Research Article

THE MECHANICAL PROPERTIES & FRACTOGRAPHY OF ALUMINIUM 6061 – TIO_2 COMPOSITES.

G.S. Kataiah[a]*, Dr. D.P.Girish[b]

Address for Correspondence

Sri Revana Siddeshwara Institute of Technology, Bangalore,Karnataka, India
Rajarajarajeshwari College of Engineering, Bangalore, Karnataka, India
Email gskataiah@gmail.com

ABSTRACT

Study of the mechanical properties of cast aluminium alloy composites containing TiO_2 particles of size 30-50 pm and of contents ranging from 0% to 20% by weight. The liquid vortex method of production was employed and the vortex created by means of a mechanical stirrer, molten metal at 700ºC . The study revealed that as TiO_2 composition was increased, there were significant increase in the ultimate tensile strength (UTS), and hardness of the composite, accompanied by a reduction in its ductility. An attempt is made in the paper to provide explanations for these phenomena. The fracture behavior of the composites was altered significantly by the presence of garnet particles and the crack propagation through the matrix and the reinforcing particle clusters resulted in the final fracture.

KEYWORDS MMC, Aluminium 6061, Ti02, Liquid vortex method, Mechanical properties, Fractography

1. INTRODUCTION

Recent increases in the performance requirements of materials for aerospace and automobile applications have led to the development of numerous structural composite materials. Among these, particle-reinforced metal-matrix composites and, in particular, ceramic particle reinforced aluminum, have already emerged as candidates for industrial application by virtue of their higher specific strength and stiffness, improved elevated performance, and the additional advantages of being machinable and workable. Therefore the mechanical properties of materials of this kind have received much attention. There are many reinforcement characteristics that influence the mechanical properties of the composites, such as the volume fraction and the shape, size and dispersion of the reinforcement. Composites containing large ceramic particles show increased modulus and wear endurance, but reduced tensile strength and high-cycle fatigue resistance [1-3] by comparison with small-particle-reinforced composites. As for low-cycle fatigue life, that of large-particle-reinforced composites raises at higher strain amplitudes, but decreases at lower strain amplitudes. [4] However, investigations of the effect of particle size on low-cycle fatigue behavior of the composites are still limited, [5] especially at elevated temperature. The present study investigates the cyclic deformation behavior and low-cycle fatigue lives of SiC/Al composites with different SiC particle sizes, together with those of the unreinforced matrix material, at elevated temperature. The tensile strengths of these materials were also studied. Moreover, since Al is such a heavy metal, any addition of dispersoid would almost certainly result in a composite of lower density. TiO_2, in contrast, is a very hard ceramic material which is often used as reinforcement material in MMCs. The present research is an attempt to test and analyse the mechanical properties of Al6061 alloy reinforced with up to 20% by weight of TiO_2 particles produced by using the vortex method of casting.

2. EXPERIMENTAL PROCEDURE

In the present work, commercially available Al6061alloy was used as the base matrix. This was melted at 700°C which is slightly more than 30°C above the liquidus temperature. The dispersoid used was TiO_2 particles of size 30-50, μm. The vortex technique was adopted to fabricate the specimens, in which a vortex was created in the melt of the matrix alloy through a mechanical stirrer coated with aluminite and rotating at 550 rpm. The TiO_2 particles were preheated to 200°C and added to the vortex of liquid melt at a rate of 120 g/min. A small amount of magnesium, which improves the wettability of the TiO_2 particles, was added along with the TiO_2. The composite melt was thoroughly stirred and subsequently degassed by passing nitrogen through at a rate of 2-3 l/min for 3 to 4 minutes. The composites were then cast in permanent moulds. Al alloy composites containing various TiO2 contents, namely 5%, 10% and 15% and 20% by weight, were fabricated and tested, and their properties were compared with those of the unreinforced matrix. All tests were conducted in accordance with ASTM Standards. Tensile tests were performed at room temperature using a Universal Testing Machine in accordance with ASTM E8-82. The tensile specimens of diameter 8.9 mm and gauge length 76 mm were machined from the cast composites with the gauge length of the specimens parallel to the longitudinal axis of the castings. For each composite, six tensile test specimens were tested and the average values of the ultimate tensile strength (UTS) and ductility (in terms of percentage elongation) were measured. The Charpy impact tests were performed in accordance with ASTM E23 using specimens that were 55 mm long and of 10 mm square cross-section. As in the cases of UTS and ductility described above, each result is an average of six readings. The hardness tests were conducted in accordance with ASTM E 10 using a Brinell hardness tester with a ball indenter of 2.5 mm diameter and a load of 31.25 kg. The load was applied for 30 seconds. Six hardness readings were taken for each specimen at different locations to circumvent the possible effects of particle segregation.

