Mechanical Characterization of Al 6082 ALLOY Reinforced with Al_2O_3 & AL_2SiO_5 Particulate's Hybrid Metal Matrix Composites Using Taguchi Method

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Abstract- Conventional monolithic materials have limitations in gaining proper combination of strength, hardness, stiffness, density and toughness. Metal matrix composites (MMC's) are most promising materials in application areas such as Automotive, aeronautical, marine etc. Metal matrix materials have high performance and better economic benefits. In this present research work Taguchi method is used to study the effects of different input process parameters namely wt. % of Al2O3, Stirring speed and stirring time on the Hardness, tensile and impact strength of stir casted Al6082/Al2O3/Al2SiO5.Taguchi's L9 orthogonal ray is used for experimental design and it shows wt. % of Al2O3 is higher influential parameter. Three process parameters i.e. wt. % of Al2O3 (3, 6, 9), stirring speed (150, 200, 250 rpm) and stirring time (5, 10, 15 min) are used to Fabricate samples of MMC's. Each parameter has 3 levels.

Key words- MMC's, Al6082, Al2O3 particulates, stir-casting, Taguchi method

I.INTRIDUCTION

Aluminium metal matrix composites (MMCs) have gained importance in various industries because of their good mechanical properties such as wear resistance, low density, high strength and good structural rigidity. Aluminium MMCs are most promising materials in the fields of aerospace, automotive, military, marine and in other domestic applications [MADEVA NAGARAL et al. (2013), Bharath V, et al.(2014), Dinesh Kumar Koli, et al (2014)].The low production cost and better mechanical properties of composites makes them very used in various applications in different areas from technological point of view [Dinesh Kumar, et al. (2014)].In AMMC's one of the constituent is aluminium, which forms continuous network and is termed as matrix phase. The other main constituent is embedded in this matrix phase and serves as reinforcement, which is usually non-metallic and commonly ceramic such as SiC, Al2O3 etc. These advantages can be used to achieve better properties.[Rajesh Kumar Gangaram Bhandare et al, (2014)]. According to the temperature of the metallic matrix during processing the fabrication of MMCs can be classified into three categories: (a) Liquid phase processes, (b) solid state processes, and (c) Two phase (solid-liquid) processes Stir Casting Process -Stir Casting is a liquid state method of composite materials fabrication, in which a dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix metal by means of mechanical stirring [Bhaskar Chandra Kandpal et al,(2013)].

Fig. 1 Stir casting facility

Stir casting method can be successfully used to fabricate MMC's with desired properties. Reinforcing Aluminium and its alloys with ceramics particles has shown an appreciable increase in its mechanical properties [Himanshu Kala et al. (2014)].[Shivaraja HB. et al, (2012), Dr. THoguluva Raghavan Vijayaram et al (2013)] has shown that the hardness increases with the increase in the reinforcement

weight fractions. And the presence of hard reinforcement particles in the matrix could impede the movement of dislocations since these particles are stronger than the matrix in which they are embedded.[Rachit Marwaha et al, (2013)] has used ANOVA to find the influenceof applied load, sliding speed, track diameter on wear rate.

[A. PAVAN KUMAR. et al (2013)] has used ANOVA method to optimize tensile strength and hardness of stir casted LM 26Al/RHA/RM hybrid composites and It was successful in predicting better parameters for highest tensile strength and hardness. [Lakhvir Singh, et al (2013)]: Has investigated theeffect of different input parameters i.e. particle sizesof alumina, wt. % of reinforcement, stirring time on Hardness, tensile strength and impact strength. Also contribution of these parameters was analysed by ANOVA. Results shows that all three parameters havea significant effect on the hardness, impact strength and tensile strength.

Investigation of mechanical behaviour of aluminium alloys reinforced by micro hard particles such as Al2O3 and Al2SiO5 is an interesting area of research. Therefore, the aim of this study is to investigate the effect of Al2O3 content on the hardness, tensile strength and impact strength of Al6068-4wt. % Al2SiO5 composites, made by stir casting method using Taguchi method by varying three parameters i.e. wt.% al2o3, stir speed and stir time.

