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MECHANICAL PROPERTIES OF AlSiMg/SiC AND AlSiMgTiB/SiC PRODUCED BY SEMI-SOLID STIR CASTING AND HIGH PRESSURE DIE CASTING

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Abstract. Mechanical properties of the AlSiMg/SiC and AlSiMgTiB/SiC composites produced by high pressure die casting (HPDC) are investigated. The mixture of ADC 11, master alloy AlMg, master alloy AlTiB and 99 % aluminium were used as metal matrix. A reinforcement particle was represented by high purity silicon carbide with an average particle size mesh 400. Aluminium matrix and SiC particle with the content: 5 %, 7.5 %, and 10 % wt were mixed by the semi-solid stir casting method. The stirring process was performed by 45^{o} degree carbide impeller at a rotation of 600 rpm and temperature of 570^{o}C for 15 minutes. The mixture of AlSiMg/SiC and AlSiMgTiB/SiC were shaped into the specimen by HPDC. Mechanical characterizations of composite specimens were done in hardness, tensile and impact tests. The density of the composites was also determined. The results have shown that adding SiC improves the hardness, tensile strength of the AlSiMg/SiC and AlSiMgTiB/SiC. The increase of % wt SiC decreases the impact resistance of the composites tested. The addition of TiB increases the hardness and ultimate tensile strength and ductility. A higher of % wt of SiC porosity of composite increases. This physical quantity was lower at the composite with TiB than without this type of ingredient. TiB caused grain refining of the matrix and enhances the mechanical properties of composites.

Keywords: Aluminium Matrix Composite, HPDC, mechanical properties

1. Introduction

Metal matrix composite (MMC) represented by aluminium alloy matrix is being preferred for numerous engineering applications [1]. Aluminium matrix composites (AMC) are the kind of material in which aluminium metal alloy is used as a matrix while another type of material is applied for reinforcement. In the case of AMC material, the properties of aluminium alloy such as high toughness and ductility are combined with properties like high ultimate compressive tensile strength and elastic modulus associated with ceramics [2-4]. Silicon carbide, alumina, and graphite are the most common reinforcing materials which can be incorporated into the base metal. Reinforcement can be in the form of continuous and discontinuous i.e. whiskers, particulates, fibers [3-11]. Due to its superior properties, silicon carbide is a common reinforcing material used as reinforcement in aluminium matrix [3,7].

The most common problem regarding the production of aluminium matrix composites in casting routes is some defects such as porosity and particle agglomeration that hinder

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getting the uniform distribution of reinforcement within the matrix. For achieving the better properties of the aluminium matrix composites, the reinforcement distribution in the aluminium alloy should be uniform, the wettability between these reinforced particles should be optimized and the porosity needs to be minimized. For producing aluminium matrix composites, there are some techniques are developed, the methods include powder metallurgy, spray decomposition, liquid metal, infiltration, squeeze casting, and casting [8-12]. Among these processing techniques, casting is one of the methods accepted for the production produce large quantities and relatively complex shaped economically. Homogeneity distribution SiC particle on aluminium alloy matrix and adhesion interface between aluminium and SiC particles is a common problem in manufacturing Al/SiC composites. Using Mg as the wetting agent and stirred the reinforcement particle in semi-solid phase can improve the wettability of SiC particles in aluminium matrix [13,14]. In order to minimize the porosity of casting products, high-pressure die casting is known as a powerful method to reduce porosity [15-17].

Grain refinement is considered to be one of the most important melt treatment processes for aluminium casting products. It is well accepted that finer grain size improves mechanical properties. TiB master alloy is knowing as once of grain refiner for aluminium alloy. It also changes the grain morphology from dendritic to equiaxed grains. Grain refiners TiB have improved tensile strength of aluminium alloy [18-21]. The aim of the study follows manufacturing and examining of AlSiMg/SiC and AlSiMgTiB/SiC produced by High Pressure Die Casting (HPDC) with respect to the determination of selected mechanical properties in tensile, hardness and Charpy impact tests.

