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Rapid Prototyping Technology Using for Casting Process of Mini Turbine Runner

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Abstract

The previous mini-hydrogenator rotors' prototypes were made of ABS thermoplastic material with use of fused deposition modelling (FDM). However, there is a need for such rotors made of metallic materials with higher strength. In paper three dimensional printing (3DP) as rapid prototyping technology, was presented, to execute a shell mould of rotor prototype. In initial phase, the moulds were prepared which allow to cast a simple geometric solid with different alloys, for comparative reasons. The form of rotor and testing cast moulds were designed using universal CAD environment and printed composite using material zp151 (Calcium sulfate hemihydrate) with a binder zb63 (2- pyrrolidone) for preparation of colourful presentation models or casting models. The suitability of technology usage with alloys of copper , aluminium and zinc, was analyzed. The strength of the mould during casting, a material resistant to high temperature, the quality of received casting and its surface roughness were assumed as the comparative parameters which characterized method.

Keywords: Innovative Foundry Technologies and Materials, Rapid Prototyping, Ceramic Moulds, Mini-turbine Runner.

1. Introduction

Miniature hydrogenerator of electricity energy transform flow of water streams for electricity. The main unit of these machines are various turbines, transmission parts and generators. In the past few years, interest of those type of devices in water and sewage sector, was increased [1]. A very important factor influenced on device efficiency is a water turbine. Its geometry is created as a result of flow analysis, strength and working conditions. Also producibility and feasibility are very important parameters.

In previously built prototype constructions, turbine performed using Rapid Prototyping systems (RP) as FDM technology [2], was used. Simplicity of performing, allowed for laboratory researches of very complex rotors geometry, but with requirement of rotors which is made from metal. In foundry, RP technologies are mainly used to perform: casting models for the sand formation or shell moulds execution by melting or burning plastic models or wax [3,4]. Issue of plastics used on models made with RP methods, is broadly described in paper [5].

Materials and printers devices that can produce moulds for direct filling, can be found in 3DP manufacturers offer [6]. However, such machines are not very popular and have many limitations taking consideration presentation aspects.

For making moulds used for direct metal casting, ZCast501 powder is used. Rotor moulds prototype for direct metal casting, expand technological capabilities taking into consideration relatively low cost. To execute this mould, modern universal 3D printers and high-strength composite powder which are made colourful presentation or casting models, was proposed to use.

2. Material and method

On the base of numerical analysis, solid model was designed of primarily for mini-wheels casting of copper alloy in Solid Works environment (Figure 1).

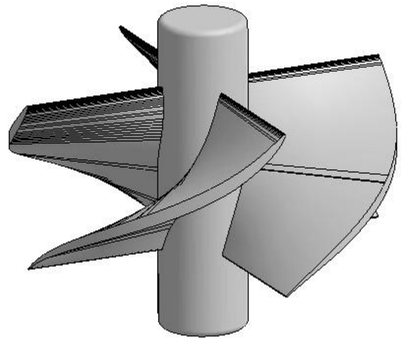


Fig. 1. Mini turbine runner

For comparison, moulds were prepared from zp151 material with a binder zb63, printing its using ProJet 660Pro machine of 3DSYSTEMS. Before performing of proper rotor casting, test were done using solid model (Figure 2). Trough solid model geometry, it was possible to analyze: possibility of casting thin walls and walls with small inclination, surface roughness measurements. The brass CuZn37 and silumin AK11 with low-melting zinc alloy Znal5, were used for casting. Basic chemical composition and alloy casting temperatures were presented in Table 1. To facilitate filling, printed moulds were placed in a box and covered with moulding compacted sand. (Figure 2c).

