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Microstructure and Mechanical Behavior of Al-AlB$_2$ Metal Matrix Composites

Samuel Dayanand
Mechanical Engineering,
Government Engineering College, Raichur
Karnataka, India

Dr Satish Babu B
Associate Professor, School of Engineering, Presidency University, Bangalore
Karnataka, India

Abstract:**Insitu process becomes one of the best method for processing of aluminum composite material because of its various advantages over the traditional method.The present paper deals with the preparation and fabrication of inistu AlB2(1, 3 and 5 wt.%) reinforcement in aluminum alloy through the chemical reaction between the molten aluminum and halide salt potassium tetra fluoro borate at a temperature of 800^{0}C to 850^{0}C using liquid metallurgy route.Equipment SEM/EDS used for the characterization of the composites and microstructure reveals that clean and fine inistu developed AlB$_2$ particles were distributed throughout the base matrix with good proper bonding and located near the grain boundariesand exhibited various different shapes including spherical, cylindrical and hexagonal shapes. The formed AlB$_2$ particles patterns without any compound were revealed by the XRD technique. The prepared inistu composites were investigated forvarious mechanical properties like hardness, tensile and compression by the standard methods. The insitu formed AlB$_2$ particulates enhanced the mechanical properties continuously with increase in the weight fraction of AlB$_2$ particles but ductility of the composite is decreases with the increases in the % of reinforcement.**

Keywords-Insitu;aluminium; diboride; mechanical; stircasting;

1. INTRODUCTION

AMCs have had impressive effect in the materials field because of their alluring properties which incorporate high strenght to weight ratio, high wear resistance, low thermal expansion and so forth. AMCs are inevitably eliminating tradaitional aluminum and its alloys in a various products in aviation, car, automobile and marine enterprises. With expanding interest for light weight and superior materials in aviation and automobile sectors aluminium metal matrix composites (AMMCs) are picking up rather more significance and to satisfy these requirements distinctive production procedures with different ceramic reinforcement have been utilized [1-4].

AMCs have just supplanted or supplanting tradaitional alloys in numerous applications because of astounding mix of different properties, for example, high wear opposition, low thermal expansion, and high strength to weight proportion, and so forth Increased interest of light weight and prevalent execution materials in aviation and automobile enterprises makes aluminum matrix composite (AMCs), a potential possibility for some applications [5-6]. Thus, AMCs are broadly utilized in production of different part like brake drums/rotors, brake liners, cylinders, gears, drive shafts and suspension frameworks [7-8]. Different reinforcemntssuch as carbides, oxides, nitrides, borides of metals, graphite, fly ash remains, and so forth have been utilized in aluminium or aluminium alloy to produceAMCs by various preparing strategies[9]. The advancement in manufacturing methods empowered scientists to deliver AMCs strengthened with different carbides, oxides, borides, nitrides particulate is a decent decision for various reinforcement.AMC’s are created utilizing different solid and liquid state [10-11]. Each technique can't be utilized to deliver each blend of AMCs. The decision of generation strategy is transcendently constrained by the size and different properties of support particulates. Liquid metulurgy route are generally supported to deliver AMCs in view of effortlessness, simplicity of appropriation, cost adequacy and materialness to large scale manufacturing. Liquid state methods are commonly utilized on the grounds that these are monetarily reasonable, straightforward and pertinent in vast amount creation [12-13].The hardparticulates are either externally added to the liquid aluminum (ex-situ) or internally produced inside the liquid aluminum (in-situ) in liquid metallurgy route. liquid metallurgy route is the most prominent ex-situ technique wherein the reinforcement particulates are added at the fringe of the vortex created in the liquid aluminum by a mechanical impeller. The real difficulties of stir casting method is poor wettability of ceramic particulates, conceivable interfacial responses between liquid aluminum and ceramic particulates and presence of porosity [14]. AMC’s prepared with In-situ process comprises of chemical reaction responses between among compound and elements. The natural benefits of in situ production technique are the generation of fine size of ceramic particulates, great interfacial holding between the aluminum matrix and the ceramic particulates, homogeneous appropriation of ceramic particulates in the aluminum grid, thermodynamically stable particulatesandeconomy of processing [15-16]. The possibility of the in-situ process has been set up to effectively deliver AMCs reinforcement with Al2O3, TiC,TiB2, ZrB2 and AlN [17-21] particulates 'in-situ' process the creation of reinforcement happens inside the matrix because of compound response. The in-situ composites represent a few focal points over ex-situ, for example, uniform circulation of support particles, grain refinement, clear interface, improved thermal stablity and prudent preparing. **R. Kayikci et.al [22]**,concluded that the

