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Microstructure-based Finite Element Analysis of Composites

G. Mallesh[1]*, H. S. Manjunatha[2] and R. Pavankumar[2]

[1]Department of Mechanical Engineering, Sri Jayachamarajendra College of Engineering, Mysuru – 570006, Karnataka, India; mallesh.sjce@gmail.com

[2]Department of Mechanical Engineering, JSS Science and Technology University, Mysuru – 570006, Karnataka, India

Abstract

Synthesized Al6061-TiB_2 composite material by varying wt.% of TiB_2 through In-situ process by adding 1.5% Mg to evaluate mechanical properties. It is noticed that the tensile, impact strength and hardness of the composites increases with increase in wt.% of TiB_2 with reduces in ductility. Microstructure analyses were conducted through SEM to observe the distribution, presence and formation TiB_2 particles and found that particles were homogeneously distributed and EDX analysis confirms the presence of TiB_2. Later, SEM images are converted into 2-D models using Matlab, FE analysis was conducted using ANSYS software to evaluate the stress at the matrix and reinforcement interface. The information revealed from this study is useful in design and selection of Al 6061-TiB_2 AMCs for various applications.

Keywords: *Al 6061, EDX, In-situ, Microstructure Based FEA, SEM, TiB_2, XRD*

1.0 Introduction

Evolution of advanced materials towards the end of 20th and early 21st century is quite admirable. This steady development in advanced materials can be directly associated with the necessity and demand in the modern industrial sector. Nowadays, industries demand flawless material which produces efficient product that matches the demands of the destination. One of those advanced materials is composite materials. Composite materials in this modern world have reached every other corner of the industrial domain, because of its impressive physical, mechanical and chemical properties[1]. Matrix material is the major constituent in the composite and reinforcements are the additives, which are added to improve the characteristics of an end product. Metal Matrix Composites (MMC) find their applications, where there is a high demand of Temperature resistance, higher transverse stiffness, strength and better electrical and thermal conductivities[2].

Out of all these Al stands out as an exclusive material with properties like, Higher specific strength, stiffness, High temperature creep resistance, better environmental damage tolerance, higher toughness and Ductility etc. Hence in this experiment Grade-6 of Aluminium i.e., Al 6061 chosen as a matrix material.

To enhance the properties of the matrix, type of reinforcement added plays an important role. Different reinforcements embed different properties into the matrix. To fabricate a material of desired property, there is a necessity of selecting an appropriate reinforcement. Some of the reinforcements available in the market are Alumina (Al_2O_3), Silicon carbide, Boron Carbide (B_4C), Titanium Di-Boride (TiB_2), Titanium Carbide[3] (TiC) etc. Out of which TiB_2 shows better properties in comparison with TiC and B_4C. TiB_2 possess properties

*Author for correspondence

like High hardness at extreme temperature, better elastic modulus, higher toughness, higher compressive strength and excellent temperature resistance[4]. Hence from the literature and present study, it can be said that, inclusion of TiB_2 into the matrix improves the characteristics of the composite eminently[5]. *In-Situ* process along with stir casting technique is used to develop Al-TiB_2-1.5 % Mg composite system, as this fabrication process is generally acknowledged as a promising way to manufacture metal matrix composites in large volumes economically. Fabricated composites are further subjected for characterization, in this experiment Tensile, and Hardness properties of composites are evaluated as per ASTM Standards. In addition to that, FEM Analyses is also conducted to verify the experimental and analytical results. Surface morphology of the specimens of different weight fractions are also studied to observe uniform distribution of the reinforcement in the matrix. FEA Microstructure study is also performed by mapping the reinforcement particles, using ANSYS and Matlab Software to analyse the distribution and behaviour of the composite.

2.0 Literature Review

Simulation of stir casting process was conducted by Naher[6] for varying vortex height, settling times and speed on stirrer geometry using batch composite casting technique. Particles dispersion and flow patterns was studied by varying the wt. % of SiC and found that castings produced exhibits higher strength and particles are uniformly distributed without any defects. Fabrication and characterization of Al-SiC composite were performed by Manoj Singla[7]. Mechanical properties were enhanced with increase in wt. % of reinforcement. Veeresh Kumar[8] conducted tensile test on SiC (150 μm) reinforced composite by stir casting method to determine the ultimate tensile strength and hardness, as the SiC content increased from 0 to 6 wt. % ultimate tensile strength and hardness increase intern the ductility reduced to 96%. El-Sabbagh[9] fabricated Al6061and Al6082 reinforced SiC alloys to study the effect of rolling on distribution of reinforcement particles in the composite. El-Sabbagh[10] Al 6061 and Al 7108 reinforced with different volume fractions SiCp were fabricated to study the effect of rolling and heat treatment and observed that Al 7108 alloy exhibit improved UTS and Young's modulus. FeiXie[11] analysed the characteristics of Al-6-Cu-0.2Mg-1Mn alloy reinforced with different weight fractions of TiB_2 developed by *in-situ* technique. XRD study revealed that TiB_2 particles formation without the presence of any other inter-metallic compounds. Mechanical properties of Al6063 reinforced with different weight percentage of TiB_2 fabricated using stir casting technique were analysed by Selvaganesan[12], Zhong[13] investigated the microstructure and mechanical properties of Al7055 reinforced with TiB_2 particles synthesized by direct magneto chemistry melt reaction. The tensile strength of the composite increased with increase in the content of the reinforcement because it acts as barriers to the move dislocations under the load. Zhang Peng[14] prepared Al-6061 reinforced with SiCp by powder metallurgy process. Distribution of particles during deformation, effect of shape and size were analysed using finite element method. It is evident from the literature that many researchers are developed and investigated mechanical and tribological properties of Al based composites for many engineering applications using experimental technique. In the present research work attempts are made to evaluate various properties of Al-TiB_2 composite using finite element software ANSYS.

