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ARCHIVES
of
FOUNDRY ENGINEERING

ISSN (2299-2944)
Volume 19
Issue 4/2019

95 – 98

10.24425/afe.2019.129637

16/4

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

Application of 3D Printed Casting Models for Disamatch Forming Method

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Received 12.07.2019; accepted in revised form 23.09.2019

Abstract

This paper presents results of a research on the possibilities of applying 3D printed casting models for small production series as alternative to traditional tooling production on automated DisaMatch mould production lines. The main task was to verify and compare the dimensions of the 3D printed models before and after moulding process. The paper discusses main advantages and disadvantages of the 3D printing methods used like FDM (Fused Deposition Modeling)/FFF (Fused Filament Fabrication), SLA (stereolitography) and DPP (Daylight Polymer Printing). Measurement of casting model outside dimension change resulting from moulding sand friction on their surface was made with the use of GOM INSPECT software on the basis of 3D scans made with ATOS TripleScan optical scanner. Hardness of 3D printed models made of ABS, Z-ULTRAT, three different photopolymer resins (from FormLab and Liquid Crystal companies) was verified. The result of the research printed models usability for the foundry industry was presented.

Keywords: Rapid prototyping, FDM, DPP, SLA, Casting models

1. Introduction

High costs of unit or small-lot production have a direct impact on the final cost of the product offered. Hence due to high costs of the necessary equipment (dies, casting models, model plates, core boxes, etc.) the casting process itself is unprofitable. The most common method of foundry tools production is loss treatment with the use of multi-axis CNC machine tools.

In the 80s of the last century, there used to be modellers in every foundry. They used to produce the necessary equipment manually or using conventional machines based on the supplied technical drawings. The development of computers and the continuous growth of industry automation, which is currently called the Industry 4.0 [1], has reduced the role of or sometimes caused complete disappearance of the traditional modeller's profession in favour of computer spatial solids designer.

Currently, the rapid development of incremental technologies has contributed to a significant drop in prices of 3D printers offered on the market, which made them more available to various industries. Further to the above, there is a necessity to analyse the possibilities of their application in the foundry industry as a device for quick and cheap production of foundry equipment such as e.g. casting models or core boxes [2, 3, 4].

One of the cheapest and most common methods of 3D printing is the FDM/FFF technology. It consists of multiple application of plasticised plastic material bond to each previous layer until a complete model is obtained (Fig. 1). Currently, dual-head printers are becoming ever more popular. Thanks to using an additional nozzle they enable printing supports made of another material, which makes it easy to separate the supports in post-processing. The main limitation of this method is the layer thickness, usually of about 0.09 mm.

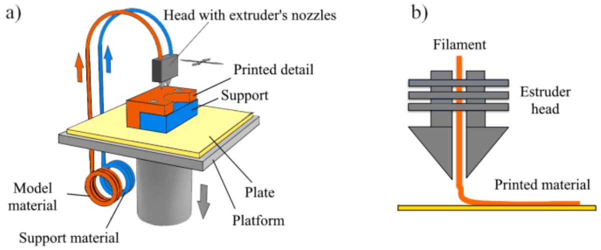

Fig. 1. FDM/FFF operation principle: a) general scheme, b) applying plasticised material [5, 6]

In order to eliminate this disadvantage and thus to reduce the surface roughness value using photopolymer printing technology, e.g. SLA or DPP might be considered.

Stereolitography is the oldest 3D printing method. The official birth date of this technology is 1984, when Charles W. Hull patented his prototype. This technology is one of the most accurate with the minimum layer thickness of 25 micrometres [7]. The method is based on top-down or bottom-up irradiation of a liquid resin with a laser beam, thanks to which a printed 3D model is created as a result of the polymerisation process (Fig. 2).

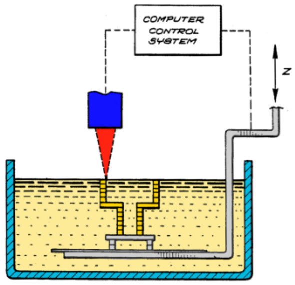

Fig. 2. SLA printer with a top irradiation system operation principle [based on 8]

Another method applicable to photopolymer printing is the DPP technology, which is one of many current classic SLA method developments available on the market. Specially developed photopolymer resin crosslinks under the influence of LCD display light replacing the laser beam as shown in Fig. 3.

