Assessment of the Optimal Manufacturing Technology of the Brake Triangle Sleeve Casting Model Prototype using Multi-criteria Analysis

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Abstract— **Assessment of the optimal manufacturing technology allows increasing productivity, short product development time and prototype manufacturing time, and increasing the competitiveness of companies. This paper presents the methodology for selection the optimal manufacturing technology for casting model prototype. Presented methodology implies the use of multi-criteria analysis, i.e. the Analytic Hierarchy Process (AHP) method. Three alternatives were developed and examined: 3D printing, manufacturing of wood on CNC milling machines, and manufacturing of styrodur on CNC milling machines. In order to assess alternatives, six criteria are selected: manufacturing time, manufacturing cost, dimensional stability, complexity of the manufacturing technology, model destruction, and model precision. The result of the analysis shows that the optimal manufacturing technology, according to the selected criteria, is 3D printing.**

Keywords-optimal manufacturinug technology; 3D printing; manufacturing on CNC milling machines; mullti-criteria analysis, AHP method.

I. Introduction

The application of modern manufacturing technologies increases productivity shortens product manufacturing time and increases the competitiveness of companies in both domestic and foreign markets. By combining modern technologies with computer product development, maximum productivity and competitiveness on the global market is achieved with optimal engagement of production capacities. However, the creation of a physical model can be very complicated and expensive, so in recent times, the creation of a virtual product model is applied, that is, the creation of a product model in a virtual environment. By applying reverse engineering, product improvement starts from the final product and through the design process in the opposite direction, an improved product is obtained. Variant solutions are also sought for similar products from competing companies [1]. Also, due to frequent changes in the model, it is necessary to make more physical models, which requires additional time during product development, but also additional financial costs. By creating a 3D product model, a model in a virtual environment can be made, i.e. in the appropriate software package. Any change in the model can be done very easily and without the need to create a new physical model, which makes the product development process cheaper and development time significantly shorter. The simulation procedure, i.e., stress-strain analysis, gives answers as to whether the produced part will meet the required characteristics, but the main word is the behavior of the work in operation [2]. After the procedure of testing the virtual model, it is necessary to get a real (physical model).

The choice of real prototype technology also requires special analysis. To select the modeling technology in this paper, a case study was performed for making a triangular pole sleeve, Fig. 1 for a wagon braking system using VKA, which is made by sand casting technology.

This paper presents the methodology for selection the optimal manufacturing technology for casting model prototype. Presented methodology implies the use of multi-criteria analysis, i.e., the Analytic Hierarchy Process (AHP) method. Three alternatives were developed and examined: 3D printing, manufacturing of wood on CNC milling machines, and manufacturing of styrodur on CNC milling machines. In order to assess alternatives, six criteria are selected: manufacturing time, manufacturing cost, dimensional stability, complexity of the manufacturing technology, model destruction, and model precision.

II. Methodology

A. *Casting tehnology and model description*

The choice of manufacturing technology of a real prototype also requires special analysis. In this paper illustration of the choice of model manufacturing technology, is presented by a case study of a triangular rod sleeve by using MCA. Model prototype of sleeve which is manufactured by sand casting technology is shown at Fig. 1.

Figure 1. Cast prototype model

Sand casting, also known as sand molded casting, is a metal casting process characterized by using sand as the mold material. The term "sand casting" can also refer to an object manufactured by the sand casting process. Over 60% of all metal castings are manufactured by sand casting process. The mold cavities and gate system are created by compacting the sand around models. Illustration of sand molded casting is shown in Fig. 2 [3].

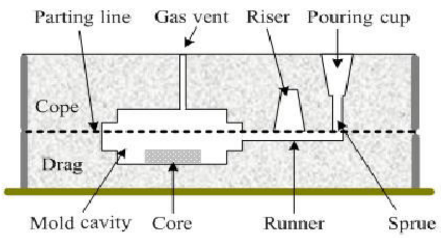

Figure 2. Sand cast tool model

Model of the object than will be casted, can be manufactured by wood, metal, or a plastic such as expanded polystyrene. Direct carving, machining, 3D printing, 3D tooling are technology of model manufacturing [4].

