rubber kit and vacuum degassing the liquid silicon;
- Pour liquid silicone rubber over the master model until it fills the mould box and repeat the vacuum degassing;
- Cure the silicon mould;
- Remove the mould box, cut with a knife the silicon mould in order to define the parting surface and finally open the mould and extract the master model.

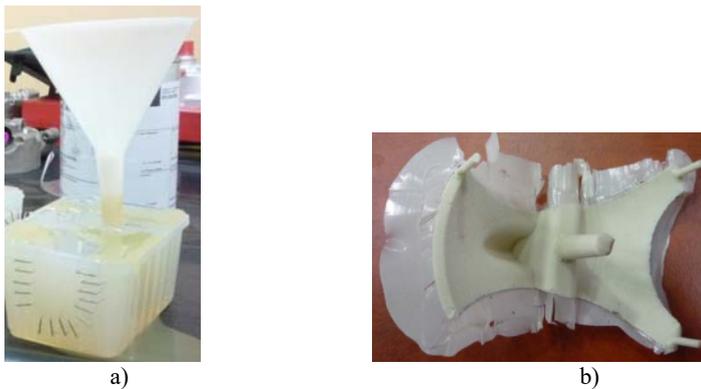


Fig. 4. a) Silicon mould, b) Polyurethane cast part.

Two components (A + B) addition silicon rubber from Alpina Technische Produkte GmbH, having a very low linear shrinkage (around 0.1%) was used, obtaining a transparent mould. The mould is prepared for fill, by applying a release agent on its internal surface, and then closes the mould and binds it to prevent separation. Two fill variants of the silicon mould were experimented: cast by gravity (Fig. 4a) and injection using a syringe. The resin is inserted into the mould until it begins to exit from the vents. A polyurethane resin G26 / G53, similar with high density polyethylene, was casted into the mould. The resin potlife is around 7-10 minutes and demoulding time 20-30 minutes. The final step consists in extracting the part from the mould and make post processing operations (remove the gates, vents and parting surface).

4.2 Low pressure Reaction injection moulding (RIM) with silicon moulds

Reaction injection moulding (RIM) is a technique that basically consists in mixing two thermosetting polymers (resin A-polyol and hardener B-isocyanate) with a curing reaction followed by the rapid injection of the mixture at low pressure and temperature into the mould. RIM is used in the development and preproduction stages of plastic components, allowing to simulate the thermoplastic materials for serial production. RIM technology applications are focused on the field of technical parts for aerospace, automotive etc.

The advantages of RIM technique compared with other plastic technologies are the following:

- a quick cycle times compared to typical cast materials;
- a high-density skin is formed with a low-density core;
- the bi-component mixture has a much lower viscosity than molten thermoplastic polymers;
- less clamping forces are required, which leads to smaller equipment.

A UNIDOS 100 RIM machine was used to make this experiment. The RIM machine has two separate containers, two pumps for each one and a mixing head. The mixing ratio between resin A and hardener B is adjusted by the pumps volume adjustment. After the resin and hardener were mixed, there is a very short potlife (timeframe) for injection the material and fill-up the mould. In this case study, a polyurethane resin RG53/ G53 from Sika, similar with thermoplastic injection mouldable material like HDPE (high density polyethylene), was low pressure injected into the mould. The potlife is 55 seconds and demoulding time around 15-20 minutes.

5 Direct rapid tooling made by PolyJet technology

Direct rapid tooling is a manufacturing process of tools using additive manufacturing. The additive manufactured tools can be made from different materials, such as plastics, metal alloys or ceramics. In this case study the tools are manufactured from polymeric material by Polyjet 3D printing technology. 3D printing of mould is an important method used in plastic parts manufacturing allowing shortening of the manufacturing time of the mould and decreasing the manufacturing cost, comparing with CNC milling of the mould. The mould can be designed using software tools such as CATIA, SolidWorks, Creo etc. In this case study the mould was designed using SolidWorks by Dassault Systemes.

5.1 Low pressure Reaction injection moulding (RIM) with 3D printed moulds

PolyJet technology having main advantages high quality printing, smooth detailed parts and highly accuracy [5, 6], is suitable technique to manufacture 3D printed moulds and tools.

