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Temperature and microstructure characteristics of silumin casting AlSi9 made with investment casting method

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Abstract

This work presents the research result of the temperature distribution and the microstructure in certain parts of the field-glass body frame casting made from silumin AlSi9 using the investment casting method in the ceramic mould.
It was proved that the highest temperature of the silumin appears in the sprue in which the silumin is in the liquid-solid state, though the process of silumin crystallization in the casting is finished. It was stated that in certain elements of the casting the side opposite to the runner crystallizes and cools fastest. The differences in the rate of crystalline growth and cooling of certain casting elements cause different microstructure in them which can also influence the mechanic properties.
It is necessary to state that the temperature of the initial heating of the ceramic mold equal to $60^{o}C$ guarantees obtaining of the castings without defects and of little porosity. Incomplete modification of the silumin with strontium causes silica precipitation to appear close to the spherical ones.

Keywords: Innovative foundry technologies and materials, Lost-wax molding, Investment casting, Silumin, Microstructure

1. Introduction

The technology of making the silumin castings using the investment casting method is used in the USA, Canada and in Western European countries for different machine and equipment elements. Currently, two technologies are used in the world. The first one is called SOPHIA ® [1-6], and the second one is HERO Premium Casting ® [4; 7-9]. Both technologies are characterized by very fast dissipation of heat from the ceramic mold irrespective of the thickness of the casting wall. In SOPHIA process the rate of crystalline growth and the mold cooling is faster than in HERO process. Crystallization and cooling is controlled by a computer in both technologies. In France the fast crystallization and cooling of the casting was made using local coolers in the ceramic mold [10]. The temperature of the initial mold heating recommended by different authors is placed in a very wide range from $20^{o}C$ to even $500^{o}C$ [11-14]. Preparation of the physic-chemical state of the silumin is kept secret and there is no information on this topic in the literature.

In Poland the technology of making the silumin castings by investment casting method was worked out in the frames of the purposed grant [15]. It was implemented in Spółdzielnia Pracy Armatura in Łódź.

The aim of the current work is to analyze the temperature distribution and the microstructure of the field-glass body frame casting from silumin AlSi9 made using the investment casting method in the shell mold.

2. The methodology of the research

The construction of the field-glass body frame from AlSi9 for investment casting is shown in Figure 1.

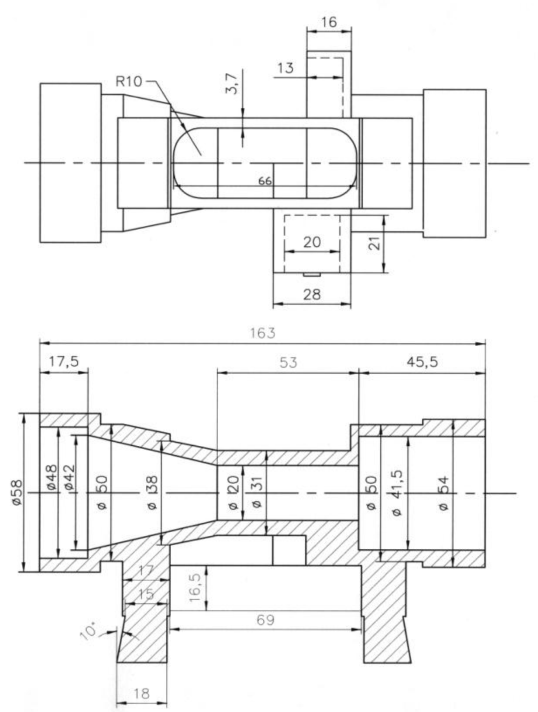

Fig. 1. The construction of the field-glass body frame from alloy AlSi9

The shell molds were made of fire resistant materials REFRACORSE (fine flour and sands). The molds were built from 7 coatings made in the mixers and fluidizer in the foundry "Armatura" in Łódź. Every coating appeared as a result of application of the bonding agent on the wax model and then was dusted with the siliceous sand of certain grain fineness. The configuration and the type of the used coatings are presented in Table 1.

Table 1.
Characteristics of different coatings

Coating number	**Viscosity [s]**	**Kind of bonding agent**	**Sand grain fineness [mm]**
1	38	Ludox	0.1 – 0.3
2	20	Ludox	0.1 – 0.3
3	17	Ethyl Silicate	0.2 – 0.5
4	18	Ethyl Silicate	0.5 – 1.0
5	19	Ludox	0.5 – 1.0
6	18	Ethyl Silicate	0.5 – 1.0
7	20	Ethyl Silicate	0.5 – 1.0

When the ceramic mold had dried, the model mass was cast in the autoclave at the temperature of 550°C. Then the form was strengthened at the temperature of 980°C in a tunnel furnace. After burning, the mold was cooled to the temperature of about 60-70°C and then it was poured with liquid silumin in the temperature of 760 °C ± 10 °C. The chemical composition of silumin AlSi9 is presented in Table 2.

Table 2.
Chemical composition of AlSi9

Si	Fe	Cu	Mn	Mg	Ni	Ti	Zn	Sr
%	%	%	%	%	%	%	%	%
10.06	0.66	1.29	0.27	0.31	0.05	0.06	0.54	0.05

The silumin was cast in a resistor crucible furnace of 100 kg capacity in S.P. ARMATURA in Łódź. Small silumin AlSi9 ingots were used as charging material. After melting the charging material and heating it to the temperature of 780°C the dross was removed and 0.3% AlSr10 was added to the liquid silumin mass in the furnace. The amount of strontium was smaller than the required for obtaining fiber silica because with a smaller amount of it silica close to spherical was obtained. 15 minutes later after the strontium was added, the silumin was refined for 15 minutes with nitrogen. After refining the molds were cast with silumin. The measurement of the temperature distribution was performed using thermo elements type S (Pt10Rh-Pt) and 16 band register type 16K produced by PPHU "Z-Tech". The thermo elements were located regularly in the mold; their places in the casting are shown in Fig. 2. The distance between the thermo elements is presented in Fig. 3.

