Processing and Mechanical Characterization of 8 wt. % of Micro B_4C Particulates Reinforced Al7020 Alloy Composites

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Abstract : ***In the current study, an investigation made on fabrication of B_4C reinforced Al7020 alloy composites and evaluation of properties. Al7020-8 wt. % of B_4C composites were synthesized by liquid stir casting process. Microstructural characterization was carried out by using scanning electron microscope and energy dispersive spectroscope. Prepared composites were evaluated for density, hardness and tensile strength as per ASTM standards. Scanning electron micro photographs revealed the distribution of B_4C particulates in the Al matrix and were confirmed by EDX analysis. Further, density of Al7020-8 wt. % of B_4C composites exhibited lesser density as compared to base alloy. B_4C particulates reinforced composites were shown more enhanced properties as compared to A7020 alloy.***

IndexTerms - Al7020 Alloy, B_4C particulates, Microstructure, Hardness, Tensile Strength

I. INTRODUCTION

Particulate reinforced aluminium metal matrix composites (MMCs), a class of metal matrix composites takes wide attention in aerospace and automobile industries due to their light weight, low cost, easy fabrication, wear resistance and isotropic properties [1-3]. Metal matrix composite materials are advanced composite materials reinforced with one or more than one reinforcement material in order to achieve the high wear resistance [4]. A large number of fabrication techniques are currently used to manufacture the MMC materials according to the type of reinforcement used like stir casting, liquid metal infiltration, squeeze casting and spray co-deposition. Stir casting is suitable for manufacturing composites with up to 30% volume fractions of reinforcement [5]. A major concern associated with the stir casting process is the segregation of reinforcing particles which is caused by the surfacing or settling of the reinforcement particles during the melting and casting processes. The effectiveness of this two-step processing method is mainly attributed to its ability to break the gas layer around the particle surface. Particles usually have a thin layer of gas absorbed on the surface, which impedes wetting between the particles and molten metal's.

Worldwide efforts are going on to minimize the carbon dioxide gas emission and the uncertainty over oil prices have been pushing researchers to look for alternative solutions. One of these is to use the environmentally friendly light weight components and aluminium is the best candidate due to its lightness and strength. Aluminium has a density of 2.70 g/cm^3 which is approximately two thirds that of steel (7.80 g/cm^3). Aluminium also possesses good castability, formability, recyclability and dimensional stability, in addition to having moderate absolute strength value [6]. Aluminium materials are thus attractive for many applications, particularly in automobiles, aerospace, defence and sports industries. Despite its advantages, the use of aluminium based structural materials is still largely limited by its low stiffness and ductility, inadequate creep resistance at elevated temperatures. These limitations are often improved through the addition of reinforcements to form a composite. In certain applications, the components made from these composites are subjected to sliding movements resulting in the possibility of wear damage. This paper, thereby, studies wear characteristics of Al2214 alloy reinforced with B_4C particulate composites.
Several attempts have been done to examine the effect of sliding velocity and applied load on the wear behaviour of aluminium alloy and its composites. Rao et al. [7] studied dry sliding wear maps for AA7010 matrix composites. Reliability of sliding wear test procedure was examined by comparing the measured wear rate data with calculated wear rate. D. S. Prasad and Shoba [8] reported the dry sliding wear behaviour of aluminium matrix hybrid composites reinforced with rice husk ash and silicon carbide particulates up to 8% volume fabricated by vortex method. The results showed that the hybrid composites exhibits higher wear resistance than the unreinforced alloy. Selvam and his co workers investigated the dry sliding wear behaviour of a magnesium matrix composite reinforced with zinc oxide nano particles. Furthermore, the wear rate was higher under higher loads at all sliding velocities [9]. However, the literature shows that no significant work so far been done to study the wear characteristics of Al2214-B_4Ccomposites fabricated by novel two step mixing method of reinforcements.

In this study, an attempt has been made to prepare Al7020 alloy composites by adding 8 wt. % of B_4C particulates into matrix by using a novel two stage reinforcement addition method. Further, the prepared Al7020 – B_4C composites were studied for hardness and tensile behavior.

