

**SELECTED THE CASTING PROPERTIES OF THE COMPOSITES AlMg10+C<sub>gr</sub>**

The paper is a review of the previous investigations concerning the influence of graphite particles both on the casting properties of metal matrix composites (MMCs). The work presents the examination results of casting properties (i.e. castability and shrinkage) of the MMCs with matrices of a selected aluminium alloy reinforced with graphite particles. There is also presented the influence of graphite particles on the surface tension and viscosity of the flowing and filling the mould composite suspension. The suspensions containing various percentages of graphite particles (namely 5%, 10%, or 15% in volume) were prepared in order to perform the above mentioned examinations. Castability (fluidity) of these suspensions was measured in two ways, i.e. by means of both the spiral test and the rod test, while their shrinkage was determined with the use of a device designed and assembled in the Department of Foundry Engineering, CUT. The device enables to determine changes in the length of a casting during its solidification with respect to the specified length of the test rod. The surface tension was determined by the wedge casting method consisting in the pouring of metal into an open shell mould with the cavity of wedge geometry, the sharp edge being perpendicular to the free metal surface. The change in viscosity corresponding to the change in graphite particles percentage was calculated from Einstein's equation. The results of examinations show that the introduction of reinforcing graphite particles results in both a significant increase in the viscosity of the flowing suspension and a considerable decrease in its castability. The greater dimensional stability of castings was observed, i.e. the shrinkage of composite castings was smaller than the shrinkage of matrix alloy itself. An increase in surface tension index value with an increase in volume percentage of graphite particles in composite was also noticed.

*Keywords:* aluminium alloys, metal composites, graphite particles, castability, surface tension

**1. Introduction**

Production of metal matrix composite castings reinforced with ceramic particles involves many processes and is influenced by various factors. The most important processes are: introduction of particles into the metal matrix along with their uniform distribution, as well as generation of the final permanent bond between the particles and the matrix. The processes resulting in the final casting of good quality are strongly related to the phenomenon of wetting the particles with liquid metal matrix, while the wetting itself is influenced by physical, chemical, and thermodynamic factors. The main problem in obtaining the strong bonding in particulate MMCs is that the ceramic particles either are completely non-wettable substances or exhibit only poor wettability by the liquid matrix alloy [1,2]. This problem is often tried to be solved either by modification of the matrix alloy or by coating the non-wettable particles with a layer of metal or salt, or another compound [3-5]. Sometimes the reinforcement is held in high temperature in order to either generate or disintegrate certain compounds at the surface of particles [6-8] thus achieving surface activation and the enhanced wetting [9-11]. The wetting phenomenon influences also the arrangement of particles during

the preparation of composite suspension, as well as their sinking down or floating up both in the ladle and during the mould filling process. The phenomena of sinking down/floating up proceed uninterrupted from the moment of pouring the suspension into the mould till the solidification of the composite and therefore they can result in a considerable non-uniformity of the final structure. They are affected not only by wetting properties, but also by the temperature and the viscosity of the produced suspension.

One of the important casting properties of a metal is its castability in the aspect of fluidity. This property depends upon a series of factors including not only the characteristics of molten metal, such as chemical composition, viscosity, surface tension, oxide and gas content, but also the properties of the mould and the casting conditions [12-15]. Fluidity is a measure of both internal and external flow resistance. The internal friction is characterised by the coefficient of viscosity, therefore an increase in the alloy viscosity results in a decrease in its fluidity and castability. The external resistance is a measure of interaction between the flowing metal surface and the walls of the mould, therefore it depends on the metal surface tension and the wetting angle between the mould wall and the liquid metal [13]. Surface tension exerts a significant influence on metal castability, especially in very

\* CZĘSTOCHOWA UNIVERSITY OF TECHNOLOGY, THE FACULTY OF PRODUCTION ENGINEERING AND MATERIALS TECHNOLOGY, 19 ARMII KRAJOWEJ AV., 42-200 CZĘSTOCHOWA, POLAND

# Corresponding author: cis@wip.pcz.pl

thin channels [13,14]. Fluidity and surface tension become of particular importance with respect to cast metal matrix composites, and one of the reasons is that the mixture flowing in mould channels is a solid-liquid one, often composed mainly of the readily oxidizable matrix alloy (e.g. Al, Mg). In such a system, the wetting phenomena can be strongly affected by the oxide layer forming at the composite stream front, which increases the capillary pressure counteracting the flow [16].

