

INFLUENCE OF THE EXTERNAL MAGNETIC FIELD ON THE STRUCTURE AND PROPERTIES OF THE HYPEREUTECTIC ALUMINUM-SILICON ALLOY

ВЛИЯНИЕ ВНЕШНЕГО МАГНИТНОГО ПОЛЯ НА СТРУКТУРУ И СВОЙСТВА ЗАЭВТИЧЕСКОГО АЛЮМИНИЕВО-КРЕМНИЕВОГО СПЛАВА

Ass. Prof., Dr. Eng. Donii O.¹, Narizhna T.¹, Dr. Eng. Voron M.², Berest D.²

National Technical University of Ukraine "Kyiv Polytechnic Institute named after Igor Sikorskyi" - Kyiv, Ukraine¹
Physical Technological Institute of Metals and Alloys, National Academy of Science of Ukraine²

Email: dosha@iff.kpi.ua

Abstract: The effect of a constant magnetic field during the crystallization of a hypereutectic aluminum alloy on its structure in the solid state investigated. It is shown that the superposition of the magnetic field positively affects the structure of the alloy. A uniform distribution of the doped phases and eutectic in the volume of the alloy is observed. The phase of primary silicon significantly changes the size and the shape. It is established that the influence of an external magnetic field reduces the dimensions of the shrinkage defects. In general, the effect of an external magnetic field on the structure of the alloy leads to an improvement in the operational properties. The obtained measurement results showed more stable hardness values over the cross section of the sample in comparison with the alloy that was not processed.

KEYWORDS: CRYSTALLIZATION, STRUCTURE OF ALLOYS, HYPEREUTECTIC ALUMINUM-SILICON ALLOYS, EXTERNAL MAGNETIC FIELD

1. Introduction

Aluminum casting hypereutectic alloys are used in engineering for the manufacturing of critical parts. Pistons are produced from these alloys for internal combustion engines. These parts should have high operational properties. Without further processing, the structure of the alloy in the bulk of the metal is distributed unevenly. The primary silicon phase is predominantly large in size and is in the form of clusters. It has sharp angles that act as stress concentrators. The primary silicon is strong and brittle at the same time. Its uneven distribution in the structure contributes to the formation of various defects during operation, which lead to the destruction of parts.

2. Preconditions and means for resolving the problem

To improve the operational properties of hypereutectic silumin, doping, modification, physical or physicochemical treatment are used [1-10]. In the first two cases chemical elements are added to the melt; they, as a rule, are expensive, improvement of metal's characteristics is not always achieved. Hypereutectic alloy in any country has a normalized chemical composition, which must be adhered to and therefore the possibility of entering chemical elements is limited. The use of melt processing by energy fields of different physical nature also makes it possible to obtain the necessary properties of the material. Such techniques are easier to implement in practice, but they are not yet perfect. Therefore, in this paper we give results of our investigations of the effect of an external magnetic field during crystallization process on formation of the structure of the hypereutectic silumin and on some of its properties in the solid state.

The aim of the work was to study the effect of a constant magnetic field during the crystallization of a hypereutectic alloy on its structure and properties in the solid state.

The alloy was melted at 700° C and poured into a metal mold. A permanent magnet was placed beneath the bottom of the metal mold, which interacted with the material to create a magnetic field in the middle of the alloy.

3. Results and discussion

3.1. Results of metallographic analysis

Figure 1 shows the macrostructures of the original hypereutectic alloy and of alloy after exposure to it of a constant magnetic field

