

Tribological Properties of AlSi11-SiC_p Composite Castings Produced by Pressure Die Casting Method

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Abstract

The measurement results concerning the abrasive wear of AlSi11-SiC particles composites are presented in paper. The method of preparing a composite slurry composed of AlSi11 alloy matrix and 10, 20% vol.% of SiC particles, as well as the method of its high-pressure die casting was described. Composite slurry was injected into metal mould of cold chamber pressure die cast machine and 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. Very good uniform arrangement of SiC particles in volume composite matrix was observed and these results were published early in this journal. The kinetics of abrasive wear and correlation with SiC particles arrangement in composite matrix were presented. Better wear resistance of composite was observed in comparison with aluminium alloy. Very strong linear correlation between abrasive wear and particle arrangement was observed. The conclusion gives the analysis and the interpretation of the obtained results.

Keywords: Composites, Pressure die casting, Tribological properties

1. Introduction

The aluminium alloy matrix composites containing hard SiC particles offer very good tribological properties such as very good wear resistance and high coefficient of friction. These properties depend largely on the uniformity distribution of particles in composite matrix, good bonding between reinforcing phase and matrix as well as casting defects. Very good abrasive properties can be obtained at high volume fraction, up to 30% of hard SiC particles but viscosity of composite suspension increases and fluidity is lost [1-3].

The rate of abrasive wear of composites grows rapidly if the hardness of abrading particles is by at least 20% greater than the hardness of the abraded surface [4]. Large and angular particles cause greater composite wear than the small and rounded ones.

Introducing larger volume fraction of particles is more beneficial than increasing their size [5]. Significantly less matrix material loss occur if there exist a strong bonding between the ceramic particles and the matrix. Frequently the pushing-in of hard particles e.g. silicon carbide into the soft aluminium alloy matrix is observed during the abrasion process. This phenomenon, however, should not affect negatively the increase of abrasion resistance of composites. This process can first of all result in matrix strengthening within microregions directly beneath the carbide. Such strengthened regions stop ceramic particles from being further pushed into the matrix [6,7]. Mechanisms of wear comprise also plastic flow and cracking. Increasing material hardness would reduce the plastic flow, but then the danger of cracking can grow. The fracture toughness should also be taken into account while abrasive wear of composite material is

concerned. The high material hardness should be composed with the high fracture toughness to achieve a metal matrix composite of the best abrasion resistance. A dangerous phenomenon occurring in metal matrix composites during abrasion is the process of pullout of the reinforcing particles. It results mainly from the interaction at the particle/matrix interface. This phenomenon brings about the rapid increase in abrasive wear of composites and can lead to the severe destruction of the abraded surfaces.

Particulate reinforced metal matrix composites can be effectively fabricated by pressure die casting method. This method has a few essential advantages in comparison with other technique. Uniform distribution of nonmetallic particles can be achieved as a consequence very fast pouring, intensive mixing in a chamber of machine and higher cooling rates during solidification. In this conditions the effects of quite poor wettability and poor particle-matrix interfacial bonding are less important. When the pressure die casting of composite slurry is used the heat release of die and risk of blown castings production are lower [8,9].

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 formula.

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 [10-12].

2. Material and methodology

The composite suspension was prepared by mechanical mixing of the aluminium-silicon foundry alloy AISI11 (EN AC-44000) and 98C silicon carbide of particle size 71-100 μm . The

prepared slurries 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 2³ type of design of experiment, where the variable factors were: the piston velocity in the second stage of injection (v_{k2}), taking the values of 1.2 or 3.6 m/s, the intensification pressure (p_{II}), being 20 or 40 MPa, and the gate width (d_w) equal to 1.5 or 3 mm.

Examination of tribological properties for the produced composites has been performed by means of a T-05 tribological tester. This testing device is intended for examining abrasion resistance of metals and plastics and for examining of seizing resistance of low friction coatings. Fig. 1 schematically illustrates the principle of operation of the T-05 wear tester.

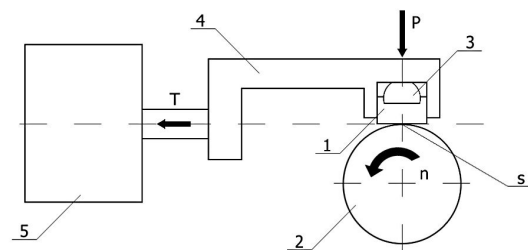


Fig. 1. Principle of operation of the T-05 tester; 1 – specimen, 2 – counter surface, 3 – spherical pivot, 4 – specimen fixture, 5 – tensometric bridge

Examination has been done by measuring the composite specimen mass loss corresponding to the specified wear path at the following characteristic parameters: specimen load – 50 N, total wear path – 3630 m, motion type – sliding with constant velocity of 0,4 m/s, specimen type – flat cubicoidal specimen of dimensions 10.00×15.75×6.35 mm with concentrated contact area.