2. Materials and Methods

Aluminium Silicon (ADC 11) and aluminium 99 % of commercial purity produced by Merck were used as the base composition of a metal matrix. AlMg and Al1Ti1B were used as master alloy to produce specific metal matrix composition. SiC powders with particle size 320-450 mesh produced by Sigma-Aldrich. Co was used as a reinforcement particle. Mixtures of the ADC 11 and aluminium (purity 99 %) with a specific weight ratio were melted in an alumina crucible electric furnace. The electric furnace was equipped with a controllable temperature. This process resulted in an aluminium alloy with 7 % Si. To achieve alloying composition, some weight of master alloy AlMg and Al5Ti1B were added into molten aluminium. SiC powder was pre-heated to 523K (250ºC) and was poured using a funnel into the aluminium melted at temperature 1023K (750ºC). To get aluminium matrix composite with a weight fraction of 5 %; 7.5 %; 10 %, the weight of the added SiC powder was determined. The temperature of melted aluminium was reduced up to 540 ^{o}C to get semi-solid phase and then the semi solid aluminium was stirred for about 10 min, using graphite stirrer. After mixing was completed, the mixture was heated up to the temperature of 700^{o}C. The melted composite was poured into the shot sleeve of High Pressure Die Casting (HPDC) machine. The slurry was die-cast into samples shaped. The pouring temperature of the composite slurry was equal to 700°C, the die temperature was taken of 200ºC and the pressure reached 8 MPa.

ASTM E 8 sub size specimens with 30 mm gauge length and 3 mm diameter were obtained from the HPDC. To achieve a good surface and acceptable dimensions of specimens, casted products were finished by CNC turning machine. The tensile tests were carried out by means of a Shimadzu EHF-EB 20-40 L tensile testing machine. These experiments were performed at a displacement velocity of 2 mm/min. Six specimens were tested for each composite variables. The tensile strength, strain, and elongation were determined basing on ASMT E8 procedure. The density of composites was tested according to the Archimedes Law. The hardness measurements were carried out with a Rockwell hardness tester test basing on the ASTM E18-11 standard. Microstructural analysis was performed using an optical microscope on etched HF solution polished specimens.

3. Results and Discussion

The porosity of composite products was calculated using the following formula:

$$\%\, porosity = \frac{theoretical\ density - experimental\ density}{theoretical\ density}\, x\ 100. \quad (1)$$

The theoretical density of aluminium matrix composites was determined the rule of mixtures and can be represented as:

$$\rho_{theoretical} = \rho_m \varphi_m + \rho_r \varphi_r, \quad (2)$$

where φ_m represent wt. fraction of matrix and φ_r represent wt. fraction of reinforcement; ρ_m and ρ_r represent density of matrix and reinforcement respectively; $\rho_{theoretical}$ represents the theoretical density of a composite. The rule of mixtures was adopted to compute the theoretical density of a AlSiMg/SiC and AlSiMgTiB/SiC composites. The experimental density of composites products was tested based on the Archimedes principle [22,23]. Figure 1 shows the % porosity of AlSiMg/SiC and AlSiMgTiB/SiC high pressure die casting composites. These graphics show the effect of alloy and % wt. SiC on porosity of composite products. It's shown for each alloy element, that composite with 10 % wt. SiC has the highest porosity. AlSiMg with 10 %wt. SiC reaches porosity of 2.67 %, while the case of AlSiMgTiB with 10 % wt. SiC this parameter is 1.93 %. The increase of % wt. SiC enlarges the porosity, this might is associated with particle agglomeration, clustering, and pore nucleation at the interface [24]. A higher fraction of SiC caused a higher degree of defects and microporosity rise amount of interface area and resulted in higher porosity [3,25]. The SiC particles were added in the melt during the casting process, this process caused gas trapped in the liquid among the particles. Increasing the wt % of SiC particles produce higher the gas trapped in which may result in the higher porosity [26]. The porosity of composite AlSiMgTiB/SiC is lower than AlSiMg/SiC. Alloying titanium on aluminium matrix formed AlTi that reduced the contact angle between aluminium and SiC and improved the wettability at the interface [27]. TiB particles act as nucleating agent for aluminium solidification [13,28,29]. The effect of nucleating agent TiB, produces finner grain of AlMgSi (Fig. 2(a); Fig. 2(b); Fig 2(c); Fig. 2(d)). Therefore, TiB alloys promote the nucleation around the SiC particle and suppress the interfacial reaction between aluminium liquid and SiC that could generate porosity.

