Computer and laboratory research of condition of MIM 4140 alloy after injection molding and sintering

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ABSTRACT

The results of a computer simulation of an injection molding process in a mold (changing of liquid phase of melt during filling and crystallization) and laboratory research of condition of MIM 4140 alloy after heat treatment are presented in the article. Color contours showing a value of linear shrinkage and porosity of a casting material before heat treatment are obtained. It is determined that maximum linear shrinkage and porosity occur in an area of the casting bottom. A general picture of condition of inner layers of the castings material before and after heat treatment is given.

Keywords *– a casting, linear shrinkage, porosity, filling, crystallization, sintering.*

I. Introduction

MIM technology is processes of injection molding and sintering of castings which are made of special alloys [1 – 8].

Comparison of linear shrinkage of the casting material “Plunger” before and after heat treatment was performed in the article [9]. Linear shrinkage of the casting material after sintering is 17 – 19% from the casting dimensions to sintering in accordance with requirements specification for development of design documentation and manufacturing of a mold. Increasing of pore dimensions in surface layers of material was determined after heat treatment of the casting.

The required accuracy of dimensions and shape, surfaces roughness and material structure of the casting after injection molding and sintering are achieved by careful manufacturing of the mold, compliance of casting modes and proportions selection of the chemical elements of alloy. Analysis of this technological process before operation of the mold in production conditions is recommended to perform in special computer programs. Changing of liquid phase of melt during cooling, linear shrinkage, porosity and other casting defects of the casting material after crystallization (a semi-finished product before heat treatment) are determined in special modules of these programs. Comparison of the simulation results and laboratory researches will allow to make a conclusion about the accuracy of a performed computer calculation.

II. Material and method

The simulation of the injection molding process of the castings was performed in the computer program LVMFlow. The solid model of the casting “Plunger” is presented in the Fig. 1.

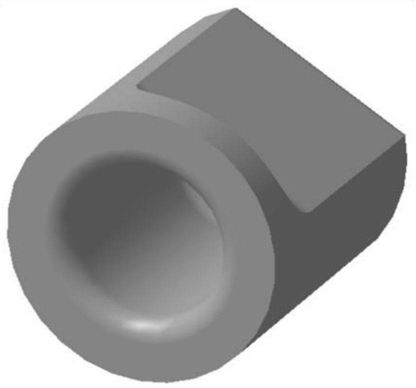

Fig. 1. The model of the casting "Plunger".

The created casting model had the following dimensions and elements: a maximum outer diameter – 7.01 mm, a total length – 8.14 mm, the hole diameter – 3.9 mm, the hole depth – 6.43 mm, radii on an outer and inner side of bottom – 0.35 mm. The casting was made of MIM 4140 alloy. A weight of one casting is 1.1 g.

Conditions of the computer simulation of injection molding (filling of a chamber of a molding machine by melt, injection phase of melt into the mold and melt cooling) are presented in the summary table 1.

TABLE I. DESCRIPTOR INFORMATION.

Mesh						
	Box dimension	***Casting position***	***Number of cells***			
along X, mm	81.250	40.494	65			
along Y, mm	201.250	100.321	161			
along Z, mm	60.000	30.000	48			
Size of cells, mm	1.25					
Total cells	502320					
Casting cells	60052					
Boundary conditions						
	Low	***High***				
YZ plane	Normal conditions	Normal conditions				
XZ plane	Normal conditions	Normal conditions				
XY plane	Normal conditions	Normal conditions				
Materials temperature						
Materials	***T, °C***					
MIM 4140	180.000					
1044	20.000					
Air	20.000					
Air gap (interfacial heat transfer model)						
	Coefficient, %					
v Upper	100.00					
v Lateral	100.00					
v Lower	100.00					
Mold parameters						
Mold material	***Total emissivity***	***Gas-permeability, 10^{-6} m^2/Pa×s***	***Radiolucency***			
1044	0.93	1.53	-			
Air	-	-	1.00			
Shrinkage calculation model						
Medium gravity influence						
Influence coefficient	50					
"Feeding" pressure, Bar	0.000					
Alloy	***Compr., 1/Mbar***	***CLF up, %***	***CLF down, %***	***CLFpres, %***	***CLF Niyama, %***	***Property created***
MIM 4140	30.00	70.00	30.00	24.00	3.00	by phases
Quasi-equilibrium model calculation, without segregation						
With taking gas into account at filling						
Initial gas pressure in mold, Bar	1.000					
Gas pressure outside mold, Bar	1.000					
With convection						
Aggressive AMG						
The Gauss-Seidel method						

