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STUDIES ON MECHANICAL BEHAVIOUR OF AL2024-TIC COMPOSITES

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Abstract

Al2024-TiC particle composites were fabricated using stir cast technique. Composites containing 2, 4, 6 and 8 wt. % TiC particles were processed. Microstructural characterization was carried out by using scanning electron micrographs and energy dispersive spectrograph analysis. Density, hardness, tensile strength and compression strength characteristics of the unreinforced alloy and composites have been measured. Hardness, ultimate tensile strength, yield strength and compression of Al2024-TiC composites are higher compared to that of the unreinforced Al2024 alloy. Additions of TiC lead to increase in mechanical properties. Al2024-TiC composites were found to exhibit the increased density when compared to unreinforced alloy at ambient temperature.

Keywords: Al2024 Alloy; TiC Particulates; Microstructure; Density; Hardness; Ultimate tensile strength; Yield strength; Compression strength

INTRODUCTION

Metal Matrix Composites (MMCs) are increasingly becoming attractive materials for advanced aerospace applications due to their properties can be tailored through the addition of selected reinforcement. MMCs offer designers requirements, they are particularly suited for applications requiring high strength to weight ratio at high temperature, good structural rigidity, dimensional stability, and light weight. The inadequacy of metals and alloys in providing both strength and stiffness to a structure has led to the development of various composites particularly metal matrix composites (MMCs) [1-3]. Composite materials are used extensively as their higher specific properties (properties per unit weight) of strength and stiffness, when compared to metals, offer

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interesting opportunities for new product design. MMCs are metals reinforced with other metal, ceramic or organic compounds. They are made by dispersing the reinforcements in the metal matrix [4]. Reinforcements are usually done to improve the properties of the base metal like strength, stiffness, conductivity, etc. The particle distribution plays a very vital role in the properties of the Al MMC and is improved by intensive shearing [5].
Addition of hard ceramic particles like SiO_3, SiC, Al_2O_3, TiB_2, B_4C, TiC etc. to Al matrix lead to strengthening of the matrix with improved properties [6]. Among the various matrix materials available, aluminium and its alloys are widely used in fabrication of MMCs and have reached the industrial production stage. The particulate reinforced aluminium matrix composite are gaining importance because of their low cost with advantages like isotropic properties and the possibility of secondary processing facilitating fabrication of secondary components. Cast aluminium matrix particle reinforced composites have higher specific strength, specific modulus and good wear resistance as compared to unreinforced alloys.
In recent years, ceramics have widely been considered as reinforcement materials. Apart from the very popular SiC and Al_2O_3 reinforcements, researchers have also tried out mica, zircon and graphite [7-9]. The ceramic reinforcement of the metal matrix can lead to the improvement of mechanical properties like yield strength, ultimate tensile strength and compressive strength, although there might be loss in ductility [10].

In general aluminium based MMCs offer substantial increase in elastic modulus and strength over the unreinforced alloys and often accompanied by large reduction in percent elongation. Properties of composites are affected by the reinforcement particle size, shape and volume fraction of the reinforcement, matrix material and reaction at the interface. Further, heat treatment played important role on the properties of Al based MMCs. The present investigation focuses on fabrication and evaluation of mechanical behaviour of Al2024 alloy matrix reinforced with TiC particles.

EXPERIMENTAL DETAILS

Matrix material

The matrix material used in the experimental investigation is aluminium 2024 alloy whose chemical composition is listed in Table 1. Al2024 alloy is one type of wrought aluminium alloy, containing copper as a major alloying element. The theoretical density of Al2024 is taken as 2.80 g/cm^3.

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Table 1: Chemical Composition of Al2024 alloy

Material	Components	Amount (wt. %)
Al2024	Aluminium	90.7 – 94.7
	Copper	3.8 – 4.9
	Magnesium	1.2 – 1.8
	Silicon	Max 0.50
	Iron	Max 0.5
	Manganese	0.3 – 0.9
	Zinc	Max 0.25
	Titanium	Max 0.15

Reinforcement material

The main advantage of introducing reinforcement material to base metal or alloy is to increase the properties there by enhancing the mechanical and tribological properties of composites. In the current research Titanium Carbide particulates of size 10-15 microns (μm) were used as a reinforcement material, which was procured from Chngasha Langfeng Metallic Material Co., Ltd., China. The density of TiC is 4.93 g/cm^3 which is little bit higher than the base Al matrix, contributes in weight increasing.

