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Investigation of mechanical properties on Al 6061-B_4C composite by squeeze casting process technique

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ABSTRACT

Aluminum alloy is widely used in automotive, aerospace and other engineering industries because of its excellent mechanical properties. The main objective is to enhance 6061 Al alloy's mechanical properties by producing 6061-B4C composite through squeeze casting process. Experimentation was carried out with different micron sizes and weight fraction of B4C particles. The mechanical properties of reinforced metal matrix were experimentally investigated in terms of Ultimate Tensile Strength and Hardness. We observe that these two properties are improved by the reinforcement of B4C particles and applied squeeze pressure.

Key words: 6061 Al matrix, Boron Carbide, Squeeze casting

1. INTRODUCTION

At present there is an escalating demand for new class of light weight materials having superior mechanical properties than the conventional materials. Common industries such as aerospace, automotive, marine have their attention to aluminum matrix composites. Due to high strength, less weight, good corrosive resistance and good wear resistance, aluminum composite are extensively used in automobile parts and products. Among various manufacturing processes, the liquid metal process so called squeeze casting process, is the most favorable process for producing aluminum metal matrix composite, since it reduces the contact between the reinforcing material and the aluminum metal. Squeeze casting is considered as an advanced casting process which produces components by lowering the metal wastage and lowering the casting defects. In squeeze casting, applied pressure found to have significant effect for producing sound casting [1]. Through squeeze casting route homogeneous mixing and good bonding can be attained by proper selection of processing parameters like squeeze pressure, stirring speed, stirring time, temperature of the molten metal, preheating temperature of mould and uniform feed rate of reinforcing particles. Also in squeeze casting, by the application of high pressure on the solidifying metal, the component produced can be made free from porosities and inclusions.

As the mechanical properties of Aluminium alloy without reinforcement are comparatively poor, their applications in industries are limited. The advantage of using AMC in the industries is due to its high hardness and good fracture toughness when compared with the conventional materials. 6061 Al alloy is widely used in aerospace industries, whose mechanical properties can be improved by the reinforcement of particles such as B4C, TiC, SiC, Flyash and Al2O3 [2]. It is necessary to apply load in any reinforcement, so that the reinforcing material get bonded with the matrix and distribute uniformly.

The distribution of the reinforcement depends on how well the applied squeeze force is transferred to the reinforcing phase [3-4]. Boron carbide (B_4C) reinforced 6061 aluminum composite acquire unique mechanical properties, because B4C possess low density (2.52 g/cm3) and higher hardness (30 GPa) when compared with other ceramic materials. Also the strength of the B4C composite was greater than that of the Al-SiC composite [5]. The main objective is to enhance the mechanical properties by producing 6061/B4C aluminum alloy composite through squeeze casting route.

In this research, the effects of B4C particle content in 6061Al alloy were investigated by examining its mechanical properties such as hardness, ultimate tensile strength and fracture toughness. Experiments were designed to full factorial to have integration between the responses.

When an aluminum alloy is reinforced with B_4C particulates, the resulting composite will possess both the physical and mechanical properties of the aluminum alloy and the boron carbide [5-7]. That is when 6061 aluminum alloy is reinforced with B4C particles, the ductility of the 6061 Al alloy and the strength of the boron carbide will be present in the resulting composite. In few researches it is reported that increasing B4C content increases the hardness and yield strength [8] but it is also stated that it decreases wear rate as the hardness increases [9]. By reinforcing B4C particles to aluminum alloy the Tribological properties can also be improved [10].

It is already found in many observations that, the Al-B4C composite can be positively produced with minimum wear rate in the composite. In this present study, we limit our investigation to three different B4C particle sizes (25µm, 50µm, 75µm) with three different weight percentage (6%, 8%,10%) of reinforcing and to evaluate the mechanical properties, that is the hardness and Ultimate tensile Strength

To improve the bonding between the matrix and reinforcing material, potassium hexafluorotitanate (K2TiF6) flux is introduced in the molten aluminum, because better mechanical property can be achieved only if better bonding is established. To overcome the wetting problem between AA6061-B4C particles, titanium can also be used, but K2TiF6 flux is sufficient, which form TiC and TiB2 at the interface between AA6061 alloy and B4C to improve the wettability [11-12]. Few researches have been made so far in this area, due to higher raw material rate and poor bonding between B4C and aluminum alloys.