<table>
<tr><th colspan="6">Gatings</th></tr>
<tr><th>X, mm</th><th>Y, mm</th><th>Z, mm</th><th colspan="3">Boundary conditions</th></tr>
<tr><td>40.45</td><td>183.12</td><td>43.76</td><td colspan="2">Heat radiation</td><td>20.00</td></tr>
<tr><th colspan="6">Pouring type</th></tr>
<tr><td colspan="6">Lip pouring</td></tr>
<tr><th colspan="2">Friction factor</th><th>Pressure height, mm</th><th colspan="2">Teta</th><th>Fi</th></tr>
<tr><td colspan="2">1.000</td><td>80.000</td><td colspan="2">20.000</td><td>0.000</td></tr>
<tr><th colspan="2">Stream diameter, mm</th><th colspan="2">Flow, kg/s</th><th colspan="2">Stream area, mm^2</th></tr>
<tr><td colspan="2">8.000</td><td colspan="2">0.408</td><td colspan="2">50.265</td></tr>
</table>

High casting properties of melt and excess pressure allow to perform the filling process of the mold in full volume. Coefficient of turbulence of melt when filling of the mold was taken 0.3.

The model of a gating system and the model of the chamber of the molding machine for injection molding of eight castings are presented in the Fig. 2.

The chamber model of the molding machine ARBURG Allrounder 270C 400-100 was built to the right of the gating system model of the mold. Melt enters into a feeder and then into the gating system of the mold from the chamber of the molding machine. Eight castings are poured at the same time into the mold. The feeder diameter is the hole diameter of a heat treated steel sprue bushing (the length of 50.5 mm). Through hole in the bushing is performed conical. The maximum hole diameter of the sprue bushing is 3 mm, the minimum hole diameter of the sprue bushing is 2 mm. The central hole in the castings is formed by eight rods placed in the mold cavity. The chamber length of the molding machine was 173.501 mm, which corresponds to capacity of 102461.4 mm^3. Effective mass of a piston at specified dimensions of the chamber of the molding machine was 0.048 kg.

The chamber model of the molding machine was filled by melt in the volume of 4.531% (or 0.032 kg). Movement phase of the piston in the chamber of the molding machine occurs after filling of the required volume of melt (no downtime after filling). Pressure on the piston was set by the value of 1667.139 Bar in accordance with requirements specification for development of design documentation and manufacturing of the mold. Maximum allowable pressure on the piston is 2000 Bar.

