Study of abrasive resistance of foundries models obtained with use of additive technology

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Abstract. A problem of determination of resistance of the foundry models and patterns from ABS (PLA) plastic, obtained by the method of 3D printing with using FDM additive technology, to abrasive wear and resistance in the environment of foundry sand mould is considered in the present study. The description of a technique and equipment for tests of castings models and patterns for wear is provided in the article. The manufacturing techniques of models with the use of the 3D printer (additive technology) are described. The scheme with vibration load was applied to samples tests. For the most qualitative research of influence of sandy mix on plastic, models in real conditions of abrasive wear have been organized. The results also examined the application of acrylic paintwork to the plastic model and a two-component coating. The practical offers and recommendation on production of master models with the use of FDM technology allowing one to reach indicators of durability, exceeding 2000 cycles of moulding in foundry sand mix, are described.

1. Introduction

In article [1], Singh, S. & Singh examined in detail the areas of application of additive technologies for the castings manufacture for various purposes. In study [2, 3], D.L. Bourell and professor Ravi performed a qualitative review of the trends of foundry production with an emphasis on the use of 3D printing technologies, including a detailed roadmap. If the existing approaches extend to increasing transition to additive technologies in casting for investment and gasification models, then in the long term, two long and separate trends can be distinguished. The first is the use of additive technologies for the manufacture of foundry equipment in place of traditional wooden (for mass production of castings). The second one is a complete transition to metallic 3D printing of finished parts. Professor Leushin et al. [4] investigated the features of the use of the solid model of foundry equipment, manufactured using technology of layer-by-layer application of ABS plastic. The choice of this plastic as a material for foundry equipment showed a significant increase of its service life over the foundry equipment, which made from wood materials.

Also, the problems of using FDM (Fused deposition modelling) technologies for foundry models manufacture are well known. The problems of surface condition and surface finish for investment casting process are described in article [5], the traditional wax patterns have higher surface roughness indicators than plastic models do. The problems of surface condition and surface finish for the investment casting process are described in [5]; the wax patterns have higher surface roughness indicators than plastic models. Partially, this problem can be solved by chemical post-treatment of the surface of ABS and PLA plastic models, but this process will lead to a rise in the cost of disposable models. The problem of dimensional accuracy of models obtained using 3D printing is known and described. In works [6, 7], the authors carried out the research and issued recommendations on prevention of warping and distortion of printed models.

One of the perspective directions of FDM in foundry technology is the production of auxiliary templates for both mould stabilization and core manufacturing, the technological advantages of such methods are disclosed in [8]. Also FDM technology is very promising for the development of new foundry technologies, which require a large number of iterations on geometry, including the use of the methods of geometric and topological optimization [9].

2. Methods and Technology for Research

The foundry equipment for the obtaining of prints and cavities in sandy mould is considered as the main direction in this paper. The main indicator of the quality of technological equipment is its life cycle, i.e. resistance to wear and destruction. Green sand casting, Alfa-Set process and manual moulding are chosen as a technological process of forming. Traditionally, plastic equipment is not used in such technological processes, or it is used very narrowly, as it does not stand competition with metal equipment in terms of "wear" and "durability" and with wooden equipment in terms of "production cost" and "manufacturing speed". At present, the cost of professional model set made of plastic exceeds the cost of wooden equipment approximately five times. This is also due to the cheapening of wooden models, since they are manufactured on CNC machines, and plastic models are still extruded into a metal mould, which is extremely expensive. Therefore, the use of equipment made of plastic is justified only for large runs of castings, as well as for large industrial enterprises that are equipped with modern moulding facilities.

The main task of this paper is the development of apparatus and techniques for studying of the foundry model equipment wear that was printed on a 3D printer made of ABS and PLA plastic. Under wear, let us consider the conditions of abrasive and shock power interaction with the sand mixture at a print forming. The options of protective coatings (composite and paintwork) for foundry models and an estimation of their cost were investigated additionally.

The quantity of renting (contact) for the plastic patterns has a rather wide interval and can vary from 100 to 10000 without repair. Thanks to use of special additives at production of polymeric materials the foundry equipment from plastic considerably increases the resistance to shock loading and abrasive wear. However, the use of plastic as material for the foundry equipment is limited due to first of all the high price of material. Besides, production of the plastic equipment requires the special expensive equipment.

FDM technology allows to overcome price and technological barriers, but in its turn has limitations on dimensional accuracy of models and applied materials (there is no possibility to use high-strength plastic with additives). The commercial component of this process is described in sufficient detail in dissertation [10]. At the same time, only plastic materials with standard properties are present as consumable threads from ABS and PLA in the open market. Plastics reinforced with additives are not currently available. Functional properties of plastic here are increased strength to deformations, shocks, a high range of operating temperatures (from -40 to + 90°C), resistance to the influence of aggressive chemicals (acids and alkalis used in foundry production). At the same time, models made of plastic are environmentally friendly for humans, they are durable and reliable.

