INFLUENCE OF STIRRING PROCESS ON THE MECHANICAL PROPERTIES OF ENAC-46000 REINFORCED BY NANO-PARTICLES

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Abstract

In this study, ENAC-46000 alloy was reinforced by nano-particles in order to improve its mechanical properties. ENAC-46000 alloy-based composites were produced via the stir casting method. Three different reinforcement volume fractions, stirring speeds, and stirring temperatures were determined to study their effects on the mechanical properties of ENAC-46000 alloy-based composites. Brinell hardness test and three-point bending test were applied to determine the hardness and the flexural strength of ENAC-46000 alloy and composite samples. The results showed that the mechanical properties of the particle reinforced composites were improved due to nano-sized reinforcement particles. The hardness and the flexural strength of the composite samples increased with the increase in the volume fraction of nano-sized reinforcement particles. The mechanical properties of ENAC-46000 alloy declined as the stirring speed was increased. On the other hand, the mechanical properties of the composites improved with the increase in stirring speed due to uniform reinforcement particle distribution. As the stirring temperature was raised, the mechanical properties of the nano-particle reinforced composite samples improved because the fluidity of the molten alloy increases due to the increase in stirring temperature. However, when the highest values of volume fraction, stirring speed, and stirring temperature were simultaneously applied for the production of composite materials, these highest values of the investigated parameters resulted in a significant deteriorating influence on the mechanical properties of ENAC-46000 alloy-based composites.

Keywords: ENAC-46000 alloy, nanocomposite, stirring speed, stirring temperature

1. Introduction

Aluminum alloys are widely used in many applications of manufacturing and technology (automotive, aerospace, etc.). Among aluminum alloys, ENAC-46000 consists of aluminum, silicon, copper and iron elements, and is preferred in the automotive industry because there are some benefits of using this alloy, such as high strength to weight ratio, excellent castability, and low cost (Voncina et al., 2017).

Alloying elements such as silicon, copper, and zinc determine the microstructural properties of Al-based alloys, which has a strong influence on the improvement of the mechanical properties such as high-temperature strength and tensile properties (Hernandez et al., 2017; Michael et al., 2018; Shaji et al., 2013). Moreover, silicon in aluminum alloys increases the fluidity of alloy during the casting process. Therefore, transmission parts and components for the automotive industry are made of Al-Si-based alloys (Shaji et al., 2013).

In order to further increase in the mechanical properties of Al-based alloys, micro and nano-sized reinforcement particles are added into alloy, which improves thermal performance and wear resistance in addition to other mechanical properties such as tensile strength (Huda et al., 2019; Karthikeyan et al., 2017; Khalid et al., 2015; Okumus et al., 2012). The tensile strength and the wear resistance of Al-based alloys that are reinforced with micro and nano reinforcement particles increase as the volume fraction of reinforcement particles increases (Huda et al., 2019; Khalid et al., 2015; Kumar et al., 2011; Ugwuoke et al. 2018; Yong et al., 2019). The effect of nano-sized reinforcement particles on the microstructure and mechanical properties of particle-reinforced composites is stronger than that of micro-sized reinforcement particles (Sajjadi et al. 2011; Harichandran and Selvakumar, 2016).

In the automotive industry, the parts produced from Al-based alloys are manufactured by several production methods. Casting is one of the most preferred production methods because of the low cost and simple process to manufacture the parts which are made of Al-based alloys (Otarawanna and Dahle, 2011). However, there are some problems with the production of particle-reinforced composites via the casting method. The distribution of reinforcement particles is the main problem in the production of particle-reinforced composites. The uniform distribution of nano-sized reinforcement particles in the microstructure is more difficult than that of micro-sized reinforcement particles. Therefore, the size and volume fraction of reinforcement particles determine the distribution of reinforcement particles, which affects the mechanical properties of particle-reinforced composites. Moreover, in the production of particle-reinforced composites via the stir casting method, the production parameters such as stirring speed and stirring time are influential on the distribution of reinforcement particles (Balasivanandha et al. 2006).

In this study, ENAC-46000 alloy and ENAC-46000 alloy-based composites reinforced with Al_2O_3 particles (Al-Al_2O_3) were produced by using the stir casting method. The effects of volume fraction of nano-sized Al_2O_3 particles, stirring speed, and stirring temperature on the mechanical properties of Al-Al_2O_3 composites were investigated.