II. EXPERIMENTAL DETAILS

2.1 Materials Used

Metal matrix composites containing 8 weight rates of B_4C particles were created by liquid metallurgy course. For the generation of MMCs, an Al7020 alloy was utilized as the framework material while B_4C were utilized as the fortifications. The theoretical density of grid material Al7020 amalgam is 2.80g/cm^3 and support particulates B_4C is 2.52g/cm^3. The chemical substance of Al7020 composite utilized as a part of the work is given in the table 1.

Table.1 shows the chemical composition of the Al7020 alloy used in the present study

Elements	Si	Fe	Cu	Mn	Mg	Cr	Zn	Al
Percentage	0.35	0.4	0.2	0.5	1.2	0.3	5.0	Balance

2.2 Preparation of Composites

The B_4C particle reinforced Al7020 alloy metal matrix composites have been produced by using a vortex method. Initially calculated amount of Al7020 alloy was charged into SiC crucible and superheated to a temperature 730˚C in an electrical resistance furnace. The furnace temperature was controlled to an accuracy of ±10 degree Celsius using a digital temperature controller. Once the required temperature is achieved, degassing is carried out using solid hexachloroethane (C_2Cl_6) to expel all the absorbed gases. The melt was agitated with the help of a zirconia coated mechanical stirrer to form a fine vortex. A spindle speed of 300 rpm and stirring time 3-5 min. were adopted. The B_4C particulates were preheated to a temperature of 500 degree Celsius in a pre-heater to increase the wettability. The pre-heated B_4C particles introduced into melt in steps of two at constant feed rate of 1.2-1.4 g/sec. After holding the melt for a period of 5 min., the melt was poured from 710 degree Celsius into a preheated cast iron mould having dimensions of 120mm length x 15mm diameter.

2.3 Testing

Metallographic test specimens of 5mm thickness were prepared by cutting the as cast and B_4C strengthened Al7020 combination composites. Test samples were polished according to the standard metallographic methodology and etched with Keller's reagent. The microstructure was viewed utilizing scanning electron microscope instrument.

The experimental density of both unreinforced Al7020 alloy and Al7020-8 wt.% B_4C composites were measured by dividing the measured weight of test sample by its measured volume using an electronic weighing machine. The theoretical density of the composite was calculated by rule of mixture using formula:

$$\rho_{composite} = V_{reinforcement} * \rho_{reinforcement} + V_{matrix} * \rho_{matrix}$$

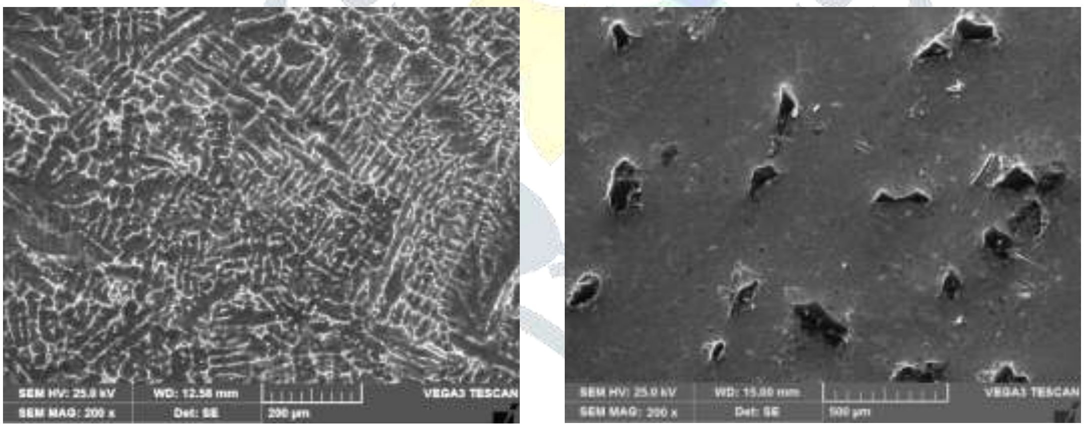
Where, V is the volume, ρ is the density.