Preparation of Al2024-TiC composites

In the engineering materials, the MMC's can be manufactured by a unique technique such as casting, as it is inexpensive and suitable for mass production of components. The synthesis of metal matrix composite used in the study was carried out by liquid metallurgy route in particular stir casting technique. Initially TiC particulates were preheated for 300-400˚C.

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In the present work, an attempt has been made to study the mechanical properties of as cast Al2024 alloy and Al2024- TiC particulate composites. The composites containing 2, 4, 6 and 8 wt. % of TiC particulates were prepared. Initially required amount of charge or matrix material was placed in a graphite or silicon carbide crucible, which was placed in electric resistance furnace at a temperature of around 730 degree Celsius. After complete melting of Al2024 alloy matrix, degassing was carried out by using Solid Hexa Chloroethane [11], which helps to remove unwanted adsorbed gases from the melt. Once degassing is over, the preheated ceramic reinforcement particles were introduced into matrix in a novel way which involves two-stage additions of reinforcement during melt stirring. A continuous stirring process was carried out during addition of reinforcement into matrix. Normally for all composite preparation, stirring speed was maintained at 300 rpm. After 10 minutes of continuous stirring, entire molten metal was poured into cast iron die. The prepared composites were machined and tested for microstructural studies. After revealing uniform distribution of TiC particles in the matrix, mechanical behaviour of as cast Al2024 alloy and its composites were evaluated as per ASTM standards. Figures 1 and 2 showing the cast iron die and stir casting set up and used to prepare the composites for the present study.

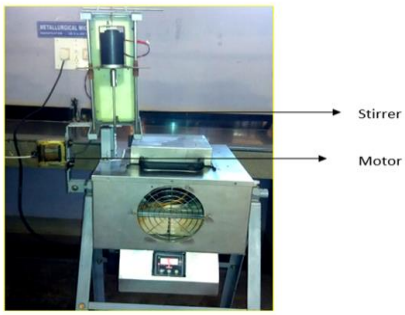

Figure 1: Stir casting equipment

Figure 2: Final prepared composites in iron mould

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Specimen Testing

The microstructure of the as cast Al2024 alloy and its composites reinforced with different wt. % of TiC particulates were examined by using scanning electron microscope. The samples of as cast and Al2024-TiC composites for microstructural study were prepared to metallorgraphic finish using a series of grinding using an etching solution. A ultra-high resolution field emission gun scanning electron microscope (SEM) equipped with an Energy Dispersive X-ray Spectrometry (EDS) was used for detailed study of the microstructural features and qualitative elemental composition of the composites produced.

The composites and base Al2024 alloy were tested for their hardness using a Brinell hardness tester. The hardness testing was carried out in accordance with ASTM E10 standard at room temperature. A test load of 250 kg was applied to the specimens for 30s. The diameter of steel ball indenter was 5 mm. The size of the indent (d) was determined optically by measuring two diagonals of the round indent. The Brinell hardness number (BHN) was calculated for the unreinforced Al matrix and TiC reinforced composite using equation (1). An average of five readings was taken for each sample for hardness measurement.

$$BHN = \frac{2P}{\Pi D\left(D - \sqrt{D^2 - d^2}\right)} \quad \text{..... (1)}$$

Where P is the applied load in kg, D is the diameter of the steel ball in mm and d is the size of the indent in mm. Each hardness value presented is an average of at least ten symmetrical indentations.

The experimental density of both unreinforced Al2024 alloy and Al2024-TiC composites were measured by dividing the measured weight of test sample by its measured volume using an electronic weighing machine. The theoretical density of the composite was calculated by rule of mixture using formula:

$$\rho_{composite} = V_{reinforcement} * \rho_{reinforcement} + V_{matrix} * \rho_{matrix}$$

Where, V is the volume, ρ is the density.
Tensile testing of the prepared samples were conducted in accordance with the ASTM E8 standard on round tension test specimens of gauge diameter 9 mm and gauge length 45 mm. Compression testing of the prepared samples were conducted in accordance with the ASTM E9 standard on round compression test specimens of diameter 15 mm and length 25 mm. Tension & Compression test was conducted by using Instron made UTM with cross head speed set at 0.280 mm/min. The

