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Comparison of Quality of Investment Castings Produced Based on the Rapid Prototyping Techniques with Products of Powder Sintering

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Abstract

The proposed research work will be related to the comparison of the dimensional accuracy and surface roughness of elements produced by two different methods. Castings are made using modern rapid prototyping techniques and investment casting. For selected parts there will be presented an assessment in terms of manufacturability, design manufacturing costs, operating parameters and energy consumption of production. The analysis of used methods allow for the evaluation of their suitability as alternative manufacturing techniques.

Keywords: Investment casting, Powder sintering, Casting quality

1. Introduction

Industries with highest demands regarding casting quality – aviation, army are a major customer of precision castings made in the investment casting technique [1]. Precision castings in many cases have better mechanical properties than the products of plastic processing [2]. Very important role in the quick production of castings have the Rapid Prototyping methods that allow reducing the cost of manufacturing and producing high quality patterns and dies using numerical calculation and simulation software's. This allows for optimal design of die's in the 3D system based on modern CAD software [3], [4], [5], [6], [7].

The use of powder sintering metallurgy in many cases may be the substitution to finished products such as precision castings, and forged products. Especially, when the production quantity is more than 50,000 [6], [8], [9].

The development of powder sintering technology in the world is heavily related to the automotive industry. Approximately 70% of the products of powder sintering are used in vehicles. The advantages of the powder metallurgy are: good dimensions repeatability, small number of defects, and low energy consumption of manufacturing [10].

2. Comparison of quality of precision castings produced in the investment casting process and products of powders metallurgy

Comparison analysis was conducted based on similar details: Fig. 1 casting, Fig. 2 product of powder sintering.

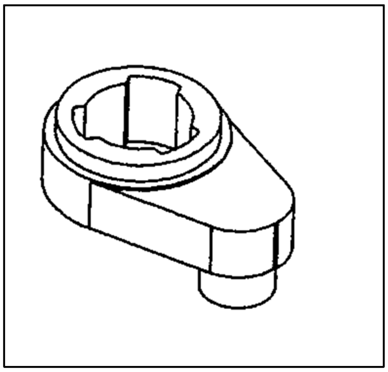

Fig. 1. Investment casting - low-alloyed steel

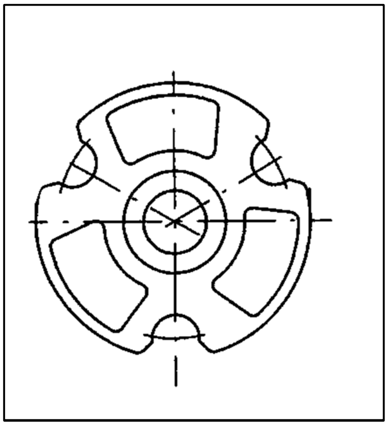

Fig. 2. Product of powder metallurgy - Material Distaloy AB

Casting made of low-alloyed steel have a carbon content of 0,5% and maximum nominal size 38 mm. Powder sintering product produced from Distaloy AB with chemical composition of C 0,55% slight amount of Cu 0,5%, Ni ~ 1,7% and Mo 0,5%. The maximum nominal size is 35mm, the average thickness of 5 mm.

2.1. Analysis of the quality of the castings

Castings were prepared in sets in the amount of 28 units per set. Figure 3 presents the view of the investment casting set. Ceramic layered shell molds were made from: binder - Ludox and ethyl silicate, ceramic material - SiO_2. The mold for the investment casting patterns can be produced by traditional method – machining of the metal block as a die or in the case of prototype production as a silicon rubber mold from the model produced by the one of available 3D printing technique [3].
In both cases, the dimensions of die cavity should be calculated. P_{nom} based on dimension chain which represent the dimensional change in the next manufacturing steps. The schematic of such measurement chain is presented in Figure 4 (methodology is presented in [11]).

