PREDICTION OF MOST SIGNIFICANT PARAMETER FOR HARDNESS AND IMPACT STRENGTH OF ALUMINIUM BASED METALMATRIX COMPOSITES AlSiC USING DOE BY ADDING CENTER POINTS

Amol Dnyaneshwarrao Sable
Head of Department, Department of Mechanical Engineering,
JSPM's Jayawantrao Sawant Polytechnic, Pune, Maharashtra, INDIA.

Abstract: Aluminum based metal matrix composites (MMCs) with Al (98.41%) matrix reinforced with SiC (320 grit) particulates were prepared by liquid metallurgy route of stir-casting. This paper presents the details of modeling the hardness and Impact Strengthof composites. A 2-level factorial design of experiments (DOE) Method by adding center points is used to develop the mathematical model to predict the influence of three process parameters viz. Mass of Al and weight fraction of SiC and stirring time on hardnessand Impact Strength of these composites.. These models can be used to select the optimum process parameters for obtaining composites possessing desired the hardness and ImpactStrength within the range of experimental framework Also this model is optimized by simplex big M method.

Index Terms: **MMCs, Design of Experiments, Stir Casting, Hardness, Optimization.**

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. In particular, SiC-reinforced, Al composites with increased hardness 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 [4-8]. To the best of our knowledge, limited research has been done to predict the properties of these MMCs [09-11]. Sahin [09] 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 [10] have employed factorial techniques to predict effect of zinc concentration on high stress abrasive wear behavior of Al-Zn alloys. Huda et al [11] have developed the hardness equation for Al/Al2O3 composites, using response surface methodology and indicated that effect of volume fraction of reinforcement is very dominant. Nowadays fabrication of Silicon-Carbide (SiC) improves the life of modern tools. Duplex-composite materials like Silicon Carbide particles reinforced with aluminium (AlSiC) gives the great strength and also greatly prevent the severe wear-tear and high stress so on. Here, we will discuss and prepare the duplex composite materials by stir casting method. MMC materials have a combination of different, superior properties to an unreinforced matrix which are; increased strength, higher elastic modulus, higher service temperature, improved wear resistance, high electrical and thermal conductivity, low coefficient of thermal expansion and high vacuum environmental resistance. These properties can be attained with the proper choice of matrix and reinforcement. In view of this, factorial design of experiments was employed in the present work to develop mathematical models [12-14] for predicting the hardness (Hv) and Impact Strength (Cv) in terms of mass of Al, weight fraction of SiC and stirring 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 and optimized this model by simplex big M method.

EXPERIMENTAL DETAILS

MMCs with Al (98.41%) matrix material reinforced with SiC (320 grit) particulates are fabricated using stir-casting technique. Figure 1 shows the schematic of the stir-casting process. The set-up used provided the flexibility of changing %Weight fraction of reinforcement, SiC (5%, 10%, 15%, ----, 30%) to produce composites as per experimental design. A 2-level factorial design of experiments (DOE) Method by adding center points was used in the present study. The levels of the three input parameters, upper level, middle level and lower level, are presented in Table I along with the notations, units for each process parameter

2. MATERIALS AND METHODS

MMCs with Al (98.41%) matrix material reinforced with SiC (320 grit) particulates are fabricated using stir-castingtechnique. Figure 1 shows the schematic of the stircasting process. The set-up used provided the flexibilityof changing %Weight fraction of reinforcement, Sic (5%, 10%, 15%, ----, 30%) to produce composites as perexperimental design. A 2-level factorial design of experiments (DoE) Method by adding center points was used in the present study. The levels of the three input parameters, upper level, middle level and lower level, arepresented in Table I along with the notations, units for each process parameter.

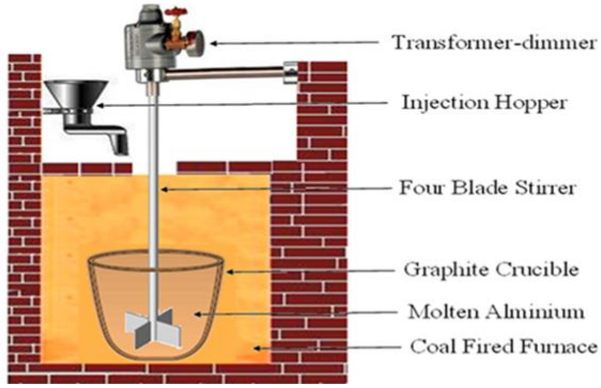

Fig. 1: Schematic of Stir-Casting Process

Sr. No	**Process Parameter**	**Notation**	**Unit**	**Lower Level**	**Middle Level**	**Higher Level**
1	Mass of Aluminium	A	gm	1400	1650	1900
2	Mass of SiC	B	gm	100	350	600
3	Time	C	min	5	10	15

Table I: Values of input variables at different levels

To develop the linear regression equation from the experimental values one must conduct at least Pn experiments, where P stands for number of parameters and n indicates the levels at which they are to maintained during experimentation. Hence, 12 sets of trial experiments were carried out as per the design matrix [12-14]. 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 [14].

