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ANALYSIS OF THE DIMENSIONAL ACCURACY OF CASTING MODELS MANUFACTURED BY FUSED DEPOSITION MODELING TECHNOLOGY

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Abstract: *The main purpose of the research was to assess the dimensional accuracy of models manufactured by additive technology Fused Deposition Modeling (FDM). The shape of the samples have been designed in a way which allow to take into account all typical geometrical characteristics of casting models, i.e. linear and angular dimensions. Machine "Dimension 1200es" has been used to build the samples using ABS P430 material. Due to the effect of anisotropy in both the mechanical properties, shape and dimensional accuracy, authors decided to analyze the effect of building direction on the dimensional accuracy of the above mentioned samples. For this purpose, have been manufactured appropriate physical models which were placed on the working platform of the machine in three typical angles: 0 °, 45 °, 90 °. Measurements of geometric dimensions have been performed on the CMM Prismo Navigator machine. Research results confirmed that the printing direction has a significant impact on the dimensional accuracy of manufactured parts. It can be conclude that Fused Deposition Modeling technology can be used to build precise casting models.*

Keywords: Technological heredity, Additive technologies, FDM, Casting draft, CMM.

1. Introduction

The dynamic development of modern, unconventional manufacturing technologies, among others, additive technologies determines the possibility of their implications in many industries, i.e. for building static sealing rings (Błasiak, 2016 and Kundera, 2014a), in foundry industry (Chhabra, 2011) or in prototyping (Takosoglu, 2016a and Takosoglu et al., 2016b). Generative technologies allow for the manufacturing of prototypes and fully functional elements of machines and mechanisms directly from the mathematical 3D CAD model. Due to the layered nature of the process it is possible to produce complex-shape physical model which are difficult to obtain by conventional methods or even impossible in some cases (Kundera, 2014b). One of the areas, where additive technologies can be widely used is foundry industry. They can be used for both, to build casting patterns and molds. Due to the low melting point of most of FDM materials, this technology can be used especially in the lost material casting method. In the case of construction of casting patterns, which shape is often impossible to perform by traditional methods, authors decided to examine the possibility of adapting FDM additive technology, to produce accurate, durable and wear resistant casting models.

Analyzing the current state of art it can be noted that preliminary studies on the possibilities of the application of FDM technology in some industries have been conducted. These works, however, does not describe in a comprehensive way the influence of technological parameters on the dimensional-shape accuracy of manufactured components. It was found that the dimensional-shape accuracy of casting patterns is very important, because the resulting inaccuracies will move through the technological

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heredity on the obtained casts. Due to the intensive development of the foundry industry it is necessary to create high-quality products, castings, which will not need to be subjected to further finishing processes. Therefore production of high accuracy casting patterns and molds is a key aspect. This processes involves the developing of measurement methods that allow to meet the requirements of modern foundry industry (Adamczak, 2016 and Nowakowski, 2016).

The possibilities of application of FDM technology in engineering are described, inter alia, in the work (Bartkowiak et al., 2015), wherein the authors examined the effects of selected process parameters, such as the orientation of layers on 3D roughness parameters of curved sample surface. The study also applied the further finishing processes by using acetone.

In the paper (Griffiths et al., 2016) authors determined the influence of layer thickness and orientation of models on the working platform on the tensile strength of samples made by FDM technology in accordance with ISO 527 standard. The material used for the construction of samples was bio-degradable polylactide PLA.

2. Research procedure

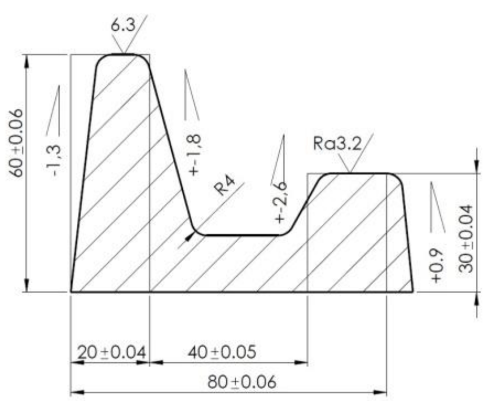
The aim of the study was to evaluate the effect of the location of the models on the working platform on the samples dimensions which represented the typical casting patterns. Due to the availability of the technology, authors were chosen FDM technology. Samples were manufactured at the Laboratory of Reverse Engineering using machine "Dimension 1200es" produced by Stratasys Company. Measurements of geometric dimensions have been performed on the CMM Prismo Navigator, which is equipped at Laboratory for Computer-Based Measurement of Geometrical Quantities located in the Department of Manufacturing Engineering and Metrology at Kielce University of Technology.

2.1. FDM Technology

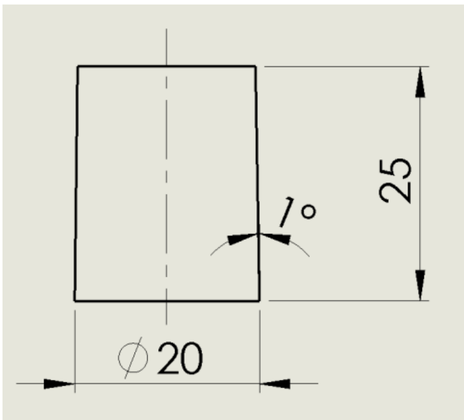
Fused Deposition Modeling technology (FDM) is based on a layered construction of physical models directly from three-dimensional CAD model. In this method input plastic material in a form of string is heats locally to obtain semi-liquid state and then through the printing nozzle is distributing into the current building cross-section of the model. An important advantage of this technology is the availability of low cost building materials and low complexity of the process, but due to the relatively thick constructed layer equal at least of 0.1 mm and a heat shrinkage, mechanical properties and dimensional accuracy significantly depends on the orientation of models on the working platform.