II.EXPERIMENTATION

A. Composite Preparation

In this study Al6082 is used as a matrix, Alumina (Al2O3) up to 9 wt. % and Aluminium silicate (Al2SiO5) 4 Wt. % particulates were used as reinforcements to Fabricate hybrid metal matrix composite. Chemical composition of Al6082 Alloy by wt. % is shown in table 1.

TABLE I Chemical composition of Al6082 Alloy by Weight Percentage

Alloy Elements	% present
Silicon(Si)	0.7-1.3
Magnesium(Mg)	0.6-1.2
Manganese (Mn)	0.4-1
Iron(Fe)	0.0-0.5
Chromium (Cr)	0.0-0.25
Zinc (Zn)	0.0-0.20
Others (Total)	0.0-0.15

Stir casting, powder metallurgy, spray deposition, liquid metal infiltration, squeeze casting are the methods available for the production of hybrid MMC's. Even though various techniques are there for particle reinforced MMC's, stir casting is the technique is very simple, flexibility, inexpensive.

In this study Al6082 was used as matrix material and aluminium silicate or Al2SiO5 (30micron) of constant 4 wt. % and alumina or Al2O3(25 micron) up to 9 wt. % were used for the preparation of MMC's. Three different wt. % 3, 6 and 9 used with different speeds i.e. 150, 200, 250 and varying stirring time i.e. 5, 10, and 15 minutes used synthesis of the Metal Matrix composites. The aluminium metal matrix composites were prepared by stir casting route. Al6082 was melted using graphite crucible in the Electric furnace at 750ºC temperature. The reinforcements Al2O3 and Al2SiO5 were preheated at 300ºC temperature for 1 hr. The stirrer also preheated. Degassing was done by using solid Hexachloroethane (C2Cl6).

Preheated reinforcement particles of size 30 μm were introduced to the vortex of the molten base alloy was made in steps of 3. i. e Required wt. % of reinforcement required was being introduced into melt 3 times. and mechanical stirring was achieved for required period of time by using Zirconia-coated steel impeller. And was placed at 2/3 height of the molten metal from the datum crucible and run at required speeds. A pouring temperature of 7500C was taken and the molten composite was poured into cast iron mould of required size. Thus, composites containing 4 wt.% of Al2SiO5 particles and 3, 6, and 9wt % of Al2O3 were obtained.

B.Taguchi technique for DOE

In this study Taguchi method used, as it is a problem-solving tool which improve the performance of products, process design and system. This method integrates the experimental and analytical concepts to decide the most influential process parameter on result response for extensive improvement in overall performance. Design of experiments is a technique which is used to define and to investigate all possible conditions involving multiple factors, parameters and variables in an experiments. A three level L9 3^3 orthogonal array was selected. To determine most influential parameters in preparation of MMC's namely (1) wt. % of reinforcement, (2) stirring speed, (3) stirring time each at three process levels were considered and are as shown below table 3.

Table II Process parameters and levels

Sl No	Factor's (Units)	Parameter designation	Level 1	Level 2	Level 3
1	Wt. % of reinforcement	A	3	6	9
2	Stirring speed	B	150	200	250
3	Stirring time	C	5	10	15

TABLE III Mean of hardness, impact and tensile strength

Trai l No	A	B	C	Mean Hard ness (RHN)	Mean impact strength (J)	Mean tensile strength (N/mm^2)
1	3	150	5	77	7.6	144.47
2	3	200	10	80	8	162.86
3	3	250	15	85	10	165.26
4	6	150	10	88	17	170.16
5	6	200	15	95	14	190.32
6	6	250	5	90	12	194.96
7	9	150	15	93	8	183.03
8	9	200	5	81	9	172.64
9	9	250	10	96	14	176.07

In this study nine different composites werefabricated with distinct process parameters and at different process levels. The effect of these process parameters on Hardness, Tensile strength and Impact strength of MMC's were analysed using Analysis of Variance (ANOVA).

Degree Of Freedom (DOF) = number of levels -1-(1)
For each factor, DOF equal to: For A; DOF = 3-1=2
For B; DOF = 3-1= 2 For C; DOF = 3-1=2

The total degree of freedom is calculated as: Total DOF=No. of experiments -1 (2)
The total DOF for the experiment is DOF= 9-1 = 8
Taguchi method gives the importance of studying the response variation using the signal – to – Noise (S/N) ratio, resulting in minimization of quality characteristic variation due to uncontrollable parameter. The responses considered with the concept of "the larger-the better". The S/N ratio used for this type of response is shown below.

