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Research Article

Mechanical Properties of Al-SiC Metal Matrix Composites Fabricated by Stir Casting Route

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Abstract

Aluminium and its alloys possess excellent properties such as low density, good plasticity and ductility. They find extensive applications in aeronautics, astronautics, automobile and high speed train fields. The matrix alloy, the reinforcement material, the volume and shape of the reinforcement, the location of the reinforcement, and the fabrication method can all be varied to achieve required properties [1]. Metal matrix composites (MMCs), such as SiC particle reinforced Al, are one of the widely known composites because of their superior properties such as high strength, hardness, stiffness, wear and corrosion resistance. SiC particle reinforced Al based MMCs are among the most common MMC and available ones due to their economical production [2].

Introduction

Composite materials are important engineering materials due to their outstanding mechanical properties. Composites are materials in which the desirable properties of separate materials are combined by mechanically or metallurgically binding them together. Each of the components retains its structure and characteristic, but the composite generally possesses better properties. Composite materials offer superior properties to conventional alloys for various applications as they have high stiffness, strength and wear resistance. The development of these materials started with the production of continuous-fiber-reinforced composites. The high cost and difficulty of processing these composites restricted their application and led to the development of particulate reinforced composites [3,4]. Aluminium and its alloys possess excellent properties such as low density, good plasticity and ductility and good corrosion resistance. They find extensive applications in aeronautics, astronautics, and automobile and high speed train fields. However, low hardness and poor impact resistance results in their limited application in heavy duty environments. Like all composites, aluminium-matrix composites are not a single material but a family of materials whose stiffness, strength, density, thermal and electrical properties can be tailored [5]. The matrix alloy, the reinforcement material, the volume and shape of the reinforcement, the location of the reinforcement, and the fabrication method can all be varied to achieve required properties [6]. Regardless of the variations, however, Al composites offer excellent thermal conductivity, high shear strength, excellent abrasion resistance, high temperature operation, non-flammability, minimal attack by fuels and solvents, and the ability to be formed and treated on conventional equipment.

Silicon carbide (SiC) is composed of tetrahedral of carbon and silicon atoms with strong bonds in the crystal lattice. This produces a very hard and strong material. SiC is not attacked by any acids or alkalis or molten salts up to 800 °C. In air, SiC forms a protective silicon oxide coating at 1200 °C and is able to be used up to 1600 °C. The high thermal conductivity coupled with low thermal expansion and high strength gives this material exceptional thermal shock resistant qualities. SiC ceramics with little or no grain boundary impurities maintain their strength to very high temperatures, approaching 1600 °C with no strength loss [7].

Metal matrix composites (MMCs), such as SiC particle reinforced Al, are one of the widely known composites because of their superior properties such as high strength, hardness, stiffness, wear and corrosion resistance. SiC particle reinforced Al based MMCs are among the most common MMC and available ones due to their economical production. They can be widely used in the aerospace, automobiles industry such as electronic heat sinks, automotive drive shafts, or explosion engine components.

Experimental

In this study, an attempt has been made to fabricate aluminum (Al-6061)/SiC (Silicon carbide) MMCs by STIR casting process [8]. The MMCs plates were prepared with varying the reinforced particles by weight fraction of 5%, 10% and 15%. The average reinforced particles size of SiC was 325 mesh respectively. The stirring process was carried out at 200rev/min rotating speed.

Composition of samples chosen for the study

Al-SiC composites have been prepared by varying the SiC weight percentage from 5 to 15%. The weight of sample taken is 400 grams and the percentages are varied accordingly. Table 1 shows the composition of samples.

Table 1: Composition of samples.