2. Materials and Methods

ENAC-46000 alloy consisting of aluminum, silicon, copper, and iron elements was used as matrix material and nano-sized Al_2O_3 particle was preferred as the reinforcement particle to manufacture the ENAC-46000-Al_2O_3 (Al-Al_2O_3) composite samples. Figure 1 shows Al_2O_3 reinforcement particles.

Al-Al_2O_3 composites were produced via the stir casting method. Three different reinforcement volume fractions, stirring speeds, and stirring temperatures were determined to study the effects of volume fraction of nano-sized Al_2O_3 particles, stirring speed, and stirring temperature on the mechanical properties of Al-Al_2O_3 composites. Al_2O_3 particles were added into the liquid Al-based alloy at the volume fractions of 1, 2, and 3%.

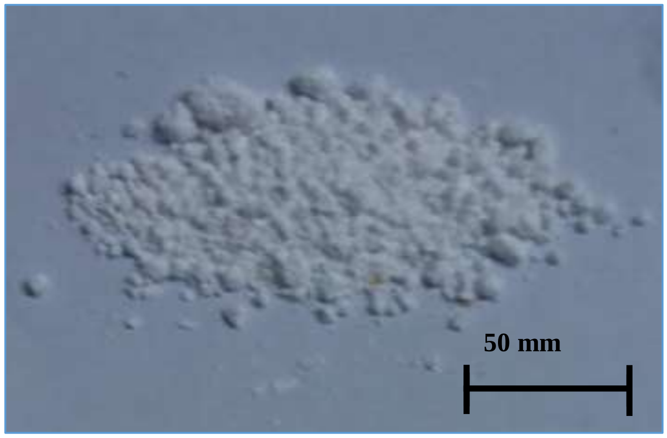

Figure 1. Agglomerated nano Al_2O_3 reinforcement particles

The stirring process of molten ENAC-46000 Al-based alloy and Al_2O_3 particles was carried out at the stirring speed of 200, 300, 400 rpm, and at the temperatures of 650, 700, and 750 ^{0}C.

After the stirring process, the molten alloys reinforced with the nano-sized Al_2O_3 particles were injected into the mold to produce cover used in the transmission pump as seen in Figure 2.

(a) **(b)**

Figure 2. (a) Front and (b) back view of the produced cover

The densities of the produced samples were measured according to the Archimedes' principle. Brinell hardness test was carried out with a 2.5 mm diameter ball indenter and 62.5 kgf load test. The three-point bending test was applied to the samples to determine the flexural strengths of ENAC-46000 Al alloy and Al-Al_2O_3 composites.

3. Results and Discussions

Figure 3 shows the relative densities of ENAC-46000 Al alloy and Al-Al_2O_3 composites. The relative density of ENAC-46000 Al alloy was higher than those of Al-Al_2O_3 composites.

As the volume fraction of Al_2O_3 reinforcement particles was increased, the relative density decreased. Because the clustering probability of nano-sized reinforcement particles increases and the clusters of reinforcement particles increase the amount of void and porosity formed in the microstructure of the composites (Bindumadhavan PN et al. 2001).

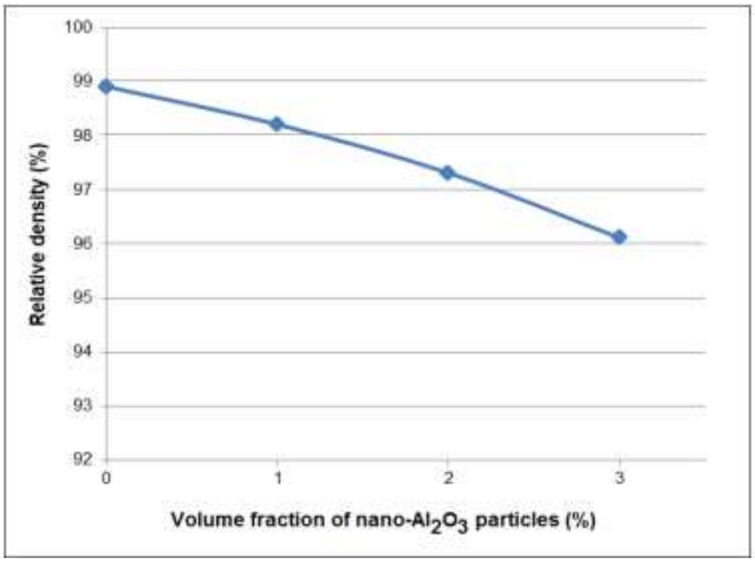

Figure 3. Relative densities of ENAC-46000 Al alloy and Al-Al_2O_3 composites manufactured at 700 ^{0}C and 300 rpm

