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The scope of application of incremental rapid prototyping methods in foundry engineering

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Abstract
The article presents the scope of application of selected incremental Rapid Prototyping methods in the process of manufacturing casting models, casting moulds and casts. The Rapid Prototyping methods (SL, SLA, FDM, 3DP, JS) are predominantly used for the production of models and model sets for casting moulds. The Rapid Tooling methods, such as: ZCast-3DP, ProMetalRCT and VoxelJet, enable the fabrication of casting moulds in the incremental process. The application of the RP methods in cast production makes it possible to speed up the prototype preparation process. This is particularly vital to elements of complex shapes. The time required for the manufacture of the model, the mould and the cast proper may vary from a few to several dozen hours.

Key words: Rapid Prototyping, casting, Rapid Tooling

1. Introduction

The Rapid Prototyping and Rapid Tooling methods are utilized in the process of fabricating prototype casts with the use of metal alloys [1-7].

One of the first incremental RP methods to be applied in foundry was the LOM technique, which consists in the formation of the casting model from paper layers. The method is rarely used nowadays. It has been superseded by methods in which models are made of acrylate and epoxide resins, such as SL and JS.

Another group of methods is based on the formation of the model from layers of thermoplastic materials (ABS, wax) [8-12].

Yet another group of RP methods is comprised of Rapid Tooling incremental systems that enable the fabrication of casting moulds using powdered moulding materials (ZCast-3DP, VoxelJet, ProMetalRCT) [13-19].

The selection of the RP method for the casting process requires an understanding of its technological parameters and a knowledge of the areas of its application as well as the role of the method in the casting process. For this reason, an attempt has been made to conduct an analysis of the incremental RP methods which are most commonly applied in casting technologies (fig. 1 and 2).

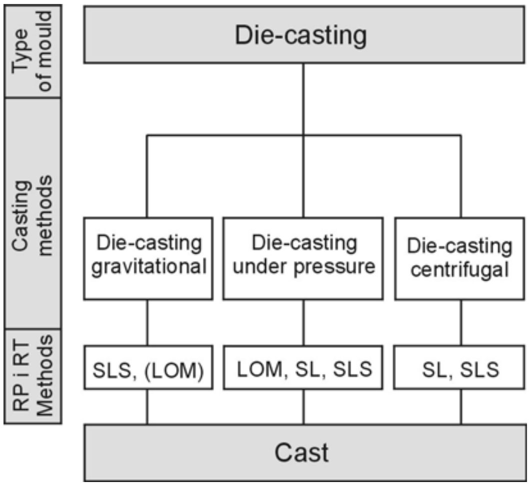

Fig. 1. Possibilities of incremental RP systems application in die casting of metal alloys

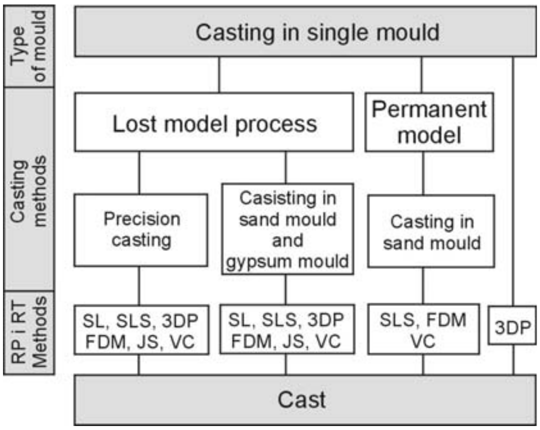

Fig. 2. Possibilities of incremental RP methods application for casting in expendable moulds

2. RP methods used in foundry engineering

2.1. Methods based on photopolymerization

Models made of photopolymer can be produced in the incremental process by means of two methods. In one of them, the model layer is formed by hardening fluid resin with a layer beam [11]. In the course of the process, the model being constructed is placed on the working platform in a container with fluid resin (the SLA method – fig. 3a).

In the other method, the model layer is formed by printing fluid polymer from the print head and hardening it by the UV light emitted from a lamp integrated with the print head (JS – Jetting Systems). During the formation of the model, two materials are applied onto the working platform: the material of the model and the material supporting the model. Models are built up on the working platform moving along the vertical axis (z) of the working space. Successive layers of polymer are applied by the print head in the parallel plane of the working platform (x, y).

