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Properties of MIM 4140 Alloy After Injection Molding and Sintering

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ABSTRACT

Testing results of a multi-cavity mold for injection molding of MIM 4140 alloy are presented in the article. Recommendations for manufacturing of forming parts of the mold were given. Based on an implemented technological process of casting and subsequent laboratory researches an information was obtained about the condition of a casting (hardness on Super-Rockwell, shrinkage and quality of a surface layer of material before and after heat treatment). Calculated overall dimensions of the forming parts of the project mold will allow making forecast of shrinkage of MIM 4140 alloy after injection molding.

Keywords *– a casting, a mold, MIM 4140 alloy, a surface layer, injection molding.*

I. Introduction

It is possible to obtain the small parts of a complex configuration by widespread methods of processing. Mechanical processing of these parts leads to increasing of implementation time of an operation (at compliance of high dimensional accuracy), range of standard and special cutting tools, and in more cases it is used an unrational workpiece and etc. Casting [1] reduces manufacturing time of these parts. However, difficulty of formation holes of the small diameter in the parts and not high accuracy of casting leads to restriction of the use this method in production. For implementation of all technical requirements for manufacturing of the described parts in serial production, rationally to select the technology of filling metals into a mold under pressure by injection method with subsequent sintering process of the obtained casting [2, 3]. MIM technology allows to obtain the finished parts of different assignment from alloys based on iron (low-alloy steel, corrosion resistant steel, tool steel, special steels), non-ferrous alloys (alloys of copper, heavy metals, hard alloys, light metals) and ceramic materials. The part manufacturing by means of MIM technology and its quality control are ensured by designing of tooling (the mold), selecting of the composition of initial mixture and determining of the material properties.

II. Material and method

The some properties of material of the one-type castings obtained by MIM technology were exposed by the research.

The manufactured casting has the shape of a body of rotation with the blind central hole. On the outer diameter of the casting by injection molding an area with a radius output is formed. The outer diameter of the casting is performed in a form of a cone. The drawing of the casting with diametric, linear and angular sizes is presented in the Fig. 1.

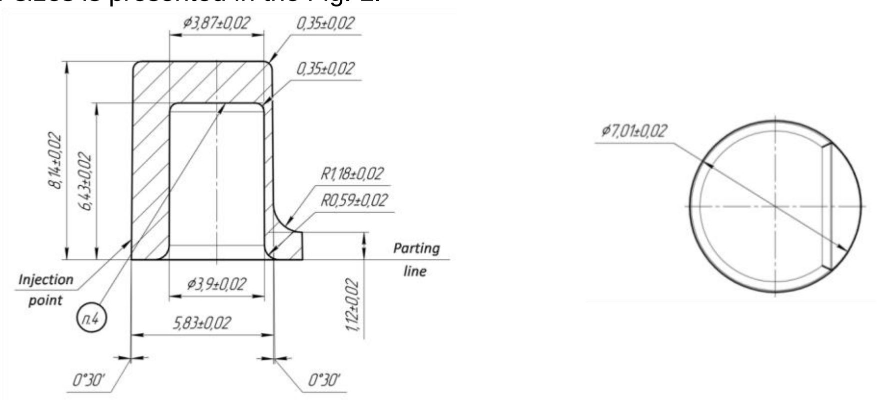


Fig. 1. The drawing of the part “Plunger”.

Unspecified tolerances in the drawing of the part were taken ±0.02 mm.
The castings were made from MIM 4140 alloy (low-alloy) [4]. Alloy contains 0.2 – 0.3% of molybdenum, 0.3 – 0.5% of carbon, 0.8 – 1.2% of chromium, 0.6% of silicon, 1.0% of manganese and rest it is iron. Density of material is 7.5 g/cm^3, ultimate strength – 1654.74 MPa, yield strength – 1241.06 MPa, elongation – 5%, Young's modulus – 203395.33 MPa, Poisson's ratio – 0.28, unnotched Charpy impact energy [5, 6] – 74.5701 N·m.
Offset of the parting line of the mold is allowed no more than 0.1 mm. Number marking of the each cavity must perform by depth of 0.2 mm. The drawings of the forming parts of the mold are presented in the Fig. 2 and 3.