B. The Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making technique, quite often used to solve complex decision-making problems in a variety of disciplines: manufacturing industry, environmental management, power and energy industry, transportation industry, construction industry, etc. [5].

The AHP hierarchical structure allows decision makers to easily comprehend problems in terms of relevant criteria and sub-criteria. Additional criteria can be superimposed on the hierarchical structure. Furthermore, if necessary, it is possible to compare and prioritize criteria and sub-criteria in the AHP practice, and one can effectively compare optimal solutions based on this information. The decision procedure using the AHP is made up of four steps: 1) define the problem and determine the kind of knowledge sought; 2) structure the decision hierarchy according to the goal of the decision; 3) construct a set of pair-wise comparison matrices; 4) use the priorities obtained from the comparisons to weigh the priorities in the neighboring level [5].

III. Experimental Research

According to the available manufacturing technology, three alternatives were selected, and examined in terms of selected criteria. The selection of the criteria is made according to which of the criteria better translates a comprehensive and meaningful assessment of optimal manufacturing technology of casting model prototype.

A. Alternative Description

According to the available manufacturing technology, three alternatives were selected: 3D printing, manufacturing of wood on CNC milling machines, and manufacturing of styrodur on CNC milling machines.

Alternative 1 – Additive technologies have recently supplanted others manufactured technologies for production of the physical models. Because of this for the purposes of this research, a model was made on a 3D printer Sindoh DP200 from ABS plastic, with a layer thickness of 0.2 mm. The process of a prototype manufacturing on a 3D printer was performed in several stages. The first was the optimization of the printing process. The optimization of the printing process includes testing the position of the print sleeve using appropriate software, in order to reduce material consumption, surface quality and print speed, as shown in Fig. 3.

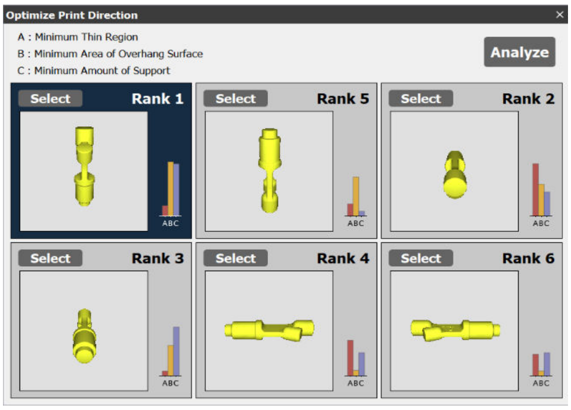

Figure 3. Optimization of the sleeve printing process using software

The optimal solution was the position of the sleeve marked with Rank 1, Fig. 3, because it does not require support (the lowest material consumption), satisfying the surface quality and the shortest production time. The procedure for making a sleeve with 3D printing is shown in Fig. 4.

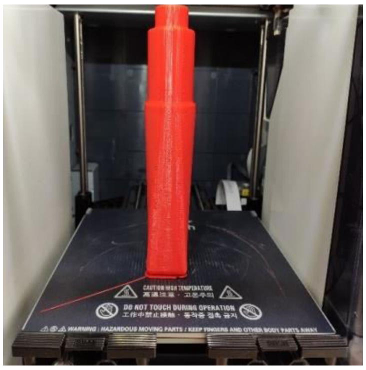

Figure 4. Manufacturing of sleeve model on a 3D printer

After the optimization procedure, the model was printed with a density of 30% and a wall thickness of 2 mm in order to extend the life of the casting model, because this is one of the criteria for the MCA. The printed parts are shown in Fig. 5.