Sample No.	Aluminium (Grams)	Sic (Grams)	Remarks
1	380	20	Al-5%SiC
2	360	40	Al-10%SiC
3	340	60	Al-15%SiC

Stir casting procedure for Al6061/SiC MMCs [9-11]

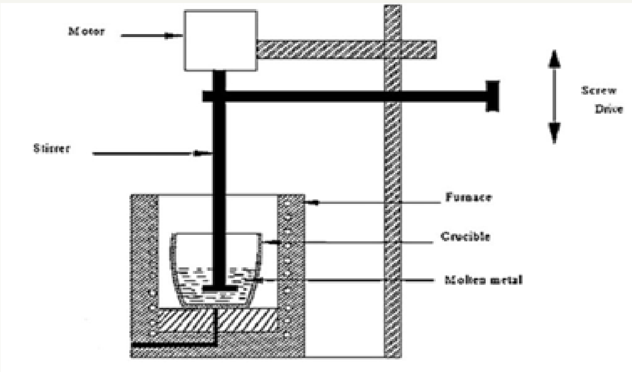


Figure 1: Stir casting setup for fabrication of Al-SiC_p MMC.

The stir casting experimental setup used for fabricating Al-SiC_p MMC is shown in Figure 1. It consists of furnace for heating the metal, Stirrer and motor for mixing of particles. First of all, the SiC particles are preheated in a separate muffle furnace at 900 °C for 2h in order to remove the volatile substances and impurities present and to maintain the particle temperature closer to melting point of aluminium alloy. The preheating of SiC particles leads to the artificial oxidation of the particle surface forming SiO_2 layer. This SiO_2 layer helps in improving the wettability of the particle. Thereafter, Al6061 billets were charged into the furnace and melting was allowed to progress until a uniform temperature of 750 °C was attained. The flux is added to Al alloy during melting to prevent oxidation of the aluminium. The melt was then allowed to cool to 600 °C (slightly below the liquidus temperature) to a semi-solid state and silicon carbide preheated mixture was added to the melt in fragments and manual stirring of the slurry was performed. Thereafter, small amount of Mg less than 1% of the total weight is added to improve the wettability between the reinforcement and the alloy. After performing 5min of manual stirring, rest amount of SiC is added along with the hexachloroethane tablets for degassing the molten metal and to prevent porosity in the cast composites.

After the manual stirring, the composite slurry was reheated and maintained at a temperature of 750 °C±10 °C (above the liquidus temperature) and then mechanical stirring was performed. The stirring operation was performed for 10 minutes at an average stirring rate of 150rpm. Platinum-Rhodium thermocouple was utilized in all cases to monitor the temperature readings of the furnace. The permanent cast iron mould is preheated at a temperature of 350 °C before the pouring of composite mixture in to it. After that the composite is solidified, dried and taken out from the permanent mould.

Results and Discussion

Metallography and microstructural analysis

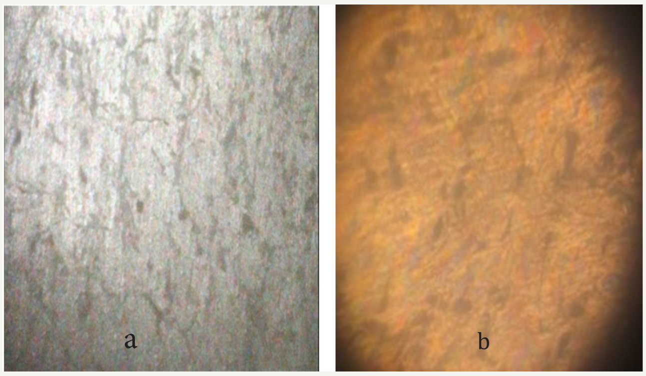


Figure 2a & 2b: Shows optical microstructures of Al-5% SiC composite at 100x and 200x magnification respectively.

