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Effect of Reinforcement and Volume Fraction on Mechanical Behaviour of AA7075/B_4C/Fly-ash MMCp

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Abstract: ***In this study, an effort has been made to develop a substitute material for automobile, aerospace and defence components with an aim to increase mechanical properties. Development of new material involves synthesis of Aluminium composite by the use of Stir casting method using AA7075 as matrix with B_4C and Fly ash as particle reinforcement with the varying volume fraction of the reinforcement (2 - 6 wt.%) B_4C and (2 wt. %) fly ash. Investigation of Mechanical properties such as hardness, tensile strength and impact strength have been done. SEM analysis of the composites was performed to observe the interfacial bonding between matrix alloy and the reinforcement and the distribution of the reinforcement in the matrix, and type of failure taking place during the tensile test. X ray diffraction of the alloy and the composite was also done to identify the major peaks of the phases present in the material. Results show significant improvement due to the addition of reinforcement in the hardness and tensile strength of the composite as compared to Al 7075 alloy whereas the impact strength has slightly decreased. Microstructural analysis of the composite shows that proper distribution of reinforcement particles in the matrix and the interface bonding was good. XRD analysis reveals the presence of $MgZn_2$ precipitates in the solid solution of aluminium as an interfacial reaction.***

Index Terms: ***Stir casting, AA 7075, B_4C, Fly ash, Composite, Microstructure, XRD***

I. INTRODUCTION

Aluminium alloys are characterized by a tremendous blend of properties, for example, high strength to weight ratio, high resistance against corrosion and great thermal conductivity making it suitable for various applications, such as aero-space and auto-motive components[1][2]. The aluminum matrix composites have come out as progressive materials for many potential applications in the automotive, aerospace, aircraft, defense and other engineering apllications because of their strength and stiffness compared to alloys.

Verma and Vettivel [3] conclude that by the increase in weight percentage of B_4C and RHA in the composite increases the hardness, compressive strength and tensile strength of the AA7075/B_4C/RHA. Wua et al. [4] studied the effect of the particle size of B_4C particles on the composite of AA7075 matrix, and concluded that the inclusion of fine paarticles as reinforcement has improve tensile behaviour of composite. Alaneme KK and Sanusi KO [5] reported the mechanical responce of AA7075 composite using RHA, Al_2O_3, and graphite as reinforcement and concluded that the RHA and graphite decreased the hardness of the composite. Baradeswaran and Perumal [6] contemplated the mechanical conduct of AA7075/B4C composite and reasoned that the hardness, tensile and compressive strength increase with the increase in reinforcing. Raturi et al. [7] investigated the mechanical behavior of AA7075 / Al_2O_3 nano composite and reported that the tensile strength and the hardness of composite increase with the weight % of Al_2O_3. Baradeswaran et al. [8] study the mechanical properties of the AA7075 matrix composite with B_4C and graphite as reinforcement and found that the AA7075 hybrid composite shows better properties than the AA 6061 hybrid composite. Abirami and Arravind [9] investigate mechanical behavior of the hybrid composite of Al_2O_3, B_4C and TiO_2. The hybrid composite has higher hardness to the Alminium Alloy base. Singla [10] evaluated the mechanical responce of the aluminium composite with AA7075 matrix and flyash as reinforcement, and concluded that the hardness was increased and the density of the compound decreased with the increase of the flyash content. Muruganandan et al. [11] AA7075 was used with fly ash and TiC as a reinforcing material and it was reported that the the increased in wt% of TiC and fly ash increases the hardness and tensile strength of the composite.

AA7075 is an alloy, having zinc, magnesium as the primary elements. It is strong and has quality practically identical to steels. In addition, it has a a decent resistance to fatigue with average machinability. However, it has low corrosion resistance than many other aluminum alloys. By reinforcing ceramic particles, the mechanical properties of the AA7075 can be enhanced [12].

Aluminium metal matrix composites are used with two or more tyes of reinforcement in different volume fraction to achieve the best properties [13]. Boron carbide is widely used as reinforce materials in aluminum alloy because of their high hardness, low density, good chemical stability and better resistance to corrosion and to high temperature [14]. Fly ash is a industrial waste which generate by the burning of coal in the combustion chamber of thermal power plants. It is a major source of energy in India; due to this, it is available in large amount the country.

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Additionally it has low-density, good mechanical properties and corrosion resistance that makes it suitable to be used as reinforcement in Al alloys [15].

