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DISTRIBUTION OF REINFORCING PARTICLES IN THE PRESSURE DIE CAST AlSi11/20% SIC COMPOSITE

ROZMIESZCZENIE CZĄSTEK FAZY ZBROJĄCEJ W ODLEWANYM CIŚNIENIOWO KOMPOZYCIE AlSi11/20% SIC

A method of pressure die casting of composites with AlSi11 alloy matrix reinforced with 20 vol. % of SiC particles and the analysis of the distribution of particles within the matrix are presented. The composite castings were produced at various values of the piston velocity in the second stage of injection, at diverse intensification pressure values, and various injection gate width values. The distribution of particles over the entire cross-section of the tensile specimen is shown. The index of distribution was determined on the basis of particle count in elementary measuring fields. The regression equation describing the change of the considered index was found as a function of the pressure die casting parameters. The conclusion presents an analysis of the obtained results and their interpretation.

Keywords: metal matrix composites, pressure die casting, reinforcing particles distribution

Przedstawiono metodykę odlewania ciśnieniowego kompozytów na osnowie stopu AlSi11 zbrojonego 20% udziałem objętościowym cząstek SiC i ich rozmieszczenia w osnowie. Odlewy kompozytowe wykonano przy różnych wielkościach prędkości tłoka w II fazie ruchu, ciśnieniu doprasowania i szerokości szczeliny wlewowej. Przedstawiono rozmieszczenie cząstek SiC na całym przekroju odlewu próbki do badania rozciągania. Na podstawie zliczeń liczby cząstek w elementarnych polach pomiarowych określono wskaźnik ich rozmieszczenia. Obliczono równanie regresji zmiany tego wskaźnika jako funkcję parametrów odlewania ciśnieniowego. W podsumowaniu przedstawiono analizę uzyskanych wyników i ich interpretację.

1. Introduction

Composite suspensions castability and capability of filling the mould cavity are significantly lower than liquid metals due to their much greater viscosity. As a result, the production of castings made of such slurries is only possible due to the casting technologies which apply the forced filling of the mould cavity. The high-pressure die casting seems to be the most suitable technology for the production of metal composite castings [1-5].

The magnitude of pressure exerted on metal during formation of a casting in the pressure die can be modified at will during the subsequent stages of the process, taking the values from 0.2 to 300 MPa. The high injection velocity, the high pressure during the die filling, and the quick crystallization of a casting in the die contribute to such advantages of the pressure die casting technology as high productivity, from 30 to 3600 shots per hour, high accuracy and dimensional stability of castings, as well as the precision of a replica, the high surface smoothness of castings which allows to avoid further machining, the possibility of obtaining the thin-walled castings of the wall thickness even less than 0.5 mm, better mechanical, physical and special properties due to the fine-grain structure of castings [2, 5-8].

The factors limiting the application range of the die casting technology include: high costs of tooling (pressure die and consumable parts) and the production machines (pressure die casting machine, manipulators), the limited size and weight of pressure castings, the limited quantity of foundry alloys which can be processed in this way.

The character of filling the die cavity with molten metal depends on the die cavity shape, the type of applied pressing unit and the assumed casting parameters, and is decisive for the quality of castings. In modern pressure die casting machines the piston velocity in the sleeve is varied during the injection cycle in order to reduce or eliminate the gas entrapment in the system and to decrease the porosity of castings.

Three stages of piston action are employed as a standard, but there are also systems allowing the continuous change of its velocity. The basic parameters of pressure die casting with regard to metal matrix composites, i.e. the injection speed, the filling time, and the injection pressure are calculated according to the appropriate formulae generally applied in metal casting [2, 9, 10].

As far as cast composites are concerned, the properties of castings are influenced most significantly by the type, the size, and the percentage of the reinforcing phase particles, as well as by their distribution within the matrix. The particles of the re-

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inforcing phase can be distributed uniformly or non-uniformly, in the latter case occupying the intergranular regions in quite disadvantageous way. The distribution pattern depends on the quality of the produced suspension, as well as on the casting technology and conditions under which a casting solidifies in the die. The quantitative determination of reinforcing phase distribution within the matrix allows to derive the functional, analytical relationships between the structural parameters and the properties of a casting [11-16].

