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EFFECT OF TECHNOLOGICAL PARAMETERS ON THE QUALITY AND DIMENSIONAL ACCURACY OF CASTINGS MANUFACTURED BY PATTERNLESS PROCESS TECHNOLOGY

WPŁYW TECHNOLOGICZNY PARAMETRÓW NA JAKOŚĆ I DOKŁADNOŚĆ WYMIAROWĄ ODLEWÓW PRODUKOWANYCH BEZMODELOWO

Submitted article deals with the effect of selected technological parameters on the quality and dimensional accuracy of prototype castings made by Patternless process technology. During experiments were used two types of molding compounds (foamed gypsum and compound based on silica sand and resin). Experiments were focused on optimization of cutting parameters in terms of efficiency, accuracy and possibilities to minimize tool wear. Article deals also with the dimensional and shape accuracy of the castings made by Z-Cast technology. The main aim of the research is to optimize Patternless process technology to such an extent, that achieved dimensional and shape accuracy will be comparable to castings made by the Z-Cast technology.

Keywords: silica sand, patternless process, cutting parameters, gypsum

Artykuł dotyczy wybranych parametrów technologicznych, które wpływają na jakość i dokładność wymiarową odlewów prototypowych wykonanych technologią bezmodelową. Podczas eksperymentów wykorzystano dwa rodzaje form (spienionego gipsu i mas do formowania na bazie piasku kwarcowego i żywicy). Badania mają na celu optymalizację parametrów cięcia w zakresie wydajności, dokładności i zminimalizowania zużycia narzędzi. Artykuł zajmuje się również dokładnością wymiarów i kształtem odlewów wytwarzanych za pomocą Z-cast. Głównym celem tego badania jest bezmodelowa technika optymalizacji tworzenia do takiego stopnia, aby osiągnąć dokładność wymiarów i kształtu odlewu wytworzonego zpomocą Z-cast.

1. Introduction

The concept of Patternless process technology is based on the fact, that the shape of the future casting is milled into the block made of molding compound. Based on 3D CAD software is created a virtual design of mold and cores. 3D model is an essential input data to generate suitable machining program, which is then inserted into the CNC milling center.

Patternless process technology is in general practice used to create molds for large castings – weighing up to 200 tons. That is the reason, why increased dimensional accuracy is not the central issue of production. One of the main advantage of patternless process technology is lower input price than the input costs for Z-Cast technology, which uses the principle of 3D printing.

Research works regarding patternless process technology aims mainly to improve the dimensional accuracy and surface quality of the mold cavity and therefore quality of the casting. This research should result in precise settings of Patternless process parameters, thus dimensional accuracy will be comparable to the dimensional accuracy of castings made by Z-cast technology.

2. Experiments

2.1. Choosing the molding compound

Milling a block of molding compound (which contains opening material such as silica sand) is accompanied by peeling of the individual grains which leads to the formation of pores on the surface of the mold. After filling the mold cavity with melt, this phenomenon manifests itself as increased corrugation of casting surface, which has negative impact on the dimensional accuracy. The basis for improving the dimensional accuracy and surface quality of the mold cavity is the choice of proper molding material which creates little porosity on the surface after milling. For the experiments was therefore chosen silica sand with the minimum grain size (mean grain size is d50 = 0.21 mm). Molding compound with this type of opening material is suitable for the production of iron castings and copper alloy castings. As a second molding compound was used gypsum, which is suitable for the production of castings from alloys with melting temperature to 800°C. Gypsum advantage is fact, that during milling no pores are produced on the surface of the mold cavity, so high dimensional and shape accuracy can be achieved. At Fig. 1 is shown dependency between corrugation of the surface and grain size

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of the opening material. When producing molds with opening material, whose mean grain size d50 is less than 0.22 mm, it is necessary to consider very low permeability (see TABLE 1).