The detailed study of the literature concluded that the particles of B_4C, TiC, Al_2O_3, fly ash, SiC, etc. as the reinforcements in the Aluminum based composites improve the mechanical and wear beahaviour of the material. Aluminum and its composites have appeared in the improvement of the mechanical properties, and the inclusion of two or more distinct reinforcements in the aluminum alloy can be improved mechanical conduct and tribological properties of the composite. Nonetheless, it has noticed that few investigations have directed to discover the impact of the inclusion of at least two reinforcements in aluminum alloys. In this way, an exertion has made to build up the aluminum matrix composite by expansion of boron carbide and fly ash particles in different weight percentages as reinforcement to AA7075 matrix.

II. MATERIALS AND METHODS

A. Materials

a) Matrix Material: The AA7075 is used as matrix material. AA7075 was purchased from Suresh Metals Mumbai, MH, India. The AA7075 received from the supplier in the form of ingots of 1 kg weight as shown in the Fig. 1. The primary elements of AA7075 alloys are Al, Zn, Cu, Mg, Si, Mn, Cr and Ti. Table I. is showing the chemical composition of the purchased AA7075.

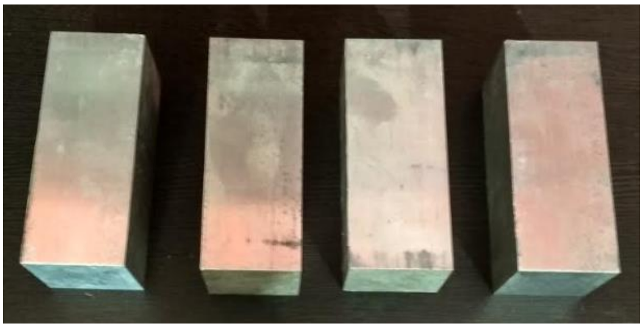

Fig. 1 Actual image of as received AA7075 ingots.

Table I. Chemical composition of as received AA7075

Element	Zn	Mg	Cu	Fe	Cr	Mn	Si	Ti	Al
wt%	5.7	2.4	1.4	0.17	0.2	0.04	0.04	0.04	Remaining

(b) Reinforcements: The Fly ash and B_4C were used as reinforcement materials. The B_4C was purchased from GEEPAX industries Ltd, New Delhi, India and Fly ash was obtained from local sources.

Boron Carbide: The fine particles of B_4C having size 10-30µm were used as reinforcements. The hardness of B_4C is 2900 to 3580 HKN [16]. The wt. % of B_4C used was 2, 4 and 6 % during the fabrication of Composite. Fig. 2 (a) shows the purchased powder of B_4C. Fig. 2 (b) shows the morphology and size of B_4C particles.

(a)

(b)

Fig. 2(a) Image of as received B_4C . (b) SEM of B_4C showing the morphology and size of the particles

Fly-Ash: Fly ash was brought from the power generation plant of MP, India. To expel the residue particles from fly ash it was cleaned with pure water after that cleaned fly ash was dried at normal room temperature for one day. The cleaned flyash powder was heated at 250° C for one hour in muffle furnace to remove moisture. Fig. 3 (a) shows the fly ash reinforcement and Fig. 3 (b) shows the morphology and size of the fly ash.

Table II. Chemical Composition of Fly ash

Compounds	SiO_2	Al_20_3	Fe_2O_3	CaO	MgO	SO_3
Composition % (wt)	55	26	7	9	2	1

(a)

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(b)

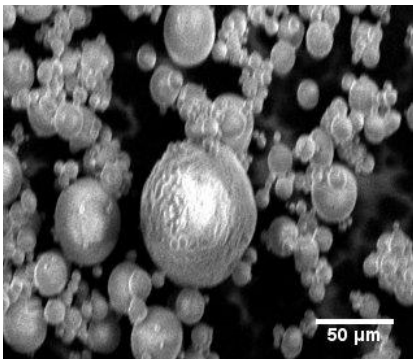


Fig. 3 Details of Fly ash :(a) Image of as received Fly ash (b) SEM of Fly ash showing the morphology and size of fly ash particles

