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Impact strength of squeeze casting AlSi13Cu2–C_F composite

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Abstract

The paper presents the results of research on microstructure and impact strength of AlSi13Cu2 matrix composite reinforced by Ni-coating carbon fibers (C_F) with a volume fraction of 5%, 10% and 15%. The composite suspensions were prepared using by stirring method and subsequently squeeze casted under different pressures of 25, 50, 75 and 100 MPa. As part of the study, fiber distribution in aluminum matrix was evaluated and variation in impact strength of composite as a function of the carbon fibers volume fraction and pressure applied were determined. It has been found that the presence of Ni coating on carbon fibers clearly improves their wettability by liquid aluminum alloy and in combination with the stirring parameters applied, composite material with relatively homogeneous structure can be produced. Charpy's test showed that the impact strength of composite reaches the highest value by carrying out the squeeze casting process at 75 MPa. In the next stage of research, it was found that the impact strength of composites increases with the increase of carbon fibers volume fraction and for 15% of fibers is close to 8 J/cm^2. Observations of fracture surfaces have revealed that crack growth in the composites propagates with a quasi-cleavage mechanism. During the creation of the fracture, all fibers arranged perpendicular to its surface were sheared. At the same time, the metal matrix around the fibers deformed plastically creating characteristic ductile breaks. The fracture surface formation through the fibers indicates a cohesive and strong connection of the reinforcement with the matrix. In addition to the phenomena mentioned, debonding the fiber-matrix interfaces and the formation of voids between components were observed on the fracture surface.

Keywords: Squeeze casting composites, Carbon fibers, Impact strength, Microstructure

1. Introduction

Composites based on silumins reinforced with carbon fibers are an attractive construction material due to: high specific strength, high modulus of elasticity, high crack resistance, creep resistance at elevated temperatures, low coefficient of thermal expansion and corrosion resistance [1-5]. However, obtaining a good quality casting with a homogeneous structure and high operational properties is a serious technological problem. The fibers used for the production of composites have a diameter of several micrometers and are prepared in the form of a bundle with a high packing density - up to several thousand individual filaments. Carbon fibers at temperatures below 1100^{0}C are practically not wettable by aluminum, and with prolonged contact they react with liquid metal to form brittle and hygroscopic Al_4C_3 carbide [6 - 8], which turn in can lead to significant weakening or destruction of composite. The above factors cause segregation of fibers in the composite suspension and consequently the structural heterogeneity of the cast [9]. In order to improve wetting conditions and protect carbon fibers, various types of reinforcement surface preparations are made, as a result of which [7, 8, 10, 11] are produced: technological coatings (e.g. from Ni, Cu), barrier coatings (e.g. SiC, B_4C, TiC, SiO_2) and special coatings (e.g. with Na, $Na_2B_4O_7$, B_2O_3).

Other technological problems are high viscosity and very low fluidity of composite suspensions. Viscosity increases with the participation of strengthening filaments and depends on their dimensions and surface phenomena at the metal-reinforcement interface (wetting, adhesion work) [6, 12, 13]. In AlSi matrix composites with chopped carbon fibers, the dynamic viscosity coefficient of the suspension increases tenfold compared to the liquid alloy. Correct filling of the mold cavity can be achieved only under elevated and high external pressures, which limits the choice of casting methods. For this reason, methods of high pressure die casting and squeeze casting are particularly effective techniques [3, 5, 12, 14, 15].

Aluminum composites with carbon fibers are applied in many sectors such as aerospace, marine, automotive, chemical, sports, and mineral industries [16]. The aim of the study is to assess the influence of squeeze casting pressure and carbon fibers volume fraction on the impact strength of AlSi13Cu2- C_F composite.

2. Material and research methodology

The material for the composite matrix was the normalized AlSi13Cu2 alloy. Nickel-coated carbon fibers with a diameter of 7.5 μm and a length of 5 mm from TENAX were used to reinforce the composites. The research was carried out in two stages. In the first, composite suspensions with a fibers volume fraction of 10% were prepared and squeeze casted under different pressure: 25, 50, 75 and 100 MPa. In the second stage, composite squeeze castings with fibers volume fraction of 5, 10 and 15% were produced by applying the optimum pressure value.

