Enhancement of Mechanical properties of AlSi5Cu3 Aluminum alloy using TiB₂ reinforcements

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Abstract. In present investigation, ex situ composite of AlSi5Cu3 aluminum alloy reinforced through TiB₂ reinforcement particles has been developed. Different weight percentage of TiB₂ particles were incorporated in liquid melt via stir casting method. Combine effect of stirrer speed (500,700 rpm), and weight percentage (1, 2, 3) TiB₂ particle on mechanical properties were studied. Microstructural study has been carried out using optical microscopy and SEM analysis, which shows homogeneous distribution of particles and improvement in grain size compare to aluminum alloy AlSi5Cu3. Presence of TiB₂ was confirmed using XRD analysis. Improvement in tensile strength and hardness was observed due to homogeneous distribution of particles.

Keywords: Aluminum, TiB₂, Stirring, Composite, Metal.

1. Introduction

Aluminum alloys are widely used in many engineering applications including automobiles, where high mechanical properties such as hardness and tensile strength are required [1]. It is observed that low ductility and poor tribological characteristics are limiting applications of aluminum alloys. Aluminum based composites established as a high performance material due to its low density, good corrosion resistance, high damping capacity, high electrical, thermal conductivities and their high mechanical
properties, leading to overcome these problems and have wide range of application in aerospace and automobile industries.

AlSi5Cu3 alloy widely used in fabrication of automobile components like crankcase, gearbox, piston, tool handles, etc; due to excellent machinability and mechanical properties [2]. Desired mechanical properties can be achieved by adding secondary elements or compounds that refine and/or modify grains. Kumar et al. [3] observed that secondary reinforcement particles work as nucleating sites and refine the grain structure. Mechanical and tribological properties can be enhanced by reinforcing aluminum alloys with oxide, boride and carbide particles like SiC [4,5], Al2O3 [6], B4C [7], AlN [8], ZrB2 [9]. The most studies have been carried out on silicon carbide (SiC) reinforced aluminum composites, but the formation of aluminum carbides (Al4C3) deteriorate mechanical properties as reported by Lu et al. [10]. Kennedy et al. [11] proposed that the drawback of SiC reinforcement can be eliminated by focusing on more stable reinforcements like TiB2 and TiC. Recently incorporation TiB2 as reinforcement in matrix material is active area of due to excellent properties of TiB2 like, low density, wear resistance, high Young’s Modulus and high hardness [12]. Moreover TiB2 is most stable material, which does not react with aluminum matrix as discussed by Natrajan et al. [13]. In present study an attempt has been made to develop AlSi5Cu3/ TiB2 composites using stir casting method and to investigate combine effect of stirring speed and weight percentage of TiB2 on mechanical properties.

2. Materials and methodology

In present study, stir casting setup as shown in Fig.1 was used for development of Al/TiB2 composite slurry. Matrix material used was aluminum alloy (AlSi5Cu3) and TiB2 reinforcement particles (12-16 micron) were added externally. Table 1 shows composition of AlSi5Cu3 alloy.

Table 1 Composition of AlSi5Cu3 alloy

| Element | Si  | Cu  | Fe  | Mn  | Ni  | Zn  | Mg  |
|---------|-----|-----|-----|-----|-----|-----|-----|
| Weight %| 5.23| 2.98| 0.38| 0.38| 0.31| 0.18| 0.15|
AlSi5Cu3 alloy ingots were melted at 800°C in electrical resistance furnace. Muffle furnace was used for preheating of TiB₂ particles at 550°C for 60 minutes. Clay based graphite crucible was used for melting and mechanical stirrer has been placed in the melt from top of the furnace as shown in Fig. 1. After melting of alloy, stirrer having four blades at an angle of 90° was lowered down in the melt and stirring was performed for 10 minutes at 500 and 700 rpm respectively. Preheated TiB₂ particle were added in the melt during mechanical stirring. Subsequently, the melt was degassed using hexa-chloro-ethane tablet and poured into a cast iron mold (125×110×13 mm). Flow chart of the process followed is as shown in Fig. 2.
3. Results and discussion

3.1. XRD analysis

XRD analysis was performed on polished specimens using BRUKER made D2 PHASER analyser and diffraction peaks are collected in 30° - 80° range. XRD analysis as shown in Fig. 3 clearly reveals presence of TiB$_2$ without any reaction compounds. TiB$_2$ peaks observed at 34.18°, 61.22°, 68.17° [14]. TiB$_2$ is one of the most stable compound and does not form any reactive elements at interface as discussed by Murty et al [15].