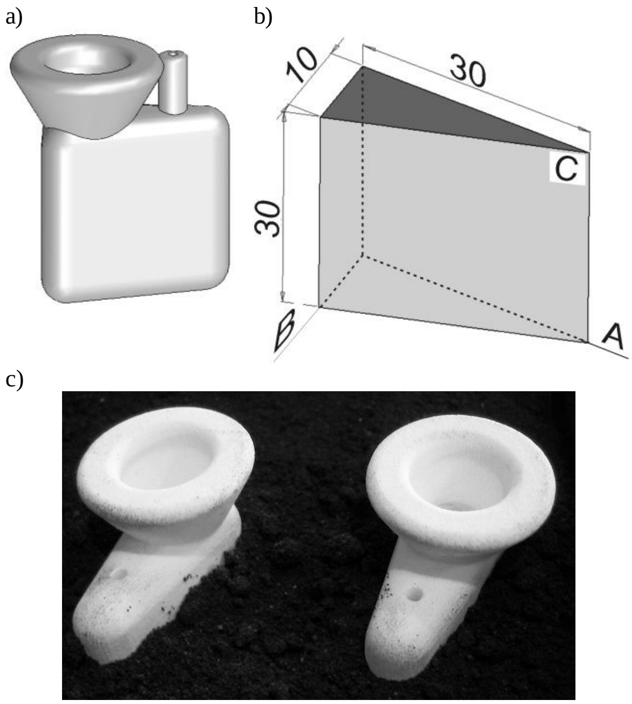


Fig. 2. Mould for direct metal casting using RP: a) 3D solid model, b) inside geometry, c) printed moulds placed in a box and covered with moulding compacted sand

After results analysis and possibility of using the method to form rotor prototype, the rotor cast will be made from zp151 powder with binder zb63, taking into consideration technological and machining tolerance (Figure 3). The runner was not included in Figure 3, for economic reasons it was made as an additional element.

Table 1.
Alloys basic composition and casting temperatures

Alloy	Alloys basic composition	Casting temperature
	%	K
Znal5	Zn 95, Al 4, Cu 1	693
AK11	Al 89, Si 11	973
CuZn37	Cu 63, Zn 37	1323

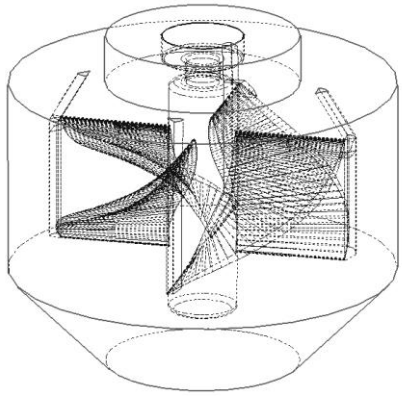


Fig. 3. Ceramic mould for direct metal casting of hydroturbine rotor using RP 3DP technology

3. Results and discussion

Castings were inspected, its geometry and roughness were measured after extracting.

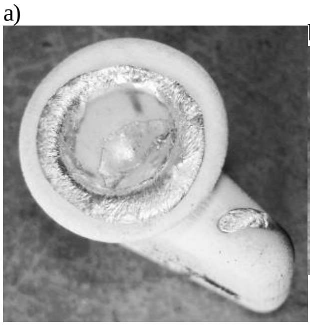
In the described cases, initially concluded that the material used to build ceramic moulds allows to obtain a satisfactory quality of the casting in a temperature range not exceeding 973 K.

3.1. Effect of temperature

Based on visual inspection, it was found that the ceramic material can be used for mould with direct metal casting of aluminium or zinc alloys. In the case of lower filling temperatures (about 673 K) mould material sustain its density and hardness. The effect of temperature is noticed to a depth of approximately 1 mm of mould wall without affecting significantly on casting process (Figure 4a). With increase of temperature it was noticed that mould material colour changes and degradation of its structure is. Material discolouration indicates on mould strength decrease.

Strong gassing and smoke from burned-up binder (Figure 4b) was also noticed. The printed ceramic material heated to 973 K is deprived of binder, but still retains consistency with a low hardness.

a)



b)

Fig. 4. Ceramic mould after pouring: a) ZNAL5, b) AK11

Mould for brass filling was placed in a box with compacted sand as the other moulds. Before pouring mould was dried and heated to a temperature of 373 K. Liquid metal effects on binder, which was partially burned which bonded ceramic powder (Figure 5). Pigmentation were noticed, due to heat influence, dark layers were noticed on inner walls of the mould. Characteristic wall layered structure, as a result of mould performance using 3DP, was observed also.

Difficulties in fulfilment of mould by alloys was caused by strong gassing. The quality of the cast was very low. It is necessary to mention that the moulds were not specially prepared for pouring process. They were not impregnated or strengthened additionally.

Before non-ferrous alloys pouring, it is recommended to prepare mould by burning out at 973 K until white colour receiving. Nextly, to improve strength and heat resistant of mould, soaking is required.

