IIETA International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Annales de Chimie - Science des Matériaux
Vol. 46, No. 6, December, 2022, pp. 333-338
Journal homepage: http://iieta.org/journals/acsm

Fabrication and Mechanical Behaviour Investigation on Aluminium 7075 Boron Carbide and Inconel Alloy 625 Metal Matrix Composite Using Ultra Sonic Stir Casting Method

M. Thayumanavan*, K.R Vijaya Kumar

Dr. M. G. R Educational and Research Institute, Chennai 600095, India

Corresponding Author Email: thayu1511@gmail.com

https://doi.org/10.18280/acsm.460607

Received: 2 November 2022
Accepted: 17 November 2022

Keywords:
aluminium metal matrix composite, ultrasonic stir casting, uniform dispersion, particle distribution, reinforcement

ABSTRACT

Aluminium metal matrix composites produced using the ultrasonic stir casting method offer important benefits in aerospace and automotive applications. Aluminium composite material utility has recently increased in all engineering sectors due to its high strength, good wear and corrosive resistance. This study was designed to disperse boron carbide and Inconel Alloy 625 reinforced with aluminium 7075. By varying the weight percentages of boron carbide (2wt percent,4wt percent,6wt percent, and 8wt percent) and Inconel alloy 625 (2wt percent,4wt percent,6wt percent, and 8wt percent) for aerospace applications. The scanning electron microscope was used to examine the morphology and distribution of reinforced particles in a synthetic aluminium composite material. It virtually depicts the uniform distribution of reinforcement particles in the base material matrix (Aluminium 7075). To determine the hardness of the hybrid composite material, a Brinell hardness test was performed. It has been discovered that increasing the reinforcement percentage increases the hardness of the synthesised hybrid composites when compared to the aluminium 7075 base matrix material. Mechanical property testing on fabricated composites specimens of various compositions has been carried out.

1. INTRODUCTION

Engineering materials should have properties such as light in weight, stronger, cost effective expensive, and corrosion resistant. Nowadays metal matric composites are reinforced with soft ductile metal alloys. Aluminium metal composites are mostly used in aerospace, automobile, marine sectors. Aluminium metal matrix composites offers cost effective, high stiffness, good strength to weight ratio, dimensional stability wear resistance at high temperature, these kind of properties makes replacement for conventional materials [1-4] Aluminium and magnesium are usually used to fabricate metal matrix composite because of its low density property. It was reinforced with particulate materials such as aluminium oxide or boron carbide. In recent days, Toyota diesel engine pistons are made by aluminium silicon carbide composites. Conventional piston materials has been substituted by metal matrix composite materials because it provides more wear resistance and higher temperature withstanding stability [5, 6]. According to the literature review, reinforcements such as SiC, Al_2O_3, SiO_2, B_4C, and Al–N are usually used as reinforcements in the mixture of aluminium alloy composites [7-9].

It was found that increasing the ceramics particles increases hardness of hybrid composite material so it was difficult to machining. These kind of difficulties overcome by adding some additional reinforcement in the composite material [10]. To improve the mechanical properties of the composites numerous research studies have been conducted and different reinforcement of different applications were studied [11-14]. Nevertheless, only few research studies have been accompanied of two ceramic reinforcements in the aluminium hybrid composites. B_4C and graphite reinforced aluminium hybrid composites were studied by means of a liquid casting technology and its wear and mechanical behaviour were identified it was significantly higher than of Aluminium Alloy 6061 [15]. The mechanical properties of Al–B_4C composites was significantly higher than Sic and B_4C composites [16]. According to the literature survey, liquid phase method utilized to fabricate with addition of boron carbide and boron nitride in aluminium matrix material is not broadly specified and its mechanical properties have not been characterised. Even though the both reinforcements has a moderate density it was chosen as reinforcement in the current study [17]. When compared to conventional alloy, metal matrix composites have important enhanced properties damping capacity, stiffness, toughness, wear resistance. Boron carbide have a low density that was accessible in huge quantities as a by-product of coal combustion in the thermal power plant, so boron carbide reinforced metal matrix composites overcome the cost barrier and it widely used in automobile industries for piston fabrication. Boron carbide has a characteristics of low density and low cost it was very effective reinforcement for the aluminium matrix material [18]. Fly ash was used as a reinforcing material it was found that high electrical resistivity, low thermal conductivity, and low density characteristics of fly-ash may be beneficial for making light weight insulating composites [19]. Because of following characteristics of aluminium 7075 such as high strength to density ratio, high tensile strength, high yield strength, and high elongation at failure these are all the key selection criteria for aerospace, automobile, marine industries. Owing to the reason aluminium 7075 chosen as matrix material and it has some drawbacks of highly reactive to caustic acids, water, and oxygen. Powder metallurgy and stir casting was the commonly used method for fabricating metal matrix composite. The stir casting method fabrication is well suited for to make metal matrix composites [20-26].