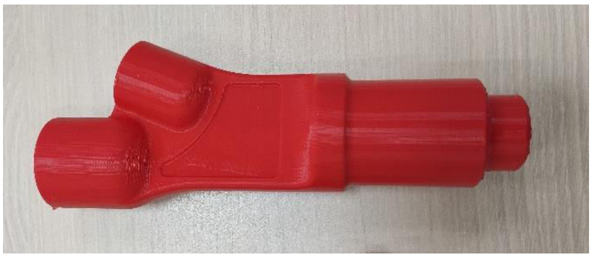

Figure 5. Cast model made on a 3D printer

Alternative 2 – The conventional approach to model casting relies mainly on machining technologies. Therefore, these procedures were considered as other alternatives. As previously mentioned, different materials are used for these types of production. So wood as a material will be considered here as one of the alternatives. CNC milling machine was used as a manufacturing system for model production, since the part is non rotation but symmetrical. In this model design, the pre-processing procedure is quite demanding. Feature CAM software was used for G-code development. in this research which is shown in Fig. 6.

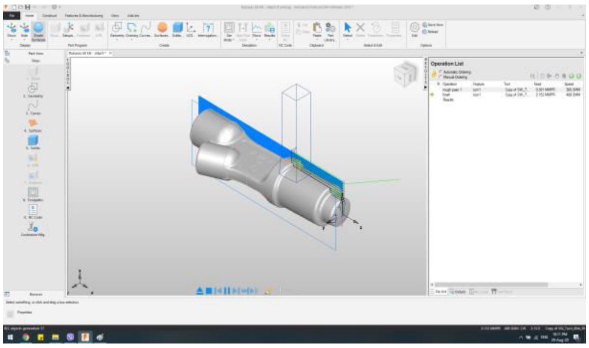

Figure 6. Feature CAM G-code development

Spruce was used as a material, and three types of milling cutters were used in the modeling process (end mill, ball mill and V-bit).

Alternative 3 –Styrodur is recently also used as a material for models manufacturing. The reason lies in the fact that it is easy to find, does not need additional processing and is very cheap. The process of styrodur model manufacturing is identical as the wood model. The process of making a model on a CNC milling machine is shown in the Fig. 7.

Figure 7. Manufacturing of styrodur model at CNC mill

The same G-code software and same milling cutters were used for the styrodur model manufacturing. Styrodur model is shown in Fig. 8. The pre-processing time is identical as in case of wood, but the manufacturing time on the CNC milling machine is twice as short in case of Styrodur.

Figure 8. Styrodur model made on a CNC mill

The reason for such a difference in time lies in the far weaker mechanical characteristics of styrodur compared to wood. It should also be noted that at high spindle speeds, wood causes fire. Another positive characteristic of styrodur is that it can be used in sand casting with the destruction of the model

B. *Indicators Selection and Evaluation*

Fig. 9 shows the hierarchical structure considered in the selection of optimal manufacturing technology of casting model prototype.

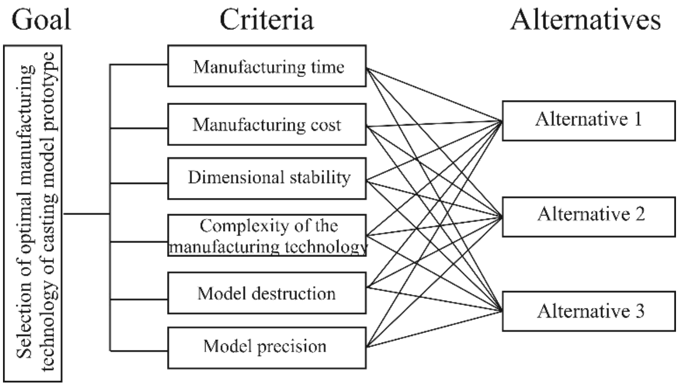

Figure 9. The hierarchical structure for selection of optimal manufacturing technology of casting model prototype.

In order to select optimal manufacturing technology of casting model prototype six criteria were selected: manufacturing time, manufacturing cost, dimensional stability, complexity of the manufacturing technology, model destruction, and model precision.

Manufacturing time – It is time needed to produce a model without pre-processing time.

Manufacturing cost – Consumption of material and its price.

Dimensional stability – Depending on whether the piece is casted immediately or not, the size of the wood can be changed due to the high air temperature and low humidity in the foundries.

Complexity of the manufacturing technology – With complex part geometries, (functional openings, holes, etc.)

there are limitations in the application of convection technologies, so preference is given to additive technologies.

Model destruction – The property of the material that it can be used even in sand casting with the destruction of the model.

