Manuscripts for Materials Physics and Mechanics

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Dear Dr. Dmitrii Indeitsev and Andrey Rudskoy
Principal Editors of Materials Physics and Mechanics

Enclosed please find the manuscript entitled: *Mechanical properties of AlSiMg/SiC and AlSiMgTiB/SiC produced by semi-solid stir casting and high pressure die casting* submitted for publication in Materials Physics and Mechanics. The authors are Sulardjaka, Sri Nugroho, Norman Iskandar.

The basic findings are as follows.

1. Semi solid and HPDC method for producing aluminum matrix composite.
2. The effect of TiB alloy on AlMgSi on mechanical properties of aluminum matrix composite.
3. The effect of TiB alloy on AlMgSi in grain of aluminum matrix and porosity of composite.
4. Strengthening mechanism of AlMgSiTiB matrix.

This is an original paper which has neither previously, nor simultaneously, in whole or in part been submitted anywhere else.

Kind regards,

Sulardjaka

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

Sulardjaka[1,2*], Sri Nugroho[1], Norman Iskandar[1,2]

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Abstract, Mechanical properties of AlSiMg/SiC and AlSiMgTiB/SiC produced by high pressure die casting (HPDC) have been investigated. The mixture of ADC 11, master alloy AlMg, master alloy AlTiB and 99 % aluminum were used as metal matrix. High purity silicon carbide with average particle size mesh 400 was used as reinforcement particle. Aluminum matrix and SiC particle with the variation: 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 specimen test by HPDC. Mechanical characterizations of composite specimens were: hardness, tensile and impact test. Density test also conducted on AlSiMg/SiC and AlSiMgTiB/SiC composites products. The results show that introducing SiC reinforcement in the aluminum matrix increases the hardness, tensile strength of AlSiMg/SiC and AlSiMgTiB/SiC. The rise of % wt SiC decreases impact strength of composites. The addition of TiB increases the hardness and tensile strength and ductility of composites. Higher of % wt of SiC caused porosity of composite increases. The porosity of composite with TiB lower than composite without TiB. TiB caused grain refining of the matrix and enhances the mechanical properties of composites.
Keyword: Aluminum Matrix Composite, HPDC, mechanical properties

1. Introduction

Metal matrix composite using aluminum matrix is being preferred for numerous engineering applications. Aluminum metal matrix composites are the materials in which aluminum metal is used as matrix material reinforced with other materials. In aluminum matrix composites, the properties of aluminum such as high toughness and ductility are combined with properties like high strength and elastic modulus associated with ceramics [1-4]. Silicon carbide, alumina and graphite are the most common reinforcing materials which can be incorporated in the base aluminum matrix. 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 aluminum matrix [3,7].

The most common problem regarding production of aluminum matrix composites in casting routes is some defects such as porosity and particle agglomeration that hinder to get the uniform distribution of reinforcement within the matrix. For achieving the better properties of the aluminum matrix composites, the reinforcement distribution in the aluminum alloy should be uniform, the wettability between these reinforced particles should be optimized and the porosity needs to be minimized. For producing aluminum matrix composites, there are some techniques have been 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 which is accepted for the production produce large quantities and relatively complex shaped economically. Homogeneity distribution SiC particle on aluminum matrix and adhesion interface between aluminum and SiC particle is common problem on manufacturing Al/SiC composites. Using Mg as the wetting agent and stirred the reinforcement particle in semi-solid phase can improve wettability of SiC particles in aluminum matrix [13,14]. In order to reduce 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 aluminum casting products. It is well accepted that finer grain size improves mechanical properties. TiB master alloy has been knowing as once of grain refiner for aluminum alloy. It also changes the grain morphology from dendritic to equiaxed grains. Grain refiners TiB has improved tensile strength of aluminum alloy [18-21]. The aim of the study is the preparation and investigation of mechanical properties (tensile strength, elongation, hardness, impact strength) of AlSiMg/SiC and AlSiMgTiB/SiC produced by high pressure die casting (HPDC).

2. Materials and Methods

Aluminum Silicon (ADC 11) and aluminum 99 % of commercial purity have been used as base composition of 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 has been used as reinforcement particle. Mixtures of ADC 11 and aluminum (purity 99 %) with specific weight ratio were melted in an alumina crucible electric furnace. The electric furnace was equipped with controllable temperature. This process resulted aluminum alloy with 7 % Si. To achieve alloying composition, some weight of master alloy AlMg and Al5Ti1B were added into molten aluminum. SiC powder was pre-heated to 523K (250 ◦C) and was poured using a funnel into the aluminum melted at temperature 1023K (750 ◦C). To get aluminum matrix composite with weight fraction of 5 %; 7.5; 10 %, the weight of the added SiC powder was determined. The temperature of melted aluminum was reduced to 540 ^{o}C to get semi-solid phase and then the semi solid aluminum was stirred for about 10 min, using graphite stirrer. After mixing was completed, the mixture was heated to temperature 700 ^{o}C. The melted composite was poured to 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 700 °C, the die temperature was 200 °C and the pressure was 8 MPa.

ASTM E 8 sub size specimens with 30 mm gauge length and 3 mm diameter were obtained from the HPDC. To achieve good surface and accurate dimensions of specimens, casted products were finished by CNC turning machine. The tensile tests were carried out with a Shimadzu EHF-

EB 20-40 L tensile testing machine. The tests were done at a crosshead speed of 2 mm/min. Six specimens were tested for each composite variables. The density of composites was tested according to the Archimedes Law. The hardness measurements were carried out with a Rockwell hardness tester test based on ASTM E18-11. Microstructural analysis was performed using optical microscope on etched HF solution polished specimens.

3. Results and Discussion

The porosity of composite products was calculated using the formula:

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

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

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

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]. Fig. 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 highest porosity. AlSiMg with 10 %wt. SiC has porosity 2,67 %. AlSiMgTiB with 10 % wt. SiC has porosity 1,93 %. The rise of % wt. SiC increases the porosity, this might have been associated with particle agglomeration, clustering and pore nucleation at the interface [24]. A higher fraction of SiC caused higher degree of defects and microporosity rise amount of interface area and resulted 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 it may result in the higher porosity [26]. The porosity of composite AlSiMgTiB/SiC is lower than AlSiMg/SiC. Alloying titanium on aluminum matrix formed AlTi that reduce the contact angle between aluminum and SiC and improve the wettability at the interface [27]. TiB particles act as nucleating agent for aluminum 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 aluminum liquid and SiC that could generate porosity.

It is shown in Fig.3, that the hardness of AlSiMg/SiC and AlSiMgTiB/SiC linearly rise when the % wt. of SiC particulates increases. The addition of SiC in the aluminum alloy matrix enlarges the surface area of the reinforcement. The presence of such 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 (aluminum) 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 due to reduction of ductile metal content which significantly increases the hardness value evaluated against the weight percentage of SiC particulates [3]. 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 on AlMgSi produced more finner grain than AlMgSi without Al5Ti1B (Fig. 2). Al5Ti1B on AlMgSi causes mechanism of aluminum magnesium grain refinement, (Al,Ti)B2 and AlB2 were considered as the nucleation site during solidification of Al-Si alloy [31]. This phenomenon has shown in Fig. 2, that composite with TiB alloys has finer grain structure on AlMSi alloy matrix.

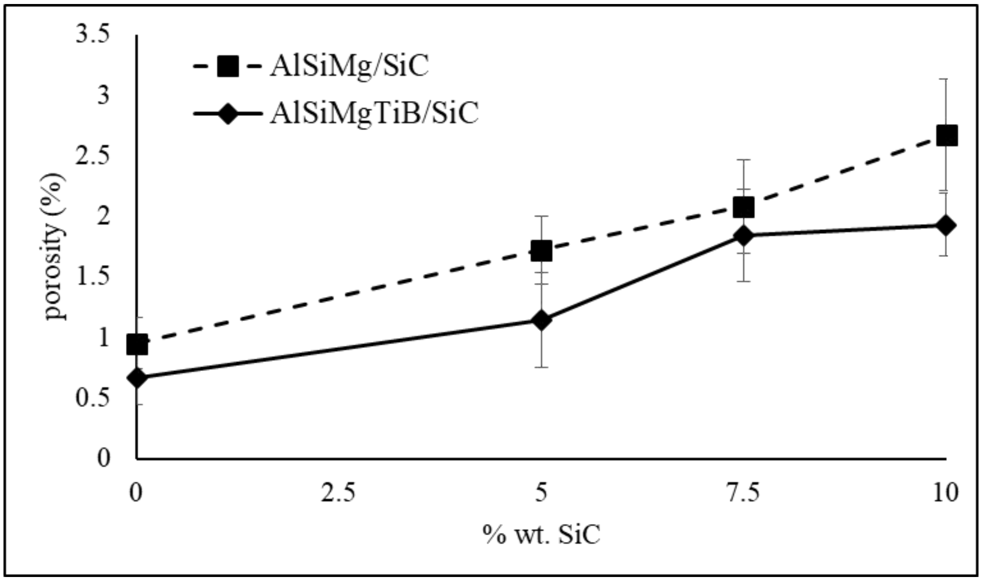
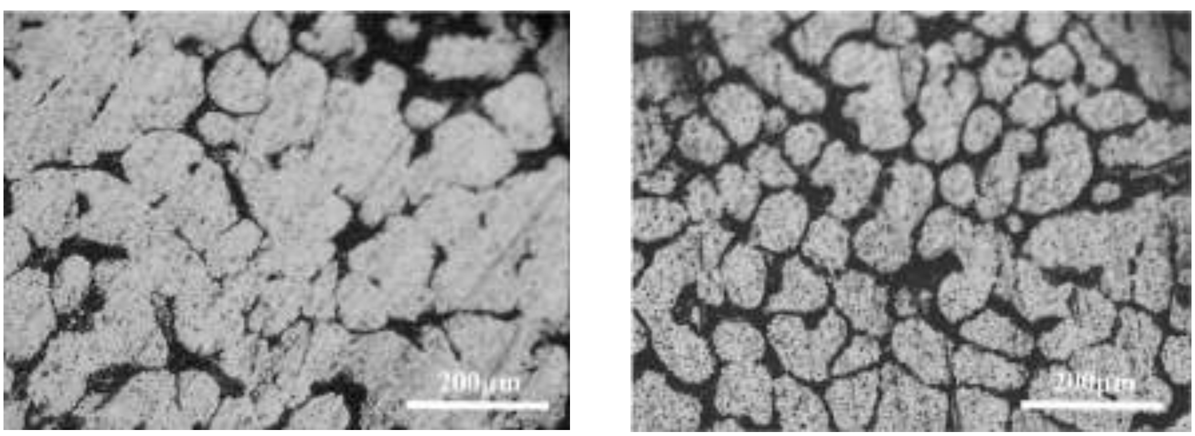
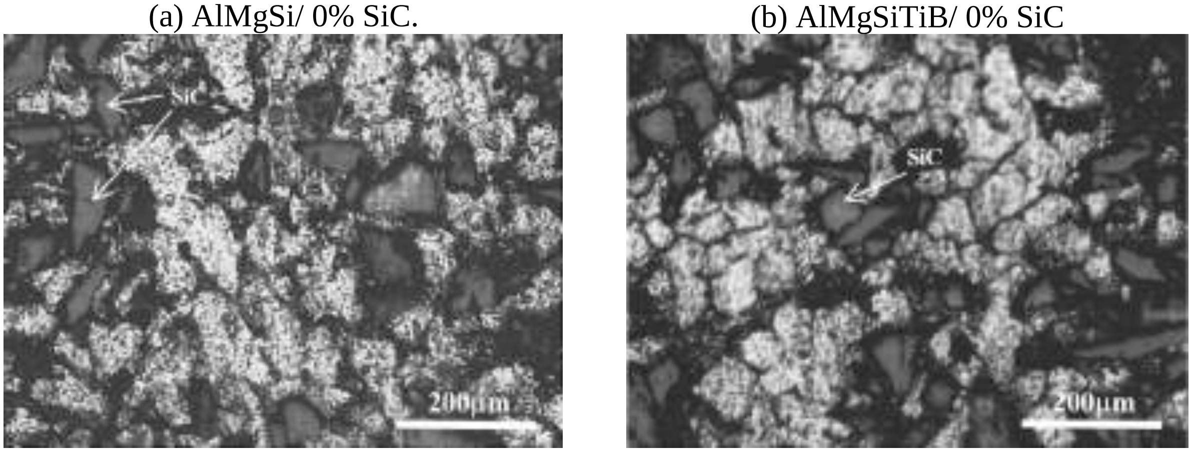


Fig. 1. Porosity of AlSiMg/SiC and AlSiMgTiB/SiC composite.



(a) AlMgSi/ 0% SiC. (b) AlMgSiTiB/ 0% SiC



(c) AlSiMg/10% SiC. (d) AlSiMgTiB/10 % SiC

Fig. 2. Microstructure of AlSiMg/SiC and AlSiMgTiB/SiC Composite

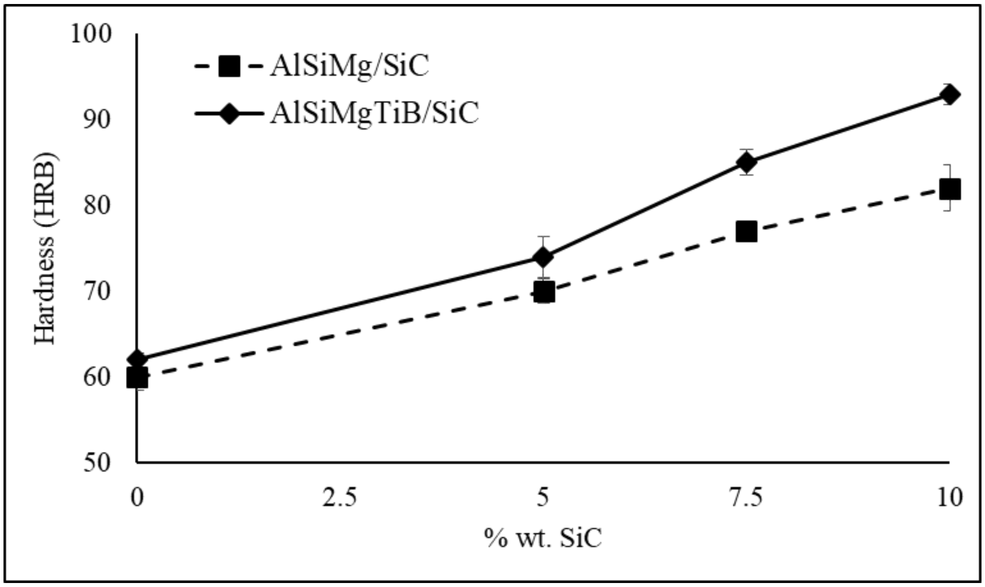


Fig. 3. Hardness of AlSiMg/SiC and AlSiMgTiB/SiC Composite.