Measurements have been taken after every 330 m of wear path during first stage of sliding to examine precisely the kinetics of abrasion and 660 m during final stage of sliding. The weight of specimens has been determined by means of a laboratory scales with 0.00001 g accuracy. Composite casting was shown in Fig. 2.



Fig. 2. Composite castings for mechanical and tribological investigations

The parameters of pressure die casting of composites according to the 2³ type of design of experiment were presented in Table 1. First serie of experiments was designed as 10.1-10.8 for composites containing 10% SiC particles and second serie as 20.1-20.8 for composite containing 20% SiC particles.

Table 1. Parameters of pressure die casting of composites

No. of exp.	V _{II} [m/s]	P _{III} [MPa]	d _w [mm]
1	1.2	20	1.5
2	1.2	40	3.0
3	1.2	20	3.0
4	1.2	40	1.5
5	3.6	40	3.0
6	3.6	20	1.5
7	3.6	40	1.5
8	3.6	20	3.0

3. Results of investigation

Examples of reinforcing particles arrangement in composite matrix were presented in Fig. 3, 4 and Fig. 5.

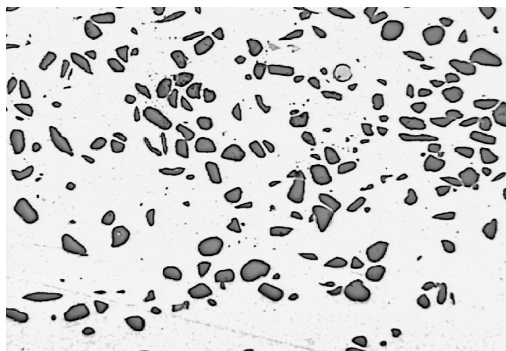


Fig. 3. Arrangement of SiC particles in composite matrix (AlSi11/10 vol.% SiC, experiment no. 10.7)

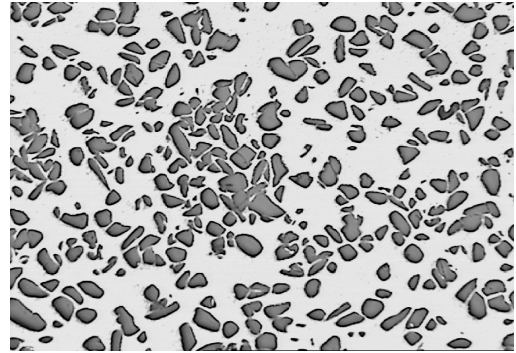


Fig. 4. Arrangement of SiC particles in composite matrix (AlSi11/20 vol.% SiC, experiment no. 20.7)

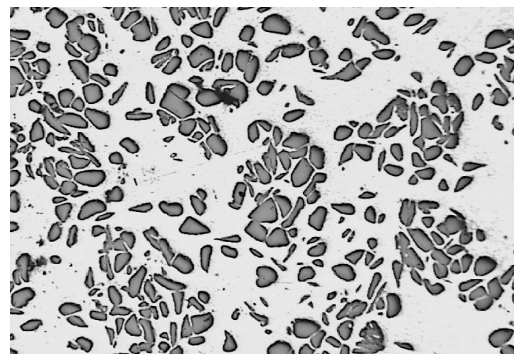


Fig. 5. Non uniform arrangement of SiC particles in composite matrix (AlSi11/20 vol.% SiC, experiment no. 20.3)

The distribution of SiC particles in composites is exemplified for the extreme values of v index which is calculated as ratio of standard deviation of the average quantity of particles over the unit surface area and the average quantity of particles over the unit surface area [mm⁻²].

The v 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 [13].

