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The Influence of Pressure Die Casting Parameters on the Mechanical Properties of AlSi11/10 Vol.% SiC Composite

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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 tensile strength, the yield point, the elongation and hardness 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 mechanical properties 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, Mechanical Properties

1. Introduction

Fabrication of composite products is well reasonable for many applications, when composite properties surpass those of the matrix alloy itself. The strengthening of matrix is demanded if mechanical properties are of concern; other properties, e.g. thermal or tribological, are designed in a way providing the achievement of the desired level. The properties of composite materials depend on the properties of their components, fractions of individual constituents, their shape, and the bond strength between them, as well as on the technology of final product. Theoretical considerations indicate that the best properties are achieved by metal matrix composites reinforced with continuous fibre. Introduction of particles into the metal matrix creates wide-ranging possibilities of controlling thermal, chemical, electric, and tribological properties. [1].

Two characteristic strengthening mechanisms are distinguished in particulate composites. One of them is the dispersion strengthening mechanism, being realised when small particles, 0.01÷1.0 μm in diameter, are introduced and uniformly distributed over the material volume. However, when the size of introduced particles exceeds 1 μm, the character of their interaction with the matrix changes and the strengthening mechanism can be qualified as the particle strengthening.

The mechanism of dispersion strengthening of plastic composite matrix consists in arresting the dislocation movement by means of the particles: the dislocation line is first bent by a particle, then the dislocation loop is formed. This increases the yield point value the more the shorter is the average distance between particles [2].

The composite yield point value decreases parabolically as a function of the average distance between particles, i.e. with the reduction of reinforcing phase fraction. A composite strengthening is achieved when the average distance between particles falls between 0.01 and 0.3 μm, which corresponds to the volume fraction of the particles $V_P = 1 \div 20\%$ [3].

The main advantage of dispersion strengthening is not the increased strength at ambient temperature, but the high creeping resistance of the resulting material. Such composites can retain their improved mechanical properties up to the temperature of about 80% of the melting point value [4].

As far as composites containing larger particles are concerned, their ability to bear a load is enhanced not only by arresting of dislocation movement, but also by the occurrence of shearing and slipping inside the particles. However, the yield point value decreases with an increase in particle size [5].

Composite suspensions are characterised by much greater viscosity than liquid metals, therefore their castability and capability of filling the mould cavity is significantly lower. As a result, the production of castings made of such slurries is only possible when casting technologies applying the forced filling of the mould cavity are involved. The high-pressure die casting seems to be the most suitable technology for the production of metal composite castings [6, 7].

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.

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 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 [8-10].

As far as particulate 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 reinforcing phase can be distributed uniformly or non-uniformly; in this latter case they occupy the intergranular regions in most 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, 12].

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 98C silicon carbide of particle size 71-100 μm. The prepared slurry contained 10 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.

Four tensile specimens of gauge diameter of 6 mm and gauge length equal to 130 mm were cast during each shot [3]. Twenty five shots were performed for each machine setting corresponding to the specific point of the design of experiment, so that 100 specimens for static tensile test were produced. Such a large number of castings was necessary in order to achieve and to hold the thermal equilibrium of the die, so that the castings were made under stable and recurrent conditions. The obtained specimens did not require machining.

All mechanical parameters were determined during the tensile test performed according to the PN-EN ISO 6892-1:2010 standard by means of computer controlled Zwick 1488 tensile tester at the following parameters: initial stress equal to 1 MPa, crosshead velocity of 7 mm/min, force capacity – 10 kN. Relevant graphs were recorded during the tensile tests.

3. Results of investigation

Average results of 100 measurements concerning tensile strength, yield point, unit elongation and hardness of the examined composite for various casting parameters are presented in Table 1, while Table 2 shows the values of standard deviations of these measurements.

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

No. of exp.	v_{II} [m/s]	p_{III} [MPa]	d_w [mm]	R_m [MPa]	$R_{0.2}$ [MPa]	A_c [%]
1	*2*	*3*	*4*	*5*	*6*	*7*
1	1.2	20	1.5	229.4	213.0	1.44
2	1.2	40	3.0	246.0	196.4	1.41
3	1.2	20	3.0	219.2	183.8	0.98
4	1.2	40	1.5	275.8	226.8	1.64
5	3.6	40	3.0	281.2	224.6	1.57
6	3.6	20	1.5	276.2	225.0	1.63
7	3.6	40	1.5	298.0	235.6	1.91
8	3.6	20	3.0	272.6	218.6	1.45

Table 2.
Standard deviations of the measured values of mechanical properties of the examined composite

No. of exp.	v_{II}, m/s	p_{III}, MPa	d_w, mm	S_{Rm} MPa	S_{R02} MPa	S_{Ac} %
1	*2*	*3*	*4*	*5*	*6*	*7*
1	1.2	20	1.5	7.7	11.0	0.13
2	1.2	40	3.0	9.0	9.6	0.17
3	1.2	20	3.0	13.8	12.2	0.08
4	1.2	40	1.5	10.1	8.8	0.25
5	3.6	40	3.0	9.5	10.6	0.17
6	3.6	20	1.5	7.4	6.0	0.23
7	3.6	40	1.5	5.9	6.6	0.11
8	3.6	20	3.0	8.8	9.9	0.16

Taking into account the results shown in Tables 1 and 2, there were derived the regression equations describing the influence of pressure die casting parameters on the mechanical properties 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 tensile strength

$$\hat{y}_{10} = 262.30 + 19.70x_1 + 12.95x_2 - 7.55x_3 \quad (1)$$

– for the yield point

$$\hat{y}_{10} = 215.4750 + 10.4750x_1 + 5.37500x_2 - 9.6250x_3 - 5.2750x_1x_3 \quad (2)$$

– for the unit elongation

$$\hat{y}_{10} = 1.5035 + 0.1370x_1 + 0.1300x_2 - 0.1500x_3 \quad (3)$$

Graphic representations of these equations are shown in Figs. 1-3.

