A Review on synthesis of AlB2 reinforced aluminium matrix composites

Samuel Dayanand1, Dr Satish Babu B2

1Department of Mechanical Engineering, Govt., Engineering, College, Raichur and affiliated to Visvesvaraya Technological University, Belgavi, Karnataka, India
2Department of Mechanical, School of Engineering, Presidency University, Bengaluru

Abstract. In order to meet the demands of light weight high performance of materials in aerospace, automotive, marine and other devices, Aluminium matrix composites (AMCs) are developed. The combinations of matrix, reinforcement and processing route helps in proper bonding and uniform distribution in the matrix can be customized by the AMC’s. The properties of AMCs are considered to be the best alternatives for making light weight and high strength applications. AMCs can be prepared by different methods with various reinforcements which are usually metallic compounds of oxygen, carbon, boron, nitrogen and their combinations. Due to its very good stiffness, hardness and wear withstand, high temperature applications aluminium diborides (AlB2) holds attention in metal matrix composite. The paper tries to explore the capabilities of combing aluminium diboride reinforced AMCs with various methods.

1. Introduction

Nowadays, in the upcoming fields of engineering aluminium and aluminium alloy based composites are gaining importance [1]. There are two or more physically and chemically distinct phases in the Metal-matrix composites (MMCs) which are well spread to make available, the properties which cannot be obtained with either of the single phases. The reinforcement may be metallic or ceramic in MMCs but generally a metal or an alloy is used as a matrix phase. Particle reinforced, short fiber and continues fiber are the main three types of MMCs [2]. Usually aluminium, magnesium, copper and other their alloys are used as a matrix .Fibers, whiskers and particulate of various metal oxides, nitrides and carbides are forms commonly used in the reinforcement [3-4]. Chiefly due to the ease of processing, lower fabrication costs and isotropic properties particle reinforced MMCs are a better option over fiber reinforced materials [5-8]. The form, size and the shape of the reinforcement controls the characteristics of the composites. The overall properties are nevertheless affected by the quality of interface in between the bulk material (matrix) and the dispersoid (reinforcement) [9-12]. Nami et al. [13] reported that composites with Al matrix are gaining prominence due to their properties such as improved strength, stiffness, hardness, coefficient of thermal expansion, improved wear and corrosion resistances, performance at higher temperature and the increasing need of light weight and genuine materials. Sharifitabar et al. [14] found the improvement of these composites is driven by the development of these materials has been driven by structural and non structural applications in...
automobile and aerospace industries. Various manufacturing methods with different ceramic reinforcement have been used to fulfill these demands. Alidokht et al. [15] mentioned AMC’s are potential candidates in applications such as engines, aircraft skins, landing gear struts, sea vehicles, turbine engines components, space structures etc. Michael Rajan et al. [16] and Kumar et al. [17] reported due to its unique combinations of properties AMC’s have replaced conventional material in a number of applications. SiC [18], B₄C [19], Al₂O₃, TiC, B₄C, TiO₂, SiO₂, BN, AlN, fly ash, AlB₂, TiB₂ and ZrB₂ [20] particles are the different dispersoids of ceramic material commonly utilized in Al composites [21-39]. Tee et al. [40] found new processing techniques are being used to produce high performance in situ composites. Kumar et al. [41] and Gotham et al. [42] investigated that these insitu composites to improve the interfacial capability and reduce the reinforcement size and exothermic reaction between aluminum and the ceramic compounds. Dumitru et al. [43] found the information on the in situ AlB₂ particle composites is very limited.

2. Synthesis of AlB₂ Reinforced Aluminium Matrix Composites

The two broadly classified categories for processing AlB₂ MMC’s on the basis of state of matrix and reinforcement are solid-state processing and liquid state processing. The other method of classifying to process Al-AlB₂ MMC’s are based on exsitu process and insitu process. The former process includes adding separately produced dispersoid materials in the form of particulate to the aluminium or Al alloy melt. Exsitu process has many restrictions like weak bonding and varying distributions of the particulate, weak isometric characteristics, reaction at interface, thermodynamic instability and lower adhesions of matrix with the dispersoids. The latter technique includes formation of dispersoids within the matrix through insitu reactions between matrix and reinforcing material such as halide salts. C.S. Ramesh et al. [44] revealed that the insitu method has several advantages such as uniform distribution of dispersoid particulates, clear interface, refined grains and improved high temperature stability. Different methods are discussed in the following sections.