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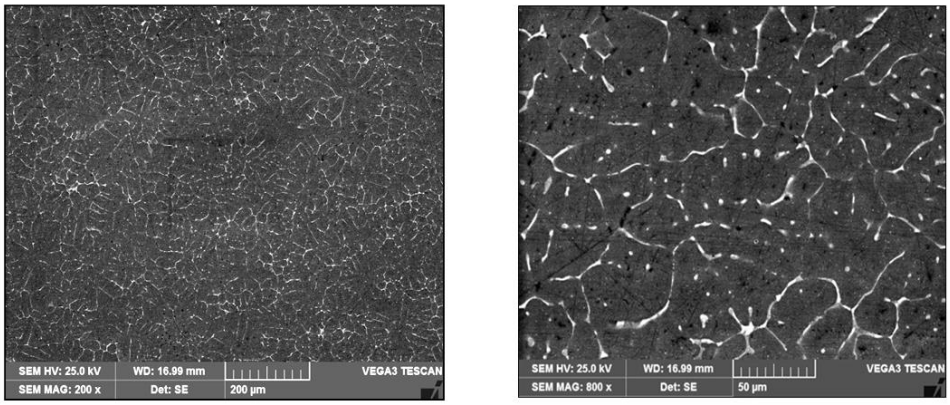
experiments were conducted at room temperature. Stress versus strain graph was plotted to know the effect of TiC particulates on tensile behaviour of Al2024 alloy composites

RESULTS AND DISCUSSION

Microstructural study

Figures 3a and 3b shows the SEM micrographs of a cast Al2024 alloy and Al2024-8 wt. % TiC composite respectively. The grain size of the composite was much smaller than that of the alloy because particles act as nucleation sites. Figure 3b reveals good distribution of reinforcements and there is no agglomeration in the composite. From the microphotograph, it is clear that a good crack free bonding was formed at discrete locations between the reinforcement and the matrix alloy.

Figures 4 shows the energy dispersive spectrographs of Al2024-8 wt. % TiC composite. A typical EDS spectrum is portrayed as a plot of x-ray counts vs energy (in keV). Energy peaks correspond to the various elements in the sample. Generally, these are narrow and readily resolved, but many elements yield multiple peaks. For example, iron commonly shows strong K_α and K_β peaks. Elements in low abundance will generate x-ray peaks that may not be resolvable from the background radiation. From figure 4 it is revealed that the presence of TiC in the form of Ti and C elements along with Al, Cu, Zn and other elements.



(a) (b)

Figure 3: SEM micrographs of (a) as cast Al2024 alloy (b) Al2024-8 wt. % TiC composite

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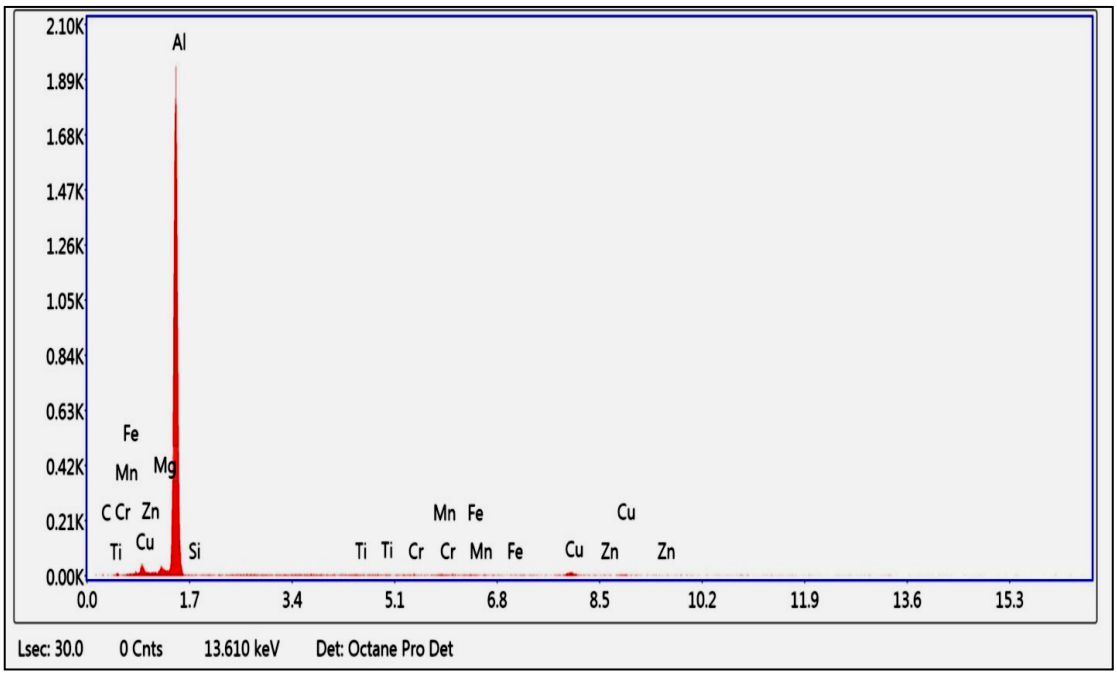

