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The Influence of Pressure Die Casting Parameters on the Castability of AlSi11-SiC$_p$ Composites

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Abstract

The paper presents the method of preparing a composite slurry composed of AlSi11 alloy matrix and 10 vol.% of SiC particles, as well as the method of its high-pressure die casting and the measurement results concerning the castability of the obtained composite. Composite castings were produced at various values of the piston velocity in the second stage of injection, diverse intensification pressure values, and various injection gate width values. There were found the regression equations describing the change of castability of the examined composite as a function of pressure die casting process parameters. The conclusion gives the analysis and the interpretation of the obtained results.

Keywords: Composites, Pressure die casting, Castability

1. Introduction

In previous works many different problems concerning AlSi11 matrix composites with SiC particles were presented as: arrangement of reinforcing particles, mechanical properties and tribological properties. Influence of main parameters of pressure die casting technology on these composite properties was described [1-3]. A great deal of metal matrix composites is produced using multi-stage technologies where one of stages consists in producing stable and uniform composite suspension which after matrix solidification turns finally into a composite. Production of stable and uniform composite suspension depends on a set of surface phenomena occurring at the interface between metal and the non-metallic particle, such as wetting, dipping, adhesion, chemical reactions, and diffusion. They are decisive for the strength of bonding between components, as well as for the reinforcement arrangement in the composite volume, which in turn provides for achieving the demanded level of composite material properties. Ceramic particles cause the increase in viscosity of the flowing liquid so the problem of proper filling of the mould or die cavity arise [4-9].

This disadvantageous phenomena can be practically eliminated by employing the pressure die casting method for composite casting production. Then casting parameters can be selected by controlling the injection speed, pressure, and the gate thickness so as to achieve a sound casting containing reinforcing particles uniformly distributed within the matrix [10].

Achieving the high quality of pressure casting depends on the mechanism of filling the die cavity with molten metal [11]. The way of cavity filling is in turn influenced by multiple factors, among which there are the shape and massiveness of a casting, the mass ratio between the casting and the die, the arrangement of the runner and gating system, the shape and the area of the main sprue, the volume of the die cavity, the area and the arrangement of air vents, the injection speed and pressure, and the intensification pressure [12, 13]. Filling of the die and subsequent metal cooling and solidifying strongly depends on such physical properties of cast alloy as its viscosity, solidification range, latent heat of solidification, density, thermal conductivity, and metal temperature, as well as on the die temperature at the moment of pouring [14].

If the pressure die casting technology is applied for particulate composites, the temperature difference between the metal and the die should be kept at the lowest possible level. The best solution here is to increase the die temperature first, and then the metal temperature when the viscosity of metal increases. This means that the pressure casting should proceed at the lowest possible temperature of the cast metal. It is common practice to maintain the casting temperature only slightly exceeding the liquidus temperature, and quite often, if an alloy exhibits wide solidification range, to keep it even below the temperature of crystallization beginning. Casting of composites in the semi-solid state is possible only by means of the cold chamber diecasting machines, because high pressure can be applied during pouring operation. The strongly turbulent flow through the gating system results in intensive suspension mixing, what accompanied by quick solidification in the metal die promotes the uniform distribution of reinforcing particles within the volume of matrix.

The factors limiting the application range of the high-pressure 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.

In modern high-pressure die casting machines the piston velocity in the sleeve is varied during the injection cycle in order to reduce or eliminate gas entrapment in the system and to decrease the porosity of castings. Three stages of piston action are distinguished as a standard, but there are also systems with a continuous change of piston 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 [15-18].

The purpose of the present work is an assessment of the castability in pressure cast composites in relation to the casting parameters.

2. The material and the method of investigations

The composite suspension was prepared by mechanical mixing of the aluminium-silicon foundry alloy AlSi11 (EN AC-44000) and silicon carbide of particle size 71-100 μm. The prepared slurry contained 10 and 20 vol. % of the reinforcing phase. The laboratory stand used for its preparation 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°. 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 to ensure thorough mixing of the whole liquid phase volume and the relatively long lifespan of the mixer itself. The whole mixing system was constructed in such a way that the furnace could be closed after adding all components to the crucible. The mixing time was 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 by means of the cold chamber horizontal pressure die casting machine of 1.6 MN clamping force.