Other very important casting property is undoubtedly the shrinkage [17]. Shrinkage is influenced by a series of factors such as chemical composition of the matrix, the overheating or pouring temperature, factors restricting the free shrinkage, and the mould technology [13,15]. One should know the characteristics of material shrinkage over the whole range of solidification and cooling temperature to produce a sound metal or composite casting [18]. The shrinkage of composite materials is interesting insofar as the properties of components (e.g. the coefficient of thermal expansion) can be quite different, and the resulting behaviour of the new material is often not a result of simply averaging the properties of individual components, but is specific to this particular composite. The requirements which are to be met by composite materials are often very high since these materials are willingly applied in machines and devices working at the elevated temperature. Such materials should therefore exhibit low coefficient of thermal expansion and low shrinkage [19], so the studies concerning the shrinkage phenomena in composite materials are of importance.

## 2. Methodology and the results of examinations

The influence of graphite particles on the selected casting properties was investigated by performing measurements and calculations with respect to the following properties: viscosity, castability (fluidity), surface tension, and the shrinkage of the material. To do this, a series of AlMg10 alloy metal matrix composites reinforced with graphite particles of average size equal to 100  $\mu\text{m}$  were prepared. Composite mixtures were produced by mechanical mixing of liquid matrix alloy with simultaneous introduction of particles. The volume percentages of graphite particles were 5% $C_{gr}$ , 10% $C_{gr}$ , or 15% $C_{gr}$ . The pure AlMg10 matrix was also examined for the purpose of comparison. The fluidity of suspensions and matrix alloy was measured both by spiral test and by rod test. The spiral test was performed in bentonite bonded green sand mould, and the measure of fluidity was the length of the achieved spiral casting. The rod test was carried out in metal mould with straight horizontal channel of 7 mm diameter. Surface tension was examined by the static method of wedge casting. The method consist in pouring the examined material into an open shell mould of wedge-shaped cavity, the sharp edge of it being arranged perpendicularly to the free metal surface. The measure of surface tension was the distance between the tip of the casting at its sharp edge and the corresponding tip of the theoretical triangle circumscribed upon the wedge section. The test mould is shown in Fig. 1.

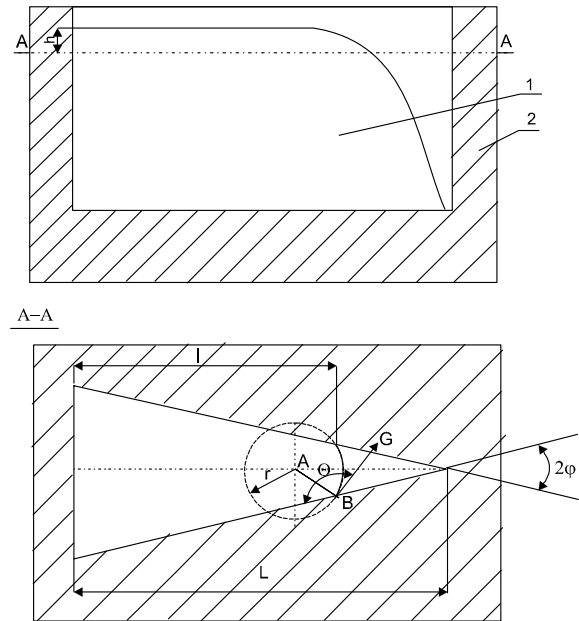


Fig. 1. The wedge test for measuring the surface tension coefficient (1 – wedge casting, 2 – mould)