It is shown in Fig. 3, that the hardness of AlSiMg/SiC and AlSiMgTiB/SiC linearly increases with increasing the % wt. of SiC particulates. The addition of SiC into the aluminium alloy matrix enlarges the surface area of the reinforcement. The presence of such a hard surface area of SiC offers more resistance to plastic deformation which leads to enhance in the hardness. SiC as a hard ceramic phase in the soft ductile matrix (aluminium alloy) reduces the ductility and significantly increases the hardness value against the % wt. of SiC [30]. The presence of hard ceramic phase in the soft ductile matrix reduces the ductility of composites because of lowering of metal content and significantly increases the hardness value evaluated against the weight percentage of SiC particulates [3]. Figure 3 shows that in any variation of % wt. of SiC the hardness of composite with AlSiMgTiB/SiC is higher than AlSiMg/SiC. The addition of AlTiB master alloys in AlSiMg makes the microstructures of the composites finer and more homogeneous with the result that enhances the hardness of composite [28]. Adding Al5Ti1B master alloy on AlMgSi produced finer grain than AlMgSi without Al5Ti1B master alloy. This phenomenon is shown in Fig. 2, that composite with TiB alloys has finer grain structure on AlMSi alloy matrix. Figures 2(a) and 2(b) show that AlSiMgTiB has finner grain than AlSiMg. Figures 2(c) and 2(d) show that AlSiMgTiB/10 % SiC also has finer grain than AlSiMg/10% SiC. TiB from Al5Ti1B master alloy on AlMgSi causes mechanism of aluminium magnesium grain refinement, (Al,Ti)B2 and AlB2 were considered as the nucleation site during solidification of Al-Si alloy [31].

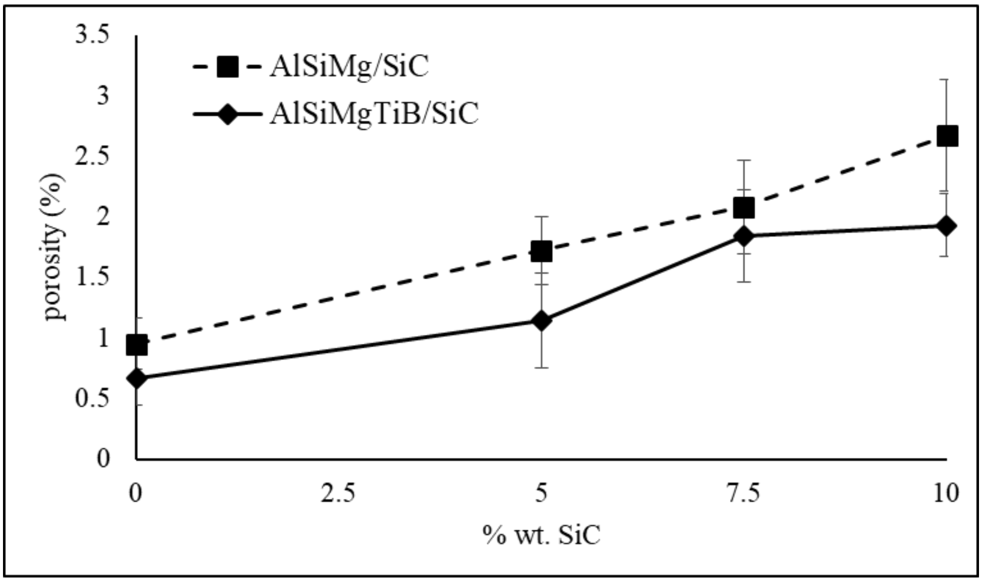

Fig. 1. Porosity of AlSiMg/SiC and AlSiMgTiB/SiC composite as a result of % wt. SiC