The tensile properties of the example were measured by utilizing a universal testing machine at room temperature in light of ASTM E 8 standard. Hardness of as cast Al7020-B_4C amalgam composites were directed to know the impact of small scale B_4C particles in the network material ASTM E 10 standard. The cleaned examples were tried for their hardness, utilizing Brinell hardness testing machine having ball indenter for 250 kg stack and abide time of 30 sec., three arrangements of readings were taken at better places of the example and a normal esteem was utilized for figuring.

III. RESULTS AND DISCUSSION

3.1 Microstructural Studies

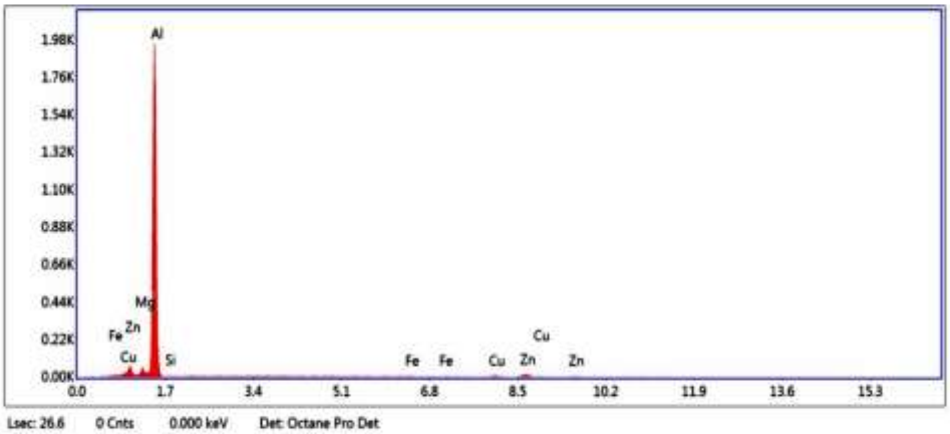
Figure 1 (a-b) shows the SEM microphotographs of Al7020 alloy as cast and Al7020 with 8 wt. % of B_4C particulate composites. This reveals the uniform distribution of B_4C particles and very low agglomeration and segregation of particles, and porosity.



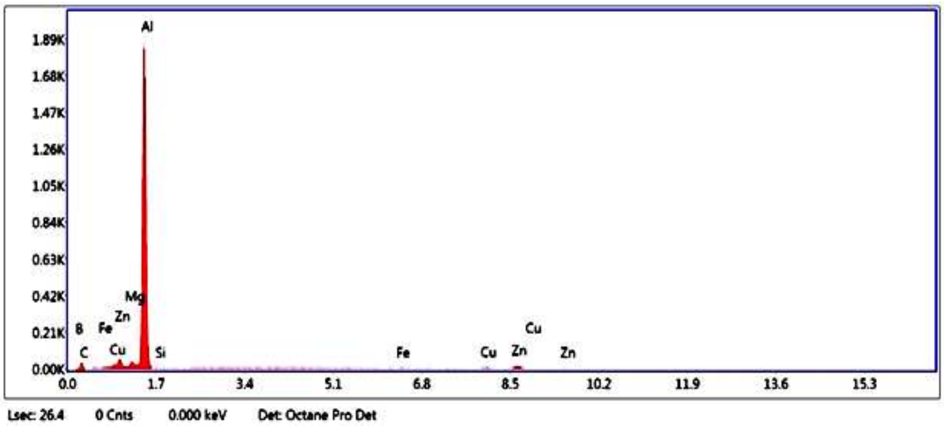
(a) (b)

Figure 1 Showing the scanning electron microphotographs of (a) as cast Al7020 alloy (b) with 8 wt. % of B_4C composites

Fig. 1b clearly shows and even distribution of B_4C particles in the Al7020 alloy matrix. In other words, no clustering of B_4C particle is evident. There is no evidence of casting defects such as porosity, shrinkages, slag inclusion and cracks which is indicative of sound castings. In this, wetting effect between particles and molten Al7020 alloy matrix also retards the movement of the B_4C particles, thus, the particles can remain suspended for a long time in the melt leading to uniform distribution.



