

Investigation of Microstructural and Tensile Behaviour of Stir-Casted Al5052-Based Composites With Nano-Reinforcements

Saamy Agarwal^{1,*}, Satnam Singh²

Abstract

Aluminium-based composites have gained popularity in the aviation, automotive, and marine sectors as a result of their exceptional strength-to-weight ratio and also due to resistance to wear and corrosion. The current investigation involves the examination of the microstructural and tensile behaviour of stir-casted Al5052-based composites. The nanoparticles of 1% titanium diboride and 1% zirconia were added as reinforcement materials. To better understand the microstructure of the composite specimens, scanning electron microscopy and energy dispersive investigation were used. The reinforcement particles distributions in the Al5052 matrix were found to be rather uniform. The tensile test was performed at ambient temperature and with a crosshead rate of 0.5 mm/min. The tensile strength of composites was improved by 9.05% and elongation % was reduced to 6.75% upon adding the reinforcement particles. The change in the strength and elongation % was attributed to the increase in the dislocation density as a result of adding hard and brittle nano-particles.

Keywords: Aluminium matrix composites, stir casting, reinforcements, mechanical properties, titanium diboride, zirconia

INTRODUCTION

Aluminium matrix composites (AMCs) are a class of metal matrix composites that utilize Aluminium alloy matrices and ceramic reinforcements leading to properties superior to monolithic metals. AMCs allow for tailored properties by modifying the reinforcement materials, particle size, and weight fraction. This enables extensive applications from the aerospace and automobile sectors [1], [2].

Common reinforcements include silicon carbide (SiC), alumina (Al₂O₃), graphite, carbon nanotubes (CNT), titanium diboride (TiB₂), graphene nanoplatelets (GNP), zirconia (ZrO₂) and Silicon nitride (Si₃N₄) [3]–[6]. The reinforcement type, shape, and volume fraction influence tensile properties, compressive properties, wear resistance, damping capacity, machinability, and other factors [7]–[10]. For instance, SiC addition increases yield and tensile strength, hardness and wear resistance, while graphite can increase damping capacity and act as solid lubricant [11]–[14]. Optimizing the composite composition is critical to achieve the desired attributes.

This paper focuses on the Al5052 alloy as the matrix material for composites. Al5052 is an Al-Mg alloy, notable for its good corrosion resistance, moderate strength, weldability, and strong forming and machining capabilities [15], [16]. It has seen widespread use across marine, cryogenic, storage tank, and structural applications [17], [18]. The properties of Al5052 make it a suitable choice as the matrix for metal matrix composites used in similar applications.

Reddy et al. [19] noticed that reinforcing the Al5052 alloy with Titanium carbide (TiC) and SiC particles increased the hardness of produced AMCs along with the tensile strength of the specimens. Yuan et al. [20] prepared Al5052-based AMCs with Al_{0.6}CoCrFeNi alloy particles and observed the improvement in hardness and elastic modulus.

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Kishore et al. [21] tested the Al-based AMC which was reinforced with Tungsten Carbide (WC) particles for wear characteristics. It was found that addition of WC particles by up to 5 weight% reduced the wear rate in composite. Hybrid-AMCs were developed by Venkat et al. [22] using Si_3N_4 and Al_2O_3 as reinforcements utilizing stir casting. Substantial enhancements in tensile and impact strength were noted.

The current investigation includes fabricating Al5052-based nanocomposites (reinforced with TiB_2 and ZrO_2 nanoparticles) employing the method of stir-casting and evaluating the microstructure and tensile behaviour of the specimens. The nanocomposites have any one component in nanoscale (about 1 -100 nm). Nanoparticles are also known as zero-dimension nanomaterial which are usually spherical in shape with average particle size less than 100 nm. The analysis of stir-casted Al5052-based AMCs with TiB_2 and ZrO_2 nano-reinforcements is novel in this study. This investigation will pave the way for further exploration and potential applicability.