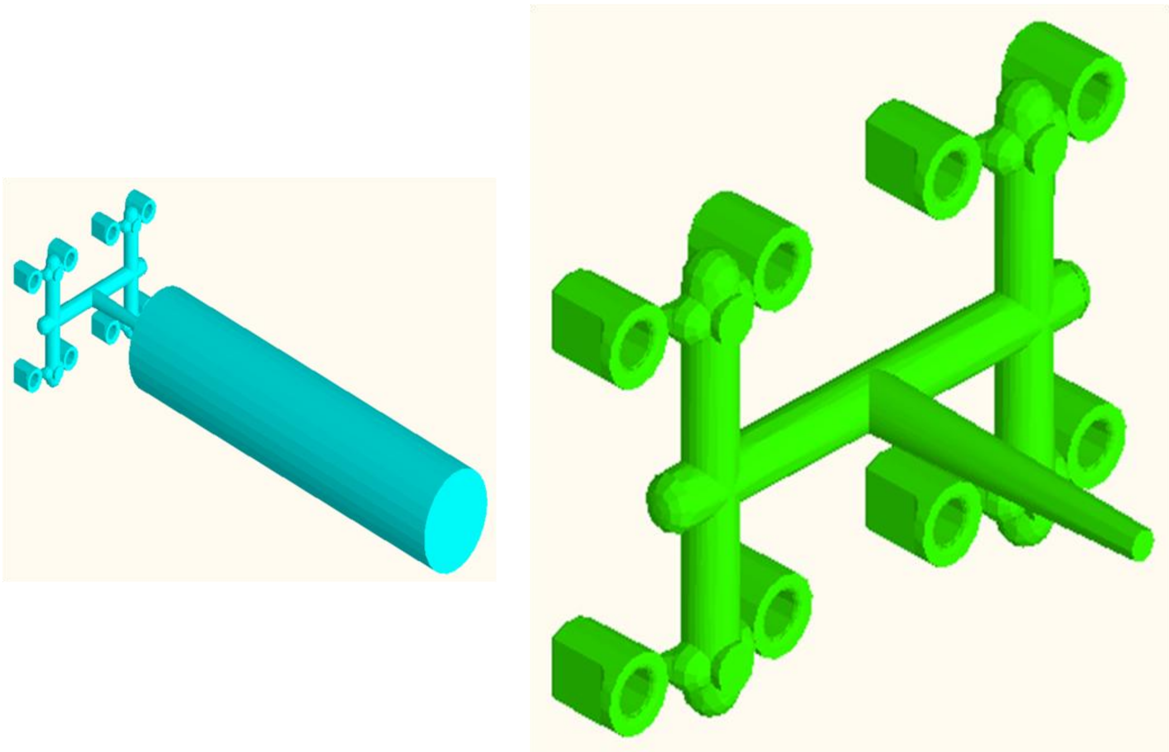

Fig. 2. The model of the gating system of the multicavity mold for injection molding.

The computer calculation was completed when complete filling of the mold cavity by melt (100%) and cooling melt in the mold to a temperature below the solidus temperature.

III. Result and discussion

Steps sequence of the mold filling by melt is presented in the Fig. 3.
The following stages show on the figure:
A and B – filling of the chamber model of the molding machine by melt;
C – F – movement of the piston in the chamber model of the molding machine;
G – O – injection phase of melt into the forming cavity of the mold.
The piston model was not displayed at the calculation. The diameter of a pressing part of the piston was equal to the diameter of the chamber model of the molding machine. So as the presented process lasts less than one second then crystals nucleation is not observed and liquid phase in melt is not less than 95%. Filling time of the mold by melt was 0.095 s.
Steps sequence of melt crystallization (cooling) in the mold is presented in the Fig. 4.
First of all, the castings are subjected to crystallization (cooling), so as their volume is less than the volume of the gating system of the mold. The significant volume of material remains in the gating system of the mold after crystallization, which is an irrational using of material for this casting process.
Time crystallization of melt in the mold was 0.678 s.
Total time of injection molding was 0.773 s.

