

EFFECT OF NANOMODIFIERS ON THE DENSITY AND THE POROSITY OF AlSi7Mg ALLOY CASTINGS

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Abstract: The influence of nanomodifiers AlN, SiC and nanodiamond (ND) with various metal cladding on the density and the porosity in areas with different section size and cooling rate of AlSi7Mg alloy castings is investigated. Experimental castings "Holding boat" for electrical supply lines are produced in metal mold before and after introducing of the nanomodifiers in the melt. Two alloys with different Fe content are used. It is shown that the nanomodification of both alloys results in an increase of the density and in a decrease of the porosity, especially in areas with bigger size and lower cooling rate as well as in a decrease of the difference between their values in different areas. The usage of SiC leads to comparable low porosity values independently of Fe content in the alloy, i.e. in some degree eliminates its harmful action. The established possibility for improvement and homogenization of the density with minimizing of the microporosity in different casting sections by help of nanomodifiers is a premise for a high quality and reliability nanomodified castings production.

Keywords: NANOMODIFIERS, AlSi7Mg ALLOY CASTINGS, DENSITY, POROSITY

1. Introduction

AlSi7Mg alloy is widely used for casting responsible dynamically loaded parts, which require a high density in the volume shaping. However, it is characterized by a wide temperature range of crystallization (550-625°C), which is a prerequisite for the occurrence of gas- and microshrinkage porosity formation. When correctly designed, degassed and properly organized the crystallization, AlSi7Mg castings can exhibit low shrinkage porosity - 0.5 % or less [1, 2]. Of particular importance to reduce the tendency to the formation of voids is the grain size - larger grains determine larger shrinkage voids and vice versa [1-3]. A high level of impurities, primarily Fe, produce intermetallic phases that precipitate in the grain boundaries and further impede the flow of liquid metal and, thus, increase microshrinkage propensity [3]. That is why actions such as the use of suitable modifiers for structure refinement can affect favorably the volume shaping of AlSi7Mg castings. In this regard may be appropriate application of nanomodifiers (NM) – specially processed with cladding metals nanopowders of nitrides, carbides, borides, nanodiamonds (ND) etc. with particles size 4-100 nm. Their strong modifying effect on the structure of Al-Si alloys is reported in [4-7]. It is found [4, 5] that the modification of AlSi7Mg alloy by NM leads to a significant presence of cell structure instead completely dendritic, to decrease of the mean α -cells diameter and DAS as well as to a refinement of Si-particles and intermetallic phases. However, information about NM influence on the density respectively porosity is poor without bringing specific data [6] or concerns densities of separately cast samples [5]. It is of particular interest to investigate the effect and degree of NM influence on these characterizing the volume shaping parameters in zones with different section size and crystallization conditions as well as in case of different Fe content.

The purpose of this work is to investigate the influence of different types nanomodifiers on the density and volume porosity in real AlSi7Mg alloy castings.

2. Experimental

The object of study is a casting "Holding boat" (Fig. 1) of 0.470 kg weight (0,860-870 kg with gating system) with complex configuration conditioned by emptiness in the volume. It is designed for installation in electrical supply lines. The use of aluminium alloy with possibility for detail machining is required. This requirement is driven by necessity to ensure montage sizes and a good trade look. Another important requirement is the density of the casting, given that it operates under high cyclic loads. The casting is produced in a metal mold through gravimetric pouring. Two movable metal cores, which are an integral part of the mold, are used to form the joining hole.

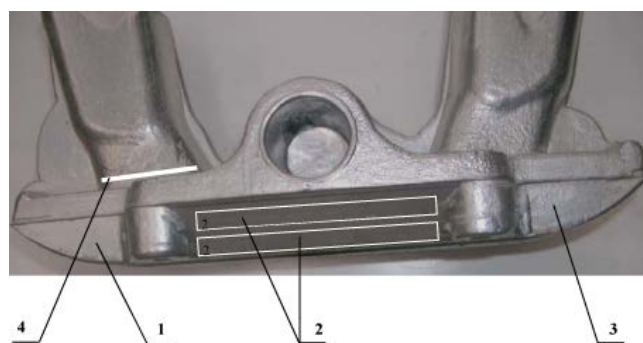


Fig. 1. The outlook of experimental casting "Holding boat" and investigated zones:

zone 1 - from the side of the feeder head with section area 6.6 cm²; zone 2 – with section area 12.1 cm²; zone 3 - from the side of the gate with section area 6.6 cm²; zone 4 - slice from a feeder head

Two alloys with different Fe content are used: alloy I - A356.2Sr of Dubal - OAE firm with 0.11% Fe (Table 1) and alloy II - EN AC-42000 AlSi7Mg according Bulgarian standard EN 1706 of „Superalloy" OOD - Plovdiv firm with 0.39% Fe (Table 2).