B. Synthesis of Composite

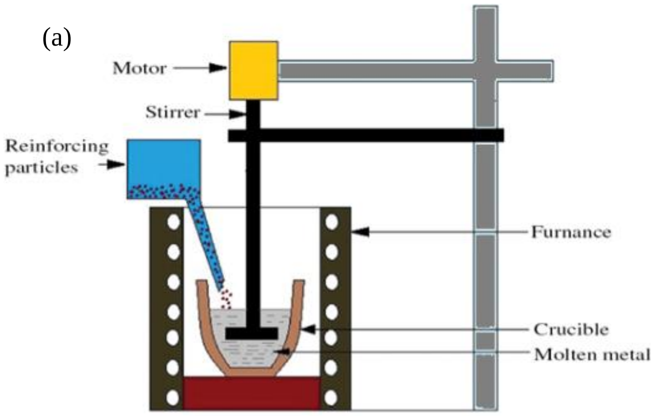
From various composite fabrication processes stir casting method was used to synthesis of composite. This liquid casting rout is the most cost-effective method for the synthesis of aluminium matrix composites. Fig. 4 (a) illustrates the schematic diagram of stir casting setup. The aluminium alloy was kept in a graphite crucible shown in Fig 4 (b) for the melting at 780°C.

The temperature of the melt was raised to approximately 800 ° C more than the liquid temperature of the matrix alloy. A mechanical stirrer was used with electric motor to create vortex in the molten metal. In order to improve wettability between matrix alloy and reinforcement, reinforcement particles were preheated to 300°C to do away with the moisture content present in the reinforcement. Then, the heated B_4C and Fly ash particles with various weight percentages were added to the crucible. Uniform scattering of the reinforcement particles in the aluminium alloy relies upon the rotational speed of stirrer and mixing time. In the current study, stir speed of 550 rpm for the time of 5 minutes was maintained to ensure uniform scattering of reinforcement particles in the melt. After the complete mixing of the particles, the rotational speed of the stirrer was reduced to 200-400 rpm and mixing constantly for 4 to 5 minutes. Now, the temperature of the liquefied mixture was reduced to 680°C to provide the ultrasonic vibration in the melt for the proper mixing. After stirring in semi-solid phase the mixed mixture was re heated and liquid mixture was maintained at a temperature of 800 °C to prepare a mixed mixture. Then the stirrer was gradually removed from the melt. The mixture was poured into permanent cast iron die to cast the composite in the form of fingers and plate and solidifies at room temperature. The six samples with different wt. % of reinforcement are fabricated shown in table III.

Table III. Weight % of Alloy and reinforcement for different samples

S No	Wt% of AA7075	Wt % of B_4C	Wt % of Fly ash
1	100	0	0
2	98	0	2
3	98	2	0
4	96	2	2
5	94	4	2
6	92	6	2

(a)



(b)

Fig.4 (a) Schematic diagram of stir casting process, (b) Molted metal in graphite crucible

C. Microstructure Study

In the analysis of alloy and composite, microstructure plays an key role in evaluating the properties of the material. The properties of aluminum matrix composites depend on the microstructure, interfacial bonds with the matrix, shape and size of particles, distribution of reinforcement particle in the matrix. JEOL make Tungsten Electron Microscope (SEM) Model JSM-6010LA; was used to characterize the alloy and composites. The range of the resolution of SEM varied from 100 to 100000X. An electric conductive carbon tape was used to mount the sample for observation.

D. X-ray Diffraction Study

X-ray diffraction studies were conducted to determine the different phases present in the samples of alloy and composite. X-ray diffraction test shows the relation between the diffraction angle (2θ) and relative intensity. An automated powder defactometer RIGAKU-Japan (MINIFLEX) was used for the X Ray Diffraction (XRD) of the AA7075 Alloy and composite at Cu Ka radiation (k = 1.54186 Å). A rectangular cavity sample holder of 15 mm x 20 mm and 2 mm deep was used to packed the solid sample. The diffraction angle range (2θ) from 10 to 90° was kept with scan rate of 0.02 ° (2θ) per second. The analysis was carried out at a with 30mA current and 40 kV voltage.

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The result was determined by comparing the experimental values from the Joint Committee of Powder Defrition Standard (JCPDS) file.

E. Hardness Test

The hardness is the capability of material to with stand against the indentation, cutting and scratching. Polished samples of alloy and composite was tested to check the hardness of the specimen, using Digital hardness testing machine, FIE make model No RASNE-1. The Rockwell hardness test was carried out at room temperature as per the ASTM E-18 standard. To take the indentation on each sample load of 100 N was applied for 10 s, with steel indenter of (1/16"). Each polished sample was tested at three different location and three values were recorded of the same sample, and the average of them was reported as the hardness result.