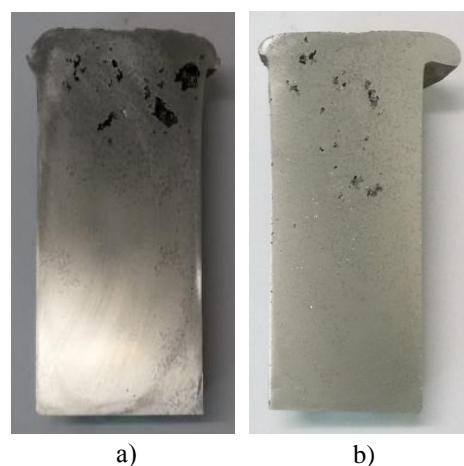


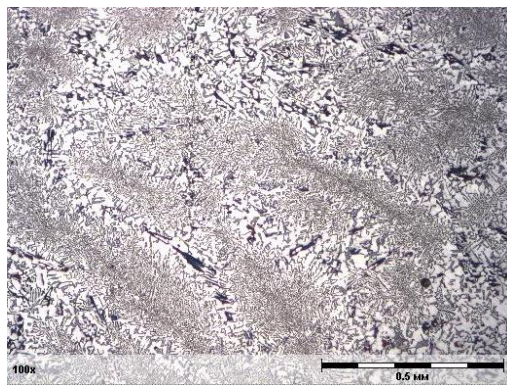
Fig. 1. Section of hypereutectic alloy: a) without processing; b) overlapping the magnetic field.

during the crystallization. It can be seen from the figure that in the alloy that was being processed, shrinkage defects are much smaller in size than shrinkage defects in the alloy without treatment. On the macrosection of the alloy the phase components are distributed, which are probably phases with alloying elements. In Silumin, which was exposed to a magnetic field, the distribution of such phases is uniform in comparison with the alloy without treatment.

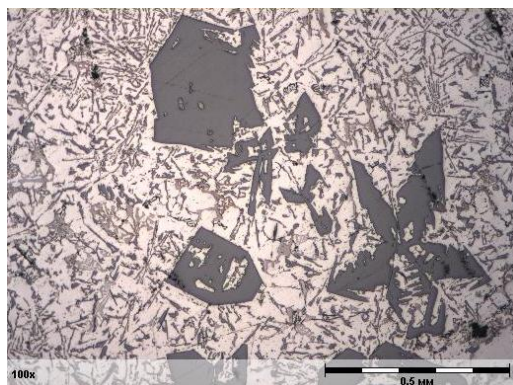
With the help of light metallography, the microstructure of the alloy was analyzed. The size of the structural components and their distribution were estimated. The main attention was paid to the shape, size, distribution in the volume of the investigated samples of primary silicon crystals and phases with iron. Images of the microstructures of the alloy without and after the action of the magnetic field are shown in Figures 2 - 3.

The microstructure of the untreated alloy is characterized by a nonuniform distribution of the eutectic and inclusions of the needle phases observed in the form of colonies. In some places in the structure of the alloy, the available silicon phases are large in size, from 180 μm to 300 μm with sharp angles. Also, phases with a star-shaped structure, whose size is from 350 μm to 500 μm, are observed.

It can be seen that silicon, which is unevenly distributed in the alloy structure, is mainly in the form of clusters. The sharp corners of the silicon phase can be stress concentrators, this significantly reduces the mechanical properties of the material. Such a distribution of crystals of primary silicon leads to a rapid destruction of a part of

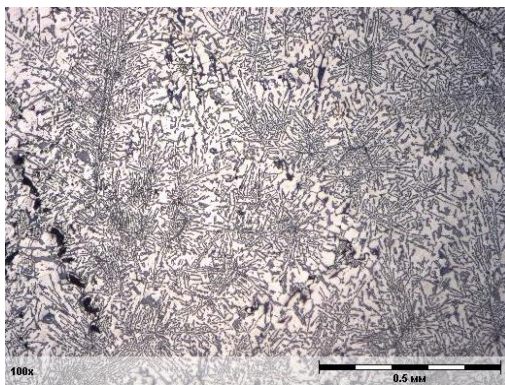


a)

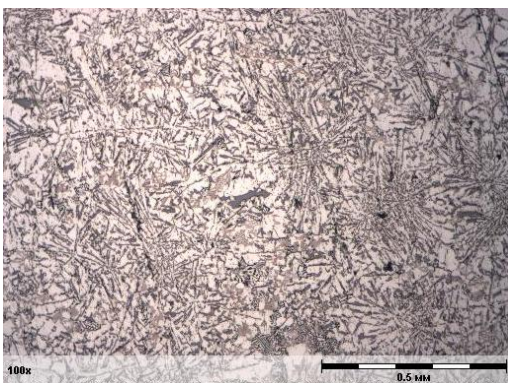


b)