Tensile test results of AlMgSi/SiC and AlMgSiTiB/SiC composites are shown in Fig. 4 and Fig. 5. Fig. 4 shows that increasing % wt. of SiC increases tensile strength composites product, but decreases ductility (Fig. 5). The rise of tensile strength was caused by the strengthening mechanism by load transfer from aluminum matrix to SiC reinforcement [32]. The presence of the hard and higher modulus SiC particles embedded in the aluminum matrix acts as a barrier to resist plastic flow when the composite is subjected to strain from an applied load [33]. Increasing tensile strength also causes by SiC particles in the matrix by induces much strength to aluminum alloy matrix by offering more resistance to tensile stresses. The thermal expansion coefficient of SiC particle is 3.25 x 106/° C and for aluminum alloy is 23 x 106 /° C. The differences of thermal expansion between AlMgSi matrix and the SiC reinforcement causes higher dislocation density in the matrix and load bearing capacity of the hard particles which subsequently increases the composite strength [34]. Tensile test results as shown in Fig. 4 and Fig. 5 also shown that AlMgSiTiB/SiC composites have higher 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 (ductility) of composites decreased by the rise of % wt. SiC as shown in Fig. 5 and Fig. 6. Decreasing ductility and impact strength because of clustering of SiC particles at higher reinforcement content. The clustering of SiC particles causes porosity and stress concentration and hence provides sites for crack initiation which reduces the strength [36].

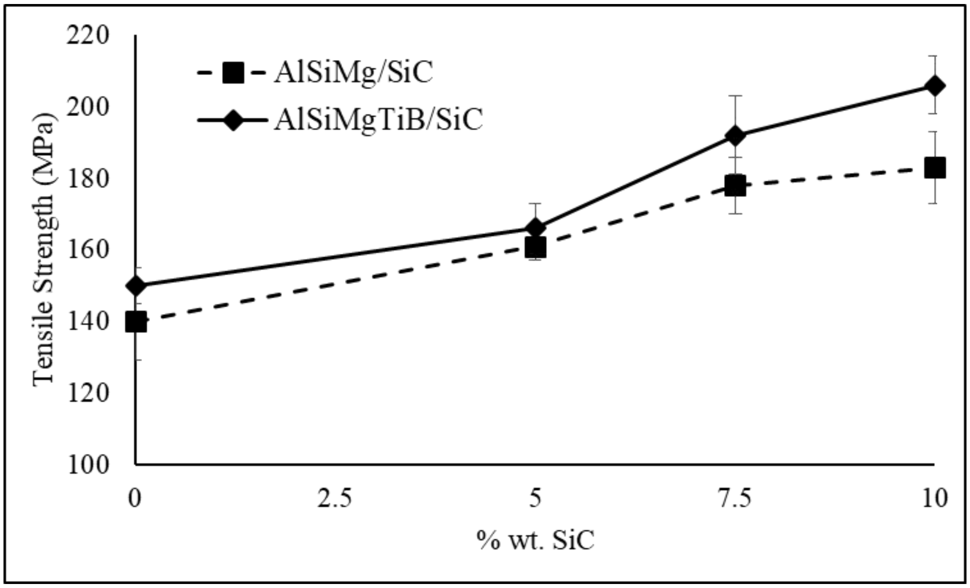


Fig. 4. Tensile Strength of AlSiMg/SiC and AlSiMgTiB/SiC Composite

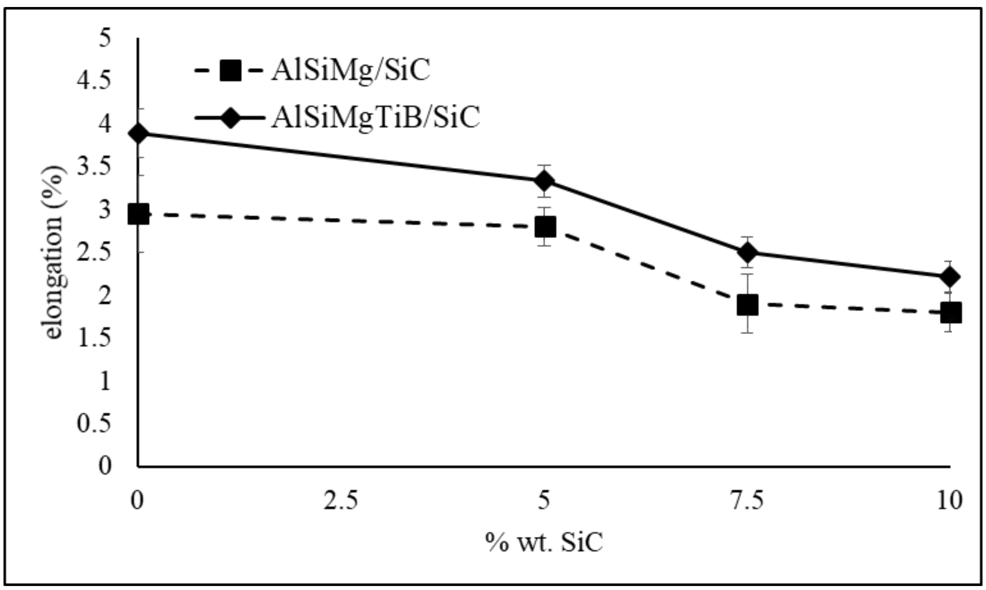


Fig. 5. Elongation of AlSiMg/SiC and AlSiMgTiB/SiC Composite

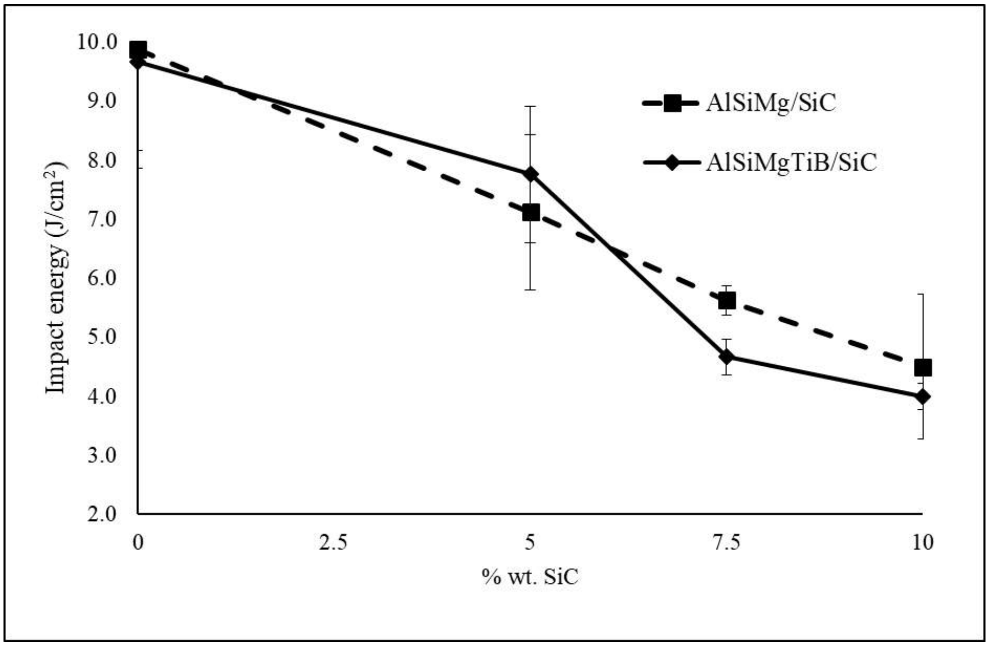


Fig. 6. Impact Strength of AlSiMg/SiC and AlSiMgTiB/SiC Composite

4. Conclusions

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

The addition of SiC particle on aluminum matrix, increases hardness, tensile strength and elongation of AlSiMg/SiC and AlSiMgTiB/SiC composites. The impact strength of composites decreased with adding of SiC on the aluminum matrix.

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

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Abstract, Mechanical properties of the AlSiMg/SiC and AlSiMgTiB/SiC composites produced by high pressure die casting (HPDC) have beenare 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 Hhigh purity silicon carbide with average particle size mesh 400 was used as reinforcement particle. Aluminium matrix and SiC particle with the variationcontent: 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 ºC for 15 minutes. The mixture of AlSiMg/SiC and AlSiMgTiB/SiC were shaped into specimen test by HPDC. Mechanical characterizations of composite specimens were done in: hardness, tensile and impact test. Density of the compoite test was also conducted on AlSiMg/SiC and AlSiMgTiB/SiC composites productsdetermined. The results have shown that adding introducing SiC reinforcement in the aluminium matrix increasesimproves the hardness, tensile strength of the AlSiMg/SiC and AlSiMgTiB/SiC. The rise increase of % wt SiC decreases impact strength resistance of the composites tested. The addition of TiB increases the hardness and ultimate tensile strength and ductility of composites. A hHigher of % wt of SiC caused porosity of composite increases. The porosityThis physical quantit was lower at the of composite with TiB lower than without composite without TiBthis type of ingridient. TiB caused grain refining of the matrix and enhances the mechanical properties of composites.

Keyword: Aluminium Matrix Composite, HPDC, mechanical properties

1. Introduction

Metal matrix composite (MMC) using represened by aluminium alloy matrix is being preferred for numerous engineering applications [ ]. Aluminium metal matrix composites (AMC) are the kind of material materials in which aluminium metal alloy is used as a matrix material reinforced with other materialswhile another type of material is applied for reinforcement. In

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~~aluminum matrix composites~~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 [1-4]. Silicon carbide, alumina and graphite are the most common reinforcing materials which can be incorporated in the base ~~aluminum matrix~~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 to get 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 ~~have been~~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 ~~which is~~ 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 particle is a common problem on 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 ~~reduce~~ 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 ~~has been~~is knowing as once of grain refiner for aluminium alloy. It also changes the grain morphology from dendritic to equiaxed grains. Grain refiners TiB has improved tensile strength of aluminium alloy [18-21]. The aim of the study follows ~~is~~ manufacturing ~~the preparation~~ and ~~investigation~~examing ~~of mechanical properties (tensile strength, elongation, hardness, impact strength)~~ of AlSiMg/SiC and AlSiMgTiB/SiC produced by ~~h~~High ~~P~~pressure ~~D~~die ~~C~~casting (HPDC) with respect to ~~determing~~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 ~~have been~~were used as the base composition of a metal matrix. AlMg and Al1Ti1B were used as a master alloy to produce specific metal matrix composition. SiC powders with particle size 320 – 450 mesh produced by Sigma – Aldrich. Co ~~has been~~was used as reinforcement particle. Mixtures of the ADC 11 and aluminium (purity 99 %) with specific weight ratio were melted in an alumina crucible electric furnace. The electric furnace was equipped with acontrollable temperature. This process resulted of 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 (250 ◦C) and was poured using a funnel into the aluminium melted at temperature 1023K (750 ◦C). To get aluminium matrix composite with 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 °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

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temperature of 700 ºC. The melted composite was poured to 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 200 °C and the pressure ~~was~~ 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 good surface and ~~accurate~~ acceptable dimensions of specimens, casted products were finished by CNC turning machine. The tensile tests were carried out ~~with a~~by means of a Shimadzu EHF-EB 20-40 L tensile testing machine. ~~The tests~~These experiments were ~~done~~ performed at ~~a crosshead speed~~displacement velocity of 2 mm/min. Six specimens were tested for each composite variables. The density of composites was tested according to the Archimedes Law. The hardness measurements were carried out with a Rockwell hardness tester ~~test based~~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 folowing formula:

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

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

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

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]. Fig. 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 ~~has~~ reaches porosity of 2,67 %, while the case of~~.~~ AlSiMgTiB with 10 % wt. SiC ~~has porosity~~this parameter is of 1,93 %. The ~~rise~~ increase of % wt. SiC ~~increases~~ enalrges the porosity, this might ~~have been~~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 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 it 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 ~~rise~~ increases with increasing ~~when~~ the % wt. of SiC particulates ~~increases~~. The addition of SiC ~~in~~ into the aluminium alloy matrix enlarges the surface area of the reinforcement. The presence of such 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

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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 ~~due to reduction~~ lowering of ~~ductile~~ metal matrix content and ~~which~~ significantly increases the hardness value evaluated against the weight percentage of SiC particulates [3]. 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 on AlMgSi produced more finner grain than AlMgSi without Al5Ti1B (Fig. 2). Al5Ti1B 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]. This phenomenon ~~has shown~~is shown in Fig. 2, that composite with TiB alloys has finer grain structure on AlMSi alloy matrix.