TABLE IV S/N for hardness, impact and tensile strength

Trai l No	A	B	C	S/N Ratio Hardness	S/N Ratio impact strength	S/N Ratio tensile strength
1	3	150	5	37.7298	17.616	43.195
2	3	200	10	38.0618	18.061	44.236
3	3	250	15	38.5884	20	44.363
4	6	150	10	38.8897	24.609	44.617
5	6	200	15	39.5545	22.922	45.589
6	6	250	5	38.0849	21.583	45.798
7	9	150	15	39.3697	18.061	45.250
8	9	200	5	38.1697	19.084	44.742
9	9	250	10	39.6454	22.922	44.913

$S/N = -10\log\left(\frac{1}{N}\sum\frac{1}{y^2}\right)_{10}$

The S/N ratio was calculated for hardness, impact strength and tensile strength in each of the nine conditions to see the effects of each parameters on the response.

II.RESULT AND DISCUSSION

The hardness value for unreinforced composite was65 RHN. An average hardness value from 77RHN to 96 RHN were obtained for the Al2O3/Al2SiO5particles reinforced Hybrid composites. The presence of stiffer and harder Al2O3 reinforcements leads to the increase in constraint to plastic deformation of the matrix during the hardness test. Hardness of Al6068 increases with the increase in addition of Al2O3/Al2SiO5reinforcements.Overall increase in hardness of composites

The hardness, impact strength and tensile strength of the composites were measured in three trails. The mean of these values is as shown in below Table 3

A. Effect of wt. % of reinforcement, stir speed and stirtime on Hardness

The ANOVA results tabulated below for Hardness of the MMC's shows the effect of each process parameter at each process level on the response.

Table V Mean S/N ratio for Hardness

Level	Wt. %	Stir speed	Stir time
1	38.13	38.66	38.33
2	39.18	38.60	38.87
3	39.06	39.11	39.17
Delta	1.05	0.51	0.84
Rank	1	3	2
Total	6		