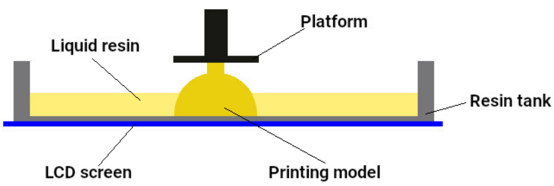

Fig. 3. DPP printer operating principle

Apart from a reduced electricity consumption, the type of energy carrier and material, the technology differs from stereolytography also by the quality and nature of the external surface as the surface cross-section depends on the resolution number (pixel number) of the screen used.

The amount and cost of the 3D printing technologies to apply is connected to the necessity to thoroughly analyse the future equipment requirements. A foundry producing pump bodies or semi-finished products will purchase a 3D printer different to the one bought by a goldsmith producing high quality finished goods.

2. Research methodology

The wear resistance of printed casting models was tested on the example of models the share of selected dimensions of which are shown in Fig. 4. The designed geometry takes into account casting curves and fillets in models used in the selected foundry as well as inscriptions of 1mm thickness denoting the material they were made of.

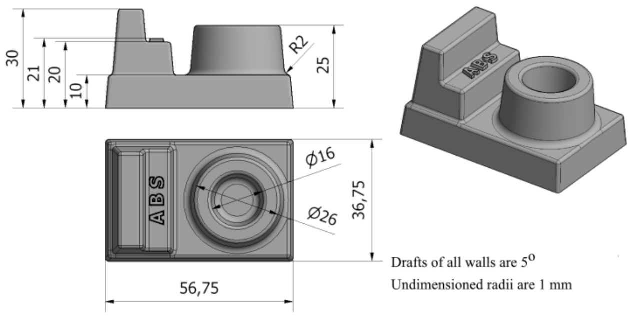

Fig. 4. CAD geometry dimensions of a casting model

Taking into account the technology availability, time and cost of producing a single casting model the authors decided to print samples using FDM, SLA and DPP technology 3D printers. In order to examine the impact of moulding sand on the shape of the printed model more accurately, 5 prints were made of various materials. Selected printing process parameters are shown in table 1.

Table 1.
Casting model printing parameters set

Sample number	1	2	3	4	5
Printing technology	FDM	FDM	DPP	DPP	SLA
Marking	ABS	ULTRAT	CASTABLE	HARD-R	BLACK
Printer	Zortrax M200	Zortrax M200	LiquidCrystal HiRes	LiquidCrystal HiRes	FormLab Form1+
Material	filament Z-ABS	filament Z-ULTRAT	Light-curing resin	Light-curing resin	Light-curing resin
Layer thickness [mm]	0,09	0,09	0,1	0,1	0,1
One model priting time [h:min]	3:20	3:22	4:20	5:15	3:30
One model material cost	0,7 $	1,24 $	3,5 $	3 $	7 $

Material hardness was the selection criterion for printing casting models. Models printed of various materials are presented in Fig. 5.

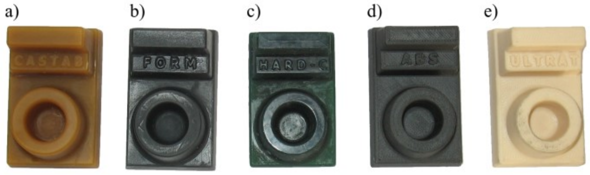

Fig. 5. Casting models printed by
FDM (d, e), DPP (a, c), SLA (b) methods

The models were subject to the Shore D hardness test using a Shore D HDB hardness tester mounted on a tripod. Surfaces marked in Fig. 6 were measured 5 times and the arithmetic average was calculated.

Fig. 6. Hardness test places (marked in white)

Before placing the models on the model board external values were measured using an ATOS Triple Scan optical scanner with the measurement accuracy of 0.1mm. Thus a spacial surface model was received.

After scanning all 5 models were attached to the pattern plate (Fig. 7) and then covered with a DEMOTEX S separator.

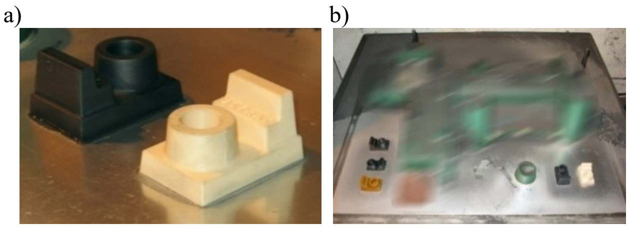

Fig. 7. Printed models: a) attached casting models, b) placing the casting models on a 711x822 mm model board

The DISA MATCH 28/32 automatic moulding line was used for the moulding sand compaction process. The total number of moulding was 213.