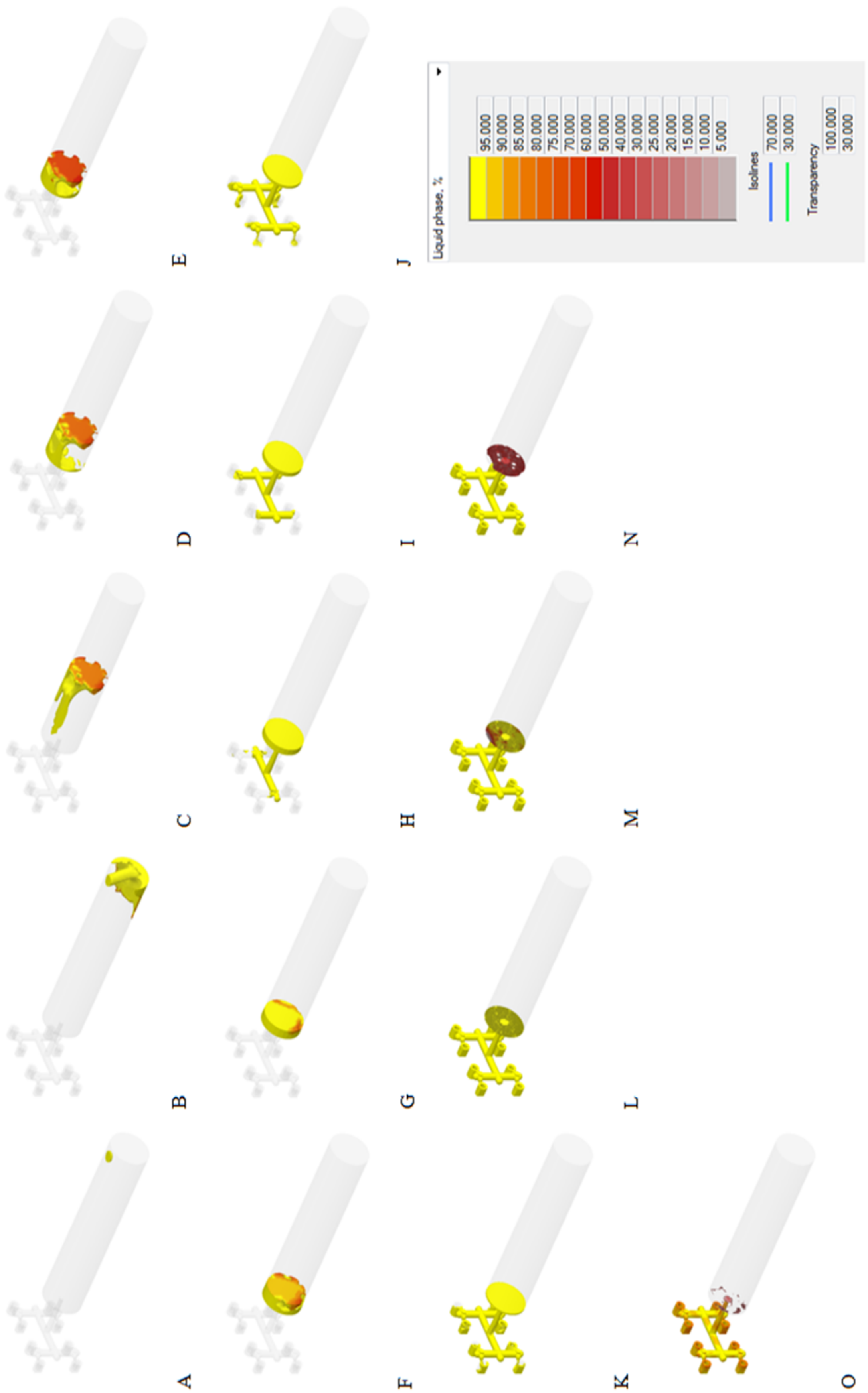

Fig. 3. Sequence of the mold filling by melt.