The interface between 6061 Al alloy with B4C particles and its microstructure were studied through optical microscopy (OM) and Scanning Electron Microscopy (SEM). The microstructures of the composites are characterized based on the image attained and suitable weight fraction is proposed for obtaining optimum mechanical properties. The B4C particles are distributed in-between the DAS of 6061 Al alloy which is revealed by optical microscopy images. In this paper, the production, characterization, evaluation of hardness and UTS of the 6061 aluminum alloy reinforced with different weight % of B4C particles are detailed.

The result shows that the hardness and ultimate tensile strength of the composite were increased at reinforcing various micron sizes and weight % of B4C particles to 6061 Al alloy. It was reported that UTS and fracture toughness of the Al-B4C composites were found to increase as the content of B4C particulates was increased up to 6% by weight and further addition of B4C particulates (9%) only serves to reduce these two mechanical properties. Squeeze pressure also gives different properties at different levels [13].

The levels of the three factors which were used to produce the composite are shown in the table 1.

Table 1. Chosen levels of process parameters to produce composites

Composite	*No. of Levels*	*B_4C particle sizes (μm)*	*Wt% of B_4C particles*	*Squeeze Pressure (MPa)*
AA6061-B_4C	Level 1	25	6	70.7
	Level 2	50	8	106.1
	Level 3	75	10	141.47

2. EXPERIMENTAL SETUP

2.1 Experimental Setup

The squeeze casting machine (ALSCF900) which is shown in the figure 1 consists of a cylindrical furnace able to withstand 1000˚C. For a leak proof bottom pouring arrangement, the furnace is fitted with stainless steel retort. In the furnace, provision is made to pass Argon gas during melting and stirring to prevent atmospheric contaminations. A stirrer which moves linearly, is present to agitate the aluminum melt at a variable speed of 100 -1500 rpm. A pre-heater is placed above the furnace for pre-heating and adding B_4C particles directly to the melt while stirring. A pathway tube made of stainless steel is placed between the furnace and die, which takes the molten metal to the mould. Provisions are given to heat the pathway to prevent cooling of melt in the tube. Hydraulic system capable of providing pressure up to 60 Ton is used to squeeze the casting at desired pressure. The application of pressure is made by a plunger which is attached to the hydraulic system.

Fig.1 Squeeze casting with Bottom poring and Die setup

Fig.2 Casted samples made from squeeze casting process

2.2 Material and equipment

The base metal used in this study as matrix material is 6061 aluminum alloy, which is commercially available aluminum acquired from Coimbatore metal mart, Coimbatore. The chemical composition and mechanical properties of 6061 Al alloy are shown in the tables 2 and 4 respectively.

Table 2. Chemical composition of 6061 aluminum alloy

Elements	*Si*	*Fe*	*Cu*	*Mn*	*Zn*	*Ti*	*Mg*	*Cr*	*Al*
Percentage	0.45	0.7	0.17	0.13	0.25	0.1	0.95	0.09	Balance

Table 3. Mechanical properties of 6061 aluminum alloy

S. no	*Properties*	*Values*	*Units*
1	Vickers Hardness	68	VHN
2	Ultimate Tensile strength	125	MPa
3	Fracture Toughness	29	MPa √m
4	Fatigue Strength	96.5	MPa

In the study three different micron sizes of boron carbide powders were used. The B_4C particles sizes were 25µm, 50µm, 75µm. The B_4C particles of 6, 8, 10 weight % were dispersed in the matrix. The properties of the boron carbide are shown in the table 4.