3. RESULTS AND DISCUSSIONS

Fig. 1-4 show the effects of TiO_2 content on the UTS, hardness, torsional strength and ductility and impact strength of the composites respectively. Each value represented is an average of six measurements. The results are repeatable in the sense that each individual result did not vary more than 2% from the mean value.

3.1 Ultimate tensile strength (UTS)

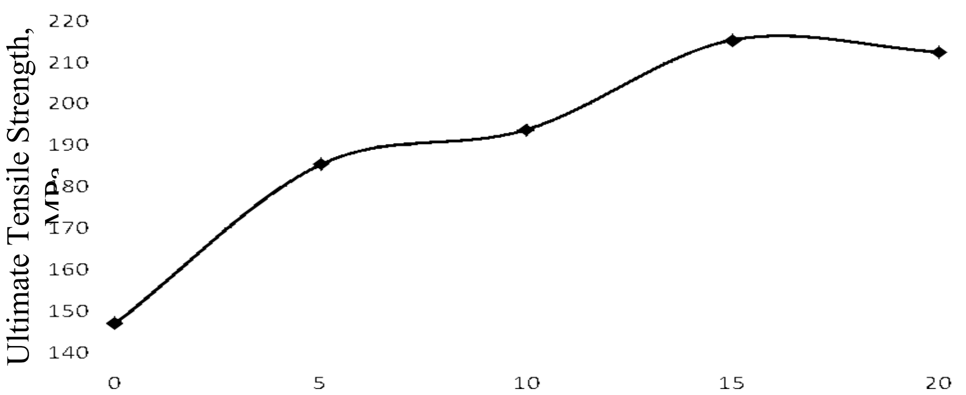

Fig. 1 Effect of TiO_2 content on UTS of the Al composite

Fig. 1 is a graph showing the effect of TiO_2 content on the UTS of the Al alloy composite. It can be seen that as the TiO_2 content increases, the UTS of the composite material increases monotonically by significant amounts if other factors are kept constant. The strength of the particle reinforced composites is most strongly dependent on the volume fraction of the reinforcement with a somewhat weaker dependence on the particle size. TiO2 particle reinforcement in various aluminium alloy matrices, reported up to 60% increase in the UTS, depending upon the type of the alloy, percentage of reinforcement and the matrix alloy temper. Other researchers [6 & 7] have also performed tests on discontinuous reinforcement MMCs and found remarkable improvements in the mechanical properties such as UTS and Young's modulus ranging from 50% to 100% by the incorporation of reinforcements. Slightly less spectacular improvements by addition of 15% TiO_2 to the Al alloy specimens. Quantitatively, as TiO_2 content is increased from 0% to 20%, there is an improvement in UTS of 46.3%. This increase in UTS may be due to the TiO_2 particles acting as barriers to dislocations in the microstructure[8]. As more TiO_2 is added to the composite, the decrease in interparticulate distance between the hard TiO_2 particles causes an increase in dislocation pile-up. One great advantage of this dispersion-strengthening effect is that it is retained even at elevated temperatures and for extended time periods because the inert TiO_2 particles are unreactive with the matrix phase[9]. It worth noting that the most spectacular increase in the UTS occurs when the TiO_2 content is increased from 0% to 5%. Quantitatively, this increase in UTS is more than 25%. Subsequent equivalent additions of TiO_2, however, do not result in such great increases in UTS. From the trend of the graph, it is possible that as more and more TiO_2 is added to the composite, the UTS might finally reach an asymptotic value.

