Investigation of Mechanical and Tribological Properties of Aluminum Composite Reinforced by Boron Carbide, Silicon Carbide and Carbon Nanotubes

Sunil Kumar Tiwari[1], Harsh Sharma[2], KM Deepmala[3], Akula Umamaheswararao[4]

[1]Assistant Professor, department of Mechanical engineering, Dev Bhoomi Group of Institutions, Dehradun, 248007, India

[2]Assistant Professor, department of Mechanical engineering, Dev Bhoomi Group of Institutions, Dehradun, 248007, India

[4]Assistant Professor, department of Mechanical engineering, Dev Bhoomi Group of Institutions, Dehradun, 248007, India

[3]Research Scholar, Department of Mechanical Engineering West Godavari, Andhra Pradesh, 534111, India

---

Abstract - *In this study, hybrid Aluminum alloy (Al-7075) composites have been fabricated after reinforcing Al matrix with boron carbide (B_4C), Silicon carbide (SiC), and multiwall carbon nanotubes (MWCNT) through stir casting process. The reinforcements have been used in different ratios by their weight percent. Three samples of the composite have been prepared as Al7075-0wt% reinforcements, Al7075-2.5wt%B_4C+2.5wt%SiC, and Al70752.5wt%B_4C+2.5wt%Sic+ 0.1wt%MWCNT. Samples have been characterized with hardness test, tension test, and wear resistance test. The results indicate that, the tensile strength and the hardness of the material have increased after reinforcing with B_4C and SiC at the same time while the composite became brittle. Reinforcing with B_4C, SiC in second case with additional 0.1wt%MWCNT has reported further increase in the tensile strength, but the ductility of the composite is increased as compared to base material (Al7075-0wt%reinforcements) and Al7075-2.5wt%B_4C+2.5wt%SiC composite. The wear resistance of the composite has significantly increased in both the cases of reinforcement and was best in Al7075-2.5wt%B_4C+2.5wt%Sic+0.1wt%MWCNT composite.*

Key Words*: *Metal matrix composite, Stir casting, Reinforcement, Optical microscope, tensile strength

1. INTRODUCTION

Aluminum composite are the best replacement of Aluminum alloys and most of the steel in automobile and aerospace industries because of their high strength to weight ratio, good wear resistance, specific modulus [8] and durability. Different reinforcements and different methods have been used by researchers for fabrication of hybrid Al composites. Seeing in condition of machinability [2] and high strength, researchers have also moved toward the fabrication of hybrid aluminum Nano composites through powder metallurgy, equal channel angular pressing, friction stir processing, casting and many more processes. But they have comforted the common problem of non-homogeneous distribution of reinforcement while fabricating Nano Al composites and the challenge of mass production in case of fabricating hybrid micro Al composites. In this work, we have fabricated the composite using stir casting method keeping in mind the case of mass production. The matrix material used is Aluminum alloy 7075-t6 and the reinforcing materials are B_4C (40~50μm), SiC (40~50μm), and MWCNTs (10~12nm diameter and 4~8μm length). B_4C has higher thermal and chemical stability along with good young's modulus of and Vickers hardness of 38GPa. For fabrication of the composite, we have gone through mechanical stir casting process. Matrix material was melt in crucible of graphite in muffle furnace and was stirred by four-blade stirrer of graphite for a particular time. The molten metal was then solidified in a mold of graphite.

2. EXPERIMENTAL DETAILS

In this section, we have shown the properties and composition of the base materials taken for the fabrication of the composite along with the testing of the composite thus fabricated.

2.1 Details of matrix and reinforcing materials

The matrix material used for this investigation was 100% ultrasonically tested Al-7075-t6 billets. The chemical-composition and properties of the material has been shown in table 1 and table 2 respectively. The materials used for reinforcement were B_4C, SiC and multiwall carbon nanotubes. Particle size of both B_4C and SiC was 40~50µm, while the diameter and length of purity >90% MWCNTs were 10~12nm and 4~8µm respectively supplied by Nano Partech, Chandigarh.

