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APPLICATION OF THE SELECTED TECHNIQUES OF RAPID PROTOTYPING TO THE DESIGN AND MANUFACTURE OF PROTOTYPE ELEMENTS OF MACHINES AND EQUIPMENT

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Summary. By using rapid prototyping techniques, prototype parts, components or finished products can be quickly manufactured. The elements of a new device can serve as an example of the practical use of this solution. The result of the studies was a short series of prototype parts. Due to the functions performed by these elements, they were made from specially selected plastics characterised by mechanical properties allowing for the initial testing of prototype. The design of parts was based on the three-dimensional computer models. Owing to the availability of the FDM Titan device, in a short time real patterns were obtained. They were used to make silicone dies which, in turn, were used for casting a short series of prototypes from plastics. The components obtained in this way were subjected to tests to check their functionality. A series of test castings was also made.

Keywords: rapid prototyping, designing of new products, metalcasting, plastics.

INTRODUCTION

In a modern market economy and competition, quick manufacture of prototypes of the highest quality becomes a must. To satisfy high requirements of customers and shorten the lead times, manufacturers are forced to use innovative methods of production, based on the computer-aided design and the latest achievements of rapid prototyping and tooling performance. For several years these issues have been the subject of research conducted by the Centre for Design and Prototyping at the Foundry Research Institute in Cracow. Until now, numerous application works for different customers have simultaneously been implemented. [7÷11]

The last decade has seen a tremendous progress in the application of computer-aided product manufacturing. The abbreviations like CAD (Computer Aided Design), CAM (Computer Aided Manufacturing), CAE (Computer Aided Engineering) are now generally known, and the opportunities offered by them are widely used by engineers in various industries [2÷6, 13].

In particular, significant progress can be seen in the rapid manufacture of new products, which is usually preceded by the need of making prototypes. This is particularly true in the automotive industry, engineering, defence, aviation and more recently in telecommunications. Metalcasting, being major supplier of components for a wide range of customers, including also the aforementioned sectors of industry, must use and uses the possibilities offered by the advanced application of CAD / CAM / CAE systems.

The most notable progress has been observed in the last few years in the field of rapid prototyping (RPS) and rapid tooling (RT). Rapid prototyping technique came into use in 1987, when the 3D Systems Company launched the first device for the manufacture of foundry patterns from liquid synthetic resin, the successive layers of which were hardened with a beam of ultraviolet laser light. In this way the technique known as stereolithography RPS was born.

Considering the benefits offered by rapid prototyping, the subsequent years witnessed its outstanding development. New techniques and stands for the manufacture of patterns were developed. Currently, rapid prototyping is seen as an obvious step in the preparation of a new product.

According to data for the year 2008 [1], the area of application of patterns/parts made by RP and RT is as follows:

- 13.7% utility models – for presentation,
- 10.0% parts of complex models,
- 15.3% visualisation (aid) in engineering studies,
- 3.4% models as a part of tooling,
- 6.5% patterns for foundry,
- 12.5% models to make prototype tools,
- 5.3% models to aid the implementation of various projects,
- 4.6% other applications.

The best-known techniques of RP and RT with their respective applications have been broadly described in information materials published by different companies offering equipment for practical implementation of these techniques, and also in numerous publications and online data. Considering the above, the presentation of these techniques has been omitted in this paper. [1,12÷22]

The general principle of RP and RT is essentially the same and consists in reproduction and successive application of very thin layers of the pattern. The shape of the formed piece is written in advance in computer memory, using a graphical editor operating in a triaxial (3D) system.

Depending on the used techniques, the pattern is usually built from liquid synthetic resin, paper, powders of different materials, wax. High precision of the manufactured patterns ensures the application of advanced optics (including laser technology) for curing the individual layers or cutting them out.

Patterns are made on specially equipped work stands, typical for a given technique. The size of the manufactured patterns is limited by the dimensions of a worktable. If larger patterns are to be made, it is sometimes possible to apply techniques which enable joining various elements reproducing parts of a workpiece. Different RP techniques have strictly determined the scope of application and precision (the accuracy of reproducing pattern shape). They differ quite obviously in the cost of the equipment and materials used.

The application of RP techniques caused revolutionary changes in the way the new production has been prepared and new equipment designed.

Currently, in the world market, a strong competition is going on within a large group of the well-known companies that offer all the available techniques of rapid prototyping, supplying the equipment, materials, maintenance and services.

