Fabrication and Characterization of Al_2O_3–TiC-Reinforced Aluminum Matrix Composites

Anbesh Jamwal, Umesh Kumar Vates, Pallav Gupta, Ankur Aggarwal and Bhupendra Prakash Sharma

Abstract With a wide range of applications, aluminum matrix composites (AMCs) play an important role in many of the engineering applications and industries, i.e., automobile and aerospace. AMCs are the composites having aluminum as matrix and ceramics or some other metals as reinforcement. The aim of the present study is to develop the Al_2O_3–TiC-reinforced AMCs and study the effect of reinforcements on the mechanical properties. In the present case, the Al_2O_3–TiC content is varying in composition of (0, 5, 10, 15, and 20 wt%) in aluminum matrix, fabricated by stir casting technique. It is found that reinforced AMCs show the better mechanical properties as compared to unreinforced AMCs. Various properties which were improved include tensile strength, hardness, and wear resistance. It is expected that the present composite will be useful for developing lightweight aerospace components.

Keywords Aluminum matrix composites · Stir casting · Mechanical properties

1 Introduction

With the rapid change in manufacturing scenario, materials play an important role. Materials are deep-seated in our life at the present time [1]. Our manufacturing system, daily needs, communication, and transportation all the segments depend upon the materials [2]. The material is simply a form of the matter [1]. Materials are being used in many applications, but with a change in time and human needs, new materials are being developed [3]. With the change in manufacturing scenario and human needs, a new form of materials is developed with better properties [4–6]. In the past few decades, composite materials gain more popularity because of the better properties and wide applicability. Composites materials are advanced forms of materials in which reinforcement is dispersed into the matrix either in the continuous phase or discontinuous phase [7, 8]. Composites are widely used in cutting tools these days, seal rings, bearing parts, and variety of engine parts where high temperature is

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required [9]. In the twenty-first century, the development of aluminum metal matrix composite is one of the major research areas for the development of lightweight materials because of their wide range of applicability in automobile industries and aircraft applications [10–12]. Aluminum metal matrix composites are composites in which aluminum is reinforced with other metals, organic compounds, or ceramics [13, 14]. These composites are prepared by dispersing the reinforcement (i.e., metal or ceramic) in the aluminum matrix [15]. The reinforcement in aluminum matrix composites (AMCs) could be in form of particulates, continuous or discontinuous fibers, and whiskers depending upon the industrial application [16]. Al-MMC can be categorized into four types on the basis of reinforcements, i.e., particle-reinforced AMC [17], continuous fiber-reinforced AMC [18], short fiber or whiskers-reinforced AMC [19] and monofilament-reinforced AMC [20]. It is found in some studies that reinforcement should be non-reactive and stable in given working temperature [21, 22]. The major advantage of using aluminum metal matrix composites is reduced density [23], greater strength [24], thermal stability [25], improved damping properties [26], improved abrasion [27], as well as wear resistance [28]. In order to provide better material properties like tensile strength, hardness, and wear resistance, SiC, B_4C, and Al_2O_3 ceramics are used as reinforcements [24, 29, 30]. A lot of research has been done on the improvement of aluminum metal matrix composites. AMCs can be manufactured by stir casting [31], infiltration [32], squeeze casting [33], powder metallurgy [34–36], and semisolid processing [37] techniques. Over the years, aluminum metal matrix composites were synthesized and characterized and used in many engineering applications for the better combination of properties. With a wide range of applicability in the transport system, Al-MMC provides low fuel consumption and less noise as compared to other materials [38]. The aim of the present study is to observe the effect of TiC and Al_2O_3 reinforcements addition in the aluminum metal matrix composites on the tensile strength, hardness, and wear resistance.

2 Experimental Procedure

2.1 Materials

Aluminum-1100 alloy was used as a base material or matrix material, and Alumina-TiC particles were added as reinforcement in powder form to metal. Al-1100 is an aluminum-based alloy with minimum 99% of aluminum. It is most heavy alloy in the 1100 series. The chemical composition of Al-1100 alloy is shown in Table 1.