The hardness of all Al-Al_2O_3 composites was higher than that of ENAC-46000 Al alloy for all stirring speeds (Figure 4). As expected (Ünal ve Diler, 2018), the hardness of the samples increased with the increase in the volume fraction of nano-sized Al_2O_3 particles because Al_2O_3 ceramic particle is much harder than Al alloy. The hardness of ENAC-46000 alloy declined as the stirring speed was increased due to the turbulence formation in the molten. On the other hand, the hardness values of the composites increased with the increase in stirring speed due to uniform reinforcement particle distribution. The stirring speed of 200 rpm was low to obtain uniform particle distribution for composite samples. However, with the increase in stirring speed, the stirring shear forces decrease and the displacement of particles per unit of time increases, which distributes the reinforcement particles more uniformly (Yang et al., 2017). Therefore, the hardness of Al-Al_2O_3 composites improved with the increase in stirring speed.

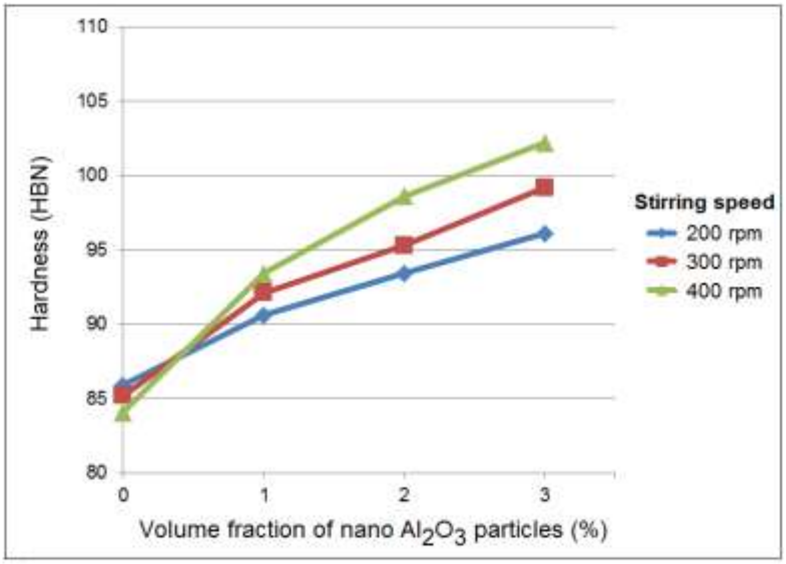

Figure 4. The hardness of ENAC-46000 Al alloy and Al-Al_2O_3 composites depending on stirring speed at 700 ^{0}C

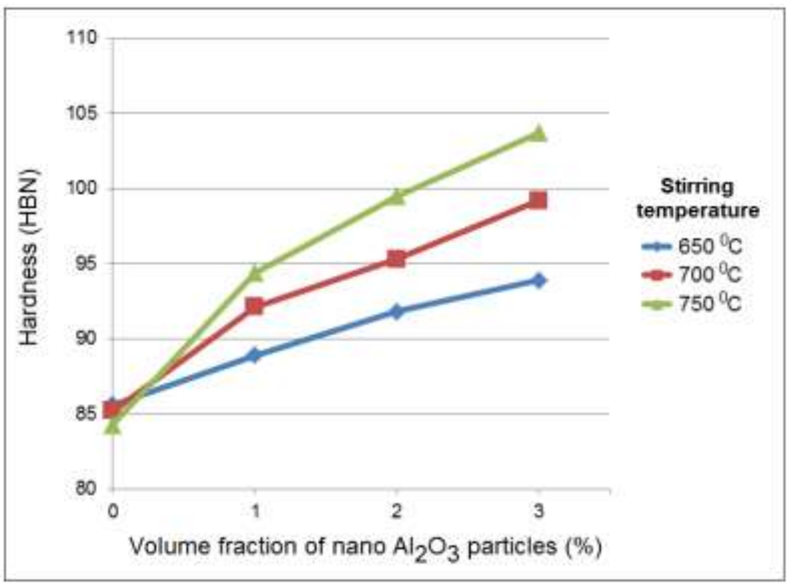

Figure 5. The hardness of ENAC-46000 Al alloy and Al-Al_2O_3 composites depending on stirring temperature at 300 rpm

The hardness of Al-Al_2O_3 composites was higher than that of ENAC-46000 Al alloy for all stirring temperature (Figure 5). Because the melt becomes more fluid as the stirring temperature increases (Heidarzadeh et al., 2014) and more fluid melt can easily fill the porosities and voids in the microstructure and wets better the reinforcement particles. Therefore, the hardness of the Al-Al_2O_3 composites increased as the stirring temperature raised.