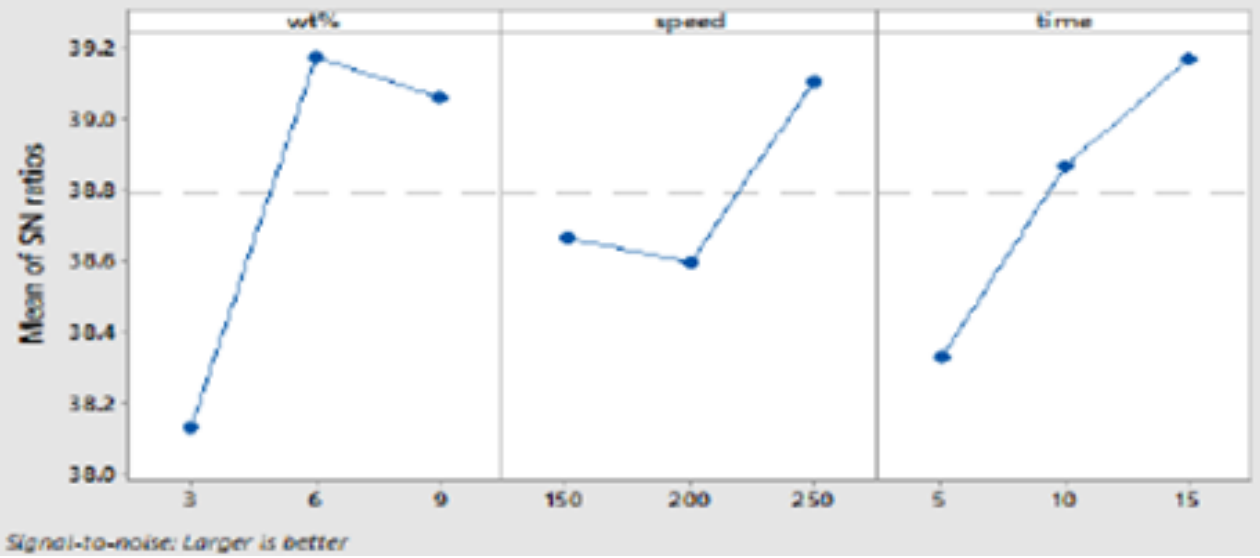

Fig. II Effect of wt. % of reinforcement, stir speed and stir time on Hardness

*1.Effect of wt. % of Al2O3 and Al2SiO5 as reinforcement***:** From the fig4.2 it is clear that with increase in wt. % of Al2O3 as reinforcement increases the hardness of the composites upto 6 wt. %. For the further increase in wt. % of reinforcement, the hardness of the material start decreases considerably. Hence, the composite with 6 wt.% Al2O3 and 4 wt. % Al2SiO5 shows the maximum hardness.

2.Effect of stir speed: From the fig4.2 it is clearthat with increase in stir speed there is a decrease in hardness of the material upto 200 rpm. And for the further increase in stir speed, hardness increases considerably. The hardness of the material is maximum for the stir speed 250rpm.

3.Effect of stir time: From the fig 4.2 it is clear that the hardness of the material shows maximum for 15 min of mechanical stirring. Hence, more the stirring time better the hardness of the material as it provides sufficient time for uniform distribution of the reinforcements in the matrix.

Analysis of Varience (ANOVA) for Hardness of the Composites

The Analysis of variance (ANOVA) was applied to study the contribution of all parameters.Table 6 shows the ANOVA results for the S/N ratio for the hardness of the composite.

Table IV ANOVA for S/N ratio for hardness of composites

Factor	Degree of freedom	Sum of squares	Mean square= Sum of square/DOF	F-Rati o	Contribution
A	2	1.26	0.63		
B	2	0.9	0.45		
C	2	1.73	0.86		
Error					

The highest rank 1 of wt. % signifying the highest contribution about **.** % in the hardness ofcomposites. After that stirring time showed its contribution up to **.** %. At last stirring speed showed up to **.** % contribution in the hardness.

A. Effect of wt. % of reinforcement, stir speed and stirtime on impact strength

The ANOVA results tabulated below for impactstrength of the material shows the effect of each process parameter at each process level on the response

Table VII Mean S/N ratio for impact strength

Level	Wt. %	Stir speed	Stir time
1	18.56	20.10	19.43
2	23.04	20.02	21.86
3	20.02	21.50	20.33
Delta	4.48	1.48	2.44
Rank	1	3	2

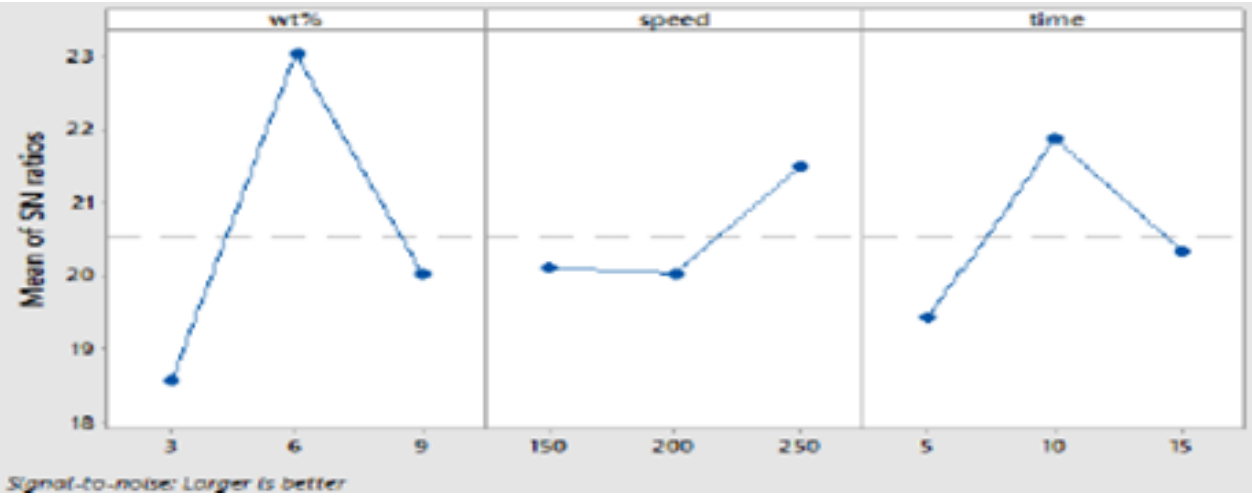

Fig. III Effect of wt. % of reinforcement, stir speed and stir time on impact strength