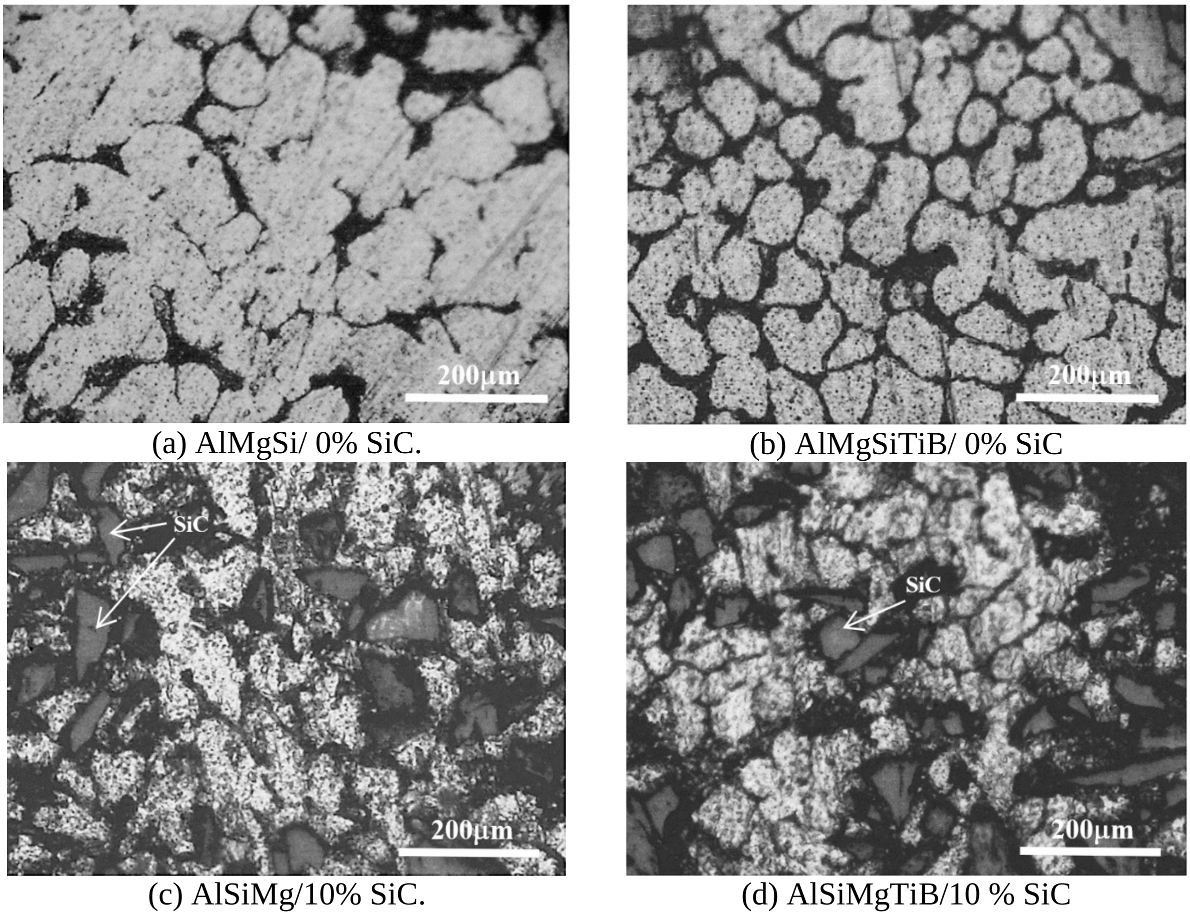

Fig. 2. Microstructure of AlSiMg/SiC and AlSiMgTiB/SiC composite with a different percent content of SiC