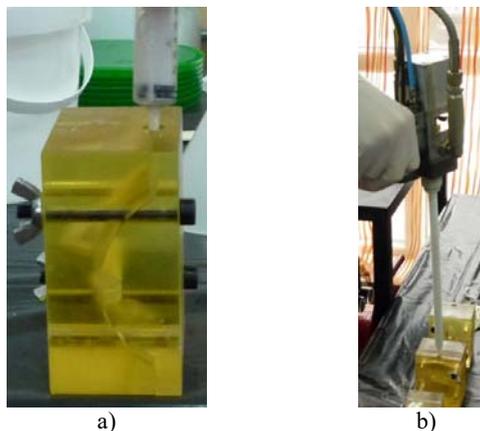


Fig. 5. a) Fill the mould with a syringe, b) RIM with PolyJet 3D printed mould.

Both components of the mould (Fig. 5) were 3D printed by PolyJet, having the cavities oriented upwards and using glossy surface finish. Smooth surfaces with the roughness around of $3.8 \mu\text{m}$ [10] are obtained. In this way the cavities of the mould does not need any post processing operations. The components of the mould (Fig. 5a) are assembled using two screws. An important preparing step, before assembling the components of the mould, is

applying of a release agent on all surfaces of the mould cavity. Using the UNIDOS 100 RIM machine, the polyurethane resin RG53/ G53 from Sika, was low pressure injected into the 3D printed mould (Fig. 5b). The potlife and demoulding time were the same like in the silicon mould reaction injection moulding.

5.2 Plastic injection moulding with 3D printed moulds

In this case, PolyJet 3D printed moulds needs to replace machined injection moulds. The moulding temperature of the thermoplastic materials (PE, PP, ABS, etc) is up to 300°C. Thus, PolyJet injection mould tooling (PIMT) needs to be cool between shots, at a target temperature around 50°C. Digital ABS material [6] is recommended to be used for PolyJet printing of the injection plastic mould. Its mechanical and thermal properties will offer longer mould life and reduced cycle times [9]. Depending on material and part complexity, PIMT are suitable for the injection moulding of up to 100 parts.

6 Conclusions

Rapid tooling based on additive manufacturing is an important method utilized in small series production where the conventional tooling like as CNC milled and spark erosion moulds are expensive. RT integrated into CAD/ CAE/ CAM systems allows rapid product development, low cost optimizing the product in a short period of time, reduce time-consuming mould corrections and increase product innovation.

The paper presents solution for prototyping, functional testing and short-run production applications. PolyJet 3D printed moulds are not production tools. Two different techniques to make moulds with PolyJet technology were experimented: silicon moulding (indirect rapid tooling) and direct 3D printing of mould (direct rapid tooling). Reaction injection moulding and casting techniques were used to fill with polyurethane base resins the moulds. The RIM materials have good mechanical properties comparable with thermoplastic mouldable materials but the potlife is very short. Cast resins have longer potlife than RIM materials. Direct rapid mould is more durable than silicon mould. Thus, using RIM technique can be manufacture up to 50-80 parts in the first case, and 300-500 parts in the second one. The Sika resins can simulate injection mouldable materials. The productivity of RIM is smaller than Injection Mould process but the tooling cost is lower.

References

1. R. Udriou, *3rd WSEAS International Conference on Manufacturing Engineering, Quality And Production Systems*, Romania, 177 (2011)
2. P. Bere, C.Neamtu, *Centr. Europ. J. of Eng.*, **4**, 148 (2014)
3. C.K. Chua, K.H. Hong, S.L. Ho, *Int. J. of Adv. Manuf. Techn.*, **15**, 604 (1999)
4. F. Rayegani, G. C. Onwubolu, A.Nagy and H. Singh, *ASME International Mechanical Engineering Congress and Exposition*, 810 (2014)
5. R. Singh, *Int. J. of Autom. and Mech. Eng.*, **6**, 777 (2012)
6. ***, *Stratasys Ltd*, <http://www.stratasys.com> (2017)
7. ***, *Biresin® Low pressure RIM-system and casting*, Sika Group (2010)
8. R. Udriou, A. Nedelcu, *Optimization of Additive Manufacturing Processes Focused on 3D Printing in Rapid Prototyping Technology - Principles* (Intech, 2011)
9. B.O. Thorsten, *The AM Magazine*, **6**, 8 (2015)
10. R. Udriou, L.A. Mihail, *Proceedings of the 8th WSEAS international conference on circuits, systems, electronics, control & signal processing*, Spain, 283 (2009)