The mechanical properties and wear behaviour of metal matrix composites Al_{6061}-SiC and Al_{7075}-Al_2O_3 were investigated the inclusion of hard ceramic particles enhances the composites' micro hardness, tensile strength, and density [27]. The mechanical properties of Aluminium alloy 7075 metal matrix composites reinforced with 10% volume fractions of boron carbide, Silicon carbide, and aluminium oxide made by using stir casting were investigated. According to the author, Aluminium alloy7075 with boron carbide reinforced composite has better mechanical properties than other particle reinforced composites [27, 28]. It investigated the mechanical and wear properties of hybrid Aluminium alloy 7075/Aluminium oxide/graphite composites. It was revealed that enhancing the weight percentage of reinforced particles improved mechanical properties [29]. Because of its appealing properties, Aluminium Alloy 7075 matrix is usually used as structural materials in the aeronautic industry [30]. It's been used in a variety of applications, including aircraft fittings, shafts, gears, and defence applications. It has poor tribological properties for the reason that it was problematic to make a fully homogenised microstructure for aluminium alloys and aluminium matrix composites [31]. Mentioned above literature survey is very important to analyse the material characterization in the metal matrix composite and also to understand the fracture mechanism. There was no other research into the reinforcement of Inconel alloy 625 with aluminium 7075. The current research study emphases on the reinforcement of Inconel alloy 625 and boron carbide with aluminium 7075 utilizing ultrasonic stir casting method.

2. STIR CASTING PROCESS

In this research work, conventional alloy 7075 melted in resistive heating furnace at 710℃. In order to attain the uniform dispersion melt the furnace temperature has been enhanced to 7500C and has been maintained for 20minute.Because of the occurrence of magnesium in Aluminium alloy 7075 a Argon gas 4.5L/minute has been passed to enter in to furnace to avoid oxidation and excessive burning. The boron carbide reinforcement (2%, 4%, 6%, 8% as varying wt) has been added into molten metal has been increased to 8500C. The stirring speed has maintained at 500rpm with the stirring time of 20 minutes to make sure even dispersal of reinforcement in the matrix melt. The Inconel alloy of particle size 40µm size of varying wt % (2%, 4%, 6%, 8%) has been added in to molten matrix. Considering this the temperature has been enhanced 9500C and stirring speed and stirring time have been enhanced to 700rpm and 25 minutes, respectively in order to attain even dispersal of reinforcement in the matrix material. Magnesium 2 wt % added in the hybrid composite slurry to attain good wettability. To avoid sufficient uniform mixture and rapid cooling the mild steel die has been pre-heated to 3000C. An ultrasonic probe made of titanium has been used to produce a frequency of 20 kHz with 2 kW power. The titanium probe has 30 mm diameter and 250 mm long. After this mixing process, the ultrasonic stirring has been performed for 15 minutes. Then the fabricated aluminium hybrid composite slurry has been poured in mild steel die and allowed to solidify at surrounding temperature.

