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STUDY OF MECHANICAL BEHAVIOUR OF METAL MATRIX COMPOSITES USING DESIGN OF EXPERIMENTS

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Abstract:
Aluminium metal matrix composites (MMCs) with Al-7075 matrix reinforced with Al_2O_3 particulates were prepared by liquid metallurgy route of stir casting. A 2-level factorial design of experiments (DoE) was used to study the influence of process parameters like size and weight fraction of reinforcement, sintering temperature and sintering time on micro-hardness and impact strength of the composites. Mathematical models were developed to investigate which parameter significantly affects the selected mechanical properties. The results of the study indicate that both micro-hardness and impact strength of Al-7075/Al_2O_3 composites are affected by individual parameters as well as their 2-factor interactions. These models can be used to select the optimum process parameters for obtaining composites possessing desired hardness and impact strength within the range of experimental framework. However, more detailed investigations are undertaken by the authors to gain a deeper insight into the behaviour of these composites.

Key Words: MMCs, Design of Experiments, Stir Casting, Micro-Hardness, Charpy-V

1. INTRODUCTION

Metal matrix composite materials (MMCs) are exponentially growing and gaining importance because of their potential to produce components which possess high strength–to-weight ratio at elevated temperatures, improved shock-resistance properties, relatively higher wear resistance, toughness, etc, which make them candidates in automotive, aerospace and many engineering fields [1-3]. In particular, Al_2O_3-reinforced, Al-7075 composites with increased micro-hardness and Charpy-v values are considered for the above applications. They can be produced by various processes such as stir casting, powder metallurgy, spray atomization, plasma spraying, etc [4-9]. To the best of our knowledge, limited research has been done to predict the properties of these MMCs [10-13]. Sahin [10] has studied wear behavior of aluminium alloy and its composites using statistical analysis and concluded that reinforcement size and fraction influences the wear behavior of these composites. Mondal et al [11] have employed factorial techniques to predict effect of zinc concentration on high stress abrasive wear behavior of Al-Zn alloys. Charles & Arunachalam [12] have developed mathematical model for machining properties of aluminium alloy hybrid composites produced by liquid metallurgy and powder metallurgy. Huda et al [13] have developed the hardness equation for Al/Al_2O_3 composites, using response surface methodology and indicated that effect of volume fraction of reinforcement is very dominant.

In view of this, factorial design of experiments was employed in the present work to develop mathematical models [14-16] for predicting Vickers micro-hardness (H_v) and impact Charpy-v (C_v), in terms of reinforcement size, weight percent, sintering temperature and sintering time. Analysis of Variance (ANOVA) has been performed to determine the influence of the input parameters. Fisher's F-test has been carried out to test the adequacy of models.

2. EXPERIMENTAL DETAILS

MMCs with Al-7075 matrix material reinforced with Al_2O_3 particulates of various sizes were fabricated using stir-casting technique. Figure 1 shows the schematic of the stir-casting process. The set-up used provided the flexibility of choosing and controlling the size and fraction of reinforcement to produce composites as per experimental design. A 2-level factorial design of experiment was used in the present study. The levels of the four input parameters, upper level and lower level, are presented in Table I along with the notations, units and codes for each process parameter.