Figure 5 shows clustering of SiC particles formed during composite slurry fabrication. The main problem in achieving the uniform arrangement of ceramic particles in the metal matrix is that there occur difficulties in obtaining proper bonding between metal matrix and the particles because the latter are poorly wettable by liquid metal. The wettability of components can be improved by surface preparation of particles or by liquid metal modification. The non-uniform arrangement of reinforcing particles in the matrix can be caused by sinking down or floating up of the particles during composite flow. Frequently such a phenomenon occurs during gravity casting of composite suspensions. The arrangement of particles is also influenced by the crystallization process, during which the particles can be engulfed or pushed out by the moving crystallization front what finally results in placing them within interdendritic areas. Ceramic particles cause the increase in viscosity of the flowing liquid so the problem of proper filling of the mould or die cavity arise. 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 results of the abrasive wear of examined composites were presented in Table 2.

Table 2.
The abrasion wear of AlSi11-SiC_p composites

No. of exp	v	Mass loss, g·10 ⁻⁴ g on sliding distance, m						
		330	660	990	1650	2310	2970	3630
AlSi11	-	32	67	102	139	169	203	242
10.1	0.32	9	18	32	70	99	128	154
10.2	0.67	14	26	43	70	100	128	155
10.3	0.87	19	38	58	100	137	163	187
10.4	0.27	13	30	38	66	95	117	151
10.5	0.29	10	24	31	39	95	125	149
10.6	0.25	11	20	32	62	88	113	143
10.7	0.19	13	26	40	64	100	121	142
10.8	0.28	17	31	48	83	110	133	153
20.1	0.28	9	38	27	69	94	112	128
20.2	0.47	20	29	39	65	85	105	131
20.3	0.65	12	22	28	48	72	98	122
20.4	0.26	21	35	49	74	103	120	127
20.5	0.18	13	28	43	63	81	89	99
20.6	0.20	14	27	44	63	82	91	102
20.7	0.15	12	20	23	36	48	62	74
20.8	0.23	18	30	46	63	83	101	118

The kinetics of abrasion wear examples for composite castings obtained in extremally different pressure die casting conditions were presented in Fig. 6 and 7.

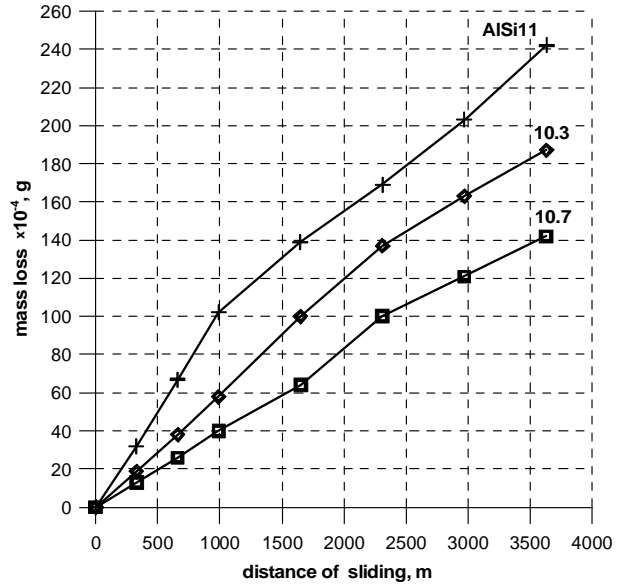


Fig. 6. The abrasion wear of AlSi11/10 vol.% SiC composite

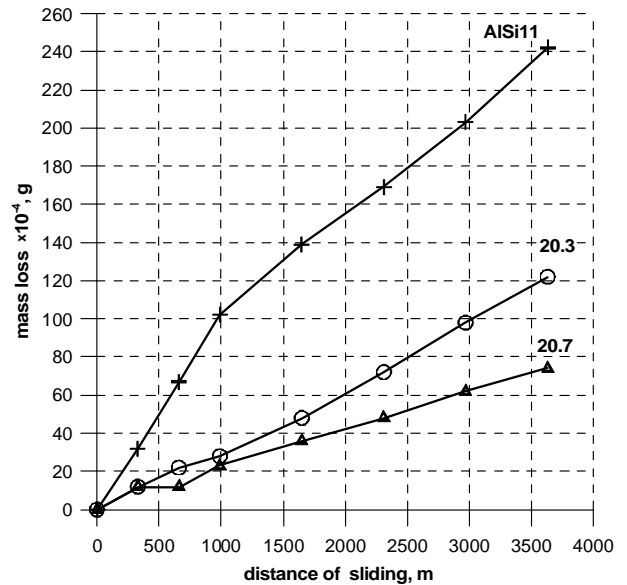


Fig. 7. The abrasion wear of AlSi11/20 vol.% SiC composite

Dependence between SiC particles arrangement in composite matrix (index v) and mass loss of samples during sliding test was presented in Fig. 8