The machine equipped with the pressure multiplication system allowed for controlling the intensification pressure up to the value of the clamping force reduced by the safety range. The injection parameters were measured by means of DMT-200 sensors made by EMTEC Company. The following values were constant during the process: the diameter of pressing piston d_k = 40 mm, the piston velocity in the first stage of injection v_{k1} = 0.3 m/s, the degree of shot sleeve filling (60%), the clamping force N_Z = 1.6 MN, the suspension temperature (650°C), the die temperature (300°C).

The examinations were 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.

Castability sample casting has the following dimensions: width 20mm, length 150mm and varrying thickness from 3 mm at the gate to 0,2 mm at the overflow. Castability sample casting has 15 sections, 10mm in length and different thickness of each section. One castability sample was cast during each shot. Ten shots were performed for each machine setting corresponding to the specific point of the design of experiment. The view of die is presented in Fig.1

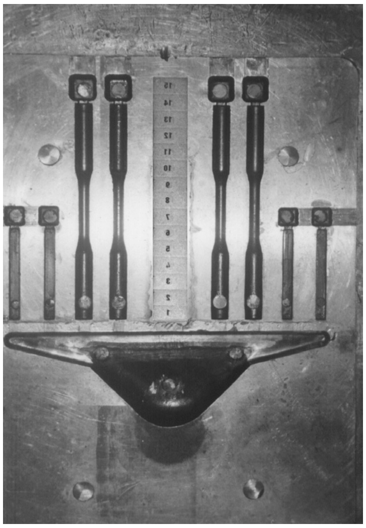

Fig. 1. Die for composites samples

3. Results of investigation

Average results of 10 measurements concerning castability the examined composite for various casting parameters and their variations are presented in Table 1.

Table 1.
Average values of castability obtained for subsequent runs of the experiment

No. of exp.	v_{II} [m/s]	p_{III} [MPa]	d_w [mm]	v_i [m/s]	$\overline{L}$ [mm]	$s^2(L)$ [mm^2]
1	*2*	*3*	*4*	*5*	*6*	*7*
10.1	1.2	20	1.5	50	92.0	12.5
10.2	1.2	40	3.0	25	91.2	8.9
10.3	1.2	20	3.0	25	79.2	14.7
10.4	1.2	40	1.5	50	105.2	10.0
10.5	3.6	40	3.0	75	133.2	8.0
10.6	3.6	20	1.5	150	141.0	7.7
10.7	3.6	40	1.5	150	148.6	11.9
10.8	3.6	20	3.0	75	110.0	6.9
20.1	1.2	20	1.5	50	79.6	18.6
20.2	1.2	40	3.0	25	63.0	20.1
20.3	1.2	20	3.0	25	47.6	15.0
20.4	1.2	40	1.5	50	57.6	16.3
20.5	3.6	40	3.0	75	93.6	12.7
20.6	3.6	20	1.5	150	112.2	19.9
20.7	3.6	40	1.5	150	128.4	22.1
20.8	3.6	20	3.0	75	80.6	17.0

Taking into account the results shown in Table 1 there were derived the regression equations describing the influence of pressure die casting parameters on the castability of the obtained composite castings. These equations take the following form for coded independent variables ($x_1 = v_{II,}$ $x_2 = p_{III}$ and $x_3 = d_w$):

– for the composites containing 10% vol. SiC particles

$$\hat{y}_{10} = 110.7 + 22.5\,x_1 + 5.1\,x_2 - 7.3\,x_3 \tag{1}$$

– for the composites containing 20% vol. SiC particles

$$\hat{y}_{20} = 85.8 + 23.9\,x_1 + 1.8\,x_2 - 14.6\,x_3 \tag{2}$$

To calculate castability values from regression equations independ variables x_1, x_2 and x_3 takes –1,0 and +1 values. Graphic representations of these equations are shown in Figs. 2 and 3. Generally composites containing 20% vol. SiC particles have smaller castability then composites with 10% vol. SiC. Summarized influence of piston velocity in second stage of composite suspension injection into mould and width of gate are represented as a injection velocity v_i. This influence on composite castability was shown in Fig. 4.