The metal melting process was carried out in an induction electric furnace with carborundum crucible. After melting and overheating the matrix alloy to a temperature of 650 - 700˚C, the appropriate amount of carbon fibers was gradually introduced. During the addition of reinforcement, the suspension was mixed with a paddle mixer at a speed of 600 - 800 rpm. The total loading and mixing time ranged from 3 to 5 minutes depending on volume fraction of fibers. Subsequently, the composite suspensions were subjected to squeeze casting and plate shaped castings with dimensions of 200x100x25mm were produced. The squeeze casting was performed on a hydraulic press with a nominal pressure of 250 tons. Before filling, the die for composite castings was protected by a lubricating coating (a solution of colloidal graphite in water) and heated to a temperature of about 200^0C. Composite suspensions were dosed into the die in the amount of 1300 g and squeeze casted under the assumed pressure values. The duration of the pressure on solidifying casting was always constant - 50s. Parameters for squeeze casting and mixing composite suspensions were determined on the basis of preliminary studies, literature review [1, 6, 8, 12, 14] and own work [5, 15].

Metallographic observations were made with the use of NIKON EPIPHOT light microscope. The Charpy impact test was performed according to the PN-EN ISO 179-1:2010 on 10 × 10 × 50 mm un-notched specimens. Fractographic studies were carried out on the fracture surfaces of composite samples with a fibers volume fraction of 10%, by the SEM JSM-5400 Joel scanning electron microscope.

3. Research results

Typical microstructures of AlSi13Cu2 alloy and composites with a volume fraction of carbon fibers 5%, 10% and 15% are presented in Figs. 1a-1d.

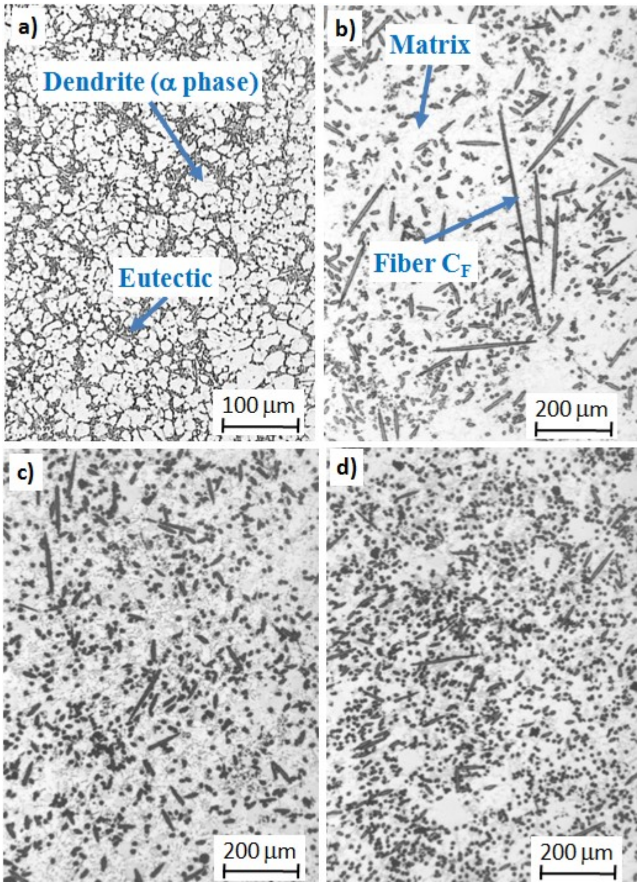

Fig. 1. The microstructure of squeeze casting AlSi13Cu2 alloy a) and the composite reinforced by Ni-coating carbon fibers (C_F) with a volume fraction of 5% b), 10% c) 15% d)