In order to analyse the model dimension change resulting from the moulding sand impact on the models' surface, external measurements were made again.

Dimensional changes of the actual models (before and after the forming process) were interpreter using the GOM INSPECT software, which analysed the map of dimensional deviations from the designed CAD model (nominal dimensions). The places of the analysed measurement points are shown in Fig. 8.

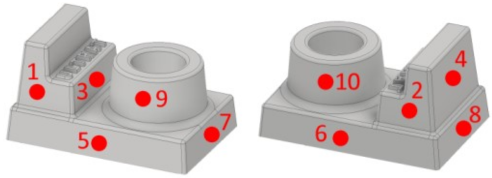

Fig. 8. Dimensional deviation's analysed places before and after the forming process

3. Research results

Casting models hardness measurement results including the material used are presented in Fig. 9.

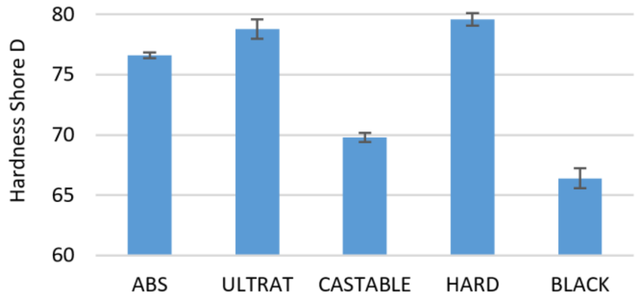

Fig. 9. Analysed deviation places

Regardless of the printing method used the measured model hardness is in accordance with the information provided by the manufacturers. Z-ULTRAT (FMD/FFF technology) and HARD resin (DPP technology) are the hardest with the hardness of about Shore 78D, so in theory they should be the first taken into account for foundry applications. CASTABLE resin (DPP technology) dedicated for jewellery applications has the hardness lower by about 13% and the BLACK resin (SLA technology) – by some 16%, which may have a significant impact on the abrasive wear of models for a large moulding series.

Table 2 presented the measured model dimension deviations before and after the forming process

Table 2.
Dimension changes in the analysed places of the printed models (in mm) before and after moulding

No	ABS	ULTRAT	CASTABLE	HARD-R	FORM
1.	-0,02	-0,18	-0,20	-0,04	-0,07
2.	+0,03	-0,15	-0,27	+0,03	-0,02
3.	+0,05	-0,01	-0,08	-0,10	-0,03
4.	+0,03	+0,06	-0,02	-0,07	-0,05
5.	-0,15	-0,05	-0,05	-0,08	+0,01
6.	-0,12	-0,01	-0,11	-0,03	-0,03
7.	-0,02	-0,03	-0,08	-0,02	-0,10
8.	-0,04	-0,03	-0,04	+0,01	-0,06
9.	+0,01	-0,07	-0,11	-0,03	+0,02
10.	-0,07	-0,16	-0,15	+0,02	-0,06

The research shows that model dimensions before and after moulding practically remain unchanged, so 3D printing technology is possible to use in making casting models for small casting series and the dimension deviations fluctuated within the measurement error of the Atos Triple Scan optic scanner.

When using printed models for small production series additional factors must be taken into account. The first one is the cost of the material used for printing. Table 1 clearly shows that the FDM/FFF technology offers definitely cheaper materials than the photopolymer printing. Production costs of the cast model presented by the authors using the SLA technology was 10 times more than that of the FDM/FFF, whereas in case of the DPP technology it was merely 5 times. The second factor is the preparation and finishing time as well as post-processing, which among others includes resin tank preparation, cleaning the platform before printing, removing the printed model, mixing resin, cleaning the resin tank, removing supports and hardening the model. Taking the above into account, the FDM/FFF has undoubted advantages over the DPP and SLA as the next printing preparation time is several times shorter. In case of the printed surface quality factor and the model edge sharpness the DPP and SLA technologies are more accurate. In case of FDM/FFF the model should be additionally grinded with sandpaper to even out the surface between subsequent printed layers.

4. Conclusions

The most important conclusions encompass:

- It is possible to use the 3D print technology to make casting models for small casting series,
- The printed models were characterised by sufficient compressive strength for machine forming applications,
- When choosing the print technology the time for creating models should be considered, so the printing itself as well as the time of preparation and finishing, which in case of the DPP and SLA technologies have an important influence on the whole process.

Acknowledgements

The research was supported by 02/25/SBAD/4630 project realized at Poznan University of Technology

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