The choice of an RP technique is usually determined by a number of factors, among which the following ones should be mentioned here:

- pattern dimensions,
- pattern application,
- pattern dimensional accuracy,
- pattern price.

All these factors were analysed at the Foundry Research Institute before a decision was taken about the purchase of various stands for rapid prototyping, mainly for the needs of foundry industry, but not only. When the decision was taken to establish a Centre for Design and Prototyping at the Foundry Research Institute, the above criteria were considered, the most useful techniques of RPS were selected, and the necessary equipment was purchased.

As a result of these actions, the Centre uses the following devices and the following techniques:

- LOM
- Solidscape
- FDM
- 3Dprinting.

PURPOSE AND SCOPE OF STUDY

The aim of this study was to examine the possibility of using one of the techniques of rapid prototyping (FDM - Fused Deposition Modelling) in the manufacture of parts of a prototype device. The scope of the study included design and manufacture of prototype components.

MATERIALS AND METHODS

In the studies, the FDM Titan device from Stratasys (Figure 1) was used. It enabled making patterns from plastics. The FDM Titan is a modern facility, used to create functional and visual patterns from plastics. The pattern-building process involves depositing successive layers of material fed to the worktable in semi-solid state. In this technique, the pattern material are various types of plastics, which in the form of a wire wound on a spool are supplied from trays to a head moving in the X-Y axes. In the heating elements of a thermal head unit, two nozzles are mounted: the nozzle feeding pattern material and the nozzle feeding support material. In these nozzles, the wire fed from a tray is preheated until it reaches a semi-solid state. Then the melted pattern material and support material are squeezed by nozzles onto a special base board placed on the worktable moving vertically in the Z-axis to form the first layer of a built pattern, according to horizontal cross-sections generated by an Insight programme cooperating with the FDM Titan device. With modelling of a specific layer of the item completed, the worktable is lowered by a preset thickness, and the solidified shell is acting as a support for further applied layers. The thickness of the material filament fed during pattern building depends on the nozzle type and on the type of pattern material used and can be: 0.127 mm, 0.178 mm, 0.254 mm and 0.33 mm. The worktable size is limited to 406 x 355 x 406 mm, but the built patterns have no size restrictions, since individual components of a complex structure can be combined by gluing.

Fig. 1. FDM Titan device made by Stratasys

Despite the commercial availability of many similar printers using FDM technique, the FDM Titan device is the only device in the country which enables modelling of plastics. Patterns are made from several materials like:

- ABS (acryl-nitril-butadienestyrene),
- PC (polycarbonate), PC-ISO (for medical applications),
- PPSF/PPSU (polyphenylsulphon).

The available pattern plastics can be divided into two groups, depending on the type of the used support material:

- pattern materials using broken off support (PC, PC-ISO, PPSF),
- pattern materials using support soluble in appropriate basic solutions (ABS and PC-ABS).

The proposed pattern materials are supplied in white colour, while in the case of ABS seven-colour palette is available. Additionally, it is possible to build patterns from two types of transparent materials: ABSi (three colours of transparency) and PC-ISO. As already mentioned, ABS is the material from which both colour and transparent patterns can be made, but apart from visual effects, owing to the use of soluble support, an additional advantage of this material is the ability to make complex patterns with a series of internal channels.

The second material using soluble support is the material of a trade name PC-ABS, combining the properties of ABS and PC. Patterns made from ABS and PC are characterised by relatively high strength and low shrinkage. Their basic drawback is the loss of shape at temperatures as low as 100°C.

The material offering the highest strength and temperature of plastic deformation is PPSF. At temperatures up to about 190°C, patterns made from this material do not undergo deformation, are characterised by relatively good thermal and chemical resistance, as well as environmental resistance to aggressive liquids such as unleaded petrol, engine oil, coolant and washer fluid.

Items made from these materials, apart from visual - advertising value can serve as useful parts, (otherwise called Real Parts™), as patterns for castings made in ceramic moulds by the lost foam process or by direct moulding in traditional processes, or as master-patterns to make silicone dies for wax patterns. The ready prototype patterns can be subjected to finishing treatment by e.g. grinding or drilling; finally, to obtain the required outer surface quality, they are painted or chrome-plated.