2.1 Solid - liquid reaction Processes

2.1.1 Exothermic Reaction Process

This process also termed as XD™ technology was developed in 1980’s in USA [45-47]. During the process the ceramic phase forming elements say X and Y are heated along with a metallic element A above its fusion temperature but below the temperature needed to form the ceramic reinforcement material of XY phase. The nature of chemical reaction between X and Y is exothermic and as a result sub microscopic hardening particles are formed in the solvent phase as shown in ‘figure 1’.

![Figure 1. Schematic diagram XD Dispersion Hardened composite to fabricate MMC’s][1](image)
Modovan P et al. [48] observed that composites with high volume fractions of ceramic reinforcement are produced. Thus required quantity of reinforcement can be obtained by adding this material and again melting with a matrix or base material. Composites with different base material like Copper, aluminum, iron, titanium etc can be produced with the ultra-fine metallic compounds of oxygen, boron, nitrogen, carbon etc. as reinforcement with the XD™ technology. By using this procedure Al-AlB₂ MMC’s have been produced by the various authors [49-51, 77].

2.1.2 Reactive Hot Processing (RHP)
Sirtl et al.,[52] reported RHP is the other process used for preparing Al-AlB₂ insitu composites to produce dense aluminum composite, during the process high temperature compaction is as well as production of dispersoid particulates by insitu reaction occurs in a single step with a theoretical density of about 65% of Al. Stoichiometrical quantity of boron and Al in powder form is mixed together to form green bars by cold compaction. Combustion reaction takes place when these bars are heated to a temperature above 850°C and held at this temperatures for 10 minutes in vacuum and hot pressed at 600°C. Various investigators [53-56, 77] used the RHP technique to produce Al-AlB₂ composite by using B₂O₃ powder as a reinforcement.

2.1.3 Lanxide TM Process
The lanxide process is developed by the Lanxide Corporation. Earlier this process was used to process Al-AlB₂ MMC’s by oxidizing the melt of Al in preforms by boron compounds using insitu technique. This process involves controlled oxidation molten al alloy to form metal ceramic mixture to form Al-AlB₂ composites is as shown in ‘figure 2’ [57-58, 77].

![Figure 2. Schematic diagram Lanxide process to fabricate MMC’s](image)

2.1.4 Stir Casting
During the process reinforcement or the material which helps in the formation of reinforcement i.e, reinforcing material is added to the melt of Al matrix with continues stirring for uniform distribution of reinforcement throughout the matrix. Al₂O₃ particles were added to Al melt with constant stirring of molten Al by S. Ray in late 1960’s is as shown in ‘figure 3’. The stirring of the melt using the stirrer mechanically is the most distinct aspect of this method. After the removal of the slag the melt of the matrix along with the particulate reinforcement is cast into the die. The in situ AMC with AlB₂ reinforcement particles are developed by this process using KBF₄ halide salt. High porosity in the composite is the major disadvantage of this process. In this process there is a uniform distribution of AlB₂ particles and formation clear and proper bonding Al-AlB₂ composites can be achieved. Due to
the BF$_3$ gas there is a formation AlB$_{12}$ compound Wang et.al [59] [77].

\[\text{Figure 3. Schematic diagram Stir casting process to fabricate MMC’s [59-60, 78]}\]

2.1.5 Squeeze Casting
In this process to ensure optimal filling, highly porous reinforcing fibers or particle of proper shape and size are prepared. Later on the entire volume of the preform is filled with the melt of the matrix at high pressure. Fine grains are obtained as the transfer of phase takes place rapidly during the process due to directional solidification as shown in ‘figure 4’. Ghamoshi et al. [60] and Tjong et al. [77] found a strong bonding between the matrix and the reinforcement is provided by this method. High productivity can be achieved because of faster pressing work. The composites prepared by this method have high density and are homogenous in nature. The cost of the tool which withstand higher temperature and pressure is high and this forms the major disadvantage of the squeeze casting process.

\[\text{Figure 4. Shows Schematic diagram Squeeze casting process and fabricating process [60][78]}\]

2.1.6 Flux Assisted Synthesis (FAS)
London Scandinavian Metallurgical Company developed this process and it is also known as mixed salt reaction. It is the commonly used technique to fabricate Al-AlB$_2$ type MMC’s. Dragus Marco et.al [61], Tjong et al. [77] investigated during the process halide salts such as KBF$_4$ is added to the Al melt as per the required weight fraction of reinforcement. Continues stirring is carried out until the reaction
is complete, the nature of chemical reaction between the halide salt and Al is exothermic, and the sequence of reaction is as follows.

