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APPLICATION OF ADDITIVE TECHNOLOGY OF FUSED DEPOSITION MODELING FOR MANUFACTURING SMALL SERIES OF ELASTIC MODELS

Abstract

The paper presents an application of additive method of Fused Deposition Modeling for manufacturing of small series of elastic models. Additive FDM technology is used to produce a casting mould for multiple use. Process of manufacturing of small series of products consists in casting a two-component silicone rubber degassed using vacuum chamber into a multiple use mould. The paper shows the course of the process and related problems on the example of industrial product – a cylindrical seal. The casting mould was produced out of ABS material using BST 1200 machine, whereas casted elastic models were made out of XTX 45 silicone rubber.

1. INTRODUCTION

1.1. Basic information

Additive Manufacturing Technologies (AMTs, also known as 3D printing techniques) allow to manufacture physical, three-dimensional models, prototypes and also some products or parts directly from their digital representation [8]. There are three main groups of applications of these technologies – Rapid Prototyping, Rapid Manufacturing and Rapid Tooling [2,10].

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Rapid manufacturing of small series of finished products is often based upon the Vacuum Casting technology – a process complementary to additive technologies [9]. This technology allows to effectively create copies of elements manufactured by additive technologies, using chemically hardened resins as a build material, usually for thorough testing and evaluation of prototyped elements [3]. Molds for this method are manufactured using two component silicone rubbers vulcanizing in the room temperature and the casting material – two component resin – is usually composed in a way to mimic properties of various plastics. Both mold manufacturing and subsequent casting (the mold can be used many times depending on the geometry and conditions, but never more than for approx. 100 castings) requires degassing of the liquid material using a vacuum chamber [7].

The Vacuum Casting method is efficient and popular, but it has certain limitations – there is no possibility of manufacturing elements with elastic properties [12]. This paper presents a new process (designed and tested by the authors) of manufacturing short series of elastic products. The process is based on principles of the VC method, using the silicone rubber (similar in properties to some widely used elastomers) as a build material. A casting mold for this process is manufactured using one of the additive technologies – namely Fused Deposition Modeling.

1.2. Place and subject of the practical studies

Research of the process of manufacturing short series of elastic products using FDM method was conducted in the Laboratory of Rapid Manufacturing, localized in the Chair of Production Engineering and Management of Faculty of Mechanical Engineering at Poznań University of Technology. As a base model for process development and tests, a seal of cylindrical shape was selected (Figure 1).

Process of manufacturing of short series of products out of elastic material using the described process consists of the following stages:

- design and manufacturing of the reusable casting mold out of the ABS material, using additive technology – Fused Deposition Modeling,
- casting in the manufactured mold using additive silicone vulcanizing in the room temperature as a build material,
- finishing and evaluation of the obtained castings.

As the additive FDM technology is in this case used to manufacture tooling for the casting process, this application of AMTs should be considered as the Rapid Tooling.

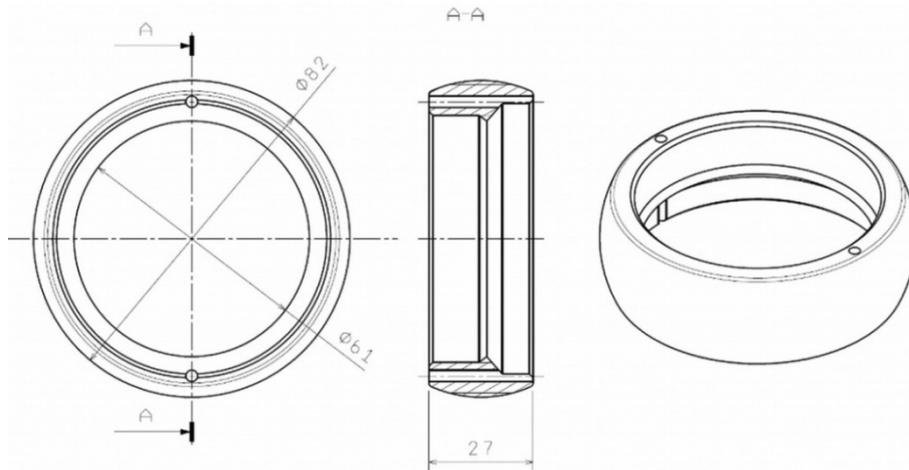


Fig. 1. Model of a seal selected for the study [source: own study]