Based on metallographic observations, it can be concluded that the reinforcement distribution in the matrix of composites is uniform. Composites do not have internal defects characteristic for these materials, such as fiber clusters, oxide impurities, gas porosity, etc. [6]. The correct structure of composites is the result of a good developed technological process. The carbon fibers used in the research are introduced into the molten metal in the form of packets with the amount of monofilaments about 12,000. Separation of individual fibers and their homogenization in the matrix volume was possible due to the well-wettable nickel layer covering the surfaces of the fibers [12]. The good wettability of this coating by the liquid alloy also causes that the stir time necessary to obtain a homogeneous composite suspension is relatively short. As a consequence, a small number of oxide impurities and gas bubbles are introduced into the liquid metal. The positive side of the entire composite casting process is the direct squeeze casting stage [8]. The addition of carbon fibers to liquid aluminum reduces its fluidity. At volume fractions above 10%, composite suspensions cannot be properly cast by gravity. The applied squeeze casting method allows for trouble-free production of shape castings from composites with a higher volume fraction of carbon fibers. In addition, due to the intensive heat dissipation through the die and punch during cooling and solidification of castings, the metal matrix of composites acquires a fine-grained structure. As a result of high pressures acting on the solidifying composite suspension, it is also possible to eliminate the shrinkage of the castings and reduce the dimensions of the gas pores that may appear when stirring the suspension [6, 12].

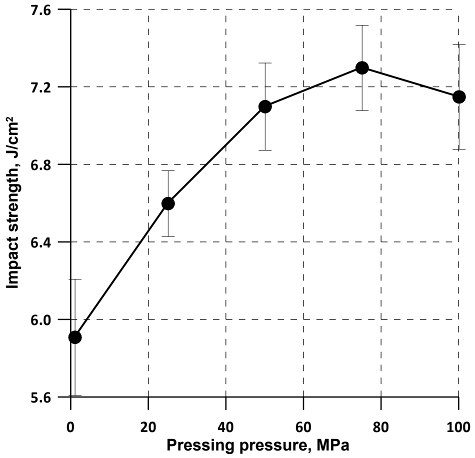

Fig. 2. The effect of squeeze casting pressure on the impact strength of a composite with a fiber volume fraction of 10%

The results of the impact strength tests of a composite with a fibers volume fraction of 10% squeeze casted in the pressures range of 0.1-100 MPa are shown in Figure 2. The figure shows that the highest impact strength of the analyzed composite is obtained applying a pressure of 75MPa. Higher pressures slightly reduce impact strength. This effect may be associated with the generation of local internal stresses or damage to the surface of the fibers as a result of pressures transmitted by growing matrix crystals in the final solidification period. The determined squeeze casting pressure of the AlSi13Cu2 –CF composite is similar to the value used in the production of composites based on other Al alloys [8]. The variation in impact strength of the AlSi13Cu2 – C_F composite pressed at 75 MPa as a function of fibers volume fraction is shown in Figure 3.The tests indicated that the impact strength of the composite increases with an increase in the carbon fibers volume fraction and is close to 8 J/cm^2 for 15% of fibers. In the percentage category, the impact strength of this composite is about 35% higher compared to the AlSi13Cu2 alloy (5,85 J/cm^2). Along with the increase in the volume fraction of carbon fibers, other mechanical properties of composites also improve. Kumar et al. [1] investigated a composite reinforced by fibers with a Ni coating and a fraction of 2, 4, 6 and 8%. It was found that with increasing volume of reinforcement, the ultimate tensile strength, Young's modulus and hardness of composites clearly increase.

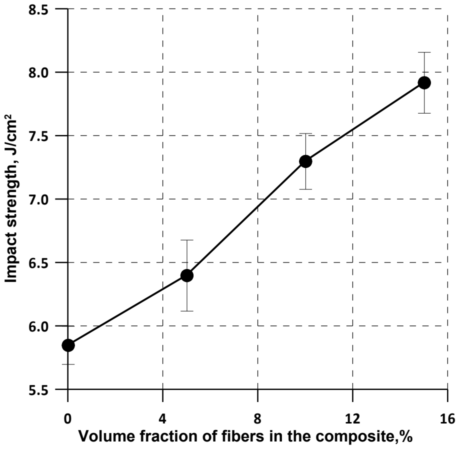

Fig. 3. The influence of the volume fraction of C_F on impact strength of the composite– squeeze casting pressure of 75 MPa

Figures 4a and 4b present the results of fractographic observations of the fracture surfaces of AlSi13Cu2 – 10% C_F composite samples.