***3.2** Hardness*

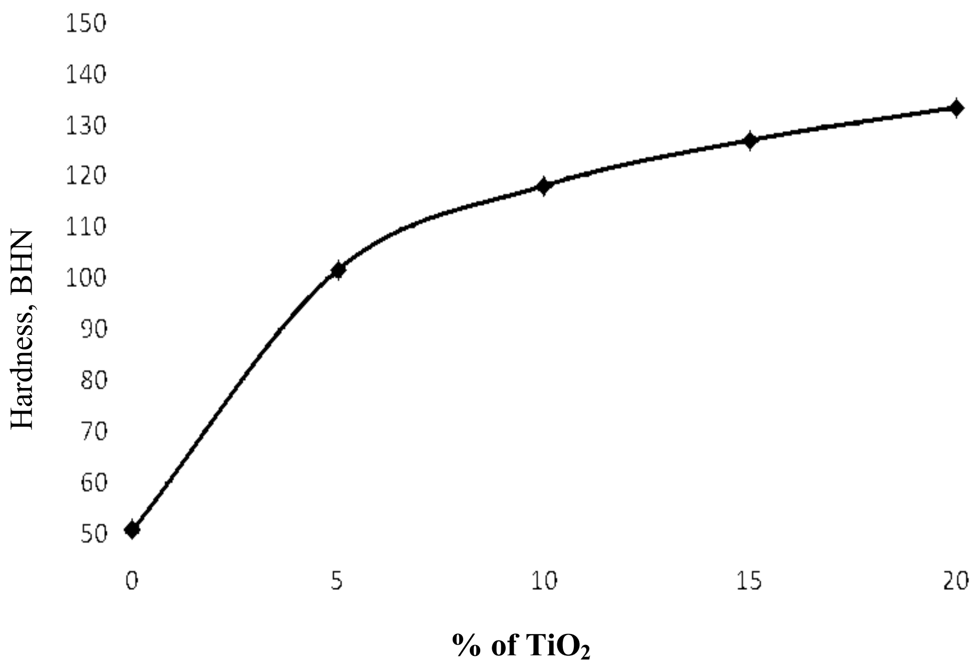

Fig. 2 Effect of TiO_2 content on BHN of the Al composite

Fig. 2 is a graph showing the effect of TiO2 content on the hardness of the Al alloy composite. It can be seen that as the TiO_2 content increases, the hardness of the composite material increases monotonically by significant amounts if other factors are kept constant. Quantitatively, as TiO_2 content is increased from 0% to 20%, there is an increase in hardness of about 150%. Ghadwick et al[10] reported an improvement in hardness in aluminium-based MMCs by about 120% on addition of such reinforcements. This increase in hardness is to be expected since Al alloy is quite a soft material, and TiO_2, being a very hard dispersoid, contributes positively to the hardness of the composite. As is well known, hardness is the resistance to indentation, wherein there will be localized plastic deformation under standardized conditions. The increased hardness is attributable to the hard TiO_2 particles acting as barriers to the movement of dislocations within the matrix. As in the case of UTS described above, this dispersion-hardening effect is expected to be retained even at elevated temperatures and for extended time periods because the inert TiO_2 particles are unreactive with the matrix phase. As in the case of UTS described above, the most spectacular increase in the hardness occurs when TiO_2 content is increased from 0% to 5%. In fact, the hardness value is doubled. Subsequent equivalent additions of TiO_2, however, do not result in such great increases in hardness. From the trend of the graph, it is possible that as more and more TiO_2 is added to the composite, the hardness might finally reach an asymptotic value.

3.3 TORSIONAL STRENGTH

As TiO_2 content is increased from 0% to 20%, there is an improvement in torsional strength of 35.6%. As in the case of UTS above, this increase in torsional strength may be due to the TiO_2 particles acting as barriers to dislocations in the microstructure [11]. As more TiO_2 is added to the composite, the decrease in interparticulate distance between the hard TiO_2 particles causes an increase in dislocation pile-up.