![XRD analysis of TiB$_2$ reinforced composite](image-url)
3.2. Optical microscopy

Metallographic samples were prepared from casted pure AlSi5Cu3 and composite according to ASTM E3. Samples were grind on double disc grinding machine with various grit size papers. Subsequently, samples were polished on velvet cloth using alumina paste followed by etching using Keller’s reagent according to ASTM E407. Microstructure examination of etched samples is performed by inverted microscope (Carl Zeiss). Fig. 4 shows microstructure of AlSi5Cu3 alloy and AlSi5Cu3/TiB2 composite. Microstructures show homogeneous distribution of reinforcements, leading to improvement in mechanical properties. On an average 12% reduction in grain size was found in casted composite compare to pure AlSi5Cu3 when measured through BIOVIS software.

![Microstructure](image)

Fig.4. Microstructure (a) Pure AlSi5Cu3 (b) AlSi5Cu3/TiB2 composite
3.3. SEM micrographs

SEM micrographs reveal microstructural features of AlSi5Cu3/TiB2 composite, which show reaction free interface between reinforcement and matrix as shown in Fig. 5. Reaction free interface increases mechanical properties of material as detachment of particle from matrix material is difficult due to strengthening [16]. SEM analysis show that as TiB2 percentage increases chances of cluster formation is high at 500 rpm, may be due to less intensive stirring.

![SEM micrographs](image)

Fig. 5. SEM micrographs (a) AlSi5Cu3 alloy (b) AlSi5Cu3/TiB2 composite at 700 rpm (c) AlSi5Cu3/TiB2 composite at 500 rpm
3.4. Tensile behaviour of AlSi5Cu3/TiB₂ composite

Tensile tests were performed on universal testing machine (TINIUS OLSEN) as shown in Fig. 6. ASTM E8 standard was used for preparation of tensile specimens having gauge length of 25 mm and gauge width of 6 mm. Three samples were tested to get average tensile strength. UTS of composites are as shown in Table 2. Tensile data show increment in UTS with increment in stirring speed and weight percentage of TiB₂. Homogeneous distribution of TiB₂ particles will strengthen the grains and presence of reinforcement reduces mobility of atoms (reduces dislocation) [17], leading to increment in tensile properties with increase in TiB₂ percentage. UTS of pure AlSi5Cu3 alloy is 167 MPa. UTS of composites reinforced with 1%, 2% and 3% TiB₂ increased by 19%, 24% and 26%, respectively after stirring at 700 rpm.

Fig. 6. Tensile testing of AlSi5Cu3/TiB₂ composite
Table 2 Average value of UTS

| No. | Weight percentage of TiB₂ | Stirring speed(rpm) | Average UTS(MPa) |
|-----|---------------------------|---------------------|------------------|
| 1   | 1                         | 500                 | 181              |
|     |                           | 700                 | 200              |
| 2   | 2                         | 500                 | 201              |
|     |                           | 700                 | 207              |
| 3   | 3                         | 500                 | 203.5            |
|     |                           | 700                 | 210.5            |

3.5 Hardness of AlSi5Cu3/TiB₂ composite

Hardness of composites was measured according to ASTM E18 standard. 100 Kg load is applied on the specimen for dwell time of 10 second using 1/16" ball type indentation. Hardness of composite is increased considerably compared to pure AlSi5Cu3. TiB₂ present at grain boundaries will increase the load bearing capacity of the material, which is the key reason behind increment in hardness. Hardness of pure AlSi5Cu3 alloy is 72 BHN. Hardness of composites reinforced with 1%, 2% and 3% TiB₂ increased by 32%, 33% and 37%, respectively after stirring at 700 rpm as shown in Table 3.

Table 3 Average value of hardness

| No. | Weight percentage of TiB₂ | Stirring speed(rpm) | Hardness (BHN) |
|-----|---------------------------|---------------------|----------------|
| 1   | 1                         | 500                 | 92             |
|     |                           | 700                 | 95             |
| 2   | 2                         | 500                 | 98             |
|     |                           | 700                 | 96             |
| 3   | 3                         | 500                 | 98             |
|     |                           | 700                 | 99             |
4. Conclusions

In present study, ex situ composites of AlSi5Cu3/TiB2 were successfully developed via mechanical stir casting. XRD analysis confirms presence of TiB2 without any reaction compound. Optical micrographs show homogeneously distributed TiB2 particles. SEM micrographs show reaction free interface between reinforcement particles and matrix material, leading to increment in tensile strength and hardness. UTS and hardness increases as weight percentage of TiB2 increases. UTS and hardness of pure AlSi5Cu3 alloy is 167 MPa and 72 BHN respectively. UTS of composites reinforced with 1%, 2% and 3% TiB2 increased by 19%, 24% and 26%, respectively. Hardness of composites reinforced with 1%, 2% and 3% TiB2 increased by 32%, 33% and 37%, respectively.

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