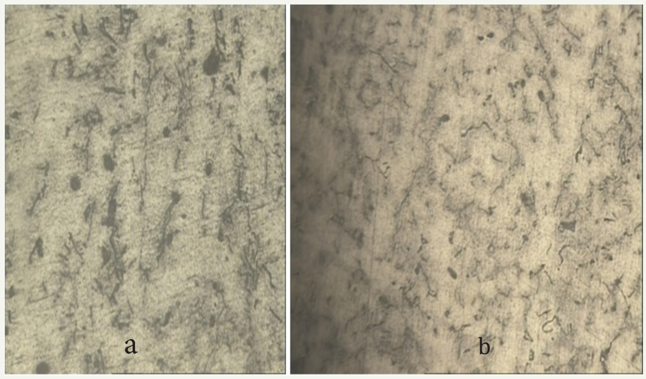


Figure 3a & 3b: Shows optical microstructures of Al-10% SiC composite at 100x and 200x magnification respectively.

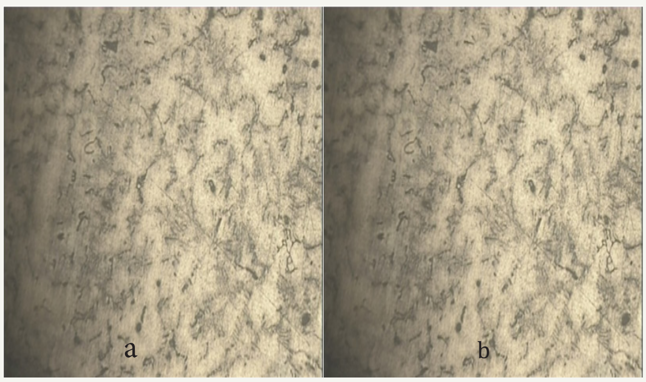


Figure 4a & 4b: Shows optical microstructures of Al-15% SiC composite at 100x and 200x magnification respectively.

Microstructural analysis: The microstructural investigation of the stir casted Al6061/5%SiC_p, Al6061/10%SiC_p and Al6061/15%SiC_p MMC has been carried out by optical microscope. The Optical microstructures are shown in Figure 2-4 at 100x and

200x. The optical micrographs of the as-cast composite revealed that the agglomerations of SiC particles are uniformly distributed in the matrix. It is apparent from the microstructure that the distributions of reinforcement particles become more uniform in the matrix as their weight percentage increases.

XRD analysis

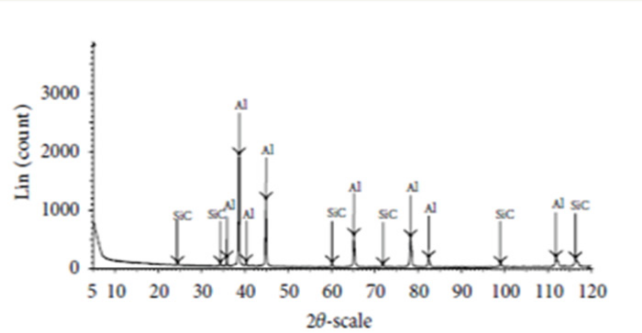


Figure 5a: Al6061/5%SiC$_p$.

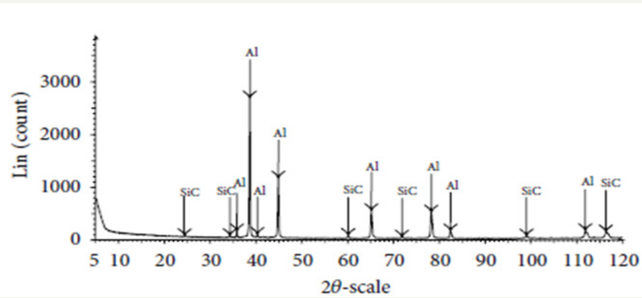


Figure 5b: Al6061/10%SiC$_p$.