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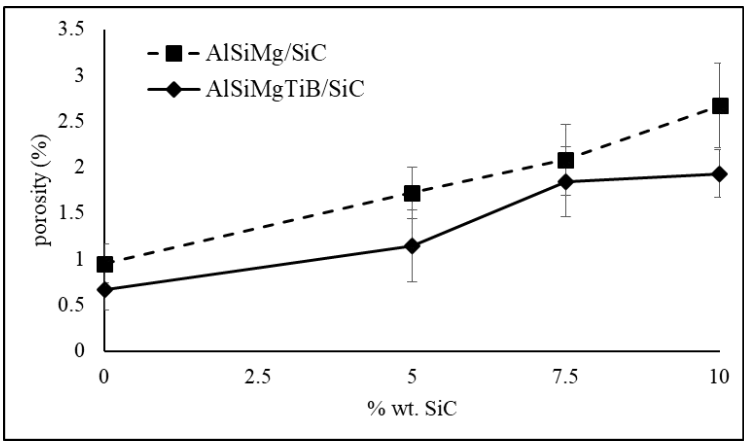

Fig. 1. Porosity of AlSiMg/SiC and AlSiMgTiB/SiC composite as a result of % wt. SiC.

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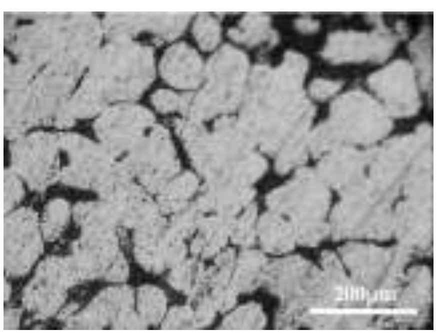
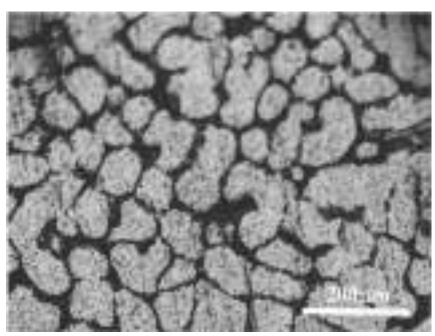
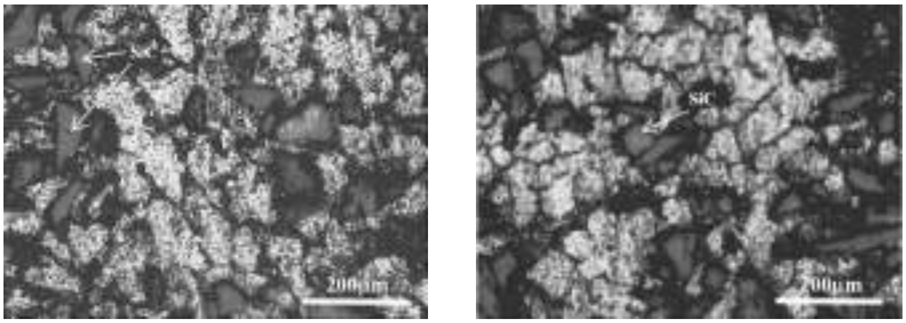


(a) AlMgSi/ 0% SiC.



(b) AlMgSiTiB/ 0% SiC



(c) AlSiMg/10% SiC. (d) AlSiMgTiB/10 % SiC

Fig. 2. Microstructure of AlSiMg/SiC and AlSiMgTiB/SiC c~~C~~omposite with a different perecent content of SiC

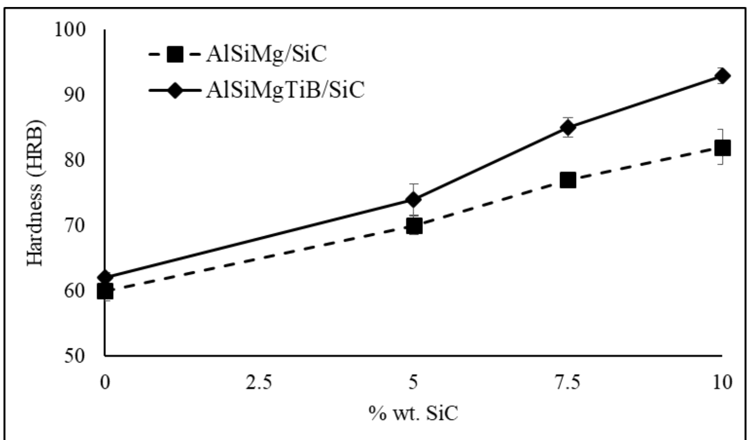


Fig. 3. Hardness of AlSiMg/SiC and AlSiMgTiB/SiC c~~C~~omposite versus % wt. SiC.

Tensile test results of the AlMgSi/SiC and AlMgSiTiB/SiC composites are shown in Fig. 4 and Fig. 5. Fig. 4 shows that increasing % wt. of SiC increases ultimate tensile strength ~~composites product~~, but decreases ductility (Fig. 5). ~~The rise of~~This change in a value of tensile strength was caused by the strengthening mechanism resulted of~~by~~ 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 ~~subjected to strain from an applied load~~under loading [33]. Increasing ultimate tensile strength is also caused by response of SiC particles ~~in the matrix by inducing much strength to aluminium alloy matrix by offering more resistance to tensile stresses~~and matrix on loading. The thermal expansion coefficient of SiC particle is 3.25 × ~~x~~ 10^6/° C and for aluminium alloy is 23 × ~~x~~ 106 /° C. The differences of thermal expansion between AlMgSi matrix and the SiC reinforcement causes higher dislocation density in the matrix and loading bearing capacity of the hard particles which subsequently increases the composite strength [34]. ~~Tensile test results~~Results of tensile tests ~~as~~

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~~shown in~~ (Figs. 4 and ~~Fig.~~ 5) also shown that 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 ~~(ductility)~~ of composites decreased by the ~~rise~~ increase of % wt. SiC (~~as shown in~~ Figs. 5, ~~and Fig.~~ 6). Decreasing ductility and impact strength was observed because of the clustering of SiC particles at higher reinforcement content. The clustering of SiC particles causes porosity and stress concentration and hence provides sites for crack initiation which reduces material ~~the~~ strength [36].

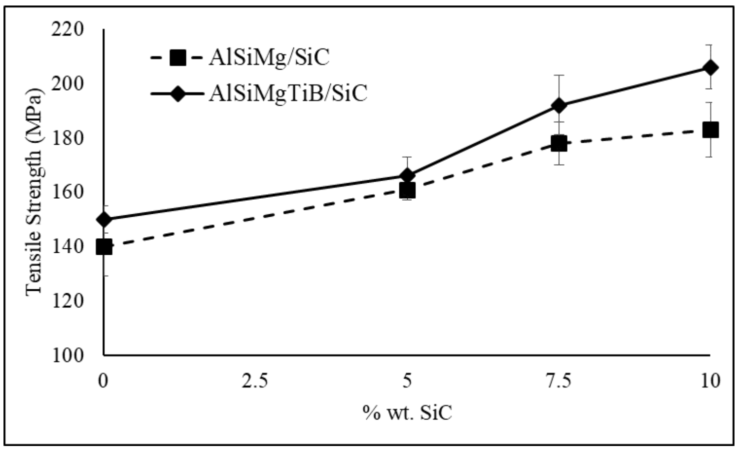

Fig. 4. Variations of Ultimate Tensile Strength (UTS) of AlSiMg/SiC and AlSiMgTiB/SiC c~~C~~omposite due to %wt. SiC

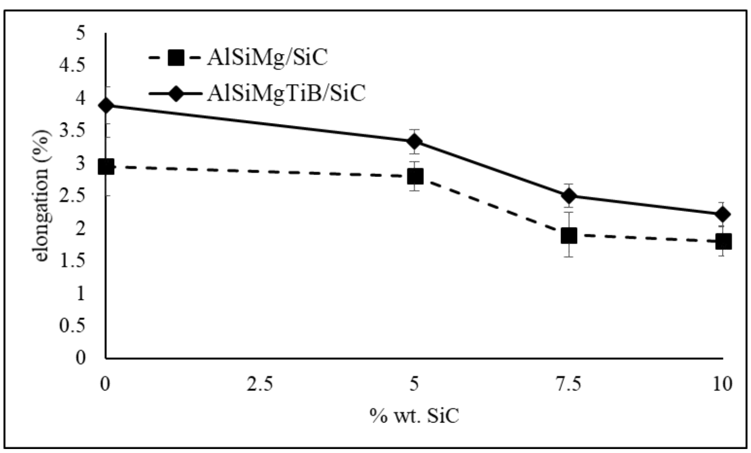

Fig. 5. Elongation of AlSiMg/SiC and AlSiMgTiB/SiC c~~C~~omposite versus %wt. SiC

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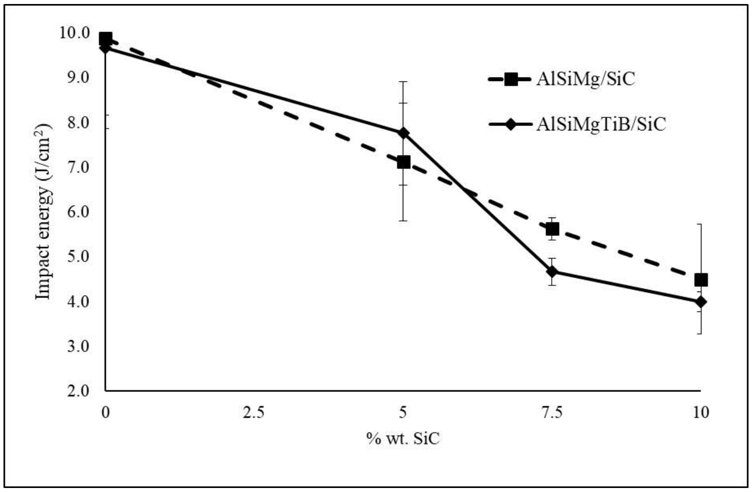

Fig. 6. Impact Strength of AlSiMg/SiC and AlSiMgTiB/SiC Composite as results of %wt. SiC

4. Conclusions

The AlSiMg/SiC and AlSiMgTiB/SiC composites were successfully ~~produced~~ 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 ~~on~~ into aluminium matrix, producing the AlSiMg/SiC and AlSiMgTiB/SiC composites, increases~~increases~~ hardness, ultimate tensile strength ~~and~~ ~~elongation~~ and decreases elongation ~~of AlSiMg/SiC and AlSiMgTiB/SiC composites~~. The impact strength of the composites decreased with adding of SiC ~~on the aluminum matrix~~.

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

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1) Please add a Figure to confirm this sentence in Abstract: "The addition of TiB increases the hardness and tensile strength and ductility of composites."
2) Please correct terminology for the alloy of pure aluminium (see comments in pdf file).
3) Section 2: "Aluminum Silicon (ADC 11) and aluminum 99 % of commercial purity have been used as base composition of metal matrix." – Please add the name of company and addtitional point in reference.
4) "Six specimens were tested for each composite variables." – Please add some comments on strain determination.
5) Section 3: You mentioned "Adding Al5Ti1B on AlMgSi produced more finner grain than AlMgSi without Al5Ti1B (Fig. 2)." But it is not indicated in Figure.
6) Figure 3: Please add a unit to the hadness axis (MPa).
7) "Decreasing ductility and impact strength because of clustering of SiC particles at higher reinforcement content. The clustering of SiC particles causes porosity and stress concentration and hence provides sites for crack initiation which reduces the strength [36]." - Any difficulties in the technology? Consider the following sentence: Decreasing ductility and impact strength was related to the mechanical feaures of SiC i.e. low impact strength, fracture toughness and elongation, taking as of: ……..
8) Conclusions: " Al5Ti1B alloy on AlMgSi alloy, increases hardness, tensile strength and elongation of composites." – Please add a Figure to this sentence.

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Respond to reviewer:

Thank you very much for your suggestion. The following sentences were added in the results and discussions:

… "Fig. 3 shows that in any variation of % wt. of SiC the hardness of composite with AlSiMgTiB/SiC is higher than AlSiMg/SiC." …..

…" The results of tensile test (Figs. 4 and 5) also shown that ini all variation of % wt. SiC AlMgSiTiB/SiC composites have higher ultimate tensile strength and elongation (ductility) than AlMgSi/SiC." …

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Respond to reviewer:

Thank you very much for your suggestion. The terminology has been corrected as suggestion from reviewer.

3) Section 2: "Aluminum Silicon (ADC 11) and aluminum 99 % of commercial purity have been used as base composition of metal matrix." – Please add the name of company and addtitional point in reference.

Respond to reviewer:

Thank you very much for your suggestion. The name of company has been added.

4) "Six specimens were tested for each composite variables." – Please add some comments on strain determination.

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Thank you very much for your suggestion. We added in the manuscript "The tensile strength, strain and elongation were determined basing on ASMT E8 procedure."

5) Section 3: You mentioned "Adding Al5Ti1B on AlMgSi produced more finner grain than AlMgSi without Al5Ti1B (Fig. 2)." But it is not indicated in Figure.

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Thank you very much for your suggestion. We corrected the sentences in these paragraph as:

"Adding Al5Ti1B master alloy on AlMgSi produced more 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. Fig. 2(a) and Fig. 2(b) show that AlSiMgTiB has finner grain than AlSiMg. Fig. 2(c) and Fig. 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.”

6) Figure 3: Please add a unit to the hadness axis (MPa).

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Respond to reviewer:

Thank you very much for your suggestion. We corrected the sentences in these paragraph as:

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. 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].

8) Conclusions: " Al5Ti1B alloy on AlMgSi alloy, increases hardness, tensile strength and elongation of composites." – Please add a Figure to this sentence.

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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 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 ºC for 15 minutes. The mixture of AlSiMg/SiC and AlSiMgTiB/SiC were shaped into specimen by HPDC. Mechanical characterizations of composite specimens were done in hardness, tensile and impact test. 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 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 ingridient. TiB caused grain refining of the matrix and enhances the mechanical properties of composites.

Keyword: 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 in 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 to get 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 particle is a common problem on 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 has 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 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 reinforcement particle. Mixtures of the ADC 11 and aluminium (purity 99 %) with specific weight ratio were melted in an alumina crucible electric furnace. The electric furnace was equipped with a controllable temperature. This process resulted of 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 (250 ◦C) and was poured using a funnel into the aluminium melted at temperature 1023K (750 ◦C). To get aluminium matrix composite with 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 temperature of 700 ^{o}C. The melted composite was poured to 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 200 °C 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 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 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 folowing 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]. Fig. 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 of 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 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 it 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 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]. Fig. 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 more 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. Fig. 2(a) and Fig. 2(b) show that AlSiMgTiB has finner grain than AlSiMg. Fig. 2(c) and Fig. 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].