Al composite is prepared by using boron oxide powder by liquid metallurgy route and the composite having good wear resistance because of increase in hardness of the composite. Dumitru-**Valentin et.al [23]**, prepared the composites by AA6060 and halide salt KBF_4 by liquid metallurgy route.He reported thepresence of AlB2 compounds in the condition of high cooling rate of the composite material.**P. Moldovan et.al [24]**, investigated the inistu composite by Al alloy and KBF_4 by stir casting route, is reported that the presence of AlB_2 particles improvedthe mechanical properties of the composites.**Sakip Koksal et.al [25]**,prepared thecomposite by Al and AlB_2 flakes using B_2O_3 powder by liquid metallurgy route and concluded that the incorporation of AlB_2 flakes phase increases hardness of the composite increase hence good wear resistance of the composite. **Omar Savaş et.al [26]**, prepared the composite by centrifugal casting byAl-Mg with AlB_2 flakes using B_2O_3 powder. The results showed that, depending on the increase in the reinforcement phase in external zones, up to 20 % increase in the hardness of the composite has been achieved.**H. Elcicek et.al [27]**, prepared the composite by Al-Cu/AlB_2 using inistu casting methodby using B_2O_3 by liquid metallurgy route at 1400^0C.**Azharuddin Kazi et.al [28]**, investigated the composite by using Al6061 with KBF_4 using liquid metallurgy route and reported that by increasing the weight % of reinforcement the hardness increases.The literature on the in situ AlB_2 particle composites is very limited[29].

In this present work, an attempt is made to synthesize aluminum alloyAA6061 reinforced with AlB_2 particulates by the in situ reaction of preheated halide salts $KBF_4$and $Na_3AlF_6$to molten aluminum and study the formation of AlB_2 particulates and its effect on microstructure and mechanical properties.

2 EXPERIMENTAL PROCEDURES

Commercially available pure alumnium alloy 6061 in theform of billets acquired form PMC, Bangalore and analyzed for the chemical composition is shown in table 2.1. Inorganic halide salts KBF_4 (Madras Fluorine Factory, Chennai) are used as a reinforcement material to develop the inistu AlB_2particle in the Al-AlB_2 Metal Matrix composites.

Table:2.1 Chemical composition of 6061Al

E	Si	Fe	Cu	Zn	Ti	Mn	Mg	Cr	Al
%	.76	.27	.24	.04	.09	.05	.90	.07	Bal

AA6061 billets were cut into small pieces and charged into a graphite crucible kept in a electrical resistance furnace for melting. A coating (WOLFRAKOAT) was applied inside the crucible to avoid contamination. Temperature of the furnace is raised to 850^0C above the melting temperature of the aluminum alloy.Temperature of the melt was measured by a K-Type thermocouple. Before adding of the reinforcement into the crucible the melt was degassed and refined by hexa chloro ethane(C_2Cl_6) tablets inorder to avoid the oxidation. Measured quantity of preheated halide salt KBF_4 and Na_3AlF_6 was dehydrated in muffle furnace at 300^0C for about 20 minutes and cooled. To develop a composite with different weight fraction of (1, 3 and 5 wt.%) of AlB_2 particles, the measured quantity of premixed halide salts are wrapped in a aluminum foil and incorporated into the molten aluminum at a temperature of 800^0C to form the AlB_2 particles.The melt was continuously stirred using a zirconia coated stirrerat a speed of 150-200 rpm to attain the insitu reaction.After 60 minutes of reaction the slag formed and floated on the melt is skimmed off and is poured intothe preheated cast iron die [30-31]. The prepared composites were machined and cut to characterize for the different studies. Specimens were machined from the castings to perform microstructure and mechanical characterization. The specimens were polished following standard metallographic procedure (220 grit SiC paper to 1200 grit SiC paper and fine polished with diamond paste and etched with Keller's reagent. Microstructures of the prepared composites were examined using SEM equipment to determine the formation and morphology of AlB_2 compound in the composite.

3. RESULTS AND DISCUSSIONS:

3.1 MICROSTRUCTURAL STUDIES:

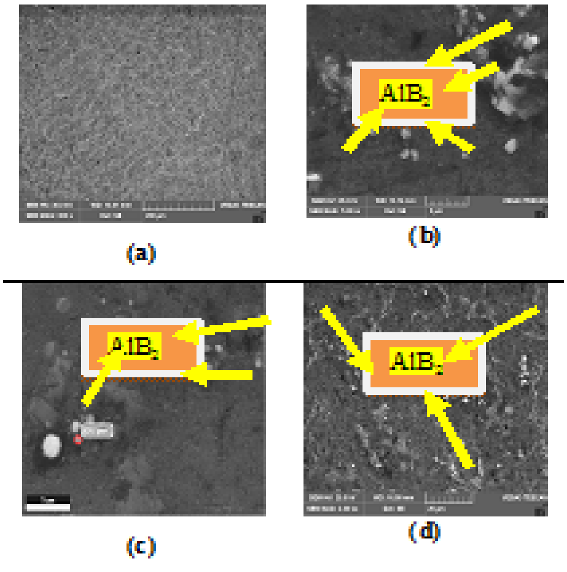


Figure 3.1 (a)-(d) shows the SEM Microstructure images of (a) Al6061 (b) Al6061 + 1wt.% ofAlB_2 (c) Al6061 + 3wt.%of AlB_2 (d) Al6061 +5 wt.%ofAlB_2