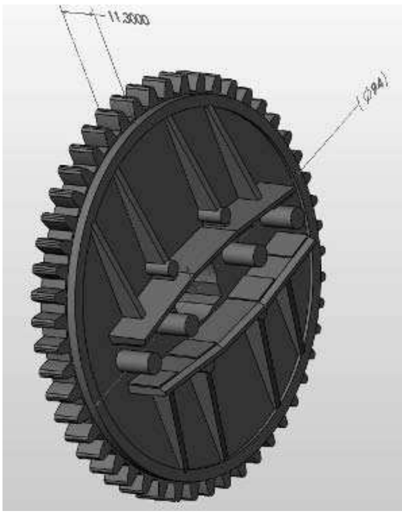
RESULTS OF INVESTIGATIONS

Studies discussed in this article formed part of Development Project 0R00004005 executed in 2010 by the Centre for Design and Prototyping at the Foundry Research Institute in Cracow. During tests, prototype items varying in size and complexity were made. In future they will be produced by the gravity and die casting processes.

At the present stage of research, prototype castings were made by the lost wax process and vacuum casting in plaster moulds. The necessary drawing documentation of those elements was prepared in a 3D system using a SolidEdge graphical editor.

The ready drawings helped to prepare the equipment for operation and making FDM models. Prior to casting manufacture, the following technology steps were developed: filling mould cavity, casting solidification and cooling. The technology was checked using a specialised MAGMAsoft software. Below a specification of the examined items is given.

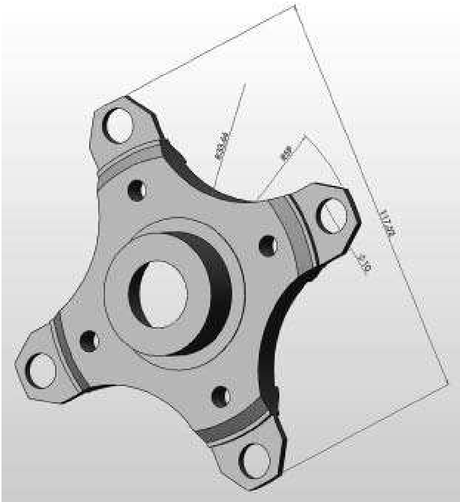
Item No. 1



Name : Wheel
Cast material : AK7 aluminium alloy
Weight : 0,1 kg
In future this item will be made by die casting process.
The following elements were successively made: FDM model, silicone resin die and wax patterns.
Castings were made by the lost wax process.
Items were cast in ceramic molochite moulds.
Altogether 4 sets with 6 castings in each set were made.

The following checking tests were performed on castings:
- structure examinations;
- hardness measurements;
- dimensional accuracy : RPS model, die, wax pattern, casting.

Item No. 2



Name : Cross.
Cast material : AK7 aluminium alloy.
Weight : 0,10 kg (10 g).
In future this item will be made by die casting process.
The following elements were successively made: FDM model, silicone resin die and wax patterns.
Castings were made by the lost wax process.
Items were cast in ceramic molochite moulds.
Altogether 4 sets with 6 castings in each set were made.
The following checking tests were performed on castings:
- structure examinations,
- hardness measurements,
- dimensional accuracy: RPS model, die, wax pattern, casting.

Ceramic moulds were made on an automatic CYKLON device from MK Technology GmbH in Germany.

Photographs below present successive operations performed at this stand:
- pattern set ready for application of the first ceramic coating,
- application of ceramic coating,
- supporting mould with loose ceramic material,
- drying of ceramic coating.