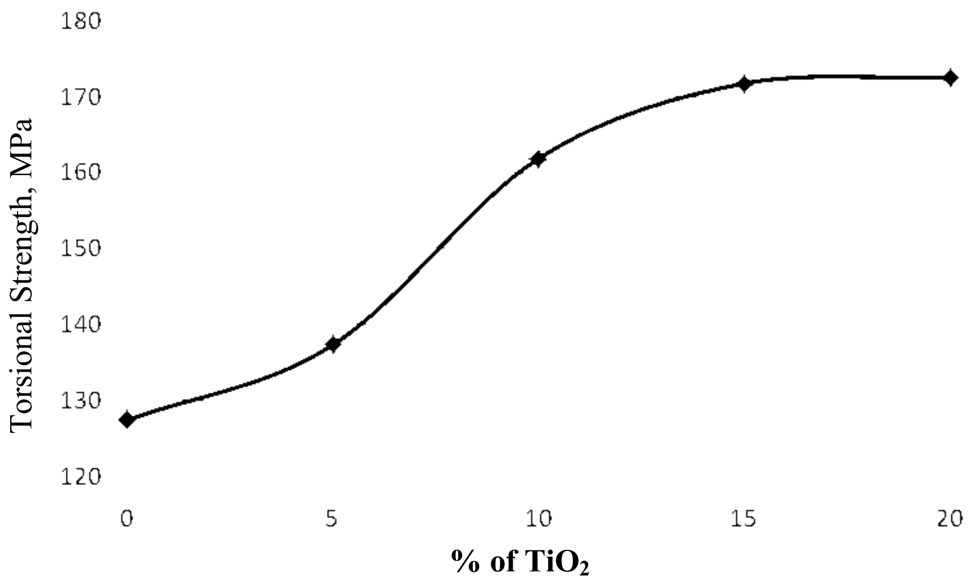

Fig. 3 Effect of TiO_2 content on Tensional strength of the Al composite

Since the modulus of rigidity of a material has a positive relationship with its Young's modulus [12], torsional strength is expected to have a positive relationship with UTS, as is evident in these experimental results. As in the cases of UTS and hardness described above, this dispersion-strengthening effect is expected to be retained even at elevated temperatures and for extended time periods because the inert TiO_2 particles are unreactive with the matrix phase[13]. From the trend of the graph, it is possible that as more and more SiC is added to the composite, the torsional strength might finally reach an asymptotic value.

3.4 DUCTILITY

Fig. 4 is a graph showing the effect of TiO_2 content on the ductility of the Al alloy composite. It can be seen that as the TiO_2 content increases, the ductility of the composite material decreases monotonically by significant amounts if other factors are kept constant. Quantitatively, as TiO2 content is increased from 0% to 20%, there is a reduction in ductility of 36.3%. All these results are in agreement with the conclusions made by Hung[14], who believe that the ductility of discontinuous reinforcement MMCs deteriorates with increase in reinforcing content It is evident that the most serious loss in ductility occurs when TiO_2 content is increased from 0% to 5%. Quantitatively, this reduction in ductility is more than 20%. Subsequent equivalent additions of TiO_2, however, do not result in such great reductions in ductility. From the trend of the graph, it is possible that as more and more TiO_2 is added to the composite, the ductility might finally reach an asymptotic value. There is an embrittlement effect due to the hard TiO_2 particles which cause increased local stress concentration sites. These TiO_2 particles resist the passage of dislocations either by creating stress fields in the matrix or by inducing large differences in the elastic behaviour between the matrix and the dispersoid. As in the cases of UTS, hardness and torsional strength described above, the embrittling effect of TiO_2 is expected to be mechanical in nature since the inert TiO_2 particles are unreactive with the matrix phase. It is evident that the most serious loss in ductility occurs when TiO2 content is increased from 0% to 5%. Quantitatively, this reduction in ductility is more than 20%. Subsequent equivalent additions of TiO_2, however, do not result in such great reductions in ductility. From the trend of the graph, it is possible that as more and more TiO_2 is added to the composite, the ductility might finally reach an asymptotic value.