F. Tensile Test

To determine the tensile propeties of material, the tensile test was used. Tensile tests were conducted using Mechatronic Control systems, India make computerized universal testing machine (UTM) Model No Mech.CS.UTE, 40T, in accordance with ASTM E-8 standard at room temperature Standard. All the test pieces were machined as per the ASTM E-8 standards. As per the standards, gauge length of 50 mm was taken (G.L.=5d) as shown in Fig. 5.The test samples were fixed in the jaw of cross head of universal testing machine (UTM) and loaded up to fracture. The tensile test was conducted with a constant strain rate (0.5 mm / minute), the crosshead was moved upwards with this fixed strain rate until the fracture, at the time of fracture applied load was measured.

Fig. 5 Dimensions of the tensile test sample as per ASTM–E8

G. Impact Test

Digital Impact tester of FINE make Model No FIT-300-D was used to determine impact strength of alloy and composites. Charpy method was used to determine the impact strength of the materials. The test samples were made as per the ASTM E-23 standards.

III. RESULTS AND DISCUSSION

A. Microstructure

Micrographs of the aluminium alloy and composite are showing in Fig. 6 (a)-(d). Microstructures of AA7075 alloys and composite are showing the distribution of reinforcement particles in the matrix and interfacial bonding between the reinforcement and matrix. Microstructure of pure AA7075 is showing in Fig. 6 (a). It shows the formation of intermatallic compound $MgZn_2$ which is trapped between the dendroids of aluminium shown by arrows. Fig. 6 (b) shows the Microstructure of AA7075+2%Fly ash composite. It shows the proper interfacial bonding of the Fly ash particles with AA7075 matrix. Fig. 6 (c) and (d) showing the microstructures of AA7075+2% B_4C+2% Fly ash and AA7075+6% B_4C+2% Fly B_4C respectively. SEM image reveals the uniform distribution of the B_4C and fly ash particles in the AA7075 matrix as shown in Fig 6 (c), Fig 6 (d) showing the interfacial bonding of B_4C particles with the alloy, it also confirms that some micro voids are formed around the particle due to the less wettability of B_4C with AA 7075.

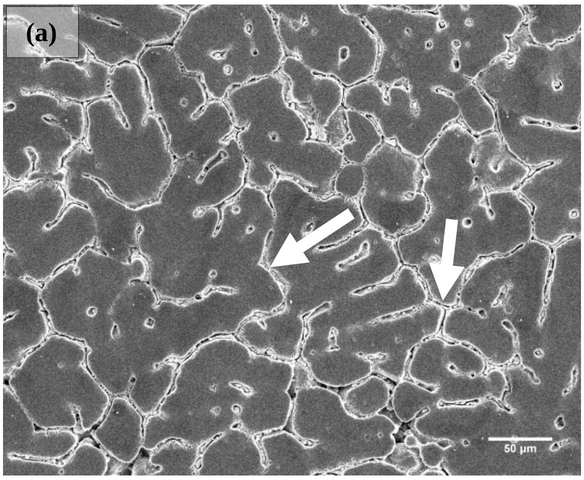

Fig. 6 (a) SEM analysis of synthesized AA7075

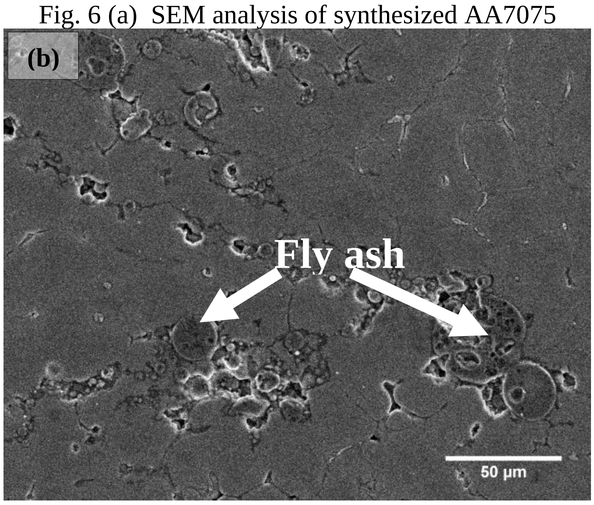

Fig. 6 (b) SEM analysis of synthesized AA7075+2% Fly-ash

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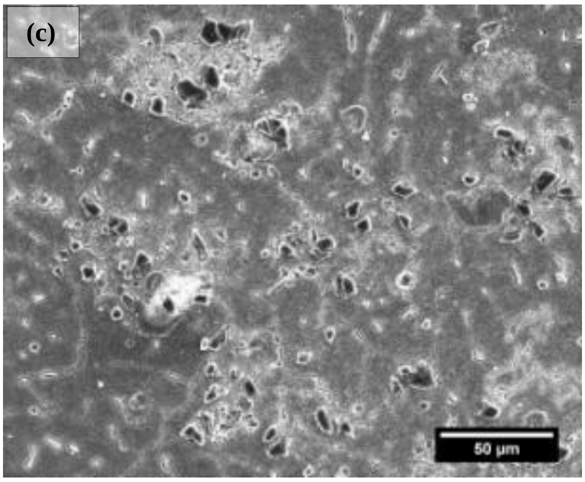