Table 1. Chemical composition of alloy I (A356.2Sr)

Chemical composition of alloy I (A356.2Sr) w. %; Al – the rest								
Si	Mg	Ti	Fe	Cu	Mn	Zn	Pb	Sr
6.80	0.35	0.16	0.11	0.04	0.01	0.01	0.08	0.01

Table 2. Chemical composition of alloy II (AlSi7Mg)

Chemical composition of alloy II (AlSi7Mg) w. %; Al – the rest								
Si	Mg	Ti	Fe	Cu	Mn	Zn	Pb	Sn
7.50	0.39	0.02	0.39	0.05	0.03	0.10	0.08	0.05

The treatment with six type of modifiers AlN, SiC and nanodiamond (ND) with various metal cladding is applied.

The type and concentration of the modifiers are as follows:

- 0.1% SiC+Al (SiC:Al 1:3) – clad in planetary mills
- 0.05% AlN+Al+Cu (AlN:(Al+Cu)1:1.41) – clad in planetary mills
- 0.05% AlN+Al (USD) (AlN:Al 1:3) – clad in planetary mills and additional ultrasonic dispersion (USD)
- 0.1% ND+Ni (ND:Ni 1:0.1) - covered by free current method
- 0.1% SiC+Cu (SiC:Cu 1:0.1) - covered by free current method
- 0.05% AlN+Al (USD) + 0.03% SiC+Cu

The method for casting of a part type 'Boat' is as follows:

- melting in electric-resistance furnace with crucible capacity of 2.5 kg for Al;
- degassing at 730-740°C with Ar during 3-4 min;
- introducing NM encapsulated in aluminum patron in the melt at 740-750°C using mechanical stirring by Ti mixer during 3-4 min;
- casting in metal mold using established technology for producing experimental castings "Holding boat" before and after treatment by NM. Equal initial conditions of casting and crystallization are maintained – metal temperature 710-720 °C and mold temperature 150-160 °C. The melt temperature monitoring is conducted using thermocouple (protected by quartz shield). The mold temperature is measured using in-built thermocouple central situated on 1 mm on the mold wall.

For the study of the density and porosity zones of castings with different section size and cooling rate and also to compare - from a feeder head (Fig. 1) are selected as follows:

Zone 1 - with cross section area of 6.6 cm² (30x22 mm) from the side of the feeder head, in which the cooling rate is highest;

Zone 2 - with cross section area of 12.1 cm² (55x22 mm) - almost double than that in zone 1 and therefore the cooling rate is lower;

Zone 3 - with cross section area of 6.6 cm² (30x22 mm) from the side of the gate. It is symmetrical with zone 1, but due to the close location of the metal pouring, the cooling conditions are unfavourable;

Zone 4 - segment from a feeder head (high 10 mm from the surface of the casting).

The castings are halved along the length and segments are cut out: from zones 1 and 3 – 2-3 specimens ("prow" of the boat), from zone 2 – 2 specimens (parts for mechanical tests) and 1 segment from a feeder head - zone 4. It is important to notice that after cutting a presence of macroshrinkages and knots are not observed. That testifies to a correctly degassing and a properly carried out casting process.