(a)



(b)

Figure 2 EDS spectrum of (a) as cast Al7020 alloy (b) Al7020-8% B_4C composites

In order to confirm the presence of B_4C energy dispersive spectroscope analysis was carried out at the edge of the B_4C particle and Al alloy matrix. The EDS spectrum reveals the presence of Al, Zn, Cu, Mg, B and C in the interface reaction layer (fig. 2-b).

3.2 Density Measurements

In the present research work, the measured densities of as cast Al7020 alloy, Al7020- 8 wt. % B_4C composites are presented in the figure 3.

It is observed that, by the addition of B_4C particles the density of the composite is slightly decreased. This decrease in density is mainly due to lower density of B_4C particles as compared to the base Al7020 alloy. Further, from figure 3, the experimental densities for both alloy and composites are in line with the theoretical densities but slightly lesser than the theoretical densities.

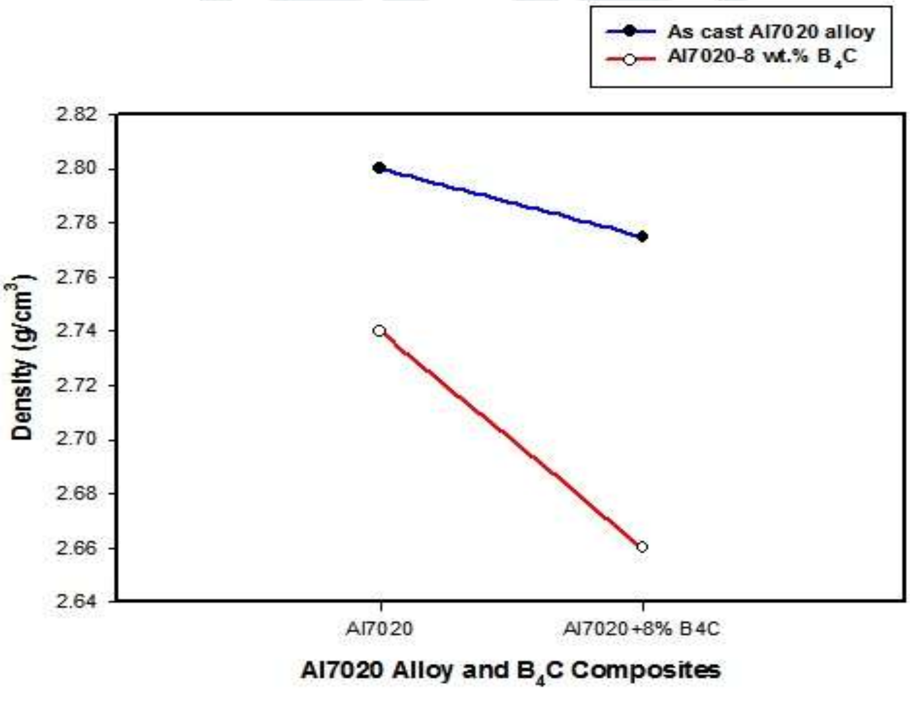


Figure 3 Shows the densities of Al7020 alloy and B_4C reinforced composites

3.3 Hardness Measurements

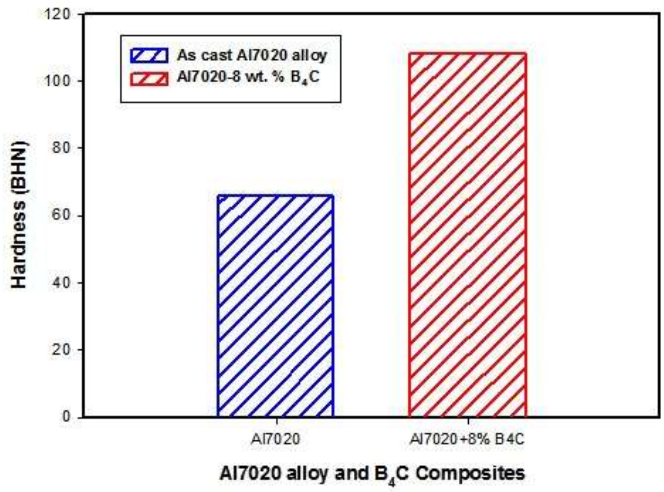


Figure 4 Shows the hardness of Al7020 alloy and B_4C reinforced composites

Hardness is a property of a material that indicates the ability of the material to resist local plastic deformation. Fig. 4 shows the influence of the micro B_4C particle contents on the hardness of the Al7020 alloy. The hardness values are positively correlated with the weight percentage of micro particles, because