3.0 Materials and Methods

Al6061 is an alloy with outstanding mechanical properties such as higher corrosive resistance, and higher stiffness etc. Chemical composition of Al6061 is shown in Table 1. Various reinforcements are added to the composites to enhance strength, stiffness, and toughness, mechanical and tribological properties. Further, use of reinforcements

Table 1. Chemical Composition of Al

Elements	Mg	Si	Ti	V	Mn	Cu	Fe	Al
Wt.%	1.08	0.63	0.02	0.01	0.52	0.32	0.17	Remainder

Table 2. Weights of Salts

Sl. No	Weight of Salts		TiB_2 (wt. %)
	K_2TiF_6(g)	KBF_4 (g)	
1.	10.36	10.87	3%
2.	20.72	21.74	6%
3.	31.08	32.61	9%
4.	41.45	43.48	12%

in the composite helps to improve; secondary properties like increased heat resistance, corrosion resistance and enhanced rigidity[16]. In the present work, TiB_2 is used as reinforcement along with 1.5 % Mg to produce lightweight high strength composite[19].

In the present research, In-situ process was used to fabricate the Al6061-TiB_2 composite by adding KBF_4 and K_2TiF_6 salts. The weight of salts added to obtain different wt.% of TiB_2 (3, 6, 9, and 12%) was tabulated in Table 2.

Al 6061 rods were placed in an electrical furnace, weighted inorganic salts are added at uniform feed rate of 1.5 g/sec by maintain melt temperature at 850°C, stir speed of 300 rpm at regular intervals for about 45 minutes. 1.5 wt. % of Mg is added in a controlled environment and stirring was continued further to disperse Mg particles

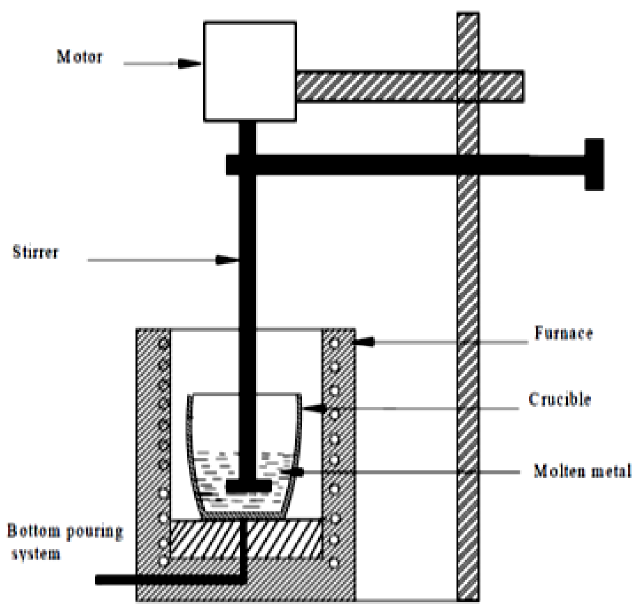


Figure 1. Stir casting process.

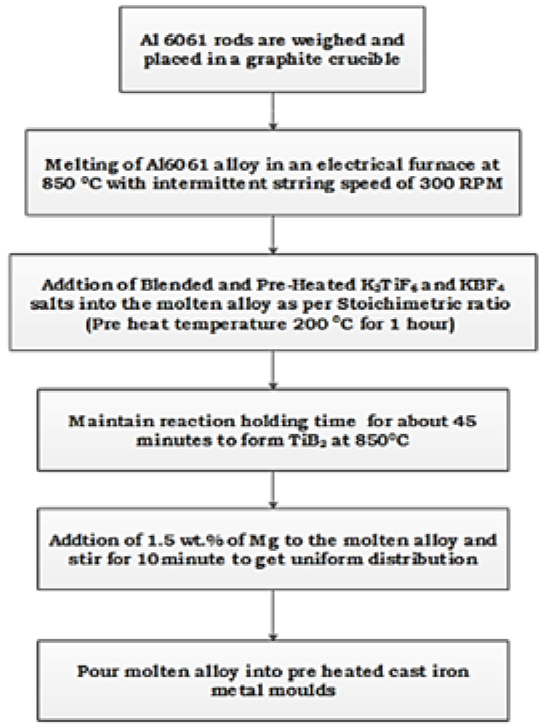


Figure 2. Process chart.