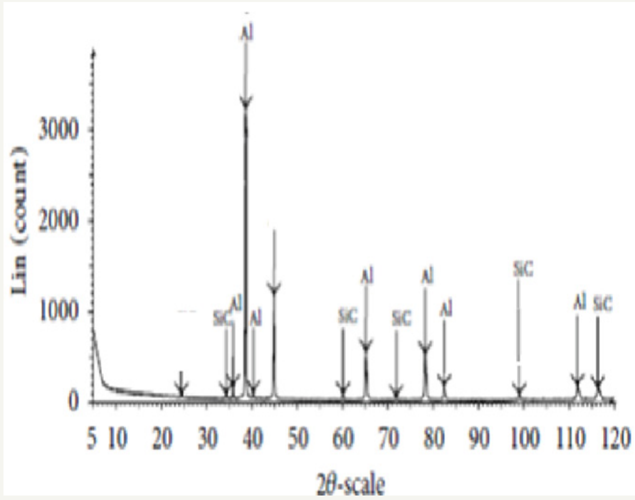
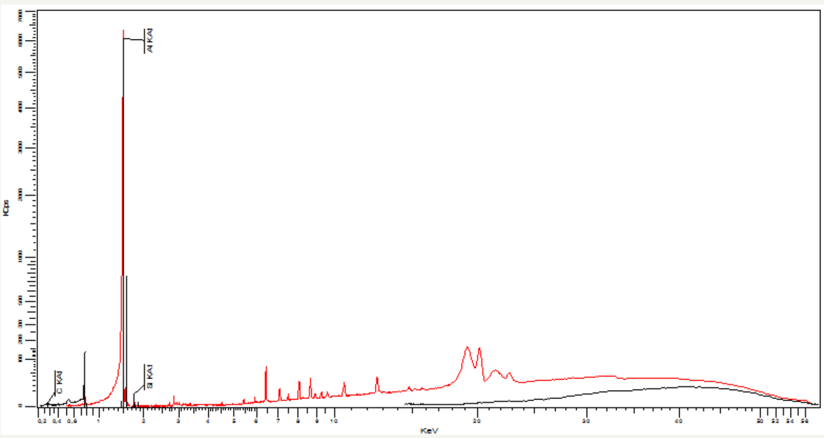


Figure 5c: Al6061/15%SiC$_p$.

XRD analysis shows that no other unwanted materials were present instead of Al and SiC. Figure 5a-5c shows the XRD patterns of Al-SiC$_p$ MMC at 2-theta scale. The diffraction angle (2θ) is maintained between 5° and 120°.

X-Ray fluoroscence spectroscopy (XRF)

A WD-XRF Spectrometer Model-S8, Make TIGER Bruke has been used for analyzing the elemental composition and spectrum of Al-SiC MMC. Circular samples of 34mm diameter are prepared for XRF analysis. It has been concluded that the SiC is uniformly dispersed throughout the matrix. Moreover, compositional analysis reveals the presence of Silicon and carbon Figure 6a- 6c.

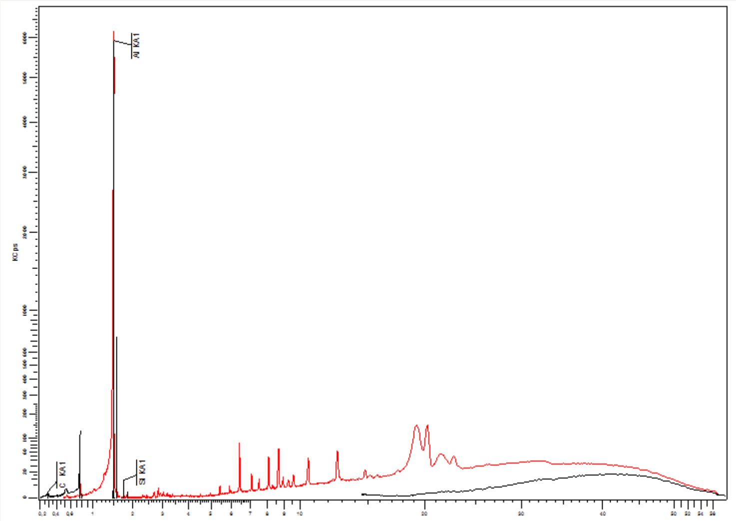


Al	C	Si	Fe	Pb	Zn	Cu
2314,4 KCps	0,9 KCps	9,5 KCps	86,8 KCps	56,4 KCps	65,8 KCps	46,5 KCps
90,53 %	3,02 %	1,17 %	0,55 %	0,15 %	0,14 %	0,13 %