3. RESULT AND DISCUSSION

3.1 Tensile strength of Aluminium 7075/ Boron carbide / Inconel alloy composites

At room temperature 32℃, the tensile strength of hybrid composites was measured using the ASTM E-8 standard. To reduce error, three standard specimen sets were prepared, and the average value of these was used. When compared to monolithic Aluminium alloy 7075, the tensile strength of fabricated hybrid composites was found to be lower. The presence of hard ceramic reinforcement in the Aluminium alloy 7075 matrix acts as a nucleation site and promotes recrystallization of the aluminium matrix. As a rigid mechanism to dislocation motion, the grain boundaries of aluminium hybrid composites improve. As the percentage of ceramic reinforcement added to the matrix material increased, the percentage elongation of aluminium hybrid composites decreased. Brittle behaviour of ceramic reinforced particles contributes significantly to ductility reduction. A 2wt% boron carbide +2wt% inconel alloy 625 achieved a maximum tensile strength of 130 MPa. It cost 39.63% less than standard aluminium alloy 7075. Figure 1 depicts the tensile strength of a hybrid composite material.

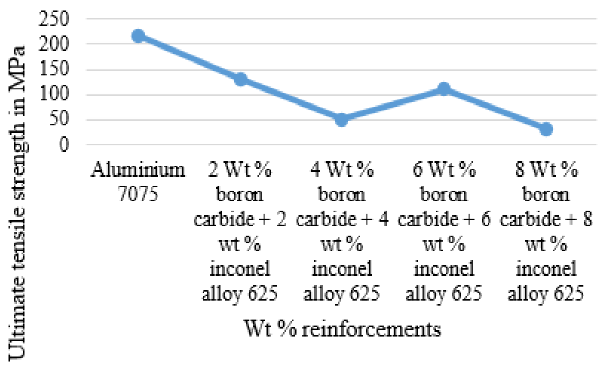

Figure 1. Tensile strength of the hybrid composite material

3.2 Compressive strength of Aluminium 7075/ Boron carbide/ Inconel alloy 625

The compression test of fabricated aluminium hybrid composites was performed at room temperature in accordance with the ASTM E 9 standard. The hybrid composites compressive strength improved because of the strengthening effect as well as the uniform dispersion of boron carbide and Inconel alloy 625 reinforced particles in the matrix alloy. The interface boundaries between the boron carbide and the Aluminium alloy 7075 matrix grow as the percentage of boron carbide reinforcement in the aluminium matrix grows. As a result, displacement is stacked up at interface boundaries similar to grain boundaries. Aside from the dispersal strengthening effect, the addition of Inconel alloy 625 shows an important role in defining the firming effect, enriching the grain size, and constraining high dislocation density in the aluminium alloy 7075 matrix. As a result, the fabricated hybrid composites have a high compressive strength, as shown in Figure 2. At 2 wt% boron carbide+2wt% Inconel alloy 625, the maximum compressive strength was 269 MPa. It was 22.83 percent more than unreinforced aluminium alloy 7075.