Table 4. Mechanical properties of boron carbide (B_4C)

Properties	*Density*	*Hardness, Vicker*	*Melting Point*
	g/cm^{-3}	kg/mm^2	°C
Values	2.52	2400	2445

To overcome the wetting problem between 6061 Al alloy & B_4C and to enhance uniform particle distribution, potassium hexafluorotitanate (K_2TiF_6) flux was used. To prepare the specimen and perform the lapping process for obtaining the 1μm finish, specimen mounting press and double disc polishing machine were used.

2.3 Composite Fabrication

In the study, the composites were fabricated by squeeze casting technique, which is a combination of casting and forging process. Each experiments begins by charging 800g of 6061 Al alloy into the furnace of squeeze casting machine which is shown in the figure 1 and were melted at a set temperature of 750°C. Boron carbide particles of three different micrometer sizes were charged accordingly into the preheater of the squeeze casting machine which is shown in the figure 2 and were preheated to a set temperature of 900°C, since the melting point of B_4C particles is around 2445°C. Then the preheated B_4C particles were allowed to fall at a fixed rate into the molten 6061Al alloy vortex.

The same amount of K_2TiF_6 flux was introduced into the molten metal, to facilitate the bonding between molten aluminum and B_4C particles [14]. For the purpose of degasification 12g of C_2Cl_6 (Solid hexachloroethane) tablet was used [15]. To prevent the atmospheric contamination, 8g of cover flux was used. For enhancing the mechanical property, the squeeze pressure is also taken as one of the factor. Stirring speed is kept constant for all sizes and ratio of dispersion. The stirrer present in the squeeze casting machine which is shown in the figure 1 is attached to a stainless steel blade, was introduced into the melt while the addition of flux and B_4C particles. The stirrer is used to agitate the melt was maintained at a speed of 350 rpm and it stirred the melt for 10 min.

The molten aluminum and B_4C mixture is poured into the mould which is clamped on both the sides. The bottom opening present in the furnace is switched to allow the flow of molten metal into a 50mm internal diameter metal mould as shown in the figure 1. The metal reaches the mould through the preheated pathway. To the hydraulic system a plunger is attached which is kept above the mould. After the melt is poured completely, the hydraulic system is activated by a toggle switch which moves the plunger inside the die for applying the squeeze pressure.

The plunger squeezes the melt, while the melt is solidifying. Because of this squeezing action, the contact between the aluminum and B_4C particles get shorter and the reinforcement was made. The squeeze casting process parameters are shown in the table 5 and the composites that are produced using these parameters are shown in the figure 2. From the cast bar, the metallographic samples are parted using carbide tipped parting tool of P-3 grade.

Table 5. Squeeze casting process parameters

S. No	*Process Parameters*	*Values*	*Units*
1	Melt Temperature	700	°C
2	Squeeze time	60	sec
3	Preheating Temperature of B_4Cp	900	°C
5	Stirring Speed	350	rpm
6	Stirring Time	10	min

2.4 Preparation of test sample

The specimens are prepared as per *ASTM E3-11* Preparation of Metallographic Specimens. As design, 27 specimens were prepared as per the standard from the samples in the same procedure with different micron sizes, weight fractions and squeeze pressure.

2.5 Microstructure

For microstructure study, the composite of 50mm diameter and 150mm height is machined to diameter of 10mm and parted to a thickness of 5mm. Microstructure characterization was carried out using trinocular metallurgical microscope METZ - 780. Fracture surface and crack propagations were examined on the composites through scanning electron microscopy (SEM).

2.6 Hardness test

The Vicker hardness is measured using Die Hard Microhardness Tester equipment with a square based pyramidal diamond indenter. The vicker's hardness tests are made at test force of 1kgf to 120kgf as per *ASTM E92-82*. For each sample, five indentations were made on selected region and the mean is taken as hardness value. If the indentations were made on the B_4C particles, it will give very high hardness value, so all the indentations were made in-between the B_4C particles [16].

2.7 Ultimate Tensile strength

To determine the mechanical behavior, tensile test was also performed to the produced composites. The specimens are prepared as per *ASTM E8* standard. Then the tensile strength was tested on ZWICK Universal testing system (2000N capacity, microprocessor controlled).