Fig. 2. Microstructure of hypereutectic alloy without processing (a, b - different fields of view), $\times 100$



a)



b)

Fig. 3. Microstructure of the magnetic field after treatment of the hypereutectic alloy (a, b - different fields of view), $\times 100$.

such an alloy during operation. It is known [11] that the presence of primary silicon in the structure of large crystals leads to large intervals of α -solid solution between them, which are easily scratched by abrasive particles, which leads to a decrease in the wear resistance of the piston and to formation of such operational defects as scuffs.

The microstructure of the hypereutectic alloy treated with a constant external magnetic field compared with the previous case has a more evenly distributed eutectic, and the dimensions of the inclusions of primary silicon are much smaller. The distribution of primary silicon in the volume of the alloy is uniform, and this helps to reduce the interstitial spaces of the α -solid solution between the primary silicon crystals and increases the wear resistance of silumin with an increased silicon concentration [11]. According to the metallographic analysis in the hypereutectic alloy after the action of the magnetic field, the sizes of the primary silicon particles were in the range 20-60 μm .

To obtain a more contrast image of the distribution of different phases and determine their chemical composition, raster electron microscopy was used. The obtained images of microstructures with the help of REM for an alloy without and after exposure to it a magnetic field are shown in Figures 4 - 5.

Analyzing the structure of the alloy in the initial state, it is worth noting that it has an inhomogeneity in the distribution of both the main phases and the alloying elements at the grain boundaries. This is evidenced by the uneven location of light areas on the image.

A local chemical analysis of the phases and structural constituents for the alloy without treatment was also determined. Analysis of the image and local chemical composition shows the formation of the $\text{Al}_{15}(\text{FeMn})_3\text{Si}_2$ phase, which has no classical needle shape, that is due to the action of nickel (point 2). The eutectic $\text{Al} + \text{Si}$ (point 1) and the solid solution based on aluminum (point 3) were also found. The presence of a primary silicon phase was determined (point 4, figure 4 b).

The data of the local chemical phase analysis for the hypereutectic alloy, which crystallized without the influence of external magnetic action, are given in Table 1.

Table 1 - Chemical analysis of the phases of a hypoutectic alloy without processing by a magnetic field

№	Chemical composition of the phase, % mas					Phase
	Al	Si	Mn	Ni	Fe	
1	76,83	23,17	–	–	–	(Al+ Si) eutectic
2	40,43	0,46	0,59	52,90	5,61	$\text{Al}_{15}(\text{FeMn})_3\text{Si}_2 + \text{Ni}$
3	96,88	2,68	0,10	0,13	0,21	(Al)
4	1,06	98,80	0,02	0,016	0,047	(Si)

According to the data of the local chemical phase analysis (Figure 5), in the structure of the alloy after the action of the magnetic field the following things are observed: the $\text{Al} + \text{Si}$ eutectic (point 1), the $\text{Al}_{15}(\text{FeMn})_3\text{Si}_2$ phase containing nickel (point 2), the solid solution point on the basis of aluminum (point 3) and the primary phase of silicon (point 4). Local chemical phase analysis data for the alloy after the action of the magnetic field are given in Table 2.

Table 2 - Chemical analysis of the phases of a hypoutectic alloy after its treatment by a magnetic field

№	Chemical composition of the phase, % mas					Phase
	Al	Si	Mn	Ni	Fe	
1	43,17	3,41	–	33,60	19,81	$\text{Al}_{15}(\text{FeMn})_3\text{Si}_2 + \text{Ni}$
2	6,30	93,43	0,11	0,16	–	(Si)
3	98,76	0,89	0,02	0,30	0,02	(Al)
4	68,81	30,91	0,07	0,17	0,04	(Al+ Si) eutectic

At point 2 (Figure 4) and 1 (Figure 5) there are phases whose chemical composition and stoichiometry indicate that Ni interacts with iron. Due to the presence of Ni, the stoichiometry of the $\text{Al}_{15}(\text{FeMn})_3\text{Si}_2$ phase changes, as well as its appearance. Instead of extended inclusions of a needle-like shape, compact inclusions are observed.