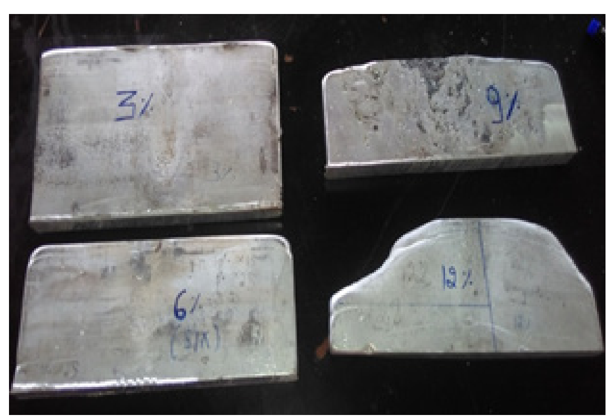


Figure 3. Al6061-TiB_2 castings.

uniformly in the melt. TiB_2 is formed from K_2TiF_6 and KBF_4 salts through the *in-situ* process.

4.0 Testing Methods

4.1 Energy Dispersive X-Ray (EDX) and XRD Analysis

EDX analyses were conducted using scanning electron microscope to know the presence of different elements in the castings produced and it is noticed form the Figure 4 that the particles comprising of TiB_2 and magnesium was confirmed. Further, it is noticed form the Diffraction peaks of TiB_2 particles that intensity of the peaks increases as TiB_2 content is increased[3]. It is also observed that the addition of Mg and formation of TiB_2 shows that Aluminum peaks are slightly shifted to higher 2θ compared to that of pure aluminum alloy.

4.2 Mechanical Properties of Al6061/TiB_2 Composites

Mechanical properties of the composites were evaluated as per ASTM E23, ASTM E8M-13a and ASTM E-384 respectively. Specimens used for the same is shown in Figure 6.

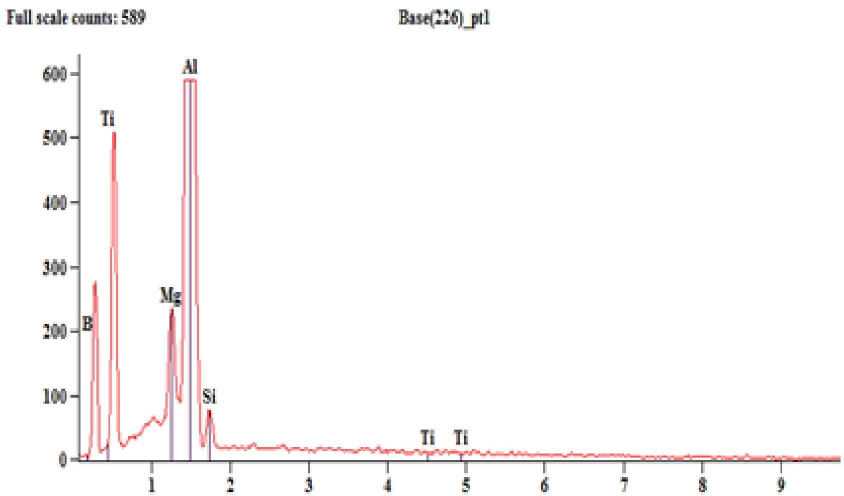


Figure 4. EDS spectrum Al6061+ 6% of TiB_2.