Figure 6 shows the flexural strength of ENAC-46000 Al alloy and Al-Al_2O_3 composites depending on stirring speed. The flexural strength of Al-Al_2O_3 composites was higher than that of ENAC-46000 Al alloy. As the stirring speed was increased, the flexural strength improved since the uniform distribution of reinforcement particles could be achieved due to the decrease in shear force and the increase in the displacement of particles per unit of time (Aqida et al., 2003; Sijo and Jayadevan, 2018). On the other hand, the stirring speed of 400 rpm had a detrimental effect on the flexural strength for the composite reinforced with vol.3% Al_2O_3 particles because the high stirring speed forms turbulence in the melt, creating new voids and porosities. Both the high porosity level forming in the composite with vol.3% Al_2O_3 particles and the created new voids and porosities due to turbulence formation cause weak regions, which can cause early crack formation in the microstructure. Both the high clustering probability due to the high volume fraction of Al_2O_3 particles and high porosity formation due to high stirring speed weakened the flexural strength of Al-Al_2O_3 composites in this study.

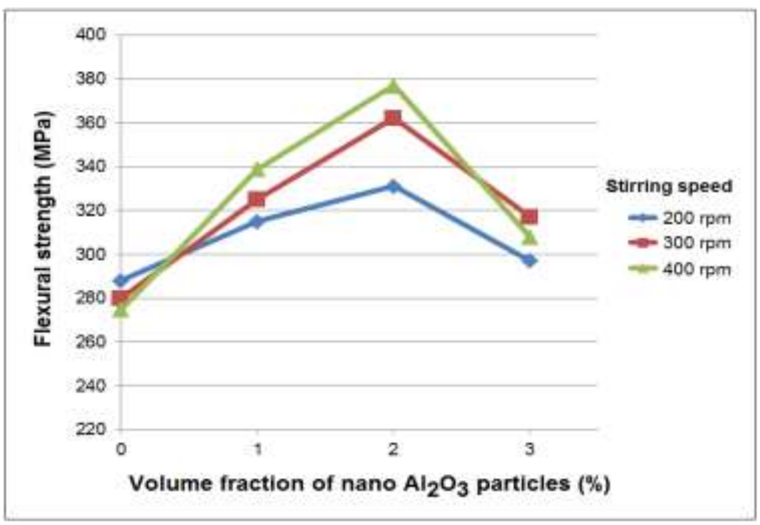

Figure 6. The flexural strength of ENAC-46000 Al alloy and Al-Al_2O_3 composites depending on stirring speed at 700 ^{0}C

The effect of stirring temperature on the flexural strength of ENAC-46000 Al alloy and Al-Al_2O_3 composites is shown in Figure 7. The flexural strength of ENAC-46000 Al alloy decreased as the stirring temperature increased because the amount of the bubbles formed in the melt raises with the increase in stirring temperature. On the other hand, the higher values of stirring temperature had a positive influence on the Al-Al_2O_3 composite. This can be attributed to the decrease in the viscosity of the melt (Bihari and Shing, 2017; Dixon et al., 2019). The melt can easily fill the voids and porosities in the microstructure as the fluidity of the melt increases. Moreover, the nano-sized reinforcement particles are easily wetted by the melt. In this case, strengthening mechanisms are more effective for Al-Al_2O_3 composites. However, the stirring temperature of 750 ^{0}C had a significant deteriorating effect on the flexural strength for the composite with vol.3% Al_2O_3 particles. This can be attributed to the high porosity level due to the clustering of nano Al_2O_3 reinforcement particles and the increase in undesired chemical reactions formed between the melt and reinforcement particles because these undesired chemical reactions can act as a source for the crack initiation, which weakened the flexural strength of the composites.