Mg	Cr	Mn	Ni	Ti	Ga	Cl	Ca	V
4,2 KCps	4,1 KCps	3,9 KCps	9,3 KCps	0,5 KCps	6,0 KCps	0,1 KCps	0,2 KCps	0,4 KCps
0,11 %	0,06 %	0,04 %	0,03 %	0,02 %	0,01 %	0,01 %	84 PPM	80 PPM

S	K	Mo	Zr	Intensity Scal
0,2 KCps	0,1 KCps	4,5 KCps	2,4 KCps	
77 PPM	57 PPM	23 PPM	11 PPM	0,9438

Figure 6a: XRF Spectrum and composition of Al-5%SiC$_p$ MMC.

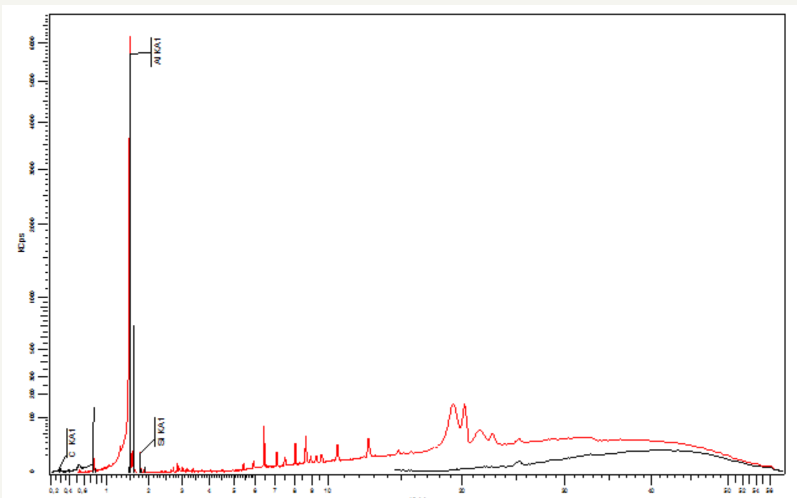


Al	C	Si	Fe	Mg	Zn	Pb
2306,0 KCps	1,0 KCps	14,4 KCps	72,1 KCps	9,2 KCps	41,1 KCps	30,7 KCps
88,90 %	8,27 %	1,73 %	0,45 %	0,24 %	0,09 %	0,08 %

Cu	Cr	Mn	Cl	Ni	Ti	Ga	K	S
27,8 KCps	2,6 KCps	3,5 KCps	0,3 KCps	6,2 KCps	0,4 KCps	5,8 KCps	0,2 KCps	0,2 KCps
0,07 %	0,04 %	0,03 %	0,02 %	0,02 %	0,01 %	99 PPM	80 PPM	80 PPM

Ca	Ag	Pd	Mo	Zr	Intensity Scal
0,2 KCps	0,4 KCps	0,3 KCps	3,2 KCps	2,3 KCps	
75 PPM	55 PPM	39 PPM	15 PPM	11 PPM	0,9370

Figure 6b: XRF Spectrum and composition of Al-10%SiC_p MMC.