1.Effect of wt. % of Al2O3 and Al2SiO5 as reinforcement: From the Fig4.4 it is clear that with increase in wt. % of Al2O3 as reinforcement increases the impact strength of the material upto 6 wt. % Further increase in wt. % of reinforcement, the impact strength of the material start decreasing slowly. Hence, the composite with 6 wt. % Al2O3 and 4 wt. % Al2SiO5 shows the maximum impact strength.

2.Effect of stir speed: From the Fig4.4 it is clear that with increase in stir speed there is a considerable increase in impact strength of the material. The impact strength of the material is maximum for the stir speed 250rpm.

3.Effect of stir time: From the Fig 4.4 it is clear that the impact strength of the material showsmaximum for 10 min stirring. Hence, optimum stirringtime better the impact strength of the material as it provides sufficient time for uniform distribution of the reinforcements in the matrix.

Analysis of Varience (ANOVA) for Impact strengthof the Composites

The Analysis of variance (ANOVA) was applied to study the contribution of all parameters. Table 6 shows the ANOVA results for the S/N ratio for the impact strength of the composite.

TABLE VIII ANOVA for S/N ratio for impact strength of composites

Factor	Degree of freedom	Sum of square	Mean square= Sum of square /DOF	F-Rati o	Contribution
A	2	15.95	7.97		
B	2	24.87	12.43		
C	2	3.71	1.85		
Error					
Total	6				

The highest rank 1 of wt. % signifying the highest contribution about **.** % in the hardness of composites. After that stirring time showed its contribution up to **.** %. At last stirring speed showed up to **.** % contribution in the tensile strength.

D. Effect of wt. % of reinforcement on stir speed andstir time on tensile strength

The ANOVA results tabulated below for the Tensile strength of the material shows the effect of each process parameter at each process level on the response

TABLE IX Mean S/N ratio for tensile strength

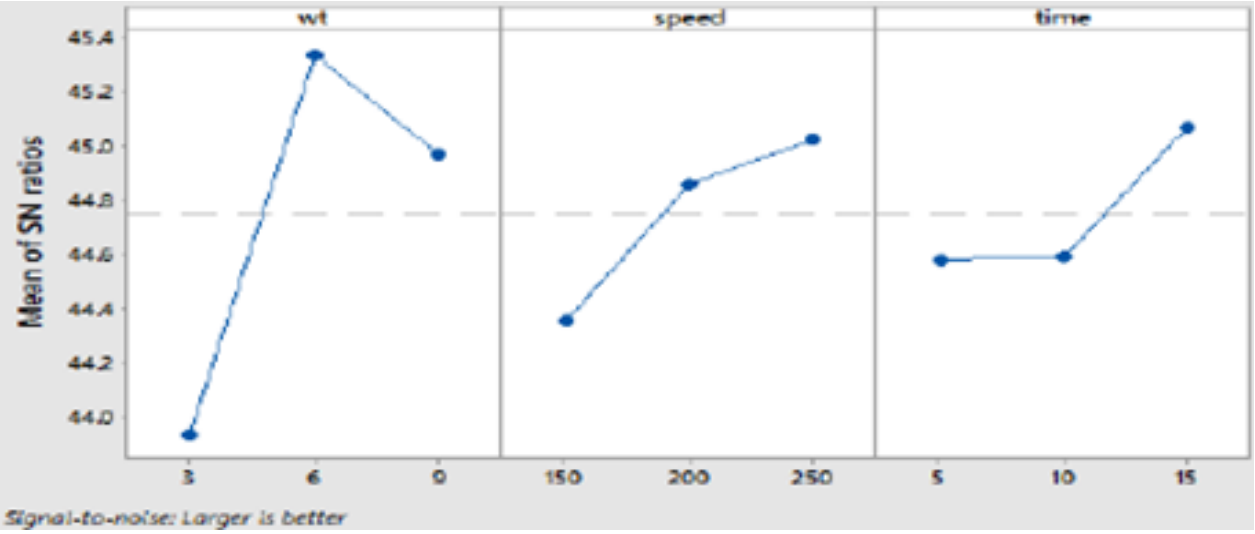

Fig. IV Effect of wt. % of reinforcement, stir speed and stir time on tensile strength