3. RESULT AND DISCUSSION

In the present work, 6061 Al alloy reinforced with various sizes (25µm, 50µm, 75µm) and weight fractions (6, 8, and 10 %) of B_4C particles at different levels of squeeze pressure (70.7, 106.1, 141.47 MPa) have been successfully produced using squeeze casting method. The effect of applied pressure is found to be a dominant factor in the improvement of mechanical properties. Increase in applied pressure results in fine microstructure and seemed to be a cause of increase in mechanical properties.

3.1 Evaluation of microstructure

The microstructure variation, due to the addition of B_4C particles on the casted samples were shown in the figure 3 respectively. From the figures it is clear that, the addition of K_2TiF_6 flux improved the wettability between 6061 Al alloy and B_4C particles. It also produces Ti compounds around the surface of the B_4C particles.

It is observed that B_4C particles were dispersed uniformly between the dendrite branches in the matrix material for all sizes and weight fractions as shown in the figure, which may be due to the effective stirring and by means of applied pressure. The migration of alloying elements into the grain boundaries leaving behind the reinforcements in the grains result in a higher concentration of B_4C within the grains, which may be one of the main reason for the increase in strength of the composite. Amount of porosity is also decreased, even after increasing the weight fractions of B_4C particles in aluminum alloy. This is due the incorporation of squeeze casting technique for producing the composite.

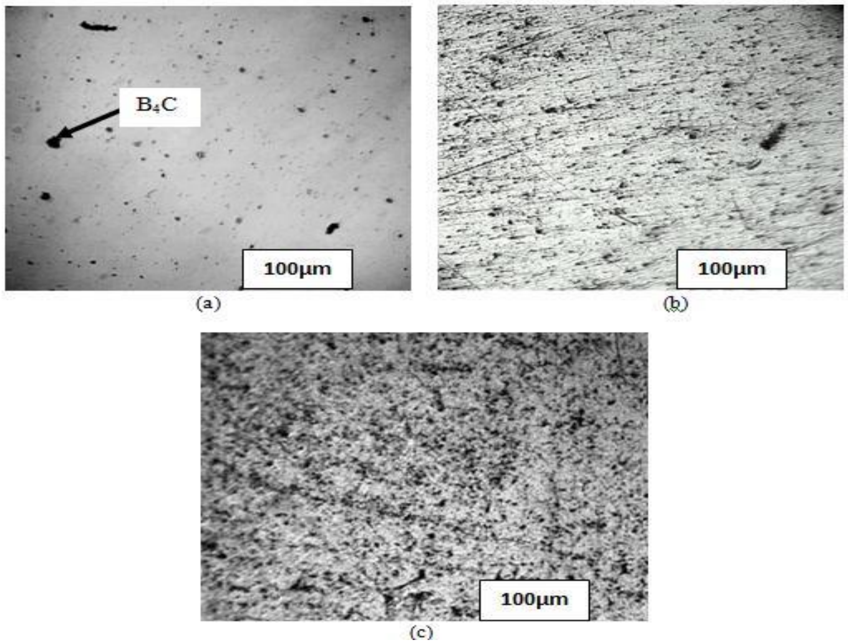

Fig.3 Microstructure of composite reinforced with 75µm sizes and (a) 6, (b) 8, (c) 10 weight % of B_4C particles

