Micro Structural and Mechanical Properties of AA 7075/TiO₂ *In Situ* Composites

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Abstract AA7075/TiO₂ *in situ* composites with different mass fractions of reinforcement were fabricated by stir casting method. During fabrication TiO₂ reacts with base alloy and form an *in situ* composites leading to a uniform distribution of reinforcements. The phase analysis and morphological characterization of composites were studied using x-ray diffraction techniques and scanning electron microscope. Mechanical test were done on the samples to study the behavior during load at different strain rates. Effect of reinforcement and the strengthening mechanism were studied in detail.

Keywords AA 7075, *In Situ*, SEM, Deformation

1. Introduction

Metal matrix composites (MMCs) are composite materials in which the basic constituent (the matrix) contribute at least 50% by volume is a metal, and the reinforcements whether one element or more could be a metal, ceramic or an organic compound [1]. The materials used as a matrix in these composites are usually Al, magnesium, copper, titanium, Al-lithium, and super alloys [2]. Al-based (MMC) are widely spreading and required by many industries due to their relatively low density, high specific stiffness, and wear resistance. MMC's can be fabricated by dispersing reinforcing materials that have unique physical properties such as oxides, carbides or nitrides in the Al matrix. The composite carries the applied load by transferring it from the matrix to the reinforcement. The produced composite will have combined properties of its constituting elements, and this is the main reason behind the development and success of MMC manufacturing since the type and amount of the constituents of the composite could easily be altered to obtain the desired properties of the new product [3].

There are different techniques for the manufacturing of (MMCs); classified as follows: (1) the solid state method

where the constituents are processed in their solid form which is considered a PM technique. (2) The liquid state method where one or some of the constituents are processed in a liquid form such as stir casting, spray casting and electroplating. (3) The vapor deposition technique[4-8].

In this work the composites were manufactured by stir casting process. And the mechanical testing methods tensile, compression and hardness and corrosion tests were tested and analyze the structure of the composites by optical microscopy and scanning electron microscopy.

2. Experimental Procedures

2.1. Material

In this study, AA7075 were used as a base metal. TiO₂ powders with 99+ % purity with average particle size of 40µm obtained from LOBA Chemicals, India was used as reinforcement. The chemical compositions of aluminum alloy 7075 were shown in Table 1.

Table 1. Chemical composition of AA7075

Composition	Al	Zn	Mg	Cu	Mn & Cr
Wt%	87.1-91.4	5.1-6.1	2.1-2.9	1.2-2.0	<0.5

2.2. Processing

AA7075 and TiO₂ were carefully weighed using microbalance with precision of 0.0001g. TiO₂ powders were preheated at 200°C for 10 minutes. Different composition of MMCs with varying mass fraction of TiO₂ powders (5, 10, 15 and 20 %) were fabricated with stir casting method. The casting furnace is developed with manual mixing with stirrer. All the melting particles were carried out in a graphite crucibles and the melting temperature is optimized as 950°C. Manual mixing was used because it was very difficult to mix using automatic device when the alloy was in a semi-solid state. After sufficient manual mixing was done,

the composite slurry was reheated to a fully liquid state and then. In the final mixing process, the furnace temperature was controlled within $900 \pm 50^\circ\text{C}$. Pouring of the composite has been carried out in the sand mold, prepared according to the specifications of the testing specimens and then the samples are machined as per ASTM standard.

2.3. Density Measurements

The densities of the extruded samples were determined using Archimedes principle. Polished samples taken from various sections of the casted rods were weighed in air and when immersed in distilled water using an A&D HM-202 electronic balance with an accuracy of ± 0.0001 g.

2.4. Microstructure Characterization

Microstructural characterization studies were conducted on polished specimens of base AA 7075 and its composite formulations to investigate the presence of porosity, reinforcement distribution, matrix-reinforcement interfacial integrity, grain size and grain morphology. The samples were examined using a JEOL JSM 35-C scanning electron microscope.