Authors in study [11] included the production of the standard model or master model with the use of additive technologies in the technological process of the model equipment manufacturing for further production of the promo model and working models.

3. Preparation and production of test samples

The most common model of 3D printer - Makerbot Replicator 2, was used for production of the castings model and pattern made by ABS and PLA (with a standard plastic thread).

Print settings were selected as follows: Object infill (%)=15; Layer height (mm)=0.15; Feedrate (mm/s)=75; Travel Feedrate =120; Print temperature =230, the temperature regime of table heating and the printing speed were chosen on the basis of surface quality parameters, the volume of filling varied for different options of models. The initial test samples are shown in fig.1.

Individual samples of castings models were subjected to post-processing with dichloromethane, which allowed achieving a high quality of the models roughness. In addition, for creation of the protective wear-resistant layer, the models were painted in one layer (approximately 0.15 mm) with Acrylic paintwork (in 1st option) by air spraying or with two-component composite coating (in 2nd option) based on polyurethane resin with special wear-resistant additives. The problems with adhesion of the coating had not been identified, however, surface pre-treatment is required for better application, including the use of special ground coating.

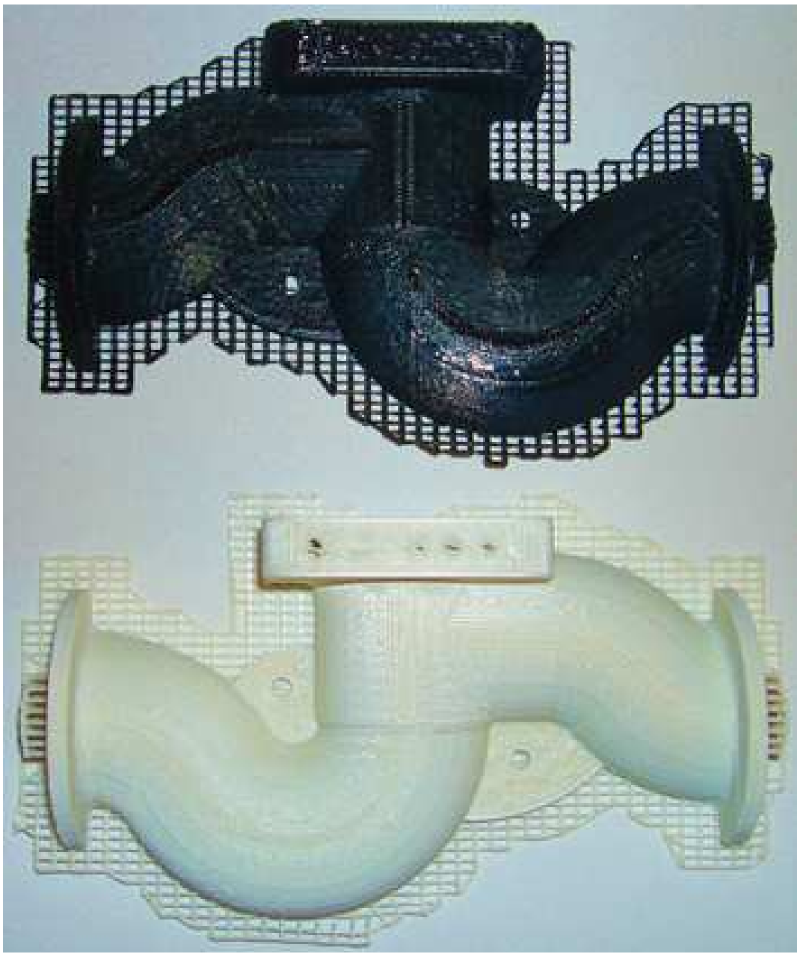

Figure 1. Castings pattern (body of valve), obtained with 3D Printing (ABS and PLA plastic)

The schematic diagram for apparatus testing is shown in Fig.2. The actual environment of the model moulding in flask with a sand mixture was reproduced for experiment setting. Used foundry sand specification was as follows: SiO_2 (Silicon Dioxide) ─ 99% (total); Al_2O_3 (Aluminium Oxide) – 0.25%; Fe_2O_3 (Iron Oxide) ─ 0.10%; K_2O+Na_2O (Potassium and Sodium Oxide) < 0.1%; MgO+CaO (Magnesium and Calcium Oxide) < 0.05%; other component < 0.5%.

The mesh size of foundry sand was as follows: 0.2, 0.3, 0.4, 0.6 mm. The hardness of sand on the Mohs scale was 6.2-7.4 units.

The composition of foundry sand was selected individually (preferably in equal proportions according to the mesh size) through a laboratory sieve. The tests of samples consisted of a temporary vibrating impact on the "castings pattern"-"foundry sand" system in a closed volume bounded by a flask (a metal box with an open top).

