Optimization of Stir Cast Process Parameters for Better Mechanical Properties

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Abstract— **Stir casting for HMMC fabrication is known to defeat the defects that acquire during the conventional casting processes. The near-net shape manufacturing ability and potential to yield higher hardness are the capability of the stir casting provided technical parameters are accurately controlled. In this research, optimization technique for stir casting process parameter is established by Taguchi technique to explore the correlation among the hardness and tensile strength. Three different process parameters namely melt temperature, die temperature and stir pressure, were selected to perform the experiments using L9 orthogonal array. The composites obtained for optimum cast conditions were melting temperature 750 oC, stirrer speed 500RPM and stirrer duration 7 min exhibited better hardness and tensile strength. The identified process parameters provide a favorable condition for processing the alloys directly on the melt up to the time of complete solidification. The results indicate that there exists a strong correlation between hardness and tensile strength.**

Keywords—Stir casting, Process parameters,Taguchi,

I. INTRODUCTION

Composites are usually products which manufactured from several chemically distinctive constituents, on the macro-scale, having a definite program separating them. A number of discontinuous phases subsequently, are inserted in a continuing phase to create a amalgamated. [1]

Generally, a lot of the composites contain a bulk content (the "matrix"), including a encouragement of some kind or type, included to raise the power and rigidity from the matrix principally. This reinforcement is normally in fiber or particulate form. [2]

In today's situation, because of growing general trends along with the ever before modifying systems, it's important to present novel product which comprises expected properties. Lately, aeronautical and transfer sector works by using amalgamated supplies for his or her structural and nonstructural programs. In Indian history "Iron Pillar of Delhi" is historic exemplary case of composite material. Even so, solid wood can be an all natural amalgamated stuff manufactured from polymer-cellulose materials. Therefore, idea of composite isn't a human invention by any means. Composite materials will vary from conventional elements. Reinforcement materials by means of fibers or debris are put in weaker stuff (i.e., matrix content) with the development of amalgamated material.

The escalating prominences of Al alloys within the fabrication of light materials have linked to stir casting. It really is discovered that Al-based material matrix composites (AMMC) provide a broad prospect of extensive usage and expansion. The reinforcements applied had been Al2O3, SiC, TiC, TiB2,graphite along with other ceramics. SiC reinforcements are employed in motor vehicle and aerospace software progressively more. Silicon carbide (SiC) and aluminium oxide (Al2O3) are mostly used reinforcements [9]. Gr are employed for lubrication goal.

Al alloy-SiC strengthened composites elevated the toughness, wear and ductility resistance. While, Gr reinforced metal matrix composite (MMC) offered poor strength and better wear resistance [10].

II. EXPERIMENTAL PROCEDURE

Samples will be fabricated as per table no 2. Because the reinforcement increases by 10 wt % the agglomeration increases because of dislocation density of reinforcement. Boosting wt % of support also escalates the density of support because of which homogenous combination production isn't possible, because the reinforcements relax due to increased density as comes even close to matrix stage (Al6061).Maintaining the Integrity of the Specifications

Table 1. Segregation of HMMC samples

	Al6061	SiC	Gr
Sample 1	90%	5%	5%

An excellent wettability between sound ceramic allergens and liquid matrix steel is necessary to obtain uniform supply and satisfactory houses in HMMC. Alloying components such as for example magnesium, lithium, calcium mineral or zirconium happen to be included once and for all wettability [17, 18-19]. Magnesium along with enhancing the wettability furthermore increases the power by solution conditioning aluminum matrix metallic matrix composites HMMC.

In a stir casting method as displayed in Fig. 1, the reinforcing stages (usually in natural powder form) are sent out into molten aluminum by mechanized stirring. The floors of both should be properly cleaned to be able to minimize the response between both of these which may create impurities such as for example material oxide and slag. A significant fear from the stir casting method is the parting of reinforcing debris which is due to the settling of encouragement debris during melting and casting method. To avoid settling of contaminants a motor influenced stirrer can be used. The final syndication of the debris in the stable depends on stuff properties and procedure parameters like the wetting condition, power of mixing, comparative density, and price of solidification. The circulation in the contaminants within the molten matrix likewise depends upon the composition with the mechanized stirrer, stirring speed, keeping the mechanized

stirrer inside the melt, melting temps, and the attributes of the contaminants added.

