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WEAR STUDY OF STIR CAST AA7075 METAL MATRIX COMPOSITES AND OPTIMIZATION OF WEAR USING GREY RELATIONAL ANALYSIS

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ABSTRACT

Aluminium Metal Matrix Composite is relatively new material that has proved its position in aerospace, automobile industries and other engineering design application due to their low density and strong corrosion resistance and wear resistance, higher hardness, low thermal coefficient of expansion as compared to conventional metals and alloys. Need for improved performance has led to the design and selection of newer variants of the composites. Present work is focused on the machining and preparation of AA7075/SiCp composites produced by the stir casting process by taking different Reinforcement % of SiCp by weight (0, 5, 7.5, and 10).Hardness Test and Wear test calculations performed on the samples obtained by the stir casting process. For wear testing a plan of experiment based on L16 Taguchi orthogonal array is used to acquire the wear data. Grey relational analysis approach is used for optimization of aluminium based metal matrix composite to determining metal matrix properties with certain chemical composition and identifies the most significant process parameters which will affect the properties. After that conduct the conformation experiment by using optimal combination of process parameters and verify the results. An analysis of variance is employed to investigate the influence of four controlling parameters, viz., SiCp content, normal load, sliding distance & sliding speed on dry sliding wear of the composites. It is observed that SiCp content, sliding distance, and Sliding Speed significantly affects the dry sliding wear while Normal Load effect on wear is almost negligible. The minimum wear is obtained by four controlling parameters of optimal combinations. At last the micro-structural study of the wear surface and composites indicates the nature of wear to be mostly adhesive & distribution of the particles in the composites.

I.INTRODUCTION

The application of Metal Matrix Composites (MMCs) as structural engineering materials has received increasing attention in recent years. MMCs exhibit significantly higher stiffness and mechanical strength compared to matrix alloys, but often suffers from lower ductility and inferior fracture toughness. MMC brings the ability to withstand higher tensile and compressive stresses by the transfer and distribution of an applied load from the ductile matrix to the reinforcement material. This load transfer is only possible due to the existence of ameter facial bond between the reinforcement elements and the matrix material. Therefore, appropriate selection of reinforcement material and its properties coupled with a good fabrication method. Stir casting technology is considered to have the most potential for engineering applications in terms of production capacity and cost efficiency. Casting techniques are economical, easier to apply and more convenient for mass production with regard to other manufacturing techniques. There are also various types of the reinforcement material continuous and discontinuous fiber and particle .Although the mechanical properties of the MMC with discontinuous fiber or particles (DRMMC), are not as good as those of continuous fiber reinforced composites, the isotropic properties and low cost of DRMMCs make them potentially useful materials. Silicon carbide and aluminum alloys have been widely used as reinforcement and matrix material respectively, because of the compatibility between these materials, and their potential properties when combined. The main factors controlling the properties of MMC's fabricated using casting techniques include: reinforcement distribution, wetting of reinforcement by matrix alloy, reactivity at the reinforcement/matrix interface and porosity content in the solidified casting. The effective introduction of a reinforcement element into the liquid matrix is difficult owing to insufficient wetting of the ceramic particles by the liquid alloy. Increasing the liquid temperature, coating or oxidizing the ceramic particles, adding some surface active elements such as magnesium or lithium into the matrix and stirring the molten matrix alloy for an adequate time during incorporation are some ways of improving the wettability and making the mixing and retention of the ceramic particles easier. The selection of high silicon content aluminum alloy was found to delay the chemical reaction whereas the use of inert atmosphere, and the controlled stirring parameters was found.

II.MATERIAL SELECTION

The aim of designing metal matrix composite materials is to combine the desirable attributes of metal and ceramics The addition of high strength, high modulus refractory particles to a ductile metal matrix will produce a material whose mechanical properties are intermediate between the matrix alloy and the ceramic reinforcement.Ceramics are normally stiff and strong, but brittle for example, aluminium and silicon carbide have very different mechanical properties with young‘s modulus of 70Gpa and 400Gpa, coefficients of thermal expansion of 24 x 10^6/°C and 4 x 10^6/°C , and yield strength of 350 Mpa and 600 Mpa respectively By combining these materials e g AA7075 (at T6condition) with 17 volume fraction of SiC particle, a MMC with Young‘s modulus of 96.6 Gpa , and yield strength of 510 Mpa can be produced by carefully controlling the relative amount and distribution of the ingredients of the composites, as well as the processing conditions these properties can be further improved. There are a number of criteria that need to be considered before a right selection of the material can be made Some of these criteria are inter-related several criteria for the selection of matrix and reinforcement materials are as follows: i) Compatibility ii) Thermal properties iii) Fabrication method iv) Application v) Cost vi) Properties vii) Recycling.