The density d of cut out from different zones specimens is determined according Archimedes' principle via measuring the weigh using an electronic balance with an accuracy of 0.01 g on air G_{air} (Fig. 2a) and in distilled water G_{water} (Fig. 2b). Then the d value is calculated through the formula (1):

$$(1) \quad d = \frac{G_{air}}{G_{air} - G_{water}} \text{ [g/cm}^3\text{]}$$

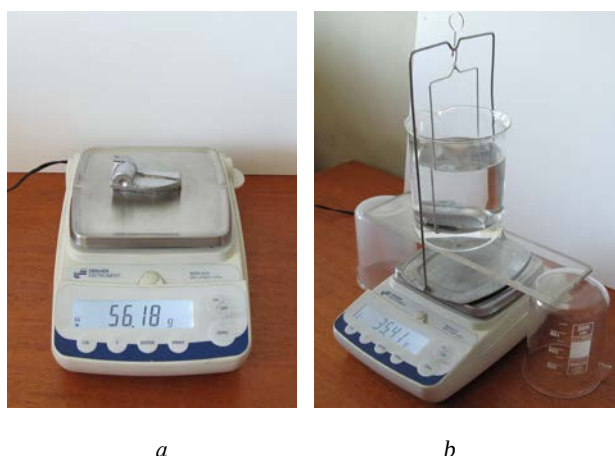


Fig.2. Measuring the weigh of the specimens:
a – on air; b – in water

The porosity P [%] is defined through formula (2):

$$(2) \quad P = \frac{d_0 - d_{av}}{d_0} \cdot 100\%$$

where: P - porosity, %; d_0 - theoretical density of the alloy, calculated via additive approach by means of the formula (3), g/cm³; d_{av} – average density value in corresponding zone, g/cm³.

$$(3) \quad d_0 = \sum_{i=1}^n d_i \cdot m_i \text{ [g/cm}^3\text{]}$$

where: d_0 - theoretical density of the alloy, g/cm³; d_i - density of the i - component, g/cm³; m_i – share of the i – component ($m_i = c_i / 100$ and c_i is the concentration of the i – component in weigh %).

The calculations of d_0 for both alloys through formula (3) are done by substitution of c_i values from tables 1 and 2 and those of d_i – from source [8], where they are precisely determined on the base of data from an X-ray examination of the atomic weights and atomic volumes of the elements. The calculated value $d_0 = 2.6812$ [g/cm³] of an alloy I (A356.2Sr) is lower than this of an alloy II (AlSi7Mg) - $d_0 = 2.7050$ [g/cm³] due to lower content of Fe and other elements with high d_i in it.

The percentage changes of the density Δd_{av} and of the porosity ΔP in different zones of NM castings in comparison with these of castings without NM are defined also.

3. Results and discussions

The results from investigations of castings of both alloys (Tables 3 and 4) show the following. Before NM treatment a casting of alloy I is characterized by significantly lower porosity than that of alloy II, which as discussed above, is due to the low Fe content. In zones 1 of the initial castings with highest cooling rate, d_{av} values are higher and those of P are lower than in others zones. The nanomodification of both alloys leads to an increase of the density, especially in zones with a bigger size and a lower cooling rate and to decreasing of the porosity. This results in a reduction of the differences in their values in different zones, i.e. in a decrease and more homogeneity distribution of the microporosity.

For example, after treatment of an alloy II by 0.15% ND+Ni the increase of density Δd_{av} in zones 1 and 3 with smaller section is 0.28-0.38%, while in zone 2 with bigger section it is more strongly expressed and reaches 0.81%, at that the P - values in all three zones become almost equal (Table 4). The differences between d of the specimens in any particular zone decrease as well.

NM compositions with SiC have a very strong effect on both alloys. In modified with 0.1% SiC+Al casting of A356.2Sr alloy P in zone 1 decreases with 98.6 % and in practice is eliminated (Table 3). In case of alloy II the strongest effect has the treatment with 0.1% SiC+Cu – the density increasing is 1.36% and the porosity decreasing - 80 %. In the most unfavourable section 2 of alloy II casting the 0.1% SiC+Cu addition (Table 4) leads to a significant increasing of d_{av} with 1.36 % and to a reducing of P with 80%. Under SiC influence in smaller section zones – 3 in case of A356.2Sr casting № 4-1 and 1 in case of AlSi7Mg casting № 14 d_{av} grows with nearly 1%. P decreases with more than 93% and reaches very low (below 0.1%) and comparable values independently of Fe content, i.e. in some degree its harmful action is eliminated. The effect of 0.05% AlN+Al+Cu addition (casting № 11) is high as well, but smaller than this of SiC+Cu. The results for castings № 15 and № 16 do not show an improvement of AlN+Al effect after additional ultrasonic dispersion (USD) in comparison with this of AlN+Al+Cu (casting № 11).