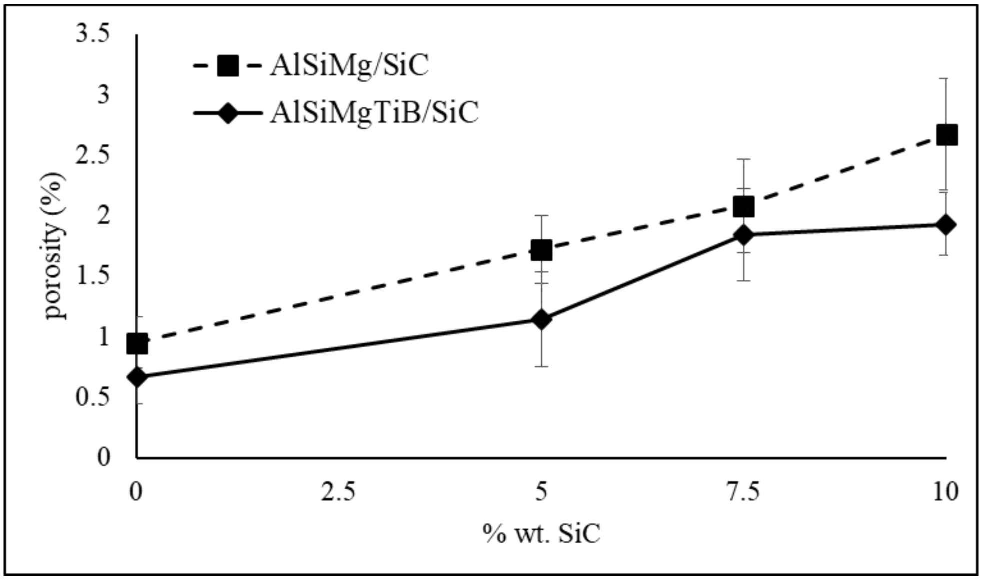
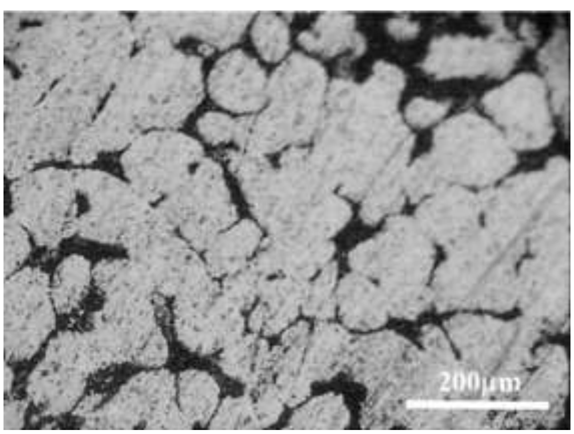
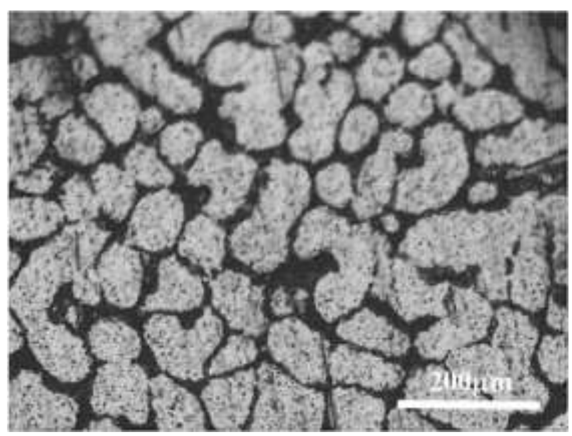


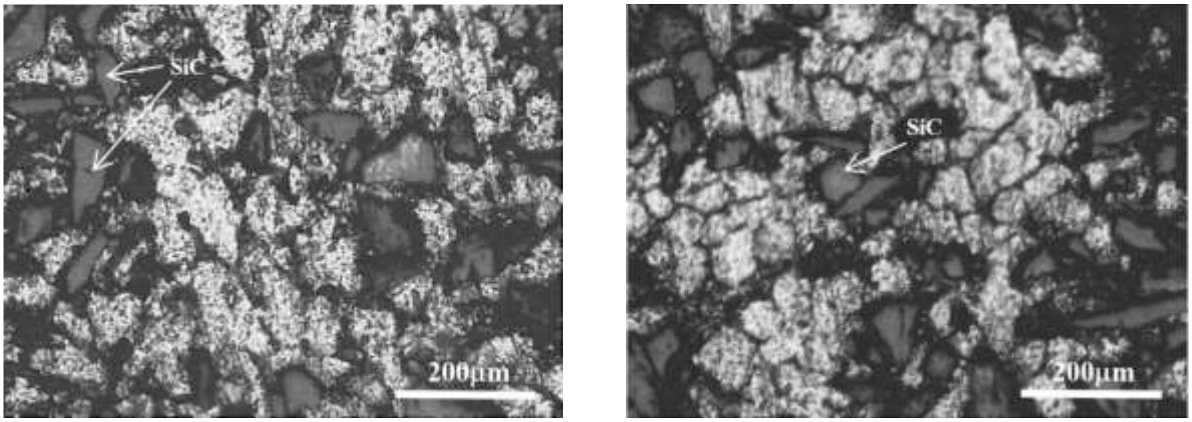
Fig. 1. Porosity of AlSiMg/SiC and AlSiMgTiB/SiC composite as a result of % wt. SiC.



(a) AlMgSi/ 0% SiC.



(b) AlMgSiTiB/ 0% SiC



(c) AlSiMg/10% SiC. (d) AlSiMgTiB/10 % SiC

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

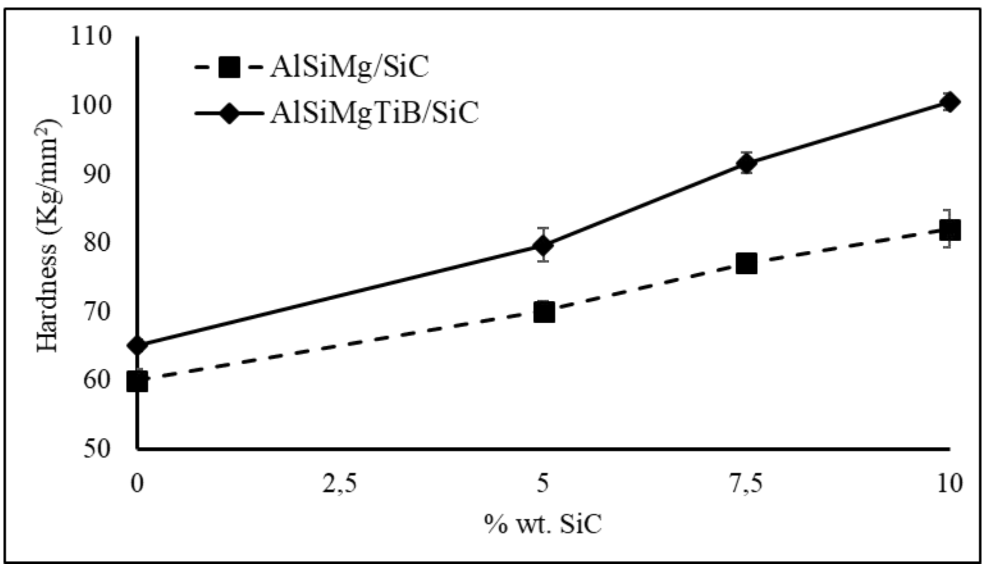


Fig. 3. Hardness of AlSiMg/SiC and AlSiMgTiB/SiC composite versus % wt. SiC.

Tensile strength of the AlMgSi/SiC and AlMgSiTiB/SiC composites are shown in Fig. 4 and Fig. 5. Fig. 4 shows that increasing % wt. of SiC increases ultimate tensile strength, but decreases ductility (Fig. 5). This change in a value of tensile strength was caused by the strengthening mechanism resulted of 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 response of SiC particles and matrix on loading. The thermal expansion coefficient of SiC particle is 3.25 x 10^{6}/° C and for aluminium alloy is 23 x 10^{6} /° C. The differences of thermal expansion between AlMgSi matrix and the SiC reinforcement causes 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 ini 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. 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].

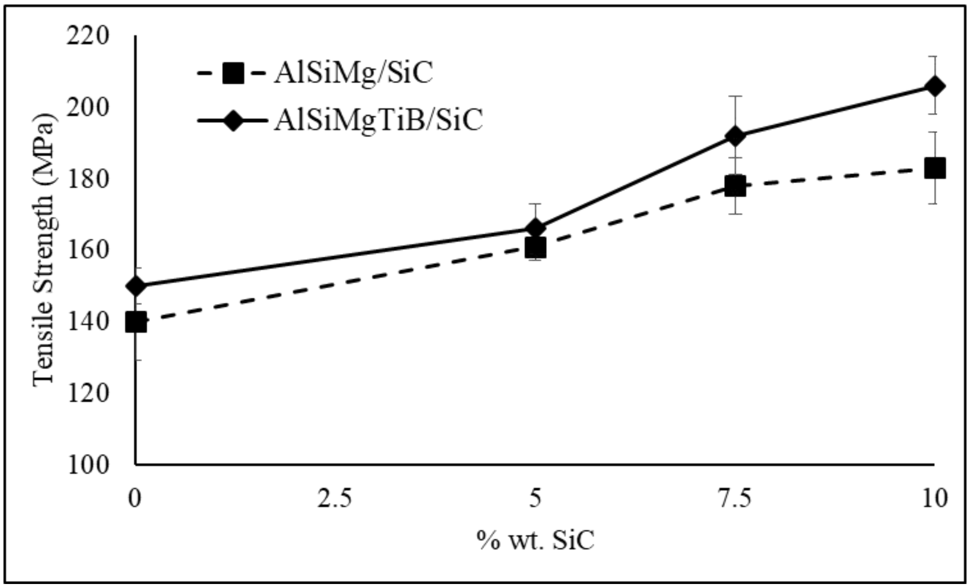


Fig. 4. Variations of Ultimate Tensile Strength (UTS) of AlSiMg/SiC and AlSiMgTiB/SiC composite due to %wt. SiC.

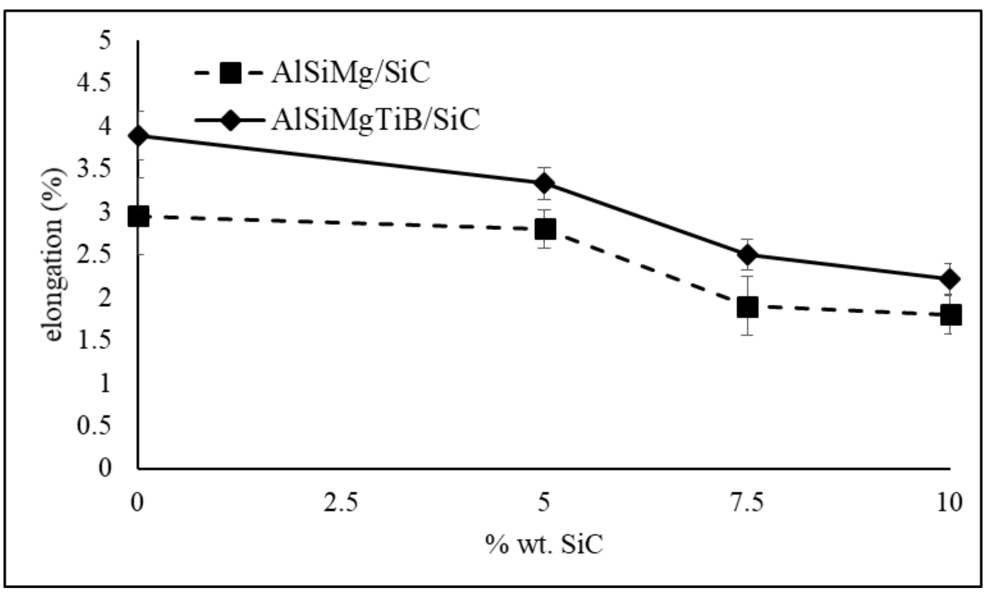


Fig. 5. Elongation of AlSiMg/SiC and AlSiMgTiB/SiC composite versus %wt. SiC.

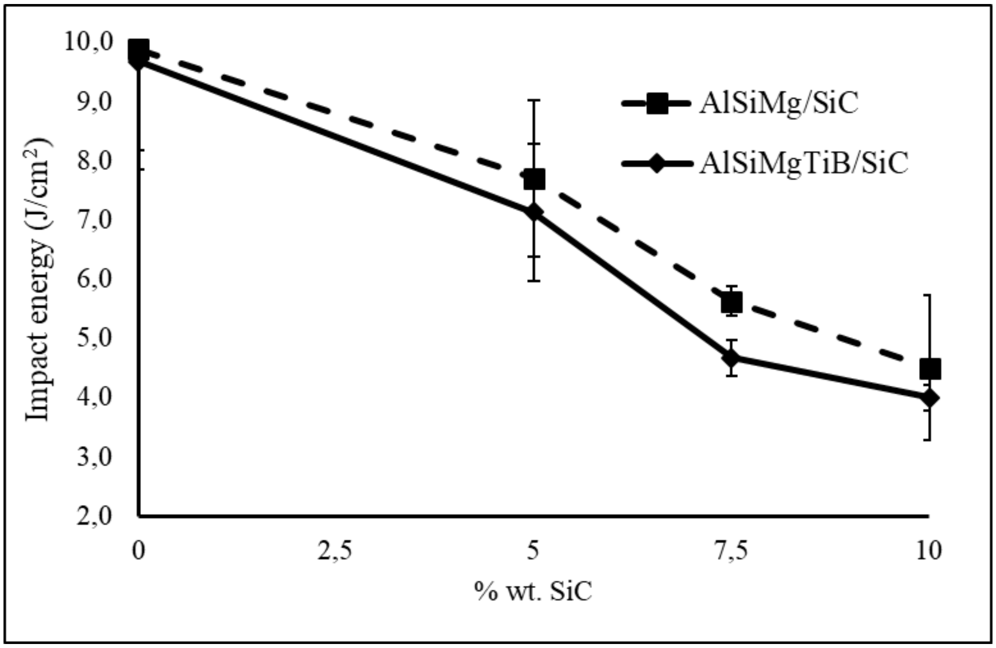


Fig. 6. Impact Strength of AlSiMg/SiC and AlSiMgTiB/SiC composite as results of %wt. SiC.