2.5. Mechanical Testing

Macrohardness was measured on the Rockwell 15T Superficial Scale using a 1.588 mm (1/16 in.) steel ball indenter with test load of 15 kgf and dwell time of 2 s. The hardness measurements were performed using a Future-Tech FR-3 Rockwell Type Hardness Tester in accordance with ASTM standard E18-02. The composite cylinder rod of dimension 250 mm X 300 mm was cut according to ASTM standards for various tests. Tensile and compression test were carried out in an UTM HRC tests was also carried out according to the ASTM standard.

3. Results and Discussion

3.1. Density Measurements

The results of density and porosity measurements conducted on base AA 7075 and composite samples are shown in Table 2. The results revealed that near dense monolithic and composite materials can be obtained using the fabrication methodology adopted in this study. The highest porosity exhibited by composite samples was limited to 1.0%. The variation in the porosity may be attributed to solidification nature during the casting environment and agglomeration of TiO₂.

3.2. X-Ray Diffraction Analysis

The X-ray diffraction technique is one of the important phase analysis method performed in the metal matrix

composite to determine the reaction between the alloy and ceramic components this method is mostly used other than many methods available to consolidate the phase analysis of metal matrix composition. XRD pattern of base AA 7075 and AA 7075 / 20 wt % TiO₂ is given in figures. Al peaks and TiO₂ were indexed using JCPDS. The XRD pattern confirmed the presence of Al matrix and TiO₂ particulate in the composite. From Fig. 1 it can be observed that besides Al reflections, there appeared a broad peak at about 20° - 45° and some other weak peaks. The broad peak at about 45° corresponds to G-P zones, and other weak peaks whose positions are little lower than those of hexagonal η phase are from the metastable hexagonal η phase whose lattice parameters are little larger than those of η phase [9]. Judging from the relative peak intensities in the XRD pattern, it is concluded that a uniform structure is formed in 7075 Al alloy.

Table 2. Results of density and porosity measurements

Materials	Theoretical density (g/cc)	Experimental density (g/cc)	Porosity (%)
AA7075 (BM)	2.788	2.7857	0.08
BM+5T (5%TiO ₂)	2.7606	2.7426	0.65
BM+10T	2.73	2.721	0.32
BM+15T	2.701	2.674	1.00
BM+20T	2.6733	2.668	0.17

Figure 1. XRD pattern of base AA 7075 alloy

From Fig. 2, it can be observed that, mainly there are peaks of Al and TiO₂. Also some traces of Al-Ti peaks also exhibited. It indicates better distribution of TiO₂ in AA 7075 alloy. It can be observed that broadening of Al peak is only marginal. If an amorphous state had existed, it would have broadened the peak to a greater extent than in the present case. In Al-Ti composites, a direct reaction takes place between aluminum and titanium leads to the formation of *in-situ* composites. This reaction results in increase in mechanical properties and enhancement of corrosion

resistance [9]. As a result composite interface plays an important role in determining the resultant composite properties.

Figure 2. XRD of AA 7075/20wt% TiO₂

3.3. Microstructural Analysis

3.3.1. Optical Microscope Analysis

Figure 3 shows optical micrographs of AA 7075 matrix composites reinforced by the TiO_2 particles with different particle volume fractions. Fig. 3(a) shows a coarse dendritic microstructure in the AA 7074 alloy.

Figure 3. Optical micrographs of (a) AA 7075 alloy ; (b) 20 wt %TiO₂ reinforced AA 7075 alloy

The optical micrograph (Fig. 3b) reveals a thin and small dendritic microstructure. In addition, the grain size presents a

tendency of decrease with the increasing of particle weight fractions.

3.3.2. SEM Analysis

SEM image of AA 7075 is shown in Fig 4. The microstructure is composed of solidification induced dendritic structure. The high rate of cooling known as super cooling during solidification formed such a structure. The dendritic structure exhibits elongated primary α -Al dendritic arms having high aspect ratio.

Figure 4. SEM micrograph of as cast AA 7075

Figure 5 is a SEM image of as cast AA7075 alloy with 20 wt.% TiO₂ reinforcements, showing uniform distribution of TiO₂. The grain refining action of TiO₂ particles is clearly seen. As the amount of TiB₂ particles increases the grain size reduces. TiO₂ particles entirely modified the dendritic structure of as cast AA7075.