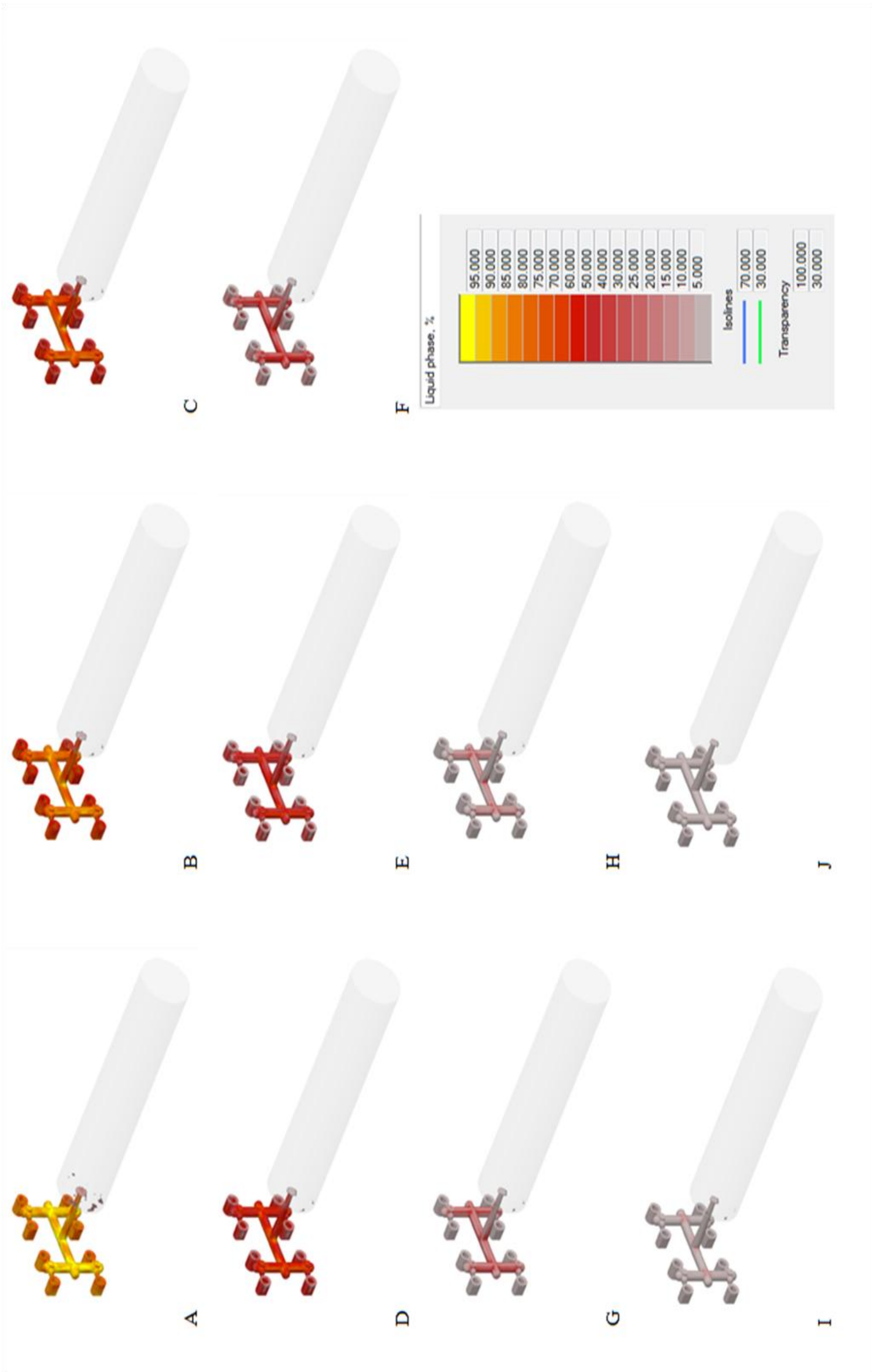

Fig. 4. Sequence of melt crystallization in the mold.

Linear shrinkage of the casting material after crystallization in the mold is presented in the Fig. 5. The color contours on the casting models show linear shrinkage of material in percentage. Maximum linear shrinkage of the casting material after crystallization is observed in the upper part of the mold. Linear shrinkage of material on side walls of the castings was determined in the range of 1 – 10%. The casting bottom is subjected to linear shrinkage in the range of 10 – 20%.