Table 3. Density and porosity of alloy I (A356.2Sr) castings - $d_0 = 2.6812 \text{ [g/cm}^3\text{]}$

Casting № Type and modifier concentration	Zone with cross section area $[\text{cm}^2]$	Weight			Density			Porosity	
		G_{air} [g]	G_{water} [g]	ΔG [g]	d [g/cm ³]	D_{av} [g/cm ³]	Δd_{av} [%]	P [%]	ΔP [%]
1-3 Without modifier	1 6.6 cm ²	14.18 36.11	8.87 22.62	5.31 13.49	2.6704 2.6768	2.6736	-	0.28	-
	3 6.6 cm ²	38.57 6.23 54.77	24.03 3.88 34.23	14.54 2.35 20.54	2.6527 2.6511 2.6665	2.6568	-	0.91	-
4-1 0.1% SiC+Al	1 6.6 cm ²	48.96 25.47	30.70 15.97	18.26 9.50	2.6813 2.6810	2.6811	0.28	0.004	-98.6
	3 6.6 cm ²	48.82 9.65	30.61 6.05	18.21 3.60	2.6809 2.6805	2.6807	0.90	0.02	-97.8

Table 4. Density and porosity of alloy II (AlSi7Mg) castings - $d_0 = 2.7050 \text{ [g/cm}^3\text{]}$

Casting № Type and modifier concentration	Zone with cross section area $[\text{cm}^2]$	Weight			Density			Porosity	
		G_{air} [g]	G_{water} [g]	ΔG [g]	d [g/cm ³]	D_{av} [g/cm ³]	Δd_{av} [%]	P [%]	ΔP [%]
8-2 Without modifier	1 6.6 cm ²	51.67 49.61	32.39 30.55	19.28 18.56	2.6800 2.6730	2.6765	-	1.05	-
	2 12.1 cm ²	78.69 81.33	49.21 50.64	29.48 30.69	2.6693 2.6500	2.6596	-	1.68	-
	3 6.6 cm ²	50.54 26.40	31.59 16.53	18.95 9.87	2.6670 2.6748	2.6709	-	1.26	-
	4 from a feeder head	16.68	10.39	6.29	2.6518	2.6518	-	1.97	-
10-2 0.15% ND+Ni	1 6.6 cm ²	57.84 47.53 54.04	36.30 29.83 33.89	21.54 17.70 20.15	2.6852 2.6853 2.6819	2.6841	0.28	0.77	-26.7
	2 12.1 cm ²	76.48 72.97	47.96 45.75	28.52 27.22	2.6816 2.6807	2.6811	0.81	0.88	-47.6
	3 6.6 cm ²	29.28 9.57	18.36 6.00	10.92 3.57	2.6813 2.6807	2.6810	0.38	0.89	-29.4
11 0.05% AlN+Al+Cu	1 6.6 cm ²	57.50 27.42	36.21 17.27	21.29 10.15	2.7001 2.7015	2.7008	0.91	0.16	-84.8
	2 12.1 cm ²	77.79 73.64	49.00 46.24	28.79 27.40	2.7020 2.6876	2.6948	1.32	0.38	-77.4
	3 6.6 cm ²	11.22 108.35	7.06 68.21	4.16 40.14	2.6971 2.6993	2.6982	1.02	0.25	-80.2
	4 from a feeder head	17.72	11.11	6.61	2.6808	2.6808	1.09	0.89	-54.8
14 0.1% SiC+Cu	1 6.6 cm ²	56.20 28.60	35.41 18.02	20.79 10.58	2.7032 2.7032	2.7032	1.00	0.07	-93.3
	2 12.1 cm ²	82.51 85.74	51.90 53.94	30.61 31.80	2.6953 2.6962	2.6958	1.36	0.34	-79.8
	3 6.6 cm ²	10.75	6.77	3.98	2.7010	2.7010	1.13	0.15	-88.1
	4 from a feeder head	15.23	9.55	5.68	2.6813	2.6813	1.11	0.88	-55.3
15 0.05% AlN+Al (USD)	1 6.6 cm ²	59.28 12.02 27.03	37.23 7.56 16.97	22.05 4.46 10.06	2.6884 2.6951 2.6869	2.6901	0.51	0.55	-47.6
	2 12.1 cm ²	78.31 81.77	49.02 51.26	29.29 30.51	2.6736 2.6801	2.6769	0.65	1.04	-38.1
	3 6.6 cm ²	114.43	71.85	42.58	2.6874	2.6874	0.62	0.65	-48.4
16 0.05% AlN+Al (USD) +0.03%SiC+Cu	1 6.6 cm ²	54.64 25.21	34.38 15.86	20.26 9.35	2.6969 2.6963	2.6966	0.75	0.31	-70.5
	2 12.1 cm ²	82.28 83.77	51.46 52.44	30.82 31.33	2.6697 2.6738	2.6718	0.46	1.23	-26.8
	3 6.6 cm ²	109.45 11.98	68.55 7.52	40.90 4.46	2.6760 2.6861	2.6811	0.38	0.88	-30.2