Figure 4: Energy dispersive spectrographs of Al2024-8 wt. % TiC composite

Density measurements

In the present research work, the measured densities of as cast Al2024 alloy, Al2024-2, 4, 6 & 8 wt. % TiC composites are presented in the figure 5.

It is observed that, by the addition of TiC particles the density of the composite is slightly increased. This increase in density is mainly due to higher density of TiC particles as compared to the base Al2024 alloy. Further, from figure 5, the experimental densities for both alloy and composites are in line with the theoretical densities but slightly lesser than the theoretical densities.

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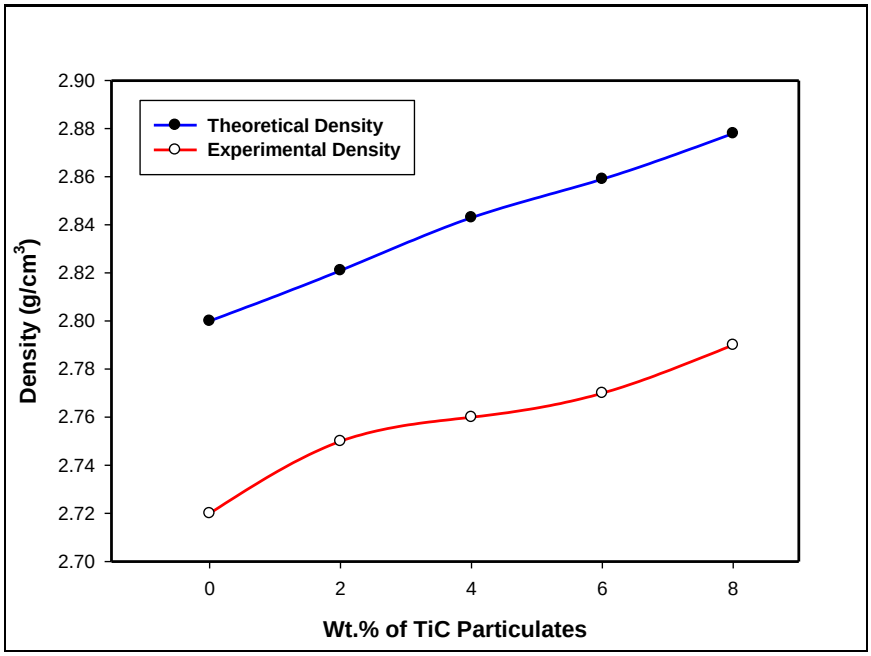

Figure 5: Comparison of theoretical and experimental densities of Al2024 alloy and its composites.

Hardness

In the present work, hardness values of the Al2024 alloy and Al2024-TiC composites have been obtained by Brinell hardness tester. The variation of hardness with Al alloy and its composite is shown in figure 6. It is noticed that the hardness of Al2024-2, 4, 6 and 8 wt.% TiC composites were more than Al2024 alloy. A notable rise in the hardness of the alloy matrix can be seen with the addition of TiC particles. This is mainly due to the presence of TiC particles in the matrix Al2024 alloy. Whenever a hard reinforcement is incorporated into a soft ductile matrix, the hardness of the matrix material is enhanced [12].

