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A REVIEW OF RAPID TOOLING TECHNOLOGIES IN TECHNICAL PRODUCTION PREPARATION

Abstract: In the paper a review of rapid tooling technologies is presented. This paper is thought as an introductory paper for the paper untitled A Review of Rapid Tooling Technologies in Technical Production Preparation – a Vacuum Casting Practical Example which is included in the current number of Selected Engineering Problems. Some aspects of rapid prototyping techniques and their importance in the development of rapid tooling techniques are considered. The paper gives a short description of direct and indirect rapid tolling techniques. The Vacuum Casting process is described more precisely.

1. Introduction

Recent achievements in a manufacturing technology have a big influence on the global market and industry. Enterprises, which want to survive on the global market successfully, have to compete each other. During this competition they are forced to apply the newest and the most innovative technologies, moreover they have to apply the holistic approach in the process of product development. Companies work under permanent pressure which cause that they have to shorten production cycles, minimise a product cost and a product lead time in the condition of still improvement of a product quality. In order to achieve these goals companies started applying the computer systems such as CAD, CAM and CAE [2]. Thanks to application of these kind of systems it was possible to reduce a product lead time, which is meant as a time which run from making a decision about undertaking tasks connected with a new product development to starting of manufacturing process, and production overall cost.

Nevertheless we apply advanced computer systems in a product development process it is still necessary to make a model prototype. Accessibility of a prototype gives a designer and product engineer possibility of checking of a new product design before making a decision about acceptance of its design. Precise analysis and also ability of avoiding of making of design faults at very early stage of a design process allow saving investment costs and lead time.

The needs of rapid manufacturing of prototypes and tools were the reason for working out rapid prototyping and rapid tooling techniques. Thanks to these techniques it is possible to create prototypes and tools just from 3D computer models within hours. RP (rapid prototyping) and RT (rapid tooling) give possibility for functional evaluation of a product, so design engineer is able to eliminate design faults at very early stage of product development. A comparison between conventional approach to a process of a product development and approach with application of rapid techniques in the figure 1 is shown.