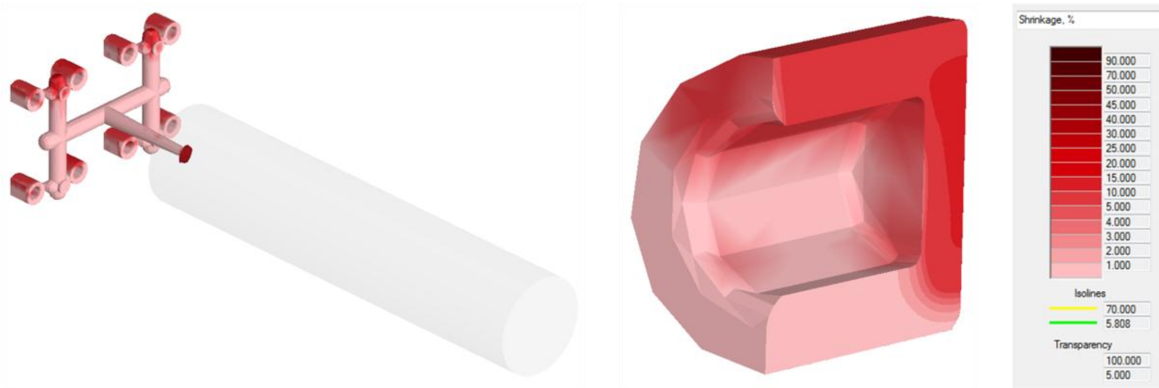

Fig. 5. Linear shrinkage of the casting material after crystallization.

Porosity of the casting material after crystallization in the mold is presented in the Fig. 6. Probability of porosity formation in the casting material after crystallization is predicted by the Niyama criterion. The Niyama criterion is found as the ratio of temperature gradient to cooling rate of the casting material at the end of time interval of crystallization. The less the Niyama criterion, the more probability of porosity formation in the casting material. Porosity is formed on the outer diametrical surface and in the area of bottom of the castings in accordance with the color contours.

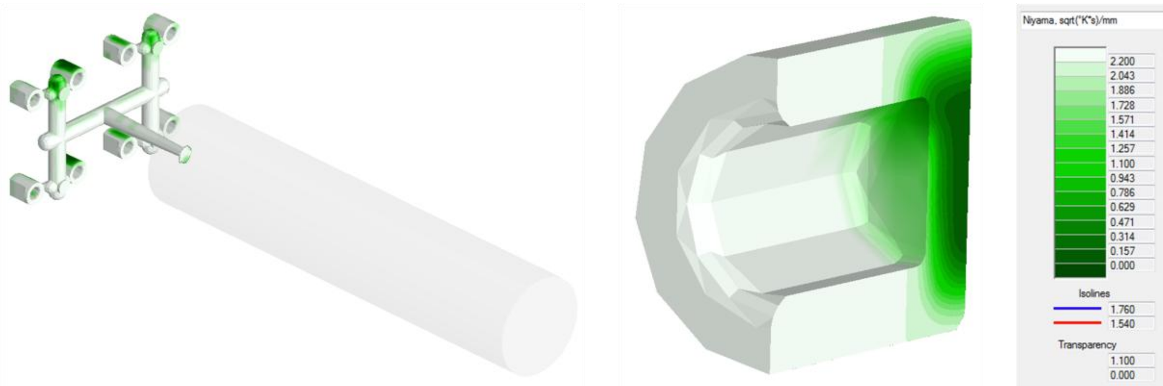

Fig. 6. Porosity of the casting material after crystallization.

Condition of the casting material after injection molding in the mold and before heat treatment is presented in the Fig. 7.

Fig. 7. Condition of the casting material after injection molding.

Longitudinal cutting of the casting into two parts after injection molding was performed by a knife, so as material was fragile and not subjected to electrical discharge machining. Material structure on the cut surface of the casting is homogeneous. Small pores are clearly visible on the casting surface. Prediction of porosity formation in the casting material corresponds to the color contours of porosity on the casting model by 85%.
Condition of the casting material after injection molding and heat treatment is presented in the Fig. 8.