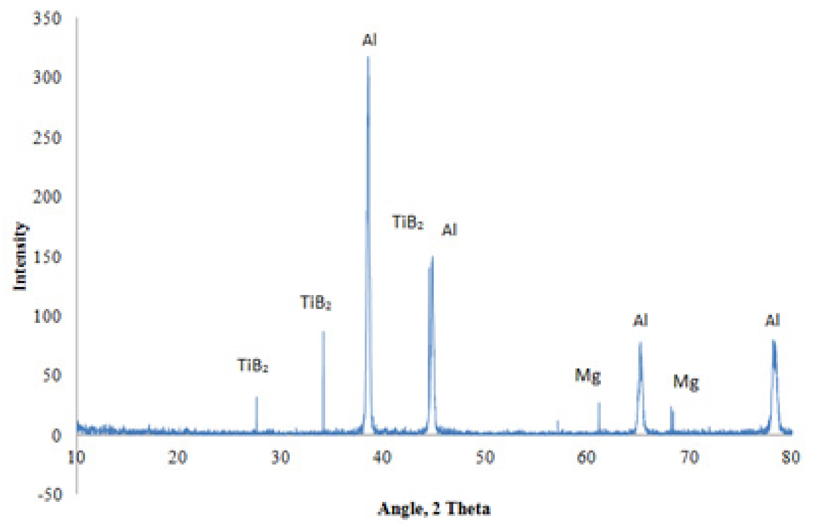
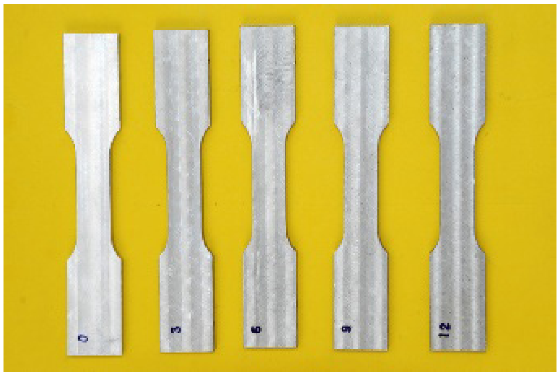
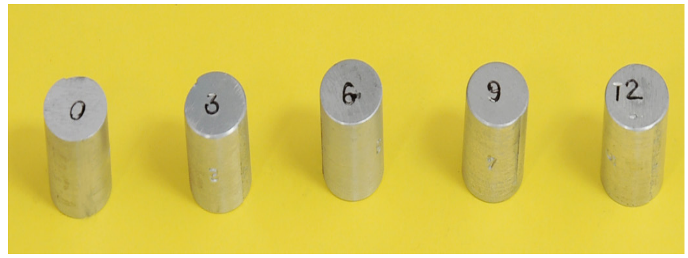


Figure 5. XRD pattern of Al6061+ 6% of TiB_2.



ASTM E8M-13a



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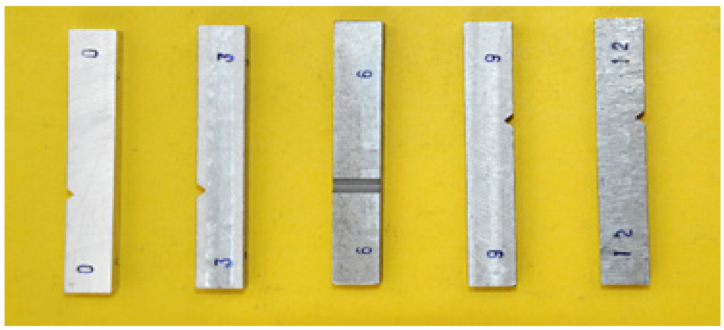


ASTM E-384

Figure 6. Test specimens.

4.3 Evaluation of Tensile Strength by FEA

Tensile strength of Al6061-TiB_2 composites was conducted using FEA software ANSYS. Initially, geometric details of tension test are created using preprocess, the discretization process is done by choice of element type and number of elements and the type analysis, the accuracy of the result is determined based on the type of problem and the material being studied. The use of 8-noded quadrilateral element in this case is appropriate for modeling the geometry and capturing the behavior of the composite material. To minimize the analysis time, problem is assumed as axisymmetric problem. To compare the experimental and FEA results, load at the fracture is used to and is converted into to a pressure of 87.53 N/mm^2 as shown in Figure 7. Similar analyses were carried out for different weight fractions of TiB_2.

4.4 Micro Structure based Finite Element Analysis

SEM image of Al6061-TiB_2 composites are converted into 2-D FE models and are converted vector format using Matlab 2015 Ra software. The edges of reinforced particles are detected using canny edge detector, the vector file is transformed into CAD file with the help of NX 8.0 modeling software to create the surface via DXF file format. In NX software, the particle edges are drafted and the unnecessary asperities present are removed. Further, *.DXF file is imported into ANSYS

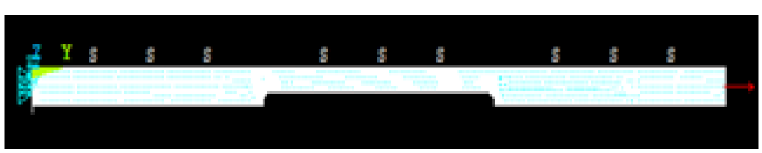
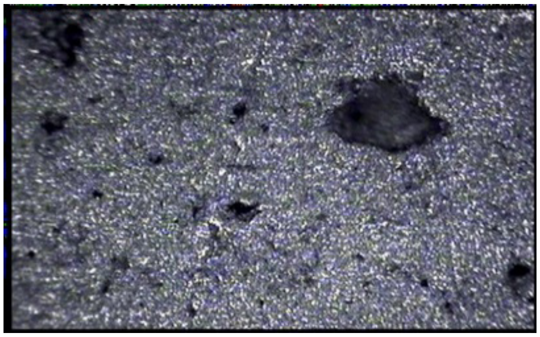
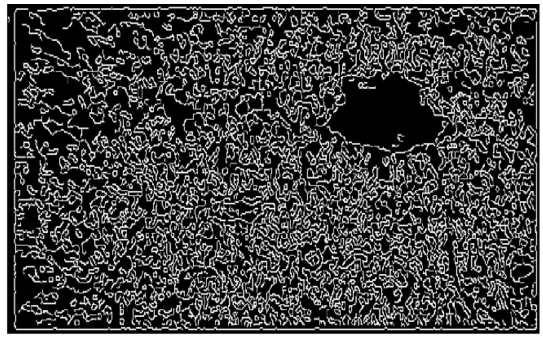


Figure 7. ASTM Test specimen with boundary conditions.