Fig. 6 (c) SEM analysis of synthesized AA7075+2%B_4C+2%Fly-ash

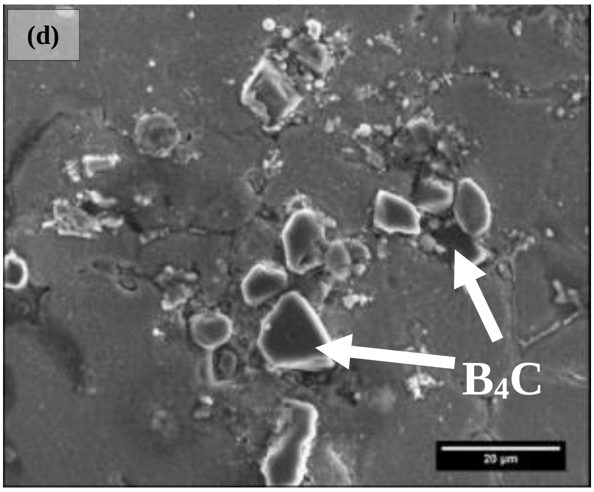

Fig. 6 (d) SEM analysis of synthesized AA7075+2%FA+6%B_4C.

B. X-Ray Diffraction

The X-Ray Diffraction pattern of the AA7075 and AA7075+6% B_4C+2% Fly ash hybrid composite is shown in Fig. 7. The X-Ray Diffraction (XRD) analysis of the AA7075 alloy and the composites shows the peaks of inter-metallic compounds $MgZn_2$ and AlCuMg in aluminium alloy and $MgZn_2$, SiO_2, Al_2O_3 in the composites as shown in Fig.

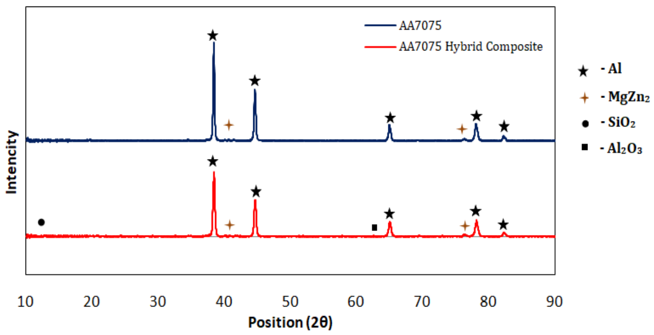

Fig. 7: XRD analysis of Al Alloy and synthesized composite AA7075 +6%B_4C+2%FlyAsh

C. Density and Porosity

Variation in the density of composites with the change in the wt% of reinforcement is shown in the Fig. 8. Actual density was determined by water displacement method and the theoretical density was measured by the empirical relation which was modified for hybrid composites, by including the volume fractions of both the reinforcements (B_4C and Fly Ash) as follows:

$$\rho_{th} = \rho_{Al}V_{Al} + \rho_{B4C}V_{B4C} + \rho_{FA}V_{FA}$$

where ρ_{Al}, ρ_{B4C}, ρ_{FA} are the densities of aluminum alloy, B_4C and Fly Ash, respectively; V_{Al}, V_{B4C}, V_{FA} are the volume fractions of aluminum alloy, B_4C and Fly Ash respectively.