particles strengthened the matrix. Furthermore, the results show that B_4C reinforced MMCs harder than Al7020 alloy due to Hall-Petch and Orowan strengthening mechanisms as well as the good interface between the reinforcement and matrix [10, 11]. Al7020-8 wt.% B_4C composites shows more hardness, the increase in hardness of these composites as the B_4C fraction increases can be attributed to the dispersion strengthening effect [12]. By adding 8 wt. % B_4C particulates into the Al7020 alloy, the hardness increased of Al7020 alloy increased to 108 BHN from 66 BHN.

3.4 Tensile Behavior

Fig. 5 and 6 shows the ultimate and yield strength of aluminium matrix composites (AMCs) reinforced with 8% micro B_4C particles. The ultimate tensile and yield strength of the composite increased in the 8% of B_4C composites. The increase in tensile strength of AMCs containing B_4C is mainly due to the load bearing effect and mismatch of the strengthening mechanism. The difference between the co-efficient of thermal expansion of B_4C ($5x10^{-6/^{\circ}C}$) and the aluminium matrix ($25x10^{-6/^{\circ}C}$) results in a high dislocation density and thermally induced residual stresses [13, 14]. These induced dislocations and thermal stresses act as a barrier to the dislocation movement. Hence, the strength of the AMCs containing micro sized B_4C increases.

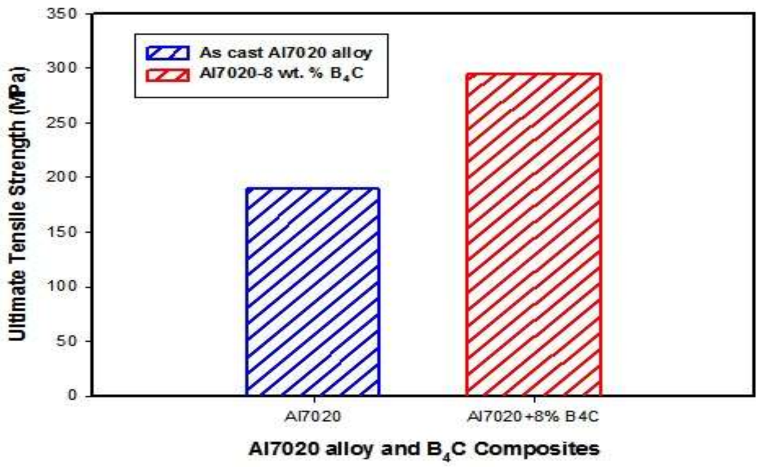


Figure 5 Shows the ultimate tensile strength of Al7020 alloy and B_4C reinforced composites