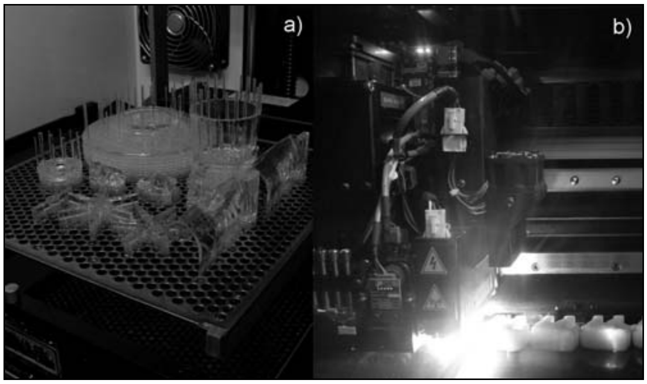

Fig. 3. Working chambers of RP devices: a) SLA 250 – SL System, b) EDEN 250 – JS System

Manufacturers of devices and materials for this kind of machines assure that their offer includes materials which can be utilized directly in the production of casting models for the technology of precision casting. An example of this is the SL5170 resin used in the SLA method. Figure 4 shows a rotor model made of SL5170 (fig. 4a) and a ceramic mould formed with the application of stereolithographic models. It should be borne in mind, though, that resins used in the SLA and JS methods are polymeric materials, which require a special construction of the ceramic mould and a special technology for removing the models from the mould.

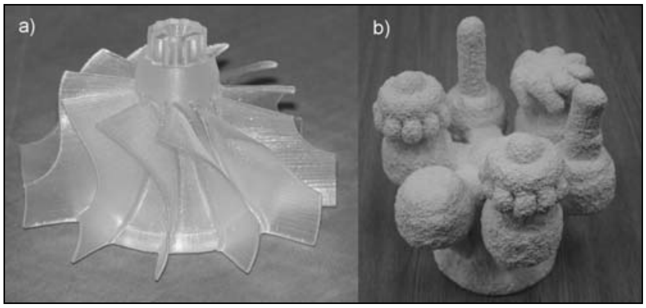

Fig. 4. Turbine rotor SLA model (a), ceramic mould (b)

The JS technology is developed by two tycoons of the RP market: 3D Systems –the InVision system and Objet – the PolyJet^{TM} system (fig. 3b), represented by the Bibus Menos company in Poland.

2.2. Methods based on powders sintering

Methods based on the sintering of powders by a laser beam (SLS – Selective Laser Sintering or SLM – Selective Laser Melting) consist in sintering the surface of a powdered material by a laser beam [13]. The physical model is constructed on the basis of the 3D-RP geometry saved e.g. in the STL format. The material, in the form of polymer thermoplastic powders, ceramics or metal alloys, is spread on the working platform layer wise (fig. 5). The layer is then fused by the laser beam according to the section defined in the process of the model division into layers.

Fig. 5. SLS device – EOS Formiga (a), device working chamber (b), model produced by SLS method (c)

The application of a method based on sintering powders is dependent on the properties of the powdered materials. The method can be used for the manufacture of casting models and moulds.

Casting models made of polymer powders utilized in the SLS method require a special construction of the ceramic mould and a special technology for removing the models from the mould.

Models fabricated by the SLS technology serve as a basis for the production of casting sand moulds.

There are several manufacturers of RP devices based on sintering powders. The leading companies include: 3D Systems – SLM and EOS – SLS, represented by Bibus Menos in Poland.

2.3. Methods based on powders bonding

Methods based on bonding powders can be called spatial printing techniques. They consist in bonding a powdered material into layers by means of a binding agent applied by the print head. These methods are usually used for the direct manufacture of casting moulds in the Rapid Tooling process (e.g. the 3DP-ZCast method – fig. 6).

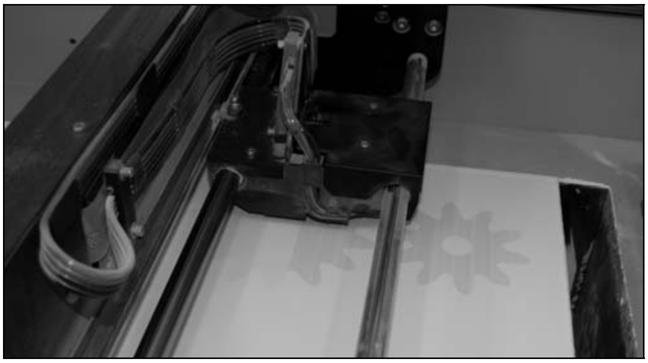

Fig. 6. Print out of model layer by 3DP method – Z510 Spectrum printer

The printing process starts with the application of a layer of powder from the supplementary container by means of a system that moves the piston in the device cylinder. The powder is then spread by a roller on the surface of the working platform and covered with a binding agent. This is the way of forming a model layer. The working platform is lowered in accordance with the layer thickness and the cycle is repeated [15, 16].