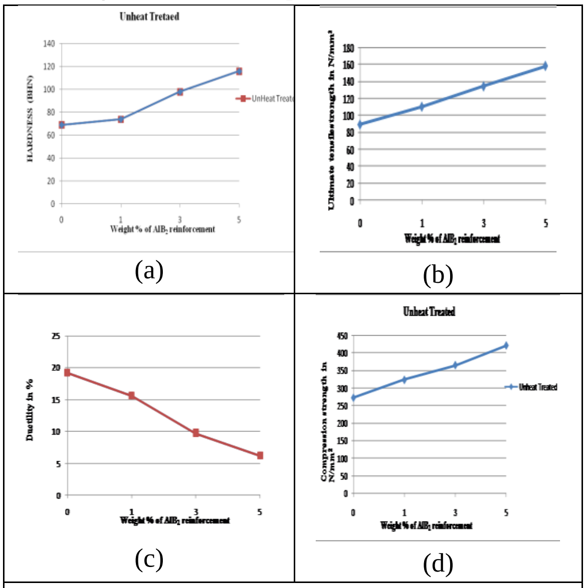
Figure 3.1(a) presents SEM image of unreinforced base alloy. It is clearly seen that the uniform distribution of grains through the region. The microstructure of as cast AA6061 displays a typical dendritic structure as a result of solidification[32-35]. The dendritic structure is formed due to high cooling rate. It is characterized with extended primary a–Al dendritic arms. The dendritic structure is completely absent in the microstructure of the composite as shown in the figure 3.1(b)-(d). Figure 3.2 (b)-(d) shows clearly the formation precipitates is observed. It is somewhat string like morphology precipitate are associated which indicated the formation during the metal salt reaction. Microstructural analysis highlights a good interfacial integrity between the AlB_2 particles and matrix. It clearly shows the formation of AlB_2, in figure (b) this indicates the there is a uniform distribution of AlB_2 throughout the base alloy and also agglomeration at few places were observed in the figure(d) composite reinforced with 5 wt% of reinforcement. AlB_2 formation was clearly seen with the higher magnification. The shape of the AlB_2 particulates includes spherical, cylindrical and hexagonal. The shape of the reinforcement has a significant role on the properties of AMCs[36-40].

3.2. Mechanical properties

Effect of AlB_2 particles on mechanical propertiesThe effect of AlB_2 particles on mechanical properties like hardness,ultimate tensile strength (UTS), ductilty and compression strength (CS) of the composites has been evaluated.

3.2.1. HARDNESS

Figure 3.2 (a) shows the variation of hardness (BHN) of base alloy andcomposites with weight percentage of AlB_2 particles. It is clearlyobserved that hardness increases with the increasing amount ofAlB_2 particles.



(a) (b) (c) (d)

Fig 3.2 (a)-(d) shows the (a) Variation of Hardness (b) Varaiton of UTS (c) Ductility and (d) CS with the weight of % AlB2 reinforcement

Figure 3.2 (a) present the effect of AlB_2 particulate content on hardness graph of AA6061/AlB_2 AMCs. The in situ formed AlB_2 particulates remarkably improved the hardness of the composite. The Brinell hardness is found to be 68% increase in Al-5wt%. AlB2 reinforcement when compared to unreinforced aluminum alloy.The improvement in hardness may be attributedto the high dislocation density around the AlB_2 particles due to differencein coefficient of thermal expansion (CTE) between Al-richmatrix and AlB_2 particles. Further, refinement of matrixphase and incorporation of hard AlB_2 particles in the soft Al-richmatrix also contributes to the hardness[41-45]. Better bonding betweenreinforcement and matrix, clean and clear interface may also contributeto the hardness of the composites by increasing the loadcarrying capacity.