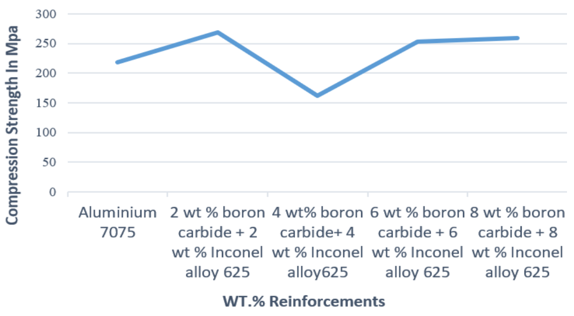

Figure 2. Compressive strength of the hybrid composite material

3.3 Hardness of aluminium alloy 7075 /Boron carbide /Inconel alloy 625 composites

To obtain accurate readings, the brinell hardness test on polished hybrid composites samples was performed with a load of 250 kg and an average of three readings at different locations. It has been deduced that two different ceramic reinforcement particulates of boron carbide changing weight percentage (2 wt%, 4 wt%, 6 wt%, 8 wt%) and inconel alloy 625 (2 wt%, 4 wt%, 6 wt%, 8 wt%) have higher hardness, which plays an important role in increasing the hardness of fabricated hybrid composites rather than using unreinforced material. The maximum hardness of 112.3 BHN was obtained using a 2 wt% boron carbide + 2 wt% Inconel alloy. It outperformed unreinforced aluminium 7075 alloy by 85.61 percent. Figure 3. shows hardness of the hybrid composite material.

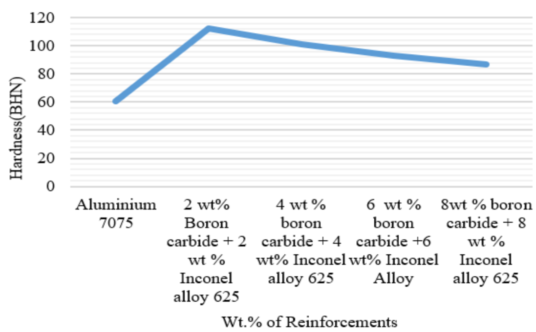

Figure 3. Hardness of the composite material

3.4 Flexural strength of aluminium alloy 7075/ Boron carbide/ Inconel alloy 625 composites

The hybrid composite material flexural strength was measured using a universal testing machine with a three-point bending fixture in accordance with the ASTM E 290 standard. The maximum flexural strength of 329.46 MPa was observed at 2 wt % boron carbide + 2 wt % Inconel alloy 625, which was 43.86 % higher than the conventional material. Internal mechanism of hybrid composite material reinforcement influences flexural strength and hardness. Hardness of material gradually increases at the same moment flexural strength enhanced. Due to grain boundary sliding restriction by reinforcements flexural and hardness property enhanced Figure 4 displays variation in flexural strength of the hybrid composite material.

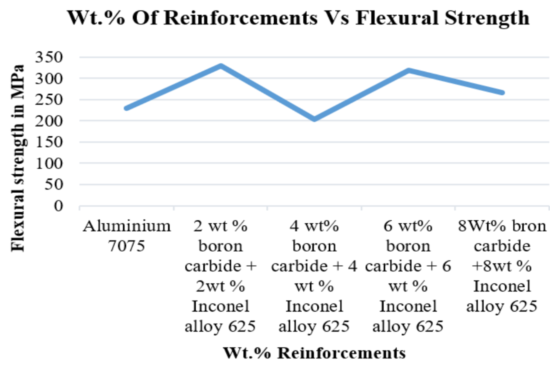

Figure 4. Flexural strength of the hybrid composite material

3.5 Impact strength of aluminium alloy 7075/ Boron carbide/ Inconel alloy 625 composites

The impact strength of the hybrid aluminium metal matrix composite material was evaluated using an impact testing machine in accordance with the ASTM E23 standard. Figure 5 depicts the impact strength of a Nano graphene and Inconel alloy 625 reinforced hybrid metal matrix obtained through an impact test. At 6 Wt percent boron carbide + 6 Wt percent Inconel alloy 625, the maximum impact strength is 6 joules. The maximum value of 6 joules, it was 200 % superior than the maximum value of conventional alloy 7075. Figure 5 exhibits impact strength of the hybrid composite material.

Wear Experimental Work

A pin-on-disc machine is depicted in Figure 6. The wear presentation of the composites specimen is determined using a wear test. ASTM G99 was followed when machining the specimen. A pin-on-disc machine slides a cylinder pin having round polished end against a counter surface of hardened steel disc under atmospheric conditions. The test pin has an 8 mm diameter and a length of 32 mm. The face disc is made of EN-31 steel hardened to 58-62 HRC. Loads of 10N, 20N, and 30N were used (Figure 7-9). All specimens are subjected to wear tests over a total sliding distance of 800m. Following the test, total weight loss was calculated using an electronic balance.