2. Methods and results of investigation

The AlSi11 (EN AC-44000) foundry alloy of aluminium and silicon was selected for the composite matrix. Its composition provides good wettability of particles, thus enabling the introduction of silicon carbide into the matrix without additional treatment or modification of the alloy. The 98C silicon carbide of particle size 71-100 μm was applied in the experiment. The prepared slurry contained 20 vol. % of the reinforcing phase.

The composite suspension was prepared by mechanical mixing. The laboratory stand at which it was prepared, was equipped with the resistance heating furnace with a crucible of about 25 kg capacity, and the turbomixer of 0.25 m diameter with four blades inclined at 45 degrees. The turbomixer rotor was placed axially in the crucible, at a distance of one third of the melt height from the bottom of crucible. The rotor, made of the WNLV steel, was covered with the protective coating which ensured thorough mixing of the whole liquid phase volume and the relatively long lifespan of the mixer itself. The complete mixing system was constructed in such a way that it was possible to close the furnace after adding all components to the crucible. The mixing time was equal to 15 min, and the angular velocity of the rotor was fixed at the level of 500 rpm. The suspension was injected into a test die on the cold chamber horizontal pressure die casting machine of 1.6 MN clamping force.

The examination was performed according to the 2^3 type of design of experiment, where the variable factors were: the piston velocity in the second stage of injection (v_{II}) taking the values of 1.2 or 3.6 m/s, the intensification pressure (p_{III}), being 20 or 40 MPa, and the gate width (d_w) equal to 1.5 or 3 mm. A casting with specimens for castability and impact strength tests, as well as for measuring the mechanical properties, is shown in Fig. 1.

The assessment of the distribution uniformity of the reinforcing phase was done for the non-etched metallographic microsections taken from the tensile specimen shoulders. The examined area was a circle of 10 mm diameter. Panoramic digital images of the whole microsection surfaces were taken at the magnification 50×, then the images were merged to achieve an integral image of the entire microsection. A square grid 1×1 mm were superimposed on the area to be measured, dividing it into 79 separate measuring fields. The reinforcing phase particles were counted for each of these unit fields in such a way that the particles crossing the right or the bottom edge of the field were excluded. The observations were performed by means of the OLYMPUS EPIPHOT optical microscope cooperating with a digital image recorder and the MULTISCAN computer data analysis software tool.

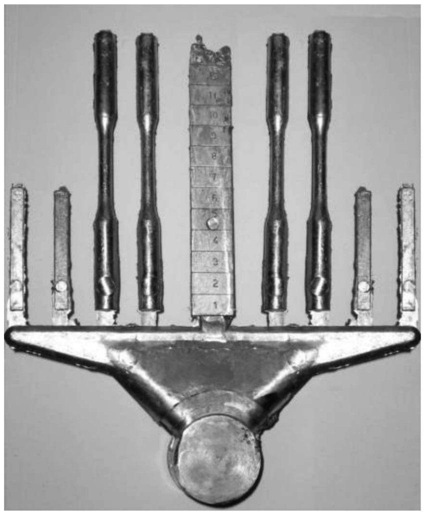

Fig. 1. Pressure cast test specimens with the gating system made in a single shot

The degree of uniformity of distribution of SiC particles within the volume of matrix was found on the basis of the ν index, which can be calculated from the equation [14]:

$$\nu = \frac{s\,(N_A)}{\overline{N}_A} \tag{1}$$

where: $s\,(N_A)$ – standard deviation of the average quantity of particles over the unit surface area, $\overline{N}_A$ – the average quantity of particles over the unit surface area [mm^{-2}].

The ν index assumes the values from 0 to 1. The zero value identifies the distribution as the uniform one, also called the complete spatial random (CSR) distribution, the value of 1 identifies it as the non-uniform one, also called clustering distribution. Hence the smaller value of the ν index, the more uniform is the distribution of the reinforcing phase particles.