Interesting is the fact that the NM influence to reduce the tendency for a microporosity formation propensity occurs in the zone 4 from a feeder head. For unmodified casting in this zone P is relatively high - about 2% (Table 4). NM as SiC+Cu and AlN+Al+Cu reduce this value by about 55% and P level decreases up to 0.90% - lower than that in other zones of the initial casting. This is illustrated on Fig. 3 with macrostructures of specimens without and with NM from a feeder head near the casting surface. After a thorough study, the established effect can be useful in designing castings to reduce the volume of feeder heads with a view to increase the yield.

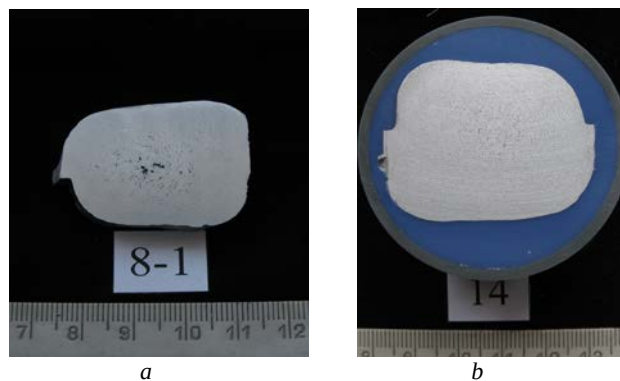


Fig. 3. Macrostructure of specimens from zone 4 - a feeder head:
a – casting without modifier, b – casting with 0.1% SiC+Cu

4. Conclusions

The influence of six type of nanomodifiers AlN, SiC and nanodiamond (ND) with various metal cladding on the density and the volume porosity in zones with different section size and cooling rate of a real AlSi7Mg alloy casting “Holding boat” is investigated. It is established:

1. The nanomodification of both alloys leads to increasing of density with more than 1%, especially in zones with bigger size and lower cooling rate and to decreasing of porosity with more than 90%. This results in a decrease of the differences between their values in the different zones, i.e. in a decrease and more homogeneitly distribution of the microporosity.

2. In modified with 0.1% SiC+Al castings of A356.2Sr alloy with low Fe content the microporosity decreases with more than 98% and in practice is eliminated.

3. In case of AlSi7Mg alloy with higher Fe content the strongest effect has the treatment with 0.1% SiC+Cu – the density increasing is 1-1.36% and the porosity decreasing - 80-93.3 %. The effect of 0.05% AlN+Al+Cu addition is high as well - the porosity decreases with up to 80-85 %. Less – up to 50% is the porosity reducing after adding of 0.15% ND+Ni or 0.05% AlN+Al (USD).

4. Under the influence of SiC-containing nanomodifiers very low and comparable values (below 0.1%) of volume microporosity in thin casting sections are achieved independently of Fe content in the alloy, i.e. in some degree its harmful action is eliminated.

In conclusion it can be said that the established possibility towards minimizing and homogenizing the microporosity in different casting sections by treatment of the alloys with nanomodifiers is a premise for obtaining nanomodified aluminium castings with high quality and reliability.

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