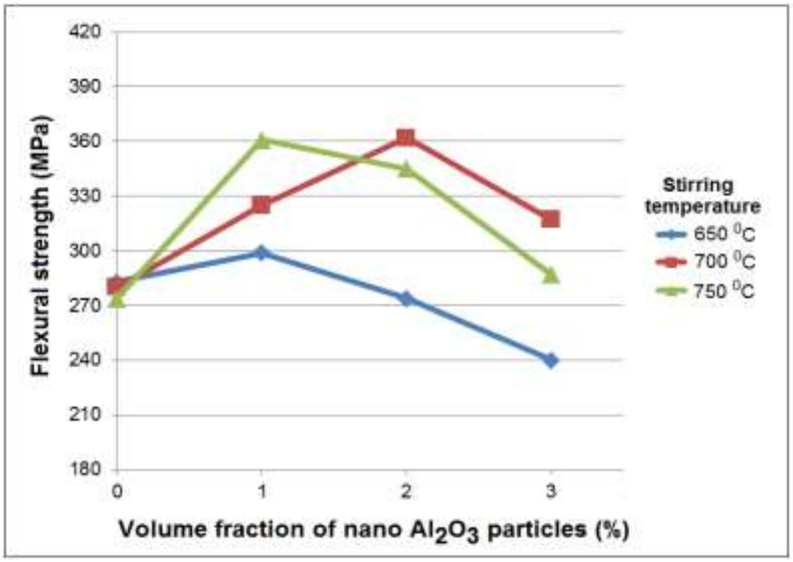

Figure 7. The flexural strength of ENAC-46000 Al alloy and Al-Al_2O_3 composites depending on stirring temperature at 300 rpm

As a result of the mentioned above, the mechanical properties of ENAC-46000 Al alloy was improved by reinforcing with the nano-sized Al_2O_3 particles. Also, the stirring speed and stirring temperature were effective on the mechanical properties. The increases in the volume fraction of nano reinforcement particles, the stirring speed and temperature have positive influences on the hardness and the flexural strength of ENAC-46000 Al alloy reinforced with the nano-sized Al_2O_3 particles. On the other hand, the highest values of volume fraction, stirring speed and stirring temperature on the mechanical properties of ENAC-46000 Al alloy reinforced with the nano-sized Al_2O_3 particles.

4. Conclusion

The following results were obtained in this study:

Relative densities of all Al-Al_2O_3 composites were lower than ENAC-46000 Al alloy. As the volume fraction of Al_2O_3 was increased, the relative density decreased due to the clustering of nano Al_2O_3 particles.

The hardness values of Al-Al_2O_3 composites were higher than ENAC-46000 Al alloy. Although the porosity increased with the increase in the volume fraction of reinforcement particles, the hardness of Al-Al_2O_3 composites improved because the positive effect of hard Al_2O_3 particles was higher than the negative effect of porosity on the hardness. As the stirring speed was increased, the hardness of Al-Al_2O_3 composites increased because of the decrease in shear force and the increase in the displacement of particles per unit of time. Similarly, the hardness of Al-Al_2O_3 composites increased with the increase in stirring temperature.

The flexural strength of Al-Al_2O_3 composites was higher than ENAC-46000 Al alloy. However, the flexural strength started to decrease after the vol.2% Al_2O_3 particles. Up to 300 rpm, the flexural strength improved as the stirring speed was increased. On the other hand, the stirring speed of 400 rpm had a negative influence on Al-Al_2O_3 composite reinforced with vol.3% Al_2O_3 particles because the high value of stirring speed caused turbulence in the melt, which increased the porosity level of the composite. The negative effect of porosity due to the high volume fraction of reinforcement particles had a higher influence than the positive effect of strengthening mechanisms of reinforcement particles, which deteriorated the flexural strength of the composite having vol.3% Al_2O_3 particles. The flexural strength of Al-Al_2O_3 composite improved with the increase in stirring temperature. However, the high stirring temperature values had a negative influence on the flexural strength of the composites with the high volume fractions of Al_2O_3 particles.

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References

Aqida SN, Ghazali MI, Hashim 2003. The effects of stirring speed and reinforcement particles on porosity formation in cast MMC. Jurnal Mekanikal, 16: 22-30.

Balasivanandha PS, Karunamoorthy L, Kathiresan S, Mohan B 2006. Influence of stirring speed and stirring time on distribution of particles in cast metal matrix composite. Journal of Materials Processing Technology, 171(2): 268-273.

Bihari B and Singh AK 2017. An overview on different processing parameters in particulate reinforced metal matrix composite fabricated by stir casting process. International Journal of Engineering Research and Application, 7(1): 42-48.

Bindumadhavan PN, Chia TK, Chandrasekaran M, Wah HK, Lam LN, Prabhakar O 2001. Effect of particle-porosity clusters on tribological behavior of cast aluminum alloy A356-SiCp metal matrix composites. Materials Science and Engineering: A, 315(1-2): 217-226.

