Synthesis and Characterization of Hybrid Metal Matrix Composites (MMCs) Reinforced With Silicon Carbide (SiC) and Aluminium Oxide (Al_2O_3)

Monika Chandel[1*], Sachin Kaushik[2], Manoj Singh[3]

[*1]M.tech Student: Department of Mechanical Engineering, GRD IMT, Dehradun, Uttarakhand, India
[2,3]Asst.Professor Department of Mechanical Engineering, GRD IMT, Dehradun, Uttarakhand, India
*Corresponding Author : Monika Chandel

Received: 08 February 2022/ Revised: 13 February 2022/ Accepted: 20 February 2022/ Published: 28-02-2022

Abstract— *This work present Metal matrix composites (MMCs) constitute process which improved properties including high specific strength; specific modulus, damping capacity and good wear resistance compared to unreinforced alloys. When analyses were carried out, two reinforcements namely silicon carbide (SiC) and aluminium oxide (Al_2O_3) were used for production of hybrid metal matrix composites. The two reinforcements were ball milled in order produce as single entity of these reinforcements. The reinforcement was varied from 0%, 2%, 4%, and 6% to produce hybrid metal matrix composites. All the composites were produced by stir casting. The mechanical properties of the metal matrix composites were investigated. The microstructure and X ray diffraction study was carried out. Similarly, Vickers hardness test, Tensile strength test, Toughness test were also used to investigate the metal matrix composites. After analyses it was found that the Al_2O_3 and SiC particles were uniformly distributed throughout the metal matrix. The tensile strength and hardness of Al_2O_3 and SiC reinforcement aluminium composites improved with the increase in volume fraction of nanoparticles and toughness decreases with the increasing volume fraction of reinforcement.*

Keywords— ***Metal matrix composites, Nanoparticles, reinforcement, Silicon carbide and aluminium oxide, Vickers hardness, X-ray diffraction.***

I. INTRODUCTION

Aluminium & its alloys offer a extensive range of properties that can be engineered accurately to the demands of specific applications, such as in aerospace, advanced nuclear reactors, surface coating and metal/air batteries, through the choice of alloy, temper condition and fabrication process. By utilizing various combinations of its advantageous properties like strength, lightness, corrosion resistance, recyclability and formability, aluminium is being employed in an ever- increasing number of applications. It is good strength to weight ratio, light weight, low density etc, so having such a wide application it attracts more to researchers, and secondly Aluminium shows excellent improvement in its properties on being reinforced with some material. In the given below literature review emphasis is given on the various Aluminium alloys and their work on the different parameters such as mechanical and metallurgical characterization.

II. MATERIALS & METHODS

2.1 Materials

Aluminium alloy 6101 T6 has been taken as the base material, silicon carbide (SiC) and aluminium oxide (Al_2O_3) as reinforced material.

2.2 Methods

In this metal matrix composites two reinforcements silicon carbide & aluminium oxide used for production of hybrid metal matrix composites. The two reinforcements were ball milled to produce as single entity .The reinforcement was varied from 0%, 2%, 4%, and 6% to produce hybrid metal matrix composites. The composites were produced by stir casting. Then afterword metallurgical and mechanical properties of the metal matrix composites were investigated by the method of microstructure and X ray diffraction .And Similarly for mechanical properties Vickers hardness test, Tensile strength test, Toughness test were also used. It was found that the Al_2O_3 & SiC particles were uniformly distributed throughout the metal matrix. The tensile strength and hardness of Al_2O_3 and SiC reinforcement aluminium composites improved with the increase in volume fraction of nanoparticles and toughness decreases with the increasing volume fraction of reinforcement.

III. RESULTS AND DISCUSSION

In this we have study mechanical properties (Toughness, Tensile strength and Hardness) of all hybrid composites are compared on the basis of results obtained from testing are discussed in detail. And also microstructure observation is done for all hybrid composites.

3.1 Microstructure

3.1.1 Optical Microscope Analysis

The microstructure of matrix aluminum alloy and various hybrid composites reinforced with 2 to 6 wt% of SiC&Al_2O_3 are shown in Fig. 1 (a-d). The microstructure was carried out using an Olympus microscope in order to find out the volume fractions of the reinforcing particles (SiC&Al_2O_3) & porosity.