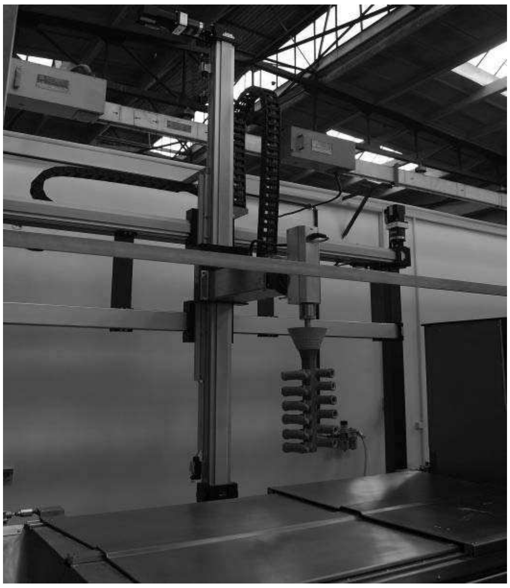


Fig. 2. Pattern set ready to make a ceramic mould

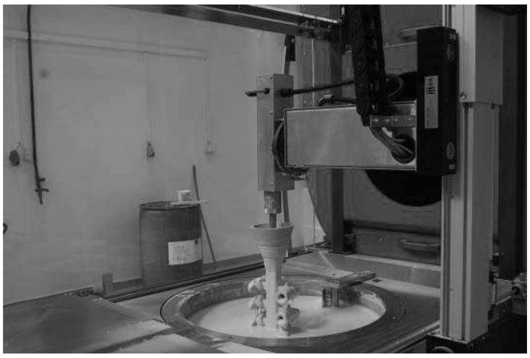


Fig. 3. Application of ceramic coating

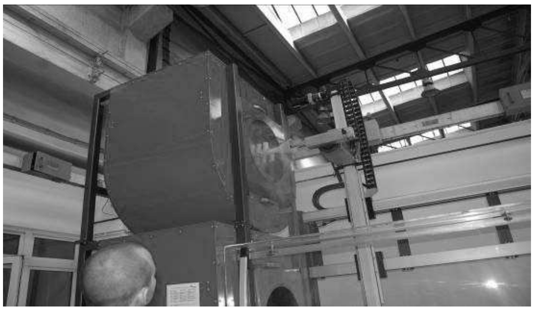


Fig. 4. Mould supported with loose ceramic material

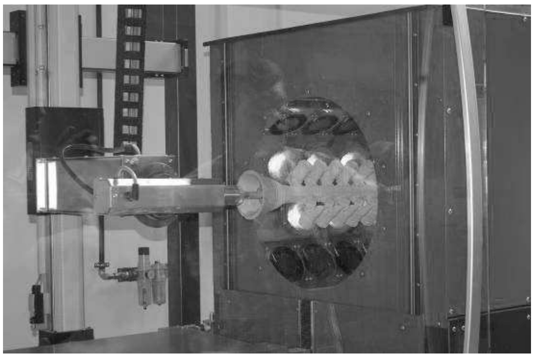
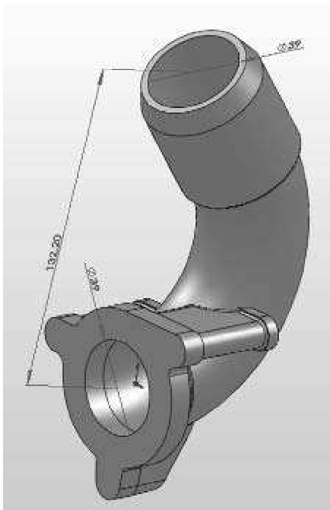


Fig. 5. Drying of applied ceramic coating

Item No. 3

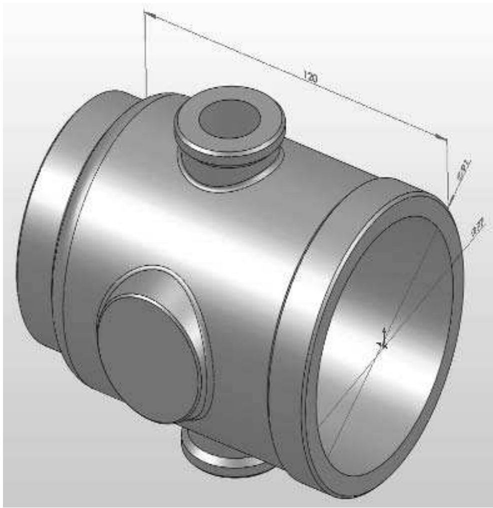


Name : Elbow.
Cast material : AK7 aluminium alloy.
Weight : 0,398 kg.

In future this item will be made by gravity die casting process with sand core.
The following elements were successively made: FDM model, silicone resin die and wax patterns.
Castings were made by the lost wax process.
Items were cast in plaster moulds.
The following checking tests were performed on castings:

– structure examinations,
– hardness measurements,
– dimensional accuracy: RPS model, die, wax pattern, casting.

Item No. 4



Name: Sleeve.
Cast material : AK7 aluminium alloy.
Weight : 0,621 kg.

In future this item will be made by gravity die casting process with sand core.
The following elements were successively made: FDM model, silicone resin die and wax patterns.
Castings were made by the lost wax process.
Items were cast in plaster moulds.
The following checking tests were performed on castings:
– structure examinations,
– hardness measurements,
– dimensional accuracy: RPS model, die, wax pattern, casting.