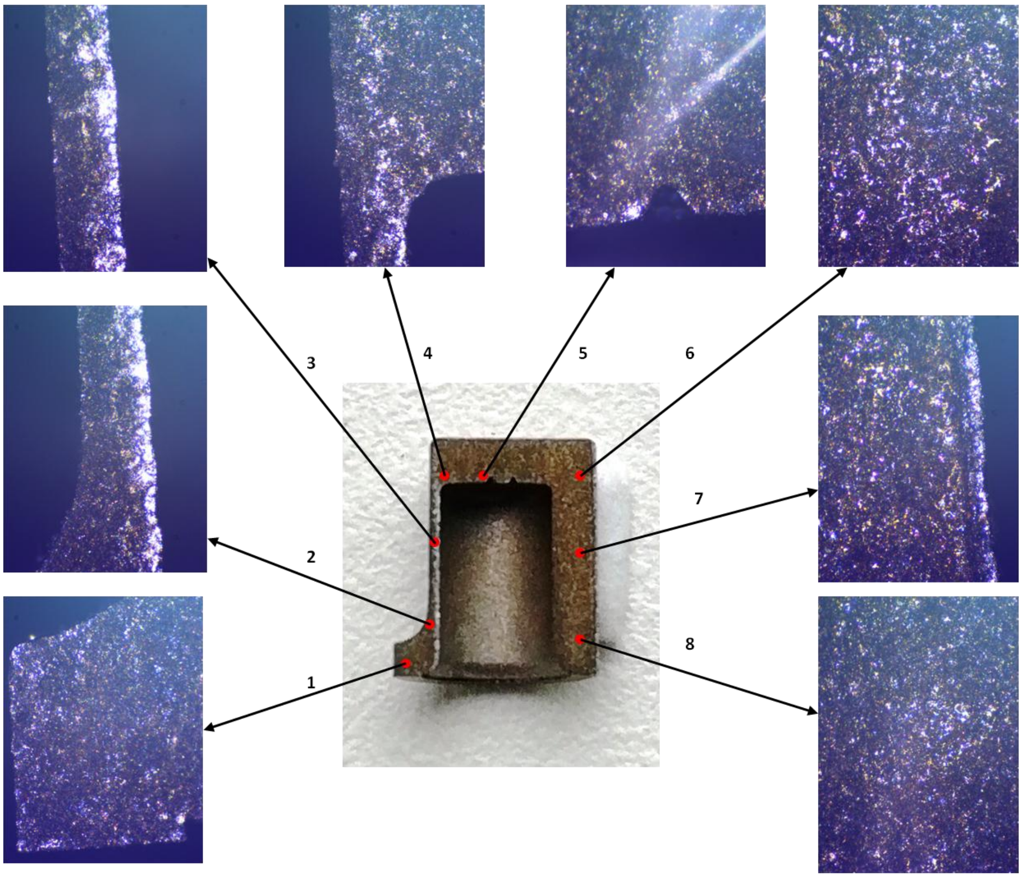

Fig. 8. Condition of the casting material after heat treatment.

Longitudinal cutting of the casting into two parts after heat treatment was performed on the electrical discharge machine. Photos of condition of the casting material were obtained by means of objective lens of the model Olympus Mplan 5 with a digital camera. The photos show that structure of the casting material remains homogeneous, and pores increased in dimensions. Thus, thermal influence leads to removing of binder material and hardening of the casting. White shine on the surface has remained from a copper wire when cutting of the casting on the electrical discharge machine.

IV. Conclusion

Based on the results of the computer simulation of the injection molding process of MIM 4140 alloy and laboratory research of condition of the casting material after sintering, the following conclusions can be made:
1. Crystallization time of the castings in the mold is calculated and the ratio of liquid phase in melt is determined during injection molding of MIM 4140 alloy.
2. Linear shrinkage and porosity of the real casting after injection molding correspond to the calculated values of linear shrinkage and porosity of the casting model by 85%. This says about the high accuracy of the computer simulation of the injection molding process. The Niyama criterion is determined for casting of MIM 4140 alloy (from 0 to 2.2 $\frac{\sqrt{^{\circ}K \times s}}{mm}$).

3. Binder material is removed after heat treatment. Structure density of the casting material does not change before and after heat treatment. Pores dimensions in the casting material after sintering are changed.

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