3.2. Analysis of microhardness and Brinell hardness

Measurements of the microhardness were performed to determine the influence of the magnetic field on the properties of the hypereutectic alloy. The study was conducted in an area that was guaranteed to be subjected to an external magnetic field, from the

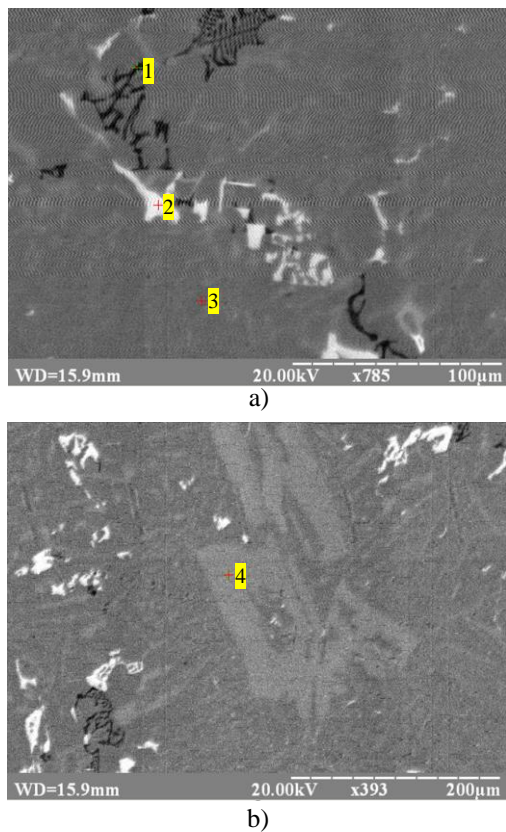


Fig. 4. Microstructure of hypereutectic alloy, which wasn't influenced by a magnetic field, with different magnitudes: a) $\times 785$; b) $\times 393$

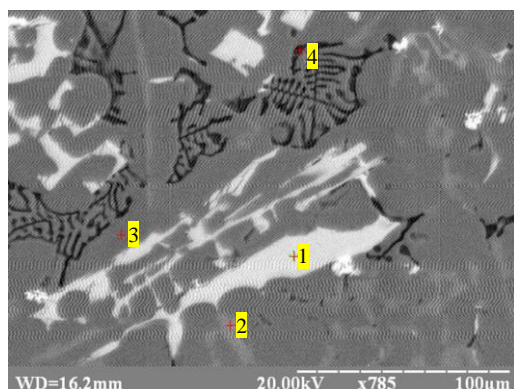


Fig. 5. Microstructure of hypereutectic alloy, which was influenced by a magnetic field, with different magnitudes, $\times 785$.

lower edge of the sample to the depth of the metal. The load on the diamond pyramid was 50 g, the holding time was 10 s. The results were compared with measurements in a similar region in the original alloy. The results obtained are presented in the form of graphs of microhardness's change in Figure 6.

From the obtained results it can be seen that the superposition of the magnetic field positively influences the structure of the hypereutectic alloy. An increase of the microhardness is observed. The graph shows the changes in the microhardness of the alloy after the action of an external magnetic field (Figure 6, b). Stable results

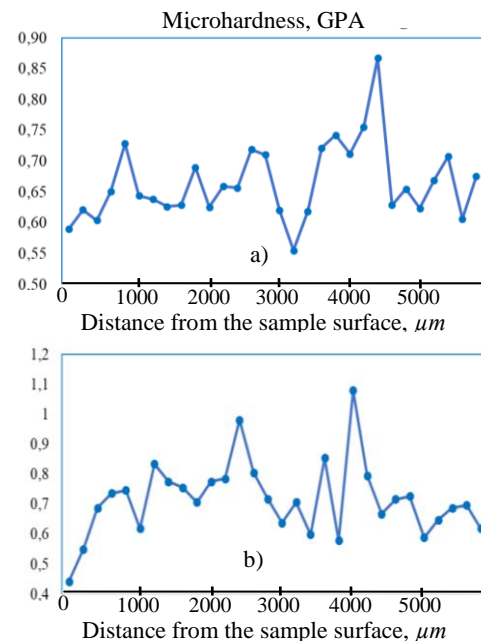


Fig. 6. Microhardness alloy: a) in the initial state; b) after external magnetic influence.