2.2. Samples

The samples were located on the working machine platform on three different angles: 0 ° (No. 1), 45 ° (No. 2), 90 ° (No. 3). For each type of direction have been made a five pieces of the samples. Fig. 1a is an example of a typical casting model with marked geometrical dimensions, while Fig. 1b shown the real physical samples with measured dimensions. The draft of the side wall at an angle of 1 ° is the typical angle used in pattern construction that allow to remove pattern from the sand mold easily.



a)



b)

Fig. 1: Testes samples: a) example of typical casting model; b) tested samples.

3. Results analysis

Measurement strategy was based on active scanning probe VAST Gold S-ACC, where linear measurement accuracy is equal 0.9 + L / 350 μm. The research results of the draft angle of side wall and the height of the samples are shown in Tab. 1, where the symbol "s" means deviation. In order to better visualize the results of calculations the mean value of relative error are presented in Fig. 2.

Tab. 1: Research results.

No. sample		high, mm	relative error, %	angle, °	relative error, %
1 (0º)	a	25.037	0.15	1.056	5.6
	b	25.015	0.06	1.060	6
	c	25.071	0.28	1.083	8.3
	d	25.033	0.13	1.067	6.7
	e	25.061	0.24	1.068	6.6
	mean	**25.043**	**0.17**	**1.067**	**6.7**
	s	0.023		0.01	
2 (45º)	a	25.146	0.58	1.032	3.2
	b	25.159	0.63	0.981	1.9
	c	25.165	0.66	0.995	0.5
	d	25.175	0.7	0.946	5.4
	e	25.148	0.59	0.947	5.3
	mean	**25.159**	**0.63**	**0.98**	**2**
	s	0.012		0.036	
3 (90º)	a	25.171	0.68	1.257	25.7
	b	25.245	0.98	1.076	7.6
	c	25.154	0.62	1.055	5.5
	d	25.194	0.78	1.057	5.7
	e	25.286	1.14	1.068	6.8
	mean	**25.21**	**0.84**	**1.103**	**10.3**
	s	0.055		0.087	

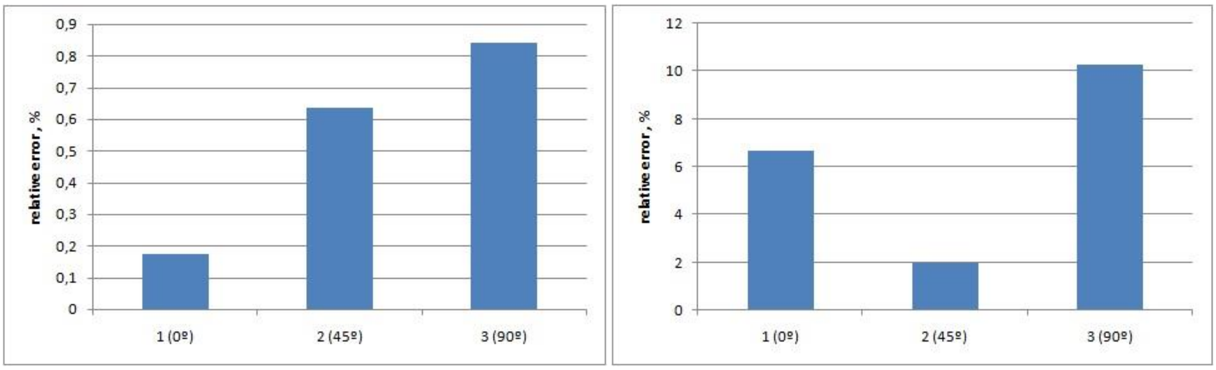


Fig. 2: Relative error of representation the nominal value a) linear dimension; b) angular dimensions.

Analyzing the research results of the linear dimension, i.e. the height of the elements, it can be noted that there is a relation between the orientation of models on the virtual platform and dimensional deviations. The relative error for samples placed at an angle of 0 ° reached the lowest value, equal to 0.17 %. In the case of the samples No. 2 the value of relative error has increased. This value was equal 0.63 %. The least favorable results were obtained for the samples produced at an angle of 90 º. The calculated value was equal 0.84 %.

A similar analysis was performed for the draft angle of side-wall. The most favorable value was achieved for the samples No. 2. The resulting value was equal 2 %. In the case of samples No. 1 the value of relative error had increased, reaching the value equal 6.7 %. The highest value of the relative error was calculated for the samples No. 3 - 10.3 %. The largest relative error was noted for sample 3a (25.7 %). For the rest of samples No. 3 (b-e) were obtained similar values as in the case of samples No. 1 and No. 2.

4. Conclusions

Analyzing the research results and the current state of art related to adaptation of additive technology into the foundry industry, it can be concluded that the FDM technology can be used in industrial practice. Moreover based on the research results it can be concluded:

1. The samples orientation on the virtual platform has directly influence on the dimensional accuracy of the model. The obtained angular dimensions were less accurate in compare to the linear dimensions.
2. The most favorable representation of the nominal value for linear dimension was achieved for samples No. 1, meanwhile the least favorable values were calculated for samples placed at an angle of 90 º.
3. By analyzing the representation of the nominal value for angular dimensions, it can be noted that the calculated value of the samples No. 2 reached the lowest value. The most inaccurate results were obtained for samples No. 3.
4. Based on the result of measurements it can be noted that almost all types of samples indicated positive material shrinkage. In all cases, the measured linear dimension value was greater than nominal value. Analogous results were obtained for angular dimension. Only for samples No. 2 the measured value was lowest than nominal value.
5. Complex analysis of the research results indicated that engineers should take into account during the design stage the geometrical deviation of manufactured parts.

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