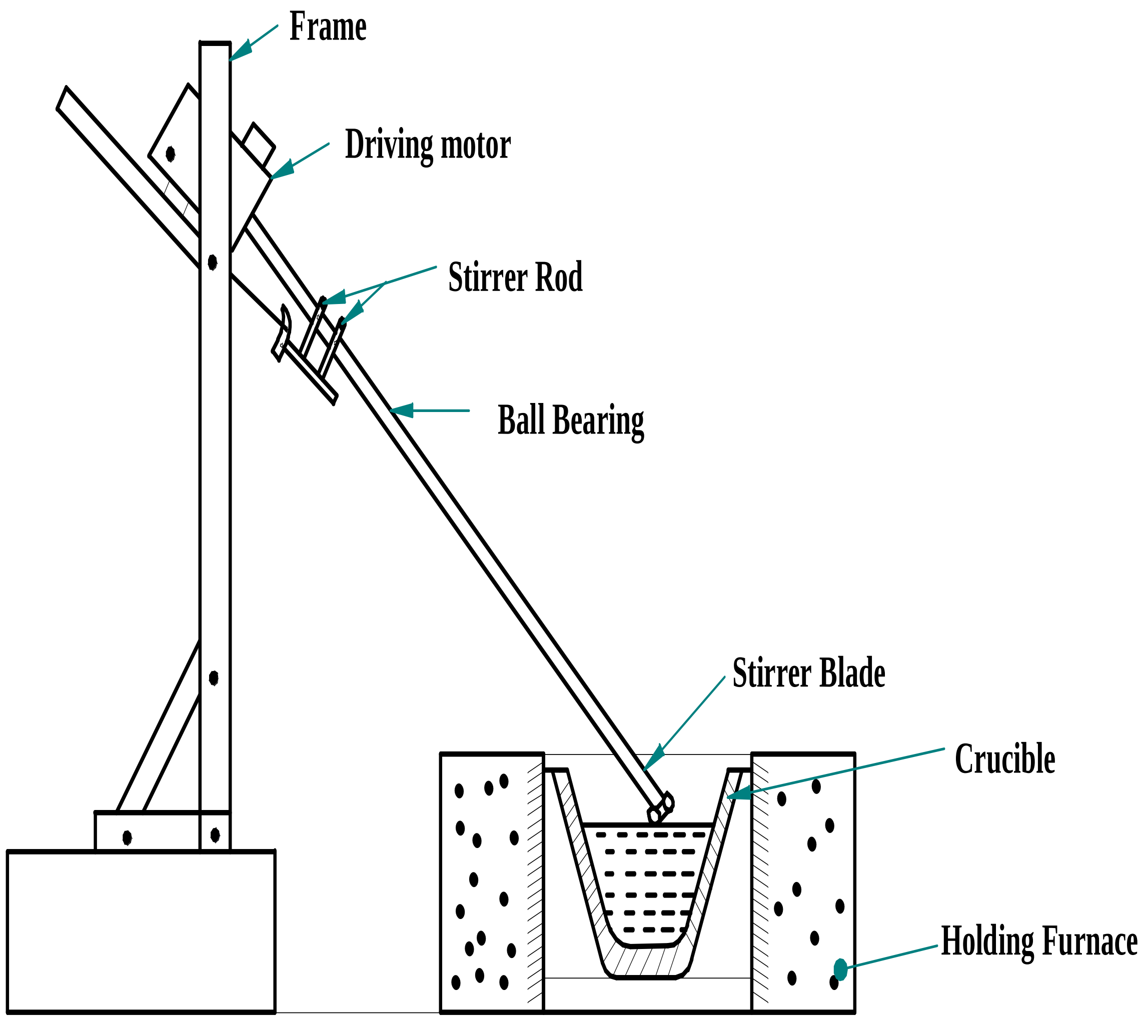

Figure 1: Schematic of stir-casting process [3, 4].

Table I: Values of input variables at different levels.

S. No.	Process Parameters	Notation	Code	Units	Lower Level(-)	Upper Level(+)
1	Reinforcement Size	D	X_1	Mesh	100	400
2	Wt.% of Al_2O_3	W	X_2	gm	5	15
3	Sintering Temperature	T	X_3	°C	150	500
4	Sintering Time	t	X_4	Hrs	1	8

To develop the linear regression equation from the experimental values one must conduct at least P^n experiments, where P stands for number of parameters and n indicates the levels at which they are to maintained during experimentation. Hence, 8 sets of trial experiments were carried out as per the design matrix [14-16]. Table II shows the design matrix developed. Various metal casts were produced following the deign matrix of Table II. Randomization was applied while producing the composite to avoid entry of any systematic error into the experimentation [16].