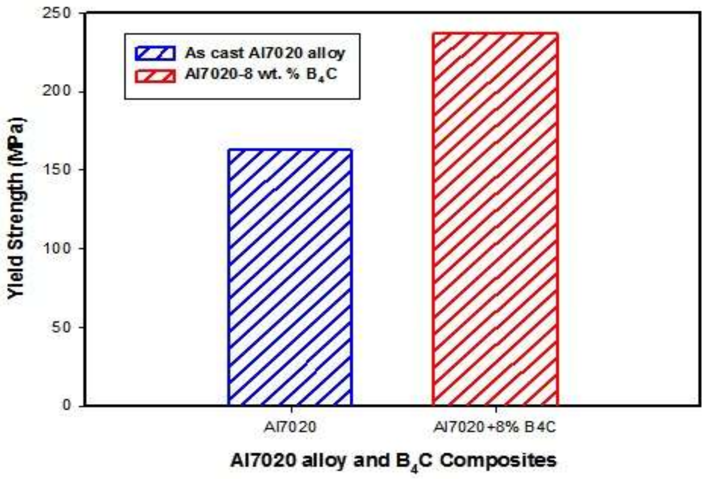


Figure 6 Shows the yield strength of Al7020 alloy and B_4C reinforced composites

The increase in the ultimate tensile strength and yield strength upon the addition of B_4C particles is 18.5% and 17.7% respectively. This is mainly due to Hall-Petch strengthening mechanism, which results from grain size refinement, the load bearing effect, and the Orowan and mismatch strengthening mechanisms [15].

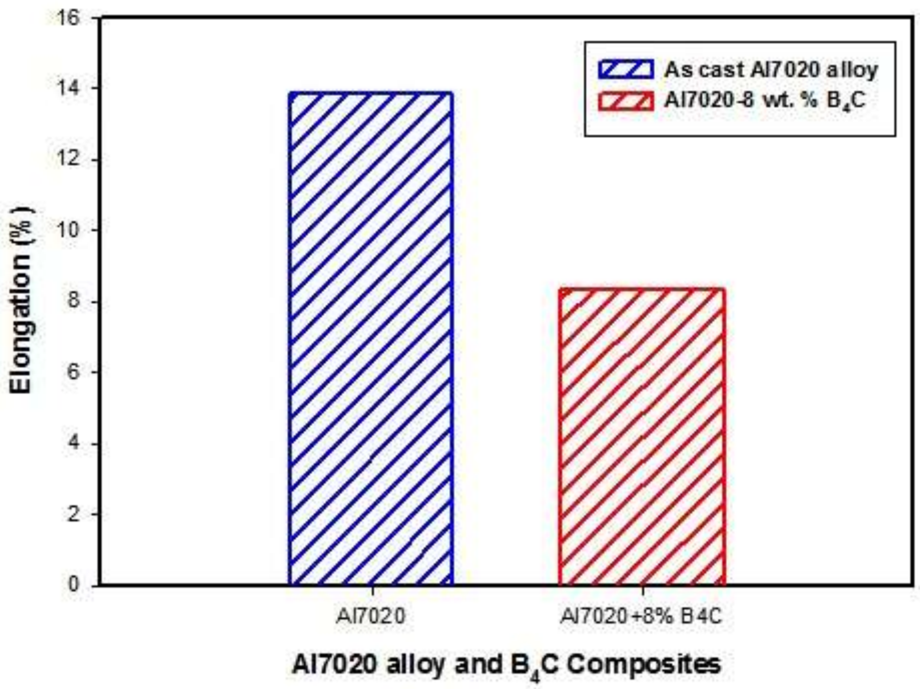


Figure 7 Shows the elongation of Al7020 alloy and B_4C reinforced composites

Fig. 7 indicates the percentage elongation of Al7020 alloy and 8 wt. % of B_4C composites. From the graph, it is revealed that B_4C reinforced composites shown decreased in ductility as compared to as cast Al7020 alloy. This decrease in ductility is mainly due to high hardness of B_4C particles, which makes the Al7020 alloy as brittle.

IV. CONCLUSIONS

The present work entitled, "Processing and mechanical characterization of micro B_4C reinforced Al7020 alloy composites" has led to the following conclusions:

- The liquid metallurgy technique was successfully adopted in the preparation of Al7020 alloy reinforced with 8wt. % B_4C particulates.
- The micro structural studies from scanning micro photographs revealed the uniform distribution of the B_4C particulates in the Al7020 alloy matrix.
- The Energy Dispersive (EDS) analysis revealed the presence of B_4C particles in Al7020 alloy composites.
- Density of Al7020-8 wt. % B_4C composites was lesser than base matrix alloy.
- Hardness of the Al7020-B_4C composite was found to be more than base Al matrix.
- The ultimate tensile strength of the composites was found to be higher than that of base matrix. The improvements in UTS by adding 8 wt. % of B_4C was increased by 56 %.