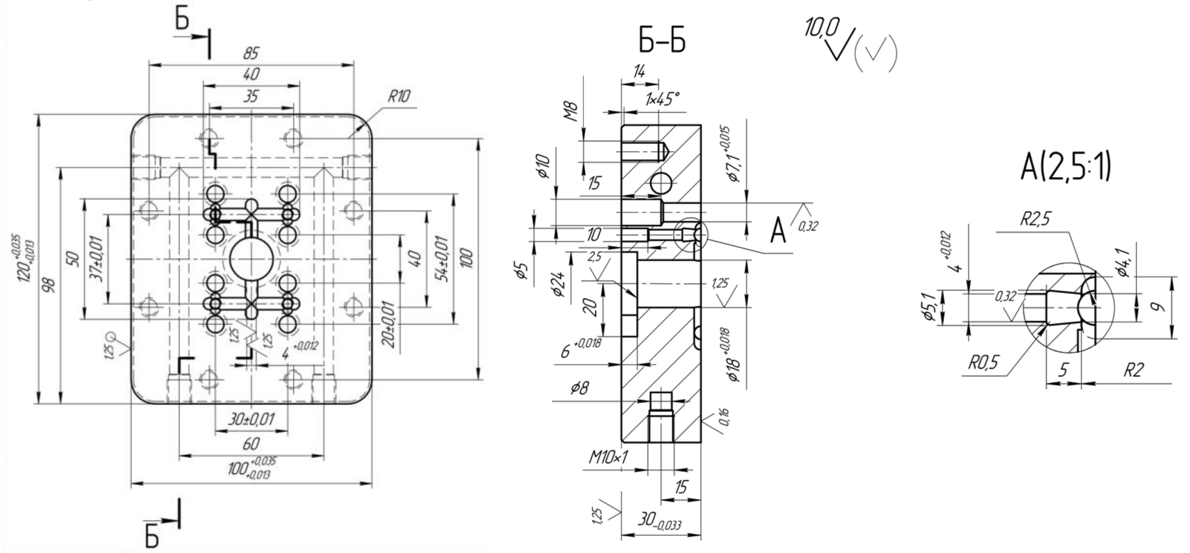


Fig. 2. The drawing of the part "Insert 149-13" (the forming part of the mold).