Table 1 Composition of Al-1100 alloy used as matrix

Element	Aluminum	Copper	Iron	Manganese	Silicon	Zinc	Residual
%	99–99.5%	0.05–0.20%	0.95% max	0.05% max	0.95% max	0.1% max	0.15% max

Table 2 Composition of Al_2O_3–TiC reinforcement in Al matrix

Sample	Composition
AMC001	100% Al
AMC002	95% Al and 2.5% Al_2O_3- 2.5% TiC
AMC003	90% Al and 5% Al_2O_3–5% TiC
AMC004	85% Al and 7.5% Al_2O_3–7.5% TiC
AMC005	80% Al and 10% Al_2O_3–10% TiC

2.2 *Preparation of Composites*

Al_2O_3–TiC-reinforced composites were prepared by stir casting process. Five composites were prepared with the different compositions of reinforcement. The composition of Al_2O_3–TiC is shown in Table 2.

The experiment was done on a controlled furnace having the maximum temperature up to 1200 °C. Al-1100 ingots were melted in the furnace up to 950 °C for 30 min, and then, melted aluminum was stirred for 3 min at 400 rpm. Heat-treated Al_2O_3 particles were added to the furnace through the funnel at 950 °C and heated at 1070 °C for 20 min. The mixture was again stirred at 1070 °C for 5 min. TiC particles were added in the furnace at 1070 °C with the help of funnel and then heated up to 1150 °C for 30 min. Before pouring into the mold, the mixture was again stirred, and finally, the melt was poured and allowed to solidify under room temperature. The mold was covered from upper side with the help of a sheet to avoid the casting defects.

3 Results and Discussion

3.1 *Hardness*

The hardness number is indicated by the instrument by applying a minor load of 10 kg and a major load of 90 kg. Hardness for the different samples is shown in Table 3. It is found in the experiments that hardness number increases with increase in the % of reinforcements in AMCs. For pure Al sample without any reinforcements, hardness number is 58.4 HRB. It is found that hardness was more in reinforced AMCs than unreinforced AMC. Specimen AMC002 with 2.5% TiC–2.5% Al_2O_3 shows the Rockwell hardness value of 92 HB. It is found that increase in the ratio of

Table 3 Rockwell hardness of different samples

Sample	Composition	Rockwell hardness
AMC001	100% Al	58.4 HRB
AMC002	95% Al and 2.5% Al_2O_3–2.5% TiC	92 HRB
AMC003	90% Al and 5% Al_2O_3–5% TiC	104 HRB
AMC004	85% Al and 7.5% Al_2O_3–7.5% TiC	110 HRB
AMC005	80% Al and 10% Al_2O_3–10% TiC	119 HRB

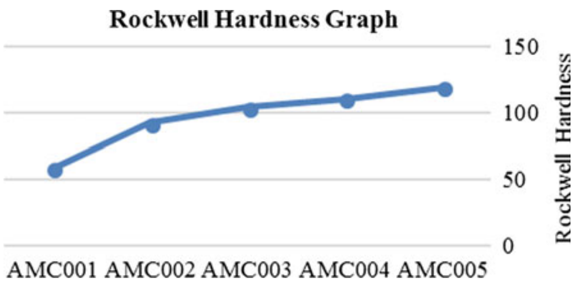

Fig. 1 Rockwell hardness of different samples

reinforcements increases the hardness. In the composites, reinforcement particles act as strengthening agents which help in creating the stronger bond between the particles. It is found that stronger bond between the particles improves the mechanical properties of the material. The presence of well bonded and harder TiC–Al_2O_3 particles in the Al matrix increases the hardness of specimens by preventing the movement of dislocations. The specimens with 15 and 20% reinforcements exhibit the higher hardness values.

Table 3 shows that the addition of Al_2O_3–TiC reinforcement in Al matrix enhances the hardness of composites. The graph (Fig. 1) shows that there is an increase in the hardness with increase in wt% of reinforcement.