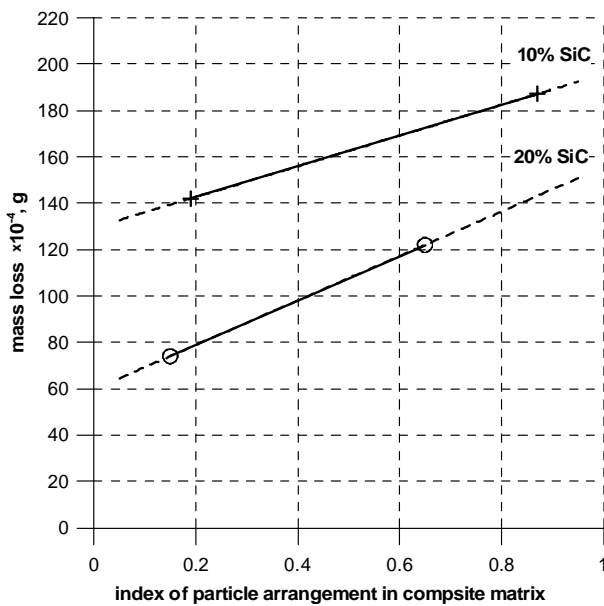


Fig. 8. The dependence of the abrasive wear of AlSi11- SiC_p composite on reinforcing particle arrangement in matrix.

4. Conclusion

The properly selected parameters of production of the AlSi11-SiC_p composites have allowed for obtaining the composites of the expected structure (Figs 3 and 4). Exemplary microstructures of examined composites show the uniform distribution of particles within the matrix volume, with neither particle clusters, though otherwise characteristic for particulate composites, nor porosity, nor non-metallic inclusions.

Examination of abrasion wear of the AlSi11-SiC_p composites containing different volume fraction of reinforcing particles confirms very strong dependence between casting parameters, composite structure and their tribological properties. Composites with AlSi alloy matrix reinforced with hard, material-strengthening SiC particles has proved to be really the materials of high wear resistance. Relationships illustrated in Fig. 5 have allowed for stating that composites of AlSi11 alloy reinforced with silicon carbide exhibit less abrasion wear than the examined pure AlSi11 matrix alloy. It has been also observed that the less abrasion wear occurs when the percentage of silicon carbide increases.

Very good wear resistance of examined composites results from the influence of SiC particles on the composite hardness. For example the addition of 10 vol. % SiC has caused the increase in hardness by about 20%. It can be generally stated that the hardness decreases with an increase of the abrasion wear.

In case of the pressure casting of composites it is possible also to use the characteristic positive properties of composite suspension that is a rheocast structure. This structure is created as

a result of partial solidification of alloy after nonmetallic particles addition. The composite suspension is poured off then as a variant of casting in the liquid-solid state. Filling of cavity die can take place considerably more freely, what remedies the terms of its form ventilation to this degree, that of castings making without gas porosity is possible. Such situation required of large runners application, reduction of injection velocity and increase of intensification pressure, that can effectively influence on solidification of casting and its high condensing. The receipt of the correct casting contacts thus with optimization of parameters of casting of such composite reinforced different particles.

The analysis of composite microstructures shows that the uniformity of the reinforcing phase distribution was indeed influenced by the variable parameters of casting process. It was noticed that the low values of parameters support the non-uniform arrangement or even generation of particle clusters in the composite suspension.

A strong influence of both the piston velocity in the second stage of injection and the intensification pressure on the distribution of particles within the metal matrix was observed. An increase in each of these parameters results in the increase in the uniformity of distribution of the SiC particles in the matrix. The influence of gate width is of minor significance for the improvement of the uniformity of reinforcing phase distribution.

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 confirmed.

The abrasion wear of composites depends on uniformity arrangement of SiC particles in composite matrix and volume fraction of these particles. Abrasion wear of AlSi11-10%SiC with non uniform arrangement of reinforcing phase ($v=0.87$) was 19% lower in comparison with AlSi11 alloy and about 42% lower for composites with uniform distribution of SiC particles ($v=0.19$).

Abrasion wear of AlSi11-20%SiC with non uniform arrangement of reinforcing phase ($v=0.65$) was 34% lower in comparison with AlSi11 alloy and about 63% lower for composites with uniform distribution of SiC particles ($v=0.15$).

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