3.2 Evaluation of SEM

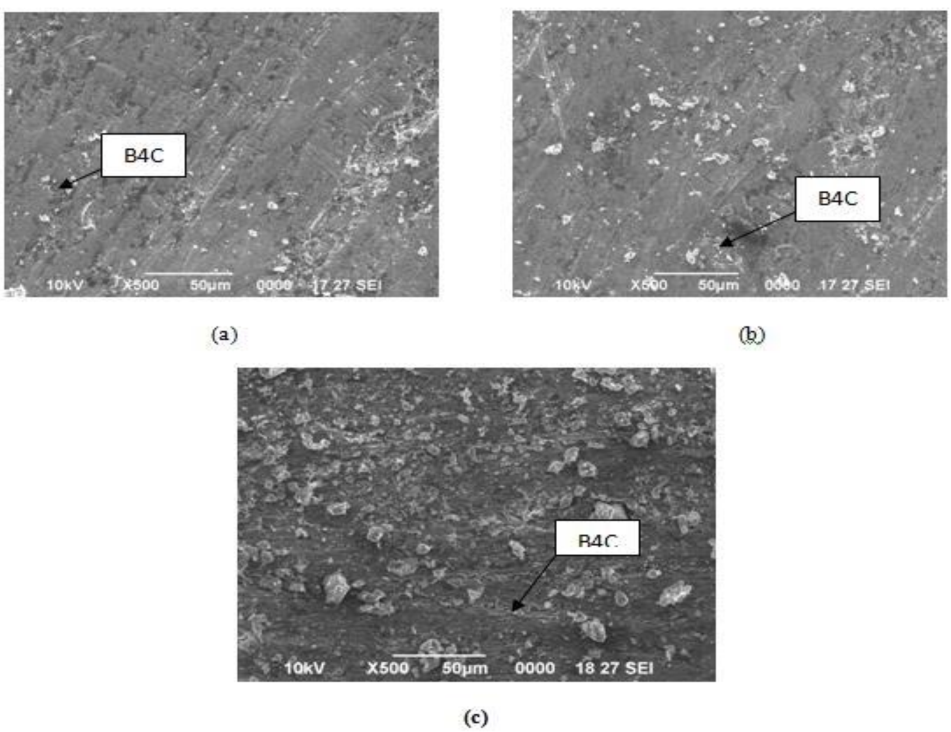

Fig.4 Scanning electron micrograph of worn surface of (a) Al 6061-6Wt% of B_4C particles, (b) Al 6061-8Wt% of B_4C particles, (c) Al 6061-10Wt% of B_4C particles.

Table 6. Experimental data on mechanical properties of B_4C reinforced 6061 Al alloy

xp	*Factors*			*Response*	
	B_4C Sizes (µm)	*Weight %*	*Squeeze Pressure (Mpa)*	*Hardness (VHN)*	*UTS (Mpa)*
1	25	6	70.7	99	187
2	25	6	106.1	105	208
3	25	6	141.47	111	228
4	25	8	70.7	106	193
5	25	8	106.1	112	214
6	25	8	141.47	117	234
7	25	10	70.7	110	191
8	25	10	106.1	115	212
9	25	10	141.47	121	232
10	50	6	70.7	104	192
11	50	6	106.1	109	213
12	50	6	141.47	115	233
13	50	8	70.7	110	198
14	50	8	106.1	115	219
15	50	8	141.47	121	239
16	50	10	70.7	114	196
17	50	10	106.1	119	217
18	50	10	141.47	125	237
19	75	6	70.7	108	197
20	75	6	106.1	113	218
21	75	6	141.47	119	238
22	75	8	70.7	114	203
23	75	8	106.1	119	224
24	75	8	141.47	125	244
25	75	10	70.7	118	201
26	75	10	106.1	123	222
27	75	10	141.47	129	242

3.3 Evaluation of Hardness

Figure 5, shows that the highest hardness value in the composite is achieved for 10 weight % reinforcement of 75µm size B_4C particles. It is observed that, increasing the boron carbide content increases the hardness value in the composites as the boron particulates are harder than the 6061 Al alloy. The table 7 shows the highest hardness value obtained for all micrometer sizes of B_4C particles.

