Investigation of impact performance of aluminum metal matrix composites by stir casting

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Abstract.
In the present study, the impact behavior of in-situ synthesized aluminum alloy 5052 reinforced with titanium carbide (TiC) was investigated successfully by stir casting process. The Charpy test was conducted to evaluate the impact strength of the composites. Field emission scanning electron microscope was utilized to examine the fracture mechanism of the impact test. With increase in the TiC content, the impact strength was found to be decreased due to the brittleness of the composites. The fracture surface of the composites was characterized by cracks, voids, delamination confirming the brittle nature.

Keywords: AA5052, TiC, stir casting, impact.

1. Introduction
Aluminum metal matrix composites (AMMCs) are preferred as suitable materials for automotive and aerospace application for its high strength to weight ratio, good wear resistance, and good machinability. Therefore, AMMCs are considered good replacement of the conventional material for the above properties. By regulating the processing parameters, types of reinforcement and suitable fabrication method, the properties can be improved as per the requirement. The in-situ synthesis process is favorable over the ex-situ process because it offers advantages such as uniform dispersion, grain refinement, and very good interfacial bonding. Many researchers had developed AMMCs by choosing different series of aluminum and different types of reinforcement such as borides [1, 2], oxides [3], carbides [4, 5], etc. Chen et al. [1] fabricated Al-TiB2 composites using stir casting method and reported that uniform distribution of reinforcement particles was achieved as a result of enhances stir casting method. A clear phase of TiB2 particle was formed by an increase in the duration of the stirring. More ever, the tensile and yield strength of the composites was found to be increased by 260% and 180% respectively upon addition of the TiC particles. Titanium diboride reinforced with AA7075 composites was synthesized by in-situ liquid metallurgy process [2]. The TiB2 particles were uniformly distributed throughout the composites with a clear interface between the matrix and the reinforcement. The interfacial bonding resulted from the in-situ process resists the detachment of TiB2 particles from aluminum thereby increasing the mechanical strength. Silicon magnesium based Al alloy reinforced with Al2O3 particulate composites were reported by Yilmaz and Buytoz [3]. The porosity content in the composites depends upon the stirring speed and time. The optical micrographs...
show the Al2O3 formation in the composites was found to be uniform. Samal et al. [4] reported the in-situ TiC composites of AA5052 alloy by stir casting method. The TiC particles were dispersed uniformly and the mechanical strength was increased significantly as a result of the clear interfacial bonding. Both the hardness and tensile strength increased considerably with the addition of titanium carbide. Hardness and ultimate tensile strength was enhanced upon addition of boron carbide and silicon carbide differently in aluminum 6061 alloy [5]. Commercially available pure aluminum composites reinforced with B₄C composites were fabricated through the liquid stirring method [6]. With increase in the stirring time, better uniformity was achieved of the boron carbide particles. Also, the intermittent secondary product was eliminated with an increase in the reaction time which provides a complete in-situ chemical reaction. SiC particles enhanced the impact strength of AA6068 particulate composites [7]. There was observed an increase of 75% in the impact strength on addition of SiC particles into AA6068 alloy. The increase in the impact strength resulted by lack of debonding due to better interfacial characteristics in the composites.

From the literature it was observed that liquid metallurgy i.e. stir casting is the most economical and productive fabrication method for the particulate reinforced aluminum composites. The objective of the present work is to study the impact behavior of the 5052 alloy composite reinforced with titanium carbide particles prepared by stir casting. The Charpy test was carried out to calculate the impact strength of the composites. The morphological behavior of the impact tested fracture surface was also studied.

2. Materials and Method

Selection of the suitable material for the matrix and reinforcement is necessary for the productive fabrication of the aluminum composites. The commercially available AA5052 alloy ingots were chosen for matrix and TiC as reinforcement material. AA5052 is primarily alloyed with magnesium. The chemical composition of the AA5052 matrix is given in Table 1. The schematic diagram of the stir casting set up used for the fabrication of the composite is shown in Figure 1. Titanium and graphite powder (purity >99%) was used for the synthesis of the reinforcement particles.