- The yield strength of the composites found to be higher than that of base matrix. The yield strength of base matrix Al7020 is increased from 162.8 MPa to 236.8 MPa after addition of 8 wt. % of B_4C particulates.
- By adding 8 wt. % of B_4C particulates the ductility of Al7020 alloy was decreased.

REFERENCES

[1] M. Kok, Production and mechanical properties of Al_2O_3 particle reinforced 2024 aluminium alloy composites. Journal of Materials Processing Technology, 161, 381-387, 2005.

[2] S A Sajjadi, H R Ezatpour, M Torabi, Comparison of microstructure and mechanical properties of A356 aluminium alloy-Al_2O_3 composites fabricated by stir and compo-casting process. Materials and Design, 34, 106-111, 2012.

[3] Madeva Nagaral, V Auradi, S A Kori, Reddappa H N, Jayachandran and Veena Shivaprasad, Studies on 3 and 9 wt. % B4C particulates reinforced Al7025 alloy composites. AIP Conference Proceedings, 1859, 020019, 2017.

[4] K. H. W. Seah, S. C. Sharma, B. M. Girish, Effect of artificial aging on the hardness of cast ZA-27/Graphite particulate composites. Materials and Design Vol. 16, No. 6, 337, 1995.

[5] S. A. Sajjadi, H. R. Ezatpour, M. Torabi, "Comparison of microstructure and mechanical properties of A356 aluminium alloy-Al_2O_3 composites fabricated by stir and compo casting processes", Materials and Design, 34, 2012, pp. 106-11.

[6] Ranjith Bauri, M. K. Surappa, "Processing and properties of Al-Li-SiCp composites", Science and Technology of Advanced Materials, 8, 2007, pp. 494-502.

[7] R. N. Rao et al., "Dry sliding wear maps for AA7010 aluminium matrix composite", Tribology International, Vol. 60, pp. 77-82, 2013.

[8] Dora Siva Prasad and Chintada Shoba, "Hybrid composites – a better choice for high wear resistant materials", Journal of Materials Research and Technology, Vol. 3 (2), pp. 172-178, 2014.

[9] B. Selvam et al., "Dry sliding wear behavior of zinc oxide reinforced magnesium matrix nano composites", Materials and Design, Vol. 58, pp. 475-481, 2014.

[10] G. B. Veeresh Kumar, C.S.P. Rao, N. Selvaraj, "Studies on mechanical and dry sliding wear of Al6061-SiC composites", Composites Part B, 43, 2012, pp. 1185-1191.

[11] J. Hashim, L. Looney, M. S. J. Hashmi, "Particles distribution in cast metal matrix composites part-I", Journal of Materials Processing Technology, 123, 2002, pp. 251-257.

[12] R. K Everest, R. J. Arsenault, "Metal Matrix Composites: Processing and Interfaces", 1991.

[13] B. Vijaya Ramnath, C. Elanchezhian, M. Jaivignesh, S. Rajesh, C. Parswajinan, "Evaluation of mechanical properties of aluminium alloy –alumina-boron carbide metal matrix composites", Materials and Design, 58, 2014, pp. 332-338.

[14] Nagaral M, Attar S, Reddappa H N, Auradi V, Sureshkumar S, Raghu S, Mechanical behavior of Al7025-B_4C particulates reinforced composites. Journal of Applied Mechanical Engineering, 4-6, 2015.

[15] Madeva Nagaral, Pavan R, Shilpa P S and V Auradi, Tensile behavior of B_4C particulate reinforced Al2024 alloy metal matrix composites. FME Transactions, 45, 93-96, 2017.