The structure examinations and hardness measurements taken on the four prototype castings confirmed that the technical parameters corresponding to standard requirements for AK7 alloy had been obtained.

The dimensional accuracy was checked using an optical 3D scanner ATOS III. It allows for the scanning (measuring the coordinates of points) of objects with overall dimensions from several millimetres up to several metres. ATOS operating principle is that of triangulation. Two cameras observe the run of fringes in the examined item and for each camera pixel the coordinate point is calculated with high precision. The maximum number of measuring points in a single shot is 4 000 000. The time for one shot is 2 seconds. The measuring fields are 150x150 and 500x500 mm.

The use of special software enables a complete analysis of the measurement (dimensioning of the item, compatibility with CAD data, coloured map of deviations, inspection sections, etc.) Quality control is one of the areas where optical 3D scanner ATOS III is used. It enables comparing the examined object with CAD model design, or comparing two identical objects. It also enables dimensioning of arbitrary cross-sections and geometrical features. The use of automatic rotary tables enables total quality control and analysis of shrinkage, ATOS III 3D is used in tool shops as a means for performance control, verification of processing, and tool reproduction. It also enables comparing the mould with pattern, digital recording and documentation. The 3D optical scanner using structured light emits onto the measured object a set of white light fringes characterised by a specific density of packing. The packing density of fringes enables specifying the amount of data received. With more fringes, more of data are received. These fringes are subjected to unequal distortion, and the image of the illuminated object is recorded by objective lenses mounted in the scanner head. As a result of the measurement carried out by this technique, a set of structured light fringes, lying on the surface of the object and at the time of illumination visible to both lenses, is obtained. The resulting sets of fringes are superimposed by means of reference points. So, prior to scanning, reference points are applied on patterns.

The image formed as a result of scanning is point cloud, and therefore the obtained model is subjected to polygonisation. This means that the point cloud is converted to a network of non-overlapping triangles. The created polygonal network is subjected to further processing, and the task of this processing is to remove reference points, fill surface discontinuities, and smooth them whenever possible. Thus prepared network of triangles is a model of the real object.

ATOS III programme for processing of scanned models allows reproduction of the model surface. It also allows fitting of models to each other.

The studies of dimensional accuracy made with the use of the described scanner fully confirmed the dimensional compatibility of models and castings made within the range of values expected for the ready cast elements.

CONCLUSIONS

The studies fully confirmed the applicability of FDM technique in creation of models used for the manufacture of prototype castings.

The possibility of making prototype castings using equipment available at the Centre for Design and Prototyping has been confirmed. The prototype castings can be used in verification of the design assumptions, while their lot production by selected casting technology can be undertaken as the next step.

Considering high surface quality and dimensional accuracy, models made by FDM techniques can successfully serve as prototype parts made from plastics.

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ZASTOSOWANIE WYBRANYCH TECHNIK RAPID PROTOTYPING DO WYKONYWANIA PROTOTYPOWYCH ELEMENTÓW KONSTRUKCJI MASZYN I URZADZEŃ.

Streszczenie. Dzięki zastosowaniu technik Rapid Prototyping istnieje możliwość szybkiego wytworzenia prototypowych części, podzespołów lub gotowych produktów. Przykładem zastosowania takiego rozwiązania są elementy nowego urządzenia. Efektem prowadzonych prac było uzyskanie krótkiej serii prototypowych części. Ze względu na spełniane funkcje, do wykonania ich zastało dobrane odpowiednie tworzywo sztuczne o właściwościach mechanicznych pozwalających na wstępne testowanie prototypu. Podstawą do wykonania detali były trójwymiarowe modele komputerowe. Dzięki wykorzystaniu urządzenia FDM Titan w krótkim czasie uzyskano modele rzeczywiste, następnie na ich podstawie zostały wykonane matryce silikonowe, które z kolei posłużyły do odlania krótkiej serii prototypów z tworzywa sztucznego. Tak uzyskane elementy zostały przekazane do testów w celu sprawdzenia ich funkcjonalności. Wykonano również serię odlewów z możliwością ich wykorzystania do testowania.

Słowa kluczowe: szybkie prototypowanie, projektowanie nowych wyrobów, odlewnictwo, tworzywa sztuczne.