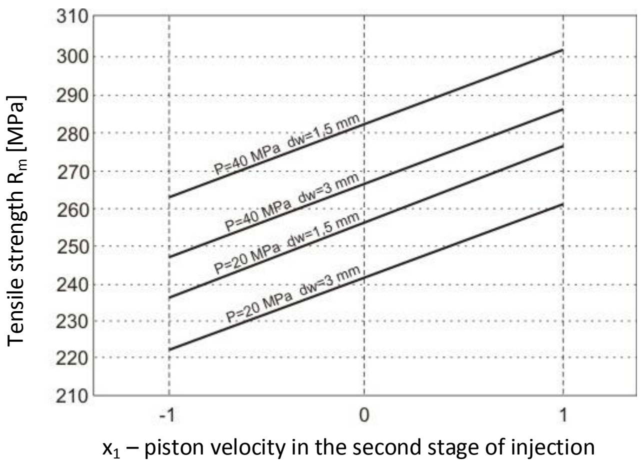

Fig. 1. The dependence of the tensile strength of AlSi11/10 vol.% SiC composite on parameters of pressure die casting process

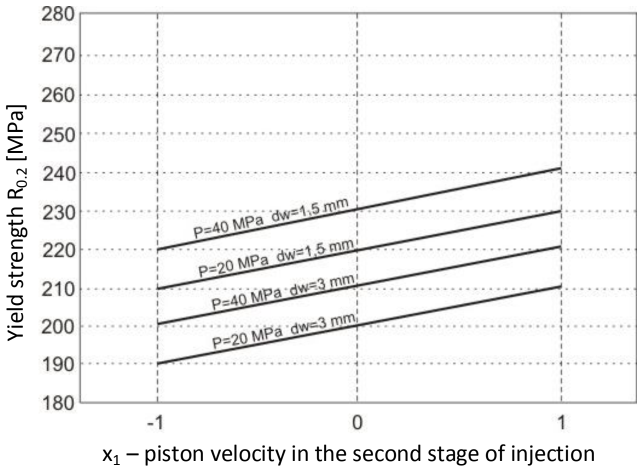

Fig. 2. The dependence of the yield strength of AlSi11/10 vol.% SiC composite on parameters of pressure die casting process

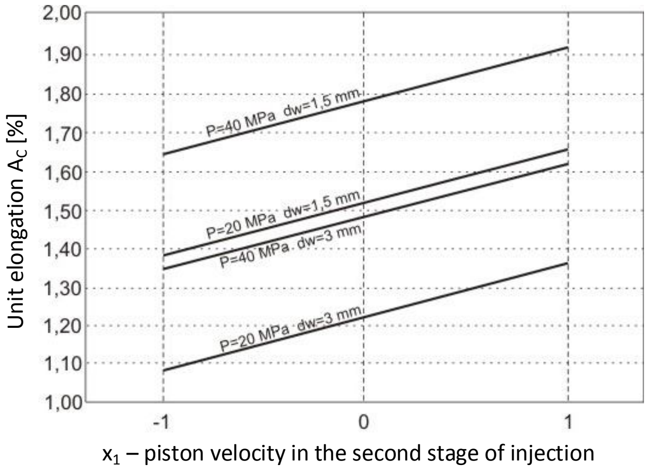

Fig. 3. The dependence of the unit elongation of AlSi11/10 vol.% SiC composite on parameters of pressure die casting process

4. Conclusion

It results clearly from the derived equations that the piston velocity in the second stage of injection influences most significantly the mechanical properties 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 tensile strength of composite castings, and the largest increase corresponds to the injection speed of 50 m/s.

High filling rates provide for intensive mixing of the slurry at the gate, thus promoting the uniform distribution of reinforcing phase particles [9] and improving the mechanical properties of castings. However, attention should be paid to the significance of intensification pressure for the improvement of mechanical properties of castings. The castings produced under the increased intensification pressure were characterised by higher strength 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.

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 AlSi11 alloy used for the purpose of experiment exhibits unit elongation of about 3%. After the introduction of 10 vol.% of particles, however, the elongation was reduced by half as an average, the results falling within the range 0.98÷1.91%.

The value of unit elongation was influenced, similarly as R_m or $R_{0.2}$, by the applied pressure die casting parameters. Comparable absolute values of regression coefficients in Eq. 3 indicate the equivalent power of affecting the results exhibited by all three considered parameters. Still, the most significant occurred to be the gate width, then the piston velocity, and only then the intensification pressure. Due to the presence of brittle ceramic particles the composite almost does not deform plastically, but brittle cracks along the weak adhesive bonding between metal and ceramics.

The significant changes in mechanical properties of the pressure die cast composites result – on the one hand – from the possibility of controlling the distribution of reinforcing phase within the matrix, and on the other hand – from the compaction of castings due to the intensification pressure, which eliminates porosity to a remarkable degree.

The performed examinations permit to conclude with the following:

– application of high-pressure die casting technology to the production of AlSi11/SiC composite castings allow to modify the character of distribution of ceramic particles in the metal matrix and to control mechanical properties of the material;
– 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 mechanical properties 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.

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