The coefficient of surface tension was determined from the force equilibrium equation according to a formula [20]:

$$\sigma = \frac{1}{2} \cdot \frac{(L-l) \cdot \rho \cdot g \cdot h}{1 - \frac{\cos \Theta}{\sin \varphi}} \quad (1)$$

where:  $\sigma$  – coefficient of surface tension,  $\rho$  – density of the liquid metal,  $g$  – acceleration of gravity,  $h$  – height of metal column above the considered location (the depth from the metal-gas interface),  $l$  – the length of the wedge section filled with metal at the depth  $h$  from the upper free metal surface,  $L$  – the total length of wedge-shaped cavity,  $\Theta$  – the angle between the wedge side plane and the free metal surface at the considered location (wetting angle),  $\varphi$  – the angle between the side planes of the wedge.

The shrinkage was examined by means of a device presented in Fig. 2. Its principle of operation is that a test specimen in the form of a cylinder, 20 mm in diameter and 200 mm in length, is cast in a special mould, and the changes in its length during its solidification and cooling induce the changes in position of the plunger of the inductive sensor. The applied system makes possible taking the shrinkage measurements for a definite measuring length of the cylinder specimen.

The suspension pouring temperature was equal to 700°C for each of the tests, i.e. the fluidity, the surface tension, and the shrinkage tests.

While examining the flow of a composite suspension, one should take into account the influence of graphite particles on its viscosity. The viscosity of a suspension depends on the volume percentage of the suspended particles, their size, the suspension temperature, and the complex phenomenon of surface interaction between the particles and the liquid. The effect of volume percentage of graphite particles on the dy-

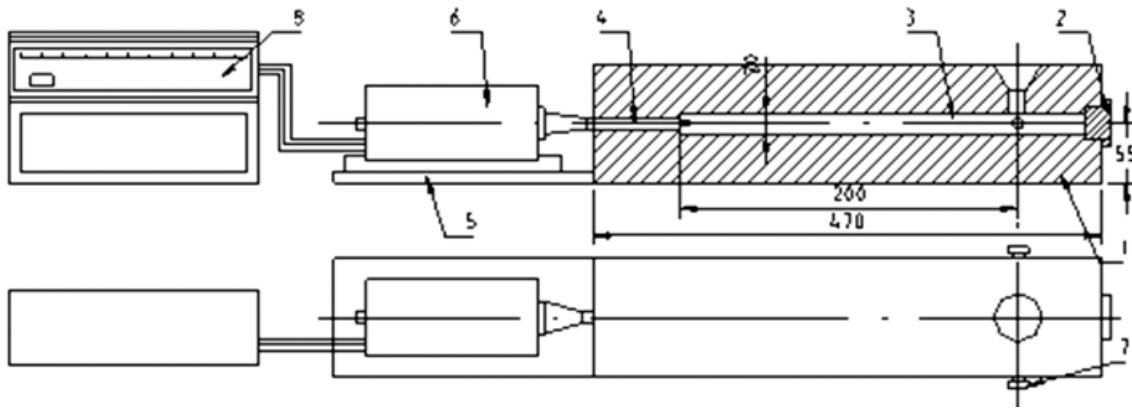


Fig. 2. Device for linear contraction examination: 1 – mould, 2 – mould closure, 3 – casting, 4 – fastening rod, 5 – base of gauge, 6 – induction gauge, 7 – clamping screws, 8 – contraction register

dynamic viscosity of a suspension is described by the well known Einstein's equation:

$$\eta_k = \eta_o \cdot (1 + 2.5V_p + 10.25V_p^2) \quad (2)$$

where:  $\eta_k$  – viscosity of composite suspension,  $\eta_o$  – viscosity of the matrix alloy,  $V_p$  – volume fraction of particles.

From this equation, the viscosity of the examined composite suspension was calculated at a temperature of 700°C, i.e. without taking into account the solidification of the material. The results of calculation are presented in Fig. 3.