2. PREPARATION OF THE CASTING MOLD – 3D PRINTING USING FDM TECHNOLOGY

2.1. Characteristics of the FDM technology

Physical prototype creation using layered deposition of thermoplastic materials is one of the most widely used AMTs in the industry. Fused Deposition Modeling is the widely acknowledged name of this method (fig. 2) [1]. It consists in deposition of the plasticized material through a special, two-nozzle head, positioned in two axes, X and Y. The support of some kind must also be created, because there are no natural supports and the created model is not stiff enough during manufacturing – it could deform under the gravity force if there were no supports. Build and support materials are supplied to the head in form of wire from the spool and they are heated inside. During single layer creation, the head moves in XY plane and deposits the material according to the cross-section profile. After one layer is completed, the model table moves down in the Z axis, value of the coordinate being equal to single layer thickness. After the thermoplastic material from the head is placed on the table, it momentarily solidifies, joining with the previous layer [8].

As in almost every other additive manufacturing technology, models are created on the basis of the CAD geometry in form of the triangle mesh (STL file format), imported to the software which controls the machine realizing the FDM process [11].

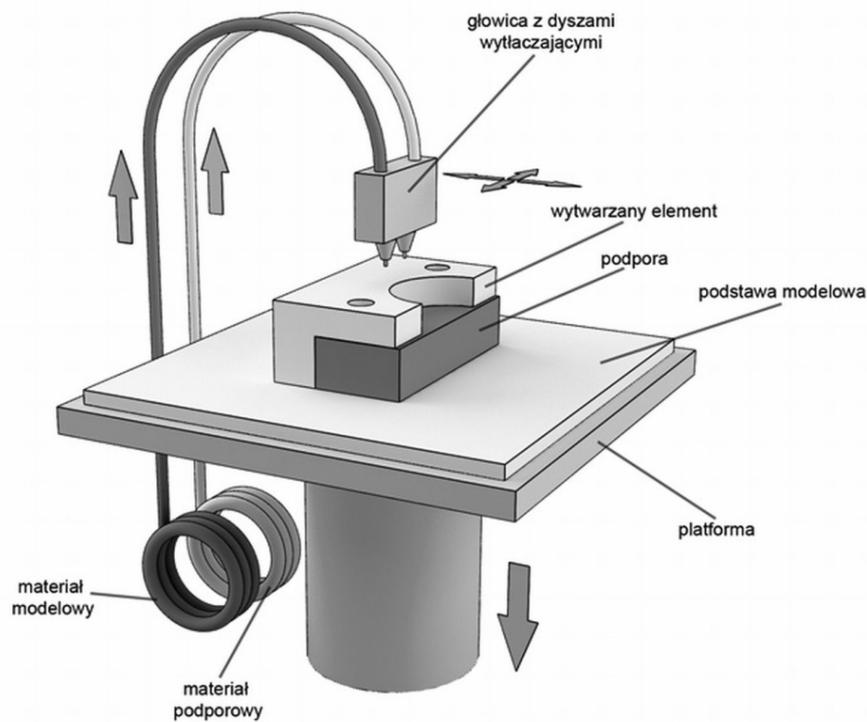


Fig. 2. Scheme of the FDM method [source: own study]

As a build material, usually the ABS material is used (ABS stands for acrylonitrile butadiene styrene), other thermoplastics can be used too. Support material type depends on method of the support removal (mechanically – by force or chemically – by dissolving the support in the liquid solution).

The Laboratory of the Rapid Manufacturing is equipped with the Dimension BST 1200 machine, manufactured by the company Stratasys. ABS material is used for both model and support, the support is removed mechanically. The machine allows to build models with maximum base size of 254 mm x 254 mm and maximum height of 305 mm. Models of larger size can be built by joining the smaller models, e.g. by gluing them together.

Models manufactured using the FDM method are ready for use immediately after the support is removed. They have good mechanical properties, but their visual quality is mostly poor due to so-called staircase effect (which occurs in each layered manufacturing technology) [4]. To obtain models with high visual quality, post-processing is required – processes like sanding, grinding, drilling or painting can be applied to the FDM model to improve its quality and functionality.