Chemical Composition of AA7075Aluminium Alloys:-

Table 1: Chemical Composition of AA7075 **Aluminium Alloys**

Element	**Mn**	**Fe**	**Mg**	**Si**	**Cu**	**Zn**	**Ti**	**Cr**	**Al**
Weight (%)	0.3	0-0.5	2.1-2.9	0.4	1.2-2	5.1-6.1	0-0.2	0-0.28	Balance

III.EXPERIMENTAL DESIGN AND OBSERVATION

Stir casting apparatus

This is the layout of the stir casting apparatus. It consist of conical shaped graphite crucible is used for fabrication of AMCs, as it withstands high temperature which is much more than required temperature [680°C].Along that graphite will not react with aluminum at these temperature. Around which heating element of wound. The coil which acts as heating element is Kanthol-A1. This type of furnace is known as resistance heating furnace. It can work up to 900°C reach within 45 min. Aluminium, at liquid stage is very reactive with atmospheric oxygen. Aluminium, at liquid stage in contact with the open air causes oxide formation. All the process of stirring is carried out in closed chamber. Closed chamber is formed with help of steel sheet. A K type Temperature thermocouple whose working range is -200°C to 1250°C is used to record the current temperature of the liquid. Due to corrosion resistance to atmosphere SS is selected as stirrer shaft material. One end of shaft is connected to 0.5 hp PMDC motor with flange coupling. While at the other end blades are welded. 3 blades are welded to the shaft at 45°C. A constant feeding rate of reinforcement particles is required to avoid coagulation and segregation of the particles. This can be achieve by using hopper. Aluminum alloy matrix will be formed in the crucible by heating aluminum alloy ingots in furnace. A stirring action is done in between 300 to 600 rpm with speed controller. A mixture of reinforcements (SiC) is to be incorporated in the metal matrix at semisolid level near 640°C. Dispersion time is to be taken as 5 minutes. After that slurry is reheated to a temperature above melting point to make sure slurry is fully liquid and then it is poured in mould.

Figure 9::Casting after solidification Cast work piece

IV. Design of Experiments:

In the present experimental study, four parameters such as Sliding distance, Cutting velocity, Load and Sliding Speed have been considered as process variables with 4,4,4,4 levels respectively. The levels have been so selected based on the effects of these parameters on the outputs and trial and error tests were conducted for deciding the values for the input variables. Experiments have been carried out using partial factorial experimental design, which consists of 16 combinations of Sliding distance, Load and Sliding Speed.

Process parameters	1	2	3	4
Reinforcement (SiC % by Vol.)	0	5	7.5	10
Load (N)	5	10	15	20
Sliding Distance (m)	500	1000	1500	2000
Sliding Speed (m/min)	179	239	298	358
Cutting velocity	0.75	1	1.25	1.50

Various levels for design of experiments

Experiment	P1	P2	P3	P4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	2	1	2	3
6	2	2	1	4
7	2	3	4	1
8	2	4	3	2

9	3	1	3	4
10	3	2	4	3
11	3	3	1	2
12	3	4	2	1
13	4	1	4	2
14	4	2	3	1
15	4	3	2	4
16	4	4	1	3

V. RESPONSE VARIABLES AND MACHINING PARAMETERS

The following are 3 input parameters are considered for the machining of the Hybrid Metal Matrix Composite (HMMC).Pulse on time is outlined because the time throughout that the machine is performed.The machining method become quicker once increasing the pulse on time the metal removal rate increase and poor surface finish on the fabric surface conjointly given within the pulseon time process.Pulse off time method is that the time throughout that re-ionization of the dielectric takes place.An insufficientoff time will results in erratic cycling and retraction of the advancing servo thereby speed down the operation cycle.The main reason for selecting the pulse on/off time is to fixing the time.This is the most reason for selecting pulse ON/OFF time.This is the amount of power used in discharge machining, measured in units of ampere, and is the most important machining parameter in EDM.In every on-time probe the current increase till it reaches a present level, which is expressed as the peak current.Highervoltage of current results in rough surface finish operations and wider creators on work material.Its higher data improves MRR, but at the cost of surface finish and tool wear.The machined cavity could be a reproduction of tool electrode and excessive wear can hamper the accuracy of materials.