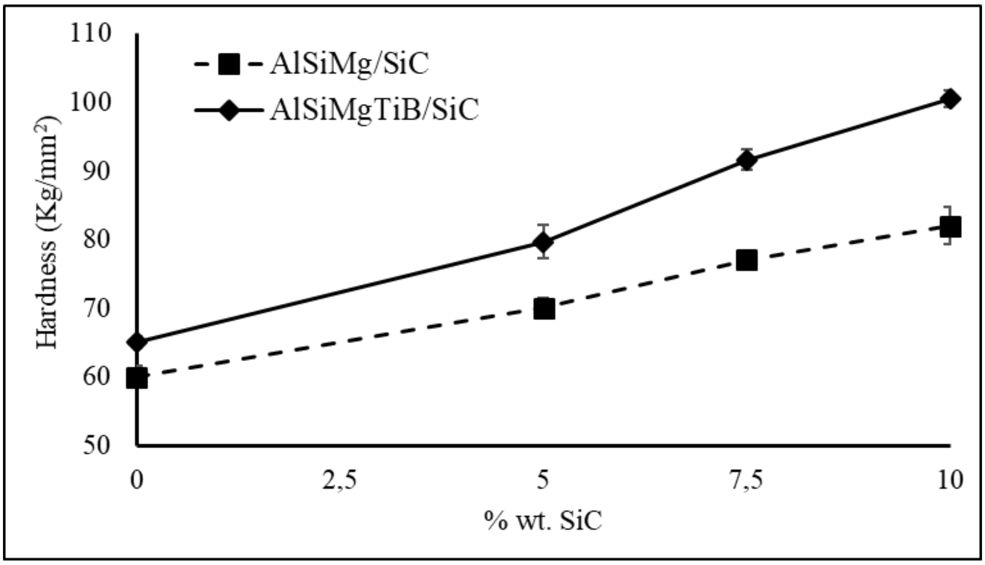

Fig. 3. Hardness of AlSiMg/SiC and AlSiMgTiB/SiC composite versus % wt. SiC

Tensile strength of the AlMgSi/SiC and AlMgSiTiB/SiC composites are shown in Fig. 4 and Fig. 5. Figure 4 shows that increasing % wt. of SiC increases ultimate tensile strength, but decreases ductility (Fig. 5). This change in the value of tensile strength was caused by the strengthening mechanism resulted in loading transfer from aluminium matrix to SiC reinforcement [32]. The presence of the hard and higher modulus SiC particles embedded in the aluminium matrix acts as a barrier to resist plastic flow when the composite is under loading [33]. Increasing ultimate tensile strength also causes by the response of SiC particles and matrix on loading. The thermal expansion coefficient of SiC particle is 3.25×10^{6}/°C and for aluminium alloy is 23×10^{6}/°C. The differences of thermal expansion between AlMgSi matrix and the SiC reinforcement cause higher dislocation density in the matrix and loading bearing capacity of the hard particles which subsequently increases the composite strength [34]. The results of tensile test (Figs. 4 and 5) also shown that in all variation of % wt. SiC AlMgSiTiB/SiC composites have higher ultimate tensile strength and elongation (ductility) than AlMgSi/SiC. Finer grain caused strengthening mechanism by grain boundary act as barriers to slip increasing the tensile strength, elongation, and impact strength [35,36].

Impact strength and elongation of composites decreased by the increase of % wt. SiC (Figs. 5 and 6). Decreasing ductility and impact strength of composites were related to the mechanical features of SiC i.e. lower in impact strength, fracture toughness, and elongation than matrix aluminium. The accumulations of the hardening phase surrounding of SiC produced brittle fracture of aluminium alloy matrix. Increasing of SiC contents also promotes clustering of SiC particles. The clustering of SiC particles causes porosity and stress concentration and hence provides sites for crack initiation which reduces material strength [36-38].

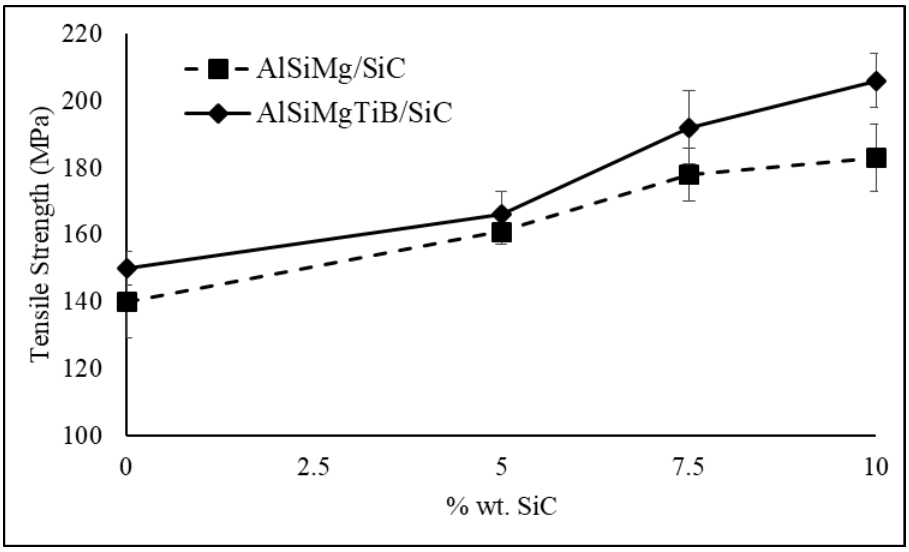

Fig. 4. Variations of Ultimate Tensile Strength (UTS) of AlSiMg/SiC and AlSiMgTiB/SiC composite due to %wt. SiC