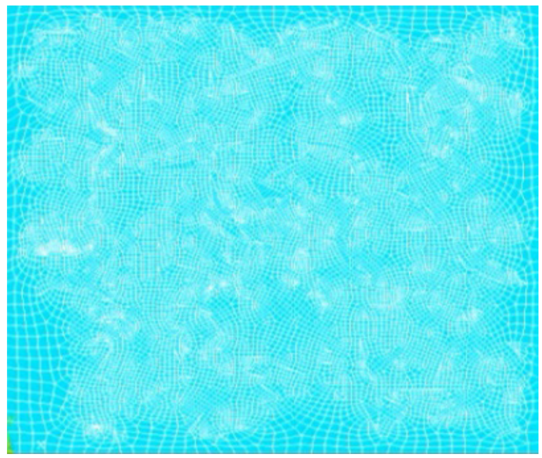


SEM image of Al6061-TiB_2

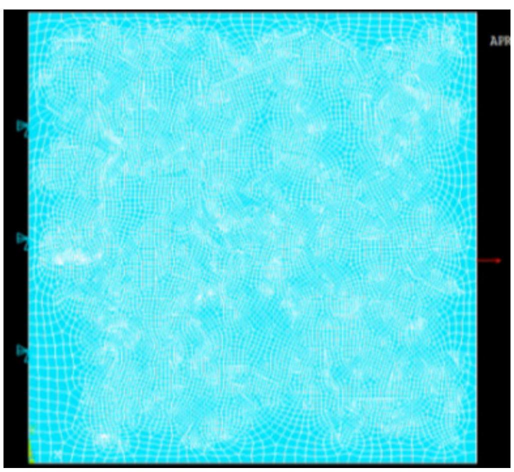


Vector form of SEM image

2-D drawing of microstructure



FEA model



Load and displacement boundary conditions for FEA

Figure 8. FE stages for microstructure analyses.

14.0 to conduct FEA analysis. Microstructure based FEA model is generated using ANSYS software, has three components Al6061, magnesium and TiB_2. The areas are overlapped and meshed suitably and necessary and boundary conditions are enforced on the model shown in Figure 8.

5.0 Results and Discussions

5.1 Mechanical Properties of Al6061/TiB_2 Composites

The tensile tests were conducted as per ASTM E8M-13a to determine the tensile strength and percentage elongation using computerized universal testing machine. Vickers micro hardness test was carried out with a load of 100 kg for a period of 10 sec and test was conducted at five different positions to evade the possibility of indenter resting on the hard reinforcement particles. Impact tests were conducted as per the standard to evaluate the impact strength of Al6061-TiB_2 composites. The addition of TiB_2 particles increases the tensile strength of the composite as shown in Figure 9. This enhancement in tensile strength is attributed to increased percentage of TiB_2 particles in the Al6061 alloy and interaction between dislocations and TiB_2 particles when the composites bear a load[4]. The effect of the distribution of the TiB_2 particle on the elasticity is endorsed to the plastic deformation of the matrix[21]. Similar trends were observed as the percentage of reinforcement increases with decrease in the percentage of elongation because addition of TiB_2 leads to formation

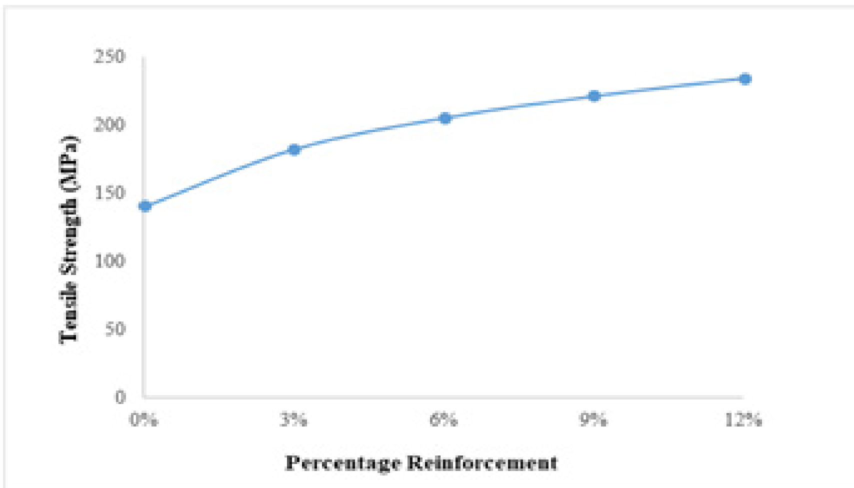


Figure 9. Tensile strength.