3.2.2 TENSILE PROPERTIES

Tensile properties of base alloy and composites were evaluatedat room temperature. UTS and percentage elongation havebeen evaluated from engineering stress–strain diagram. It isobserved that UTS of the composites improves continuouslyand ductility of the composite reduces with increasing the weight % of reinforcement.The above graphs 3.2 (b) shows there is gradually improvement obtained in ultimate tensile strength due increasing in AlB_2 reinforcement compared to the unreinforced base alloy Al6061. This improvement in ultimate tensile strength can be mainly attributed to increased percentage of AlB_2 particles in the matrix alloy. It shows Composite with 5 wt.% AlB_2 particles exhibits maximum values of UTS are improved by about 78% respectively as compared to base alloy. Another reason for the resulting strengthening is due to the interaction between dislocations and AlB_2 particles when the composites bear a load and also due to the presence of a number of appending dislocations around the AlB_2 particles because of the difference in the thermal expansion co-efficient between the matrix and AlB_2 particles. The CTE (Coefficient of Thermal Expansion) mismatch between these particles with matrix also brings dislocation strengthening at grain boundary, according to CTE mismatch strengthening [46-47]. The ductility of all composites is lower than the matrix metal due to the hindering of AlB_2 particles on the deformation of grains. But with uniform distribution of AlB_2 particles and reducing of large agglomerations, the ductility can be improved.

3.2.3 DUCTILITY

Figure 3.2 (c) shows the ductility of the unreinforced aluminum alloy and it inistu composites. It is observed that the ductility of the composites decreases with the increasing the weight of the reinforcement.Due the variation in the size and morphology of AlB_2 particulates in the developed inistu composites, the elongation of the AMCs drops when AlB_2

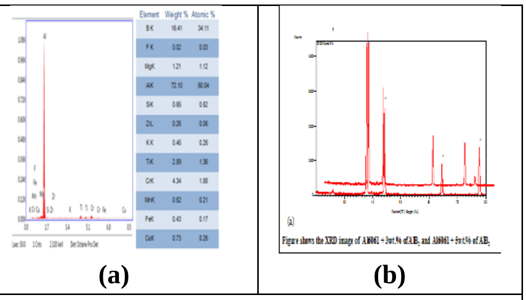
particle weight percentage is increased[48]. The grain refinement and reduction of ductile matrix content with increase in the weight percentage of AlB2 particles are increased which results in the reduction in the ductility of the AMCs.

3.2.4 COMPRESSION STRENGTH:

The increase in compressive strength is attributed to the decrease in the inter particle spacing between the AlB_2 particles, since AlB_2 is much harder than the Al6061 aluminium alloy. It is observed form the graph 3.2(d) that compression strength improves gradually with the increasing in the weight % of AlB_2 reinforcement.The presence of the AlB_2 resists deforming stresses, thus enhancing the compressive strength of the composite material. However, the addition of hard AlB_2 particles into the composites caused he metal matrix composites to behave as brittle rather than ductile materials.

4. EDS AND XRD

The EDS of the surface of the composite specimen indicates the presence of Boron from the Al matrix. The presence of all the elements viz., Si, Mg, Mn, Cr, Ti, Fe, Cu in unreinforced Al alloy and the presence of K, F and B from the halide salts in composites.



(a) **(b)**

Figure 4.1 (a)-(b) shows the EDS and XRD image of (a) Al6061 +3wt.% of AlB_2 and (b) Al6061 +3 & 5wt.% of AlB_2

When the weight % of AlB_2reinforcement increases the atomic weight of the composite increasedas shown in figure 4.1 (a). This indicates the halide slat mixed thoroughly in the melt.In Fig 4.2(b) A nickel filtered Cu radiations (*Courtesy*: PANalitical X-Pert Powder, BMSCE, Bangalore) is used to examined the Al6061-AlB_2 insitu composites by X-ray diffraction method for the measuring of the specimens. The analysis is performed using a Philips diffractrometer and the data are recorded using a specialized software X'Pert data collector. The presence of AlB_2 peaks in the XRD pattern confirms the formation of AlB_2. It is also observed that the intensity of AlB_2 peaks increases with the increasing the weight % of AlB_2 particle. From the figure it is observed that AlB_2 peak increases with increasing the weight % of the reinforcement. It is concluded that AlB_2 particle is only one phase that exists in the composites.

5. CONCLUSIONS

The following conclusions are derived from the present work.

- AA6061/AlB_2 composites containing different weight % of AlB_2can be successfully fabricated by an chemical reaction between molten aluminium alloy with inorganic halide saltKBF_4 using liquid metallurgy route.
- The microstructure of the composites depicts a clean and fairly homogeneous dispersion of AlB_2 particulates in aluminium matrix.
- The formation of in situ AlB_2 particulates improved the mechanical properties such as hardness by 68 %, the ultimate tensile strength by 78% and compressive strength by 61 % as compared to unreinforced to aluminum alloy.
- Ductility of the composite reduced with an increase in weight content of AlB_2 in the composite.
- XRD spectrum of composites confirms the formation of AlB_2 particles in aluminium matrix and AlB_2 is indicative of the completion of in-situ reaction.

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