Prototypes manufactured using FDM technology are used mostly as visual and functional prototypes. Apart from the prototyping, the ABS models manufactured additively can be also used as patterns for the Vacuum Casting process [6]. The process of elastic model manufacturing presented in the next part of this paper can be treated as an inversion of the classic Vacuum Casting method – ABS model is used as a mold, while the silicone is used as a build material.

2.2. Manufacturing of the casting mold using the FDM process

Casting mold for manufacturing of the seal models was created directly from the CAD model. The first stage of preparation of the mold was therefore a creation of such model. It was made in the CATIA v5 CAD system, basing on the CAD model of the manufactured element – the seal. Shape of the mold cavity was created using Boolean operations (subtraction of solids representing the outer frame of the mold and shape of the model – fig. 3). Additionally, holes were added for fixing elements and a simple gating system was designed (consisting of pouring cup and gas vents). The whole mold was divided into two halves.

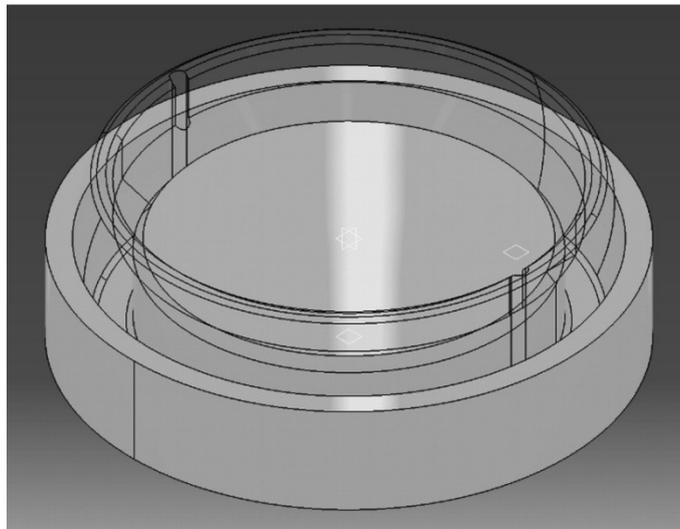


Fig. 3. CAD model of one half of the casting mould [source: own study]

On the basis of the solid model of two halves of the mold, triangle meshes were created and saved to STL files. These files were then imported to the control software of the BST 1200 machine. Then, NC programs containing information about paths of the head in subsequent layers were automatically generated and sent to the machine. After manufacturing of both mold halves, the post processing was performed. It consisted in removal of the support material, insertion of some fixing elements (namely, steel pins) and drilling

of small gas vents (it is not possible to plan these holes in the CAD model, as their diameter is very small – the same as the width of the single thread of material, so they would not be manufactured during the additive process). Finished mold parts are shown in the fig. 4.



Fig. 4. Halves of the casting mold produced using FDM technology [source: own study]

3. CASTING OF THE ELASTIC MODELS

3.1. Material characterization of the XTX 45 silicone

XTX 45 silicone belongs to a group of silicone rubbers vulcanizing in the room temperature (no necessity of heating). It is a two component material – the basis is a liquid material of very high viscosity. To obtain a solid elastomer, the base needs to be mixed with the catalyst in 10:1 proportion. Working time of the mixture in room temperature is 90 minutes since the mixing is complete (in higher ambient temperatures this time is shortened and in lower – lengthened) and hardening time is about 15 hours (it is also dependent on the ambient temperature). Properties of the silicone are presented in the table 1.

After hardening, a material from the elastomer group is obtained. Mechanical properties of the XTX 45 silicone in the solid form (after hardening) are good enough to use it for the planned task.

Tab. 1. Properties of XTX 45 silicone used during the study

Property name	Value
Mixture proportion	10 : 1
Part A color (base)	Translucent
Part B color (catalyst)	Translucent
Part A viscosity	70000 cPs
Part B viscosity	90 cPs
Mixture viscosity	35000 cPs
Density	1,12 kg / dm ³
Working time at 23°C	90 min.
Hardening time at 23°C	15 h
Shore A hardness after 24 h	43 ± 2 Shore A
Tensile strength	6,5 ± 0,5 N/mm ²
Elongation at break	400 ± 20%
Shear resistance	> 20 N/mm

3.2. Course of the casting process

The actual process of casting of elastic models using XTX 45 silicone consists of several basic stages.