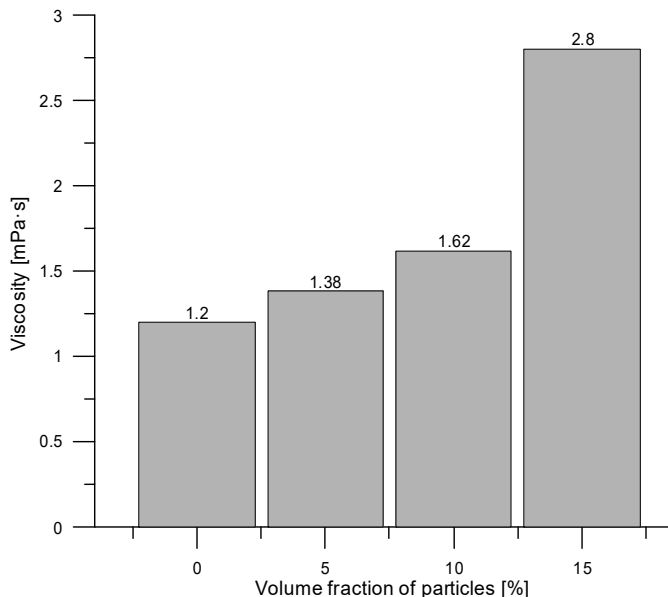


Fig. 3. Changes in the dynamic viscosity with an increase in volume percentage of graphite particles

Figure 3 clearly indicate that the viscosity of the composite suspension increases with an increase in volume percentage of graphite particles. The viscosity calculated according to the above equation takes into account volume percentage of the introduced particles, but not their type (size, density). But also the size of particles significantly influences the suspension flow. If a suspension contains small particles (up to about 100  $\mu\text{m}$  in

size), it behaves as a uniform liquid, within which the velocity of particles is equal to the velocity of the matrix alloy. However, if the reinforcing particles are of greater size, the viscosity of a system largely increases, as the particles not only move forward, but also rotate [20]. As far as the shape of particles is concerned, more intricate shapes involve an increase in total surface of particles, thus contributing to the increase in viscosity. The examined composites contained flake graphite of highly developed surface, therefore it can be supposed that the real viscosity of the examined composite suspension could be greater than the value resulting from the above presented equation.

Metallographic specimens were cut out of the rods cast during the fluidity test in order to determine the uniformity of the graphite particle arrangement within the matrix alloy volume. An exemplary microstructure of composite containing 15% of graphite particles is presented in Figure 4.



Fig. 4. Microstructure of AlMg10/ 15% $C_{gr}$  composite of AlMg10 matrix alloy composite reinforced with 15% of graphite particles

Microstructure of the composite presented in Fig. 4 exhibits the uniform distribution of graphite particles within the volume of matrix alloy. The characteristic defects of composite materials, such as non-metallic inclusions or shrinkage, were not observed. This confirms that the production technology was properly chosen with respect to the examined materials.

The results of measurements of the suspension fluidity, the values describing geometry of the wedge test specimen, and the calculated values of surface tension are presented in Table 1. Figure 5 presents an exemplary view of the tip of the composite specimen cut out of a wedge test casting along the A-A plane indicated in Fig. 1, and the graphical representation of the influence of graphite reinforcement percentage on the investigated composite suspension properties is shown in Figs. 6 and 7.

TABLE 1

Fluidity, geometry of the wedge test specimen, and the surface tension – average of three measurements

Fraction of graphite particles [%]	Fluidity in the spiral test [m]	Fluidity in the rod test [m]	Geometry of the wedge test specimen			Surface tension $\sigma$ [mN/m]
			Distance $L-1$ [ $m \times 10^{-3}$ ]	Height $h$ [ $m \times 10^{-3}$ ]	Radius $r$ [ $m \times 10^{-3}$ ]	
0	1.22	0.30	6.40	15	4.15	794
5	1.20	0.27	7.50	15	4.58	877
10	0.72	0.24	9.00	15	5.50	1053
15	0.42	0.12	9.95	15	5.94	1137