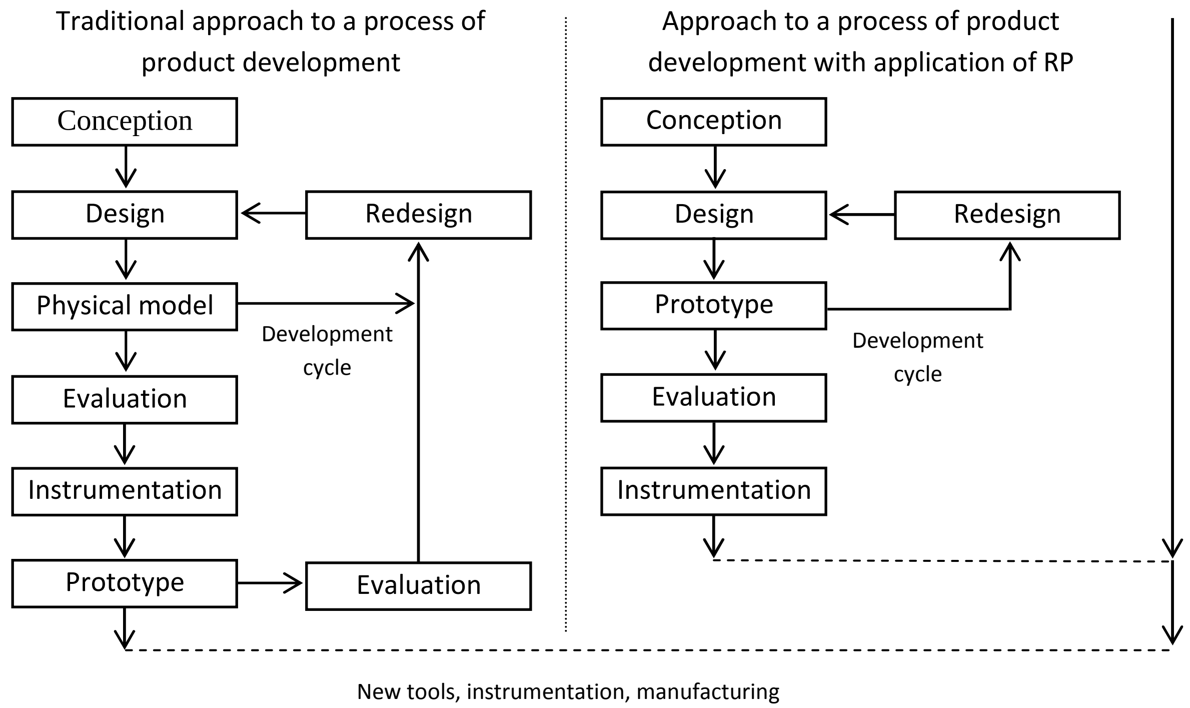

Fig.1. A traditional approach to a process of a product development vs. approach with application of rapid techniques

With application of RP techniques it is possible to manufacture several types of models and prototypes. We can distinguish the following types of models and prototypes: conceptual, ergonomic, geometrical, and functional. The conceptual model represents the external shape of product and it is made in order to demonstrate its main features to a client. The characteristic feature of this kind of model is that it is less detailed then a final product. The ergonomic model is helpful at a stage of decision making about the product future, it is about product rejection or its acceptance for a further development. It represents the main functions of a product and is more detailed (medium) then a conceptual model. A geometrical model represents all features of a final product and it its shape is very close to a real product (more detailed than an ergonomic model). Having this model it is possible to choose the best manufacturing technology. The functional model allows checking particular product functions and also demonstrating its functions to a client. A functional prototype has very similar features to a final design therefore it is possible to make an objective evaluation of a particular design solution.

The rapid prototyping technology came into existence in the 1980–s but the general idea of rapid product manufacturing was born in the late 60–s of the XX century when Herbert Voelcker was thinking about technique which would give possibility of automated controlled machines programming with a computer. In the 1970–s Voelcker worked out general rules of theory of solid modelling. In the 1980–s Carl Deckard from University of Texas figured out an idea of product manufacturing layer by layer with application of a laser beam.

This technique was next developed into technique of selective laser sintering (SLS). In the 1987 the 3D System Company was established. That company was the first in the world to be sold commercial rapid prototyping printers which manufacture product with stereolithography technology (SLA). Stereolithography was the first rapid prototyping technique.

2. **Review of rapid tooling technologies**

According to development in rapid prototyping technology new solutions such as rapid tooling came in to being. Rapid tooling technologies broaden possibilities of rapid prototyping in a domain of technical production preparation especially in technological production preparation. This technology is used in a process of rapid tools manufacturing, particularly moulds and also in manufacturing of small or medium product batches. At the beginning rapid tooling was treated as one of rapid technology branches but it developed into a separate technology branch. In spite of this new division these technologies complement each other making together an integrated manufacturing system. Thanks to this solution it is possible to introduce a new product in the market more quickly and cheaply [1]. We can distinguish the two groups of methods, it is: direct method and indirect.

2.1. Direct rapid tooling techniques

In the direct rapid tooling techniques tools are manufactured with application of rapid prototyping. In the figure 2 the comparison between a course of mould cavity preparation process and a traditional machining process of mould cavity is shown.

We can distinguish the following direct rapid tooling techniques: Direct AIM, Direct Metal Laser Sintering (DMLS), RapidTool.

Direct AIM method was established by 3D systems. In this method a mould cavity which is a negative of a model is made by curing epoxy resin with a laser beam (in the same way as in stereolithography). Moulds made in this way have good mechanical and thermal properties. They can bear forming temperature up to 300^0 C with application of proper cooling system. Manufacturing accuracy for this method is equal to ±0,12 mm. The maximum number of parts in the particular production batch is about 100.

Direct Metal Laser Sintering – DMLS was elaborated by German Company EOS. This method relies on sintering of metal powder with a laser beam. The base materials used in this process are brass and nickel powders. The DMLS machine uses a high-powered 200 watt Yb-fiber optic laser. The technology fuses metal powder into a solid part by melting it locally using the focused laser beam. Parts are built up additively layer by layer, typically using layers 20 micrometres thick. This process allows creating highly complex geometries directly from the 3D CAD data, fully automatically, in hours and without any tooling. DMLS producing parts with high accuracy and detail resolution, good surface quality and excellent mechanical properties. **RapidTool** thought out by DTM Company, uses the same method for part manufacturing as DMLS method. Thanks to application of RapidTool it is possible to produce mould cavities with different durability.

