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Synthesis of ceramic-based composite

The research paper reports on the processing of titanium carbide (TiC) strengthened aluminium metal matrix composite using a stir casting method. Al 6061 and TiC were used as starting materials for synthesizing Al-1.5TiC composite in a resistance furnace. The stir casting technique was followed owing to its simplicity and economic benefits. Microstructural studies were carried out using image analyser and micrographs revealed even dispersal of reinforcement in the alloy, while energy dispersive spectroscopy (EDS) and x-ray diffraction (XRD) studies confirmed the presence of corresponding elements and phase in the composite.

Keywords: *Al-TiC, stir casting, reinforcement, composite, metal matrix composite.*

1.0 Introduction

Metal matrix composites (MMCs) are widely used owing to their superior properties such as high stiffness, decent resistance to wear besides having better elevated temperature properties when related to conventional alloys and metals. Amongst them, aluminium matrix composites (AMCs) belong to a category of light weight and good performance materials. In the transportation sector, AMCs are preferred since they are known to consume less amount of fuel. The percentage of reinforcements in the matrix may be ranging from a small per cent to as high as 70% (Dayanand et al., 2019). Reinforcements can be particulate, whiskers or continuous/discontinuous fibres. Right combination of reinforcements and matrix can be custom made to fit specific applications in various fields.The method of synthesizing the particle reinforced composite plays a vital role on the mechanical properties of the composite (Kumar et al., 2021).

Various methods were employed by researchers (Boppana and Chennakeshavalu, 2020; Boppana 2019) to fabricate TiC reinforced metal matrix composites. The current investigation is based on the stir casting method of synthesizing ceramic reinforced composite.

AA 7075 alloy was chosen as matrix material by Rao et al. (Rao et al. 2016) and titanium carbide (TiC) particles of the range of 2 to 10 per cent were reinforced in the alloy to obtain composite using stir casting method. Wear tests were conducted for the synthesized composites. The composites offered improved wear resistance compared to the matrix material. As the ceramic content increased, the composites presented better resistance to wear. Raviraj et al. (2014) worked on Al-TiC composites synthesized through stir casting process. The alloy used was Al 6061 and the reinforcement was added in proportions of 3, 5 and 7 wt.%. A steel mould was used in the casting process. The grain structure was refined with the addition of reinforcement. The hardness of the composites increased with the growing content of the TiC, but at 7 wt.% addition, the hardness however reduced. Tong and Fang (2008) reported on rapid solidification and ingot metallurgy technique used to fabricate TiC reinforced Al based composites. The microstructures obtained through the procedure were refined and improved dispersion hardening of the TiC phase. The TiC particles exhibited a face centred cubic crystal structure. Moreover, the reinforcements were uniformly distributed in the matrix. Senthil kumar et al. (2011) worked on planetary ball mill and hot extrusion method to fabricate TiC reinforced composites. The reinforcement content was chosen as 1, 1.5 and 2 wt.%. Very less porosity was observed in the composites thus fabricated. The reinforcement distribution was uniform throughout the matrix. Bauri (2009) fabricated TiC reinforced composites using pure Al, K_2TiF_6 and carbon powders in a resistance furnace. The in-situ TiC particles appeared in the composite due to the chemical reaction taking place between the metal, halide salt and powder. Various reaction temperatures were used for processing the composite. Studies revealed that 1200°C was required to completely convert Al_3Ti particles into TiC. The composites thus processed exhibited

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better hardness compared to pure metal without reinforcement. Friction stir processing (FSP) was adopted by Shiva et al. (2018) to fabricate TiC reinforced aluminium based composites to boost the surface properties of the materials. The composite unveiled even distribution of the reinforcement in the matrix. Prem kumar and Chu et al. (1995) synthesized TiC particulates in molten aluminium by sending carbonaceous gas in to molten aluminium consisting Ti. The molten metal was finally cast and then extruded. Even dispersal of reinforcements was observed in the material. Hot consolidation technique was used for synthesizing TiC reinforced Al composites by Mohapatra et al. (2016). Titanium ore was used to synthesize the reinforcement through a carbothermic reduction method using thermal plasma procedure. The composites exhibited undeviating spread of particulates throughout the matrix. The Young's modulus of the composites thus prepared revealed enhancements when compared to the matrix. Kennedy and Wyatt (2000) compared the TiC reinforced AMCs prepared by powder metallurgy, flux casting method and by melting the powder metallurgy material. Clustering of particles were found in the cast specimen. The ductility of the composites enhanced while using extrusion process by removing porosity and minimising clusters. For enhancing the mechanical properties of the material, FSP was used by Akinlabi et al. (2014) for processing the TiC reinforced composites. The wear behaviour of the composites was evaluated by relating them to the various processing parameters used during the fabrication process. The obstruction to wear increased while incorporating the reinforcement and the results were reported.