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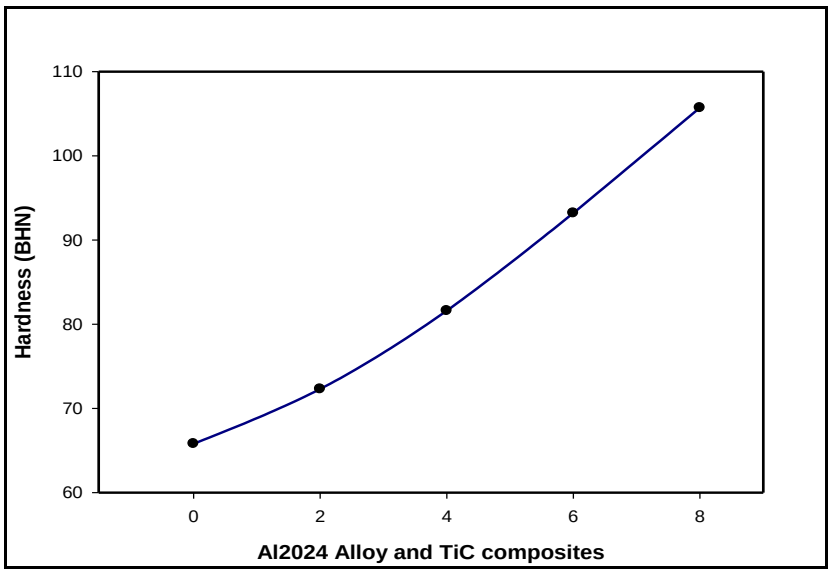

Figure 6: Shows the hardness of Al2024-TiC composites

Tensile strength

Figure 7 shows the variation of ultimate tensile strength (UTS) with 2, 4, 6 and 8 wt. % of TiC particulates. The ultimate tensile strength of Al2024-TiC composite material increases by an amount of 29.1% as compared to as cast Al2024 alloy matrix. The microstructure and properties of hard ceramic TiC particulates control the mechanical properties of the composites. Due to the strong interface bonding load from the matrix transfers to the reinforcement exhibiting increased ultimate tensile strength [13].

This increase in UTS is mainly due to TiC particles acting as barrier to dislocations in the microstructure. The improvement in UTS may be due to the matrix strengthening following a reduction in Al2024 alloy grain size, and the generation of a high dislocation density in the Al2024 alloy matrix a result of the difference in the thermal expansion between the metal matrix and the TiC reinforcement.

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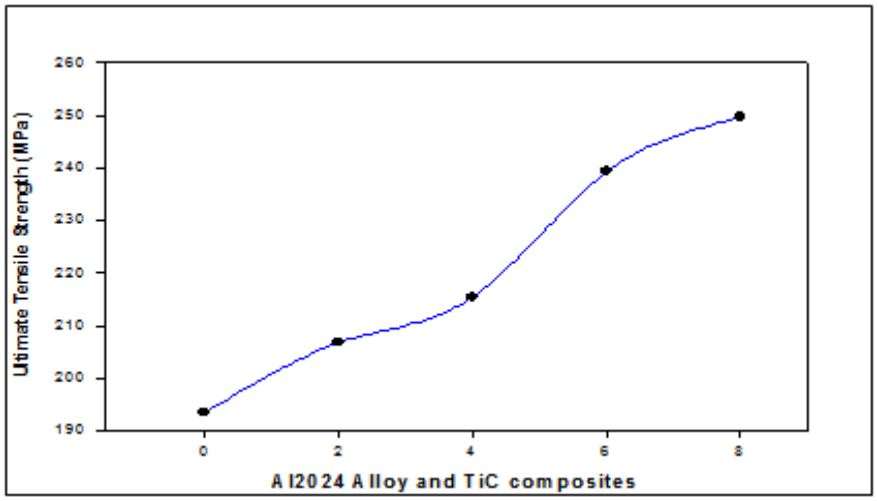

Figure 7: Shows the ultimate tensile strength of Al2024- TiC composite

Yield strength

Figure 8 shows variation of yield strength (YS) of Al2024 alloy matrix with 2, 4, 6 and 8 wt.% of TiC particulate reinforced composite. It can be seen that by adding TiC particulates yield strength of the Al2024 alloy increased from 186.86 MPa to 230.48 MPa. This increase in yield strength is in agreement with the results obtained by several researchers [14, 15], who reported that the strength of the particle reinforced composites is more strongly dependent on the volume fraction of the reinforcement. The increase in YS of the composite is obviously due to presence of hard TiC particles which impart strength to the soft aluminium matrix resulting in greater resistance of the composite against the tensile stress. In the case of particle reinforced composites, there is a restriction to the plastic flow due to the dispersion of the hard particles in the matrix, thereby providing enhanced strength to the composite.