Table 7. Hardness value for different sizes of B_4C particles reinforcement for the squeeze pressure of 141.47 MPa

B_4C Particle Sizes	*Hardness (VHN)*		
	6 Wt%	8 Wt%	10 Wt%
25µm	111	117	121
50µm	115	121	125
75µm	119	125	129

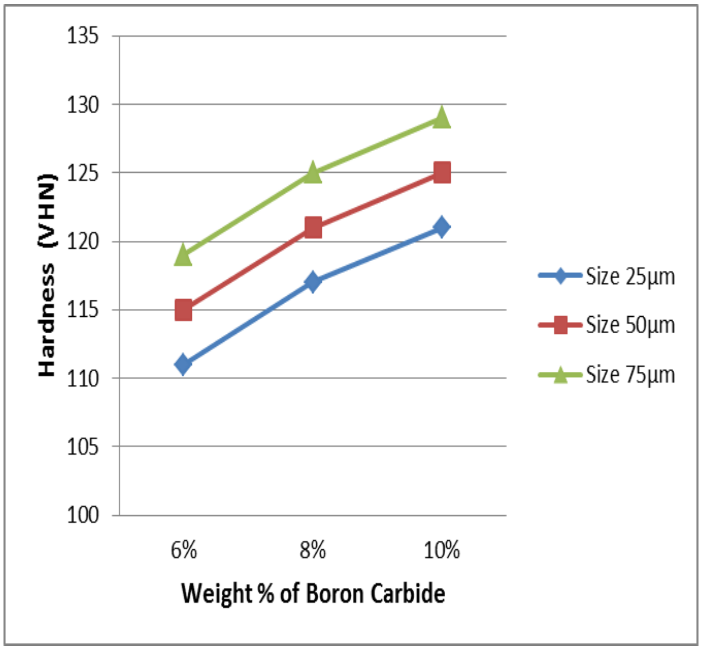

Fig.5 Variation of Hardness for different wt% and size of the B_4C Particle at max Squeeze Pressure

3.4 Evaluation of Ultimate tensile strength

The figure 6, UTS value for the composite increase as the boron content is increased upto 8 weight %. There is no advantage in reinforcing B_4C particles to increase UTS, because the UTS value doesn't show any improvement beyond 8 weight %. This is due to the over accumulation of B_4C particles in the grain structure. The table 8 shows the UTS values obtained for all micrometer sizes of B_4C particles.

Table 8.UTS values for different sizes of B_4C particles reinforcement for the squeeze pressure of 141.47 MPa

B_4C Particle Sizes	*UTS, Mpa*		
	6 Wt%	8Wt%	10Wt%
25µm	228	234	232
50µm	233	239	237
75µm	238	244	241

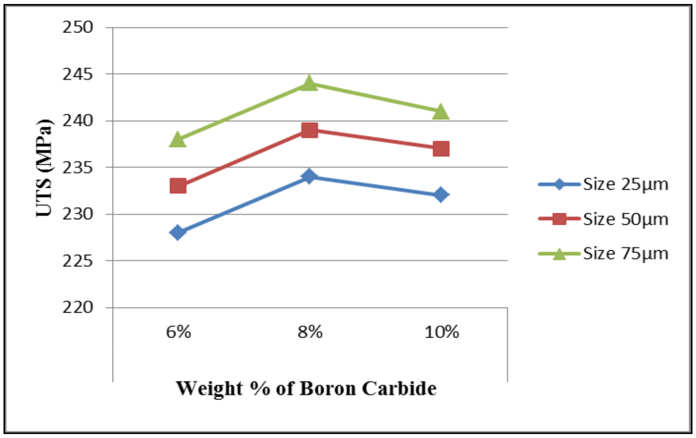

Fig.6 Variation of UTS for different wt% and size of the B_4C Particle at max Squeeze Pressure

4 CONCLUSION

Aluminum Alloy 6061-B_4C composite with different weight % of reinforcement has been successfully produced through squeeze casting process. The microstructure and SEM image of the composite reveals that there is a uniform distribution of B_4C particles in the matrix and also the composite is free from porosities.

- The B_4C particles are distributed in-between the DAS of 6061 Al alloy which is revealed by scanning electron microscopy (SEM).
- Better interfacial bonding is obtained due to the preheating of Boron particles at 900°C.
- Very good mechanical properties are obtained and it is found that there is no reaction between AA6061 and B_4C particle, until the introduction of K_2TiF_6 flux.
- Maximum hardness of 129 VHN and maximum ultimate tensile strength of 244 MPa are obtained by reinforcing B_4C particles in the AA6061 at maximum squeeze pressure (144.47Mpa).