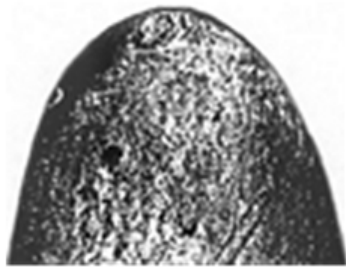


Fig. 5. View of curved surface after composite solidification (wedge section)

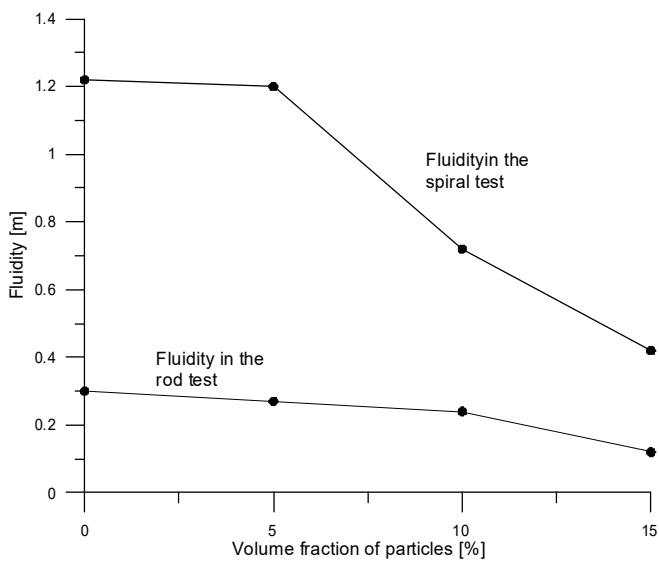


Fig. 6. The effect of graphite particles on fluidity of the AlMg10/C<sub>gr</sub> composite suspension – spiral and bar tests

The results of performed examination presented in Figs. 6 and 7 clearly indicate that the fluidity decreases significantly

as the percentage of graphite in composite suspension rises, and in the same time the coefficient of surface tension exhibit a considerable increase.

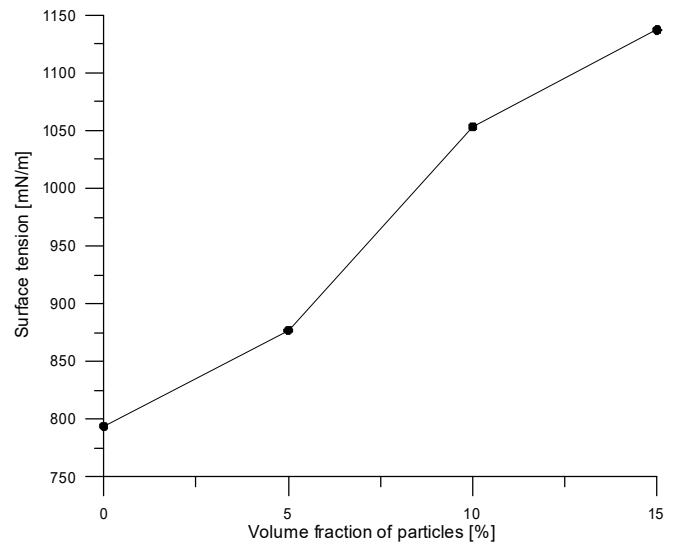


Fig. 7. The effect of graphite particles on the surface tension coefficient of the AlMg10/C<sub>gr</sub> composite suspension

The data from the linear contraction recording device allowed to obtain curves illustrating the shrinkage progress during the solidification and cooling of the test specimen. The most significant values of contraction taking place after the completion of solidification were read out of the curves both for the pure matrix alloy and for the produced composites. The final contraction values for the investigated materials are shown in Figure 8.