When the process is finished, the ready mould (fig. 7a) should be cleaned off excess powder. Next, the mould is hardened through infiltration and heat treatment. Prepared in such a way, the mould can be filled with an alloy (fig. 7b).

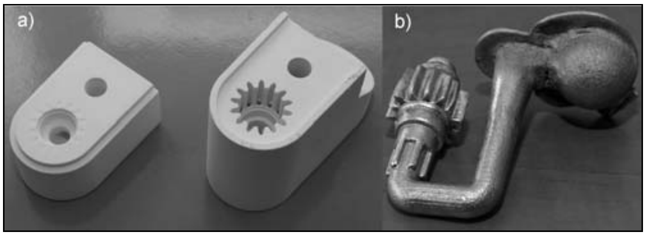

fig. 7. Casting mould produced by ZCast 3DP method (a), cast – gear wheel (b)

Incremental Rapid Tooling methods enabling the direct manufacture of casting moulds also include systems based on bonding powdered casting materials of the ProMetalRCT and VoxelJet types [17-19]. In these methods, the casting mould is formed in a layer wise process (fig. 8).

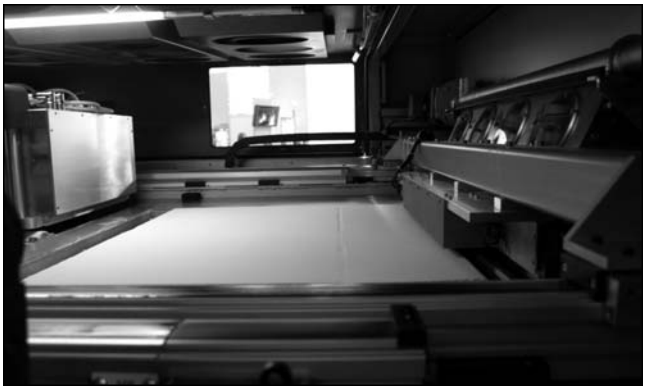

Fig. 8. Layer application in VoxelJet device chamber

The mould is formed using moulding sand whose granularity ranges from 0,09 to 0,20mm. Furan resin fulfils the role of a binding agent. The working space of the Voxeljet VX device (fig. 9) has the following dimensions 850x450x500mm [17].

Fig. 9. VoxelJet VX800 device

The ProMetalRCT technology also enables the manufacture of casting moulds (fig. 10). The working space of the ProMetal RCT MAX printer (fig. 11) has the following dimensions 1800 x 1000 x 700 mm. The thickness of the layer built with the use of this printer ranges from 0,28 to 0,5mm. The printing speed (mould volume growth) ranges from 59400 to 108000 cm^3/h [19].

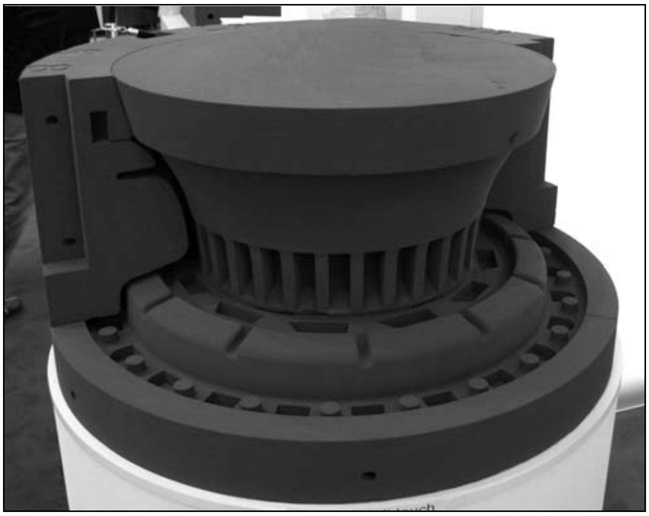

Fig. 10. Diffuser mould section printed out by ProMetal RCT device

2.4. Methods of layer wise thermoplastics binding

Methods based on binding a plasticized material layer wise consist in building up the model from layers by embossing or spraying the material, e.g. polycarbonate, ABS or wax, which is first heated in the head and fluidized.

