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Investigation of Mechanical Properties of Al-SiC Hybrid Composite using Squeeze Casting Process

A. Ramkumar[1], Dr. S. Periyasamy[2], M. Syed Easa Faizal[3]
[1, 3]PG Scholar, Manufacturing Engineering, [2]Assistant Professor, Department of Mechanical Engineering, Government College of Technology Coimbatore-641013

Abstract: Composites are made up of individual materials referred to as constituent materials with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from the individual components. Reinforcements introduced to metal matrix composites are known for their inherent properties like hardness, corrosion resistance, wear resistance and machinability. This study deals with the investigation of the effect of adding silicon carbide (SiC) and flyash reinforcements in aluminium alloy (Al 6065) hybrid composite using squeeze casting process. The silicon carbide and flyash particles were introduced in various %-wt combinations to aluminium alloy (Al 6065) as per Taguchi experimental design. The hardness, tensile strength are found to increase in the Al6065 base matrix alloy with the increase in reinforcement. The mechanical properties of Al6065 hybrid composite are significantly improved after the dispersion of SiC/flyash particles.
Keywords: Hybrid composite, Squeeze casting, Tensile strength;

I. INTRODUCTION

Aluminium is the third most abundant metal in the Earth's crust after oxygen and silicon. It makes up about 8% by mass of the crust. Due to easy availability, High strength to weight ratio, easy machinability, durable, ductile and malleability Aluminium is the most widely used non-ferrous metal. They possess low density and has high resistance to corrosion. Aluminium is a light metal with low density, about a third that of steel. For example, the use of aluminium in vehicles reduces dead-weight and energy consumption while increasing load capacity. Its strength can be adapted to the application required by modifying the composition of its alloys. The application of light weight, strong and long-lasting aluminium alloy is used in automobiles, aircraft, truck, railway cars, spacecraft etc. Aluminium naturally generates a protective oxide coating and is highly corrosion resistant. It is particularly useful for applications where protection and conservation are required. The application of highly corrosion resistance aluminium alloy is used in marine parts, chemical tanks. Aluminium is an excellent heat and electricity conductor and in relation to its weight is almost twice as good a conductor as copper. This has made aluminium the most commonly used material in major power transmission lines. The application of excellent heat and electricity conductor aluminium is used in electric wire.

The following section highlights findings of the various author's work for better understanding. Bhaskar Chandra Kandpal et al., [1] investigated the mechanical properties of aluminium 6063 based hybrid metal matrix composites. One reinforced with silicon carbide, graphite and second reinforced with silicon carbide, boron carbide by stir casting technique. Found that tensile strength, ultimate strength, hardness value and flexual strength are increased in SiC and B_4C particulates in comparision to the SiC, graphite reinforced composite.Jaswinder Singh et al., [2] stated that the incorporation of particulate reinforcements like fly ash, rice-husk ash and mica reduces the density of composites.Anthony Xavior M et al., [3] investigated that for Al 6065 matrix hybrid composites reinforced with silicon carbide and graphite particles, the wear rate increased initially up to a sliding velocity of 0.9m/s and thereafter there was a decrease in wear rate.Yashpal et al., [4] indicated in their study that that hardness and tensile strength of the composites increased with the addition of reinforcements like SiC, Al_2O_3, TiC. Composites reinforced with composite powders fabricated through stir casting showed lower porosity. Mohanavel V et al., [5] found that hardness and tensile strength of composite is linearly increased with the increase in reinforcement addition. The AA6351/Al_2O_3/Gr hybrid composite containing 20% Al_2O_3 with 3% Gr has higher mechanical properties than the pure Al matrix alloy.

B. Ravi et al., [6] stated that the Aluminium matrix is strengthened when it is reinforced with hard ceramic particles like SiC, Al_2O_3, B4C, etc. resulting in enhanced wear resistance. Among the manufacturing processes, the conventional stir casting is an attractive processing method for producing AMCs as it is relatively inexpensive and offers a wide range of materials and processing conditions. Production of homogeneous AA6065/B4C composite could be achieved by using Stir Casting Technique. Hariprasad T et al., [7] showed that the wear loss of particle reinforced Al specimens decreased due to presence of Al_2O_3- B_4C. The wear rate of Al_2O_3- B_4C 8% was approximately 10% lower than other weight percentages. Biswajit panda et al., [8] found that the hardness and