A pre-specified amount of Al6061 is melted in crucible furnace. The melting temperature of Al alloy was 700, 750 and 800 0C. The SiC and Gr reinforcement particles having 15 micron size are pre-heated upto 5000C temperature to remove the impurities. The pre-heated reinforcement is added to molten metal and stirrer. The stirrer is carried out on 500, 600 and 700 RPM for 5, 7 and 9 min. The slurry is then transmitted to die through pathway pre-heater, which was set for 3000C. The pathway also maintains some temperature so that the mixture will not solidifies. This slurry is poured into a preheated die cavity, located on the bed of a hydraulic press through pathway. The press is activated to close off the die cavity and to pressurize the liquid metal. Finally the component is ejected after solidification

Fig 1. Stir casting machine set up

III. TAGUCHI TECHNIQUE FOR OPTIMIZATION

This research is focused to produce better mechanical properties in stir casting components. Hence, the larger the better characteristic is implemented in this study. The stir cast process parameters namely, melting temperature, stirrer speed and stirrer duration each at three levels is considered in this work and the details are presented in Table 2.

Selection of an appropriate orthogonal array based on the chosen process parameters is the prime aim in the Taguchi method. The total degrees of freedom for three parameters in each of three levels are six. Then, a three level orthogonal array (L933) with nine experimental runs [degrees of freedom = 9−1 = 8] is selected for the present research. Orthogonal array (OA) is nothing but the shortest possible matrix of combinations in which all the parameters are varied at the same time and their effect and performance interactions are studied simultaneously.

In this work L9 is sufficient. Taguchi experimental design of experiments suggests L9 orthogonal array, where 9 experiments are sufficient to optimize the parameters. Based on main factor, the variables are assigned at columns, as stipulated by orthogonal array.

Table 2 Process Parameters and their levels

Process Parameters	Coding	Level 1	Level 2	Level 3
Melting Temperature (0C)	A	700	750	800
Stirrer Speed (RPM)	B	500	600	700
Stirrer duration (min)	C	5	7	9

3.1 MATERIALS CHARACTERIZATIONS

Fig. no 2 indicates the tensile evaluation samples that are machined from fabricated rods. The examples happen to be fabricated according to Taguchi orthogonal range as well as the tensile and hardness seemed to be examined. The hardness was tested at three different locations and the common value is taken to the analysis. The tensile check desired specimens had been well prepared and machined from your casting. The tensile tests were completed with the specimen within the universal testing machine at room temperature.

Fig 2 Tensile strength HMMC samples

Fig 3 Hardness HMMC samples

Table 3 Hardness and tensile strength values of HMMC

Melting Temp.(ºC)	Stirrer Speed (RPM)	Stirrer Duration (Min)	Hardness	Tensile
700	500	5	131.7	385.1
700	600	7	129.7	377.4
700	700	9	130.4	382.2
750	500	7	140.9	412.7
750	600	9	135.7	398.1
750	700	5	138.2	403.6
800	500	9	134.6	394.8
800	600	5	132.4	386.2
800	700	7	136.2	397.6

IV. RESULTS AND DISCUSSION
4.1 TAGUCHI DESIGN OF EXPERIMENT

The Statistical Taguchi technique was found to be the useful tool in optimizing the stir casting method process parameters, by decreasing, the variations in the robust design of experiments to produce quality products. This paper analyzes and studies the effect of process parameters on hardness and tensile strength of Al6061/SiC/Gr composites. The process parameters such as melt temperature (A), stirrer

speed (B) and stirrer duration (C), at three levels considered for the analysis is shown in Table 4.