MATERIALS AND METHODS

Materials Used

The matrix employed in this investigation was a commercially available Al5052 alloy. ZrO_2 nanoparticles of 30–50 nm APS and 99.9% purity were obtained from Nano Research Lab, Jamshedpur, whereas TiB_2 nanoparticles with an average particle size (APS) of up to 80 nm were obtained from Intelligent Materials Pvt. Ltd., Punjab.

Production of Composites

The stir-casting technique was used to create composite test specimens based on Al5052. The complete procedure is explained through flow diagram in Figure 1.

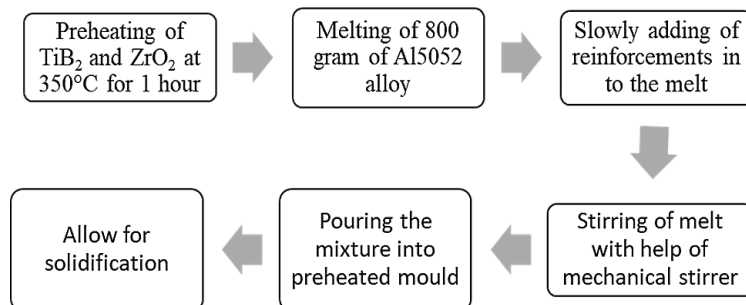


Figure 1. Flowchart of stir-casting procedure used to produce Al5052-based composites

Table 1 shows the composition of the test specimens prepared for this study. Specimen A corresponds to as-cast Al5052 alloy, specimen B is Al5052/ TiB_2 composite and specimen C is Al5052/ ZrO_2 composite.

Table 1. Specimen composition for the Al5052 composites

Specimen	Weight %		
	Al5052	TiB_2	ZrO_2
A	100	0	0
B	99	1	0
C	99	0	1

EXPERIMENT

To investigate the specimens of Al5052/ TiB_2 / ZrO_2 AMCs, a thorough examination was conducted. First, scanning electron microscopy (SEM) unveiled the material's microstructure. To ascertain the elemental makeup of the composite EDS (Energy-Dispersive Spectroscopy) investigation is also conducted. Sample surfaces were meticulously polished prior to testing. This involved a sequence of progressively finer emery sheets, ranging from grades 200 to 1200. To ensure clear observation, the

polished surface was then etched with a custom Keller's reagent solution.

Furthermore, tensile specimens were meticulously prepared according to the guidelines outlined in the ASTM E8/E8M standard (refer to Figure 2) using wire Electric discharge machining process [23], [24]. Finally, the prepared specimens were subjected to Universal testing machine with crosshead rate of 0.5 mm/min, yielding valuable tensile data.

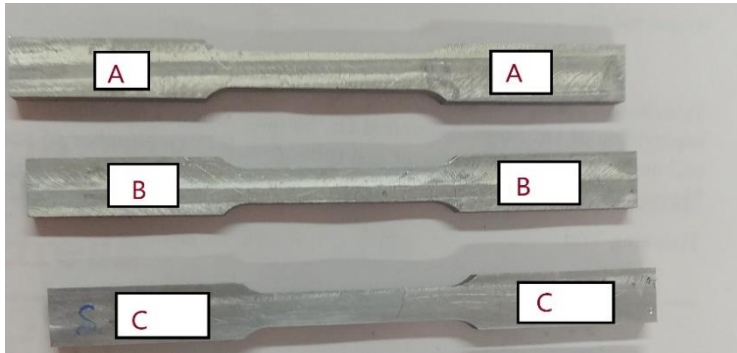
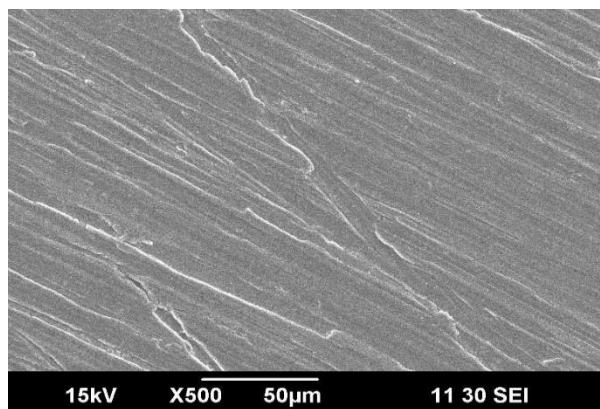