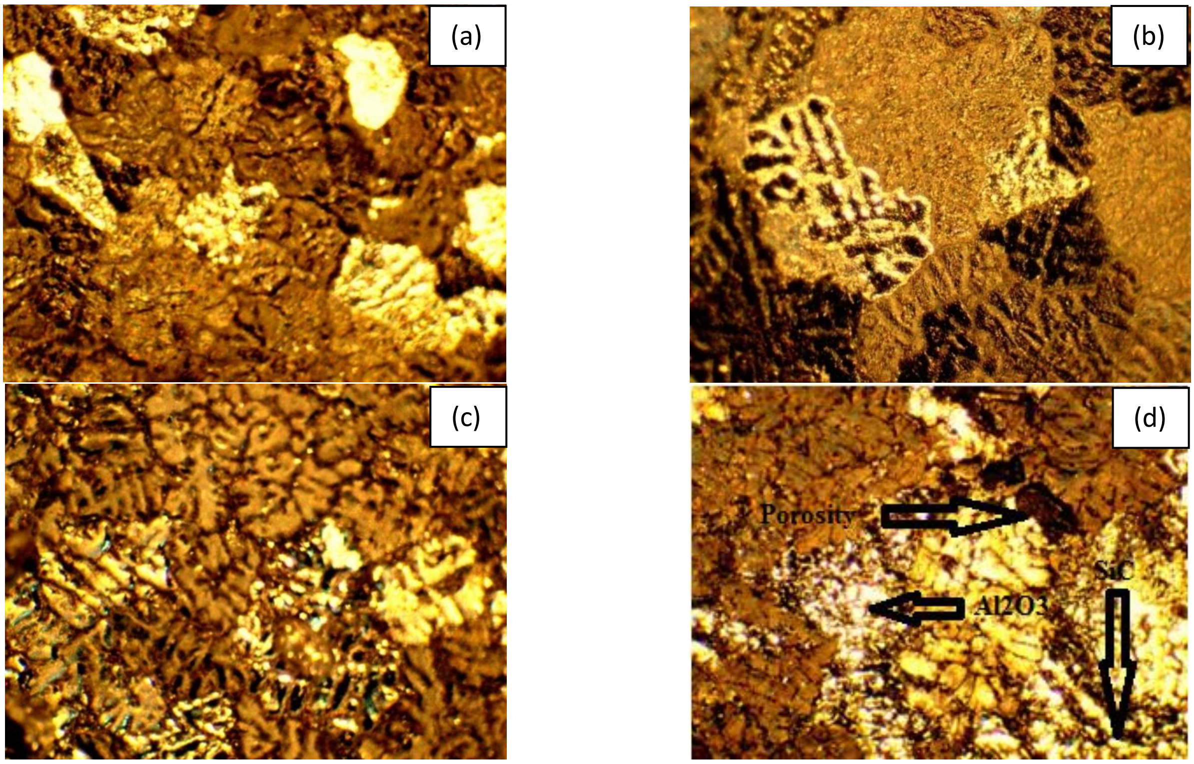

FIGURE 1: Micrographs of Al 6101 T6 and Reinforced Composite with Different Percentage of Reinforcement: (a) Al 6101 T6; (b) 2% SiC and Al_2O_3; (c) 4% SiC and Al_2O_3; (d) 6 % SiC and Al_2O_3

Aluminium alloy 6101 T6 contains Aluminium, Boron, Chromium, Copper, Iron, Magnesium, Manganese, Silicon and Zinc. The entire elements which are present in this alloy are visualized very clearly**.** As the % of reinforcement increases the area fraction also increases as evident from optical micrographs shown in Fig 1 (a-d).The microscopic analysis of these shows that the SiC and Al_2O_3 reinforcements are uniformly distributed in the metal matrix. At lower weight % of reinforcement i.e. 2% and 4 % microstructure was more homogeneous than at 6% which was found disorganized due to increased porosity.