\[
\begin{align*}
12\text{KBF}_4 + 13\text{Al} &= \text{AlB}_{12} + 12\text{KAlF}_4 & (1) \\
2\text{KBF}_4 + 3\text{Al} &= \text{AlB}_2 + 2\text{KAlF}_4 & (2)
\end{align*}
\]

The slag being less dense floats up and is to be removed. The remaining melt of composite is poured into the die and casted into the desired shapes as shown in ‘figure 5’. Ramazan Kayikci et al. [62] found this technique is economical and simple but its application is limited due to the low weight fraction of the dispersoid particles. The viscosity of molten metal Ferit et al. [63] decides quantity of AlB_2 that can be dispersed in it [64-65, 77,48].

2.1.7 Centrifugal Casting:
Sakip et al. [66], N.Radhika and Omar Savas et al. [77-78] mentioned Centrifugal Casting can be used to fabricate composites with higher weight fractions upto 10% of dispersoid particulates. The thin walled cylinders are cast by centrifugal casting technique as shown in ‘figure 6’.

This method involves pouring the melt into the die rotating at a speed in the range of 300-3000 rpm.
about its own axis of rotation. During the rotation the melt moves along the inner periphery of the cylindrical mould and solidifies on cooling. Cylindrical castings with the finer grains can be achieved by this method.

2.1.8 Master alloy technique
Boppanna et al. [67] reported metal matrix composites were prepared using master alloys for the in situ process. Ramesh et al. [68] found in order to process AMC’s with the required weight fraction of the reinforcement; reinforcement is added to the melt of matrix according to stoichiometric ratios Karantis et al. [69]. This method has been used by several investigators Wang et al. [70] to process Al-AlB2 MMC’s. Benjamin [71] and Tjong [77] reported the advantage of this method is lower amount of reaction between the matrix the reinforcement and the temperature at which the formation of reinforcement occurs is comparatively low.

2.2 Solid-state Process
2.2.1 Mechanical Alloying
Duygu Agaogullari et al. [72] found this technique is a solid state processing technique which includes repetitive cold drawing and fracture of particulates. By this technique, found alloy materials are ground to fine powder, simultaneously compressed and sintered to form a composite and properties of composites are affected by the time of mechanical alloying, quantity and the size of AlB2 particulates and also compared to the micron scale AlB2 particles the MMC’s with AlB2 size less than a micron shows improved hardness and wear resistances and further increases with the increasing content of AlB2[73-75]. Balci et al. [76] observed in regard to different mechanical alloying time, for certain limit the density and hardness values of the sintered samples increases with time. Uniform distribution of ultra-fine AlB2 particles can be achieved within the matrix.

2.2.2 Hot Isostatic Pressing
Tjong and Mingming et al. [77] reported during the process blended powder are sintered at high temperature and pressure. As the pressurizing medium argon gas is usually used microstructure of composites fabricated using this method is decided by the ratio of the particles size of Al and ceramic material. Both the densification of MMCs and better uniform distribution of ceramic particles are favored by the Relative Particle Size as shown in ‘figure7’. With the increasing AlB2 volume content, tensile properties like modulus of elasticity and fracture strength of Al-AlB2 composite improves[78-89].

![Figure 7. Schematic diagram Hot isostatic process to fabricate MMC’s](81-88)

3. Conclusions:
A review on synthesis of AlB2 reinforced aluminium metal matrix composites come to conclusion that,
Various fabrication methods are there to synthesis AlB₂ particle have been dealt with in the present review paper. Different methods are categorized as solid state processing and liquid state processing techniques. Among them the latter is largely used to fabricate Al-AlB₂ MMC’s. Stir casting route is one of the versatile, cheap and easy method to fabricate Al-AlB₂ composites, but there may be chances of cluster, agglomeration and porosity of the particles in the matrix, to overcome them proper mixing, stirring speed plays important role during casting process.

- The FAS reaction mechanism is not well understood, even though reaction mechanism of insitu formation of AlB₂ particles are reviewed and discussed.
- Insitu process can be widely used to prepare Al-AlB₂ composites owing to its simplicity and economic reasons. The advantage of this process include improved composite stability at higher temperatures, fine particulates, clean interface and an essential uniform distribution of reinforcement in matrix.
- According to the literature survey, work done in the field of Al-AlB₂ MMC’s is comparatively low and might get more attraction in future.
- As the mechanism by which the insitu formation of Al-AlB₂ composite using halide salts is not completely understood, further studies may be conducted to understand the reaction mechanisms.

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