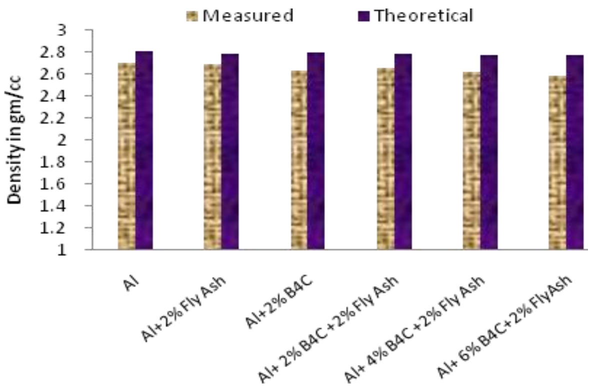

Fig. 8: Variation in actual measured and theoretical density of the composite

D. Hardness

The Rockwell hardness test has been performed on polished composite samples to evaluate the hardness of the alloy and the composite on Rockwell 'B' Scale. Three readings were taken at different locations and average value was reported. Fig. 9 shows the hardness of the prepared samples of the AA7075, AA7075+2%B_4C, AA7075+2%FlyAsh composite and AA7075+2%B_4C+2%FlyAsh, AA7075+4%B_4C+2%FlyAsh and AA7075+6%B_4C+2%FlyAsh hybrid composite. From figure 8 it is found that the Hardness of hybrid aluminium composite is higher than the AA7075 and its composite with single reinforcement. The AA7075+2%B_4C composite has more hardness when compared to AA7075+2%FlyAsh and AA7075. This is mainly due to the fact that the hardness of B_4C particles is more than the fly ash particles. Addition of two different reinforcement particulates in to the matrix alloy has significantly increased the hardness of the aluminium matrix composites than the composite having single reinforcement, further more AA7075+6%B_4C+2%FlyAsh shows highest hardness of all the fabricated composites. The hardness of the material increases with the addition of the B_4C and Fly ash as reinforcement. By the addition of 2% B_4C in the matrix shows an increment of 5.6% in hardness of composite when compare to the AA7075; however addition of 2% Fly Ash shows only 4.2% rise in hardness. The AA7075+6%B_4C+2%FlyAsh composite was found to an increase of 13% in hardness as compared to the base alloy. The dispersion of B_4C and FA particles in Al7075 alloy produced resistance for the deformation of the aluminium matrix. A good interface between the matrix alloy and reinforcements particles always gives raise to the hardness value.

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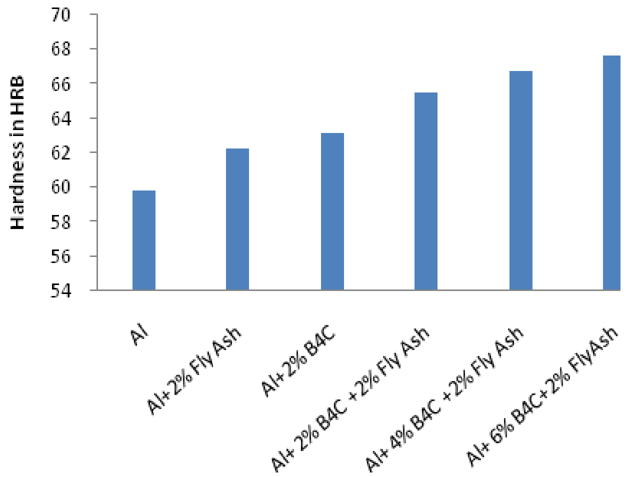

Fig. 9: Hardness of AA7075 with change in percentage of reinforcement.

E. Tensile Strength

The effect of reinforcement such as Fly ash and Boron carbide (B_4C) particles on the Ultimate Tensile Strength (UTS) of aluminium composite is showing in Fig. 10. The tensile properties of AA7075, AA7075+2%B_4C, and AA7075+2%FlyAsh composite and AA7075+2%B_4C+2% FlyAsh, AA7075+4%B_4C+2% FlyAsh and AA7075+6%B_4C+2% FlyAsh hybrid composites are shown in fig (10). From the figure it was noted that the maximum fracture load was 13.9 kN and the maximum tensile stress was 176.98 MPa for the AA7075. For the AA7075+2%B_4C and AA7075+2%FlyAsh composites, the maximum tensile load was 14.5 kN and 15.4 kN respectively, and the maximum stress was 184.62 MPa and 196.08 MPa respectively. For the hybrid composites with the combination of two reinforcement AA7075+2%B_4C+2% FlyAsh, AA7075+4%B_4C+2% FlyAsh and AA7075+6%B_4C+2% FlyAsh the maximum tensile loads were 16.7 kN, 14.9kN and 12.9 kN respectively and the ultimate tensile strength (UTS) of the hybrid composite were recorded as 212.63 MPa, 189.71 MPa and 164.25 MPa respectively. The variation in the value of Ultimate Tensile Strength of alloy composite and hybrid composites shows that, there is a sudden change in the value of Ultimate Tensile Strength with the addition of reinforcement wt% of B_4C and FlyAsh. The ultimate tensile strength of AA7075+2%B_4C+2% FlyAsh was found maximum and it was 20 % above the base alloy and 8% higher than the AA7075+2%B_4C composite. The increase in tensile strength in composites is because of the hard reinforcement particles acting as a barrier in the moment of dislocation there by increasing the stress required for moment of dislocation and fracture. There is a decrease in tensile strength when the weight% of reinforcement was increased beyond 4% as shown in Fig. 10. Dispersion of hard reinforcement particles in aluminium alloy matrix after a certain weight % tends to reduction in the tensile strength because of the fact that during the tensile deformation of the aluminium alloy matrix is higher than the very hard B_4C and FA particles. The rate of deformation is not same of the hard particles as the matrix. These non-uniform rates of the tensile deformation of aluminium alloy and hard reinforcement particles develop the cracks at the interface of reinforcement and matrix. Due to this, the decohesion of particles and formation of void take place, these cracks join together to cause brittle fracture thereby lowering the tensile strength.