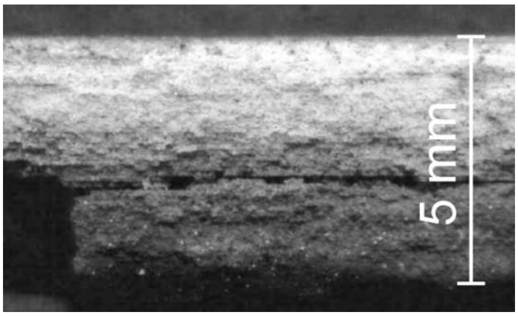


Fig. 5. Thermal degradation of ceramic mould wall (alloy casting temperature 1323 K)

3.2. The quality of die cast

Rapid prototyping 3DP technology is incremental application of successive layers of material, in present case of ceramic powder. The layers are visible in the moulds. This effect is not visible on the planes perpendicular to the axis of increments (Z-axis of the machine). On the other planes more or less is visible like stairs structure. Surfaces easily accessible can be smoothed mechanically, but it is not possible to make it with confined spaces. The received castings copy mould surfaces, thus obtained surface smoothness is related to their arrangement with respect to the mould axis increases. The highest smoothness was observed for area A (Figure 2b). The results of roughness measurements were presented in Table 2.

Table 2.
Casting surface roughness, designation of walls in accordance with Figure 2b

Alloy	Casting surface roughness Ra [um]		
	Wall		
	A	B	C
Znal5	4.6	10.2	11.9
AK11	6.4	7.8	10.7
CuZn37	5.7	11.7	12.1

Printing a closed mould also poses an additional difficulty in the removal of interior loose, binder-free building material. This is important in the case of ribs and channels with small cross sections and small inaccessible space. To facilitate the removal of unbound building material and possibly give you the opportunity to smooth internal surfaces can be used directly mounted split mould before pouring. This prevents the formation of misrun. In Figure 6 is shown the case in the near of the riser (the right side). After closer inspection the mould after removing the cast, it was found that the cause of this defect is compacted ceramic powder Not exactly removed from the mould.

Fig. 6. Zinc alloy cast

4. Conclusions

The obtained results allow to conclude about possibility of using 3DP technique for casting moulds with direct metal casting using zp151 powder with a binder zb63. This solution is notable for the low casting temperature alloys for example Znal5.

During mould designing and printing processes, casting surface arrangement should be taken into consideration. Surfaces with large smoothness requirements, should be perpendicular or parallel to growth axis.

To facilitate material removing process from interior of the mould or to allow for additional mechanical smoothing of inner surfaces, split mould can be used. In the case of aluminium alloy or copper casting mould, binder should be removed by burning its at about 973 K and afterwards consolidate the moulds with high temperature resistant material. Burned-up binder zb63 strongly gassed preventing filling of mould with metal.

Acknowledgements

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References

[1] Kaczyński, R., & Hościło, B. (2013). Prototype of Mini-Electric Power Generator for Use in Flow Channel. In XXVI Sympozjon Podstaw Konstrukcji Maszyn : 50 lat Podstaw Konstrukcji Maszyn, 09-13.09.2013 (p. 63). Poland: Politechnika Śląska, Katowice

[2] Kaczynski, R., Wilczewska, I., & Hoscilo, B. (2012). Construction analysis of mini-generator of electric energy using working medium flow as the working environment. *Key Engineering Materials, Vol. 490*, 45-53.

[3] Macku, M., & Horáček, M. (2012). Applying RP-FDM Technology to Produce Prototype Castings Using the Investment Casting Method *Archives of Foundry Engineering, Vol. 12*(3/2012), 75 – 82.

[4] Budzik, G. (2007). Properties of made by different methods of RP impeller foundry patterns. *Archives of Foundry Engineering, Vol. 7*(2/2007), 83 – 86

[5] Jesiotr, M., & Myszka, D. (2013). Thermal Analysis of Selected Polymer Materials for Precision Casting Models *Archives of Foundry Engineering, Vol 13* (2/2013), 61 – 64

[6] Chhabra, M., & Singh, R. (2011). Investigation of Optimum Shell Wall Thickness of Digitally Produced Shell Moulds for Brass Casting Using ZCast Direct Metal Casting Process. *MIT International Journal of Mechanical Engineering, Vol.1, No. 2*, pp 84-92