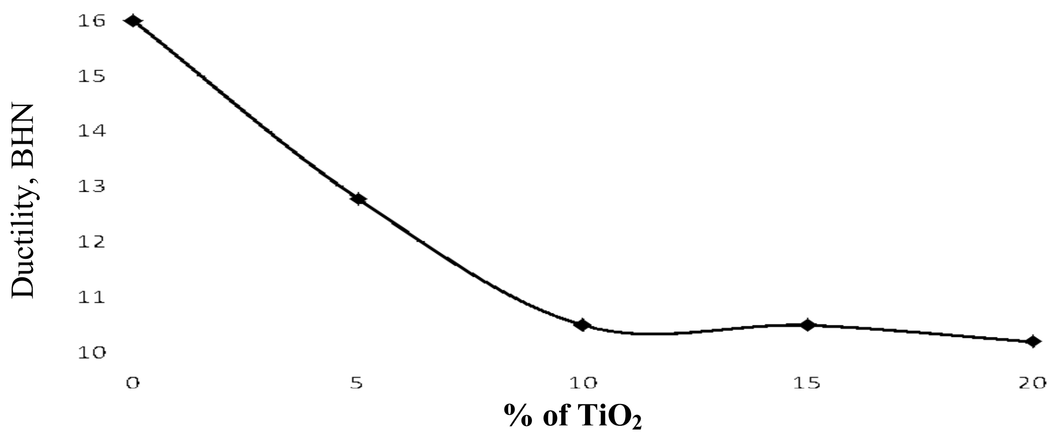

Fig. 4 Effect of TiO_2 content on Ductility of the Al composite

3.5 FRACTURE STUDIES

Typical fractured surfaces of Al and Al/ TiO_2 composite obtained from tensile tests, are shown Fig. 5. Fig. 5(a) shows the fracture in Al alloy ductility failure the same trend also seen in Al/5% TiO_2 composites shown in Fig. 5(b). SEM examination of the fractured surfaces revealed a dimpled fracture surface for the unreinforced material. The fracture surface of the unreinforced material contained a rather uneven distribution of large dimples connected by sheets of smaller dimples indicating a pattern resulting from ductile void growth coalescence and failure as seen in Fig. 5(b). The fractured surface of the reinforced material contained only smaller dimples than the fractured surface of the unreinforced material. But higher percentage of TiO_2 composites showed brittle fracture failure as shown. Only very few fracture can be seen as fractured and there is also an evidence of ductile failure in the matrix. The failure showed few fracture split longitudinally and transversally as shown in Fig 5(c). The failure of fracture in the composite may be attributed to the increase in stress on the specimen. As the load on the fracture increases, it induces strain in the particles Fig. 5(d), and the most heavily loaded fracture fractures [14]. Some fracture "pull-out" has occured in the samples, but the failure appears to be at the matrix end and not at the interfacial regions, as indicated by the conical cavities with rippled surface. Apparently more "pull-out" occurred in the matrix composite as expected due to the lower strength of the matrix Fig. 5 (e). In some places where the fracture end was exposed to SEM, it appears that the matrix sheared away from the fracture [15].