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tensile strength increases with increase in CSA weight %. The wear rate decreases with increase in percentage of CSA in aluminium matrix. Johny james et al., [9] stated that the hardness test shows that addition of reinforcement SiC and TiB_2 increase hardness value but increase in reinforcement up to 15 wt % reveals reductions in hardness value. Arjun haridas et al., [10] stated hardness of the matrix material Al 7075 has improved by added reinforcement material SiC and Ni. The matrix and reinforcement material are well mixed by the stir casting and gives better material profile. A Pramanik., [11] stated that the metal matrix composites show much higher wear resistance than the corresponding matrix material. Unlike that of matrix material, the wear of metal matrix composites is very much linear and possible to predict easily. The reinforced particles resist the abrasion and restrict the deformation of metal matrix composites which causes high resistance to wear. Kammuluri. Baburaja et al., [12] stated that the aluminium composites are processed and manufactured by novel technologies for different applications. Stir casting is widely employed for production of aluminium hybrid materials, hybrid materials are chosen by many researchers who altered the characteristics by scientific optimization of the constituents that are employed for obtaining hybrid materials of aluminium.

II. EXPERIMENTAL PROCEDURE

A. Materials

It is relatively soft, durable, light weight, ductile, malleable metal and has excellent heat conductivity. The selected aluminium alloy Al 6065 bears excellent characteristics for aerospace applications. It has major alloying elements Magnesium, Silicon which contributes for better strength, machinability and castability.

B. Process Parameters

The matrix material is aluminium alloy Al 6065. Samples are to be prepared using Al 6065 reinforced with silicon carbide (SiC) (0.5%, 1%) and fly ash (1%) by volume at melting temperature of 750°C and reinforcement pre-heat temperature as 900°C. Experiments were conducted using Taguchi L_4 orthogonal design of experiments is shown in table VI gives the various constituents levels of composite elements.

Table II. Selection of process parameters

S.no	Process parameters	Values
1	Squeeze time (min)	5,10
2	Reinforcement of SiC (%)	0.5, 1
3	Squeeze pressure (mpa)	150
4	Melt temperature (°C)	750
5	Stir time (sec)	30

III. EXPERIMENTAL DETAIL

The experiments were conducted on squeeze casting equipment in which the aluminium 6065 is melted in a crucible furnace mounted on it. It is left until the aluminium is melted. Once the aluminium is melted the reinforcement such as Silicon carbide with various percentage and fly ash is mixed. Then the mixture is stirred and the mixture is allowed to pour into the squeeze casting setup via the runway between the pour hole and die. It is then immediately forged at a high pressure for certain time. The samples attained were in cylindrical shape of length 250mm and diameter of 30mm.

Fig. 1 Squeeze casting setup

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A. Evaluation Of Mechanical Properties

The attained casted samples were then machined to a standard dimension to perform various tests respectively.Tensile strength tests are conducted on transverse specimens made as per ASTM-E8 cut from casted samples. The strength of casted samples are predicted by conducting tensile tests with the Universal Testing machine. Hardness testing is carried out using Vickers pyramid hardness testing machine with a load of 50g. The Vickers hardness is carried out on the circular side of the machined sample. The machined samples were dipped in sodium chloride solution to calculate the pitting corrosion of the composite. The corrosion solution was prepared according to the ASTM G44. This ASTM standard consists of exposure of composite by immersion in 3.5% sodium chloride solution for 20 to 90 days. It is carried out for 28 days to calculate the corrosion of the sample. Then the samples were taken to the microscopical analysis of corroded area.