On the other hand, the presence of porosity around the SiCp and Al_2O_3p reinforcements is evident. It is observed that the porosity has been pronounced more around Al_2O_3p particle reinforcement than the area around SiC particle reinforcement. It is clearly evident from the micrograph that the porosity increases with increasing volume fractions of the particulate reinforcement. Further, porosity is mainly located around the Al_2O_3p particles than around SiC particles. This may be due to wetting nature of SiC and Al_2O_3. Wetting is important in the bonding or adherence of two materials.

Wetting is the ability of a liquid metal to maintain solid surface in contact, resulting from intermolecular interactions when the two are brought together. The degree of wettability is determined by a force balance between adhesive and cohesive forces. Adhesive forces between a liquid and solid cause a liquid drop to spread across the surface. Cohesive forces within the liquid cause the drop to ball up and avoid contact with the surface.

3.1.2 X ray Diffraction Analysis

XRD is a material characterization technique that is used for analyzing the various stages present in the alloy and lattice structure of a material. In this study XRD &energy dispersive spectrometry analysis are applied to get information about the interface between the reinforcement and matrix material. XRD analysis was done on Metal Matrix Material using Phillips X-pert type Diffractometer and the values lies between 20 to 80^{o}.

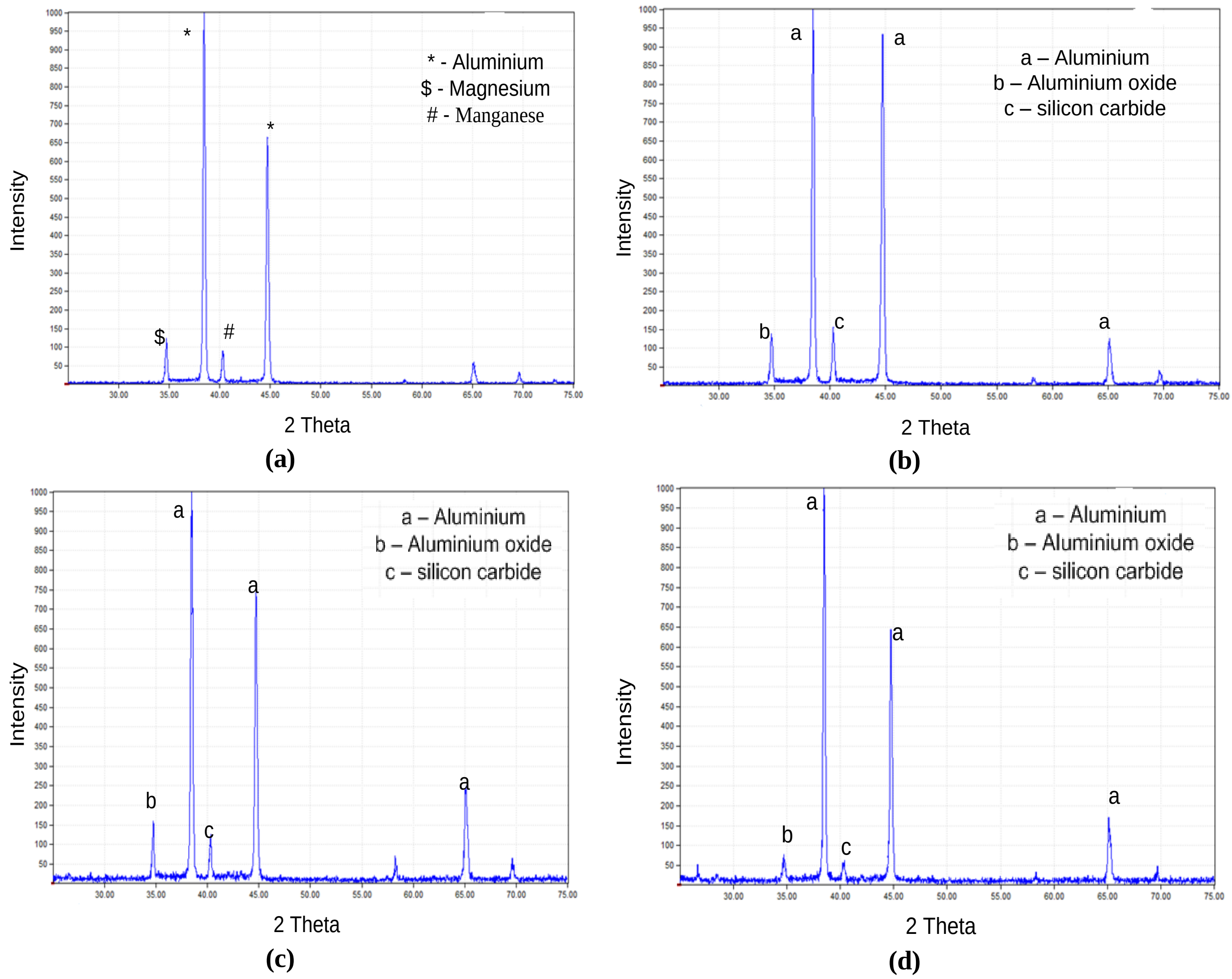

FIGURE 2: XRD Pattern of (a) Al 6101 T6; (b) 2% SiC and Al_2O_3; (c) 4% SiC and Al_2O_3 (d) 6 % SiC and Al_2O_3