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.

Acknowledgment, *This work was supported by PUPT research grant (advanced research of higher education), Directorate of research and community service, Ministry of Research, Technology and Higher Education of the Republic of Indonesia. Contract number: 344-73/UN7.5.1/PP/2017.*

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Re: Manuscripts for Materials Physics and Mechanics

Sulardjaka <sulardjaka@lecturer.undip.ac.id>
Mon 18/01/2021 10:41
To: Materials Physics and Mechanics <mpmjournal@spbstu.ru>

2 attachments (760 KB)
Cover letter for 1st round revision.docx; Manuscrip Sulardjaka et.al. Revised 1 submitted.docx;

Dear Dr. Dmitrii Indeitsev and Andrey Rudskoy
Principal Editors of Materials Physics and Mechanics

Enclosed please find the revised manuscript entitled: *Mechanical properties of AlSiMg/SiC and AlSiMgTiB/SiC produced by semi-solid stir casting and high pressure die casting* submitted for publication in Materials Physics and Mechanics. The authors are Sulardjaka, Sri Nugroho, Norman Iskandar.

Kind regards,

Sulardjaka

From: Materials Physics and Mechanics <mpmjournal@spbstu.ru>
Sent: 13 November 2020 14:29
To: Sulardjaka <sulardjaka@lecturer.undip.ac.id>
Subject: Re: Manuscripts for Materials Physics and Mechanics

Dear Author,

We have received the review for your manuscript "MECHANICAL PROPERTIES OF AlSiMg/SiC AND AlSiMgTiB/SiC PRODUCED BY SEMI-SOLID STIR CASTING AND HIGH PRESSURE DIE CASTING". We agree with the reviewer's opinion that the manuscript can be published after revision. You can find the reviewer's comment in the attached file.

We apologize for the long period of the reviewing process and looking forward to your response.

With best regards,
Aleksandra Romashkina
Materials Physics and Mechanics
Editorial Office
URL: http://mpm.spbstu.ru

От: Sulardjaka <sulardjaka@lecturer.undip.ac.id>
Отправлено: 8 сентября 2020 г. 7:42:37
Кому: Materials Physics and Mechanics
Тема: Re: Manuscripts for Materials Physics and Mechanics

Dear Dr. Dmitrii Indeitsev and Andrey Rudskoy
Principal Editors of Materials Physics and Mechanics

I have submitted my manuscript with the title: *Mechanical properties of AlSiMg/SiC and AlSiMgTiB/SiC produced by semi-solid stir casting and high pressure die casting,* on Okt 17th 2019.
May I know, how the progress for publishing of my article?

Kind regards,

Sulardjaka

From: Materials Physics and Mechanics <mpmjournal@spbstu.ru>
Sent: 17 October 2019 16:18
To: Sulardjaka <sulardjaka@lecturer.undip.ac.id>
Subject: Re: Manuscripts for Materials Physics and Mechanics

Dear Authors,

Thank you for submitting your paper "MECHANICAL PROPERTIES OF AlSiMg/SiC AND AlSiMgTiB/SiC PRODUCED BY SEMI-SOLID STIR CASTING AND HIGH PRESSURE DIE CASTING". The manuscript is received.

With best regards,
Aleksandra Zobacheva
Materials Physics and Mechanics
Editorial Office

От: Sulardjaka <sulardjaka@lecturer.undip.ac.id>
Отправлено: 17 октября 2019 г. 7:21:52
Кому: Materials Physics and Mechanics
Тема: Manuscripts for Materials Physics and Mechanics

Dear Dr. Dmitrii Indeitsev and Andrey Rudskoy
Principal Editors of Materials Physics and Mechanics

Enclosed please find the manuscript entitled: *Mechanical properties of AlSiMg/SiC and AlSiMgTiB/SiC produced by semi-solid stir casting and high pressure die casting* submitted for publication in Materials Physics and Mechanics. The authors are Sulardjaka, Sri Nugroho, Norman Iskandar.

The basic findings are as follows.

1. Semi solid and HPDC method for producing aluminum matrix composite.
2. The effect of TiB alloy on AlMgSi on mechanical properties of aluminum matrix composite.
3. The effect of TiB alloy on AlMgSi in grain of aluminum matrix and porosity of composite.
4. Strengthening mechanism of AlMgSiTiB matrix.

This is an original paper which has neither previously, nor simultaneously, in whole or in part been submitted anywhere else.

Kind regards,

Sulardjaka

1) Please add a Figure to confirm this sentence in Abstract: "The addition of TiB increases the hardness and tensile strength and ductility of composites."

Respond to reviewer:

Thank you very much for your suggestion. The following sentences were added in the results and discussions:

… "Fig. 3 shows that in any variation of % wt. of SiC the hardness of composite with AlSiMgTiB/SiC is higher than AlSiMg/SiC." …..

…" The results of tensile test (Figs. 4 and 5) also shown that ini all variation of % wt. SiC AlMgSiTiB/SiC composites have higher ultimate tensile strength and elongation (ductility) than AlMgSi/SiC." …

2) Please correct terminology for the alloy of pure aluminium (see comments in pdf file).

Respond to reviewer:

Thank you very much for your suggestion. The terminology has been corrected as suggestion from reviewer.

3) Section 2: "Aluminum Silicon (ADC 11) and aluminum 99 % of commercial purity have been used as base composition of metal matrix." – Please add the name of company and addtitional point in reference.

Respond to reviewer:

Thank you very much for your suggestion. The name of company has been added.

4) "Six specimens were tested for each composite variables." – Please add some comments on strain determination.

Respond to reviewer:

Thank you very much for your suggestion. We added in the manuscript "The tensile strength, strain and elongation were determined basing on ASMT E8 procedure."

5) Section 3: You mentioned "Adding Al5Ti1B on AlMgSi produced more finner grain than AlMgSi without Al5Ti1B (Fig. 2)." But it is not indicated in Figure.

Respond to reviewer:

Thank you very much for your suggestion. We corrected the sentences in these paragraph as:

"Adding Al5Ti1B master alloy on AlMgSi produced more 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. Fig. 2(a) and Fig. 2(b) show that AlSiMgTiB has finner grain than AlSiMg. Fig. 2(c) and Fig. 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."

6) Figure 3: Please add a unit to the hadness axis (MPa).

Respond to reviewer:

Thank you very much for your suggestion. The unit to the hardness axis was added.

7) "Decreasing ductility and impact strength because of clustering of SiC particles at higher reinforcement content. The clustering of SiC particles causes porosity and stress concentration and hence provides sites for crack initiation which reduces the strength [36]." - Any difficulties in the technology? Consider the following sentence: Decreasing ductility and impact strength was related to the mechanical feaures of SiC i.e. low impact strength, fracture toughness and elongation, taking as of: ……..

Respond to reviewer:

Thank you very much for your suggestion. We corrected the sentences in these paragraph as:

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. 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].

8) Conclusions: " Al5Ti1B alloy on AlMgSi alloy, increases hardness, tensile strength and elongation of composites." – Please add a Figure to this sentence.

Respond to reviewer:

Thank you very much for your suggestion. The following sentences were added in the results and discussions:

… "Fig. 3 shows that in any variation of % wt. of SiC the hardness of composite with AlSiMgTiB/SiC is higher than AlSiMg/SiC." …..

…" The results of tensile test (Figs. 4 and 5) also shown that ini all variation of

% wt. SiC AlMgSiTiB/SiC composites have higher ultimate tensile strength and elongation (ductility) than AlMgSi/SiC.” …

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

S. Sulardjaka[1,2*], Sri Nugroho[1], Norman Iskandar[1,2]

[1.] Departement of Mechanical Engineering, Faculty of Engineering, Diponegoro University, Semarang, Indonesia Jl. Prof. Soedharto, Tembalang, Semarang, Indonesia. 50275.

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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 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 specimen by HPDC. Mechanical characterizations of composite specimens were done in hardness, tensile and impact test. 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 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 ingridient. TiB caused grain refining of the matrix and enhances the mechanical properties of composites.

Keyword: 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 in 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 to get 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 particle is a common problem on 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 has 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 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 reinforcement particle. Mixtures of the ADC 11 and aluminium (purity 99 %) with specific weight ratio were melted in an alumina crucible electric furnace. The electric furnace was equipped with a controllable temperature. This process resulted of 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 (250 ◦C) and was poured using a funnel into the aluminium melted at temperature 1023K (750 ◦C). To get aluminium matrix composite with 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 temperature of 700 ^{o}C. The melted composite was poured to 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 200 °C 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 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 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 folowing formula:

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

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

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

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]. Fig. 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 of 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 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 it 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 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]. Fig. 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 more 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. Fig. 2(a) and Fig. 2(b) show that AlSiMgTiB has finner grain than AlSiMg. Fig. 2(c) and Fig. 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].

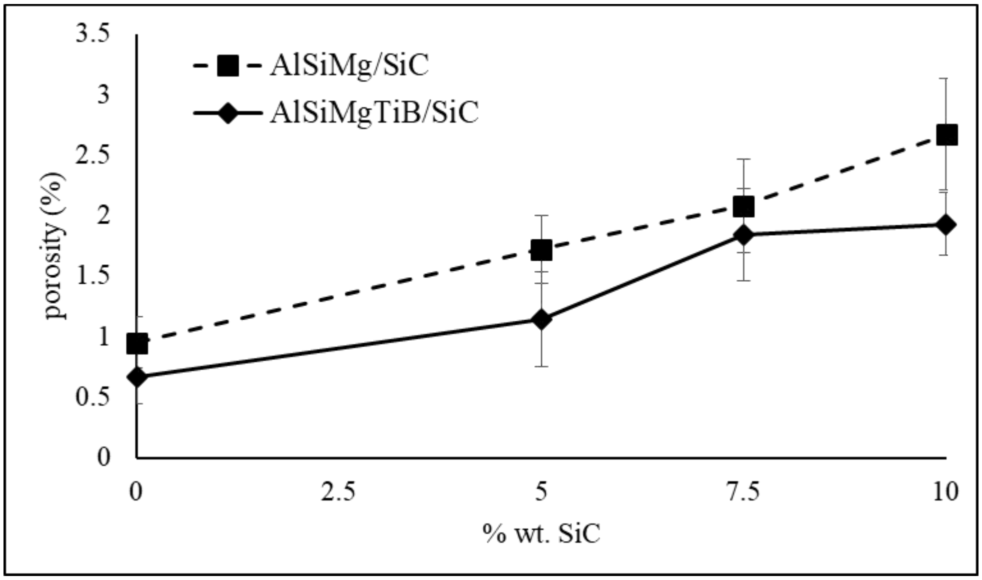
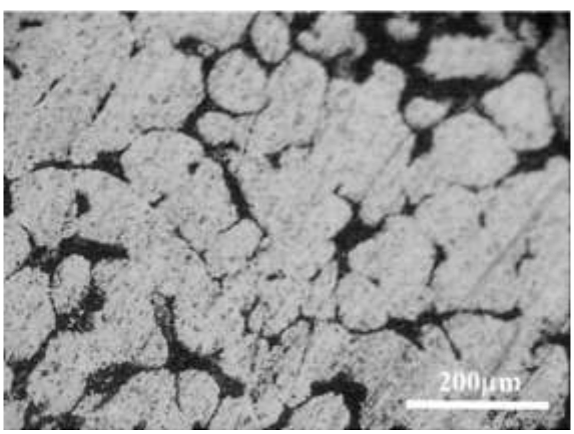
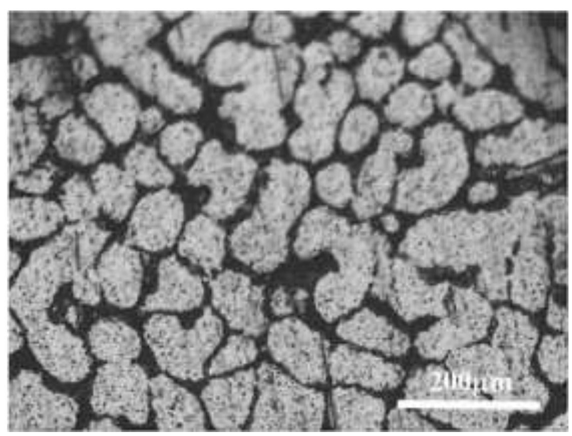


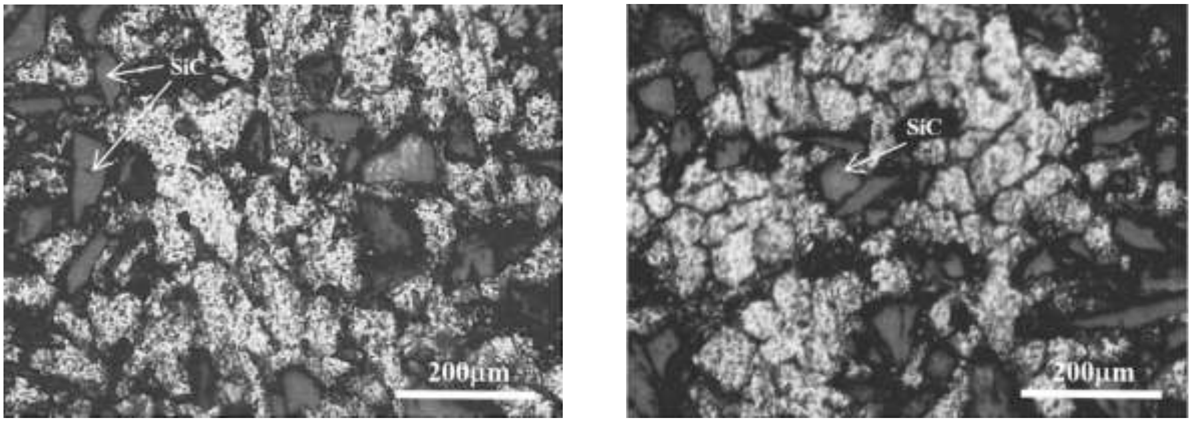
Fig. 1. Porosity of AlSiMg/SiC and AlSiMgTiB/SiC composite as a result of % wt. SiC.