FRACTURE STUDIES

Typical fractured surfaces of Al and Al/ TiO_2 composite as shown below

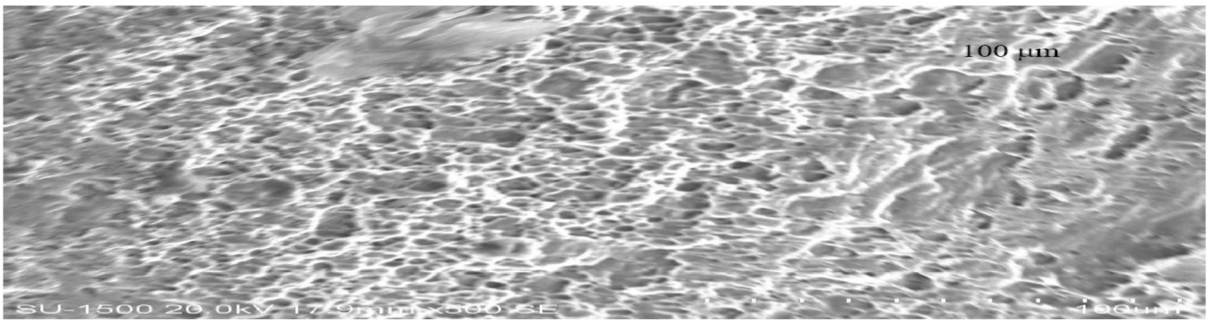

Fig. a. Fracture surface of the Al

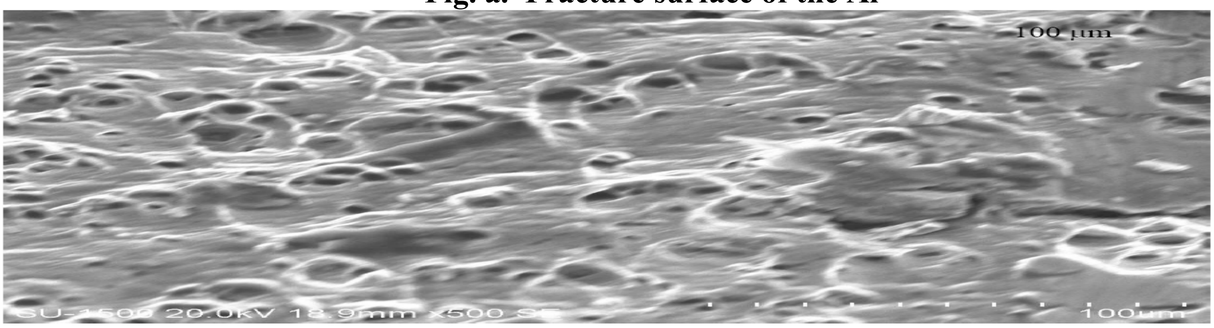

Fig. b. Fracture surface of the Al/5% TiO_2

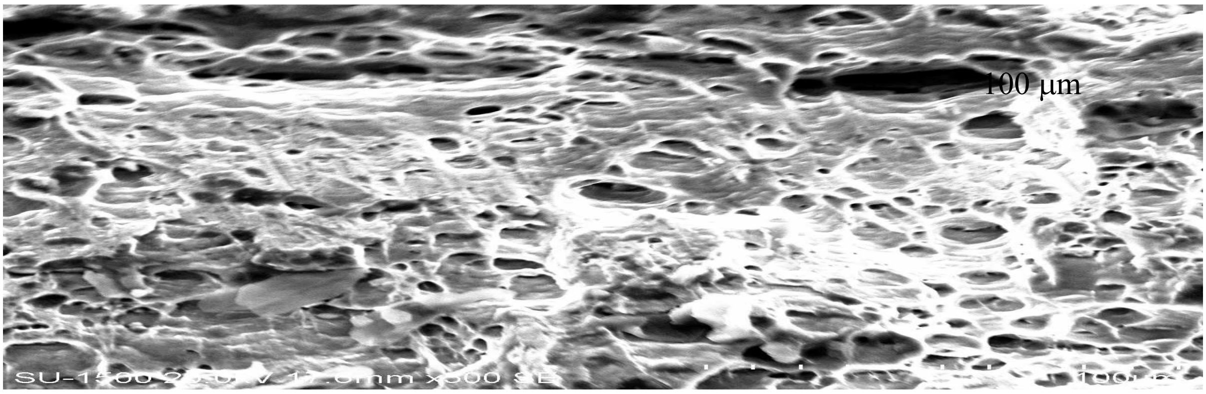

Fig. c. Fracture surface of the Al/ 10% TiO_2

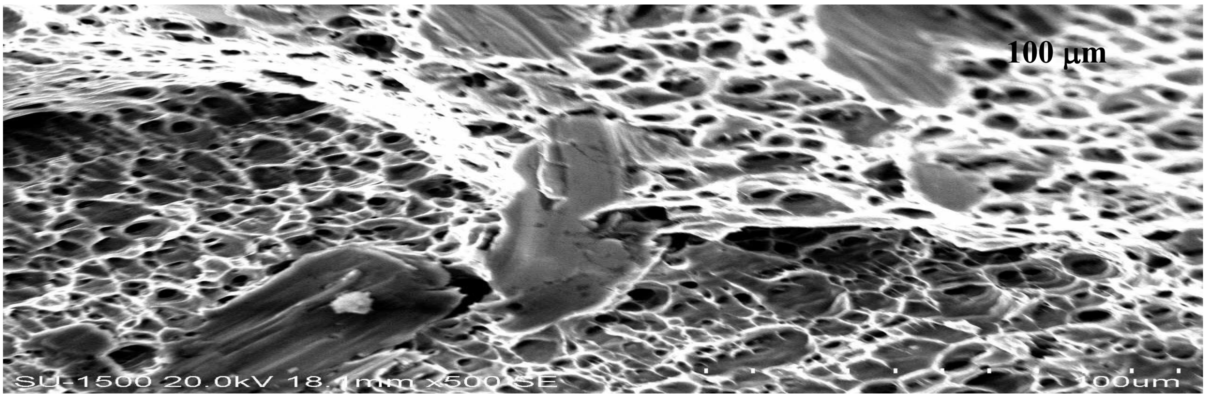

Fig. d Fracture surface of the Al/15%

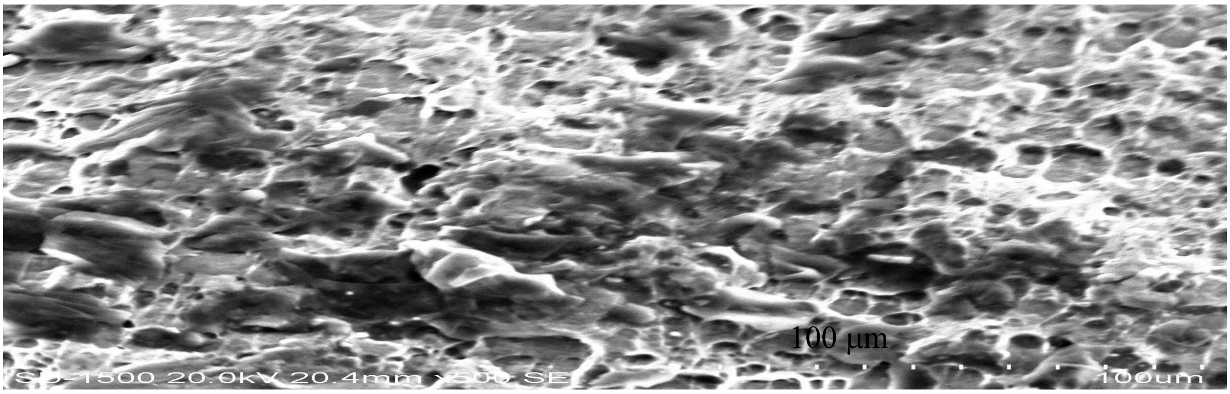

Fig. e. Fracture surface of the Al/20% TiO_2 MMCs

4. CONCLUSIONS

The mechanical properties of the cast Al 6061 alloy/ TiO_2 particulate composites are significantly altered by varying the amount of TiO_2. It was found that increasing the TiO_2 content within the Al alloy matrix results in significant increases in the UTS, hardness, torsional strength and impact strength but a decrease in the ductility. A compromise is necessary when deciding how much TiO_2 should be added to the Al alloy matrix and how much should be performed to enhance the UTS, hardness, torsional strength and impact strength of the composite without sacrificing too much of its ductility. The fracture was ductile with dimple surface showing particles de-bonding, and particle cracking. With fractography, the failure of the composites was shown to consist of transgranular fracture of the TiO_2 reinforcement and ductile rupture of the Al6061 alloy matrix.

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