The obtained results were juxtaposed with the values of the surface fraction of reinforcement corresponding to the really introduced volume of particles in order to correlate the obtained values. Then the theoretical quantity of particles over the area of 1 mm^2 was calculated from the relationship [14]:

$$N_A = \frac{\phi}{V_W} \cdot \overline{H} \tag{2}$$

where: $\overline{H}$ – average size of a particle [mm], V_W – the volume of a single particle [mm^3], ϕ – volume fraction of particles in the composite [%].

The theoretical value N_A does not take into account the distribution of particles over the microsection area and can serve only as a control value for the measured quantity. A comparison of the obtained and the theoretical values of N_A can be a measure of macroscopic distribution of particles.

The measurement results concerning the distribution of particles within the matrix of composite castings obtained by the methods of quantitative metallography are presented in Table 1.

TABLE 1
The values of ν index for individual tests of a given experiment

No exp.	v_{II}, m/s	p_{III}, MPa	d_w, mm	ν– index for an individual test					$\bar{\nu}$
				1	2	3	4	5	
1	2	3	4	5	6	7	8	9	10
20.1	1.2	20	1.5	0,32	0,27	0,22	0,34	0,24	0,28
20.2	1.2	40	3.0	0,43	0,54	0,39	0,49	0,48	0,47
20.3	1.2	20	3.0	0,62	0,74	0,68	0,59	0,61	0,65
20.4	1.2	40	1.5	0,21	0,29	0,28	0,31	0,23	0,26
20.5	3.6	40	3.0	0,15	0,17	0,20	0,16	0,21	0,18
20.6	3.6	20	1.5	0,17	0,19	0,18	0,21	0,23	0,20
20.7	3.6	40	1.5	0,12	0,15	0,14	0,15	0,18	0,15
20.8	3.6	20	3.0	0,22	0,21	0,23	0,29	0,22	0,23

The distribution of SiC particles in composites is exemplified for the extreme values of ν index in Figs. 2 and 3.

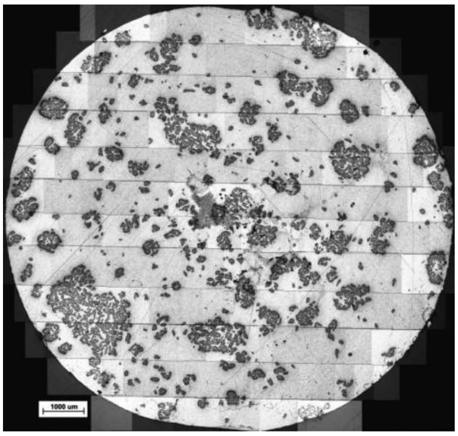

Fig. 2. The distribution of SiC particles in a composite casting, v_{II} =1.2 m/s, p_{III} =20 MPa, d_w =3.0 mm (experiment No. 3)

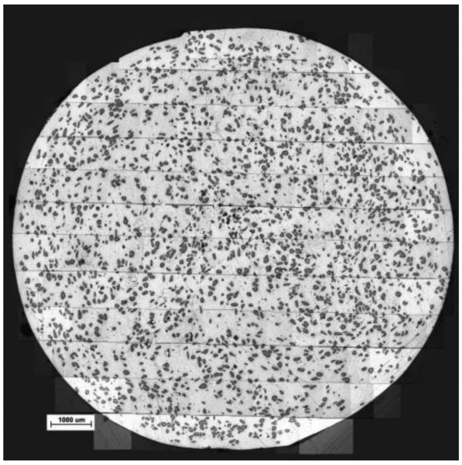

Fig. 3. The distribution of SiC particles in a composite casting, v_{II} =3.6 m/s, p_{III} =40 MPa, d_w =1.5 mm (experiment No. 7)

Results from Table 1 were used to find the regression equation describing the influence of pressure die casting parameters on the distribution of reinforcing phase particles within the matrix of composite castings. This equation for coded values of independent variables ($x_1 = v_{II}$, $x_2 = p_{III}$ i $x_3 = d_w$) takes the following form:

$$\hat{y}_{20} = 0,301 - 0,112x_1 - 0,037x_2 + 0,080x_3 - 0,063x_1x_3 - 0,022x_2x_3 \tag{3}$$

The graphic representation of Eq. 3 is presented in Fig. 4.