Worn surface morphology

Figure 10 depicts a SEM micrograph. The damaged surfaces of the composite exhibit a mixed wear pattern, slender grooves, and huge material flow along the side sliding direction, denoting a greater grade of wear and localised adhesion between the sample pin surface and the disc surface. In some aspects, the worn surface resembled that of the conventional alloy 7075, and was characterised mostly by plastic permanent distortion with some plough up and cutting unique effects. The worn edge of the composite's tribological picture indicates the prevalent abrasive wear mechanism. The quarrying of boron carbide particles from the aluminium alloy 7075 drives the abrasive wear process, which is performed simply by the ploughing up action of the abrasive particles. Plastic distortion on the composite's worn surface was greatly decreased by increasing the boron carbide particles from 6 wt% boron carbide +6 wt% Inconel alloy 625 to 8 wt% boron carbide +8 wt% Inconel alloy 625, and very minor plastic distortion was detected on the composite's worn edge.

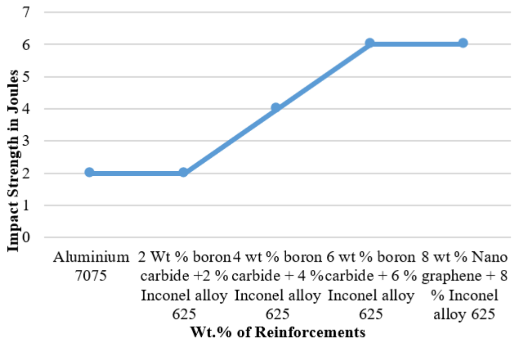

Figure 5. Impact strength of the hybrid composite material

Figure 6. Pin-on-disc machine

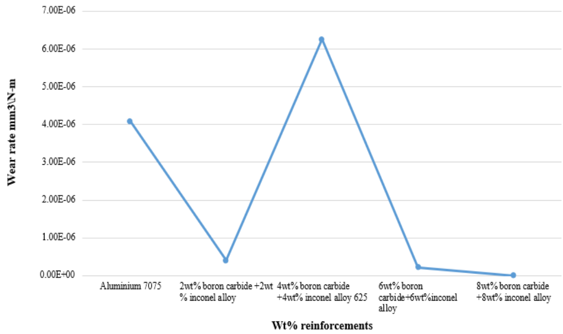

Figure 7. Wear rate at 10 N

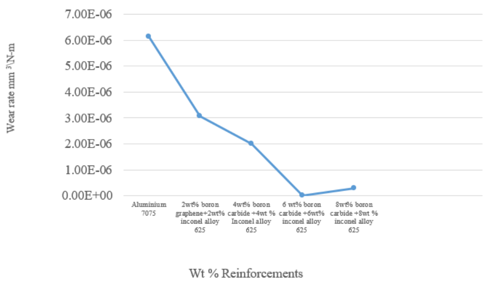

Figure 8. Wear rate at 20 N

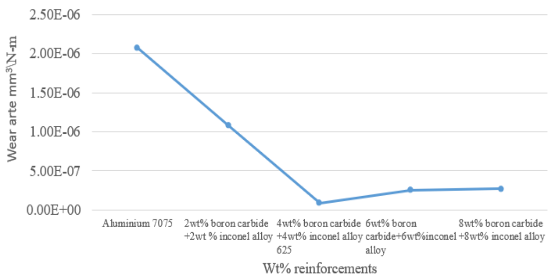

Figure 9. Wear rate at 30 N

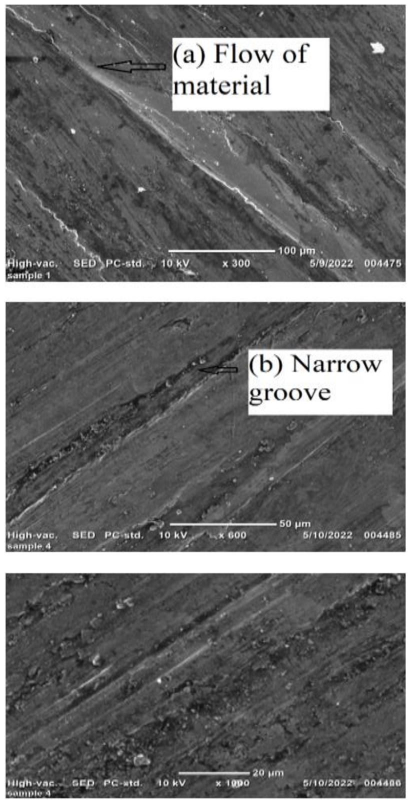

Figure 10. SEM micrograph of worn surface of (a) Aluminium 7075 (b) + 2 wt% boron carbide +2 wt % Inconel alloy 625 (c) + 8 wt% boron carbide +8 wt % Inconel alloy 625

4. CONCLUSION

1. A 2wt% boron carbide +2wt% inconel alloy 625 achieved a maximum tensile strength of 130 MPa. It cost 39.63% less than standard aluminium alloy 7075.
2. A 2 wt% boron carbide + 2 wt% Inconel alloy 625 yielded a maximum compressive strength of 269 MPa. It was 22.83 percent greater than the unreinforced aluminium alloy 7075.
3. A 2 wt% boron carbide + 2 wt% Inconel alloy yielded a maximum hardness of 112.3 BHN. By 85.61 percent, it outperformed unreinforced aluminium 7075 alloy.