Figure 5. SEM micrograph of AA 7075/ 20wt% TiO₂

It is the TiO₂ addition can change the solidification sequence of AA 7075 from that of its base alloy. As a result, matrix micro segregation is reduced; crystal morphology is modified from cellular- dendritic to a featureless structure. The reinforcement phase nucleated heterogeneously on particles and matrix grains are redefined. The modification of the matrix alloy may influence the mechanical properties.

3.4. Mechanical Properties

The mechanical properties of the alloy and composite materials can be evaluated by hardness, tensile and compression tests.

The hardness values of the AA 7075 alloy and the composites are given in Table 3. The hardness of the AA 7075/TiO₂ composite increased with the addition of TiO₂. It was higher than that of base alloy. Hardness of all the composites was significantly greater than that of the base alloy characterized to the hard nature of TiO₂ particles. The hard ceramic reinforcement act as the obstacle to the movement of dislocation thereby increases the hardness [10]. Thus, the limiting deformation resists the penetration and cutting of the surface of the composites.

Table 3. Micro hardness Test Results

% of composite	Hardness value (HRC)
Base metal	54
5% TiO ₂	68
10% TiO ₂	70
15% TiO ₂	74
20% TiO ₂	72

The variation of ultimate tensile strength with varying TiO₂ is shown in Fig. 6. The tensile strength was increased with increasing TiO₂ content. The addition of TiO₂ particles improves the mechanical properties mainly by stress transference from the aluminium matrix to the reinforced particles TiO₂. This is because of orowan mechanism by which a dislocation bypasses impenetrable obstacles where a dislocation bows out considerably to leave a dislocation loop around a particle [11]. The interaction between the dislocations and TiO₂, results in an improved in strength.

Figure 6. Ultimate tensile strength of AA 7075 and its composites

The ultimate compressive strength increases with increasing TiO₂ is shown in Fig. 7. The compressive strength of the composite is increased with the addition of TiO₂. This was persistent till the matrix can accommodate the particles without distortion and the reinforcement is hard and brittle

lead to dispersion hardening of matrix. TiO₂ act as second phase in the composite and resist the movement of dislocations and hence the composites become stronger. The structure and properties of the reinforcements controls the mechanical properties of the composites that are reasoned to strong interface that transfers and distributes the load from the matrix to the reinforcements exhibiting increased compressive strength

Figure 7. Compressive strength of composites

The fractured surface morphology after compression test is shown in Fig.8. The previous studies have shown that the high-dense dislocations are generated due to the thermal mismatch stress in the composites reinforced with crystalline particles, which contributes to dislocation strengthening effect [12-14].

Figure 8. SEM image of specimen after compression test

The difference in coefficient of thermal expansion value of both matrix and reinforcement causes dislocation around the grain boundary results in the failure of the composites. In addition, the interfaces of the matrix and particles are net and no interfacial outgrowth is observed which is shown in fig.8.

In the present material systems, the strengthening mechanism of the composites can be explained by; when the conjunction of the particles and the matrix are good, the particles can bear the stress passed from the matrix very well[15-18]. In this work, the clear interface and good

bonding delay the detachment of particles from the aluminum matrix. So stress can be effectively transferred from the matrix to the particles, and the strength of the composites improves. Hence the tensile strength and compressive strength of the composites can be improved.

6. Conclusions

An earnest attempt is made in the development of a suitable high strength metal matrix composite in connection with study of new material development, And also to find its mechanical properties and machinability parameters

It was found that the variation of the tensile strength of the composite increased by 51% from 10% w_f to 15% w_f and tensile strength increased by 20%. This factor was also facilitated by the good adhesion between the metal and matrix and as a result the composite damage at this critical length became rare, thus increasing the strength of the composite and render the variation in stress distribution of the composite.

When the mass fraction is varied from 5% to 20%, the compressive strength increases by 60% and hardness increases 27% due to the metal-matrix behaviour in the interphase and influenced greatly by the shear and normal stresses induced by the insitu composite. The optical microscopic images and XRD phase analysis shows the presence of titanium insitu composites presented in the metal matrix composite.

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