Fig. 2. Tensile Test samples

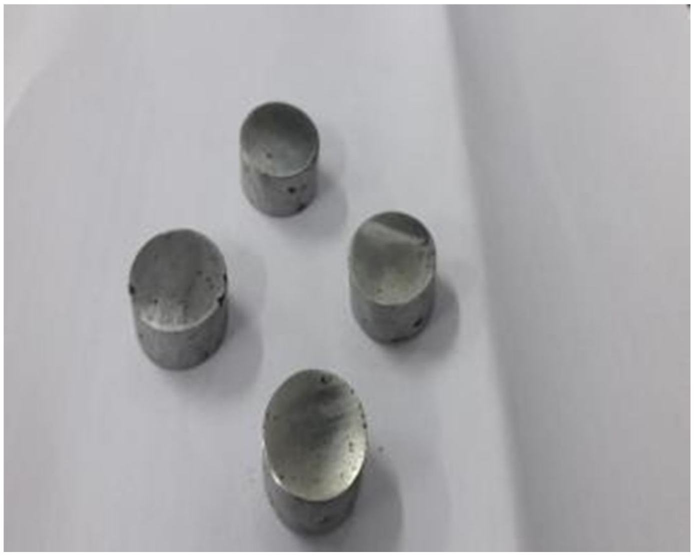
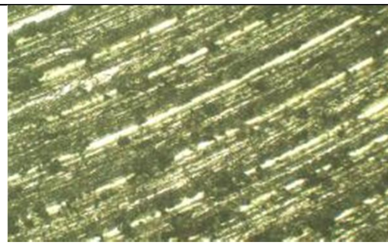
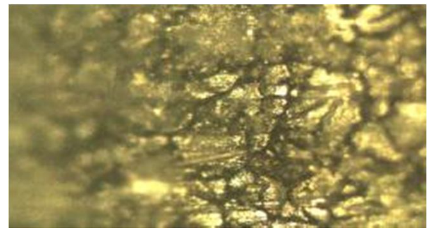
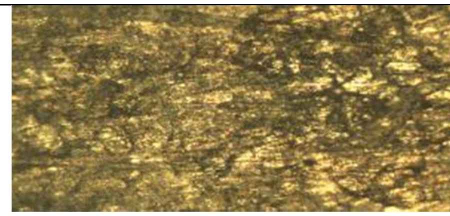
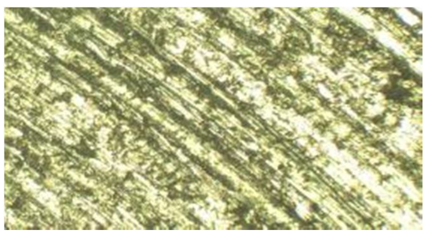
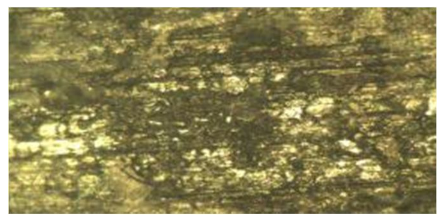
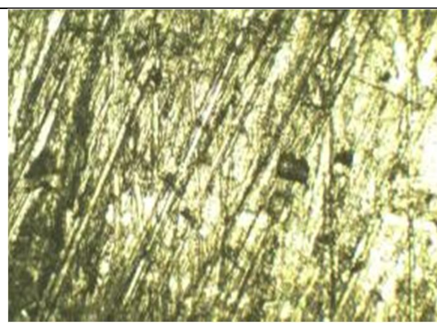
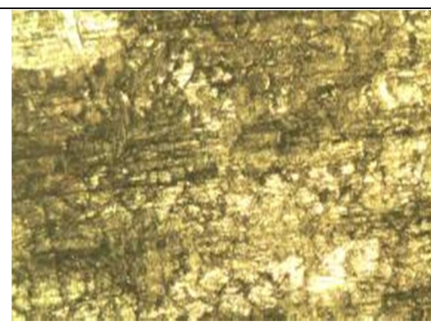


Fig. 3. Hardness test samples

B. Microstructural Analysis

The microstructural characterization of the sample was performed with the use of optical microscope and inverted microscope. The samples was comprised of base metal Al6065 and reinforcement silicon carbide, fly ash. The samples were examined with the help of standard metallographic procedure. Optical microscopy used to examine the characteristic of casted composites at the cross section. The specimens were immersed in 3.5% NaCl solution for a period of 28 days. Pitting corrosion is the most common type of corrosion occurs in aluminium. The rate of pitting were influenced by several factors such as the microstructure of the metal, the presence of inclusions in the metal matrix, pH of solutions, temperature of the environment, reinforcement added to it. The microstructure of the samples before and after corrosion were tabulated in Table III.

Table III. Microscopic appearances of corrosion

Sample .No	Corrosion rate (mpy)	
	Before corrosion	After corrosion
1		
2		
3		
4		

C. Taguchi method

Taguchi optimization techniques are powerful yet simple to evaluate the effect of multiple variables simultaneously. An advantage of this method is that it emphasizes a mean performance characteristics value close to the target value rather than a value within certain specification limits. Thus improving product quality. A large number of experiments have to be carried out when the number of the process parameters increases. To solve this task uses a special design of orthogonal arrays to study the entire process parameter space with only a small number of experiments only. The results of deviated value transferred into signal-to-noise ratio which is a measure of quality characteristics of the desired value.