1.Effect of wt. % of Al2O3 and Al2SiO5 as reinforcement: From the fig4.3 it is clear that with increase in wt. % of Al2O3 as reinforcement increases the tensile strength of the material up to 6 wt. %. Further increment in wt. % of reinforcement, the tensile strength of the material start decreasing slowly. Hence, the composite with 6 wt. % Al2O3 and 4 wt.% Al2SiO5 shows the maximum tensile strength.

2.Effect of stir speed: From the fig4.3 it is clear that the tensile strength of the material increases a stir speed increase and is maximum for stir speed of 250 rpm. Hence, more the stirring speed, tensile strength of the material gives higher tensile strength.

3.Effect of stir time: From the fig 4.3 it is clearthat the tensile strength of the material shows maximum for 15 min of mechanical stirring. Hence, more the stirring time better the tensile strength of the material as it provides sufficient time for uniform distribution of the reinforcements in the matrix.

Analysis of Varience (ANOVA) for Tensile strengthof the Composites

The Analysis of variance (ANOVA) was applied to study the contribution of all parameters. Table 6 shows the ANOVA results for the S/N ratio for the tensile strength of the composite.

TABLE X ANOVA for S/N ratio for tensile strength of composites

Level	Wt. %	Stir speed	Stir time
1	43.93	44.35	44.58
2	45.34	44.86	44.59
3	44.97	45.03	45.07
Delta	1.40	0.67	0.49

Factor	Degreeof freedom	Sum of square	Mean square=Sum of square/DOF	F- Ratio	Contributionn
A	2	2.50	1.25		
B	2	1.19	0.59		

C	2	0.73	0.36		
error					
Total	6				

The highest rank 1 of wt. % signifying the highest contribution about **.** % in the hardness of composites. After that stirring speed showed its parameters on mechanical properties ofMMC's.
The S/N ratio's shows the effects of all process parameters at all process levels on All the mechanical properties of MMC's investigated in this study.
contribution up to **.** %. At last stirring time showed up to **.** % contribution in the tensile strength.

CONCLUSION

In this present work, Hardness, Tensile strength and impact strength test were conducted on Al6082 based Al2O3 and Al2SiO5 metal matrix composites. And were fabricated using stir casting method by incorporating ANOVA method by varying three different parameters i.e wt. % of Al2O3, Stir speed and Stir time. Effects of these parameters on mechanical properties were analysed.

1. All the composites were successfully casted using stir casting procedure.
2. The composites mechanical properties were increased with the increase in addition of reinforcements.
3. The maximum hardness of Al6082- Al2O3/ Al2SiO5 hybrid composite material can be obtained for 6 wt. % of Al2O3, 250 rpm stir speed and 15 min of stirring. Also, the hardness of the material depends more on wt. % of reinforcement, the next is stir time and the last is the stir speed.
4. The maximum tensile strength of Al6082- Al2O3/ Al2SiO5 hybrid composite material can be obtained for 6 wt. % of Al2O3, 250 rpm stir speed and 15 min of stirring. Also, the tensile strength of the material depends more on wt. % of reinforcement, the next is stir speed and the last is stir time.
5. The maximum impact strength of Al6082- Al2O3/ Al2SiO5 hybrid composite material can be obtained for 6 wt. % of Al2O3, 250 rpm stir speed and 10 min of stirring. Also, the impact strength of the material depends more on wt. % of reinforcement, the next is stir time and the last is stir speed.
6. The tensile strength, hardness and impact energy of Al 6082 alloy without reinforcement was 108.7 N/mm2, 65 RHN and 4 J respectively and that for Al 6082 reinforced with Al2O3 and Al2SiO5 are increased to 194.96N/mm2, 96 RHN and 27 J.
7. Analysis of variance (ANOVA) investigated the contribution of contributions of process

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