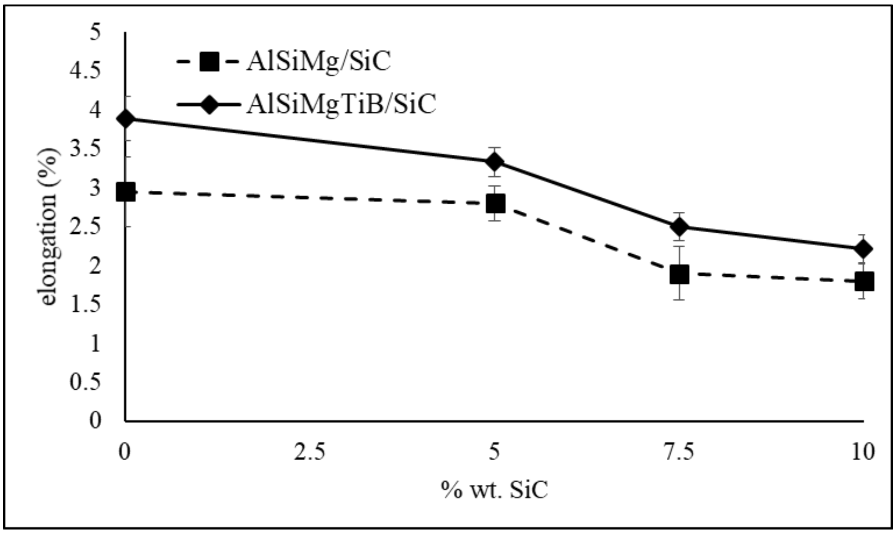

Fig. 5. Elongation of AlSiMg/SiC and AlSiMgTiB/SiC composite versus %wt. SiC

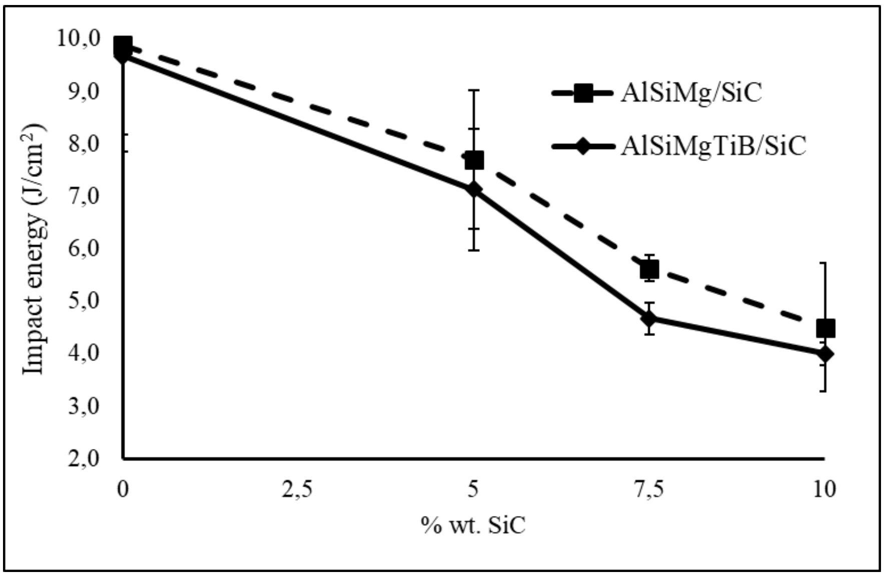

Fig. 6. Impact Strength of AlSiMg/SiC and AlSiMgTiB/SiC composite as results of %wt. SiC

4. Conclusions

The AlSiMg/SiC and AlSiMgTiB/SiC composites were successfully manufactured by high pressure die casting (HPDC), SiC was added and mixed in the aluminium matrix using semi solid stirring process.

The addition of SiC particle into aluminium matrix, producing the AlSiMg/SiC and AlSiMgTiB/SiC composites, increases hardness, ultimate tensile strength, and AlSiMg/SiC and decreases elongation. The impact strength of the composites decreased with adding of SiC.

The Al5Ti1B alloy on AlMgSi alloy, increases hardness, tensile strength, and elongation of composites.

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