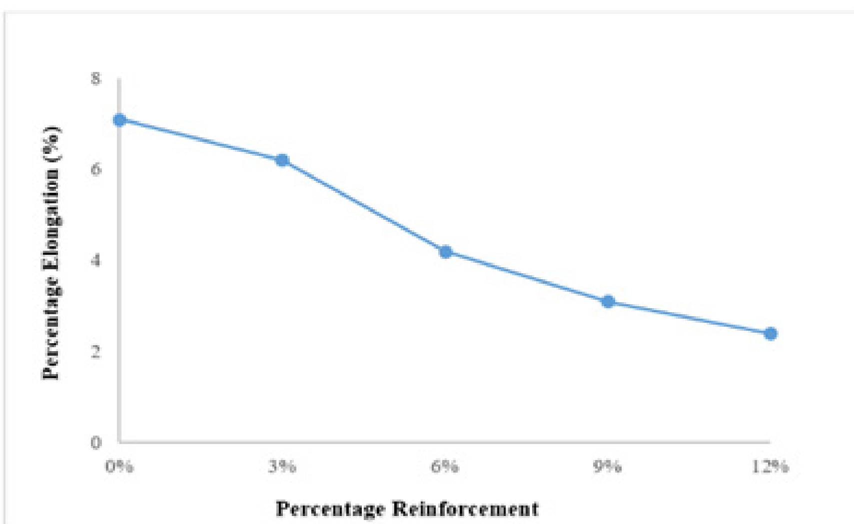


Figure 10. Percentage elongation.

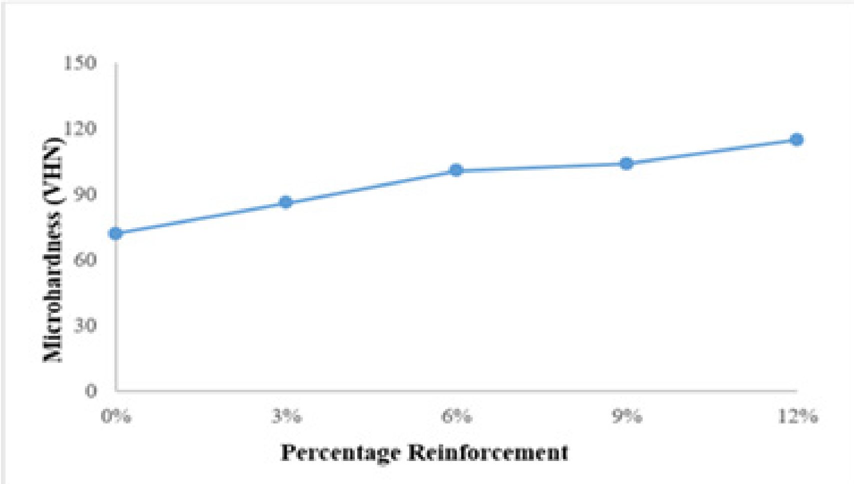


Figure 11. Micro hardness of Al6061/ TiB_2 composites.

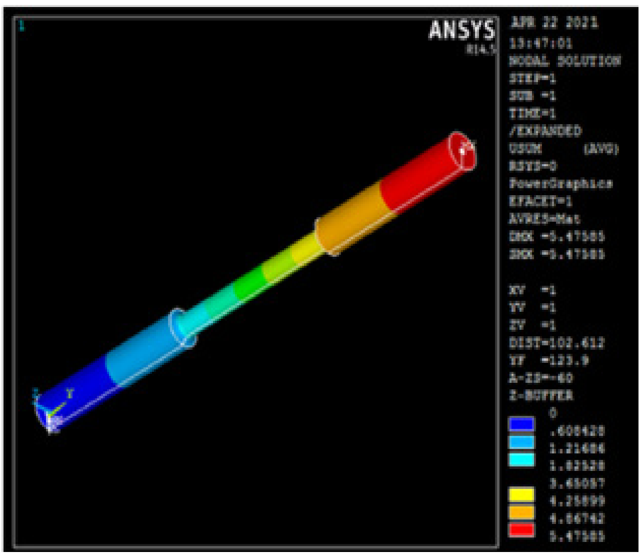


Figure 12. Percentage elongation.

of brittle phase and composite becomes hard and load carrying capacity of the system were increased as shown in Figure 10. The ductility of the AMCs reduces with the increases in weight percentage of TiB_2[14]. Addition of TiB_2 reinforcement in the Al6061 matrix alloy exhibits substantial improvements in the hardness as shown in Figure 11. TiB_2 being a hard reinforcement which is incorporated into a soft ductile matrix, hardness of the matrix material is enhanced, thereby enhancing its resistance to deformation[22].