Liu et al. (2016) reported the molten salt aided technique for fabricating TiC reinforced MMCs. $KAlF_4$ powder containing 10 vol.% TiC particles were subjected to ultrasonic pressing for obtaining powders in acetone. Later acetone was removed by evaporation process and dehydration was done in a furnace. At this stage, Al was melted in a crucible and the prepared powder was then added to the melt to get the master composites. The composites thus synthesized showed improvements in hardness with the increasing content of reinforcement. Spark plasma sintering method was followed to produce TiC based composites by Wang et al. (2019). Al and TiC powders were subjected to ball milling procedure and then sintered. Later, they were subjected to SPS process to get the composites in the form of sheets. The sheets were stacked using AA 1060 aluminium sheets to form 1060/Al–TiC/1060 laminated composites by using hot-roll bonding. The ultimate tensile strength of the laminate showed increments with the increasing content of reinforcement. However, after a certain limit of the addition of TiC, the tensile strength decreased.

Reactive slag process was used by Sheibani et al. (2007) to synthesize TiC reinforced composite. Pure Al, titanium oxide, cryolite and graphite were used in the process. Initially, pure Al was subjected to melting process in an induction furnace. Powders were then added to prepare composites of varying reinforcement content. Whisker shaped particles were found in the composites in the studies related to microstructure.

Kennedy et al. (2001) prepared TiC reinforced Al composites using casting method. TiC particles were added to Al melt during the casting process. The composites were subjected to heat treatment at different temperatures. The reaction rate was found to be maximum at 700°C. Large Al_3Ti particles in the matrix were found in the composite at the above-mentioned temperature. At the interface between matrix and particle, Al_4C_3 blocks were also found.

Bauri et al. (2001) used K_2TiF_6 and graphite powders to fabricate composites using friction stir casting method. The reinforcement was uniformly distributed all over the matrix. Single and double pass FSP was carried out on the composite, later microstructural studies revealed the uniform distribution of particulates in the matrix.

2.0 Experimental procedure

2.1 Fabrication of composite

Al 6061 ingots were used as starting materials for processing the composites. Al alloy ingots were melted in a resistance furnace to a temperature of 660°C and later superheated. TiC particulates corresponding to 1.5 wt.% of TiC in the matrix was carefully weighed in a digital balance. An Al foil was used to pack the powder. The powder was initially preheated in a muffle furnace to drive off any moisture found. The packet containing halide salt was dropped into the melt and carefully stirred with a stirrer coated with zirconia. A suitable flux was added to the melt to avoid contamination of the melt. Stirring was continued at consistent intervals of time for even mixing of the melt. After a reaction time of 30 min, the slag was removed from the top surface of molten material and was later poured into a steel mould. After solidification at room temperature, the composite was then removed from the mould (Boppana and Dayanand, 2020; Bharath et al., 2020).

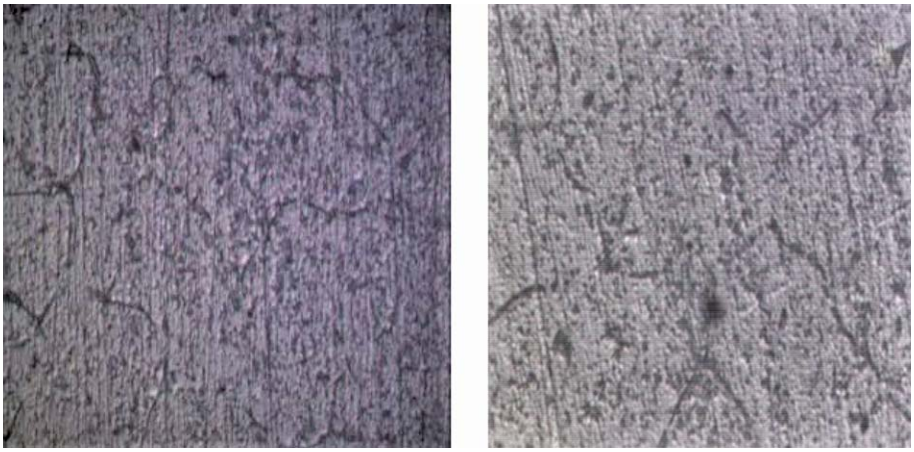
2.2 Microstructural characterization

The specimen was cut from the bottom of the casting for microstructural studies by means of a hacksaw. They were then filed to remove burrs (Boppana et al., 2021). Emery sheets were used to prepare the surface followed by disc polishing using a velvet cloth (Dayanand et al., 2021). Alumina paste was used during the polishing process to obtain a mirror finish. In order to reveal the grains, it was further etched using a suitable etchant. An image analyser was used to study the microstructure. EDS and XRD studies were conducted to determine the elements and the phases in the composite.

3.0 Results and discussion

3.1 Microstructural studies

The optical micrographs Figs.1(a) and (b) reveal the



(a) (b)

Fig.1: (a) and (b) Micrographs of Al-1.5TiC composite at a magnification of 500X.