The XRD results confirm presence of SiC& Al_2O_3 within the Al matrix of hybrid composite. In this result the presence of aluminium having large peak and SiC and Al_2O_3 in minor peaks. It is also evident from the XRD pattern that the SiC and Al_2O_3 particle did not react with Aluminium matrix and produce any other compound. Any other compound except SiC and Al_2O_3 was not found. And various other phases were also found in composites as follow:

1. $Mg_{1.13}$ $Fe_{0.8}$ $Mn_{.03}$ $Al_{0.14}$ Si_2 O_6 (Magnesium Iron Manganese Aluminium Silicate)
2. $Mg_{3.37}$ $Fe_{0.38}$ $Al6_{.09}$ $Si_{4.11}$ $B_{0.43}$ $O_{21.26}$ (Magnesium Iron Aluminium Boron Silicate Hydroxide)
3. $Si_{2.98}$ $Al_{6.81}$ $B_{.98}$ O_{18} (Silicon Aluminium Boron Oxide)

3.2 Mechanical Properties

3.2.1 Vickers Hardness Analysis

Hardness is a measure of how resistant solid matter in various kinds of permanent shape change when a compressive force is applied. Hardness of composites is found higher than the base alloy. Further, hardness increases with increase in weight % of reinforcement particles to the base alloy. The hybrid Composite reinforced with Silicon carbide (SiC) and Aluminium oxide (Al_2O_3) showed a significant increase in hardness. Fig 3 shows the variation of hardness of composite with wt % of reinforcement particle.

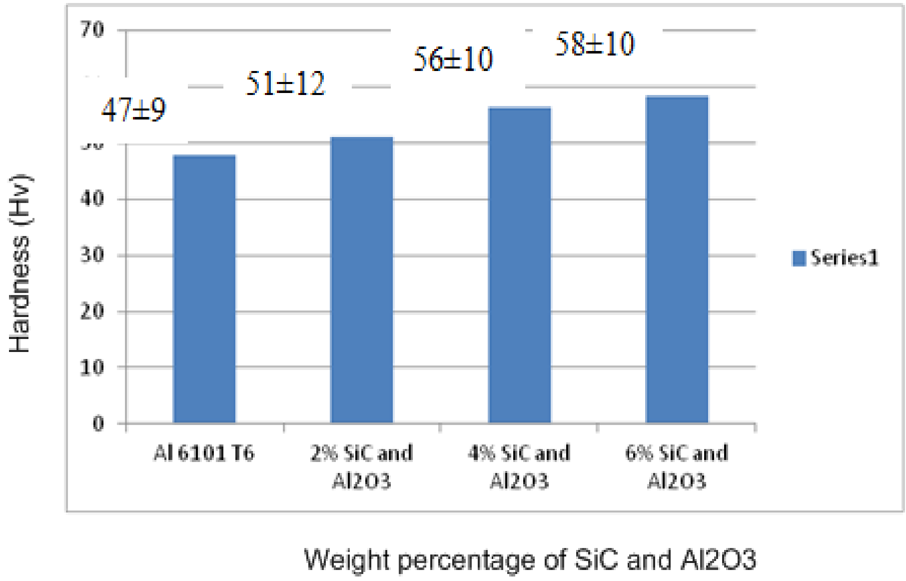

FIGURE 3: Variation of Micro hardness with wt. % Variation of SiC and Al_2O_3

The hardness of composite increases with the increasing amount of reinforcement. The addition of 0% to 6% reinforcement resulted in the increase of the hardness by 6.7%, 17.5% and 21.7 respectively in the 2, 4, and 6 wt.% of SiC and Al_2O_3. The increase in hardness after addition of reinforcement particles is due to the fact that aluminium oxide (Al_2O_3) has high wear resistance while silicon carbide has excellent hardness and high strength.