Al	C	Si	Fe	Pb	Zn	Cu
2366,2 KCps	0,8 KCps	7,9 KCps	71,8 KCps	30,5 KCps	35,0 KCps	26,3 KCps
91,42 %	6,78 %	5,98 %	0,46 %	0,08 %	0,07 %	0,07 %

Cr	Mn	Ni	Ti	Ga	Cl	V	Ca	S
2,4 KCps	3,3 KCps	5,4 KCps	0,6 KCps	5,8 KCps	0,1 KCps	0,3 KCps	0,1 KCps	0,1 KCps
0,03 %	0,03 %	0,02 %	0,02 %	0,01 %	70 PPM	66 PPM	56 PPM	55 PPM

Mo	Zr	Intensity Scal
2,8 KCps	2,5 KCps	
13 PPM	12 PPM	0,9446

Figure 6c: XRF Spectrum of Al-15%SiC_p MMC.

Hardness testing

The resistance to indentation or scratch is termed as hardness. Among various instruments for measurement of hardness, Brinell's, Rockwell's and Vicker's hardness testers are significant. Vickers hardness value of Al-SiC MMCs taken at 10Kgf load and 10sec dwell time using micro indenter of diamond is shown in Table 2 and also in Figure 7 & 8.

Table 2: Vickers Hardness value of Al-SiC MMCs.

S. No.	Samples	Hardness (HV10)
1	Al- 5% SiC	36
2	Al- 10% SiC	45
3	Al- 15% SiC	50

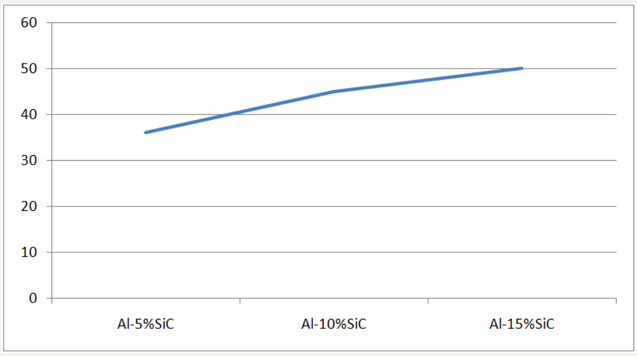


Figure 7: Shows the graph between hardness value and percentage of SiC..

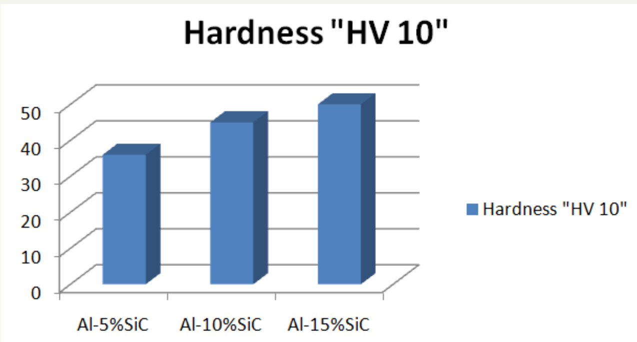


Figure 8: Shows the bar chart diagram which representing the trends in increasing hardness on increment of SiC content.

Wear testing

Wear resistance testing was done on Pin-On-Disc machine at load of 15N and rotational speed of disc of 400rpm. Standard cylindrical pin wear testing sample was prepared on the lathe machine having dimensions of 8mm diameter and 1inch length as shown in Figure 9.

Figure 9: Standard wear testing sample.

Wear testing parameters

Following parameters were used to perform wear test:

Load (N)-15 Newton, Disk Rotation speed-400rpm.

Track radius-60mm, Time-60 minutes

Wear testing results of Al-SiC MMCs on pin-on-disc setup at 15N load and 400rpm speed are shown in Table 3 and Figure 10 giving the trends in wear resistance value on increment in SiC content

Table 3: Wear Rate of Al-SiC MMCs.