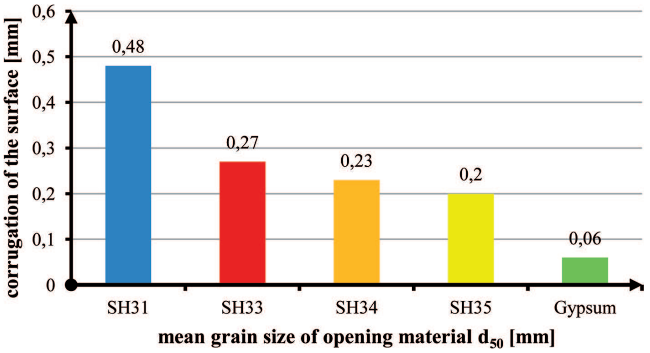

Fig. 1. Dependency between corrugation of the surface and grain size of the opening material

2.2. Effect of cutting speed on the dimensional accuracy of the mold cavity

During milling of molding compound based on silica sand occurs deration of already machined parts with milled grains which reduces the dimensional accuracy of the mold cavity. For the purposes of this part of experiments were made 68 molds with simple cavity in the shape of block – dimensions 40x40x10 mm. Molding compound based on silica sand was used during experiments. Medium grain size of the opening material and permeability of used molding compound is shown in TABLE 1.

TABLE 1

Medium grain size of the opening material and permeability of used molding compound

	OPENING MATERIAL			
	SH 31	SH 33	SH 34	SH 35
Mean grain size [mm]	0.5	0.29	0.24	0.21
Permeability [n.j.p.]	925	240	199	196

As binder was used phenol-formaldehyde resin REZOL (4 wt. %). The compound was hardened by CO_2. Investigated was the cutting speed variation impact on dimensional accuracy of the mold cavity. Evaluation of the results was carried on castings, into account was taken also 1.16% shrinkage of used aluminum alloy. As a milling tool was used mill made of sintered carbide with a diameter of 8 mm. Cutting speed variations effect on the dimensional accuracy of the mold cavity is shown at Fig. 2.

Based on the experiment results we can conclude, that increasing the cutting speed of the tool causes an increase in kinetic energy of milled grains which disrupt already machined parts of cavity, resulting in a reduced dimensional and shape accuracy of the mold cavity.

At Fig. 2 can be seen that at the range of 2000-8000 rev./min. (cutting speed of about 50 to 200 m/min.) were deviations from the requested dimensions for each type of molding compound lowest. Based on the outcome of the experiment can be concluded that the range of cutting speeds from 50 to 200 m/min. in terms of achieving increased dimensional accuracy of the mold cavity appears to be most appropriate.

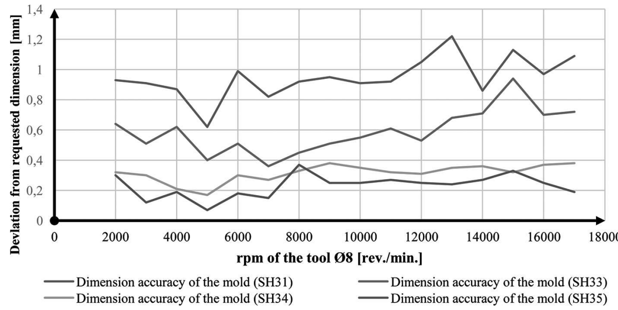

Fig. 2. Cutting speed variations effect on the dimensional accuracy of the mold cavity

2.3. Intensity of tool wear and its effect on the dimensional accuracy of the mold cavity

During milling process of molding compounds containing silica sand, intense wear of the tool is occurring, which has ultimately negative impact on the dimensional and shape accuracy of the casting. The aim of this part of experiment was to determine the optimal cutting speed which will cause the smallest wear of the tool. To speed up the wear intensity during milling process was used mill from high-speed cutting steel (HSS Ø 8 mm). Determination of cutting speeds to find the smallest tool wear is based on the graph at Fig. 2. Chosen was the variant, where the best dimensional accuracy of the mold cavity was achieved.

Experimental findings of tool wear intensity showed that, during milling of the molding compound with silica opening material SH 35, by a cutting speed of 125.6 m/min. was achieved the smallest tool wear. These results are shown at Fig. 3, where are the curves representing the tool wear at different cutting speeds. Fig. 4 shows the used tool (milling cutter HSS Ø 8 mm) before and after milling. Milling parameters are shown in TABLE 2.