(a) AlMgSi/ 0% SiC.



(b) AlMgSiTiB/ 0% SiC



(c) AlSiMg/10% SiC. (d) AlSiMgTiB/10 % SiC

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

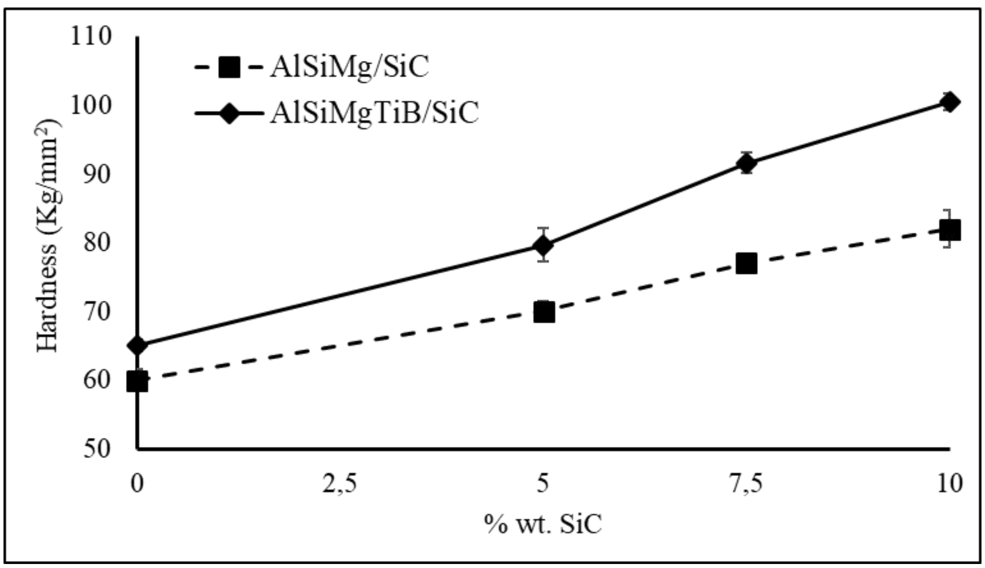


Fig. 3. Hardness of AlSiMg/SiC and AlSiMgTiB/SiC composite versus % wt. SiC.

Tensile strength of the AlMgSi/SiC and AlMgSiTiB/SiC composites are shown in Fig. 4 and Fig. 5. Fig. 4 shows that increasing % wt. of SiC increases ultimate tensile strength, but decreases ductility (Fig. 5). This change in a value of tensile strength was caused by the strengthening mechanism resulted of 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 response of SiC particles and matrix on loading. The thermal expansion coefficient of SiC particle is 3.25 x 10^{6}/° C and for aluminium alloy is 23 x 10^{6} /° C. The differences of thermal expansion between AlMgSi matrix and the SiC reinforcement causes 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 ini 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. 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].

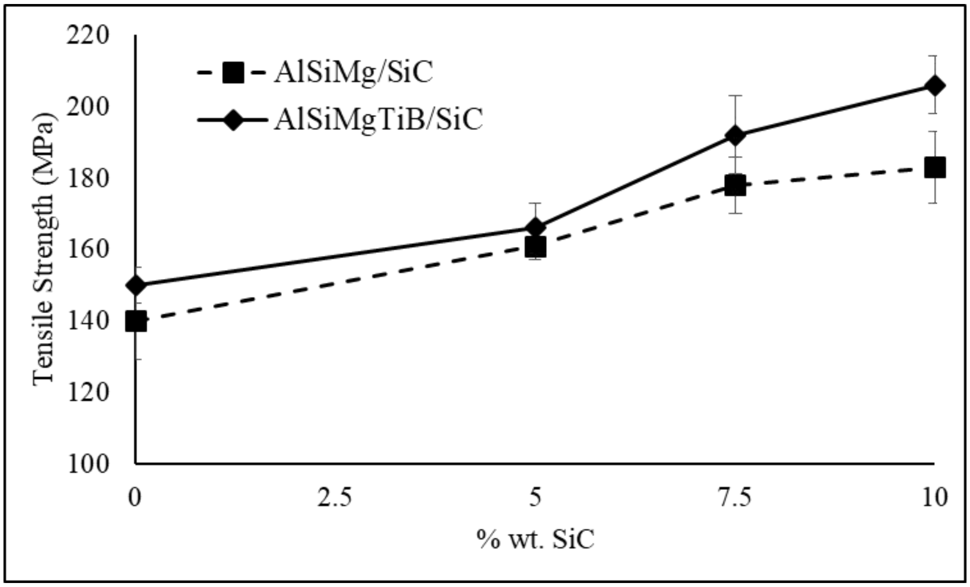


Fig. 4. Variations of Ultimate Tensile Strength (UTS) of AlSiMg/SiC and AlSiMgTiB/SiC composite due to %wt. SiC.

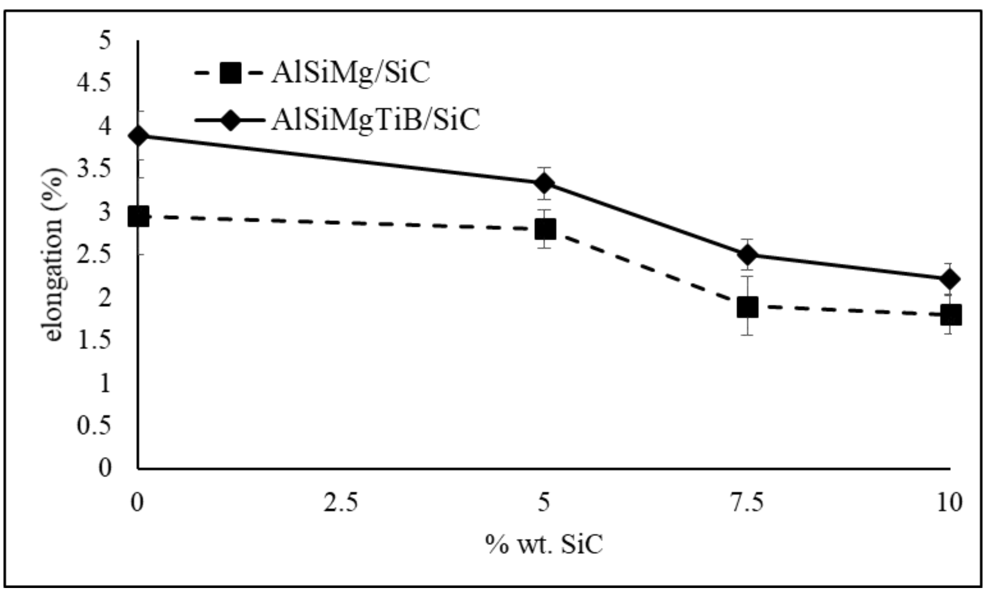


Fig. 5. Elongation of AlSiMg/SiC and AlSiMgTiB/SiC composite versus %wt. SiC.

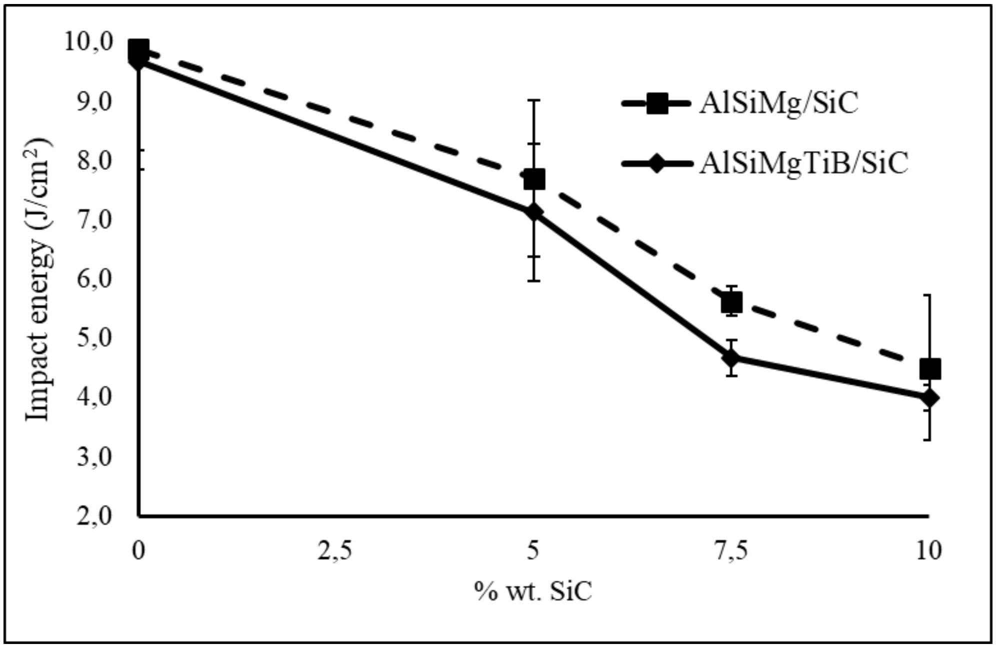


Fig. 6. Impact Strength of AlSiMg/SiC and AlSiMgTiB/SiC composite as results of %wt. SiC.

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.

Acknowledgment, *This work was supported by PUPT research grant (advanced research of higher education), Directorate of research and community service, Ministry of Research, Technology and Higher Education of the Republic of Indonesia. Contract number: 344-73/UN7.5.1/PP/2017.*

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Mon 18/01/2021 13:54
To: Sulardjaka <sulardjaka@lecturer.undip.ac.id>

Dear Author,

The revised manuscript "MECHANICAL PROPERTIES OF AlSiMg/SiC AND AlSiMgTiB/SiC PRODUCED BY SEMI-SOLID STIR CASTING AND HIGH PRESSURE DIE CASTING" is received and sent to the reviewer.

With best regards,
Aleksandra Romashkina
Materials Physics and Mechanics
Editorial Office
URL: http://mpm.spbstu.ru

От: Sulardjaka <sulardjaka@lecturer.undip.ac.id>
Отправлено: 18 января 2021 г. 6:41:14
Кому: Materials Physics and Mechanics
Тема: Re: Manuscripts for Materials Physics and Mechanics

Dear Dr. Dmitrii Indeitsev and Andrey Rudskoy
Principal Editors of Materials Physics and Mechanics

Enclosed please find the revised manuscript entitled: *Mechanical properties of AlSiMg/SiC and AlSiMgTiB/SiC produced by semi-solid stir casting and high pressure die casting* submitted for publication in Materials Physics and Mechanics. The authors are Sulardjaka, Sri Nugroho, Norman Iskandar.

Kind regards,

Sulardjaka

From: Materials Physics and Mechanics <mpmjournal@spbstu.ru>
Sent: 13 November 2020 14:29
To: Sulardjaka <sulardjaka@lecturer.undip.ac.id>
Subject: Re: Manuscripts for Materials Physics and Mechanics

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We apologize for the long period of the reviewing process and looking forward to your response.

With best regards,
Aleksandra Romashkina
Materials Physics and Mechanics
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От: Sulardjaka <sulardjaka@lecturer.undip.ac.id>
Отправлено: 8 сентября 2020 г. 7:42:37
Кому: Materials Physics and Mechanics
Тема: Re: Manuscripts for Materials Physics and Mechanics

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May I know, how the progress for publishing of my article?

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Отправлено: 17 октября 2019 г. 7:21:52
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3. The effect of TiB alloy on AlMgSi in grain of aluminum matrix and porosity of composite.
4. Strengthening mechanism of AlMgSiTiB matrix.

This is an original paper which has neither previously, nor simultaneously, in whole or in part been submitted anywhere else.

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1 attachments (764 KB)
S. Sulardjaka, Sri Nugroho, Norman Iskandar_proofs.docx;

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I am glad to inform you that your manuscript "MECHANICAL PROPERTIES OF AlSiMg/SiC AND AlSiMgTiB/SiC PRODUCED BY SEMI-SOLID STIR CASTING AND HIGH PRESSURE DIE CASTING" is accepted for publication.
Please, find attached the proofs for your paper. If you need to make any corrections, indicate them in the comments in the file or send them in a reply letter indicating the coordinates in the text of the paper.
Let us recommend that you include the paper below in your research. We believe that it fits well.
Tsemenko VN, Tolochko OV, Kol'tsova TS, Ganin SV, Mikhailov VG. Fabrication, Structure and Properties of a Composite from Aluminum Matrix Reinforced with Carbon Nanofibers. *Met Sci Heat Treat.* 2018;60(1-2): 24-31.

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Sulardjaka

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

S. Sulardjaka[1,2*], Sri Nugroho[1], Norman Iskandar[1,2]

[1]Department of Mechanical Engineering, Faculty of Engineering, Diponegoro University, Semarang, Indonesia Jl. Prof. Soedharto, Tembalang, Semarang, Indonesia. 50275

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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^oC 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. ~~Density~~ 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 ~~ingridient~~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 ~~to~~

~~get~~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 ~~on~~ 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 ~~has~~ 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 ~~of~~ 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 ºC 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 700ºC. 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 ~~of~~ 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 ~~it~~ 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 ~~more~~ 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].