3.2.2 Tensile Properties Analysis

Ultimate tensile strength (UTS), often shortened to tensile strength (TS) or ultimate strength, is the maximum stress that a material can withstand while being stretched or pulled before necking, which is when the specimen's cross-section starts to significantly contracts.

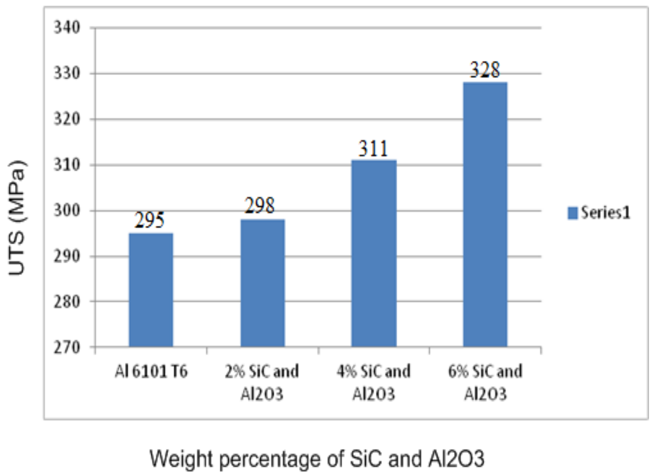

FIGURE 4 Variations of UTS with wt. % of SiC and Al_2O_3

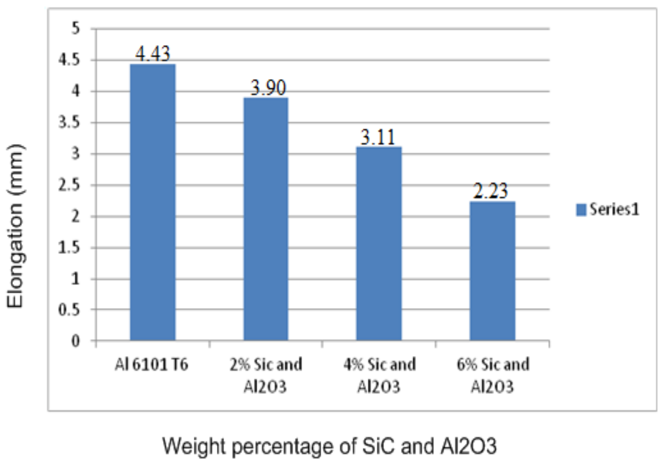

FIGURE 5 Variation of Elongation (mm) with wt. % of SiC and Al_2O_3

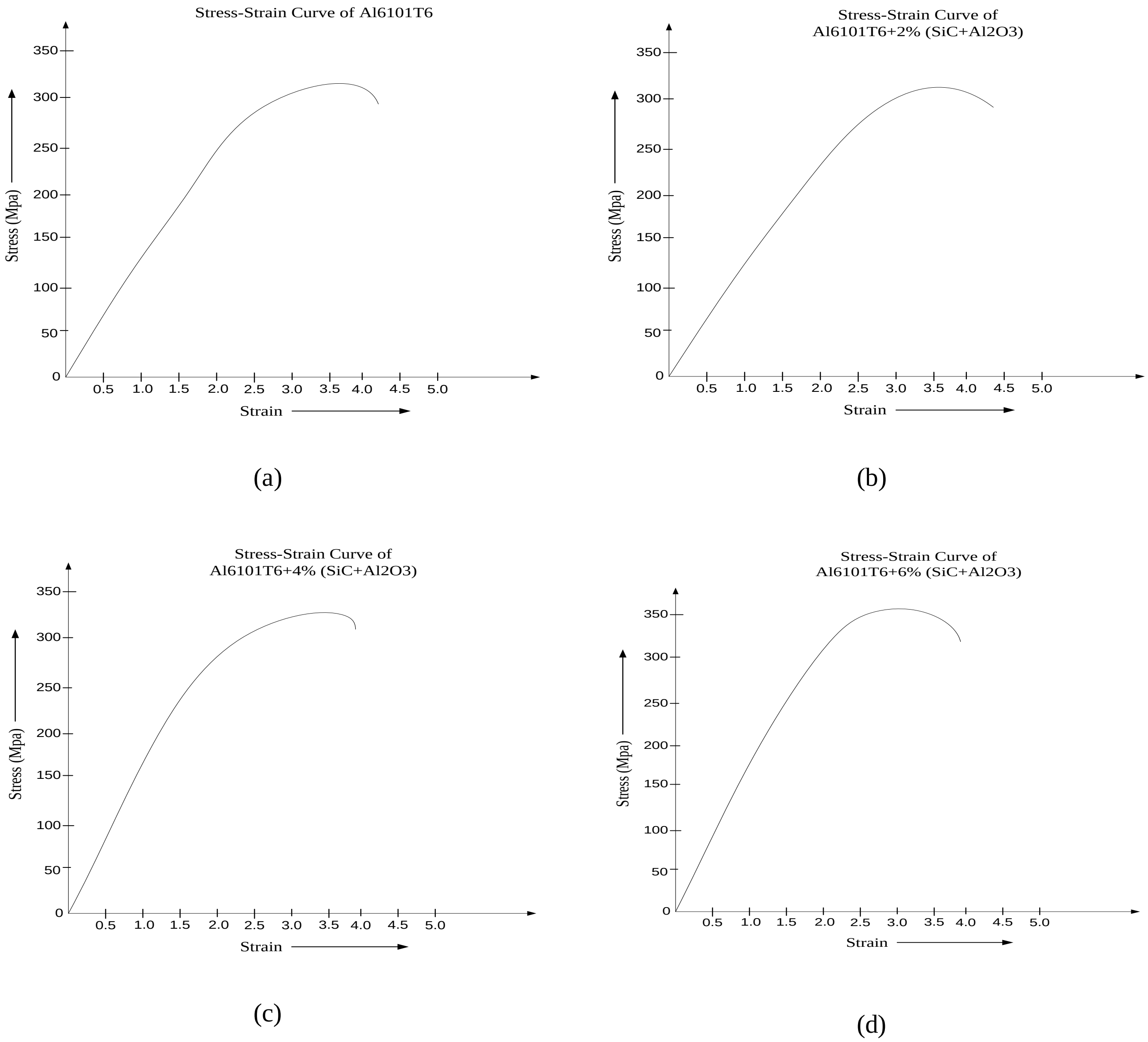

FIGURE 6: Stress Strain Curve for (a) Al 6101 T6 (b) 2% SiC and Al_2O_3 (c) 4% SiC and Al_2O_3 (d) 6 % SiC and Al_2O_3

From the above data, it is clear that the tensile strength of developed hybrid composite is greater than the unreinforced A6101T6 alloy. The increase in the tensile strength can be attributed to higher resistance to applied tensile load due to the presence of strongly bonded SiC and Al_2O_3 reinforcement in the base metal and increased dislocation density near matrix reinforcement interface. The tensile strength of unreinforced aluminum matrix was lower than that of hybrid composite. Further, addition of SiC and Al_2O_3 reinforcement 2- 6% to aluminium matrix increased the tensile strength by 1% to 11%. This can be attributed to more homogeneous microstructure and higher number of SiC and Al_2O_3 reinforcement particles. High density of reinforcement is believed to delay crack propagation. The percentage elongation was observed to reduce with the increase in wt % of SiC and Al_2O_3 from 2 to 6 wt%. It is because of brittle phase of the reinforcement. The tensile results are in good agreement with hardness and elongation results.

3.3 Impact Test Analysis

The Charpy Impact test also known as Charpy V – notch test, is a standardized high strain rate test which determines the amount of energy absorbed by the material during fracture. This absorbed energy is the measure of given material's toughness. The result shown in the Fig 7.