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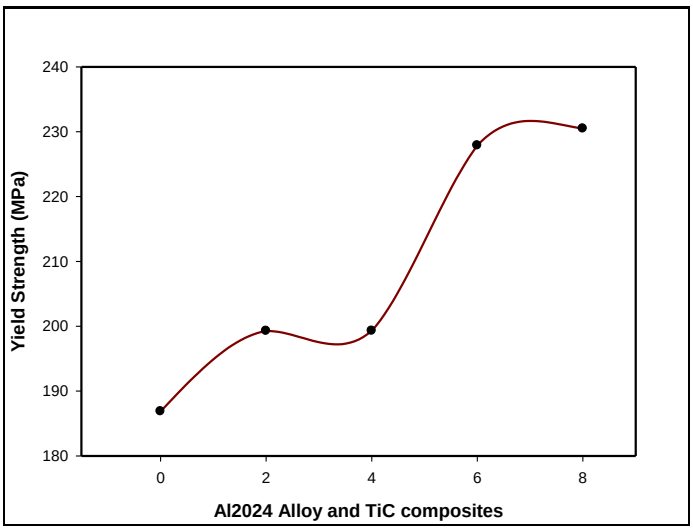

Figure 8: Shows the yield strength Al2024- TiC composites

Compression strength

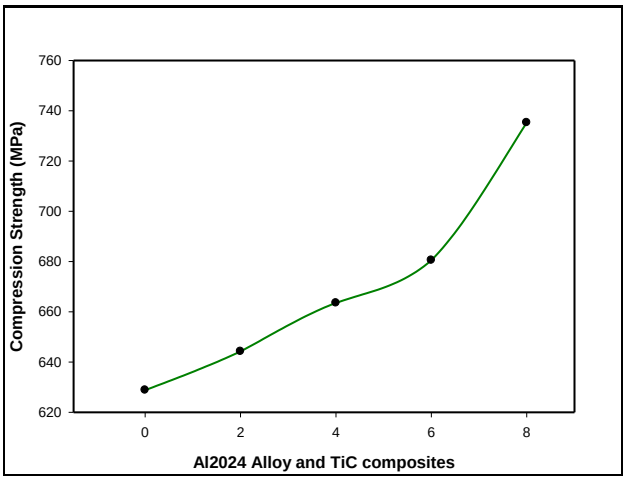

Figure 9: Shows the compression strength of Al2024-TiC composites

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Figure 9 shows the compression strength of Al2024 alloy and various wt. % of TiC composites. From the graph as weight percentage of TiC reinforcement increases from 2 to 8 wt. %, there is increase in compression strength. This increase compression strength is mainly due to high compression strength of carbide particulates. The compression strength of Al2024 alloy increased from 628.81 MPa to 735.26 MPa by adding 8 wt. % of TiC particulates in the matrix.

CONCLUSION

The mechanical properties of the Al2024-2, 4, 6 and 8 wt.% of TiC composites materials produced by stir casting are remarked as below:

• The liquid metallurgy technique was successfully adopted in the preparation of Al2024-2, 4, 6 and 8 wt. % TiC composites.

• The microstructural studies revealed the uniform distribution of the TiC particulates in the Al2024 alloy matrix.

• Density of the Al2024-TiC composites increased as compared to that of base alloy Al2024 metal. Further, experimental densities of base alloy and composites are in line with the theoretical densities, which show good casting procedure adopted for fabrication of composites.

• Hardness of the Al2024-TiC composite was found to be more than base Al matrix.

• The ultimate tensile strength and yield strength properties of the composites found to be higher than that of base matrix. The improvements in UTS and YS by adding 8 wt. % of TiC was increased by 29.1% and 23.3% respectively.

• Improvements in compressive strength of the Al2024 alloy matrix were obtained with the addition of TiC particulates. The extent of improvement obtained in Al2024 alloy after addition of 8 wt. % TiC particulates.

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