Table-1: Chemical composition of Al-7075-t6 by weight percent

Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Zr
0.4	0.5	1.2-2.0	0.3	2.1-2.9	5.1-6.1	0.2	0.18-0.28	0.05

Table-2: Mechanical properties of Al-7075-t6

Tensile strength	Yield strength	Elongation
550.00 MPa	440.00 MPa	5%

2.2 Details of Composite preparation

The fabrication method opted for hybrid composites was mechanical stir casting. The matrix material (Al-7075-t6) was melt in muffle furnace [8]. Three samples of the casting were prepared as Al7075-0wt% reinforcements, Al7075-2.5wt%B_4C+2.5wt%S_iC, and Al7075-2.5wt%B_4C+2.5wt%S_iC+0.1wt%MWCNT. In first case, B_4C and S_iC particles were preheated at the temperature of 500ºC for 60 minutes and then were poured in the vortex thus formed as a result of stirring of the molten Aluminum for 3 minutes at 500 rpm. Stirring time was fixed for 8 minutes at speed of 550 rpm after pouring the reinforcements. In second case, same approach was opted with additional stirring for 5 minutes when MWCNTs were mixed after continuous stirring of the molten material for 8 minutes with B_4C and S_iC [1]. Finally, Al-7075-0wt% reinforcement was prepared with same fabrication parameters with stirring time of 8 minutes at speed of 550 rpm. The completely stirred molten materials, in all the above three cases were poured in a mold of graphite at a constant temperature of around 700ºC. Mold of graphite was also preheated at a temperature of 200ºC for 60 minutes.

2.3 Details of testing

For mechanical characterization, we have gone through tensile tests and micro-hardness test (Vickers hardness). For tribological test, we have gone through wear resistance test. The cast samples were initially machined and then prepared according to ASTM-E8 sub size standard for the tensile tests and ASTM-G99 for wear resistance test. Figure 1 and figure 2 show the dimensions of the sample for tensile test and wear resistance test respectively. The prepared samples were subjected to ASTMD-638 universal testing machine having maximum load capacity 100kN. The constant strain rate of 50.00 mm/min was maintained in the environmental condition of 23 deg. C RH 54% at CIPET ASR. Micro-hardness test was performed on Vickers hardness testing machine at a load of 100kgf and dwell time of 12 sec at DAV College of Engineering and Technology, Jalandhar. Figure 3 shows the shape of sample prepared for micro hardness test. Wear resistance test was performed on pin on disc tribometer with parameters, load 1kgf, speed 300 rpm, track diameter 70mm and running time 2 minutes. For microstructural investigations, samples were prepared with dimension (1x1x1) cm. Samples were initially polished using fine grain size file and then with emery papers (sand papers) followed by diamond polishing. Grades of emery papers used were 180, 320, 400, 500, 600, 800, 1000, 1200, 1500, 2000, 2500 and diamond paste used for mirror polishing had grain size of 0.1µm-0.5µm. Prepared samples were etched with Keller's reagent Tiwari et al., (2019).

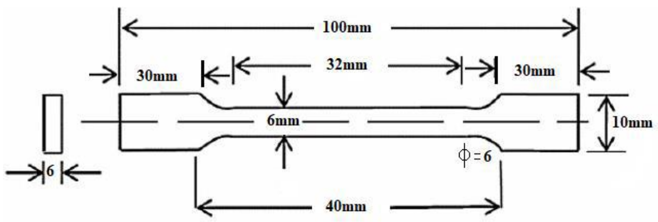

Figure-1: Dimensions of tensile specimen

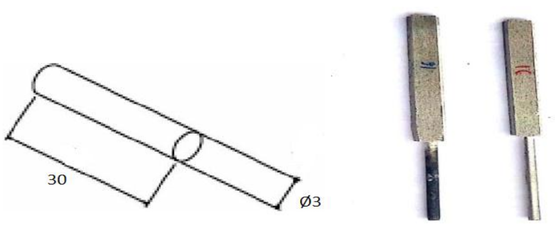

Figure-2: Samples for wear test

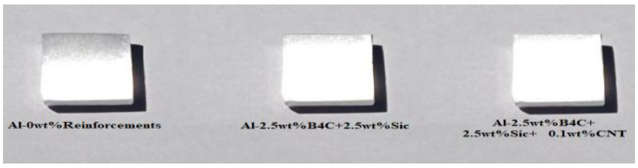

Figure-3: Samples of micro hardness test

3. RESULTS AND DISCUSSION

In this section, we have discussed the reasons behind the results that we have achieved through testing.