The first stage is preparation of the mold for casting (fig. 5). The following actions need to be performed:

- cleaning of the mold cavity,
- insertion of the fixing elements (pins),
- tight connection of two mold halves in a temporary way (to ensure the possibility of getting the model out of the mold without damaging it),
- insertion of the external gating system elements,
- placement of the mold in a way to ensure difference of height levels of gating system entry point and exit (entry point should be placed on a lower level than the exit point).

The second stage of the process is material preparation. Applied silicone consists of two components – the base and the catalyst. Preparation of the material requires performing of the following actions:

- calculation of material quantity necessary for the task,
- weighing the proper amounts of the base and the catalyst,
- mixing the base with the catalyst and optionally with some dyes, if a certain color of the finished element is required,
- degassing of the silicone by placing it in the vacuum for about one minute.

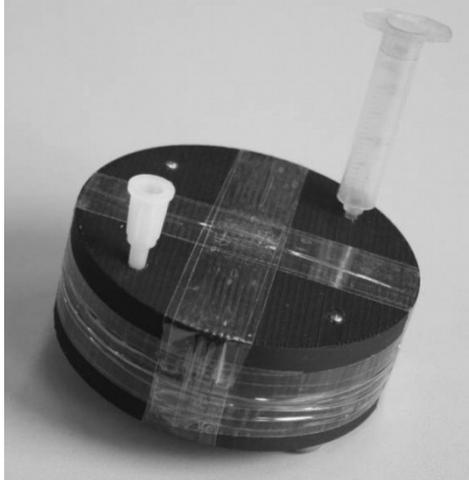


Fig. 5. ABS casting mould ready for casting [source: own study]

The last stage was performed using the MCP 4/01 HEK vacuum chamber (fig. 6). It is noteworthy that it is not entirely necessary to degas the silicone (especially when manufacturing very small elements), but models manufactured without degassing are characterized with presence of the air bubbles in large portion of the casting volume, which decreases the level of product mechanical properties in a significant way. During degassing the silicone should be placed in a vessel of volume at least twice as large as the base volume of the raw, liquid material – air bubbles running out of the material cause a significant, yet temporary increase in volume of the material.



Fig. 6. Vacuum chamber MCP 4/01 used for silicone degassing [source: own study]

The next stage is pouring the material into the mold. Filling the previously prepared casting mold with degassed silicone can be carried out gravitationally (in case of larger molds), but for more rapid and accurate filling of the mold cavity, pressure casting was used. The pressure was exerted by manual pressing of the material feeder (fig. 7). Value of the pressure and character of its variations during the mold cavity filling have no observable effects on quality and properties of obtained models.

The mold is entirely filled when the liquid material appears in the exit point of the gating system, assuming that there is a visible height difference between the pouring cup and the exit point.



Fig. 7. Pouring the silicone into the mould [source: own study]

After the silicone is hardened (solidification is usually complete after 12-15 hours), the mold can be opened and the model can be taken out (fig. 8). During mold disassembly it is important to remember that the silicone precisely fills the mold cavity, including all sub-cavities, even of a very small size. In case of the mold created using FDM technology, where the staircase effect is very distinct and mold surface is not smooth, the silicone model will require considerably high strength to divide it from the mold surface. It is therefore important to perform this process carefully, especially when using metal tools, to leave both the model and the mold intact (with no damage).



Fig. 8. Hardened model ready to be taken out of the mould [source: own study]

Directly after removal of the elastic model from the mold, it should be evaluated, especially concerning occurrence of the casting defects. The most frequently occurring defect in this type of models is presence of air bubbles and pockets (similar as shrink cavities in metal castings), appearing as a result of insufficient degassing of the raw material (fig. 9). Air pockets – if they are present – are usually located deep inside the model volume (as opposed to these appearing in resin models manufactured using classic approach to Vacuum Casting technology) and they have no impact on its shape and dimensional accuracy. Still, these flaws usually disqualify the product, especially when they have considerably large volume, as they impair the mechanical properties of the product.