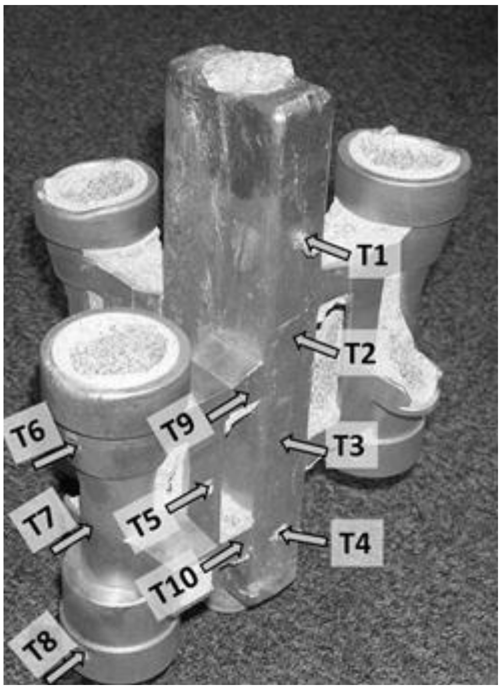

Fig. 2. Thermo elements location scheme in the ceramic mold regarding the casting

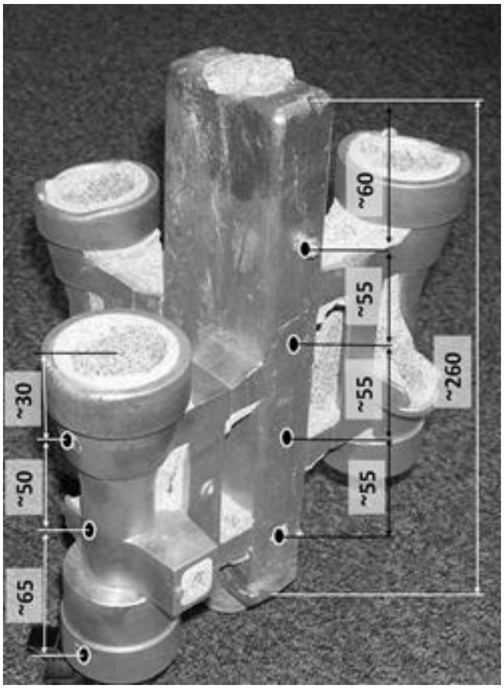

Fig. 3. Approximate distance between the thermo elements in the ceramic mold regarding the casting

3. Research results

The change in the temperature of the silumin on the sprue level is shown in Fig. 4

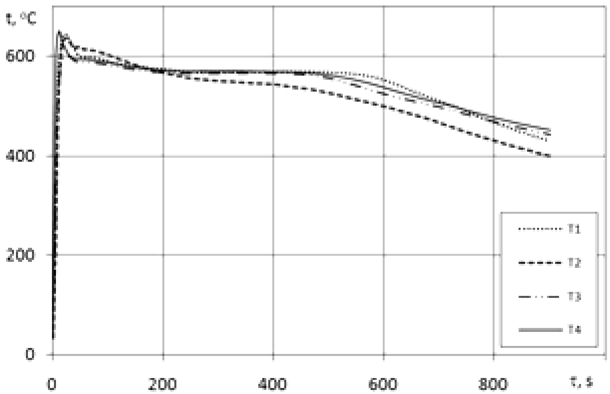

Fig. 4. The change in the temperature of the silumin on the sprue level

It follows from this that after filling the sprue with liquid silumin along the length of 260 mm, the temperature of the liquid silumin is almost the same and is 580^{o}C. It stays the same for about 300 s. Then the temperature in points T1; T2; T3 decreases almost the same during the whole range of crystallization of the eutectic $\alpha + \beta$ and after its finishing. The end of silumin crystallization in points T1; T2; T3 and T4 approximately appears in the time of about 680 s. In point 2 of the sprue the end of silumin crystallization takes place in about 560 s, thus this time is shorter than in the remaining points.

The cooling curves in particular points of the casting are shown in Figure 5.

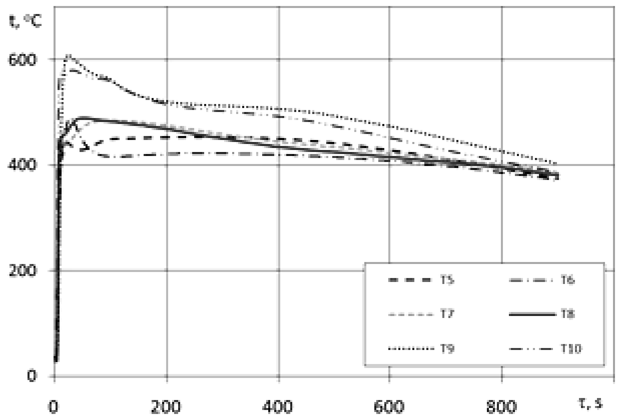

Fig. 5. The cooling curves in particular points of the casting

It follows from this that crystallization was noted only in two points T9 and T10 in the casting supports of the funnel. The silumin crystallization in these points finished after about 130 s; moreover, there was no difference if it was upper or lower support. In the remaining points of the casting T5-T8 a temperature change was observed after crystallization, it was caused by the inertness of the thermo element and too high crystalline growth rate of the thin casting walls.

The supports T9 and T10 cool slowest, besides, the upper (T9) cools slower than the lower (T10). This is due to their cross section which is 33x15 mm (Fig. 6). Apart from the supports, the upper part of the collar T6 cools fastest. The funnel wall (T7) and the lower part of the collar (T8) cool slowest. Between them there is the cooling rate of the crossbar with the thickness of 4 mm (T5; Fig. 6). The cooling rate of the whole castings becomes equal after about 900 s when the temperature reaches 380-400^{o}C.

As an example, Figure 6 shows the temperature in particular points of the sprue and the casting after the time of 300 s after the mold was poured.