4. A maximum flexural strength of 329.46 MPa was observed at 2% boron carbide + 2% Inconel alloy 625, which was 43.86% higher than the base material.
5. Significant deterioration in wear the base alloy has a wear loss of 6.45x10-6mm3/N-m, while the composites have a wear loss of 8.75x10-8mm3/N-m. Abrasive wear strengthens the aluminium matrix while also resisting the softer matrix alloy 7075.

REFERENCES

[1] Dhas, D.S.E.J., Velmurugan, C., Wins, L.D., Raja, K.P.B. (2019). Effect of tungsten carbide, silicon carbide and graphite particulates on the mechanical and microstructural characteristics of AA 5052 hybrid composites. Ceram. Int, 45(1): 614-621. https://doi.org/10.1016/j.ceramint.2018.09.216

[2] Ramkumar, K.R., Sivasankaran, S., Al-Mufadi, F.A., Siddharth, S., Raghu, R. (2019). Investigations on

microstructure, mechanical, and tribological behaviour of AA7075–x wt.% TiC composites for aerospace applications. Arch. Civ. Mech. Eng, 19(2): 428-438. https://doi.org/10.1016/j.acme.2018.12.003

[3] Akbarpour, M.R., Mirabad, H.M., Alipour, S. (2019). Microstructural and mechanical characteristics of hybrid SiC/Cu composites with nano-and micro-sized SiC particles. Ceram. Int, 45(3): 3276-3283. https://doi.org/10.1016/j.ceramint.2018.10.235

[4] Bodunrina, M.O., Alanemea, K.K. (2015). Lesley HeathChown, Aluminium matrix hybrid composites: A review of reinforcement philosophies; mechanical, corrosion and tribological characteristics. Journal of Materials Research and Technology, 4(4): 434-445. https://doi.org/10.1016/j.jmrt.2015.05.003

[5] Krishnamoorthi, K., Balasubramanian, P. (2015). Review the properties of Al7075matrix composites. Journal of Material Science and Mechanical Engineering, 2(1): 85-90.

[6] Imran, M., Khan, A.R.A. (2019). Characterization of Al-7075 metal matrix composites: A review. Journal of Materials Research and Technology, 8(3): 3347–3356. https://doi.org/10.1016/j.jmrt.2017.10.012

[7] Yamaguchi, M., Pakdel, A., Zhi, C., Bando, Y., Tang, D.M., Faerstein, K., Shtansky, D., Golberg, D. (2013). Utilization of multiwalled boron nitride nano tubes for the reinforcement of lightweight aluminum ribbons. Nanoscale Research Letters, 8(3).