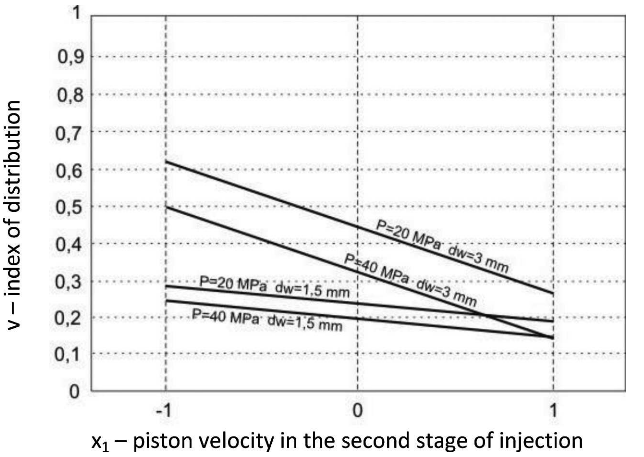

Fig. 4. The dependence of the index of particle distribution within the composite matrix on parameters of pressure die casting process

3. Conclusion

The analysis of composite microstructures and the regression equation show that the uniformity of the reinforcing phase arrangement in composite matrix were indeed influenced by all variable parameters of casting process, what was also confirmed by calculations. It was noticed that the low values of parameters support the non-uniform distribution or even generation of particle clusters in the composite suspension (Fig. 2).

Equation 3 reveals a strong influence of both the piston velocity in the second stage of injection, the intensification pressure and the gate width on the distribution of particles within the metal matrix. An increase of the v_{II}, p_{III} and decrease of the d_w parameters results in the increase in the uniformity of distribution of the SiC particles in the matrix. The obtained results point out unequivocally to the optimum parameters of pressure die casting for composites of this type.

An increased piston velocity combined with the reduced gate width also improved the uniformity of the reinforcing phase distribution. This increase results from the fact of intensive mixing of the suspension in the gate and the rapid filling of the die with the prepared suspension. The intensification pressure occurred to exert less significant influence on the uniformity of distribution of the particles at the large values of injection velocity, however – as far as the castings containing 20% of reinforcement are concerned – the uniformity achieved at high intensification pressure and low injection velocity was better than the one achieved for low intensification pressure and low injection speed.

The combined influence of piston velocity at the stage of die filling and of the gate width (or its cross-sectional area) can be expressed by the rate of the die filling (the injection rate). This rate changed from 16 m/s to 96 m/s in the course of examinations. The influence of the injection rate on the index of distribution of SiC particles in composites was presented in [17] (Fig. 5). For the purpose of comparison, the figure shows also a similar relationship for a composite containing 10 vol. % of SiC particles, its results of examination not being cited in the present paper.

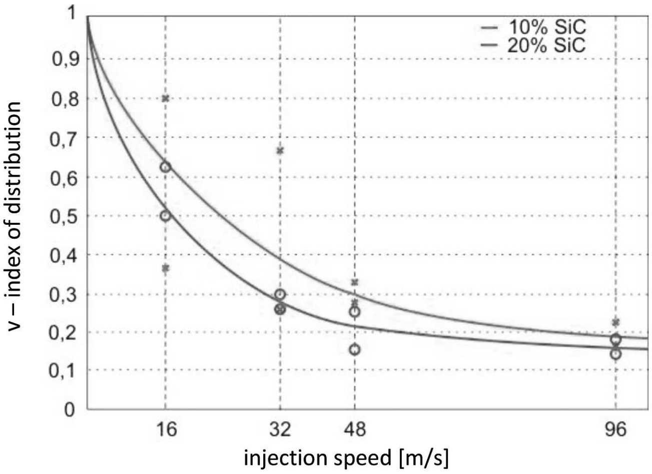

Fig. 5. The influence of injection rate on the uniformity of distribution of SiC particles in composites

It results from the above diagram that for injection rates exceeding 50 m/s there is no significant improvement in the distribution of the reinforcing phase particles in the matrix of composite castings.