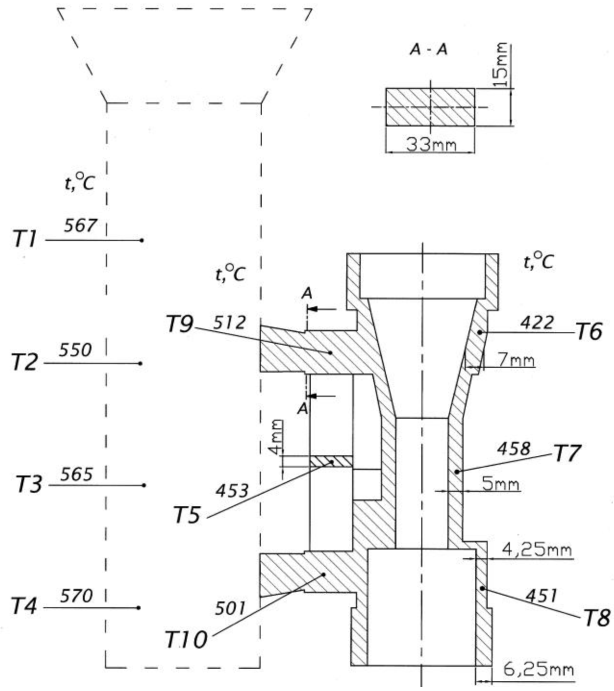

Fig. 6. Exemplifying temperature in the points of the sprue and the castings after 300 s after the mold was poured

It follows from this that the highest temperature of the silumin is in the sprue and is within the range of 550-570°C. The highest temperature of 570°C is in the lower part of the sprue (T4), and the lowest 550°C appears near the upper support (T2). It can be supposed that it is caused by the large cross-section of the support (33x15mm, Fig. 6) as a result of that a large amount of silumin is delivered from the sprue which cools relatively fast and absorbs a certain amount of the silumin heat, thus, it lowers its temperature.

It is typical that in the remaining points of the pouring gate system the silumin temperature changes somewhat within the range of 565-570°C.

The temperature of the casting changes within a relatively substantial range, which is 422-512°C. Generally, it can be stated that the lowest temperature of the casting is in the opposite side of the runner and is within the range of 422-458°C, though at the side of the gate and is 453-512°C.

It is caused by a faster cooling process of the casting at the opposite side of the runners. In this case the lowest temperature of 422°C (T6) is in the upper part of the funnel with the wall thickness of about 7 mm, and the highest is in the middle part of the funnel and is 458°C (T7) with the wall thickness of about 5mm. At the lower part of the collar with the wall thickness of about 4.25 mm the temperature is 451°C (T8).

From the sprue side and the runners the highest temperature is 512°C (T9) and it appears in the support which the runner comes to, and the lowest 453°C (T5) is in the crossbar with the thickness of about 4mm. In the lower support the temperature is 501°C (T10) and it is lower than the temperature of the upper support (512°C).

Generally, it is necessary to say that after 300 s from the moment of mold pouring, the solid-liquid state of the silumin, i.e. α phase, eutectic $\alpha+\beta+$AlFeSi and liquid appear in the sprue, though in the cast the silumin is in the solid state. Thus it can be stated that the decisive in the correct pouring of the cast in the investment casting method is the position of the casting in the sprue, runner cross-sections and their location in the casting, and at last the thickness of its walls. The tendency of enlarging the section of the sprue is more often used, which does not practically improve anything, if the particular elements of the pouring gate system are unchanged.

The presented process of the cooling and crystallization of the casting shown with the temperature distribution has an important influence on the casting microstructure and its mechanical properties.

Figure 7 shows the places of the samples taken for the metallographic tests marked as M1-M10.

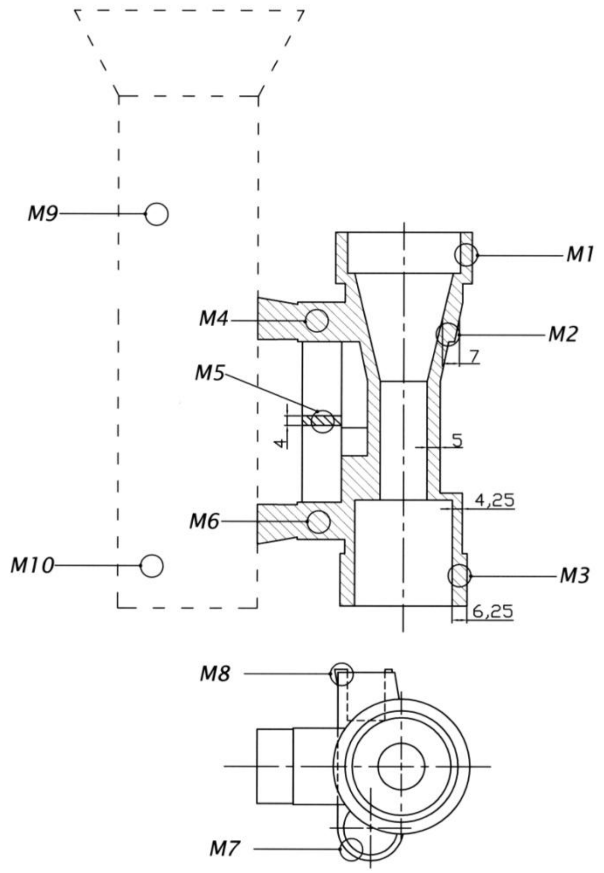

Fig. 7. Places of the samples taken for the metallographic tests

The microstructure consisted of phase α and eutectics $\alpha+\beta+$AlFeSi, $\alpha+\beta+Mg_2Si$ and $\alpha+\beta+Al_2Cu$ appeared in the whole casting. The differences in the microstructure are based mainly on different fine crushing of particular phases.
The microstructure of the castings from M1 – M10 areas is shown in Fig. 8-17 (a-c) correspondingly.