3.1 Micro-hardness test

Micro-hardness test was performed on Vickers hardness testing machine at room temperature. The dimension of the test specimen was (1x1x1) cm. Twelve hardness readings were taken on the test specimen, six on each side along its height (up and down face). Readings were taken from different locations (spots) on each face so as to confirm the effect of hardness as a result of homogeneous distribution of reinforcements. Finally, the average value of all the readings for each sample was considered as the final hardness of that composite as shown in table 3. With mixing (2.5wt%B4C + 2.5wt%SiC), hardness of the composite was increased by 16.21 percent while, with additional mixing of MWCNTs, hardness was increased by 29.72 percent as compared to base material as shown in chart 1. This is because of the high hardness of the reinforcements (B_4C and S_iC) [5].

Table-3: Micro-hardness values of samples/composites

Specimen	Al-0wt% reinforcement	Al-2.5wt% B_4C+S_iC	Al-2.5wt% B_4C+S_iC+0.1 wt%MWCNTs
Hardness (Hv)	74	86	96

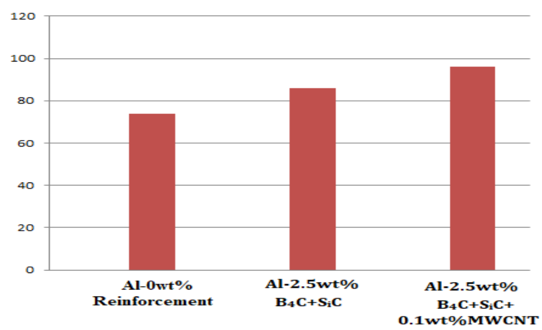

Chart-1: Micro hardness of composites

3.2 Tensile test

Tensile test was performed on ASTMD-638 universal testing machine with plate type test sample specification (total length 100mm, gauge length 25mm, width and thickness 6mm) according to ASTM-E8 sub-size as shown in figure 1. The experiment was performed at room temperature (~23ºC RH 54%). The ductility and brittleness of the samples/composites was measured in terms of their percentage elongation. After successful testing, it was found that the tensile strength of both the composites was increased as compared to base material. Tensile strength of the Al billets (heat treated Al-7075t6) specimen was initially 550MPa, which was decreased when cast and found to have 102 MPa because of the processing conditions which was completely different from the ideal working conditions [5]. With addition of 2.5wt%B4C+2.5wt%SiC in Al matrix, the tensile strength of the composite was increased by 18.75 percent as compared to base material (Al-0wt%reinforcement) while the material became brittle as a result of presence of Carbon in the sample as shown in chart 2. Further with addition of 2.5wt%B4C+2.5wt%SiC+ 0.1wt%CNT in Al matrix, the tensile strength of the composite was increased by 25.42 percent while the material became ductile as compared to base material. Table 4 shows the values of tensile test of the composite. Ductility in the composite has been increased because of dislocation pileups [5].

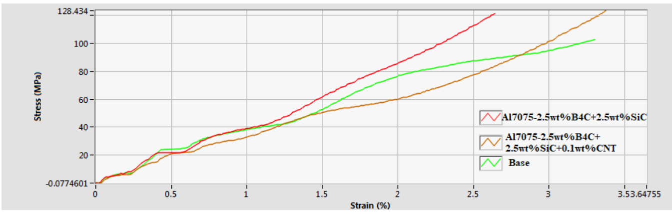

Chart-2: Graph generated through UTM

Table-4: Testing details of tensile test

Specimen	Tensile strength (MPa)	Young's modulus	Percentage Elongation
Al-0wt% reinforcement	102.4	4040.6	3.322
Al-2.5wt% B_4C+S_iC	121.6	6044.52	2.66
Al-2.5wt% B_4C+S_iC+0.1 wt%MWCNTs	128.434	7688.34	3.42

Young's modulus of the composites was increased because of the high young's modulus of ceramic particles (B_4C and S_iC) and carbon nanotubes.