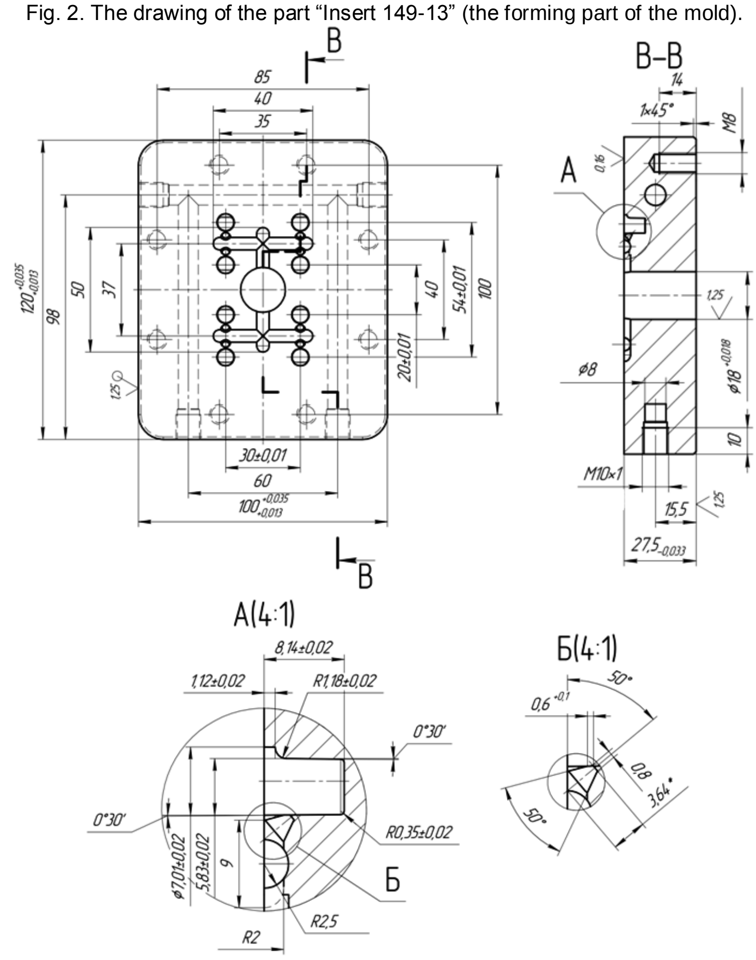


Fig. 3. The drawing of the part "Insert 149-14" (the forming part of the mold).

The part "Insert" is made from alloy tool die steel T30402. For implementation of casting process, the part is exposed to heat treatment to hardness of 58...62 HRC. Surface roughness of the gating system should be 0.63 μm. The remaining technical requirements for manufacturing of the part are according to GOST 27358-87.

Roughness of the forming surfaces obtained by electrical discharge machining should be 0.63 μm.

Preliminary quality control of the assembly mold was carried out by mating of the three-dimensional models of the parts in the unit. The general view of the mold is presented in three-dimensional formulation (Fig. 4). The assembly process of the multi-cavity mold for injection molding of MIM 4140 alloy is presented in the Fig. 5.

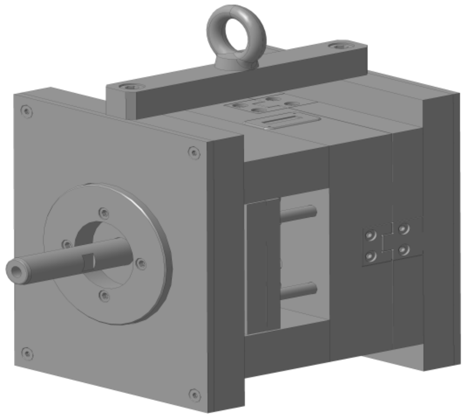


Fig. 4. The three-dimensional model of the eight-cavity mold.

Fig. 5. The assembly process of the eight-cavity mold for injection molding of MIM 4140 alloy.

Manufacturing of the castings was performed on the injection molding machine Arburg Allrounder 270C 400-100 [7]. High reliability and repeatability of the injection molding machine allow to perform casting of the parts with minimal deviations. The requirements for manufacturing of the castings and the mold for injection molding are presented in the table 1.

TABLE I. THE REQUIREMENTS FOR MANUFACTURING OF THE CASTINGS AND THE MOLD.

Parameter	**Value**
Release program of the parts	40000 pieces per year
Mass of the part	1.1 g
Calculated shrinkage of polymer material during molding process of the part	18%
Molding temperature	180 °C
Pressure	1000 – 1700 kg/cm^2
Downtime under pressure	3 s
Molding cycle	35 – 60 s
Temperature of cooling liquid (air)	40 – 60 °C
Number of the mold cavities	8
Design of an inlet channel or a sprue	tunnel
Operation mode of the mold	automated
Requirements for material of the forming parts of the mold	hardness of the forming parts at least 60 HRC, high wear resistance
Calculated guaranteed life of the mold	300000 cycles

Operations of flash trimming and sprues separation are not acceptable.