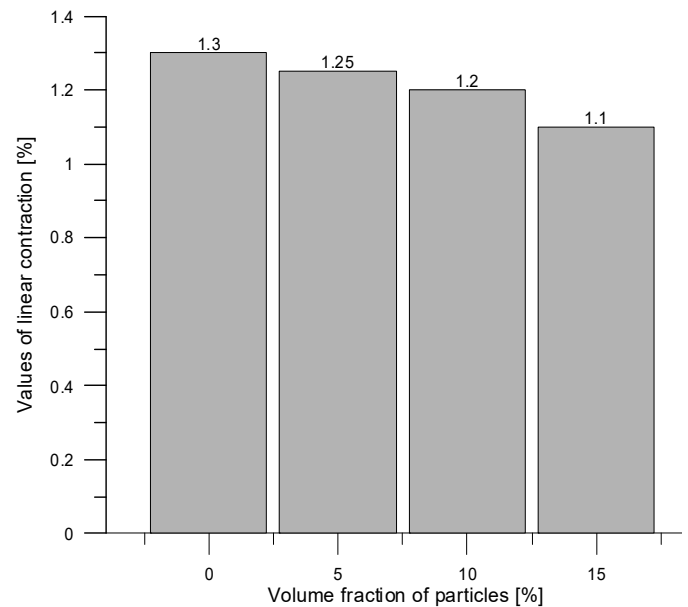


Fig. 8. Final values of linear contraction of the examined materials after 480 minutes' time of measurement

The bar chart presenting the values of linear contraction after 480 minutes' time shown in Figure 8 indicates the distinct

influence of the graphite particles on the shrinkage of the examined materials. As the percentage of the reinforcing phase grows, the linear contraction obviously drops down.

### 3. Conclusion

The obtained examination results point out to the significant influence of the graphite reinforcement in composites on all the examined properties: fluidity, viscosity, surface tension, and the shrinkage of the materials. Viscosity of the composite suspension increases with an increase in graphite particulate content according to the well known Einstein's equation. The viscosity of the examined materials vary in a wide range from 1.2 mPa·s for the matrix alloy to 2.8 mPa·s for the AlMg10 / 15%C<sub>gr</sub> composite. By the same token the fluidity is influenced, but the change is in the opposite direction: the greater is the percentage of graphite particles, the lower is the fluidity of the suspension.

The fluidity is deteriorated also by the increasing external flow resistance. Fluidity of the composite suspension decreases with an increase in graphite particulate. Both the metal surface tension and the magnitude of the wetting angle between the mould wall and the liquid metal contribute to these external resistance, the measure of which is the work of adhesion at the metal/mould interface. The presented results indicate an increase in the surface tension with an increase in graphite particulate content in the examined composites. This should involve an increase in the composite fluidity, as the external flow resistance should be lower due to the reduced wetting ability. However, the influence of the increased viscosity probably exceeds by far the advantageous influence of the increased coefficient of the surface tension, therefore the resultant fluidity diminishes.

The bar chart presenting the final values of linear contraction after 480 minutes' time (Fig. 8) shows the significant influence of the graphite particles on the shrinkage of the examined materials.

The greater is the percentage of the reinforcing phase, the lower is the linear contraction. The shrinkage value for matrix alloy is equal to 1.3%, while for the composite containing 15% of the reinforcing phase it drops down to the 1.1%, i.e. it is reduced by about 15%. The decrease in the final value of the linear contraction results primarily from the reduced volume percent of matrix alloy in composite materials, and is probably enhanced by the difference in the coefficients of thermal expansion between AlMg10 matrix alloy and the graphite particles. This coefficient

is equal to  $2.6 \cdot 10^{-5} [K^{-1}]$  for the matrix alloy, while for graphite particles is much lower and equal to  $0.7 \cdot 10^{-5} [K^{-1}]$ . The results of investigations confirm that the examined metal matrix composites are the material of greater dimensional stability than the non-reinforced matrix alloy. The paper constitutes the culmination of the foregoing investigations concerning the influence of graphite particles on the AlMg10 alloy casting properties.

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