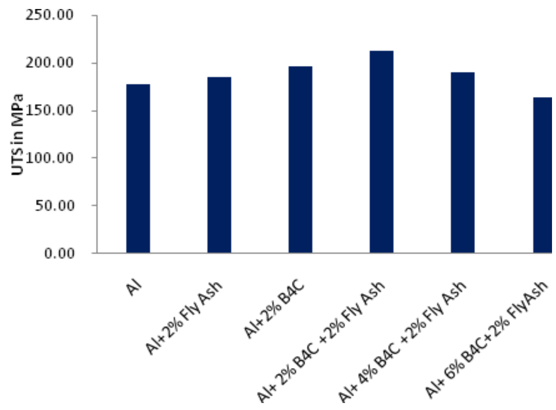

Fig 10: Ultimate Tensile Strength (UTS) of aluminium composite.

F. Impact Strength

In order to identify the energy absorption of the aluminium alloys and its composites, Impact tests were performed using a charpy method in according to ASTM–E23 Standard the tests were performed at room temperature using FINE make impact testing machine (Model FIT 300 D). It was noted that the higher wt% of hard B_4C and Fly ash particles in to the aluminium 7075 matrix alloy, Impact strength was decreased. The impact strength of the materials are shown in Fig. 11. From the test result it was noted that the AA7075 has impact strength of 4.1 joules, and AA 7075+2%FlyAsh and AA7075+2%B_4C composites have 3.2 joules and 2.6 joules respectively. The lowest impact strength 0.8 joule was found in AA7075+6%B4C+2%FlyAsh.

It is understood that the spread of hard ceramic particles in soft matrix reduces the energy absorption capacity of the material. Less impact resistance found with more dispersion of hardened renforcement particles, because in addition to rigid reinforcement particles increases the brittelness of the material, when there is sudden impact, the interface between the particles and the matrix breaks and the decohesion creates new surfaces and energy is released. On the other hand, in the case of aluminum alloy, the matrix material absorbs energy without fracturing effect.

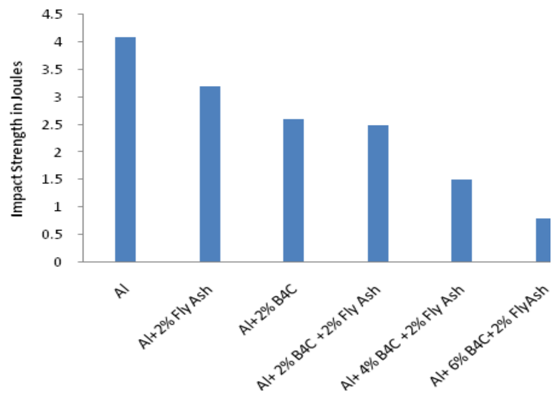

Fig.11 Impact strength of Alloy and aluminium composites

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G. Fracture Surface Study

The fractographs of the fractured tensile test samples are shown in Fig. 12 (a) & (b). Fig 12 (a) shows the that the formation of voids and aluminium dendrites. AA7075 number of small voids uniformly distributed between the dendrites, From the fractograph it is inferred that there is a ductile fracture taking place in the AA7075. The fractograph of tensile sample in Fig. 12(b) shows brittle fracture in composites because there is a stress concentration at the interface of alloy and the particles, which resulted into nucleation of cracks at the interface. These cracks join together to fracture the material in brittle nature. In some instances the fracture surface is characterized by showing the fracture of B_4C particles. This aspect is occurred when there is a good interface bonding between the reinforcement particle and Aluminium matrix.