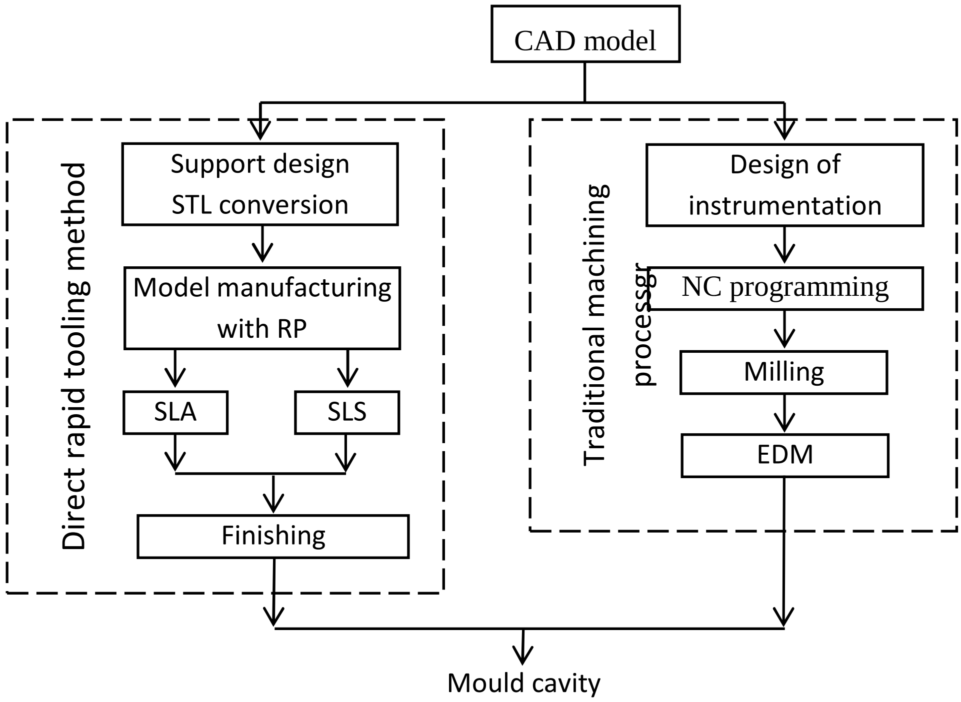

Fig. 2. A comparison between traditional machining process and rapid tooling

We can distinguish RapidTool Short Run method used in the case of small batches of moulds and RapidTool Long Run for bigger batches. In RapidTool Short Run mix of polyamide and Cu–PA powders is used. This mould allows manufacturing a batch of products up to 400 parts. RapidTool Long Run uses chrome – nickel steel as a base material and copper or brass as an infiltrate. The biggest advantage of this method is possibility of getting moulds which have similar characteristics to traditional aluminium moulds and also these moulds can be processed with chemical, mechanical and EDM treatment. In this kind of moulds it is possible to manufacture products made of plastic and light metals. The maximum number of products made with this kind of mould is 100000 parts in case of plastic materials and 1000 parts for light steels [1].

2.2. Indirect rapid tooling techniques

In indirect rapid tooling techniques negative of mould is manufactured. The basic difference between direct and indirect methods is that in indirect method in order to create a mould the positive of a product model is used. A product model is usually made with rapid prototyping technique. We can distinguish the following indirect rapid tooling techniques: Vacuum Casting (VC), Metal Spray (MCP) and Epoxy Tooling.

Vacuum Casting (VC) is an indirect method of vacuum forming in forms made of silicone. Forms are made in moulding boxes in which master's models are placed. A model and a moulding box are casted with two–component silicone resins. The process of mould formation is completely run in the condition of vacuum. Thanks to this it is possible to get very precise models. Ready to use forms are gravitational casted with two–component polyurethane and epoxy resins. This resins have reduce viscosity coefficient so it allows mould casting easily and precisely. The mechanical properties of parts are quite similar to properties of ABS, polyvinyl acetyl, polyethylene [1]. In the picture 3 the typical course of vacuum casting process is shown.