Table 1. Chemical composition of AA5052 alloy matrix.

| Element | Mg | Si | Cu | Fe | Zn | Cu | Al |
|---------|----|----|----|----|----|----|----|
| Weight %| 2.62 | 0.11 | 0.02 | 0.23 | 0.07 | 0.26 | Balance |

The aluminum base alloy 5052 was completely melted at a temperature of 700°C in a carbide crucible. The preheated titanium and graphite particles were introduced into the melt with a continuous supply of argon gas to prevent any oxide reaction. For the complete in-situ formation of TiC particles to take place, the melt was heated up to 1000°C. Simultaneously, a mechanical stirrer was employed to attain uniformity in the TiC particles. This process was continued for 30 minutes for the complete reaction as well as to avoid any secondary intermittent formation. Here, the extra heat was generated due to the exothermic reaction between aluminum and titanium carbide minimizes the formation of any unwanted reaction particles. Thereafter, the slag was removed from the surface of the molten metals and the melts were poured into a preheated die. The composite sample was then machined and cut accordingly as per the ASTM E23 standard of cross-section 55mm × 10mm × 10mm
with central v-notch of 45° for impact testing. Pendulum type Charpy impact testing machine was employed to estimate the impact strength of the aluminum composites. The Charpy impact tester (Tinius Olsen) used in this work is given in Figure 2(a) and the machined impact specimens are shown in Figure 2(b). Finally, the morphological study of the fractured surface was also carried out with the help of a scanning electron microscope.

Figure 1. Schematic diagram of stir casting process.

Figure 2 (a) Charpy impact tester, (b) Impact testing specimen according to ASME standard.
3. Results and Discussion

The effect of TiC on the impact strength of the composites is shown in Figure 3 with appropriate error bars. Increase in the weight percentage of TiC in the composites reduces the impact strength. A maximum decrease of 42% was observed in case of the 5052-9wt% TiC composites as compared with the alloy. A material’s impact strength normally calculated by the energy absorbed during its fracture. The addition of TiC in aluminum alloy increased its hardness, thus turned it into very brittle nature. As a result, the degree of plastic deformation energy for the composites reduced. This deformation energy increases the chances of debonding during the fracture which leads to the reduction in impact strength. Ravikumar et al. [8] described that the inclusion of TiC in the aluminum alloy improved the hardness, thus the composites are becoming more brittle. The aluminum alloy contains more plastic deformation energy. As the brittleness of the material decreases the plastic deformation energy thereby reducing the impact strength. When the aluminum alloys lose their ductility, the stress concentration areas increase. Therefore, it favors the crack formation and its propagation. These cracks create the debonding between aluminum and titanium carbide, thus decreasing its impact strength. Furthermore, it was also seen that the solid solubility of the composite is less than that of the alloy. Similar outcomes were also reported by Kumar et al. [9] by reinforcing fly ash in Al/3Cu/8Si alloy. Toughness of the aluminum composites was lowered due to the addition of the brittle fly ash particles. The toughness produced by the pure aluminum is generally better than carbide particles reinforced AMMCs. The aluminum alloy produced more toughness than the aluminum tungsten carbide reinforced composites [10]. The impact strength can be improved by employing secondary fabrication process such as hot forging.

The micrographs of the impact tested specimens are shown in Figure 4. The formation of dimples observed in the aluminum base alloy indicates the ductile fracture. As the content of TiC increases, the cleavages, crack formation and delamination could be visible in case of the composites. This shows the composites become brittle with the inclusion of titanium carbide in the base alloy. Presence of voids and subsequently the formation of cracks and propagation occurs because of the plastic deformation confirms brittleness of the composites. Furthermore, the loss of debonding energy due to the decrease in deformation energy of the composites can also be correlated to the reduction in impact strength.

![Figure 3. Variation of impact strength with wt% of TiC.](image)
Figure 4. Micrographs of fractured impact specimen (a) 5052 alloy, (b) 5% TiC, (c) 7% TiC, (d) 9% TiC.

4. Conclusions

The aluminum MMCs reinforced with titanium carbide were successfully fabricated by stir casting in-situ liquid metallurgy process. As TiC content increases, a decrease of 45% in impact strength of the composites was observed. The high degree of plastic deformation produced by the addition of TiC particles resulted in brittleness of the composites thereby reducing the impact strength of the composites. The base alloy shows ductile fracture indicated by the dimples. The fracture impact test surface also characterized by cracks, delamination, cleavage facets indicating the brittle nature of the composites.

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