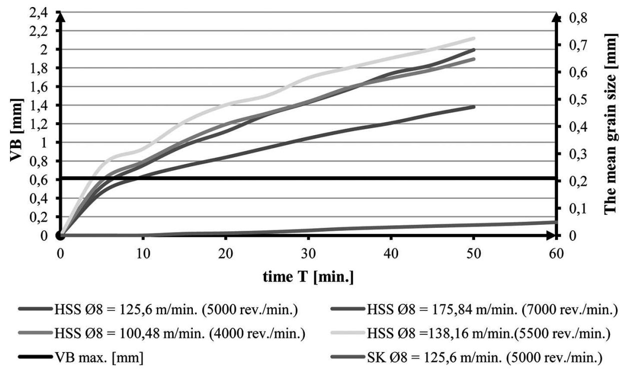

Fig. 3. Curves representing dependency of tool wear at different cutting speeds

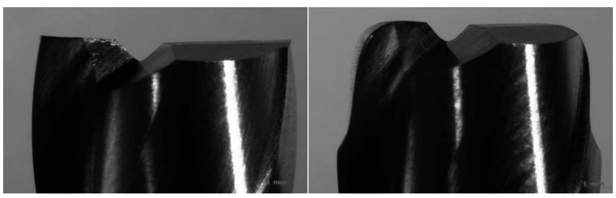

Fig. 4. Used tool (milling cutter HSS Ø 8 mm): a) before milling, b) after milling – duration 10 min, υ_c =125,6 m/min.

TABLE 2
Parameters during milling of molding compound with opening material SH 35

Diameter of the tool	*D [mm]*	8
Feed	*f [mm/min]*	1800
Rounds per minute	*n [ot./min]*	5000
Cutting speed	v_c *[m/min]*	125.6
Amount of blades	*Z*	2
Depth of cut	a_p *[mm]*	4
Time of milling	*t [mm]*	10

In common practice, for milling a molding compounds based on silica sand are used solid carbide milling cutter or cutters with replaceable cutting blades that have greater durability. When using an experimentally determined optimal cutting speed, this durability can be further increased. Fig. 3 shows the curve for tool wear of cemented carbide (red curve). From the graph can be determined, that in this case was intensity of wear significantly lower. To identify the wear of cemented carbide tool is for milling the molding compound from silica sand time consuming. The graph shows that during the milling with cutting speed 125.6 meters/minute, which lasted 60 minutes, the tool wear was 0.08 mm. In a further investigation it was found that the tool did not reach the criterion of wear (VB max.) even after 7 hours of milling. In practical terms, this means that while using a cutting speed 125.6 m/min. mold cavity can be effectively produced with the required dimensions even for time-consuming cycles and the tool does not have to be re-sharpened, what is technologically and economically advantageous. Calculation of rpm for tool with different diameter is then based on equation (1).

$$v_c = \frac{\pi * \mathrm{D} * \mathrm{n}}{1000} \, [m/min] \qquad (1)$$

where:
D – diameter of the tool (mm)
n – rpm

2.4. Practical application of determined technological parameters

The main objective of submitted experiments was to optimize the manufacturing process of Patternless process technology to such an extent, that achieved dimensional and shape accuracy will be comparable to the accuracy obtained by Z-Cast technology, which is based on 3D printing principle.

Comparison of the dimensional and shape accuracy of both technologies was performed on the real castings. During the experiment, three molds were produced and filled with aluminium alloy. Fig. 5 shows individual parts of the molds produced by Patternless process technology. Mold milled to a foamed gypsum block is intended for castings from materials with melting temperature lower than 800°C. The second mold was milled into molding compound based on silica sand SH 35 where was used as the binder phenol-formaldehyde resin REZOL (4 wt. %). This type of mold is used to produce castings from alloy with a melting temperature to 1600°C. Fig. 6 shows a mold made by 3D printing technology Z-Cast. Used molding material can withstand temperatures up to 1100°C, the main disadvantage is the high cost.