Al- SiC Composites of Varying Amounts of SiC	Wear Rate (Mm^3/M)
Al base alloy	0.832475
Al-5% SiC Composites	0.732448
Al-10% SiC Composites	0.632448
Al-15% SiC Composites	0.405977

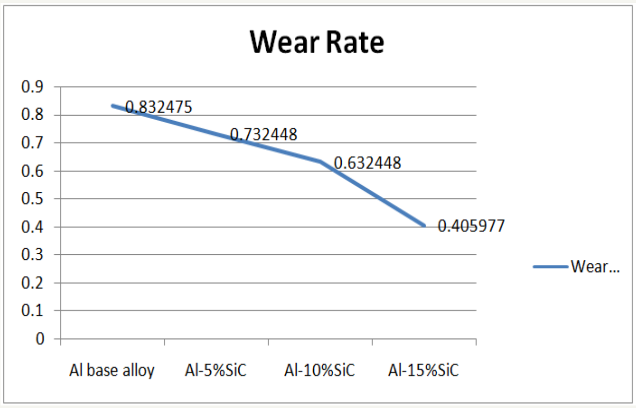


Figure 10: Shows the graph between wear resistance and percentage of SiC thus giving the trends in wear resistance value on increment in SiC content.

A. The dry sliding wear behaviour in the base alloy and composites were investigated against emery papers of 400 grit. The SiC particulate phase is found to reduce the wear rate (expressed in terms of gm/m, mm^3/m etc) significantly in the composites. The volumetric wear rate (mm^3/m) in 15 % SiC composite is reduced by 62-66% for 400 emery sliding with respect to the base alloy. In case of 5% SiC composite the corresponding reduction in the wear rate is 15-25%.

B. The wear rate is found to increase with load in all the materials studied. The increase in wear rate with load is steeper in the base alloy as compared to that of the composites. The increasing load is known to produce heating effect leading to thermal softening and seizure. Also it brings more area into sliding contact and thereby causes enhanced wear.

C. The micro mechanism of wear against the coarse abrasive emery paper was found to be characterized by deep wear tracks along with fragmented SiC particulates in the 5% SiC composite. Fine cracks were also noticed. In 15 % SiC composite wear was followed by limited extent of cutting and plowing marks keeping the overall surface smooth.

Tensile testing

Table 4: Tensile Strength of Al-SiC MMCs.

Samples	%Elongation	0.2% Y.S(Mpa)	UTS(Mpa)
Al6061 -5% SiC_p	1.9	54.6	52.2
Al6061 -10% SiC_p	1.3	42	39.1
Al6061 -15% SiC_p	0.6	51	55.8

Tensile testing was carried on Universal testing machine and the results are as under: Table 4 shows the % elongation, yield strength at 0.2% and UTS of Al6061 -5%SiC_p, Al6061 -10%SiC_p and Al6061 -10%SiCp. It has been concluded that the % elongation decreases with increase in SiC percentage. But yield strength and UTS decreases up to 10%SiC and then increases.

Conclusion

Al-SiC MMC have been successfully fabricated by Stir casting. Stirring the MMC slurry in semi-solid state helps to incorporate ceramic particles into the alloy matrix. The settling of silicon carbide particles resisted due to stirring in semisolid state due to entrapment of silicon carbide particles between the dendrite arms. Processing variables such as holding temperature, stirring speed, size of the impeller, and the position of the impeller in the melt are among the important factors to be considered in the production of cast metal matrix composites as these have an impact on mechanical properties. The microstructural investigation and XRD results reveal the uniform distribution of SiC particles in to Al matrix. Whereas, XRF tells us the chemical composition and spectrum of fabricated MMCs. It is very difficult to obtain the exact percentage of SiC, but it has been successfully achieved by adopting suitable process parameters. The testing of composites have been carried out several times by XRF and then accordingly parameters are varied to achieve the homogeneous and uniform distribution of reinforcement. The addition of silicon carbide particles to the matrix alloy improves the mechanical properties such as hardness and tensile strength of the matrix alloy. But the wear rate tends to decrease with increasing particles wt. percentage from 5 to 15%, which confirms that silicon carbide is beneficial for reducing the wear rate of MMCs. This material can be used at high elevated temperature stability. It can also be used for Better wear resistance, corrosion resistance.

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