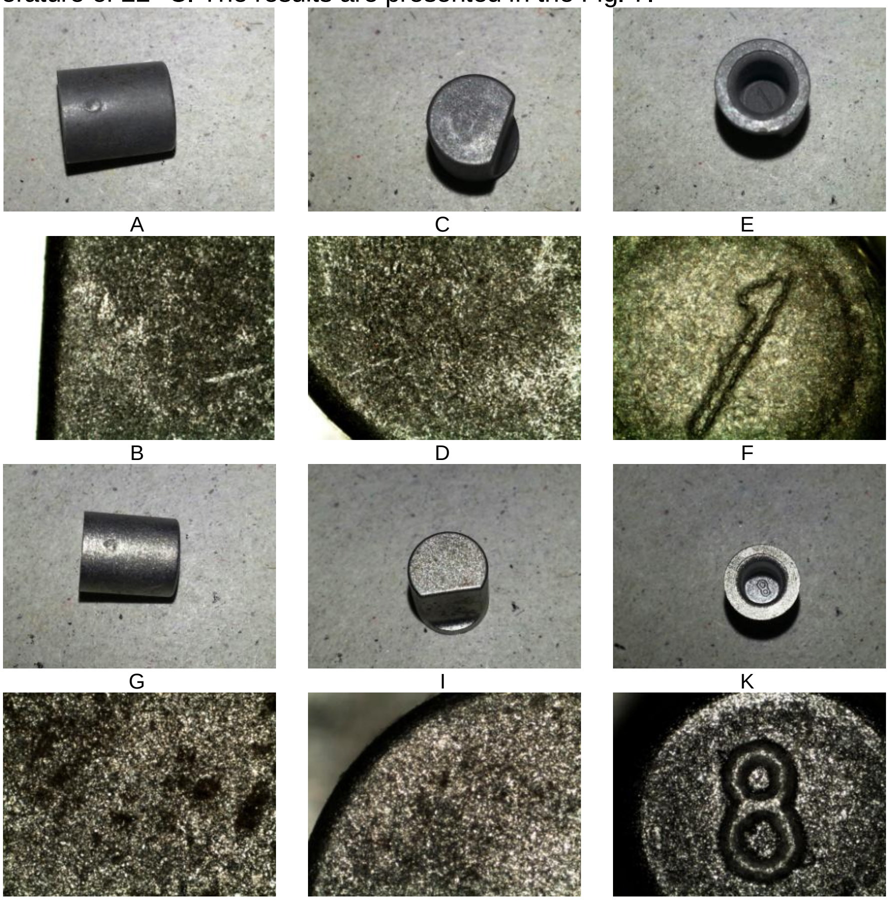
III. Result and discussion

Calculated shrinkage of the casting is achieved after material cooling in the mold. Required shrinkage of the part is achieved after heat treatment (sintering). Accuracy of linear, diametrical and angular sizes of the part is confirmed at measurement by measuring tools. Comparison of shrinkage of the castings material before and after heat treatment is presented in the Fig. 6.

A B

Fig. 6. Shrinkage of the castings material after heat treatment (A) and before heat treatment (B).

The condition of the surface layer of the castings before and after heat treatment was determined on the video-measuring microscope VP-6440 (United Kingdom) [8]. The microscope of this model is characterized by a permissible absolute error of measurements of linear dimensions along the axes X, Y and Z in the range ±(2.5 + L/150) µm (where L is a measured length in mm) and discreteness of reference of linear measurements – 0.0005 mm. Working with the microscope was carried out at an ambient temperature of 22 °C. The results are presented in the Fig. 7.



A C E

B D F

G I K

H J L

Fig. 7. The condition of the surface layer of the castings before heat treatment (A – F) and after heat treatment (G – L). Magnification ×5.

After cooling of the casting in the mold it is observed high density of material. Before heat treatment, the casting material is very brittle. After heat treatment, high density of material remains. On the surface layer of the casting material microporosity is formed. Porosity in researched material of the

casting increases resistance to cracking. Surface roughness of the casting material after MIM technology is very low.
Hardness measurement of the casting material after heat treatment was performed by the method of Super-Rockwell on the special hardness tester. Hardness (17 HRC) was obtained at indentation in the casting material of the diamond cone (indenter) with an angle of 120° at the apex. Force of indentation of the indenter was taken 150 kg.

IV. Conclusion

Thus, based on of the conducted analysis of the properties of MIM 4140 alloy after manufacturing of a semi-finished product by injection molding and sintering, it is possible to draw the following conclusions:
1. The configuration and manufacturing features of the mold are presented. Quality control of assembly of the mold should be implemented by the three-dimensional model. Casting modes are used for serial production of these castings. Recommended pressure at molding simultaneously eight castings is 1500 kg/cm^2. Temperature of the casting process of MIM 4140 alloy is similar to temperature of the casting process of thermoplastics.
2. At average hardness of material, high dimensional accuracy and low roughness of the surfaces, the casting (the part) is ready for assembly and subsequent operation. Porosity, formed after heat treatment, provides the higher crack resistance of the casting material.

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