As per the section 4.3 FEA was conducted to determine the percentage elongation of Al 6061-TiB_2 composites as shown in Figure 12 and compared with the experimental results as shown in Table 3.

It is evident that accuracy of the results obtained from experiments is influenced by operator's expertise. With the advent of computers, the degree of human errors has

Table 3. Percentage elongation between experimental and FEM results

% of Reinforcement	Experimental Results	FEM Results	Error
Al6061 + 1.5% Mg	7.1	6.83	0.27
Al6061 + 1.5% Mg + 3% TiB_2	6.2	5.88	0.32
Al6061 + 1.5% Mg + 6% TiB_2	4.2	3.94	0.26
Al6061 + 1.5% Mg + 9% TiB_2	3.1	3.01	0.09
Al6061 + 1.5% Mg + 12% TiB_2	2.4	2.23	0.17

reduced. The simplicity and power of analytical tools such as FEM has overshadowed difficulties in conducting experiments. Henceforth, FEA procedure is preferred to evaluate mechanical and tribological properties of the composites.

5.2 Microstructure Analysis

The SEM micrograph for 9 wt.% TiB_2 reinforcement is shown in Figure 13 and observed that has no common casting defects such as slag inclusion, shrinkages or porosity. Homogeneous distribution of TiB_2 particles in the Al6061matrix was seen. It appears that a more uniform distribution of TiB_2 particles with less porosity can be achieved. Beyond 9 wt. % of TiB_2 leads to clustering of particles, which leads to the formation of hard brittle Al_3Ti intermetallic phase. Spherical, hexagonal and cubic shapes were exhibited by TiB_2 particles along with hexagonal, spherical and cubic structure[21,22]

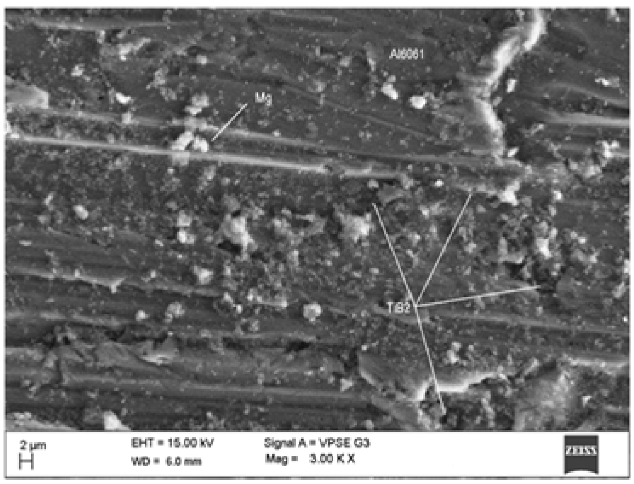
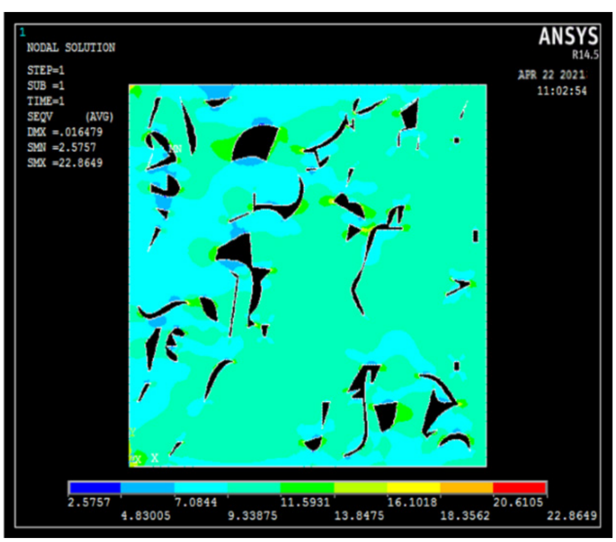


Figure 13. Al6061 + 1.5% Mg + 9%TiB_2.

5.3 Microstructure Studies

FEA of a microstructure was conducted as per the Section 5.2 and experimentally observed Young's modulus and tensile strength are used to evaluate the stress at matrix and reinforcement boundaries. Figure 14 and Figure 15 shows the Von-Mises stress distribution in Al6061+3 wt. % and 12wt. % TiB_2 reinforcement. It is observed from the microstructure that uniform distribution of the reinforcement in a matrix was noticed and maximum stresses were observed in the reinforcement compared to that of matrix because of irregular boundaries of the reinforcement[23].

Table 4 shows the displacement and Von Mises stress for different reinforcements when the models are subjected to a tensile load. It is noticed that maximum deformation was observed in Al6061+1.5% Mg + 12% TiB_2 is 0.0101 mm. Addition of the reinforcement, composite system becomes harder and minimum deformation was noticed[23].