Model precision – When casting complex geometries, it is very important that all the details of the model can be cast. i.e. high shape tolerance.

Criteria evaluation was performed by calculation (manufacturing time, manufacturing cost), i.e. on the basis of experience in practice (dimensional stability, complexity of the manufacturing technology, model destruction, and model precision). Criterion evaluation is presented in Table 1.

TABLE I. CRITERIA EVALUATION

Criteria	Alternative 1	Alternative 2	Alternative 3
Manufacturing time	8h and 45 min	3h and 12min	1h and 45min
Manufacturing cost	7,3 €	15 €	2.5 €
Dimensional stability	100%	30%	70%
Complexity of the manufacturing technology	100%	70%	30%
Model destruction	No	No	Yes
Model precision	100%	70%	30%

C. *Alternatives Ranking*

Following the pair-wise criteria, the criteria weight with respect to the goal was obtained and shown in Fig. 10.

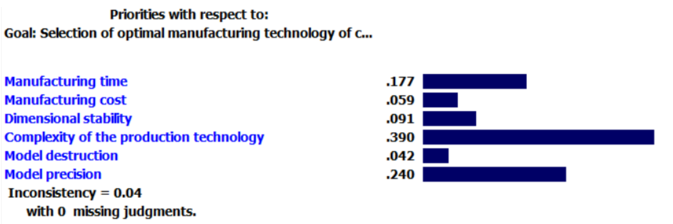

Figure 10. Priorities of criteria with respect to the goal

According to the criteria weight alternative ranking was performed and presented in Fig.

11.

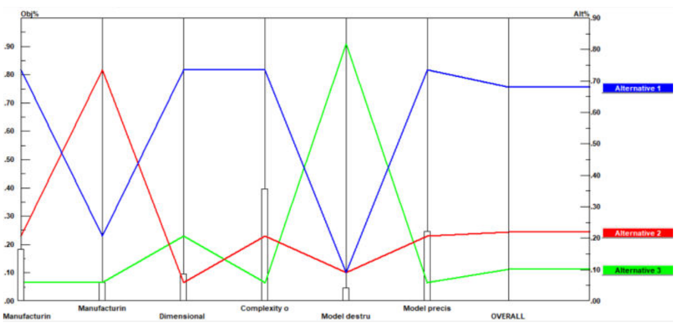

Figure 11. Alternative ranking

IV. RESULTS AND DISCUSION

The longest manufacturing time is on a 3D printer, with increasing of model complexity increases the production time. There is also a limit to the size of the model that can be made on a 3D printer.

The manufacturing process on a CNC milling machine is much faster, up to 7 times in the case of styrodur. Production in styrodur is the fastest due to the properties of the material, but it is necessary to take care because model made in this way is very brittle and have weak mechanical properties, ie. they are subject to breakage. The great advantage of these models in relation to wood and plastic is in terms of the possibility of casting with the destruction of the model, which gives the highest precision of the manufactured parts.

The disadvantage of CNC milling is the pre-processing of the model in Feature CAM software and G-code development, starting of machine, calibration and replacement of milling cutters in contrast to 3D printing where there is a short time of pre-processing, and commissioning of the machine in just a few minutes.

The cost of model manufacturing in wood is the highest considering the accessories for turning (rough and fine) as well as the accessory for mounting on the machine. The same case of material consumption is with styrodur, but the price is several times lower.

V. CONCLUSION

As mentioned above, additive technologies are supplanting conventional technologies when it comes to prototype manufacturing. This is most often reflected in the fact that it is necessary to create a complex part of high tolerances. The 3D printing is used because of freedom of form and freedom of shape.

Despite the fact that additive technologies are being used more and more, the question of their justification arises. Therefore, MCA is applied in this paper in order to assess whether this technology can replace the conventional method of prototyping models for metal casting.

Three scenarios and six criteria were considered. An analysis of the application of 3D printing and model making on a CNC milling machine in the case study of the sleeve was performed. The application of MCA determines the justification for the use of 3D printing for small parts, medium tolerance, relatively low modeling cost and even in the case when the time for making the model is not important.

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