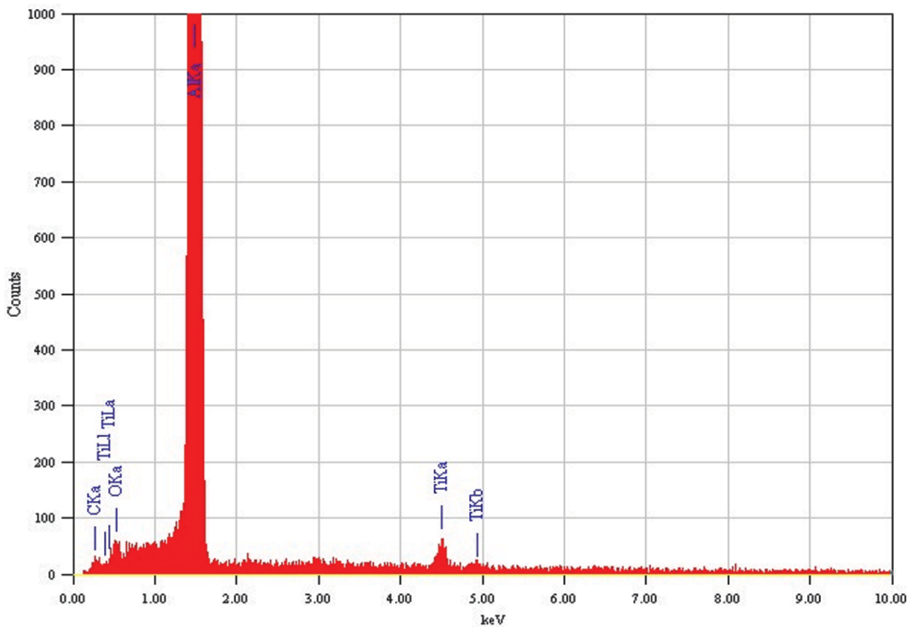


Fig.2: EDS of Al-1.5TiC composite

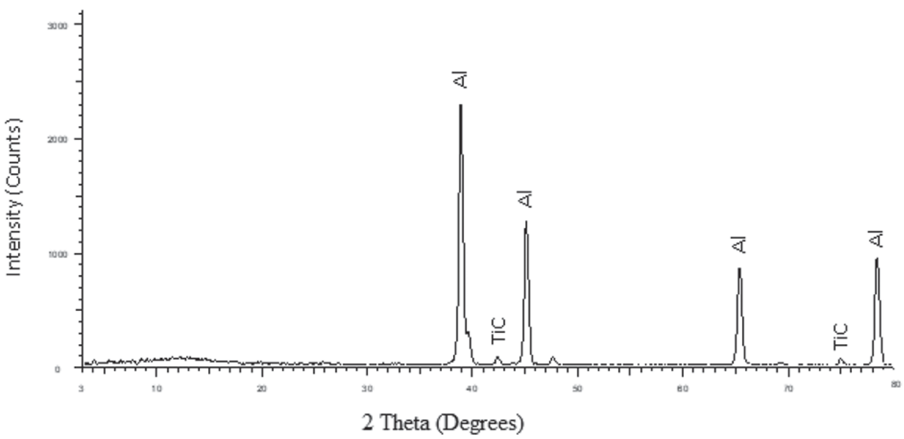


Fig.3: XRD pattern of the composite

uniform spread of reinforcement in the alloy. Grain boundaries appear to be clearly demarcated. The average size of the grain was around 40 µm. The reinforcement can be found at the grain boundaries.

Fig.2 reveals the EDS of the composite. Peaks corresponding to Al, Ti and C are seen in the figure. However, oxygen peak is also seen which might be due to the contamination during the melting process. Some amount of porosity is also seen in the matrix.

Fig.3 reveals the XRD pattern of the composite. TiC phase is seen in the patterns along with Al phase that confirm the successful fabrication of composite.

4.0 Conclusions

Stir casting method was used to successfully process the Al-TiC composite. Stir casting method was favoured to synthesize composites since the process was found to be economical compared to other processes for producing composites.

The micrographs reveal even spreading of ceramic phase in the composite. The average grain size as measured by image analyser was found to be 40 µm. EDS and XRD studies revealed the presence of individual elements and formation of TiC phase.

Aluminium based composites containing 1, 1.5 and 2wt.% of nano-sized titanium carbide particulates (TiC), with an average of 45nm, reinforcement were synthesized using low energy planetary ball mill followed by hot extrusion. Microstructural characterization of the materials revealed uniform distribution of reinforcement, grain refinement and the presence of minimal porosity. Properties characterization revealed that the presence of nano-TiC particulates led to an increase in hardness, elastic modulus, 0.2% yield strength (0.2% offset on a stress-strain curve), and the stress at which a material exhibits a specified permanent deformation, ultimate tensile strength (UTS) and ductility of pure aluminum. Fractography studies revealed that the fracture of pure aluminum occurred in ductile mode due to the incorporation and uniform distribution of nano-TiC particulates. An attempt is made in the present study to correlate the effect of nano-sized TiC particulates as reinforcement and processing type with the micro structural and tensile properties of aluminum composites. The mechanical properties, namely, the UTS, hardness, grain size and distribution of the reinforcement in the base metal were studied in as sintered and extruded conditions. Orowan strengthening criteria was used to predict the yield strength of Al-TiC composites in the present work and experimental results were compared to the theoretical results.

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