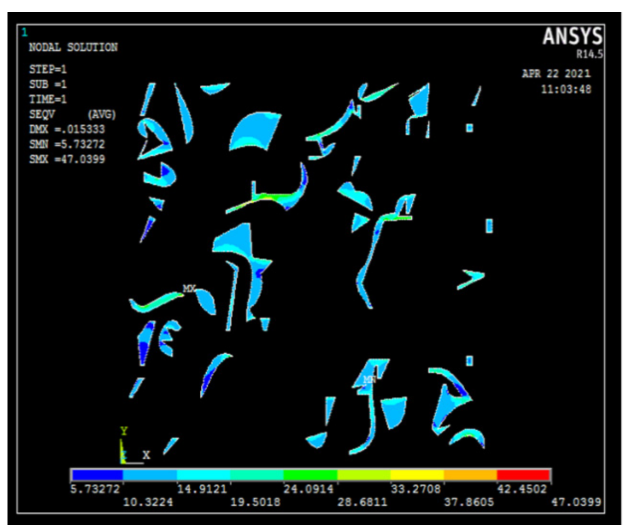


Figure 14. Al6061+1.5% Mg+3%TiB_2.

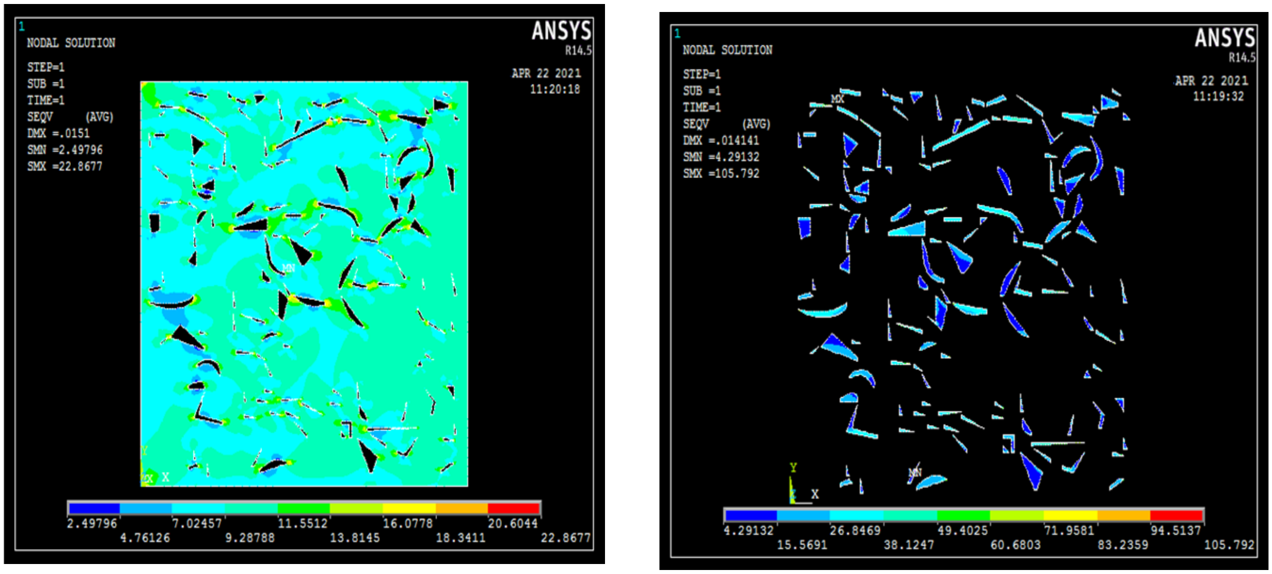


Figure 15. Al6061+1.5% Mg+12%TiB_2.

Table 4. Von-Mises stress and displacement for different reinforcements

Sl. No.	Material	Displacement, mm	Von Mises Stress (MPa)
1	Al6061+1.5% Mg	0.0151	23.7
2	Al6061+1.5% Mg+3%TiB_2	0.0145	22.8
3	Al6061+1.5% Mg+6%TiB_2	0.0137	23.4
4	Al6061+1.5% Mg+9%TiB_2	0.0128	23.6
5	Al6061+1.5% Mg+12%TiB_2	0.0101	22.8

6.0 Conclusion

- Al 6061-TiB_2 composites were synthesized successfully using *in-situ* process using K_2TiF6 and KBF_4 salts. EDS and XRD results confirms the formation of TiB_2.
- Addition of TiB_2 enhances the tensile strength by 20.7%, 30.16%, 33.30% and 37.02% compared with base alloy.
- Hardness of TiB_2 composites were improved by 14.9, 22.6, 23.87 and 30.23% respectively compared to the base alloy.
- FEA is used to evaluate percentage elongation of the composites developed and suggested the use of FEA to evaluate mechanical and tribological properties to reduce the cost of experimentation.
- Microstructure study revealed that reinforcement particles are uniformly distributed in the matrix and casting is free from defects. It is revealed from FEA that reinforcements particles absorb maximum stress in comparison with matrix because of irregular boundaries

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