[8] Venkataraman, B., Sundararajan, G. (2000). Correlation between the characteristics of the mechanically mixed layer and wear behavior of aluminium. Al-7075 alloy and Al-MMCs. Wear, 245(1-2): 22–38. https://doi.org/10.1016/S0043-1648(00)00463-4

[9] Shorowordi, K.M., Laoui, T., Haseeb, A.S.M.A., Celis, J.P., Froyen, L. (2003). Microstructure and interface characteristics of B4C, SiC andAl2O3 reinforced Al matrix composites: A comparative study. Journal of Materials Processing Technology, 142(3): 738–743. https://doi.org/10.1016/S0924-0136(03)00815-X

[10] Venkataraman, B., Sundararajan, G. (2000). Correlation between the characteristics of the mechanically mixed layer and wear behavior of aluminium. Al-7075 alloy and Al-MMCs. Wear, 245(1-2): 22–38. https://doi.org/10.1016/S0043-1648(00)00463-4

[11] Shorowordi, K.M., Laoui, T., Haseeb, A.S.M.A, Celis, J.P., Froyen, L. (2003). Microstructure and interface characteristics of B4C, SiC andAl2O3 reinforced Al matrix composites: a comparative study. Journal of Materials Processing Technology, 142(3): 738–743. https://doi.org/10.1016/S0924-0136(03)00815-X

[12] Rajmohan, T., Palanikumar, K., Ranganathan, S. (2013). Evaluation of mechanical and wear properties of hybrid aluminium matrix composites. Transactions of Nonferrous Metals Society of China, 23(9): 2509–2517. https://doi.org/10.1016/S1003-6326(13)62762-4

[13] Ramnath, B.V., Elanchezhian, C., Jaivignesh, M., Rajesh, S., Parswajinan, C., Ghias A.S.A. (2014). Evaluation of mechanical properties of aluminium alloy-alumina-boron carbide metal matrix composites. Mater Des, 58: 332-338. https://doi.org/10.1016/j.matdes.2014.01.068

[14] Fenghong, C., Chang, C., Zhenyu, W., Muthuramalingam, T., Anbuchezhiyan, G. (2019). Effects of silicon carbide and tungsten carbide in aluminium metal matrix composites. Silicon, 11: 2625-2632.

[15] Dolata, A.J., Jakub, W. (2007). Tribological properties of hybrid composites containing two carbide phases. Archives of Materials Science and Engineering, 28(3): 149–155.

[16] Baradeswaran, A., Vettrivel, S.C., Perumal, A.E., SelvaKumar, N., Isacc, R.F. (2014). Experimental investigation on mechanical behaviour, modelling and optimization of wear parameters of B4C and graphite reinforced aluminium hybrid composites. Materials & Design, 63: 620-632. https://doi.org/10.1016/j.matdes.2014.06.054

[17] Lee, K.B., Sim, H.S., Cho, S.Y., Kwon, H. (2001). Tensile properties of 5052 Al Matrix composites reinforced with B4C particles. Metallurgical and Materials Transactions A, 32: 2142-2147.

[18] Sivakumar, R., Prasanna, M., Pradeep, K., Rajkumar, V.T., Kumar, S.R. (2019), Wear characterization of ceramic tools (SiAlON and Al2O3+SiCWhisker) with dry and wet turning of Nimonic 75. AIP Conference Proceedings, 2128(1): 20–22. https://doi.org/10.1063/1.5117934

[19] Ramesh, C.S., Keshavamurthy, R., Channabasappa, B.H., Pramod, S. (2010). Friction and wear behaviour of Ni-P coated Si3N4 reinforced Al6061 composites. Tribology International, 43(3): 623-634. https://doi.org/10.1016/j.triboint.2009.09.011