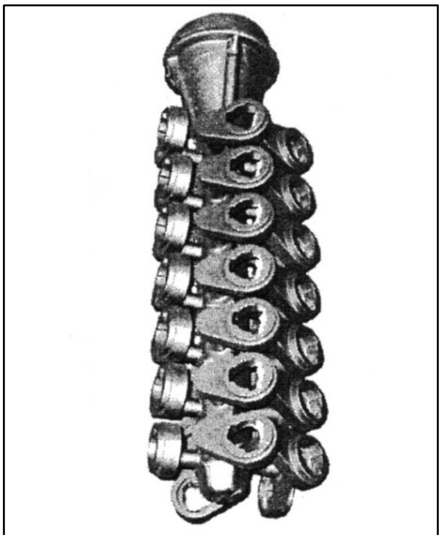

Fig. 3. Investment casting set

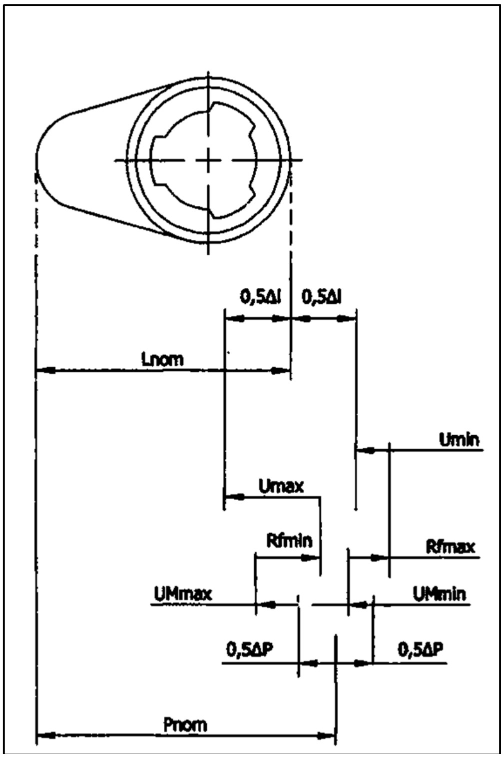

Fig. 4. The dimension chain of P_{nom}

For the calculations the following data was used:

a) L_{nom} – dimensions according to the drawing,
b) U_{Mmax} – maximum shrinkage of the wax PSWp – 1%,
c) U_{Mmin} - minimal shrinkage of the wax– 0,6 % (inhibited shrinkage),
d) R_{fmax} – maximum expansion of the ceramic layered mould – 1,4%,
e) R_{fmin} - minimal expansion of the ceramic layered mould – 1,1%,
f) U_{max} – maximal shrinkage of alloy – 2,2%,
g) U_{min} – minimal shrinkage of alloy – 1,8% (inhibited shrinkage).

Calculated value P_{nom}. based on the dimension chain (Fig. 4.) end equation:

$$P_{i\,nom} = L_{i\,nom} + U_{M\,śr} - R_{f\,śr} + U_{śr} \quad (1)$$

where:

1. P_i - dimension of the next cavity related to the subsequent casting dimension,
2. $L_{i\,nom}$ - average value, as a total value of the maximum and minimum divided by 2.

In the case of using rapid prototyping techniques in die manufacturing the calculated dimensions P_i need to be included on the design drawing of the cavity of the die.
The accuracy of the dimensions of the cavity should be (measurement uncertainty) [10], less than 0,02 mm.
The casting should be made in the accuracy grade CT7.
The surface quality of castings from the same set (Fig. 3.). for the parameter $R_a = 4{,}48 \pm 0{,}45$ µm.