are obtained in comparison with the untreated alloy (Figure 6, a). This may indicate a uniform distribution of alloying elements in the alloy structure.

In Brinell hardness measurements, the mean change in the HB of the samples from the bottom to the top of the cast was estimated. When carrying out the measurements, a steel ball with a diameter of 5 mm was used, the load F was 2452 N (or 250 kgf), and the holding time was 10 s. Graphs of the average values of the change in hardness for hypereutectic silumin are shown in Figure 7 a, b.

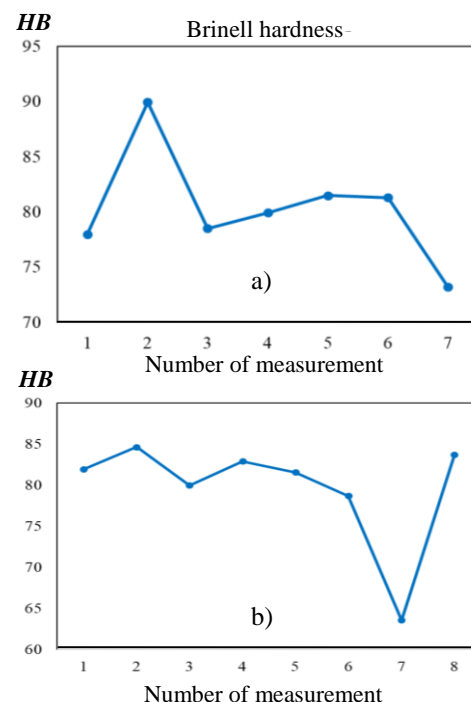


Fig. 7. Hardness of the alloy according to Brinell: a) in the initial state; b) after external magnetic influence.

Figure 7 (a) shows a different distribution of hardness values. This can be explained by a nonequilibrium structure. The stable values at the beginning of the graph (Figure 7, b) for the alloy after the action of the magnetic field can be explained by a more even distribution of the alloying elements in the alloy structure, and the decrease in

hardness observed at the end of the graph is due to the fact that the upper part was less exposed to the magnetic field.

Thus, the effect of a constant magnetic field in the process of crystallization of the hypereutectic silumin has a noticeable effect on its structure and properties.

4. Conclusions

1. The application of an external constant magnetic field for 10-15 seconds during crystallization positively influences the formation of the structure of the hypereutectic alloy of the Al-Si system.
2. It has been established that treatment with a magnetic field leads to a reduction in shrinkage defects, and the gas porosity of the treated alloy does not exceed 1 point in accordance with [12].
3. In the microstructure after treatment, a uniform distribution of the doped phases in the bulk of the material and the grinding of the primary silicon phase is observed. In an alloy without a block, the size of silicon inclusions is 150 μm - 300 μm , and after processing 30 μm - 60 μm , this indicates its uniformity, which leads to the improvement of the operating properties of the alloy.
4. It is established that the superposition of the magnetic field positively affects the microhardness of the hypereutectic silumin. An average microhardness increase by 7.5% is observed. Its minimum indicator increased by 2%, and the maximum by 72.6%.
5. An increase of the values from 3% to 15% for 66% of the Brinell hardness measurements after the action of the magnetic field on the hypereutectic silumin has been shown.
6. The developed technique can be recommended for controlling the structure formation and pulverization of the phases of primary silicon of hypereutectic silumins.