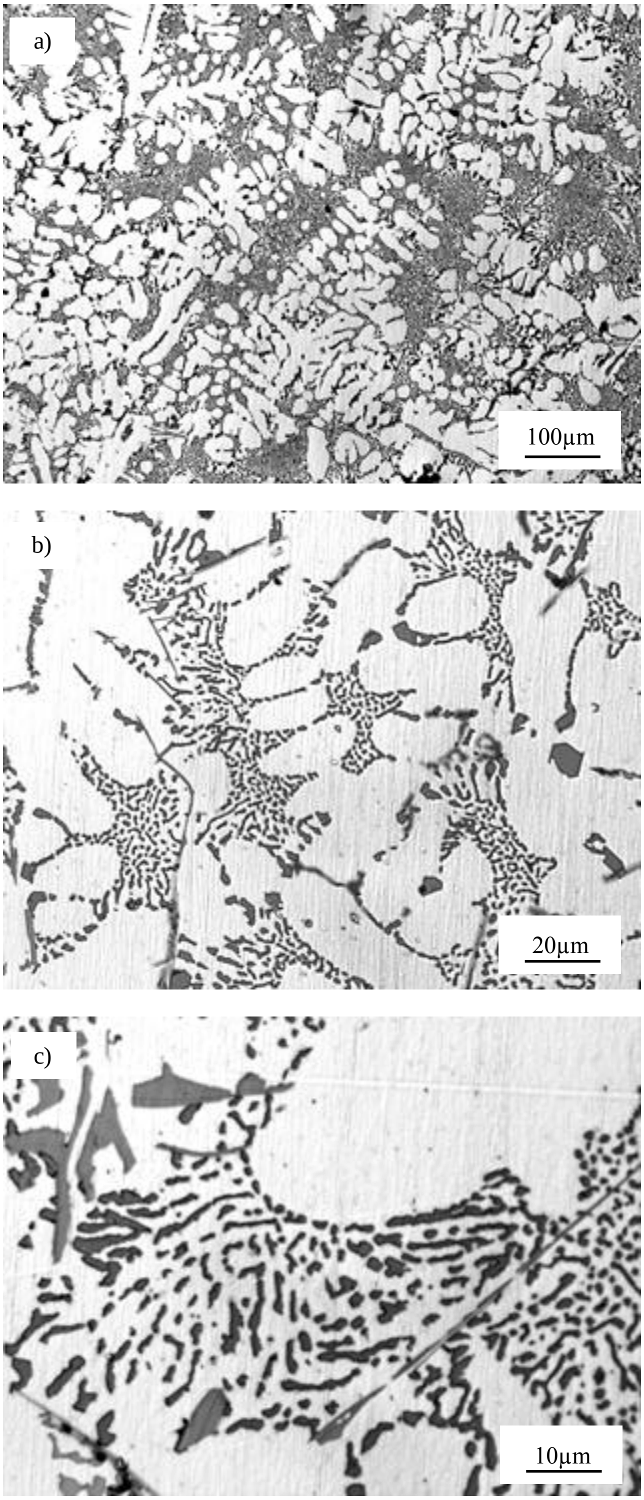

Fig. 8. Microstructure of the casting in area M1

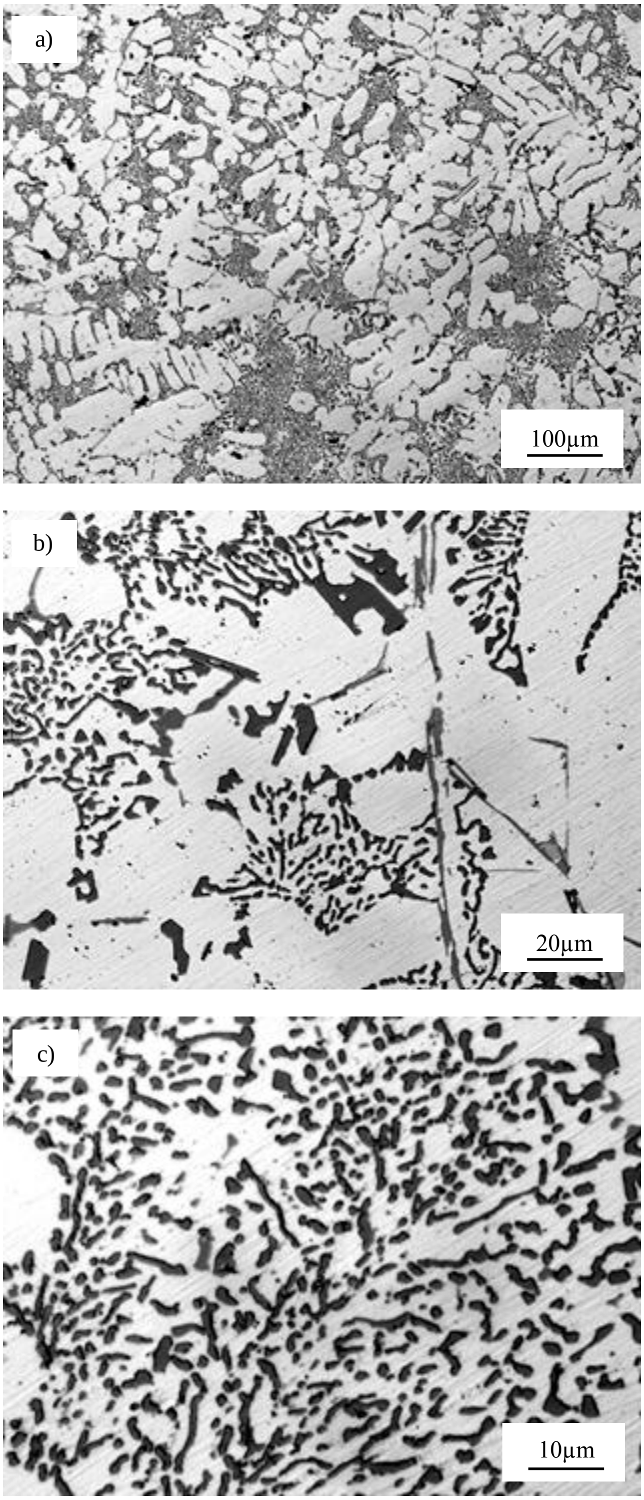

Fig. 9. Microstructure of the casting in area M2

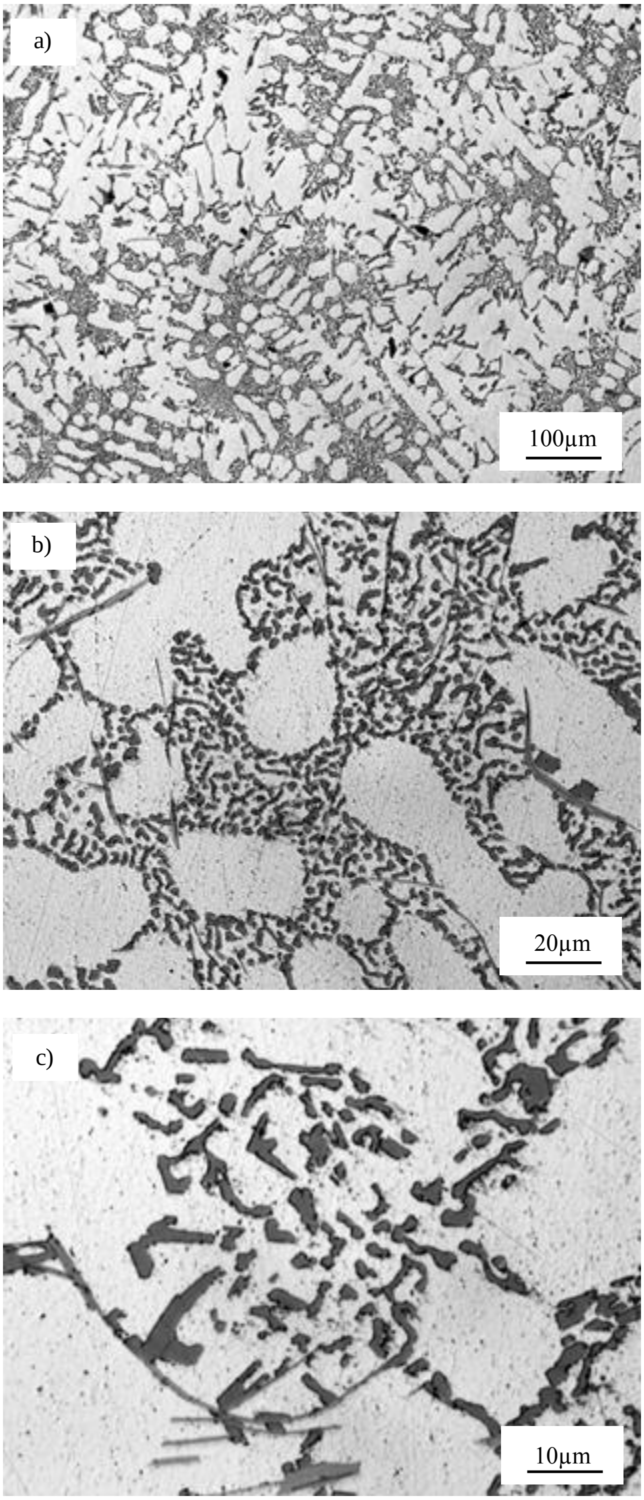

Fig. 10. Microstructure of the casting in area M3

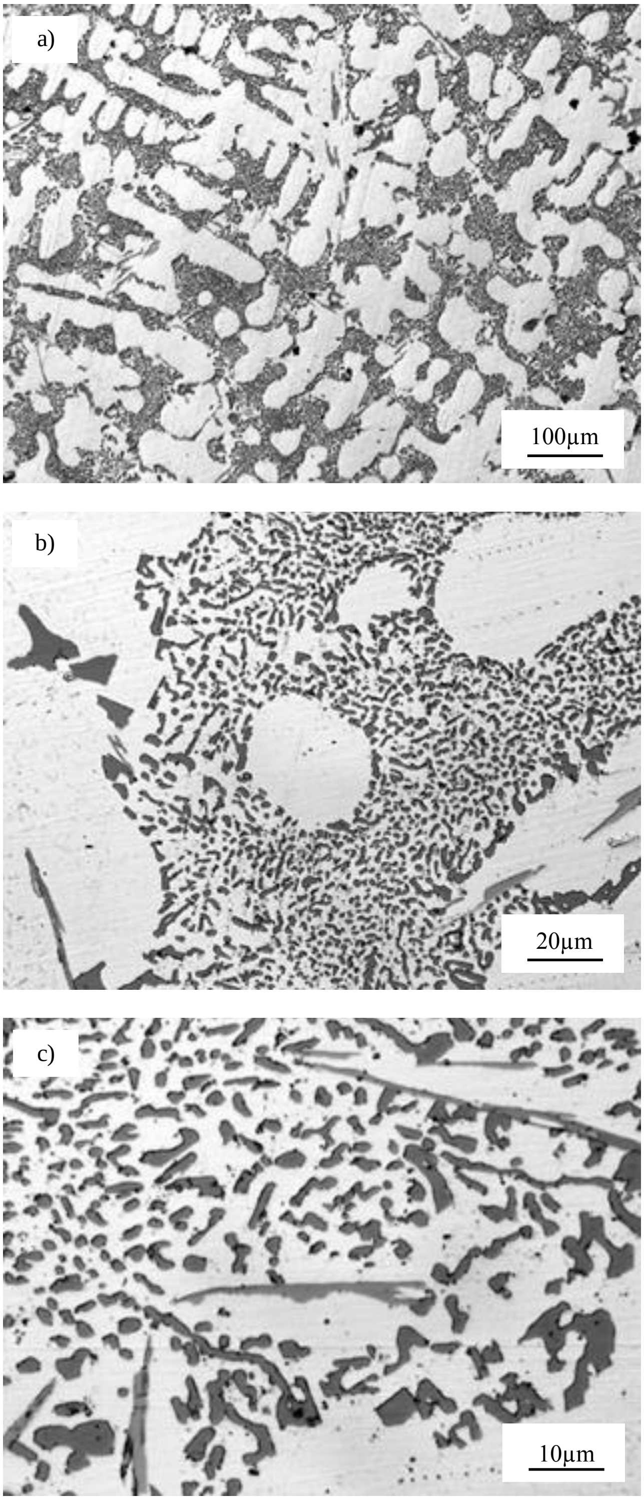

Fig. 11. Microstructure of the casting in area M4

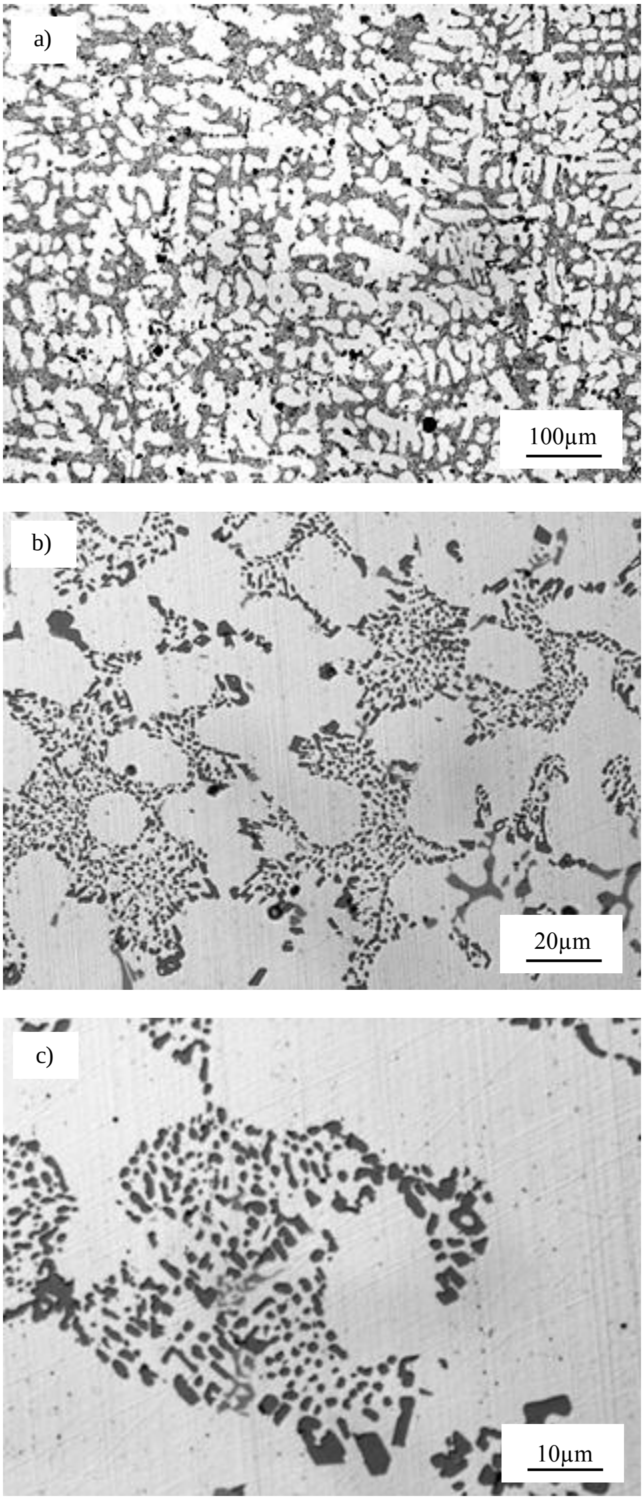

Fig. 12. Microstructure of the casting in area M5

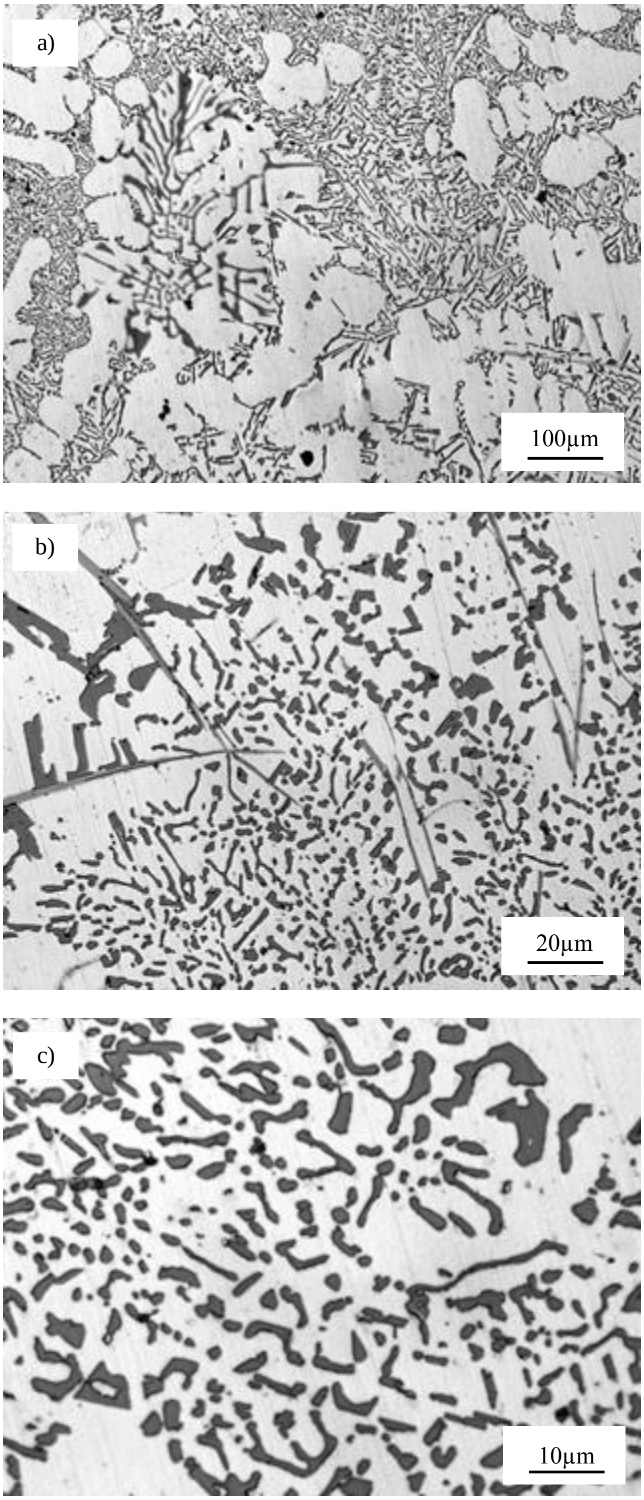

Fig. 13. Microstructure of the casting in area M6

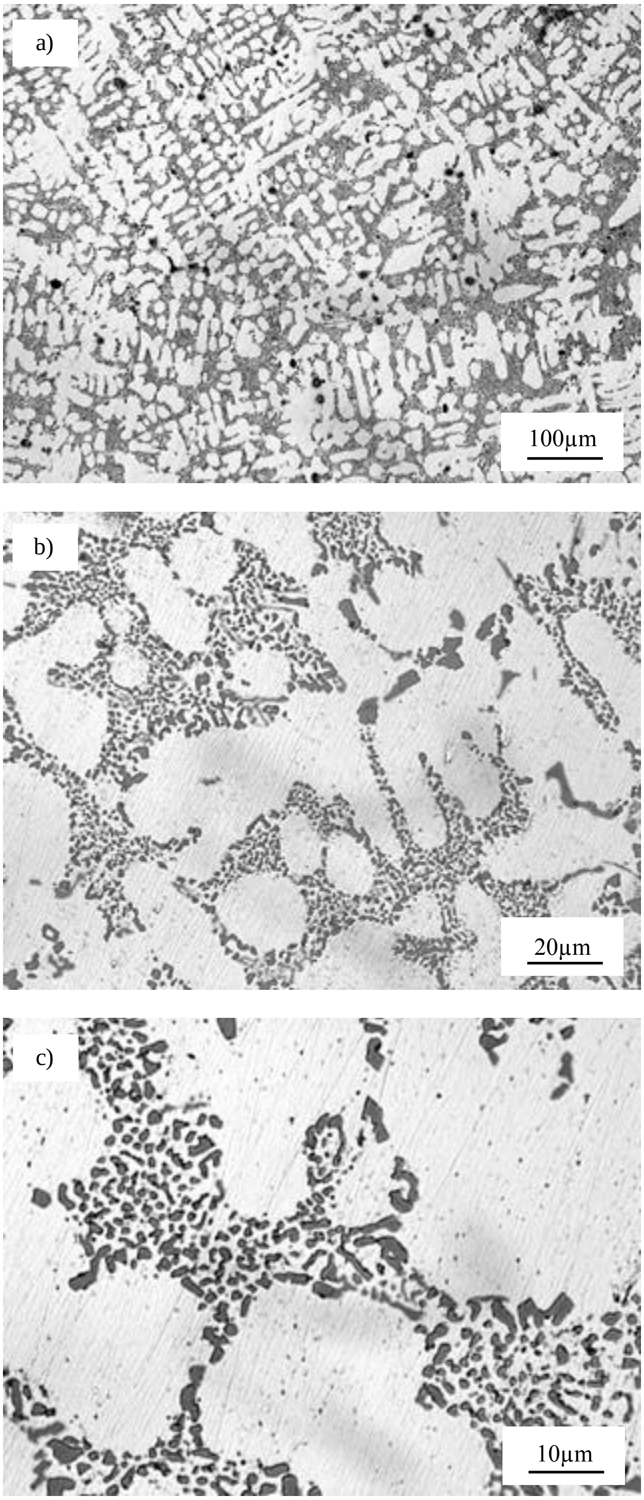

Fig. 14. Microstructure of the casting in area M7

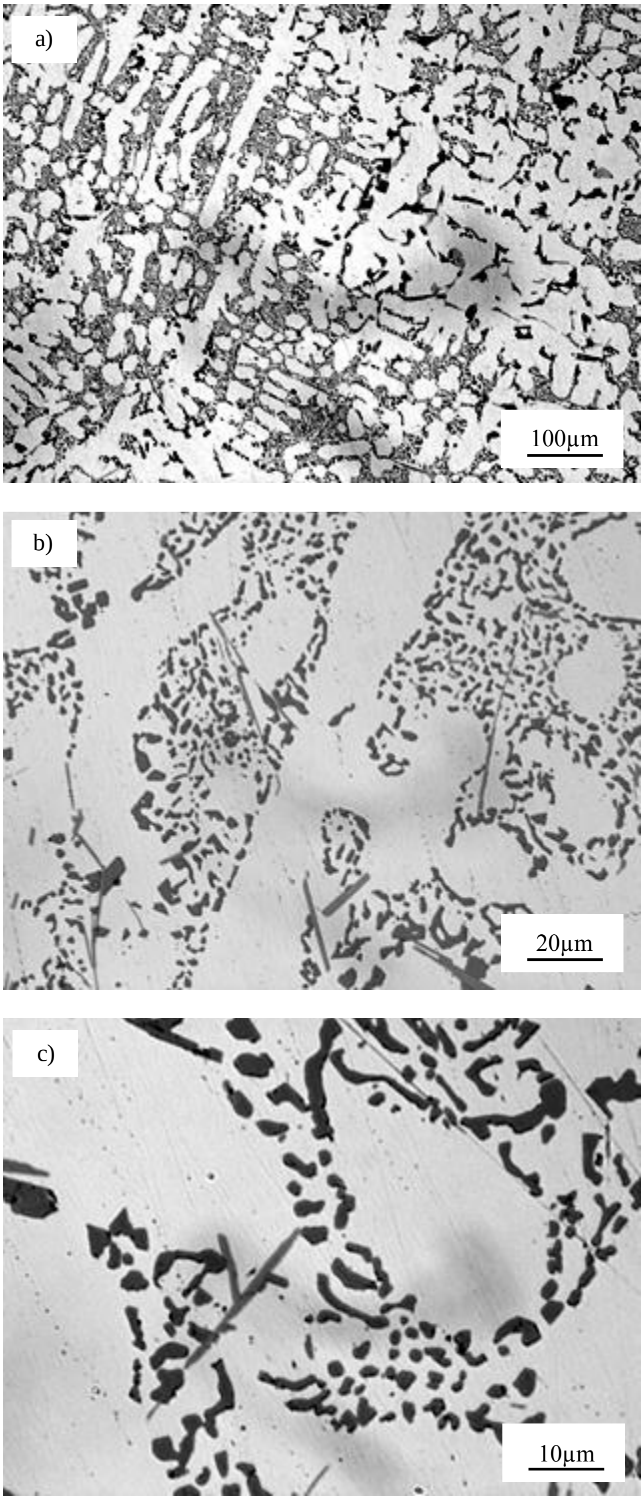