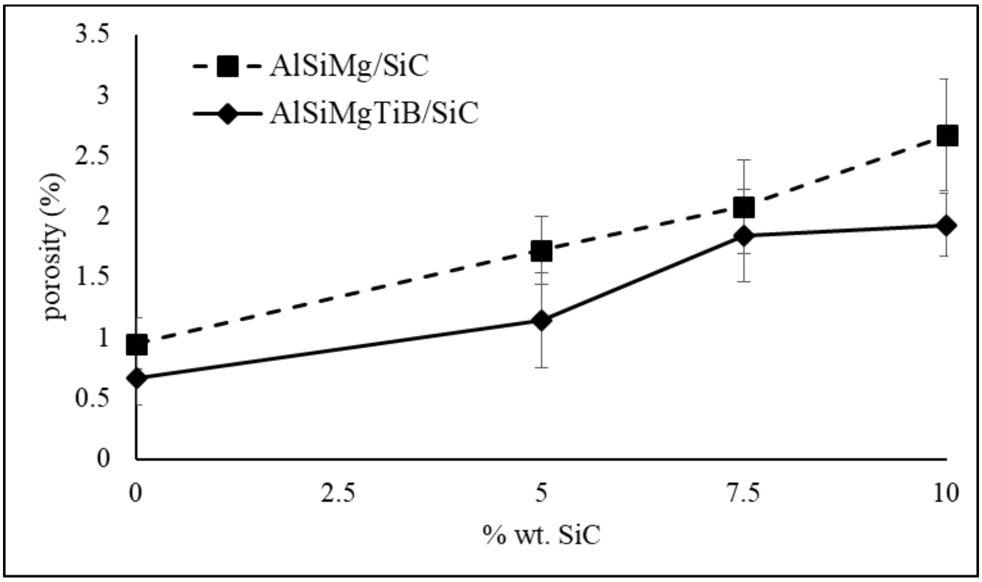
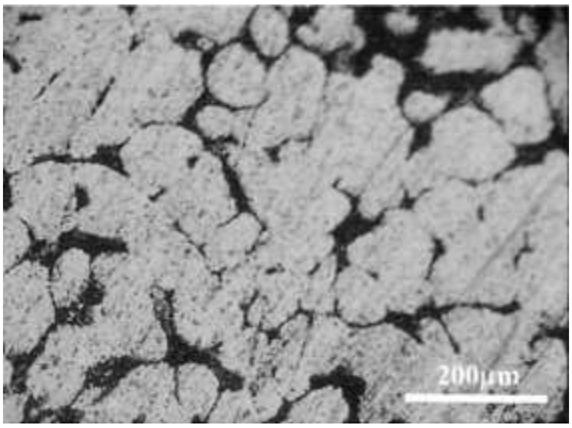
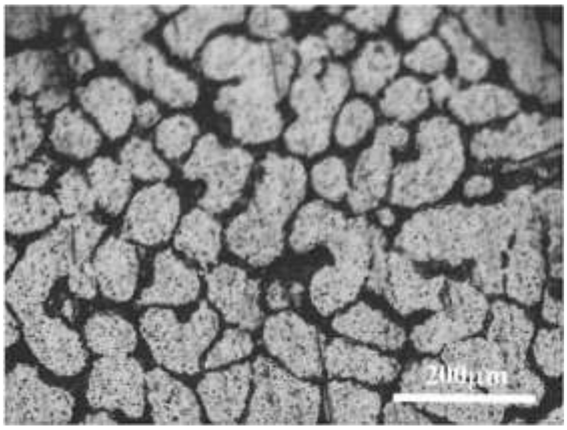


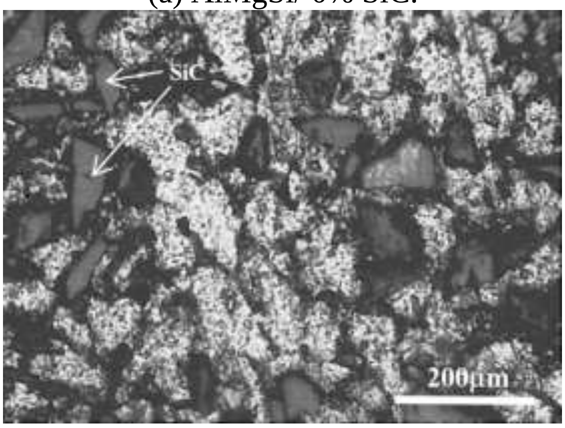
Fig. 1. Porosity of AlSiMg/SiC and AlSiMgTiB/SiC composite as a result of % wt. SiC



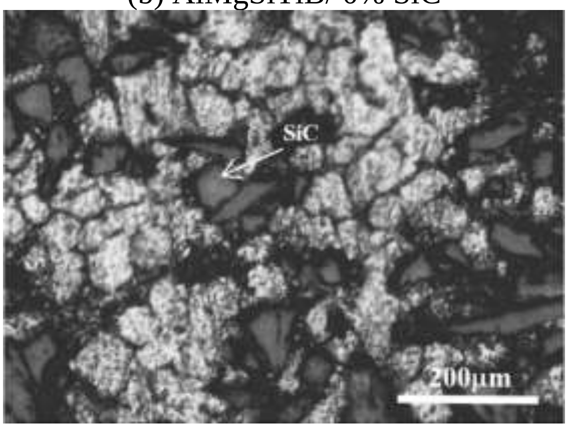
(a) AlMgSi/ 0% SiC.



(b) AlMgSiTiB/ 0% SiC



(c) AlSiMg/10% SiC.



(d) AlSiMgTiB/10 % SiC

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

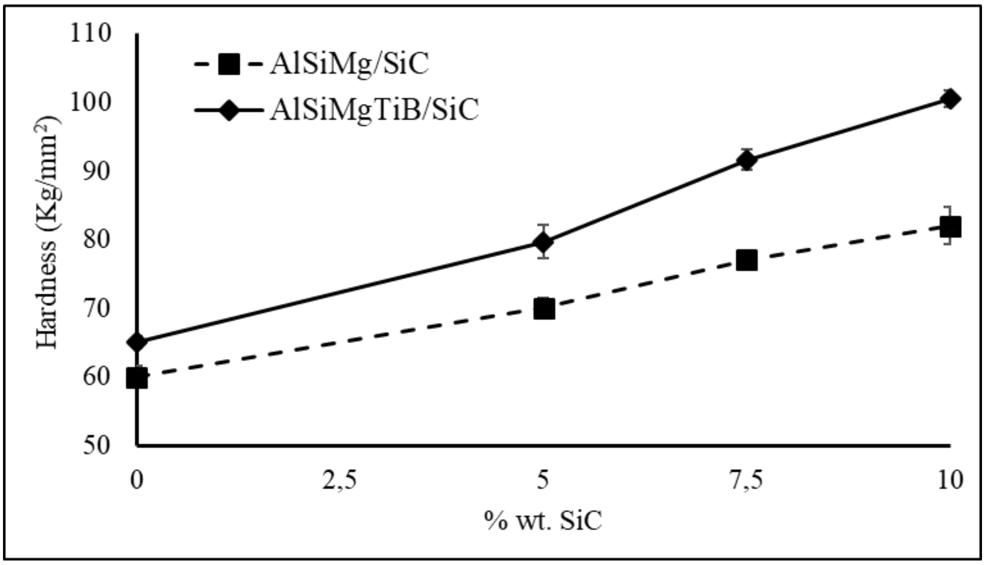


Fig. 3. Hardness of AlSiMg/SiC and AlSiMgTiB/SiC composite versus % wt. SiC

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 a the value of tensile strength was caused by the strengthening mechanism resulted of 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 causes 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 ini 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. 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].

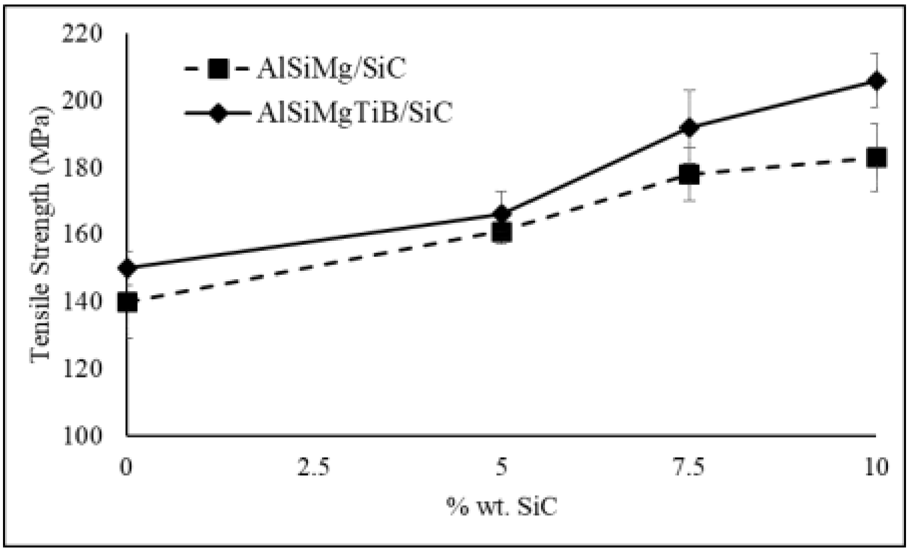


Fig. 4. Variations of Ultimate Tensile Strength (UTS) of AlSiMg/SiC and AlSiMgTiB/SiC composite due to %wt. SiC

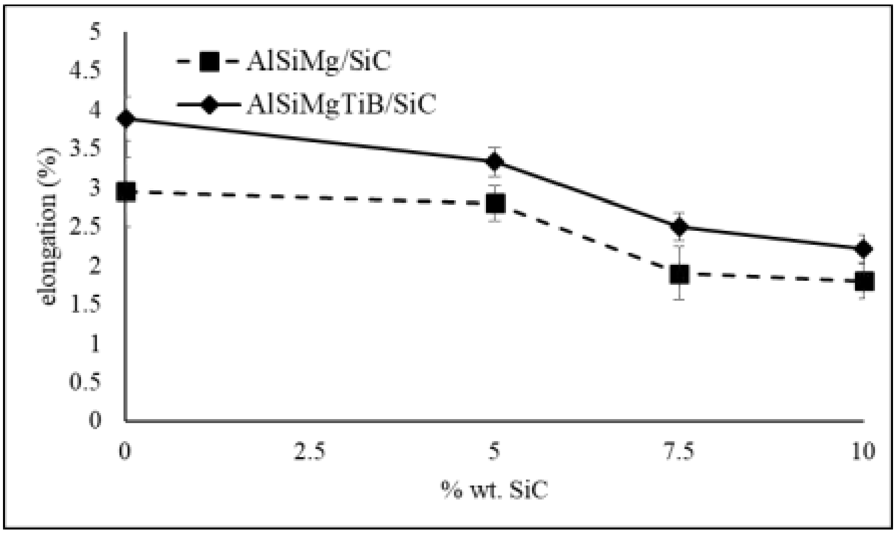


Fig. 5. Elongation of AlSiMg/SiC and AlSiMgTiB/SiC composite versus %wt. SiC

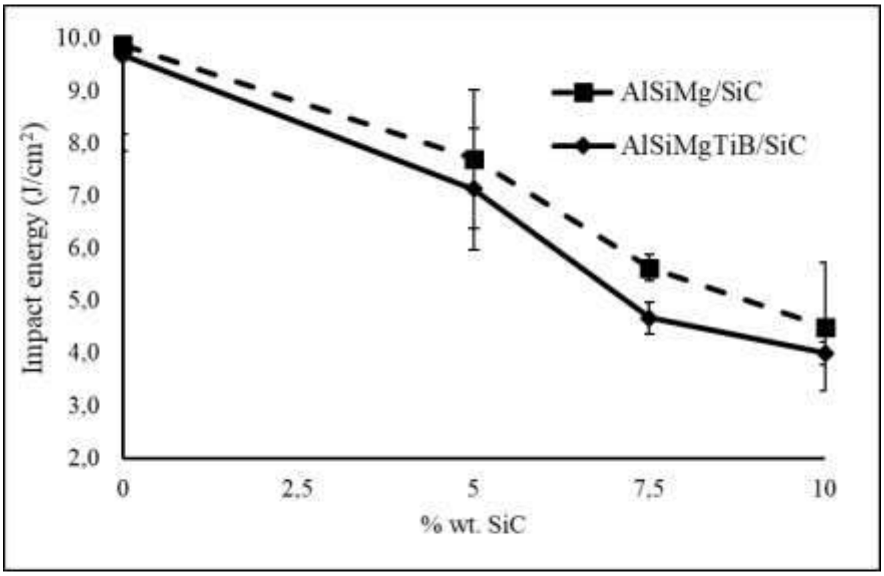


Fig. 6. Impact Strength of AlSiMg/SiC and AlSiMgTiB/SiC composite as results of %wt. SiC

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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Thank you very much for your suggestion. We accepted your suggestion to adding article: Tsemenko VN, Tolochko OV, Kol'tsova TS, Ganin SV, Mikhailov VG. Fabrication, Structure and Properties of a Composite from Aluminum Matrix Reinforced with Carbon Nanofibers. Met Sci Heat Treat. 2018;60(1-2): 24-31. this article has been added in our discussion (In Ref [38]). In last paragraph of page 5 (write with red ink).
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Enclosed please find the revised manuscript entitled: *Mechanical properties of AlSiMg/SiC and AlSiMgTiB/SiC produced by semi-solid stir casting and high pressure die casting* submitted for publication in Materials Physics and Mechanics. The authors are Sulardjaka, Sri Nugroho, Norman Iskandar.

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Enclosed please find the manuscript entitled: *Mechanical properties of AlSiMg/SiC and AlSiMgTiB/SiC produced by semi-solid stir casting and high pressure die casting* submitted for publication in Materials Physics and Mechanics. The authors are Sulardjaka, Sri Nugroho, Norman Iskandar.

The basic findings are as follows.

1. Semi solid and HPDC method for producing aluminum matrix composite.
2. The effect of TiB alloy on AlMgSi on mechanical properties of aluminum matrix composite.
3. The effect of TiB alloy on AlMgSi in grain of aluminum matrix and porosity of composite.
4. Strengthening mechanism of AlMgSiTiB matrix.