Table II: Design matrix along with experimental values of responses at various levels of input variables.

S. No.	X_0	X_1	X_2	X_3	$X_4 = X_1X_2X_3$	Vickers Hardness (H_v)	Charpy-V(C_v) in Joules
1	+	-	-	-	-	134	7.325
2	+	+	-	-	+	174	10.540
3	+	-	+	-	+	128	0.1500
4	+	+	+	-	-	150	0.2600
5	+	-	-	+	+	160	6.9880
6	+	+	-	+	-	158	10.836
7	+	-	+	+	-	120	0.1270
8	+	+	+	+	+	144	1.2660

3. RESULTS AND DISCUSSION

The Vickers micro-hardness and Charpy-V values were determined using specimens prepared for the purpose. Three readings each were taken and the average of the readings has been reported. Regression coefficients were calculated and are given in Table III. Student's t tests were performed to arrive at the significant coefficients and these were used to write the models for micro-hardness and Charpy-V.

Table III: Regression coefficients (Experimental).

S. No.	Coefficient (bj)	Vickers hardness H_v	Charpy-V, C_v in Joules
1	b_o	146	4.690
2	b_1	11.0	0.007
3	b_2	0.5	-0.117
4	b_3	5.0	1.012
5	b_4	10.5	4.235
6	b_{14}	-0.5	-0.23
7	b_{24}	-3.0	0.128
8	b_{34}	4.5	0.754

3.1 Mathematical modeling

A linear relation of the form presented in Equation 1 gives the general form of the response as per factorial design of experiments [14].

$$Yu = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_{14}X_1X_4 + b_{24}X_2X_4 + b_{34}X_3X_4 \quad (1)$$

Where, Yu is the response, X_1, X_2, X_3 and X_4 are the coded values of the variables and b_0, b_1, etc. are the regression coefficients. The details for calculating the coefficients is given elsewhere [13,14]. Substituting the values of the significant coefficients, the micro-hardness and Charpy-V models are written as,

$$\mathbf{H_V = 146 + 11D + 0.5W + 5T + 10.5t - 0.5D{*}t - 3W{*}t + 4.5T{*}t} \quad (2)$$

$$\mathbf{C_V = 4.686 + 0.077D + 1.012T + 4.2354t + 0.130W{*}t + 0.075T{*}t} \quad (3)$$

Table IV shows the details of analysis of variance for the two models. It is observed that both the models are adequate and can be used to determine the combination of four parameters to obtain the composites with the desired values of micro-hardness and impact (Charpy-V) strength.

Table IV: Analysis of variance (ANOVA).

Response	Source	DF	SS	MSR	F	R^2	$Radj^2$
Micro Hardness Hv	I order linear regression	4	2052	684	11.59	89.68	81.92
	Lack of fit	3	236	59			
Charpy-V C_V	I order linear regression	4	1.2747	0.4249	4.83	78.36	62.11
	Lack of fit	3					

Note: F value for both the responses as per Table (4, 3, 0.05) = 3.84;
$F_{HV} > F_{Table}$ and $F_{CV} > F_{Table}$. Hence the models are adequate.

4. CONCLUSION

The need for high stiffness, light weight materials for use in applications demanding higher impact strength and wear-resistance has triggered studies on development of models to predict behavior of composites and/or newer processing techniques. The following conclusions are drawn from the present investigation.

- The technology of reinforcing metal(s) with ceramic particulates and modeling their behavior appears to be an excellent approach to develop materials to meet specific demands of the future generation.
- Factorial design of experiments can be successfully employed to predict the optimum conditions for producing Al7075/Al_2O_3 MMCs.
- Within the frame work of experimental values of the parameters tested, it is seen that Vicker's micro-hardness as well as Charpy-V values increased consistently with reinforcement size, %weight of Al_2O_3, sintering temperature and sintering time.

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