Fig. 15. Microstructure of the casting in area M8

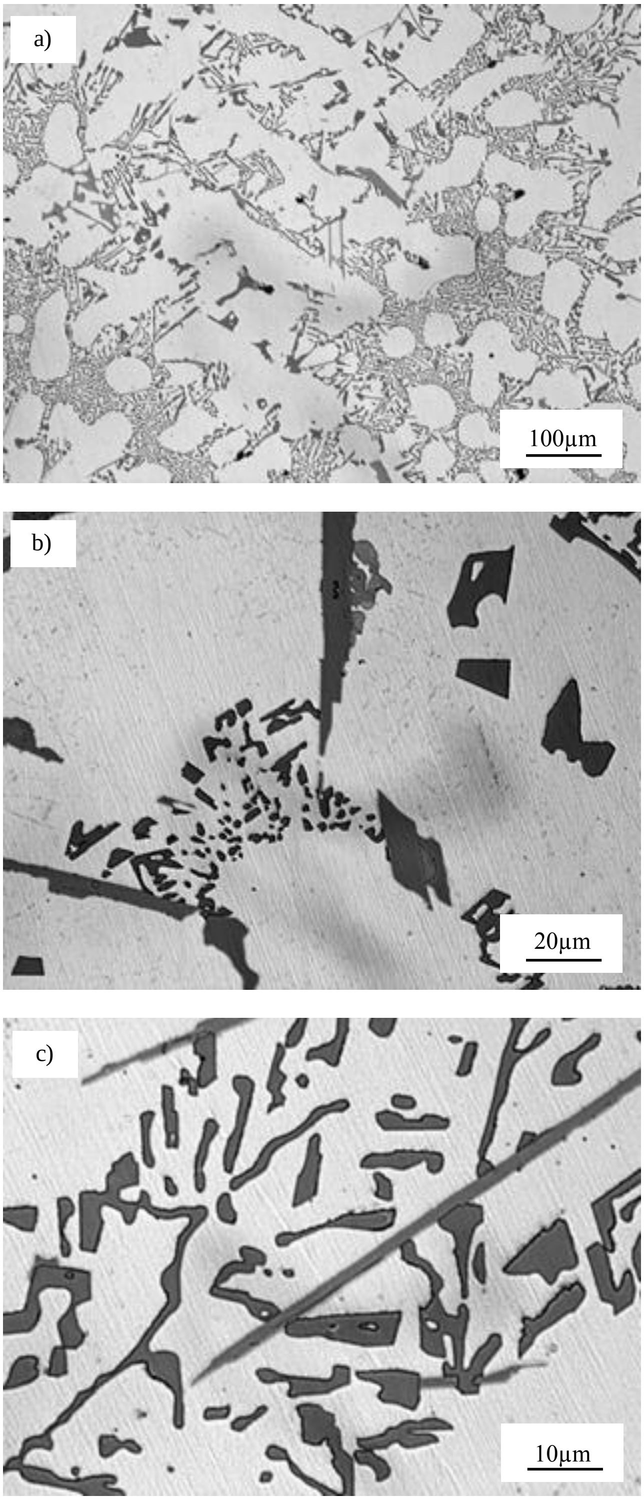

Fig. 16. Microstructure of the casting in area M9

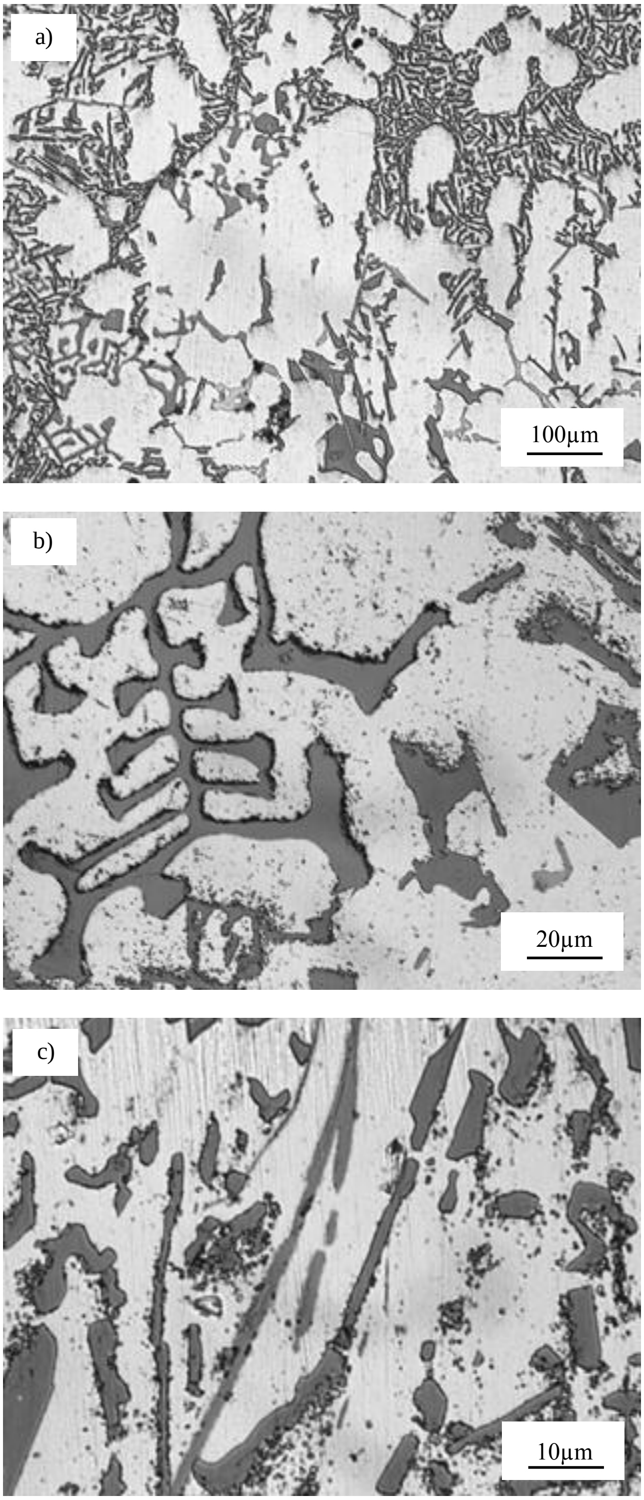

Fig. 17. Microstructure of the casting in area M10

It follows from the presented Figures 8-17 (a-c) that the largest fine crushing of the microstructure took place in part M5 of the casting (Fig. 12) and M7 (Fig. 14), that is in the walls with the thickness of 4 mm which cool the fastest during crystallization. A bit smaller fine crushing was in areas M1 and M4, i.e. in the upper collar of the funnel with the wall thickness of 5 mm (Fig. 8) and in the upper support (Fig. 11).