3.3 Wear resistance test

As result of wear resistant testing, it was found that the rate of wear was more in Al-0wt% reinforcement sample because of the weak bond formed between Al particles. Wear rate was decreased as the pure Al-7075 was reinforced and it was found best in the case of Al-2.5wt%B_4C+S_iC+0.1wt% MWCNTs. Reinforcement particles used were behaving as load supporting element between rotating disc and composite pin. The strong bond formed between reinforcement particles and matrix material and homogeneous mixing of reinforcement in Al matrix (shown in figure 4 a, b, c, d) was responsible for less wear of the particle Sharma et al., (2019). Chart 3 shows the values of wear rate of composites

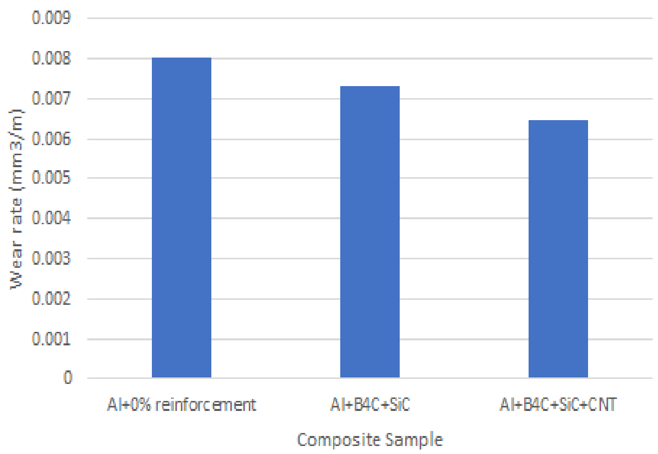

Chart-3: Wear rate of the composite

3.4 Microstructural Investigation

For microstructural investigations, we have used optical microscope for testing the samples in Lovely Professional University. The maximum magnification was 1000x. Figure 4a, 4b, 4c, 4d shows the micrographs of the samples thus tested on microscope. As MWCNTs were of Nano size, we were not able to see them through optical microscope. But continuous increase in the tensile strength and hardness of the composite make it confirm that MWCNTs were present in the sample.

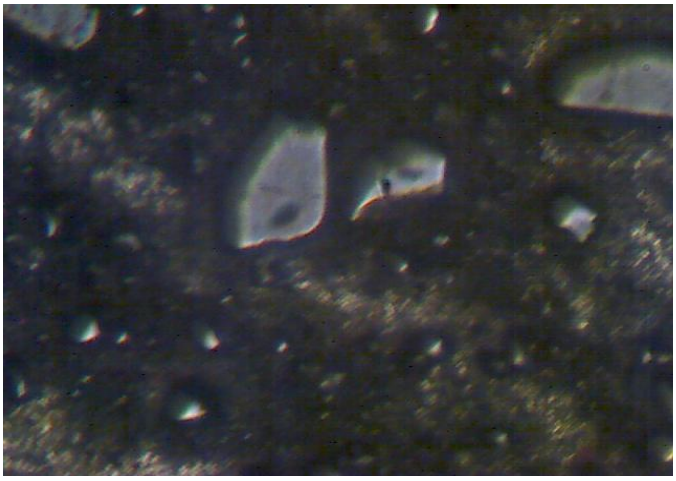

Figure-4a: Different grain size of B_4C and S_iC particles

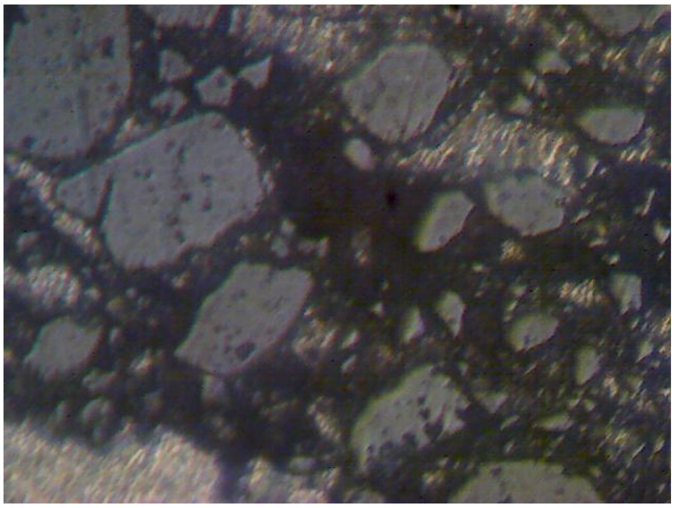

Figure-4b: Homogeneous mixing of B_4C and S_iC particles (1000x)