3.2 Tensile Strength

Tensile strength for different samples is shown in Table 3. It is found in the experiments that tensile strength is more in reinforced AMCs than the unreinforced Al composite. Tensile strength increases with increase in the wt% of Al_2O_3–TiC reinforcements in AMCs. It is found that the strong interfacial bonding between the TiC–Al_2O_3 and Al matrix increases the tensile strength of the material. In the AMCs, there is an increase in the tensile strength due to the transfer of applied load to strongly bonded TiC–Al_2O_3 reinforcements in the Al matrix. Lower the reinforcement in the

Table 4 Tensile strength of different samples

Sample	Composition	Tensile Strength (MPa)
AMC001	100% Al	120.4
AMC002	95% Al and 2.5% Al_2O_3–2.5% TiC	126.5
AMC003	90% Al and 5% Al_2O_3–5 % TiC	130.7
AMC004	85% Al and 7.5% Al_2O_3–7.5% TiC	139
AMC005	80% Al and 10% Al_2O_3–10% TiC	149.3

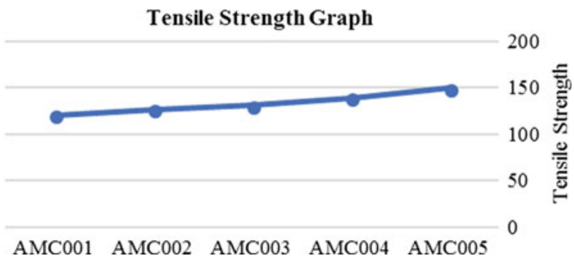

Fig. 2 Tensile strength graph of different samples

AMCs gives the lower tensile strength. Specimen AMC001 with pure Al shows the minimum tensile strength of 84.6 MPa. With increase of the reinforcement ratio in the Al matrix, the 15% and 20% reinforcements show the maximum tensile strength of 116 and 129.3 MPa, respectively.

Table 4 shows that addition of Al_2O_3–TiC reinforcement in Al matrix enhances the tensile strength of AMCs. The graph (Fig. 2) shows that there is an increase in the tensile strength with increase in wt% of reinforcement.

3.3 *Wear Resistance*

Wear behavior of the Al_2O_3–TiC-reinforced AMCs is obtained by wear test. Wear resistance of the material is the property of a material which resists the material loss by some mechanical actions. The wear test was performed at 300 rpm grinding speed for a fixed time of 4 min. A constant load of 10 N was applied to the sample. In the experiment, it is found that the mass loss in the unreinforced AMCs is greater than the reinforced AMCs. The Presence of TiC particles enhance greater wear resistance to the Al matrix. This is because of the pure Al matrix is worn out first from the surface of the specimen during the wear test and then leaving the TiC–Al_2O_3 particles on the surface. These exposed TiC–Al_2O_3 particles protect the Al matrix from further wear. It is also found that sliding distance is the most influencing parameter which affects

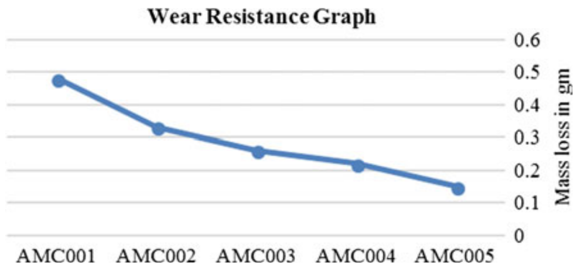

Fig. 3 Wear resistance at different samples with mass loss

the wear rate of AMCs than the applied load and sliding speed. With the increase in the wt% of reinforcements in the AMCs, there is an increase in the wear resistance also. Maximum wear resistance is obtained at 20 wt% of reinforcements. The graph (Fig. 3) shows the mass loss in grams when the wear test is conducted on the samples.

4 Conclusion

In this experimental study, AMCs were prepared with varying Al_2O_3–TiC content by using stir casting fabrication process. Hardness, tensile strength, and wear resistance of composites were studied. Based on the experimental results, the following conclusions can be stated:

- Addition of Al_2O_3 and TiC particles in the Al matrix increases the hardness of the AMCs. Maximum hardness is obtained at 20 wt% of reinforcements in the Al matrix.
- Tensile strength is maximum in the reinforced AMCs than the unreinforced AMCs. With the increase in the wt% of reinforcements tensile strength increases, 20 wt% of reinforcement in the AMCs shows the maximum tensile strength.
- Addition of TiC particles in the AMCs increases the wear resistance of the composites. It was found that the maximum wear resistance of the AMCs resulted at 20 wt% of reinforcements.

It is found that addition of TiC particles with the alumina particles shows maximum tensile strength, hardness, and wear resistance than the unreinforced aluminum.

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