The largest thickness and the size of the distinguished phases were in the sprue, i.e. in areas M9 and M10; besides the larger fine crushing was in the upper part of the sprue. The consequence of the changeable microstructure in the casting will be the different mechanical properties. In the parts of the casting which cool at a big cooling rate silica appears in the form close to the flocculated. It was caused by incomplete modification of the strontium. The same form of the silica was obtained for other castings, which is presented in work [15]. The appearance of some porosity is typical of this casting, in some parts there is no porosity at all. These results prove the correctness of the designed and verified technology of the casting making from silumins using the investment casting method.

4. Conclusions

It follows from the data presented in this work that:

- the silumin in the sprue cools and crystallizes slowest, and its temperature in the lower part is higher than in the upper part;
- the casting walls opposite the runners cool fastest;
- the cooling and crystallizing processes should be controlled by the location of the casting in the sprue, runners cross-section and their location in the casting;
- the above mentioned factors have more influence on the cooling rate and crystalline growth rate than the thickness of its walls;
- it would be desirable, if the whole casting cools and crystallizes at the same or almost the same rate, it will guarantee the homogeneous microstructure in the whole casting and the properties that follow from it;
- the correct preparation of the physic-chemical state of the liquid silumin and the ceramic mold guarantee obtaining of the castings without gas porosity.

The presented research results point at a complexness of the heat exchange and crystallization of the silumin castings using the investment casting method. The further works will be done to design general technologies of ceramic mold making and preparation of the physic-chemical state of the liquid silumns for the castings.

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