This is an original paper which has neither previously, nor simultaneously, in whole or in part been submitted anywhere else.

Kind regards,

Sulardjaka

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

S. Sulardjaka[1,2*], Sri Nugroho[1], Norman Iskandar[1,2]

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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^oC 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 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 700ºC. 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].

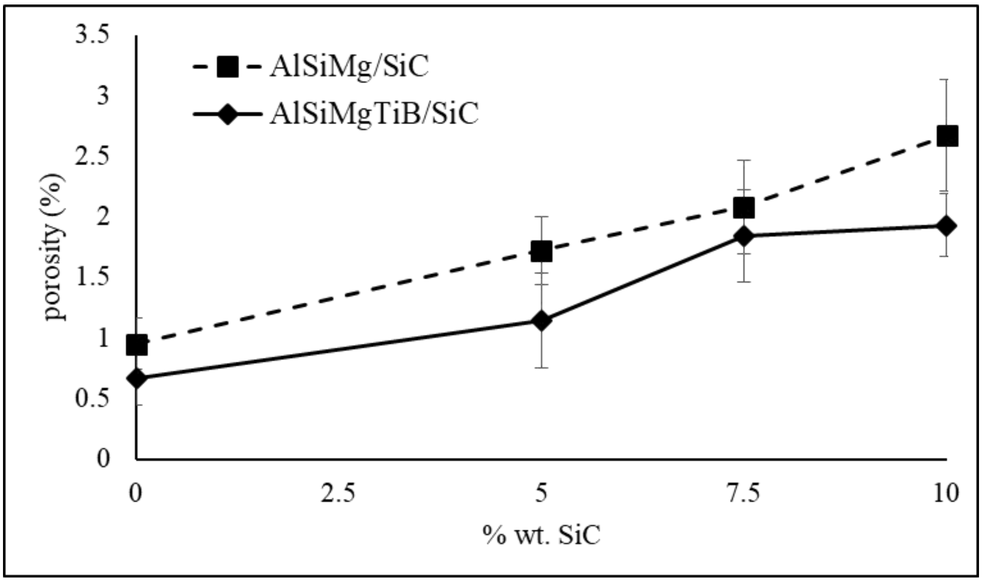
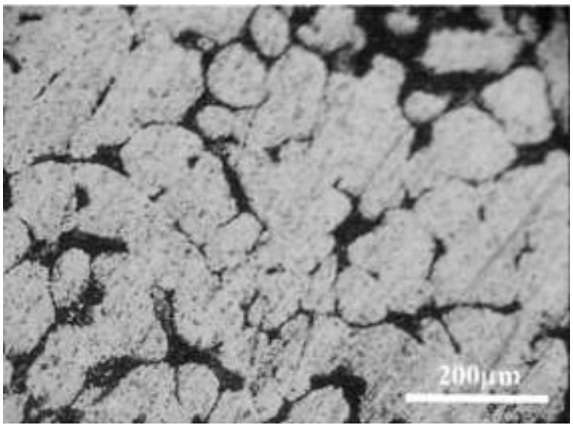
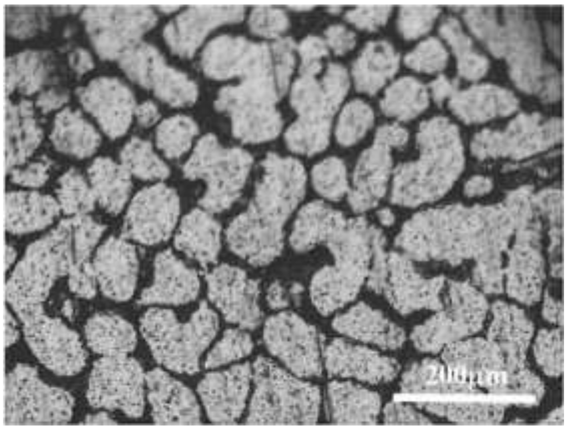


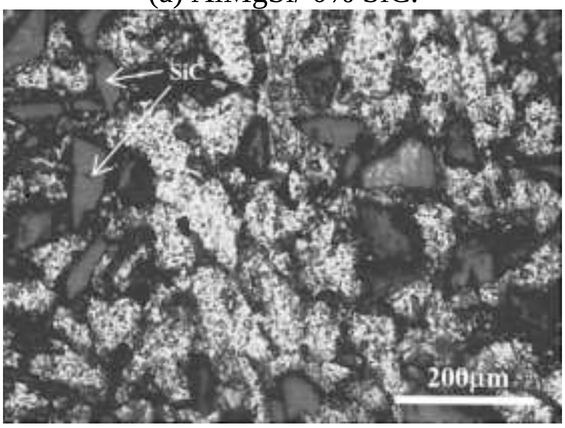
Fig. 1. Porosity of AlSiMg/SiC and AlSiMgTiB/SiC composite as a result of % wt. SiC



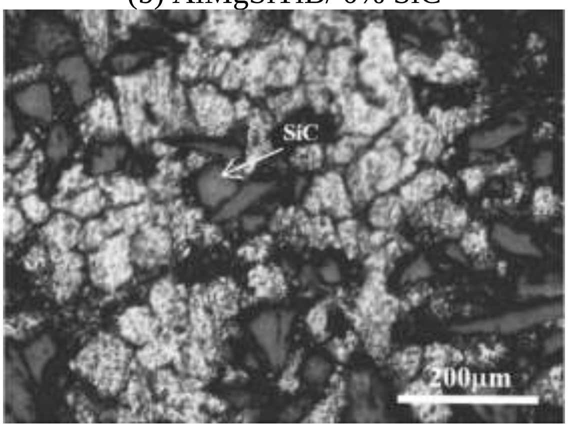
(a) AlMgSi/ 0% SiC.



(b) AlMgSiTiB/ 0% SiC



(c) AlSiMg/10% SiC.



(d) AlSiMgTiB/10 % SiC

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

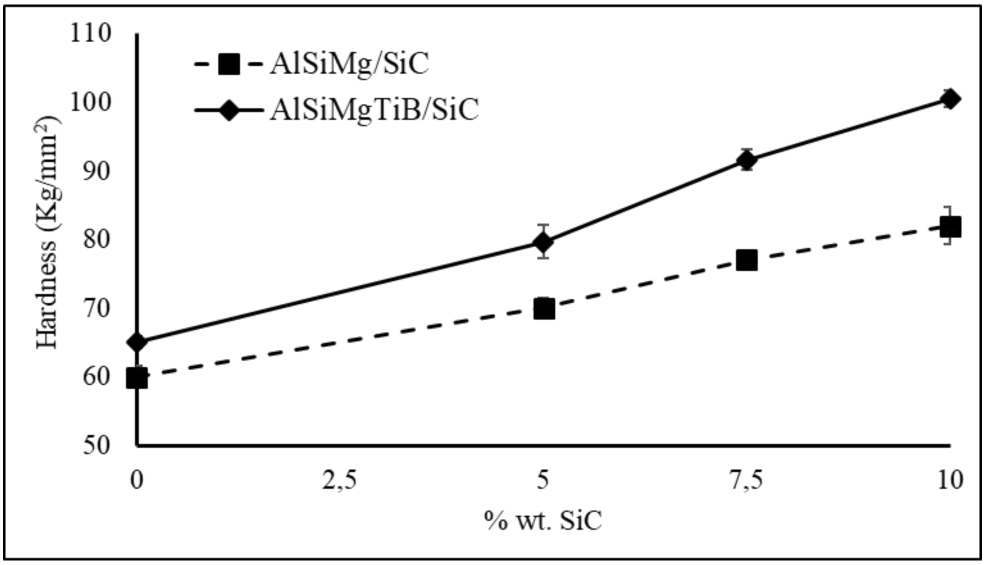


Fig. 3. Hardness of AlSiMg/SiC and AlSiMgTiB/SiC composite versus % wt. SiC

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].

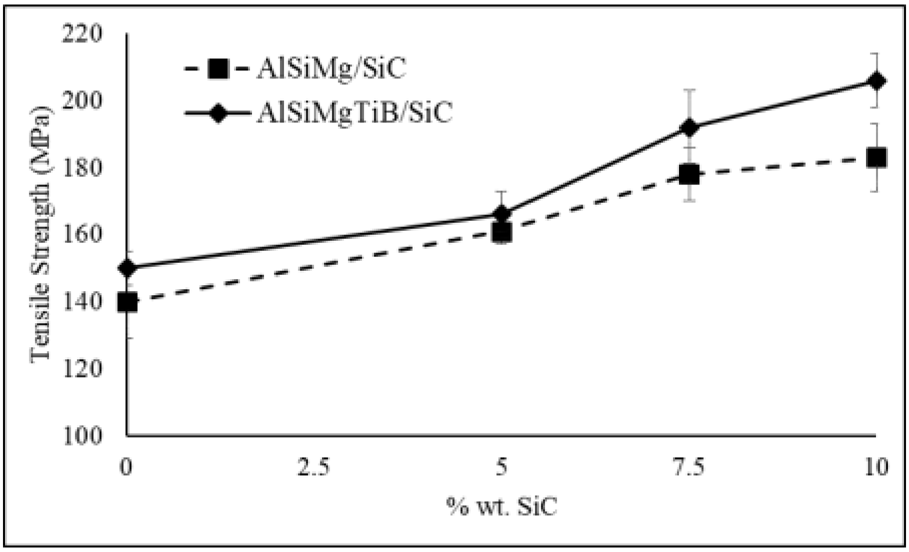


Fig. 4. Variations of Ultimate Tensile Strength (UTS) of AlSiMg/SiC and AlSiMgTiB/SiC composite due to %wt. SiC

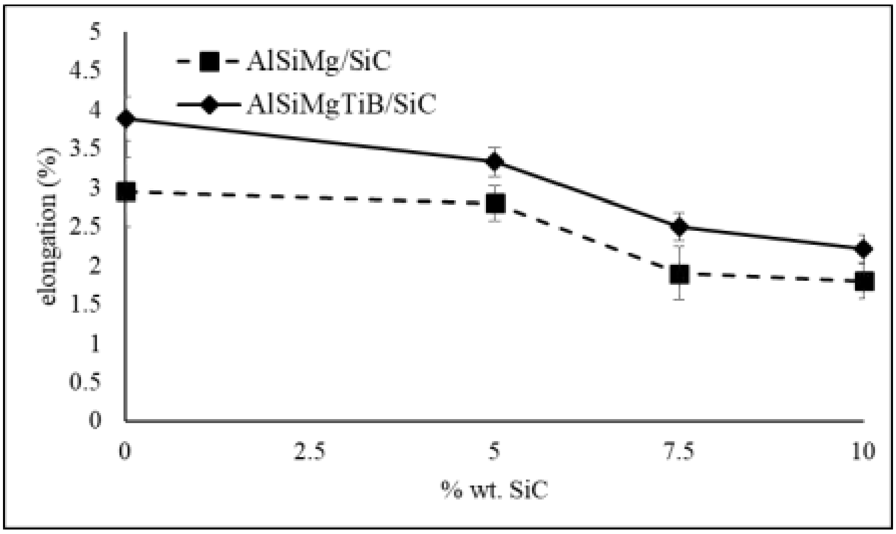


Fig. 5. Elongation of AlSiMg/SiC and AlSiMgTiB/SiC composite versus %wt. SiC

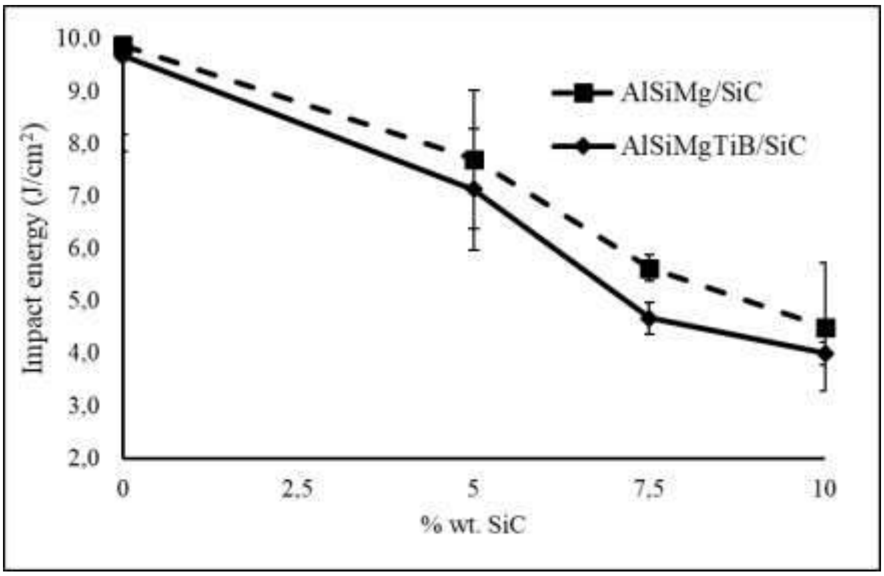


Fig. 6. Impact Strength of AlSiMg/SiC and AlSiMgTiB/SiC composite as results of %wt. SiC

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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Thank you very much for your suggestion. We accepted your suggestion to adding article: Tsemenko VN, Tolochko OV, Kol'tsova TS, Ganin SV, Mikhailov VG. Fabrication, Structure and Properties of a Composite from Aluminum Matrix Reinforced with Carbon Nanofibers. Met Sci Heat Treat. 2018;60(1-2): 24-31. this article has been added in our discussion (In Ref [38]). In last paragraph of page 5 (write with red ink).
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The basic findings are as follows.

1. Semi solid and HPDC method for producing aluminum matrix composite.
2. The effect of TiB alloy on AlMgSi on mechanical properties of aluminum matrix composite.
3. The effect of TiB alloy on AlMgSi in grain of aluminum matrix and porosity of composite.
4. Strengthening mechanism of AlMgSiTiB matrix.

This is an original paper which has neither previously, nor simultaneously, in whole or in part been submitted anywhere else.

Kind regards,

Sulardjaka