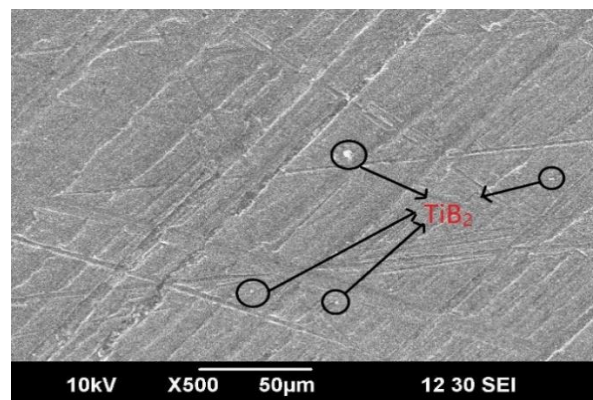
Figure 2. Tensile test specimens

Result

Figure 3 (a,b,c) shows SEM images of as-cast Al5052 and stir-casted AMCs with 1% TiB_2 and 1% ZrO_2 . These figures clearly demonstrate that there are no voids and pores in the produced AMCs. The TiB_2 and ZrO_2 nanoparticles are distributed rather uniformly, yet in some locations they agglomerate or cluster.



(a)



(b)



(c)

EDS results for specimen B and specimen C are illustrated in Figure 4a and Figure 4b respectively. Specimen B shows the presence of Al, Mg, Si and Ti, as well as traces of Cr and Fe. Elements such as Zr, O, Si, Mg, and Cr are visible in specimen C.

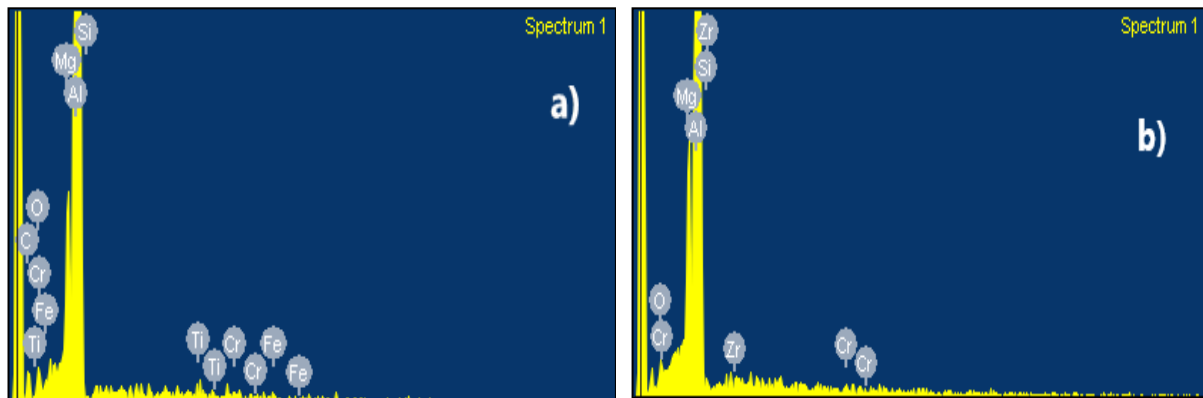


Figure 4. EDS result a) Specimen B and b) Specimen C

Figures 5 and 6 show the tensile experiment results. The experiment was conducted at ambient temperature. Both specimen B and specimen C demonstrated an increase in their ultimate tensile strength (UTS) of 5.58% and 9.05%, respectively. The ductility of AMCs decreased as the strength improved (elongation % reduced to 6.75% from 13.73%). The tensile strength of AMCs increased as an outcome of adding hard ceramic nano-particles into the matrix which restrict the dislocation motion and, due to finer grain size upon solidification [25], [26]. Coyal et al. [23] observed the increase in UTS upto 123 MPa from 67 MPa by adding SiC and jute ash into Al6061 matrix. In another research, UTS improved upto 182 MPa from 158 MPa by adding 3% alumina particles into Al6082 matrix [27]. The enhancement in tensile strength is attainable owing to load transfer from matrix to reinforcement and also due to grain refinement [28].