The vibration impact was realized due to two vibration motors (Fig. 2) fixed from the bottom of the model plate, the dynamic contact of the model with sand and the volume sealing of the sand were carried out at their work.

In the real production conditions, this vibration impact has a duration of 5-15 seconds, this cycle of mechanical oscillations is quite sufficient for the sealing of the molding mixture and strength setting.

The developed test installation is equipped with the possibility of adjustment of rotation speed (in the range of 450-1200 rpm) of the vibration motors by using frequency regulators. Thus, it is possible to regulate the compelled centrifugal force from 200 to 500 Newton’s.

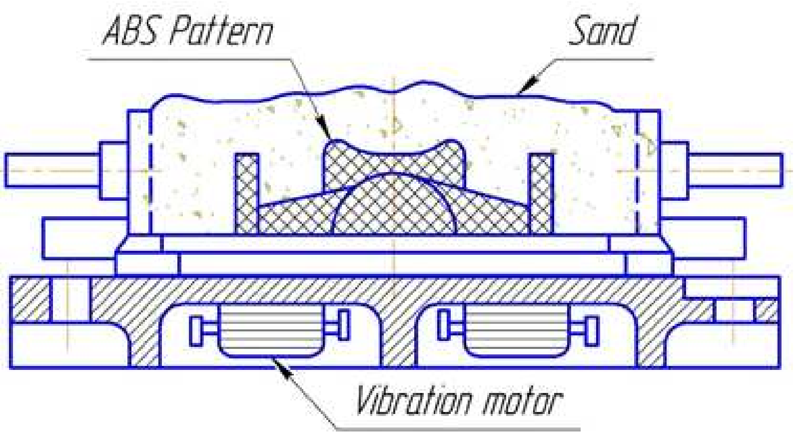

Figure 2. Scheme of test of ABS (PLA) model for surface and mass (volume) wear under vibration load

4. Results and Discussion

Measurement of plastic models wear was carried out in three parameters - mass wear, surface wear and evaluation in local areas. The results are shown in Table 2. A vibratory impact within 10 seconds, which corresponds to one moulding (model removal), was taken for one cycle.

The wear of the model surface was determined in absolute values using a magnetic indicator rack. Local areas of wear were detected visually in the wake of the most intensive destruction of the model's paintwork. At the same time, they mainly referred to the model's areas having the most closed space (external pockets), which is well correlated with the results in [12]. The used tests methods were adapted from [13, 14], where local and mass wear of materials having structural heterogeneity of the surface layer was also investigated.

Technological parameters for 3D printing of master models significantly differ from 3D printing for evaporative casting method [15]. It is necessary to apply the method of the densest 3D printing (Object infill (%)> 15) so that to avoid accelerated wear of a model. And the thickness of each layer (Layer height (mm) <0.2), on the contrary, should be as small as possible, because this will ensure a high quality of the internal adhesion of the model material.

Dismountable models should be qualitatively fastened together only mechanically, because the modern adhesives do not give high strength characteristics of the compound.

Table 1. Results of tests for castings model from ABS&PLA plastics

	Num. cycles*	PLA	ABS	PLA & AP**	ABS & AP**	PLA & CC***	ABS & CC***
Wear surface,%	100	<0.10	<0.10	–	–	–	–
	500	<0.25	<0.25	<0.15	<0.15	–	–
	1000	1.00	1.00	0.15	0.25	0.15	0.15
	2000	2.50	2.25	0.25	0.15	0.25	0.25
Mass wear, %	100	–	–	–	–	–	–
	500	<1.00	<1.50	<1.00	<1.00	<0.50	<0.50
	1000	2.5÷5	2.5÷6	<1.50	<1.50	<1.00	<1.00
	2000	5÷7.5	6÷8	<2.5	<3.00	<1.50	<1.50
Local max Linear Wear, mm	100	–	–	–	–	–	–
	500	0.50	0.50	0.25	0.25	0.25	0.25
	1000	1.50	1.50	0.50	0.75	0.50	0.50
	2000	3.50	4.00	1.00	1.25	1.00	1.00

*1 cycle = 10 seconds of vibration in sand mold
*Acrylic paintwork
** 2-component composite coating on polyurethane resin

5. Conclusion and Highlights

The conducted research implies the following conclusions:

- the testing apparatus for studying the wear of plastics foundry models obtained with FDM technology was developed. A distinguish feature of the installation is the possibility of adjustment of the vibration impact intensity on the models under study;
- the technique that allows testing plastic models obtained with the use of additive technologies for abrasive sand wear was proposed;
- the practical offers on production of master models with the use of FDM technology allowing to reach indicators of durability exceeding 2000 cycles of molding in sandy mix are formulated.

Our future researches will be devoted to the problems of an assessment of the castings quality, received in the mold cavity, executed with plastic models, which are printed on 3D printer.

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