Table 4. L9 Orthogonal array with design factors and S/N Ratio for hardness and tensile strength

Sr. No	Melting Temp. (oC)	Stirrer Speed (RPM)	Stirrer Time (Min)	Hardness (Hv)	Tensile (MPa)	S/N Hardness	S/N Tensile
1	700	500	5	131.7	385.1	42.392	51.711
2	700	600	7	129.7	377.4	42.259	51.536
3	700	700	9	130.4	382.2	42.306	51.646
4	750	500	7	140.9	412.7	42.978	52.313
5	750	600	9	135.7	398.1	42.652	52.000
6	750	700	5	138.2	403.6	42.810	52.119
7	800	500	9	134.6	394.8	42.581	51.928
8	800	600	5	132.4	386.2	42.438	51.736
9	800	700	7	136.2	397.6	42.684	51.989

A signal-to-noise ratio is a measure of robustness, which can be used to identify the control factor settings that minimize the effect of noise on the response. Minitab calculates a separate signal-to-noise (S/N) ratio for each combination of control factor levels in the design. You can choose from different S/N ratios, depending on the goal of your experiment. In all cases, you want to maximize the S/N ratio.

Table 5 Response Table for Signal to Noise Ratios for Hardness (Larger is better)

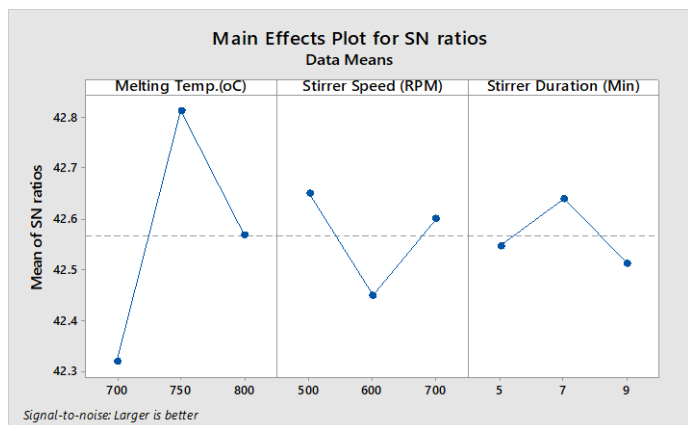| Level	Melting Temp.(ºC)	Stirrer Speed (RPM)	Stirrer Duration (Min)
1	130.6	135.7	134.1
2	138.3	132.6	135.6
3	134.4	134.9	133.6
Delta	7.7	3.1	2
Rank	1	2	3

Fig 4. S/N ratio response curve of hardness

The process parameters analyzed using MINITAB 18 was arranged in L9 orthogonal array. Table 4 shows the response table of S/N ratio for hardness and tensile strength. The effect of control factors on hardness and tensile strength established with the S/N ratio response is presented in table 4 and 5. The results showed that stir pressure have linked on tensile hardness and strength. The higher S/N ratio is known for better performance. Hence, the optimum level of process parameters is the level which has maximum S/N value. Fig.4 indicated the response curve in S/N ratio.

Table 6 Response table for signal to noise ratio for Tensile strength (Larger is better)

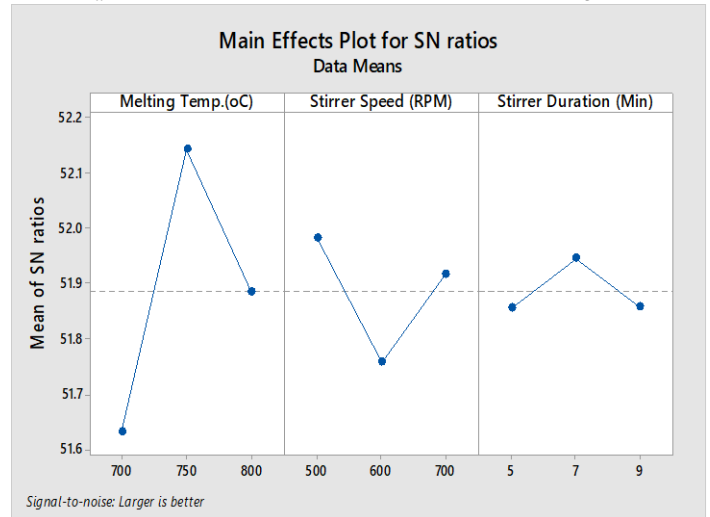| Level	Melting Temp.(oC)	Stirrer Speed (RPM)	Stirrer Duration (Min)
1	381.6	397.5	391.6
2	404.8	387.2	395.9
3	392.9	394.5	391.7
Delta	23.2	10.3	4.3
Rank	1	2	3

Fig 5. S/N ratio response curve of Tensile strength

The highest tensile strength and hardness was observed at larger the better S/N values (Fig. 4 and 5). The optimized process parameters for hardness and tensile strength are stir pressure at level 2, melt temperature at level 1 and die temperature at level 2.