Input Parameters	**Current (Amps)**	**Pulse On Time (µS)**	**Pulse Off Time (µS)**
RANGE	10-20	40-60	7-9

Optical Microscopy Test:

The microstructures at different magnifications in figures 18, 19, 20 and 21 are clearly shows grain boundaries. The grains are observed to be of a varied size range. The shape of the grains is found to be in the form irregular polygons. The microstructure consists of equiaxed grain with grain size No: 6 to 7 in the matrix. Precipitates can be observed along the grain boundary in the microstructure. These dots are carbide inclusions. The inclusions observed are of a fairly narrow size range and are randomly distributed. The precipitates differ a lot in the size; some of them are very large when compared to others, which are very small.

Density Test

Density (g/cc)	0%	5%	7.5%	10%
Theoretical Density	2.81	2.8245	2.83175	2.839
Experimental Density	2.773	2.789	2.8006	2.7822

Process Parameter and Their Levels: -

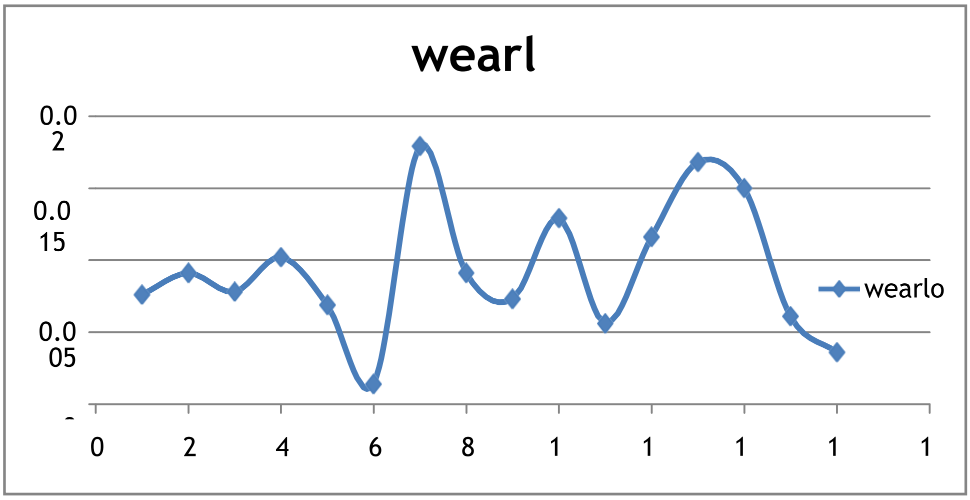
Process parameters and their levels of present study are listed in Table 19.

Process parameters	1	2	3	4
Reinforcement (SiC % by Vol.)	0	5	7.5	10
Load (N)	5	10	15	20
Sliding Distance (m)	500	1000	1500	2000
Sliding Speed (m/min)	179	239	298	358
Cutting velocity	0.75	1	1.25	1.7

Design of Experiment for Wear Test:-
Responses measured after experiment

S.No	Cutting velocity n/s)	Load I)	Sliding distance n)	Reinforce ent (%)	Speed pm)	T(s)	M1	M2	wear ss(gm)
1	0.75	5	500	0	179	11.11	2.7611	2.7535	0.0076
2	0.75	10	1000	5	179	22.22	1.5574	1.5483	0.0091
3	0.75	15	1500	7.5	179	33.33	3.5285	3.5202	0.0078
4	0.75	20	2000	10	179	44.44	3.095	3.0848	0.0102
5	1	5	1000	7.5	239	16.67	3.5128	3.5059	0.0069
6	1	10	500	10	239	8.33	3.078	3.0766	0.0014
7	1	15	2000	0	239	33.33	2.755	2.7371	0.0179
8	1	20	1500	5	239	25	1.5374	1.5283	0.0091
9	1.25	5	1500	10	298	20	3.0747	3.0674	0.0073
10	1.25	10	2000	7.5	298	26.67	3.5219	3.509	0.0129
11	1.25	15	500	5	298	6.67	1.5522	1.5466	0.0056
12	1.25	20	1000	0	298	13.33	2.731	2.7194	0.0116
13	1.5	5	2000	5	358	22.22	1.548	1.5312	0.0168
14	1.5	10	1500	0	358	16.67	2.739	2.725	0.014
15	1.5	15	1000	10	358	11.11	3.0636	3.0575	0.0061
16	1.5	20	500	7.5	358	5.56	3.4986	3.495	0.0036