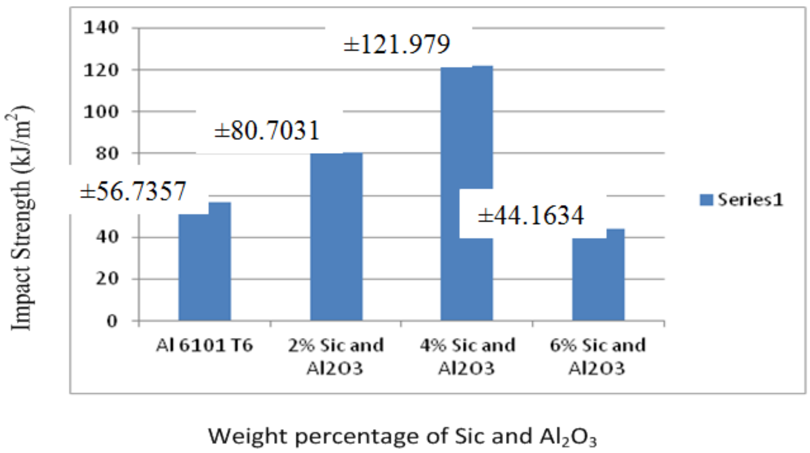

FIGURE 7: Comparison of Impact Strength with % Variation of SiC and Al_2O_3

From the above results it can be concluded that addition of SiC and Al_2O_3 reinforcement up to 4% increases toughness and beyond which toughness decreases. The highest increase in toughness is 114% for 4% reinforcement and same may be attributed to favorable combination of high tensile strength and fairly good elongation. The 22% decrease in toughness of sample containing 6% reinforcement can be attributed to lower ductility due to higher density of hard and brittle reinforcing particles and porosity. It may also happened due to the exists of brittle phases, the failure features as cracking and void in reinforcement, interface cracking and interface deboning as well as matrix damage result in the decreases of fracture toughness.

IV. CONCLUSION

The present investigation was aimed to enhance the metallurgical (microstructure), mechanical (hardness, tensile strength and toughness) properties of Al 6101 T6 aluminium base alloy with varying wt.% of SiC and Al_2O_3 from 0 wt.% to 6 wt.%. Four types of composite materials were produced by Stir Casting process by varying the wt% of SiC and Al_2O_3 from 0 wt% to 6 wt. % in Al 6101 T6 aluminium base alloy and the following conclusions are made.

- The hardness of composite increases with the increasing amount of reinforcement. The addition of 0% to 6% reinforcement resulted in the increase of the hardness by 6.7%, 17.5% and 21.7 respectively in the 2, 4, and 6 wt. % of SiC and Al_2O_3.
- And also it is found that the tensile strength of unreinforced aluminum matrix was lower than that of hybrid composite. Further, addition of SiC and Al_2O_3 reinforcement 2-6% to aluminium matrix increased the tensile strength by 1% to 11%.
- It is found that elongation decreases with increase in particle percentage, which confirms that Silicon Carbide and Aluminium Oxide together increases brittleness.
- It was examined that with the addition of SiC and Al_2O_3 reinforcement up to 4% increases toughness and beyond which toughness decreases. The highest increase in toughness is 114% for 4% reinforcement and the 22% decrease in toughness of sample containing 6% reinforcement can be attributed to lower ductility due to higher density of hard and brittle reinforcing particles and porosity.
- The microscopic analysis of these specimens shows that the SiCp and Al_2O_3p reinforcements are uniformly distributed in the metal matrix. At lower weight % of reinforcement i.e. 2% and 4 % microstructure was more homogeneous than at 6% which was found disorganized due to increased porosity.
- Also XRD results confirm the presence of SiC and Al_2O_3 within the Al matrix of hybrid composite.

REFERENCES

[1] http://www.usesof.net/uses-of-aluminum.html

[2] The Aluminum Association, Inc. 900 19th street, N.W. Washington, D.C. 2006 (202) 862-5100.

[3] http://www.azom.com/article.aspx?ArticleID=310

[4] Properties and Selection Nonferrous Alloys and Special- Purpose Material, ASM Hand Book, 1990, Vol. 2.