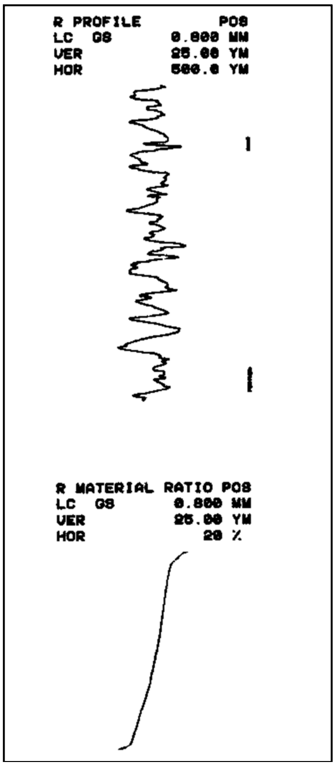

Fig. 5. Graph of the profilometer for casting Fig. 1

Example of profilometer measurements is presented in Figure 5. At the top there is a surface profilometry and at the bottom there is a participation carrier curve t_{p50} for $R_{a\,max}$=50%. The value of t_{p50} for the measured castings is 69 ± 9%. The measurements were carried out on the digital profilometer Mahr Perthen S3P.

2.2. Analysis of the quality of the powder sintering product (Fig. 2.)

The product of powder sintering was manufactured from the material Distaloy AB. Based on the computer software the pressing parameters was calculated: pressing pressure 450 MPa, sintering temperature 1150^{O}C, sintering time 30 min. Sintering process was calibrated. The surface quality for parameter R_a = 2,98 µm. Example of profilometer measurements is presented in Figure 6. The value of t_{p50} for the measured detail is 58 ± 7%.

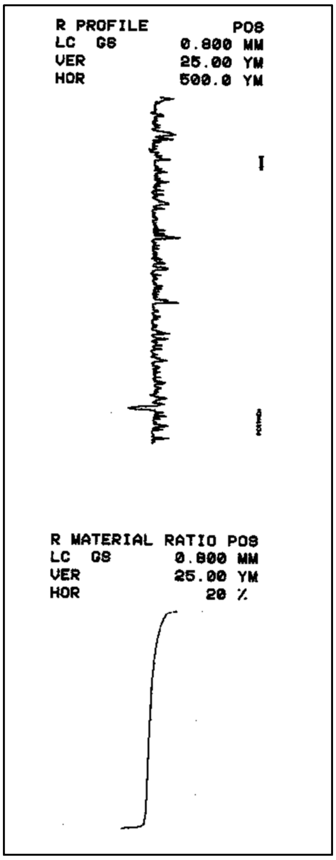

Fig. 6. Graph of the profilometer for product of powder sintering Fig. 2

The value of t_{p50} for the measured detail is 58 ± 7%. The measurements were carried out on the digital profilometer Mahr Perthen. The dimension accuracy of measured details is in grade IT7. For comparison the sinters with L_{nom} = 40mm directly after sintering process have dimension accuracy in range IT9 to IT10. After calibration the grade IT7 was achieved which is similar to the accuracy of the castings

3. Summary

Powder sintering process is performer in specially designed dies. Sintering process was performed by heating the powder at appropriate temperatures (without passing the liquid state) in a protective atmosphere. This allows moldings shape remain stable throughout the technological cycle with very low shrinking or expand. Thus the accuracy grade IT7 can be achieved.

The manufacturability of sinters compared to castings:

1) sharp contours should be avoided,
2) small diameters below 2mm,
3) depth of closed bores should be equal to their diameter,
4) on transition of walls (their connections), it is best to use radius over 1mm.

The cost of sinters is 10 – 15% lower than the cost of the castings, but only regarding mass production.

In case of sinters there is 100% yield and minimal quantity of defects.. Recycling process of defects is very simple. The maximum area of pressing is ~ 30 cm^2 and the weight of the sintered material ~ 350g.

4. Conclusions

1. The main disadvantage of the powder metallurgy is required mass production due to high cost of tooling,
2. Sinters have very low impact strength,
3. The advantage of the sinters is possibility of oil impregnation, the part can become self-lubricate, which can't be achieved with castings,
4. Sintering process have lower energy consumption compared to other castings production techniques,
5. Casting have more application because of cheaper production of small quantity batches and possibility of using unique materials,
6. Castings can be used as very large parts that can excess largest products of powder sintering,
7. Dimensions and surface quality of sinters and castings are similar for details of weight in range from 350 to 500g,
8. Higher participation carrier curve t_{p50} (for castings) allows to increase their exploitation time.

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