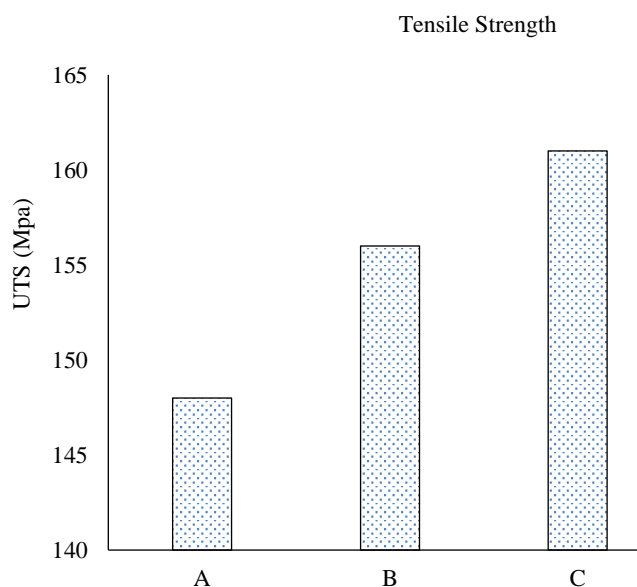


Figure 5. Tensile strength of base alloy and AMCs with 1% TiB_2 and 1% ZrO_2 .

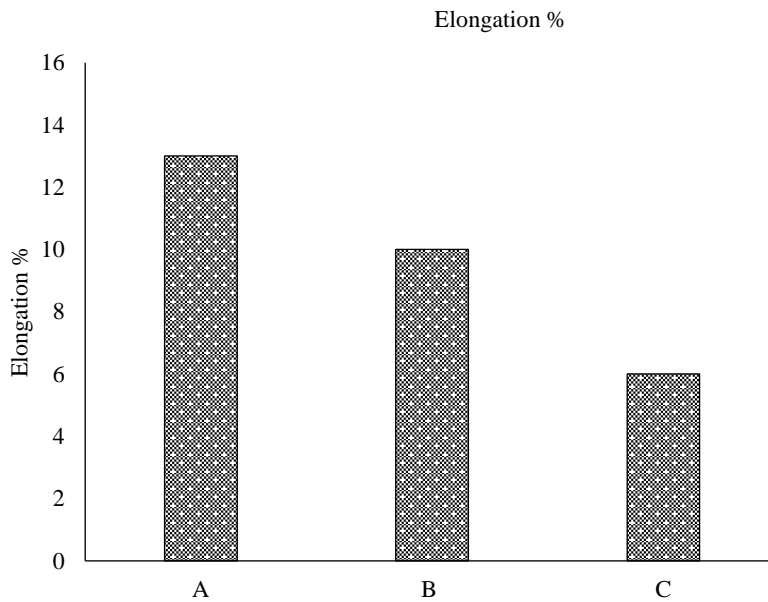


Figure 6. Elongation % at maximum load of base alloy and AMCs with 1% TiB₂ and 1% ZrO₂.

CONCLUSION

Al5052-based AMCs were stir-casted using 1% TiB₂ and 1% ZrO₂ nanoparticles. The following conclusion are made upon investigation of microstructure and tensile behaviour of AMCs at ambient temperature:

1. SEM result shows the overall good distribution of reinforcement particles except agglomeration at few locations.
2. There were no visible voids or pores within the surfaces of AMCs
3. From tensile test it was clear that the UTS improved up to 9.05% with addition of 1% TiB₂ and 1% ZrO₂.
4. The elongation percentage or ductility was reduced (upto 6.75%) as the reinforcement was added into the matrix alloy.

Declaration of Interest

The author(s) declare that there is no conflict of interest regarding the publication of this manuscript.

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