Thus in the AA6061-B_4C composite produced, the hardness and UTS were found to be increased as the weight % and size of B_4C particles reinforcement was increased.

- The hardness is attained maximum at maximum size and weight % of the B_4C particle reinforcement.
- The ultimate tensile strength is attained maximum up to 8 weight % of B_4C particles addition and on further addition there is no significant advantage.
- High strength squeeze casted AA6061-B_4C composites is suggested for real time components like cylinder block, piston, connecting rod, knuckle etc..,

REFERENCES

1. J. O. Aweda, "Evaluation of some squeeze cast parameters of aluminum", University of Ilorin (2010), P.M.B. 1515.

2. J.David Raja Selvam*, Robinson Smart, I.Dinaharan, "Synthesis and characterization of Al6061-Fly Ash-SiC composites by stir casting and compocasting methods", Energy Procedia 34 (2013) 637 – 646

3. Shang-Nan Choua, Jow-Lay Huanga, "The mechanical properties and microstructure of Al_2O_3aluminum alloy composites fabricated by squeeze casting", Journal of Alloys and Compounds 124–130

4. A. Maleki, A. Shafyei, B. Niroumand* ,"Effects of squeeze casting parameters on the microstructure of LM13 alloy", Journal of materials processing technology

5. E. Mohammad Sharifi, F. Karimzadeh, M.H. Enayati , "Fabrication and evaluation of mechanical and tribological properties of boron carbide reinforced aluminum matrix nanocomposites", Material and Design (2011) 3263 – 3271

6. Mohsen Ostad Shabani, Ali Mazahery, Mohammad Reza Rahimipour *, Mansour Razavi, "FEM and ANN investigation of A356 composites reinforced with B_4C particulates", Engineering Sciences (2012) 24, 107–113

7. Fatih Toptan, Ayfer Kilicarslan,"Processing and microstructural characterization of AA 1070 and AA 6063 matrix B_4Cp reinforced composites", Material and Design (2010) S87 - S91

8. A. Alizadeh, E. Taheri-Nassaj, "Mechanical properties and wear behavior of Al–2 wt. % Cu alloy composites reinforced by B_4C nanoparticles and fabricated by mechanical milling and hot extrusion", Materials characterization (2012) 119- 12

9. Harun Mindivan, E. Sabri Kayali, "Tribological behavior of squeeze cast aluminum matrix composites", Wear (2008) 645–654

10. Ali Mazahery, Mohsen Ostad Shabani, "Influence of the hard coated B_4C particulates on wear resistance of Al–Cu alloys", Composites: Part B 43 (2012) 1302–1308

11. K. Kalaiselvan, N. Murugan "Production and characterization of AA6061–B_4C stir cast composite", Material and Design(2011) 4004 – 4009

12. K.M. Shorowordi, T. Laoui, "Microstructure and interface characteristics of B_4C, SiC and Al_2O_3 reinforced Al matrix composites: a comparative study", Journal of Materials (2003) 738-743

13. Joel Hemanth, "Fracture toughness and wear resistance of aluminum-boron particulate composites cast using metallic and non-metallic chills", Materials and Design 23 (2002)41-50

14. Isil Kerti, Fatih Toptan "Microstructural variations in cast B_4C-reinforced aluminum matrix composites (AMCs)", - Material Letter (2008) 1215 – 1218

15. Gopal Krishna U B, Sreenivas Rao K V ,"Effect of Boron Carbide Reinforcement on Aluminum Matrix Composites" , International Journal of Metallurgical & Materials Science and Engineering (IJMMSE) (2013) 41-48.

16. Kirity Bhusan Khana, T.R.G. Kutty , "Hot hardness and indentation creep study on Al–5% Mg alloy matrix–B_4C particle reinforced composites" Materials Science and Engineering A (2006) 76–8

Conflict of Interest

None of the authors have any conflicts of interest to declare.

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