5. References

1. Kutsova V. Z. Influence of hydrocirculation treatment on the structure and properties of hypereutectic piston silumins / V. Z. Kutsova, O. A. Nosko, A. S. Sherstobitova // Metallurgy and thermal processing of metals. - 2008. - No. 4. - P. 39-49. - Electronic resource - access mode: http://nbuv.gov.ua/UJRN/mtom_2008_4_7. (Ukrainian)
2. Structure and properties of the modified piston silumin AK18 after hydrogen treatment. V.Z. Kutsova, O.A. Nosko, T.A. Ayupova, A.O. Kupchinskaya // New materials and technologies in metallurgy and machinebuilding No. 1, 2012. P. 40 - 45. (Russian)
3. Stetsenko, V.Yu. Investigation of the influence of the rod design on their cooling capacity during the refining of silumin by the numerical modeling method / V. Yu. Stetsenko, R.V. Konovalov, K.N. Baranov // Casting and Metallurgy: Scientific and Production Journal. - 2012. - No. 3 (67). - P. 63 - 68. (Russian)
4. E.I. Marukovich. Investigation of casting of hollow billets made from silumin AK18 by freezing on a water-cooled rod / E.I. Marukovich, V. Yu. Stetsenko, K.N. Baranov // Casting and metallurgy. - 2011. - No. 3 (62). - P. 65 - 67. (Russian)
5. Andrushevich, A.A. Use of methods of impulsive impact in foundry manufacture / A.A. Andrushevich, I.N. Kazanovskaya, M.N. Churik // Casting and metallurgy. - 2005. - No. 2 (34), [Part 1]. - P. 129 - 131. (Russian)
6. Stetsenko V. Yu. Modification of silumins with micro-crystalline aluminum alloys / V. Yu. Stetsenko, A.I. Rivkin, A.P. Gutev, R.V. Konovalov // Vestnik GSTUIM. P.O. Sukhogo. - 2009. - No. 1. - P. 21 - 24. (Russian)
7. Kristal M.M. Increase of wear resistance of shares of aluminum-silicon alloys by the MDO method for working in extreme frictional regimes // Proceedings of the Samara Scientific Center of the Russian Academy of Sciences, vol. 13, No. 4 (3), 2011. - P. 765-768. (Russian)
8. Marukovich, E.I. Production of castings from hypereutectic silumin by method of casting with hardening solidification / E.I. Marukovich, V. Yu. Stetsenko // Casting and metallurgy. - 2005. - No. 2 (34), [Part 1]. - pp. 142 - 144. (Russian)

9. Donii, O.M. Crystallization of hypereutecticon silumin AK18 under the action of external electromagnetic field / O.M. Donii, T.M. Narizhna // International scientific conference "Materials for work in extreme conditions - 6", December 1 - December 2, 2016, m. Kyiv. - Kyiv: KPI named after Igor Sikorsky, 2016. - P. 320-321. - Electronic resource - access mode: <http://ela.kpi.ua/handle/123456789/20373> (Ukrainian)
10. Pavlov, A.V. Influence of a pulsed magnetic field on the microhardness of an aluminum alloy of the Al-1.6% Mn system, after 3D precipitation / A.V. Pavlov, J. Prezlowski // Student Scientific Forum 2012: IV Intern. student. electron. sci. Conf., Feb. 15 - March 31, 2012 / The Russian Academy of Natural Sciences. - P. 105-112. (Russian)
11. Shemetev, G.F. Aluminum alloys: compositions, properties, application [Electronic resource]. Part 1: a textbook on the course "Manufacture of castings from alloys of non-ferrous metals" / G.F. Shemetev; St. Petersburg State Polytechnic University. - Electron. text dan. (1 file: 2.6 MB). - St. Petersburg, 2012. - In accordance with the title from the screen. - Free access from the Internet (reading, printing, copying). - Text Document. Adobe Acrobat Reader 7.0. - access mode: <http://elib.spbstu.ru/dl/2747.pdf>>. (Russian)
12. GOST 1583-93. Cast aluminum alloys. Technical conditions / Interstate Council for Standardization, Metrology and Certification. - Minsk. - 1993. 24 p. (Russian).