Dixon JJJ, Logasarathy S, Mageshwaran GS, Neveen M 2019. Fabrication of Al7075 metal matrix composite through stir casting method - A review. International Journal of Engineering Research & Technology (IJERT), 7(6): 1-7.

Harichandran R and Selvakumar N 2016. Effect of nano/micro B4C particles on the mechanical properties of aluminium metal matrix composites fabricated by ultrasonic cavitation-assisted solidification process. Archives of Civil and Mechanical Engineering, 16(1): 147-158.

Heidarzadeh A, Emamy M, Rahimzadeh A, Soufi R, Heidary DSB, Nasibi SH 2014. The effect of copper addition on the fluidity and viscosity of an Al-Mg-Si alloy. Journal of Materials Engineering and Performance, 23(2): 469-476.

Hernandez FCR, Ramírez JMH, Mackay R 2017. Al-Si Alloys: Automotive, Aeronautical, and Aerospace Applications. Switzerland: Springer International Publishing, 237 pp.

Huda AAS, Adil AM, Hussain JA 2019. Mechanical and wear behavior of AA7075 aluminum matrix composites reinforced by Al2O3 nanoparticles. Nanocomposites, 5(3): 67-73.

Karthikeyan A and Nallusamy S 2017. Investigation on mechanical properties and wear behavior of Al-Si-SiC-Graphite composite using SEM and EDAX. IOP Conf. Series: Materials Science and Engineering, 225(012281): 1-9.

Khalid AEA, Dalia S, Hossam EDMS 2015. Wear and corrosion behavior of Al–Si matrix composite reinforced with alumina. Journal of Bio- and Tribo-Corrosion, 1(5): 1-10.

Kumar GBV, Rao CSP, Selvaraj N 2011. Mechanical and dry sliding wear behavior of Al7075 alloy-reinforced with SiC particles. Journal of Composite Materials, 46(10): 1201-1209.

Michael VG, Alexandra K, Vadim SZ, Nikolai AB, Alan D 2018. Casting Aluminum Alloys: Their Physical And Mechanical Metallurgy. United Kingdom: Butterworth-Heinemann, 562 pp.

Okumus SC, Aslan S, Karslıoglu R, Gultekin D, Akbulut H 2012. Thermal expansion and thermal conductivity behaviors of Al-Si/SiC/graphite hybrid metal matrix composites (MMCs). Materials Science (Medziagotyra), 18(4): 341-346.

Otarawanna S and Dahle AK 2011. Casting of aluminium alloys. In: Lumley R, (ed.), Fundemantals of aluminium metallurgy: Production, processing and applications. Cambridge: Woodhead Publishing, pp. 141-154.

Sajjadi SA, Ezatpour HR, Beygi H 2011. Microstructure and mechanical properties of Al–Al2O3 micro and nano composites fabricated by stir casting. Materials Science and Engineering A, 528: 8765-8771.

Shaji MC, Ravikumar KK, Ravi M, Sukumaran K 2013. Development of a high strength cast aluminium alloy for possible automotive applications. Materials Science Forum, 765: 54-58.

Sijo MT, Jayadevan KR 2018. Characterization of stir cast aluminium silicon carbide metal matrix composite. Materials Today: Proceedings, 5: 23844-23852.

Ugwuoke JC, Agbo AO, Anioke S, Onoh GN 2018. Development of aluminum–silicon alloy-siliconcarbide particulate reinforced composite for automobile brake disc application. International Journal of Engineering Inventions, 7(9): 47-54.

Ünal TG and Diler EA 2018. Properties of $AlSi_9Cu_3$ metal matrix micro and nano composites produced via stir casting. Open Chemistry, 16: 726-731.

Voncina M, Mocnik N, Nagode A, Stoic A, Bizjak M 2017. Dependence of mechanical properties on Cu content in AlSi9Cu3(Fe) alloy. Tehnicki Vjesnik, 1: 229-231.

Yang Z, Pan L, Han J, Li Z, Wang J, Li X, Li W 2017. Experimental and simulation research on the influence of stirring parameters on the distribution of particles in cast SiCp/A356 composites. Journal of Engineering, 9413060: 1-11.

Yong H, Tong W, Yue G, Wenyang W, Mingkai S, Long Q, Hongwei Z, Maosen W 2019. Effects of T6 treatment, tensile temperature, and mass fraction of SiC on the mechanical properties of SiCp/6061Al composites. Materials, 12(1602): 1-14.