In this analysis of S/N ratio, three categories of quality characteristics are used. They are lower the better, higher the better, and larger the better, [14]

Taguchi orthogonal Array Design is selected the detail is as follows.

L4 (2^2)

Number of variables = 2

Number of variable levels = 2

Number of experiments = 4

Design of experiment based on the Taguchi method and ANOVA General linear model analysis using MINITAB 15 software.

Table IV. Squeeze casting parameters and levels

Parameters	Variables	
	Level X_1	Level X_2
Reinforcement percentage (SiC)	0.5	1
Squeeze time ,t sec	5	10

Table V. L4 Orthogonal array of the Squeeze parameters

Ex. No.	Reinforcement percentage	Squeeze time min
1	0.5	5
2	1	10
3	0.5	10
4	1	5

IV. RESULTS AND DISCUSSION

A. *Tensile strength and Hardness test*

Table VI. Experimental results of tensile strength and hardness

Ex.No	Weight percentage		Squeeze Time	Tensile Strength	Hardness
	SiC	Flyash	Min	MPa	HV
1	0.5	1	5	193.232	105
2	1	1	10	206.893	120
3	1	1	5	199.201	111
4	0.5	1	10	194.130	109

Tensile strength of the specimens obtained in the tests are tabulated in Table VI. This shows that the maximum tensile strength was 206 MPa for the sample of experiment 2 (19.5g, 10 min) and the minimum tensile strength was 193 MPa for the sample of experiment 1 (13g, 5 min). And the maximum hardness was 120 HV for the sample of experiment 2 (19.5g, 10 min) and the minimum hardness was 105 HV for the sample of experiment 1 (13g, 5 min).

B. *Analysis of S/N ratio*

In this study, Tensile strength and Hardness are considered the characteristic property based on which parameters of squeeze casting is optimized. Maximum tensile strength and hardness are desired so “Larger the Better” concept was adopted in the analysis using S/N ratio. Table VIII shows S/N ratio of aluminium Al6065 composite corresponding to experiments carried out as per L4 orthogonal array.

Table VII. Experimental results with SNR for response variable

Ex.No.	Weight percentage of SiC and flyash	Squeeze time	Tensile strength	SNRA1	Hardness	SNRA2
	%	min	MPa		HV	
1	13	5	193.232	45.7216	105	40.4238
2	19.5	10	206.893	46.3149	120	41.7981
3	19.5	5	199.201	45.9858	111	40.9065
4	13	10	194.130	45.7619	109	40.7485

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The best performance of squeeze casting process is indicated by the higher value of signal to noise ratio, thus the optimal level of process parameters is the level with the highest S/N value.