Taguchi based Grey Relational Analysis to Optimize the Multi Response Problem:



Optimization of Control Factor based on their Response Table and Discussion:-

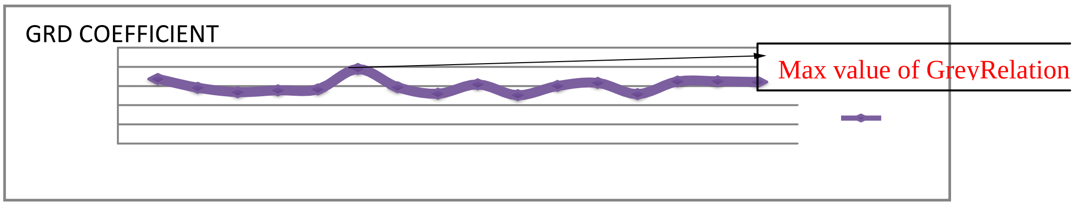
M	0.77561	0.81951	0.7561	0	0.83902	1	0.33171	0.58537	0.53659	0.62927	0.86829
hardness	0	0.29851	0.52239	1	0.52239	1	0	0.29851	1	0.52239	0.29851
Density	1	0.66047	0.32558	0	0.32558	0	1	0.66047	0	0.32558	0.66047

Table 12: Data Pre-Processing Results

Grey Relational co-efficient, Grade and Order: -

grey relational coefficient			grey relational grade	grey relational order
m	Hardness	density		
0.69023569	0.333333333	1	0.674523008	**2**
0.734767025	0.416149068	0.595567867	0.58216132	**10**
0.672131148	0.511450382	0.425742574	0.536441368	**13**
0.333333333	1	0.333333333	0.555555556	**12**
0.756457565	0.511450382	0.425742574	0.564550174	**11**
1	1	0.333333333	0.777777778	**1**
0.427974948	0.333333333	1	0.58710276	**9**
0.546666667	0.416149068	0.595567867	0.519461201	**14**
0.518987342	1	0.333333333	0.617440225	**7**
0.574229692	0.511450382	0.425742574	0.503807549	**16**
0.791505792	0.416149068	0.595567867	0.601074242	**8**
0.567867036	0.333333333	1	0.633733456	**6**
0.535248042	0.416149068	0.595567867	0.515654992	**15**
0.611940299	0.333333333	1	0.648424544	**4**
0.615615616	1	0.333333333	0.64964965	**3**
0.990338164	0.511450382	0.425742574	0.642510373	**5**

GRD vs No of experiments



Factor	Type	Levels	Values
C1	fixed	4	0, 5, 7.5, 10 **(Reinforcement in terms of weight %)**
C2	Fixed	4	5, 10, 15, 20 **(Load in Newton)**
C3	Fixed	4	500, 1000, 1500, 2000 **(Sliding Distance in meter)**
C4	Fixed	4	0.75, 1, 1.25, 1.5 **(Sliding Speed in m/s)**

C7 versus C1, C2, C3, C4 (for selection of most significant factor)
Where C1, C2, C3 & C4 are the process parameters,
C5 Response 1 (Wear rate) C6 Response 2 (density) C7 Response 3 (hardness)
Variance for S/N ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
cutting velocity	3	22.95	22.95	7.650	2.03	0.288
Load	3	10.60	10.60	3.534	0.94	0.521
sliding distance	3	267.38	267.38	89.127	23.63	0.014
reinforcement	3	131.41	131.41	43.802	11.61	0.037
Residual Error	3	11.32	11.32	3.772		
Total	15	443.66				