[5] Book of Material Science by S.L.Kakani and AmitKakani. www.esab.ca/ca/en/education/blog/understanding-thealuminium-alloy-designation-system.cfm, The Aluminium Association, Inc.www.calm-aluminium.com.au.

[6] Manufacturing Engineering and Technology Book by SeropeKalpaljian, Steven R. Schimid.

[7] M.K. Surappa, J. Mater. Proc.Tech. 63 (1997) 325±333.

[8] HaiZhi Ye, Xing Yang Liu, Review of Recent Studies in Magnesium Matrix Composites, Journal of Materials Science 39(2004) 6153 – 6171.

[9] A. Devaraju, A. Kumar. A. Kumaraswamy, B. Kotiveerachari, Influence of Reinforcements (SiC and Al_2O_3) and Rotational Speed on Wear and Mechanical Properties of Aluminum Alloy 6061-T6 Based Surface Hybrid Composites Produced Via Friction Stir Processing,Materials and Design 51 (2013) 331–341.

[10] A.Mazahery; H.Abdizadeh; H.R. Baharvandi,Development of High Performance A356/nano-Al_2O_3 Composites, Material Science and Engineering; A 518 (2009) 61-64.

[11] Ravinder Kumar, Suresh Dhiman, A Study of Sliding Wear Behaviors of Al-7075 Alloy and Al-7075 Hybrid Composite by Response Surface Methodology Analysis, Materials and Design 50 (2013) 351–35.

[12] E.Mohammad Sharifi; F.Karimzadeh; M.H.Enayati, Fabrication and Evaluation of Mechanical and Tribological Properties of Boron Carbide Reinforced Aluminium Matrix Nanocomposites, Material Science and Design; 32(2011)3263-3272.

[13] David Raja Selvam, Robinson Smart, D.S. Dinaharan, Synthesis and Characterization Of Al6061-Fly Ashp-SiCp Composites by Stir Casting and Compocasting Methods, Energy Procedia 34 (2013) 637 – 646.

[14] A. Alizadeh; E.Taheri-Nassaj, Mechanical Properties and Wear Behaviour of Al-2wt% Cu Alloy Composites Reinforced by B4c Nanoparticles and Fabricated by Mechanical Milling and Hot Extrusion, Materials Characterization; 67 (2012) 119-128.

[15] DevarajuAruria, Kumar Adepua, KumaraswamyAdepub, KotiveeracharіBazavadaa, Wear and Mechanical Properties of 6061-T6 Aluminum Alloysurface Hybrid Composites [(Sic + Gr) and (SiC + Al_2O_3)] Fabricated by Friction Stir Processing,J Mater Res Technol. 2013;2(4):362–369.

[16] M.R. Rosenberger; C.E. Schvezov; E. Forlerer,Wear of Different Aluminium Matrix Composites Under Conditions that Generate a Mechanically Mixed Layer, Wear 259 (2005) 590-601.

[17] BekirSadıkUnlu,Investigation of Tribological and Mechanical Properties Al2O3–Sic Reinforced Al Composites Manufactured by Casting or P/M Method, Materials and Design 29 (2008) 2002–2008.

[18] Hajar Farajzadeh Dehkordi; Mohammad Reza Toroghinejad; KeyvanRaeissi, Fabrication of Al/Al2O3/TiC Hybrid Composite by Anodizing and Accumulative Roll Bonding Processes and Investigation of Its Microstructure and Mechanical Properties, Material Science and Engineering, A585 (20134) 60-467.

[19] A. Baradeswaran, S.C. Vettivel, A. ElayaPerumal, N. Selvakumar, R. Franklin Issac, Experimental Investigation on Mechanical Behavior, Modeling and Optimization of Wear Parameters of B_4C and Graphite Reinforced Aluminium Hybrid Composites,Materials and Design 63 (2014) 620–632.

[20] Bijay Kumar Show; Dipak Kumar Mondal; KoushikBiswas; JoydeepMaity, Development of a Novel 6352 Al (Al_4SiC_4+Sic) Hybrid Composite with Enhanced Mechanical Properties, Material Science and Engineering; A 579 (2013) 136-149.