Applied additive silicone does not present any visible shrinkage, which means that there are no possibilities of its compensation, neither on the design stage, nor during the manufacturing process.

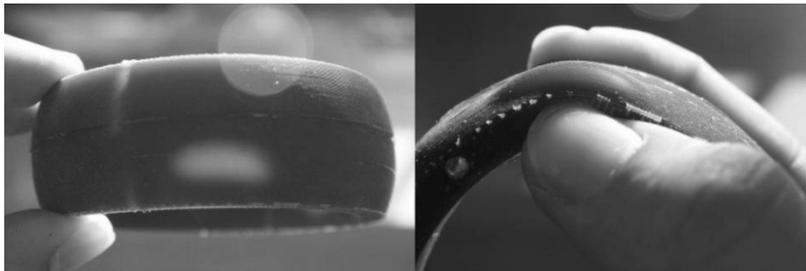


Fig. 9. Flaws occurring in silicone models – air pockets [source: own study]

The model removed from the mold is not a finished product yet – all the casting technologies make use of some type of post processing (the finishing). In this case it consists mostly in cleaning the model and removing the rest of the gating system and traces of mold division line. It is usually done using cutting tools or machining (fig. 10).

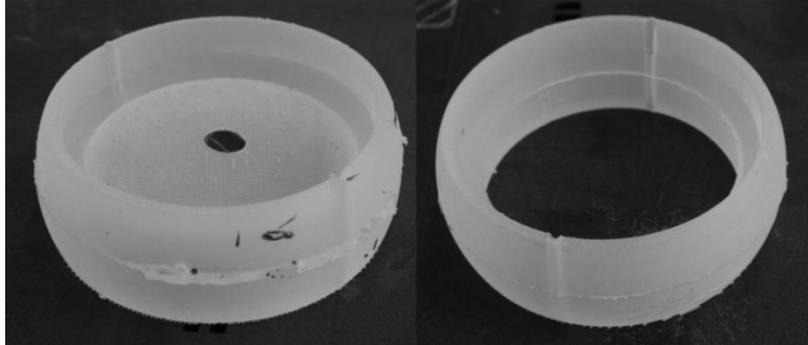


Fig. 10. Model taken out of the mould (on the left) and after post processing (on the right) [source: own study]

4. CONCLUSIONS, SUMMARY

Basing on the course and results of the casting of short series of elastic products in ABS molds, the following conclusions can be drawn:

- Applied silicone precisely fills the mold cavity, accurately representing all the surfaces (despite low castability in liquid form), so in case of surfaces that are irregular, uneven or with pockets, holes etc., there are problems with disassembling two mold halves and removing the product. These problems can be avoided by applying appropriate finishing treatment of the mold cavity (e.g. grinding).
- Silicone adheres to the mold surface strongly, so apart from appropriate surface finishing, the mold cavity should also be covered with a dedicated separator. It is well advised especially for models with more complex shapes.
- During the casting process, the ABS mold is subjected to mechanical wear (especially as a result of applying certain forces during model removal), so number of models obtained from one mold is limited – it would be advisable to further study the influence of the model geometry complexity and casting process course on the level of the mechanical wear of the mold, to be able to estimate the maximum number of pieces obtained from the given mold.
- Unlike during the regular Vacuum Casting process, the mold is not translucent, so it is not possible to determine the locations of air pockets before the model is removed from the mold – this is a clear disadvantage of using the FDM-produced molds.
- Thanks to using model material of elastic properties, the mold does not need to have any drafts or other special features to facilitate the model removal.

- Silicone does not present any visible shrinkage, so there is no need to compensate it.
- Defects in form of air bubbles and pockets can be easily avoided by thorough degassing of the base material.

To sum up, it can be stated that manufacturing products out of elastic materials using casting process in ABS molds prepared using additive FDM technology is quite possible, as long as proper process conditions are maintained. Appearing problems (defects, troubles with mold disassembly) can be solved by taking appropriate actions – modification of the mold, more thorough degassing or application of separators. It can also be said that amount of work needed to achieve satisfying results for this method is not high. A disadvantage of this process which may increase the cost of its possible implementation is necessity of applying the vacuum chamber to degas the base material. Still, described process remains one of the fastest and cheapest ways of producing short series of fully functional elastic products.

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