S = 1.942 R-Sq = 99.4% R-Sq(adj) = 98.2%

Response Table for Means

Level	Cutting velocity	Load	sliding distance	reinforcement
1	0.008675	0.009650	0.004550	0.012775
2	0.008825	0.009350	0.008425	0.010150
3	0.009350	0.009350	0.009550	0.007800
4	0.010125	0.008625	0.014450	0.006250
Delta	0.001450	0.001025	0.009900	0.006525
Rank	**3**	**4**	**1**	**2**

VI. Experimental values:

The following Table (2) shows the values obtained for the experiments carried out in EDM

Mathematical Model for Material Removal Rate (MRR)

MRR = -1.08447 + 0.019807*A + 0.018719*B + 0.12735*C + 1.37500E-004*A*B - 1.27500E-003*A*C - 1.01500E-003*B*C - 5.34400E-004 *A2 - 1.08350E-004*B2 - 3.68500E-003*C2

Mathematical Model for Surface Roughness

S.R = -5.38675 + 2.57685*A + 2.55600*B -16.22325*C - 0.012600*A*B + 0.056500*A*C + 0.036000*B*C - 0.068870*A2 - 0.026842*B + 0.84325*C2

Where ,

A = Current in Amps.

B = Pulse on time in µs

C = Pulse off time in µs

Experimental Values Std	**Run order**	**Current (Amps)**	**Pulse on time (µs)**	**Pulse off time (µs)**	**MRR (g/min)**	**SR (µm)**
1	1	15	50	8	0.0852	14.5
4	2	15	60	9	0.0872	11.43
8	3	20	40	8	0.0365	11.53
13	4	10	50	7	0.0612	10.59
3	5	10	40	8	0.0564	8.49
10	6	15	40	7	0.0325	14.36
11	7	10	60	8	0.0704	9.67
15	8	20	60	8	0.078	10.19
7	9	15	50	8	0.085	14.46
16	10	10	50	9	0.0586	11.53
9	11	15	60	7	0.0981	12.55
12	12	15	50	8	0.0842	14.54
6	13	20	50	7	0.0891	14.9
17	14	15	40	9	0.0622	11.8
2	15	15	50	8	0.0847	14.23
5	16	15	50	8	0.0835	14.15
14	17	20	50	9	0.061	16.97

Confirmatory Test

Current (Amps)	Pulse on time (µs)	Pulse off time (µs)	MRR (g/min)	SR (µm)
13	50	8	0.0821	10.3

Table 4 Confirmation test values

We can find out the effect of factors on response by analysis of variance. From the table 5.10 it is clear that sliding distance have maximum effect on wear. Speed and load also have some effect on wear followed by reinforcement but distance has a very less effect on wear.

CONCLUSIONS

The present work has successfully demonstrated the production of aluminum 7075 based metal matrix composites with % of SiCp by weight as reinforcement through stir casting process. Physical and mechanical characteristics of produced composites and the application of Taguchi based Grey relational analysis for multi-objective optimization of process parameters in mechanical and physical characterization study of Aluminum 7075-based metal matrix composites has been studied and analyzed. The conclusions of the present work are as follows:-

1) An attempt has been made to fabricate samples of AA7075-based metal matrix composites by varying % of SiCp by weight through stir casting process.
2) Hardness of the cast sample is studied and found to be increasing with increasing % ofSiCp by weight.
3) The highest Grey relational grade of 1 is observed for the experimental run 6, shown in response table (Table No. 14) of the average Grey relational grade, which indicates that the optimal combination of control factors and their levels are 10% SiC, 10N load, 500m Sliding distance and 358rpm Sliding speed.
4) The order of importance for the controllable factors to the minimum wear, density and maximum hardness in sequence, is the Reinforcement %, Sliding Speed, Load and Sliding distance; order to the minimum wear, in sequence is the Reinforcement %, Sliding Speed, and Load.As Sliding distance is almost affecting the wear.
5) From the Taguchi based Grey Relational analysis the optimal combination of process parameters for minimum wear, density & maximum hardness is found to be A2B1C4D4, i.e., higher reinforcement (% of SiC by weight), along with lowest level of applied load, sliding speed and sliding distance. With this combination we found that the wear is less than other all experimental value in the DOE.
6) From the microstructure study of wear surface and distribution of Reinforcement particles it is observed that mostly wear due to adhesive wear mechanism which has occurred on the wear track and also some traces of abrasive wear mechanism .
7) Reinforcement particles are uniformly distributed up to 10% and after that higher density particles are segregated somewhere in the metal matrix composites.

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