4.2 ANALYSIS OF VARIANCE

The main purpose of the ANOVA is the application of a statistical method to identify the effect of individual factors on the process response. Results from ANOVA can determine very clearly the impact of each factor on hardness and tensile strength. Using Minitab 18, ANOVA performed determines the parameter and interaction that significantly affect the performance characteristics. ANOVA is a computational technique to quantitatively evaluate the comparative involvement of parameters. ANOVA is described by the total sum of squares of the standard deviation equal to the sum of squares of the standard deviation produced by the respective parameter.

Table 7. ANOVA Variance table for hardness

Source	DF	Seq SS	Contri.	Adj SS	Adj MS	F-Value	P-Value
Melt. Temp. (oC)	2	88.169	79.41%	88.1689	44.0844	298.32	0.003
Stirrer Speed (RPM)	2	15.902	14.32%	15.9022	7.9511	53.80	0.018
Stirrer time (Min)	2	6.669	6.01%	6.6689	3.3344	22.56	0.042
Error	2	0.296	0.27%	0.2956	0.1478		
Total	8	111.036	100.0%				

Table 7 and 8 shows the ANOVA results for hardness and tensile strength respectively. It determines the F-ratio. The F-Ratio is defined as the ratio between regressions mean square and mean square error. Comparing all the process parameter, melting temperature plays a main role in determining the mechanical properties; depend upon the melting temperature, the mechanical properties are varied. The melting temperature was 79.41% representing the highest contribution, stirrer speed were 14.32 % and stirrer duration was 6.01% contribution for hardness. The melting temperature was 79.44% representing the highest contribution, stirrer speed were 16.46 % and stirrer duration was 3.52% contribution for tensile strength. From ANOVA results it is clearly seen that melting temperature is the most major factor control the hardness and tensile strength value.

Table 8. ANOVA Variance table for tensile strength

Source	DF	Seq SS	Contri.	Adj SS	Adj MS	F-Value	P-Value
Melting Temp.(^{o}C)	2	809.88	79.44%	809.882	404.941	137.06	0.007
Stirrer Speed (RPM)	2	167.82	16.46%	167.816	83.908	28.40	0.034
Stirrer time (Min)	2	35.85	3.52%	35.849	17.924	6.07	0.142
Error	2	5.91	0.58%	5.909	2.954		
Total	8	1019.46	100.00%				

4.3 REGRESSION ANALYSIS

A complete model of regression completed using Minitab 18 software. Three operational parameters and three levels consider in this present study. The complete regression equations are shown in equation 1 and 2. The relationship between the stir casting factors and the measured parameters such as hardness and tensile strength were found by multiple linear regression equation 1 and 2.

Regression Equation (1) Hardness   =109.3 + 0.0380 Melting Temp.(oC) - 0.0040 Stirrer Speed (RPM) - 0.133 Stirrer Duration (Min).

(2) Tensile=317.4 + 0.113 Melting Temp.(oC) - 0.0153 Stirrer Speed (RPM) + 0.02 Stirrer Duration (Min)

V.   CONCLUSION

Hybrid metal matrix composite was successfully fabricated by using stir casting route. Mechanical properties has been tested and found better than the base alloy. The increase in mechanical properties is due to hard reinforcement particles which hold the bonding between soft matrix phases. The effect of stir casting process parameters on mechanical properties of Al6061 alloy and SiC/Gr with 5 wt % each was investigated using Taguchi technique. The experiments are conducted using L9 orthogonal array by considering three process parameters and three levels. Process parameters consider are Al6061 melting temperature, stirrer speed and stirrer duration. The increase in the melting temperature resulted in smaller grain size, improved mechanical properties such as hardness and tensile strength in hybrid metal matrix composites. The optimum process parameters for better mechanical properties are, melting temperature 750oC, Stirrer speed 500RPM and stirrer duration was 7 min for better mechanical properties.

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