The examinations allow to draw the following conclusions: – application of the pressure die casting technology for production of the AlSi11/SiC composite castings allow to modify the character of distribution of ceramic particles in metal matrix within a wide range;

– parameters of the production process, i.e. the piston velocity in the second stage of injection, the intensification pressure and the gate width, exert the essential influence on the type of composite structure with respect to the distribution of the reinforcing phase particles; this distribution can be uniform, nonuniform, or non-uniform with clusters;

– the increase in injection rate due to the increase in piston velocity in the second stage of injection and the reduction of gate area strongly promote the uniform distribution of reinforcing particles within the volume of castings.

REFERENCES

[1] A. Street, The Diecasting Book. Portcullis Press Ltd. (1997).

[2] A. Białobrzeski, Pressure casting. Machines, devices and technology. Warszawa: PWN (1992) (in Polish).

[3] Z. Konopka, Metal cast composites. Częstochowa: Wydawnictwo Politechniki Częstochowskiej (2011) (in Polish).

[4] Z. Konopka, Composite chips production and properties for vibratory and surface finishing. Materials Science **5**, 243-24 (2000). WILEY-YCH.

[5] Z. Konopka, M. Łągiewka, A. Zyska, Solidification of composite suspension during flowing in a mould. Kompozyty (Composites) **5** (4), 100-103 (2005) (in Polish).

[6] A.K. Biełopuchov i in., Pressure die casting. Problems of pressing. (Lit'je pod davlenijem. Problemy podpressovki.) Moskwa: Masinostrojenie. (in Russian) (1971).

[7] M. Cholewa, Simulation of composite microregions solidification process. J.Mater. Process Technology **164/165**, 1175-1180 (2005).

[8] Z. Konopka, A. Zyska, M. Łągiewka, M. Nadolski, The influence of the composite casting wall thickness on the arrangement of particulate within the matrix. Archives of Foundry Engineering **8**, 2, 89-92 (2008).

[9] H. Barton, The injection of metal into die casting. Machinery L 64 (1642, 1650), 65 (1664).

[10] L. Frommer, Der Spritzguss. Werkstattstechnik. (1926). H4.

[11] M. Cholewa, Morfologia cząstek wzmocnienia w kompozytach odlewanych, Archiwum Odlewnictwa R **6**, 18, 1, 305-310 (2006).

[12] J. Gawroński, M. Cholewa, J. Szajnar, Aluminium SiC ceramic particles composite, the technology of shape composite production. Computer Aid Design in Composite Material Technology, 321-328 (1994).

[13] J. Gawroński, J. Szajnar, M. Cholewa, T. Wróbel, Krzepnięcie i krystalizacja kompozytów z cząstkami oraz kompozytów powierzchniowych. Przegląd Odlewnictwa **55**, 4, 216-230 (2005).

[14] Z. Konopka, M. Łągiewka, A. Zyska, M. Nadolski, Odlewanie ciśnieniowe kompozytów na osnowie stopów aluminium z cząstkami. „Postępy teorii i praktyki odlewniczej" pod redakcją J. Szajnara, Wyd. PAN, 231-241 Katowice (2009).

[15] J. Ryś, Stereology of materials, Kraków (1995) (in Polish).

[16] K. Rożniatowski, Methods of the arrangement inhomogeneity characterization of the structural elements in multiphase materials. Warszawa: Oficyna Wydawnicza Politechniki Warszawskiej (2008) (in Polish).

[17] A. Pasieka, Z. Konopka, The influence of pressure die casting parameters on distribution of reinforcing particles in the AlSi11/10% SiC composite. Archives of Foundry Engineering **13**, 3, 64-67 (2013).

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