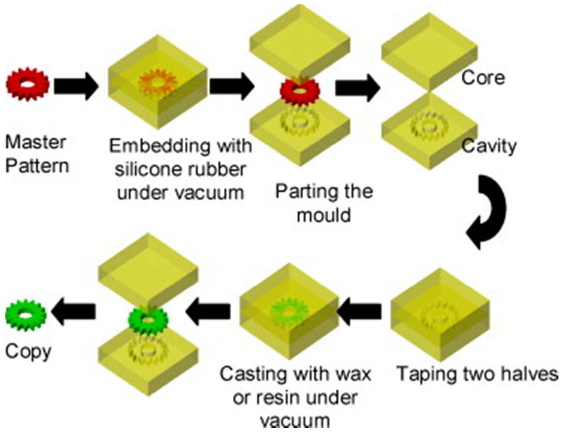

Fig. 3. Typical course of a vacuum casting process [3]

The process of a vacuum casting form preparation begins from modelling of a part model in a CAD system; sometimes this model is made by hand. Material for a model part should be low leakproofness in order to allow air and humidity getting out. The group of materials which have these features consists of: photopolymers, clay, putty, non–ferrous metals, PVC. In the next step of the process a moulding box is made. Having the moulding box done the master model of a part, a runner and degassing channels are placed in it. It is necessary to remember that the master model ought to be fixed steadily and parting lines designed properly. The proper design of parting lines might extend durability of the mould (the smaller number of parting lines the better). The part master is coated with special chemical separator which facilitates its removal from the mould. At a casting process preparation stage it is very important to set the correct proportions of resins and set proper mixing time. Depending on the extent of air bubbles in the mixture, the degassing process can last from 10 to 15 min. When the moulding box is filled it has to be degassed in vacuum chamber in order to remove air bubbles from the mould. The degassing process typically lasts around 25–35 min. The next step of the casting process relies on mould curing. The curing process is led in a special oven in the temperature about 70^0 C or in room temperature for resins with high thermal shrinkage. In the next step the mould is opened and the master model of a part is removed. Depending on a course of a manufacturing process the mould can be used immediately or stored in an instrumentation store. In vacuum casting process before manufacturing of a new product all parts of the form has to be tapped witch some kind of scotch type. After then the form is putted in to an oven and it is heated up to temperature 40^0 C and kept in this temperature for about 1h. This procedure is necessary in order to allow liquid resin to penetrate the form without any difficulties. In the meantime a mix of resins in the vacuum chamber is being prepared. Heaving the casting form heated up it is putted into a vacuum chamber and the casting procedure is started. Next the form is degassed and putted in an oven again. After curing the form ready to use part is removed from the form and the casting procedure can be repeated again. In vacuum casting method using particular form it is possible to produce up to 30 parts [1]. Low manufacturing cost, short production time and high precision of model reproducing into main advantages of this method can be counted [1].

Metal Spray (MCP) is indirect rapid tooling technique which relay on deposition of a metal layer on a model surfaces. In this way the shell model of a product which represents the model geometry is made. This technique can be used in serial production. The biggest advantage of this method is that tools produced with MCP can be used in either in convectional machine tools or in numerical controlled. The range of materials applied in MCP is limited to low–melting zinc allows, aluminium and copper. It is also possible to use steel but in this case of ceramic master models of product have to be used. Models for MCP are usually produced with the following rapid prototyping techniques SLA and SLS or in traditional way from wood or wax.

Epoxy Tooling is most often used in manufacturing of mould cavities with application of composite of epoxy resins and aluminium. In this method vacuum conditions are used for better reproducing of micro and macro structure of a product. The main advantage of this method is time shortening it means that the time which is need for technological instrumentation preparation is shorten by 8. Durability of mould cavities is counted in several thousand ready to use parts. The manufacturing process starts form fabrication of a master model. This model can be made with rapid prototyping techniques or by hand. Next this model is mounted in the moulding box, parting planes are set and cooling channels are prepared. After then the mould is casted, degassed and curried. The general procedure for the second part of mould is the same as for the first one. The complete mould is finally curried in temperature about 150^0 C.

3. Conclusion

In most cases rapid technologies are still slower than traditional manufacturing technologies, moreover the number of available materials is also limited but they have some very important advantages such as: tool preparation time is much shorter than for a conventional process of a tool preparation, so typically, time which has to run to the first products is below one–fifth that of the conventional tooling. The overall tooling coast is much less then for convectional processes it is assumed that it is below five percent of a traditional tooling cost.

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