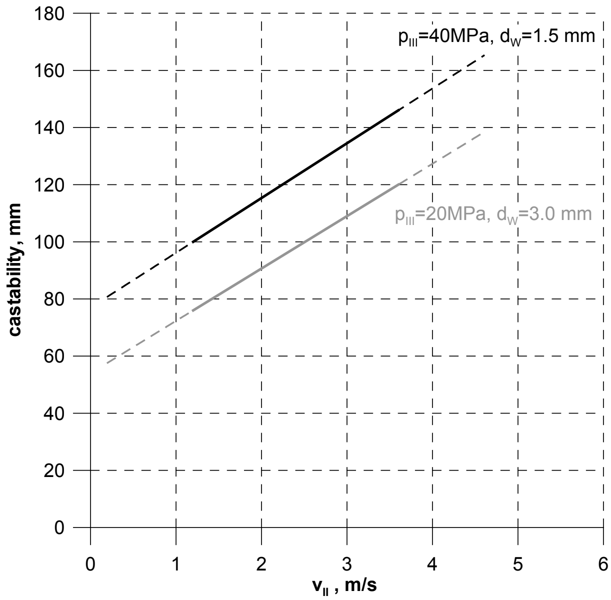

Fig. 2. The dependence of the castability of AlSi11/10 vol.% SiC composite on parameters of pressure die casting process

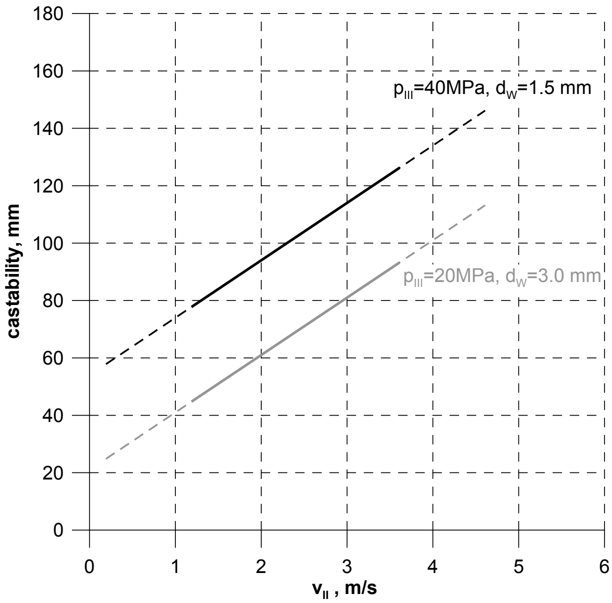

Fig. 3. The dependence of the castability of AlSi11/20 vol.% SiC composite on parameters of pressure die casting process

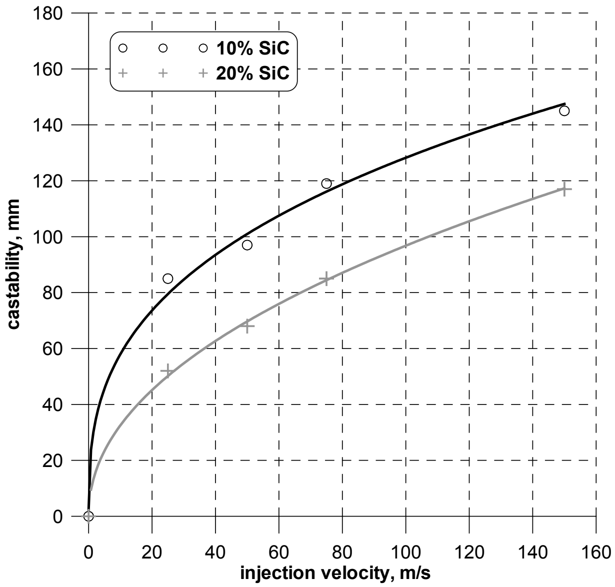

Fig. 4. Influence of injection velocity on composite castability

Above dependences shown in Fig.4 was described by the following equations with coeficient of determination R^2=0.99:

– for composites containing 10% vol SiC particles

$$L_{10} = 26.2\, v^{0.34} \tag{3}$$

– for composites containing 20% vol. SiC particles

$$L_{20} = 10.9\, v^{0.47} \tag{4}$$

Castability and filling of die cavity during injection are two times higher for composites containing 10% vol. SiC particles in comparison with composites with higher volume fraction of SiC particles. Stronger influence of injection velocity on castability is observed in composites with 20% vol. SiC particles (exponent 0.47).

Representative arrangement of SiC particles in composite casting taken from castability samples for 0.5 mm thickness section was presented in Figs. 5 and 6. Examples of arrangement of SiC particles in composite casting with wall thickness 0.2 mm were presented in Figs. 7 and 8.

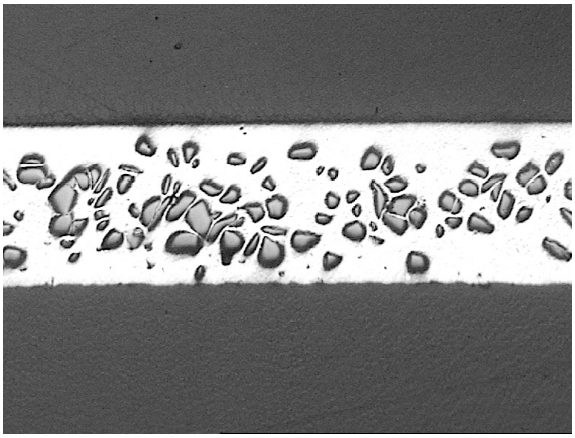

Fig. 5. Arrangement of SiC particles in AlSi11/10 vol.% SiC composite casting (exp. No 10.5)

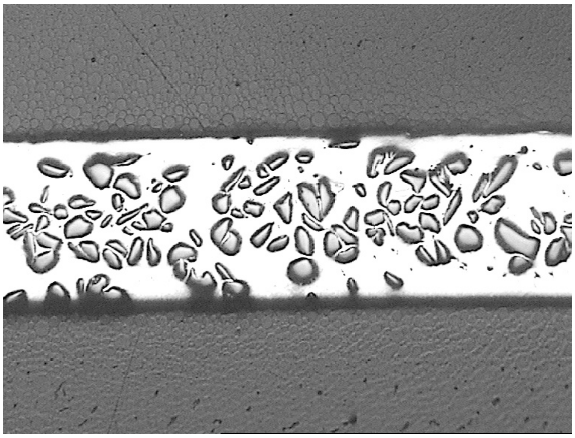

Fig. 6. Arrangement of SiC particles in AlSi11/20 vol.% SiC composite casting (exp. No 20.7)

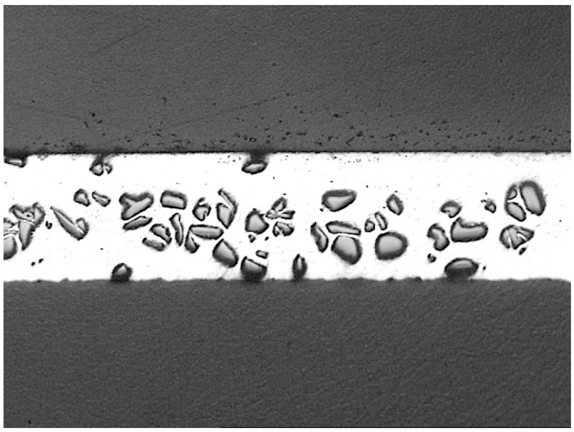

Fig. 7. Arrangement of SiC particles in AlSi11/10 vol.% SiC composite casting, wall thickness 0.2 mm