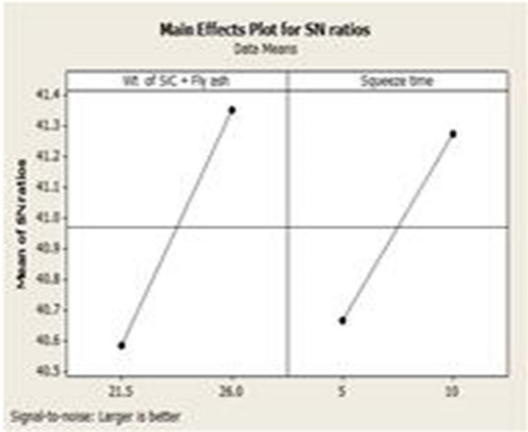

Fig. 5 Main effects plot on S/N ratio of Tensile strength

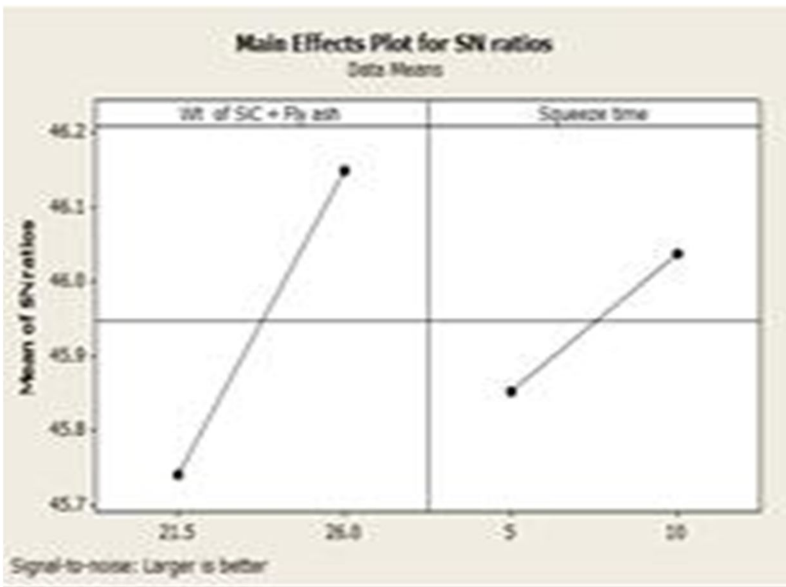

Fig 6 Main effects plot on S/N ratio of Hardness

C. Analysis of Variance (ANOVA)

Analysis of variance is carried out to know the significance of individual process parameters. Table IX shows the percentage contribution of each process parameter which is signified by column F. F-test is carried out to find the significant parameter affecting the tensile and hardness of casted aluminium Al6065 composite.

Table VIII.Analysis of variance for mean (Tensile Strength)

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Weight of SiC + Fly ash	1	87.72	74.52%	87.72	87.72	7.60	0.222
Squeeze time	1	18.45	15.67%	18.45	18.45	1.60	0.426
Error	1	11.54	9.81%	11.54	11.54		
Total	3	117.71	100.00%				

Table IX.Analysis of variance for mean (Hardness)

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Weight of SiC + Fly ash	1	100.00	55.55%	100.00	100.00	6.25	0.242
Squeeze time	1	64.00	35.57%	64.00	64.00	4.00	0.295
Error	1	16.00	8.88%	16.00	16.00		
Total	3	180.00	100.00%				

In Table VIII. F value indicates the percentage contribution of controllable process parameters to attain maximum tensile, whereas the P value indicates the probability of uncontrollable parameters which is indicated as noise. So it is desired to have maximum F value and minimum P value and the parameter which has less than 5%probability is considered as a significant parameter.

$$\% \, \boldsymbol{contribution} = \frac{\boldsymbol{Sum\ of\ square\ of\ variation}}{\boldsymbol{Total\ sum\ of\ square\ of\ variation}}$$