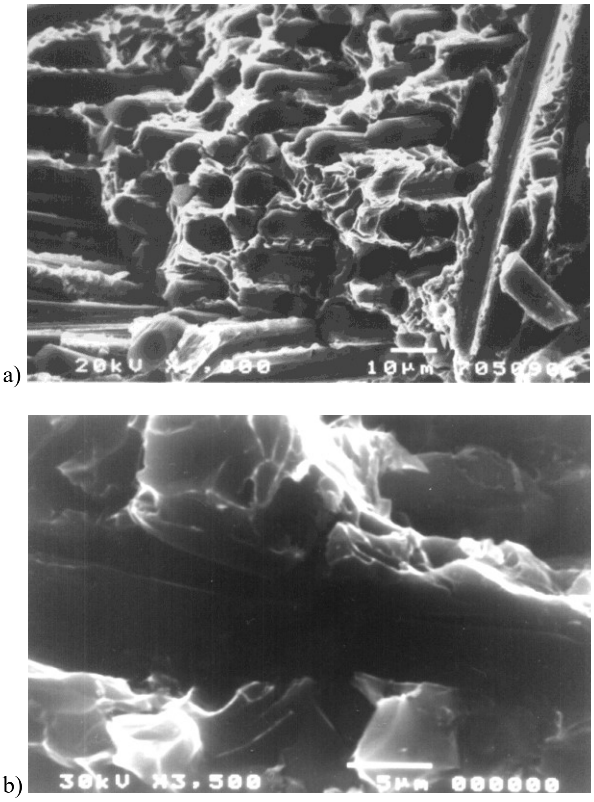

Fig. 4. The fracture surfaces of squeeze casting AlSi13Cu2 - 10% C_F composite: a) ×1000 mag., b) ×3500 mag.

The presented fractures are representative of all tested composites. The affect of carbon fibers on the cracking development in composite depends mainly on their orientation in relation to fracture surfaces. Micrograph 4a presents cracked fibers and the creation of matrix surface that reproduces the shape of the reinforcement. During the destruction of the composite, all fibers arranged perpendicular to the fracture surface were sheared. At the same time, the matrix surrounding the fibers deformed plastically creating characteristic breaks. The propagation of the crack across the fibers indicates cohesive and strong bonding of the reinforcement with the matrix. For this configuration of arrangement and connection of components, the composite material is effectively strengthened [17]. However, anisotropic distribution of reinforcements occurs in this type of composites, and in addition to the shear cracking mechanism, debonding the fiber-matrix interfaces and formation of voids between components has also been observed (Fig. 4b).

Cracking in mixed mode by shear reinforcement and debonding the fiber-matrix interface, as well as the beneficial effect of Ni and Ni-P coatings on the mechanical properties of composites were found in [8, 10, 12, 17]. In all composites, metal matrix cracking was propagated by a quasi-cleavage mechanism.

4. Conclusions

1. The presence of a Ni layer on carbon fibers clearly improves their wettability by a liquid aluminum alloy and in combination with the stirring parameters used, a composite material with a relatively homogeneous structure can be produced.
2. The impact strength of the composite achieves the highest value by carrying out the squeeze casting process at 75 MPa. Higher squeeze casting pressures slightly reduce composite impact strength.
3. The impact strength of the composite increases with the carbon fibers volume fraction and for 15% of fibers is close to 8 J/cm^2, which is an increase of about 35% compared to the metal matrix of composite.
4. Cracking of the composites occurs through a quasi-fissile mechanism. During the destruction, the fibers located perpendicular to the fracture surface break, while the fibers arranged in parallel are detached from the metal matrix along the bonding interface. The propagation of cracking through fibers indicates a cohesive and strong connection between the components of the composite.

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