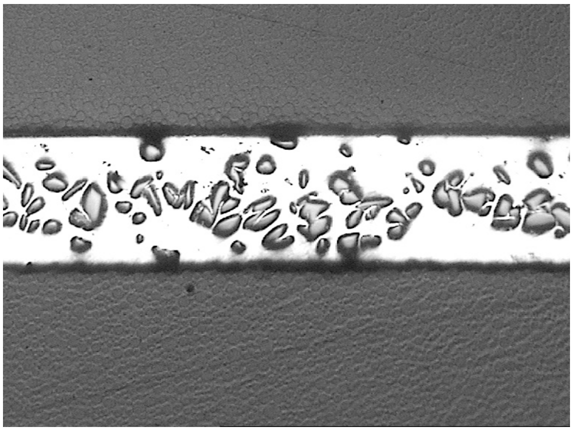

Fig. 8. Arrangement of SiC particles in AlSi11/20 vol.% SiC composite casting wall thickness 0.2 mm

4. Conclusion

Generally the castability of AlSi11 matrix composite reinforced SiC particles decreases with increasing of volume fraction of these particles. It results increasing viscosity of composite suspension and injection velocity decreasing due to higher filling resistance in gate.

Composite suspensions castability and capability of filling the mould cavity are significantly lower than liquid metals due to their much greater viscosity. The calculations of dynamic viscosity coefficient of the AlSi alloy matrix composite suspensions with SiC particles educed 5 times multiple increase of value of this factor at 30% fraction of these particles about the size of a 100 μm [18].

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.

It clearly results from the derived equations that the piston velocity in the second stage of injection influences most significantly the castability of composite castings. An increase in the piston velocity during the mould filling and the reduction of gate area (i.e. thinner gate) result in the increase in cavity filling rate. The increased injection rate is accompanied by the increased castability of composite castings, and the largest increase corresponds to the injection speed of 50 m/s.

The influence of the piston velocity in the second stage of injection on composite castability is a few times stronger then other variables. High filling rates provide for intensive mixing of the slurry at the gate, thus promoting the uniform distribution of reinforcing phase particles and improving properties of castings. However, attention should be paid to the significance of intensification pressure for the improvement of properties of castings. The castings produced under the increased intensification pressure were characterised by higher density than those which solidified under lower pressure. It is characteristic for the improvement that the high intensification pressure increased the density of castings by partial elimination or compressing the unavoidable gas oclusions, thus enlarging the adhesion area at the metal/particle interface. The metal injected under high pressure and then subjected to intensification pressure adheres tightly to the particle, filling its pores and enfolding its projections, by the same contributing to the better test results exhibited by specimens cast under the increased intensification pressure.

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 (Fig.5 and 6).

In the case of yield strength the most significant parameters occurred to be the piston velocity in the second stage of injection and the gate width. The presence of reinforcing phase lowers such characteristics as yield strength and unit elongation, and casting parameters only slightly influence their values. The increased quantity of particles in the volume of a casting results in the reduced unit elongation.

The performed examinations permit to conclude with the following:

- application of high-pressure die casting technology allow to produce complex shape and thin walled castings from composite suspensins of AlSi11/SiC particle
- application of high-pressure die casting technology allow to modify the character of distribution of ceramic particles in the metal matrix and to control properties of the castings;
- main parameters of production process, i.e. the piston velocity in the second stage of injection, the intensification pressure, and the gate width, exert fundamental influence on castability of composite castings;
- the measured values of mechanical properties of the examined composite are characterised by great uniformity, thus confirming the optimum proceeding of the slurry preparation and of the high-pressure die casting process.
- when the volume fraction of reinforced particles in composite matrix increasing the “stronger” gate system in pressure die casting process should be used In this case the intensification pressure can be effectively applied.

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