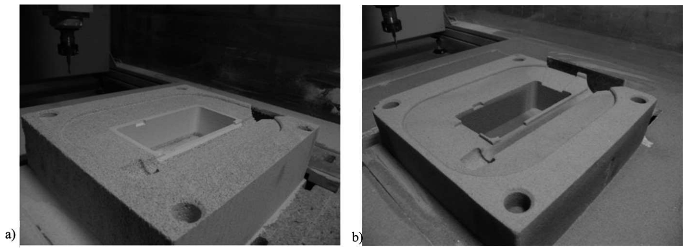

Fig. 5. Individual parts of the molds produced by Patternless process technology a) Foamed gypsum block b) Molding compound with silica sand SH35

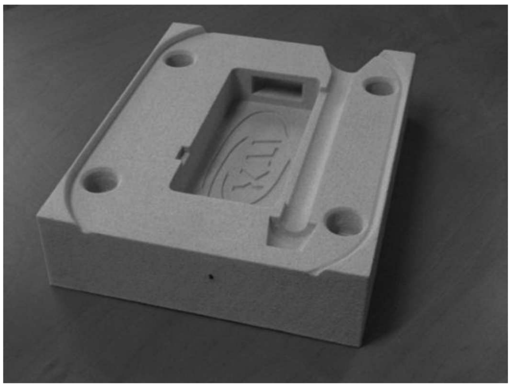

Fig. 6. Part of the mold produced by Z-Cast technology

Produced castings were subjected to measurement of selected functional dimensions. After analysis of the measured dimensions ??was found that the highest dimensional and shape accuracy was obtained by mold which has been milled into the gypsum block. At Fig. 7 is visible detail of surface for each casting. At Fig. 8 is graph representing measured deviations for individual castings. It was found that the mold produced by Patternless process technology is dimensionally more accurate than mold produced by the Z-cast technology. Is assumed, that if silica sand is with a finer grain size as SH35 (e.g., mean grain size d50 = 0.1 mm) mold produced by Patternless process technology will have equal quality of the surface as mold produced by Z-Cast technology.

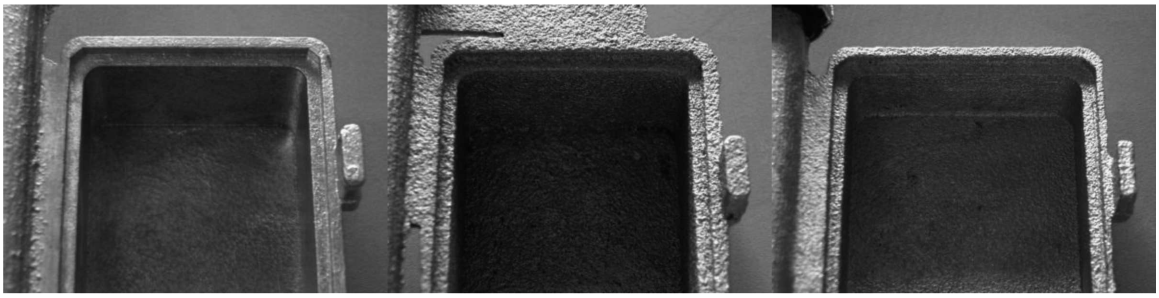

Fig. 7. Detail of surface for each casting: a) Patt. process GYPSUM b) Patt. process SH 35 c) Z-CAST

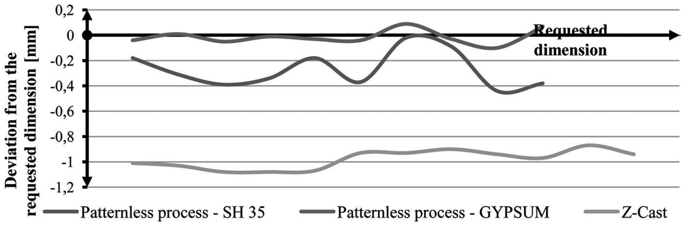

Fig. 8. Graph representing measured deviations for individual castings

3. Conclusions

The presented experiments helped to optimize Patternless process technology with positive impact on the dimensional and shape accuracy of prototype castings. It was found that the right choice of a suitable molding compound, cutting parameters, technological process and preparation methods helps to achieve a better quality castings. Finding of the optimum cutting parameters improved the shape and dimensional accuracy of the mold cavity, while extending tool life. With decreasing grain size of opening material is achieved better quality of casting surface, but with decreasing grain size, decreases also permeability of molding compound, so it is necessary to ensure sufficient gas removal from the mold cavity. From the experiment we can conclude fact, that by Patternless process technology can be made castings with increased accuracy which is of great importance in its competitiveness in the market.

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