[20] Tjong, S.C., Tam, K.F. (2006). Mechanical and thermal expansion behaviour of hipped aluminum-TiB2 composites. Materials Chemistry and Physics, 97(1): 91-97. https://doi.org/10.1016/j.matchemphys.2005.07.075

[21] Jr., W.C.H. (1998). Commercial processing of metal matrix composites. Materials Science and Engineering: A, 244(1): 75-79. https://doi.org/10.1016/S0921-5093(97)00828-9

[22] Akhlaghi, F., Lajevardi, A., Maghanaki, H.M. (2004). Effects of casting temperature on the microstructure and wear resistance of compocast A356/SiCp composites: A comparison between SS and SL routes. Journal of Materials Processing Technology, 155-156: 1874–1880. https://doi.org/10.1016/j.jmatprotec.2004.04.328

[23] Viswanatha, B.M., Kumar, M.P., Basavarajappa, S., Kiran, T.S. (2013). Mechanical property evaluation of A356/SiCp/Gr metal matrix composites. Journal of Engineering Science and Technology, 8(6): 754-763.

[24] Baradeswaran, A., Perumal, A.E. (2014). Study on mechanical and wear properties of Al 7075/Al2O3/graphite hybrid composites. Composites Part B: Engineering, 56: 464-471. https://doi.org/10.1016/j.compositesb.2013.08.013

[25] Mishra, A.K., Kumar, V., Srivastava, R.K. (2014). Optimization of tribological performance of Al-6061T6-15% SiCp-15% Al_2O_3 hybrid metal matrix composites using taguchi method & grey relational analysis. Journal of Minerals and Materials Characterization and Engineering, 2(4). https://doi.org/10.4236/jmmce.2014.24040

[26] Kumar, G.B.V., Rao, C.S.P., Selvaraj, N., Bhagyashekar, M.S. (2010). Studies on Al6061-SiC and Al7075-Al_2O_3 metal matrix composites. Journal of Minerals and Materials Characterization and Engineering, 9(1): 43-55. https://doi.org/10.4236/jmmce.2010.91004

[27] Senthilvelan, T., Gopalakannan, S., Vishnuvarthan, S., Keerthivaran, K. (2012). Fabrication and

Characterization of SiC, Al_2O_3 and B4C Reinforced Al-Zn-Mg-Cu Alloy (AA 7075) metal matrix composites: A Study. Advanced Materials Research, 622-623: 1295-1299.
https://doi.org/10.4028/www.scientific.net/AMR.622-623.1295

[28] Baradeswaran, A., Perumal, A.E. (2014). Study on mechanical and wear properties of Al 7075/Al2O3/graphite hybrid composites. Composites Part B: Engineering, 56: 464-471. https://doi.org/10.1016/j.compositesb.2013.08.013

[29] Deaquino-Lara, R., Gutiérrez-Castañeda, E., Estrada-Guel, I., Hinojosa-Ruiz, G., García-Sánchez, E., Herrera-Ramírez, J.M., Pérez-Bustamante, R., Martínez-Sánchez, R. (2014). Structural characterization of aluminium alloy 7075-graphite composites fabricated by mechanical alloying and hot extrusion. Materials & Design, 53: 1104-1111.
https://doi.org/10.1016/j.matdes.2013.08.005

[30] Flores-Campos, R., Estrada-Ruiz, R.H., Treviño-Rodríguez, G.A., Herrera-Ramírez, J.M., Martínez-Sánchez, R. (2016). Wear resistance analysis of the aluminum 7075 alloy and the nanostructured aluminum 7075-silver nanoparticles composites. Journal of Mining and Metallurgy, Section B: Metallurgy, 52(2): 163-170.

[31] Onal, M., Gavgali, M. (2017). Production of metal matrix composites by in situ techniques. The Journal of Scientific and Engineering Research, 4(2): 78-82.