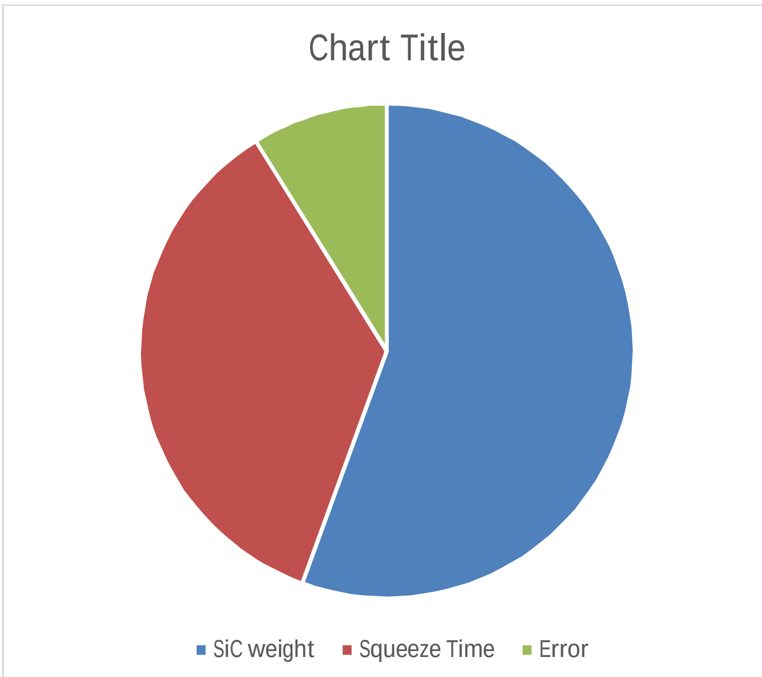

Fig 7. Contribution percentage of Hardness

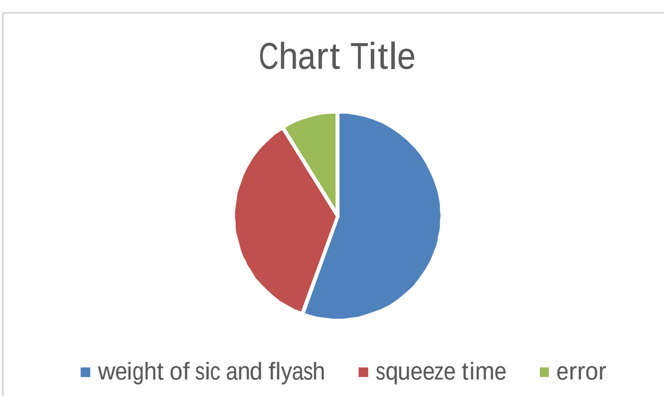

Fig. 8. Contribution percentage of Tensile Strength

V. CORROSION

A. Corrosion Rate

The casted samples are then placed in sodium chloride solution for investigating the corrosion property. By using the optical microscope and Image J software, the corroded area is calculated and the results are tabulated to calculate the contribution. In this study, corrosion rate was considered as one of the characteristic property based on which parameters of squeeze casting was optimized. "Smaller the Better" concept was adopted in the analysis using S/N ratio because corrosion is one of the microscopic defects for casted aluminium Al6065. Table 5.1 shows S/N ratio of casted aluminum Al6065 corresponding to experiments carried out as per L4 orthogonal array.

The corrosion rate of the specimen is dipped in NaCl solution and the weight loss is measured. It is calculated using the formula

$$mpy = 534\ x\ (W\ /\ DAT)$$

Where,

W = weight loss in milligrams

D = metal density in g /cm^3

A = area of sample in cm^2

T = time of exposure of the metal sample in hours

This shows that the maximum corrosion resistance was for the sample of experiment 3 (19.5g, 5 min) with the corrosion rate of 0.855 mpy and the minimum corrosion resistance for the sample of experiment 4 (13 g, 10 min) with the corrosion rate of 1.176 mpy.

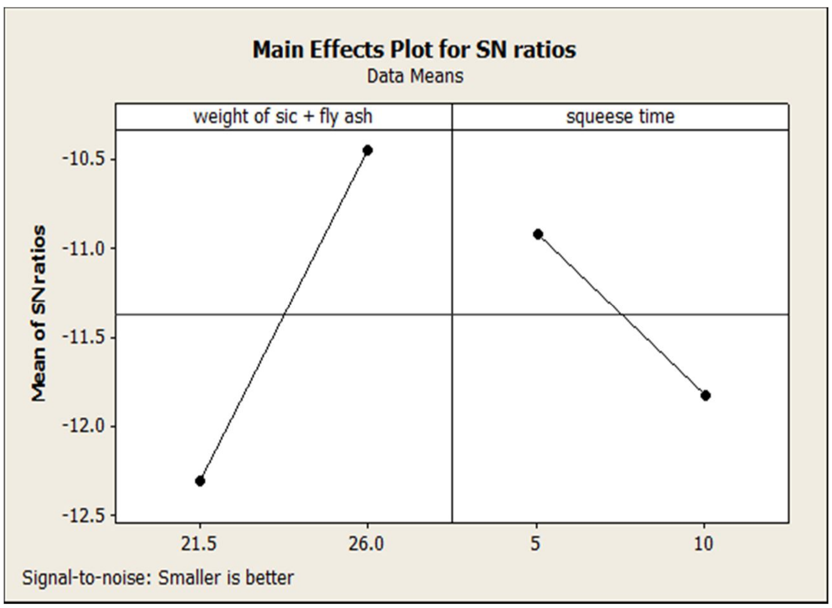

Fig.9. Main effects plot on S/N ratio of corrosion

From fig. 9. it is clear that the signal to noise ratio of reinforcement weight increases from 21.5g to 26g; hence the optimum weight percentage is 19.5g which has a maximum value. Similarly, the S/N ratio of squeeze time decreases from 5 min to 10 min so the optimum squeeze time is 5 min.

VI. CONCLUSION

A. The hybrid composite samples of Al 6065 as matrix, SiC and Fly ash particulates as reinforcements were produced using squeeze casting process. The mechanical properties such as tensile strength, hardness and corrosion rate were investigated from the produced samples.

B. Composite having 1% SiC ,1% Fly ash ,squeeze time 10 mins and 98% Al 6065 combination fabricated at melting temperature 750°C and reinforcement pre-heat temperature 900°C has higher tensile strength 206.893 N/mm^2 and hardness 120 HV compared to other combinations. The minimum Corrosion rate for Al 6065 composite is 3.055 mpy in combination of 1% SiC ,1% fly ash and squeeze time 5 mins. Whereas for others, the corrosion rate is maximum.

C. This hybrid composite can be explored for use in applications where higher strength and corrosion resistance is required.

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