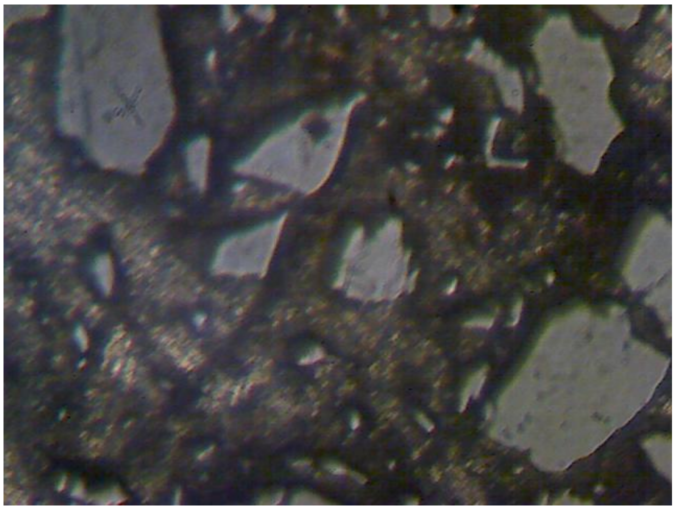

Figure-4c: Homogeneous mixing of B_4C and S_iC particles (500x)

Figure-4d: Polished surface of composite

These figures make it confirm that B_4C and S_iC particles were homogeneously distributed in Al matrix. The homogeneous mixing of the reinforcements is responsible for increasing the tensile strength of the composite. As B_4C and S_iC are very hard in nature, we can say that their properties of hardness have been transferred to the Al matrix increasing the overall hardness of the composites. Moreover presence of reinforcements has led to the generation of cracks in the composite

4. CONCLUSION

As a result of reinforcing Al matrix with ceramic particles (B_4C and S_iC), the tensile strength and hardness of the composite were increased while wear rate was decreased. Further reinforcing the Al matrix with additional MWCNTs along with (B_4C and S_iC), tensile strength and hardness was further increased while wear rate was decreased.

REFERENCES

[1] S. Sundara rajan and A. Chennakesava Reddy "Assessment of Tensile Behabiour of Boron carbide/AA2024 Alloy Metal Matrix Composites" 14-15 march 1997.

[2] S. Rama Rao, G. Padmanabhan "Fabrication and mechanical properties of aluminium-boron carbide composite" ISSN 2249-9679, 2012; 2(3):15-18

[3] Gowri Shankar M.C, Jayashree P.K, Raviraj Shetty, Achutha Kini and Sharma S.S "Individual and Combined Effect of Reinforcements on Stir Cast Aluminium Metal Matrix Composites-A Review" ISSN 2277-4106. Vol 3, No 3 (August 2013)

[4] Rajkumar, K, Charles, JMA, Kumar, KV, Praveen, JJC, Padmanathan, A. Mechanical and Machining characteristics of Al/B_4C metal matrix composite. Proceedings of the national conference on emerging trends in mechanical engineering, 2013

[5] Sankara Narayanan. S, Manickavasaham. G, Moorthy. S e- ISSN: 2278-1684, p-ISSN: 2320-334x, volume12, issue 4 ver, II (July-Aug 2015), PP30-40

[6] V.C. Uvaraja, N. Natarajan "Tribological Characterization of Stir-Cast Hybrid Composite Aluminium 6061 Reinforced with SiC and B_4C Particulates" ISSN 1450-216X Vol. 76 No. 4 (2012), pp. 539-552.

[7] A. Chennakesava Reddy "Role of Porosity and clustering on Performance of AA1100/Boron Carbide particle-Reinforced Metal Matrix composite" 8-9 june 2007, p 122-127. Defines clustering od b4c in al matrix

[8] Tiwari, S. K., Midathada, A., Sharma, S., & Ravella, U. K. (2018). Study of Fabrication Processes and Properties of Al-CNT Composites Reinforced by Carbon Nano tubes-A Review. *Materials Today: Proceedings*, *5*(14), 28262-28270.

[9] Singh, H., Singh, J. I. P., Singh, S., Dhawan, V., & Tiwari, S. K. (2018). A Brief Review of Jute Fibre and Its Composites. *Materials Today: Proceedings*, *5*(14), 28427-28437.

[10] Sharma, H., Kumar, K., Kumar, R., & Gulati, P. (2018). A Study of Vibration and Wear Resistance of Friction Stir Processed Metal Matrix Composite. *Materials Today: Proceedings*, *5*(14), 28354-28363.