Fig. 11. ProMetal RCT MAX device

The head nozzle is placed in the body having the possibility to move vertically and horizontally, which enables the positioning of the material layer in the working space in line with the section geometry.

The applied layer (e.g. in the Fused Deposition Modeling method – FDM) hardens as soon as it flows out of the nozzle, binding with the previous layer (fig. 12).

During the model formation, the other nozzle embosses a material which supports the model proper. This material is also used to join the model proper with the working platform. The supporting structures created simultaneously with the model are removed after the whole object is formed.

The supports are often made of a water-soluble material, which makes them easy to remove [12, 13].

Fig. 12. RP FDM U-Print device

These methods include incremental FDM Stratasys systems – represented by Solveere and ProSolutions in Poland.

Wax casting models can be manufactured by spraying layers of fluidized wax. There are two essential technologies: DodJet [20] used in devices produced by Solidscape^{TM} (fig. 13) and the ProJet technology applied in the devices of the 3DSystems company [21].

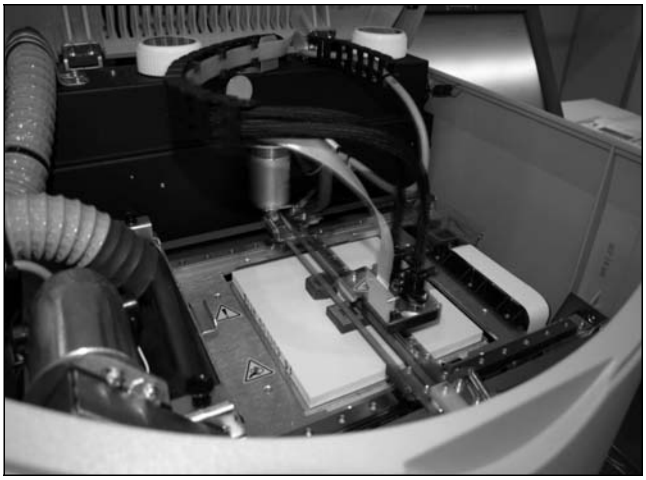

Fig. 13. Solidscape device during the formation of wax casting models

3. Conclusions

Comparing the individual methods in terms of savings, it may be concluded that the application of RP methods decreases the costs of the prototype cast manufacture. This is largely due to the shortened time required for the formation of the casting model and the mould.

For the majority of RP methods, the accuracy of the models production is satisfactory, in comparison with the demanded accuracy of the cast. The most accurate RP methods (e.g. SLA) make it possible to manufacture very complicated and precise casting models.

Rapid Tooling methods are used in the fabrication of prototype moulds. These moulds, in turn, can be utilized in the construction of individual casts and testing of gating systems for solutions later applied in batch production.

An analysis of selected casting methods, both conventional and those relying on RP (tab. 1), indicates that the application of RP speeds up the process of the prototype cast manufacture. This results from the short time required to form the casting model and the mould in RP and RT methods.

Table 1. Description of selected methods for the manufacture of prototype casts

Casting technique / Parameter	In moulding mass, traditional	In plaster mould, tradition al	Precision casting, traditional	Precision casting with RP – SLA, JS, SLS	Precision casting with RP – FDM, ProJet, DodJet	Precision casting with RP ZPrint	RP – RT 3DP- ZCast, VoxelJet, ProMetal
Cost – unit cost of production	low	average	very high	average and high	average	average and low	low
Cost – job-lot production	low	average	high	average	average and low	low	low
Cost of model	average and high	average and high	high	average	average and low	low	Lack/N/A
Time of cast formation	average	average	long	average	average	average	short
Time of model formation	long	long	long	average	average and short	short	Lack/N/A
Maximum weight [kg]	no limitations	113,6	13,6	13,6	13,6	13,6	56,8
Cast tolerance, mm	±0,75	±0,10	±0,08	±0,08	±0,15	±0,20	±0,40
Min section thickness, mm	4,0	1,0	1,3	1,3	3,5	1,3	3,0
Surface quality	satisfactory	good	very good	above good	good	good	sufficient
Possible complexity of cast shape	satisfactory	very good and the best	the best	very good and the best	very good	very good	very good
Kind of alloy used	no limitations	Al, Mg	no limitations	no limitations	no limitations	no limitations	up to 1100°C

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