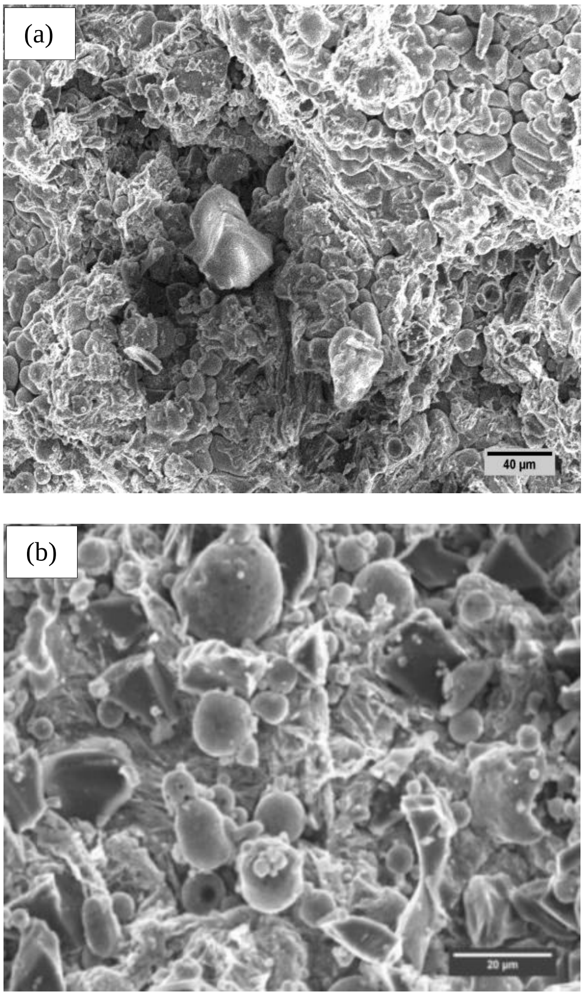

Fig. 12 Morphology of fracture surface of Aluminium alloy and the hybrid composite

IV. CONCLUSION

In the present study AA7075/B_4C/Fly Ash composites have been successfully synthesized and their microstructural and mechanical behaviour have been investigated. From the results the following conclusions have been made:

- Microstructural study of the synthesized aluminium composites reveal that there is a proper interfacial bonding between the reinforcement particles and matrix alloy and the distribution of the particles within the matrix is uniform.
- XRD analysis confirms the presence of inter-metallic compounds of $MgZn_2$ and AlCuMg in the aluminium alloy and $MgZn_2$, SiO_2, Al_2O_3 in the composites.
- The dispersion of hard ceramic particles of B_4C and Fly ash in the aluminium alloy improves the hardness of hybrid aluminium composites as compared to the AA7075. The hardness increases with increasing the weight % of reinforcement (B_4C and FA). Addition of 2% B_4C in the matrix alloy shows an increment of 5.6% in hardness whereas addition of 2% Fly Ash shows 4.2% rise in the hardness of composite. The combination of two hard particles (B_4C and Fly ash) in matrix increases the hardness up to 13% as compared to the base alloy 7075. AA7075+6%B_4C+2% Fly Ash composite is showing the highest hardness of 67.7 HRB.
- The ultimate tensile strength (UTS) of composites has improved up to 20% as compared with AA7075 due to the addition of B_4C and Fly Ash particles. The ultimate tensile strength of AA7075+2%B_4C+2% Fly Ash was found maximum and it was 20% above the AA7075 and 8% higher than the AA7075+2%B_4C composite. The tensile strength of composite decrease when the wt.% of reinforcement was increased beyond the 4%.
- The impact strength of the hybrid composites is comparatively lower than AA7075 due to dispersion of hard particles in the matrix alloy which increases the brittleness. From the test result it was noted that the impact strength of AA7075 was 4.1 Joules. However AA 7075+2% Fly Ash and AA7075+2%B_4C composites show impact strength of 3.2 joules and 2.6 joules respectively. The lowest impact strength 0.8 joule was found in AA7075+6%B_4C+2% Fly Ash composite.
- From the fracture surface analysis of tensile test samples it is concluded that there is a ductile fracture in AA7075. The fracture surface study of composites shows brittle fracture. The reason being decohesion of particle with the matrix interface which resulted into void formation. Also and shearing of the particle was observed at some places.

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