Design matrix with experimental values of responses at various levels of input variables for hardness Hv

FACTORIAL EFFECT							RESPONSE					
A	B	C	AB	AC	BC	ABC	R- 1	R- 2	R- 3	AVG	TOTAL	
-1	-1	-1	1	1	1	-1	32.1	32.6	32.8	32.50	97.5	[1]
1	-1	-1	-1	-1	1	1	36.8	37.1	37.2	37.03	111.1	a
-1	1	-1	-1	1	-1	1	40.6	40.8	41.1	40.83	122.5	b
1	1	-1	1	-1	-1	-1	42.7	42.7	42.9	42.77	128.3	ab
-1	-1	1	1	-1	-1	1	33.4	33.3	33.6	33.43	100.3	c
1	-1	1	-1	1	-1	-1	38.4	38.6	39.4	38.80	116.4	ac
-1	1	1	-1	-1	1	-1	40.9	41.3	41.2	41.13	123.4	bc
1	1	1	1	1	1	1	43.6	43.7	43.8	43.70	131.1	abc
0	0	0	0	0	0	0	37.70	38.35	38.33	38.15	114.88	--
0	0	0	0	0	0	0	38.10	38.00	38.05	38.05	114.15	--
0	0	0	0	0	0	0	39.25	37.35	39.05	38.55	115.65	--
0	0	0	0	0	0	0	38.09	37.95	37.79	37.95	113.83	--

Design matrix with experimental values of responses at various levels of input variables I for impact strength Cv

FACTORIAL EFFECT							RESPONSE					
A	B	C	AB	AC	BC	ABC	R- 1	R- 2	R- 3	AVG	TOTAL	
-1	-1	-1	1	1	1	-1	19	18	19	18.67	56	1
1	-1	-1	-1	-1	1	1	23	24	23	23.33	70	a
-1	1	-1	-1	1	-1	1	28	29	29	28.67	86	b
1	1	-1	1	-1	-1	-1	31	32	33	32.00	96	ab
-1	-1	1	1	-1	-1	1	19	18	20	19.00	57	c
1	-1	1	-1	1	-1	-1	24	26	25	25.00	75	ac
-1	1	1	-1	-1	1	-1	30	32	34	32.00	96	bc
1	1	1	1	1	1	1	32	34	35	33.67	101	abc
0	0	0	0	0	0	0	25.95	26.35	26.85	26.38	79.15	--
0	0	0	0	0	0	0	26.81	26.30	25.95	26.35	79.06	--
0	0	0	0	0	0	0	27.00	26.01	26.00	26.33	79.01	--
0	0	0	0	0	0	0	27.35	25.55	26.16	26.35	79.06	--

RESULTS AND DISCUSSION

The hardness values and The Impact Strength values were determined using specimensprepared for the purpose. Three readings each were taken and the average of the readingshas been reported. Regression coefficients were calculated and are given in Table II.And Table III

Sr. No.	Factors	Regression coefficients
01	Interpret	38.5741
02	A	1.8012
03	B	3.3337
04	C	0.4912

Table 1: Regression coefficients (Experimental). Hardness

Sr. No.	Factors	Regression Coeff.
1.	Interpret	26.47
2.	A	1.95
3.	B	5.04
4.	C	0.875

Table 2: Regression coefficients (Experimental) IMPACT STRENGTH

3.1 Mathematical modeling

A linear relation of the form presented in Equation gives the general form of the responseas per factorial design of experiments [12].

$Y = b_0 + b_1 A + b_2 B + b_3 C + b_4 AB + b_5 AC + b_6 BC + b_7 ABC$

Substituting the values of the significant coefficients, hardness models are written as,

$\therefore Y = 38.57 + 1.80 A + 3.33 B + 0.491 C$

Substituting the values of the significant coefficients, impact strength models are written as

$Y = 26.47 + 1.95 A + 5.04 B + 0.875C$

Percentage contribution of factor A ,B and C are very high than other factors, so we can consider only A, Band C factors for analysis by eliminating other factors.The elimination of other factors can be justified by residue the calculation

3.2 Analysis of variance (ANOVA).

Table V and Table VI shows the details of analysis of variance for the models. It is observed that the model is adequate and can be used to determine the combination of three parametersto obtain the composites with the desired values of hardness and Impact Strength

Regression Statistics	
Multiple R	0.987008354
R Square	0.974185491
Adjusted R Square	0.96450505
Standard Error	0.891963541
Observations	12

Regression Statistics	
	0.977892
R Square	0.956273
Adjusted R Square	0.939875
Standard Error	0.817064
Observations	12

Table No. 3: Regression statistics of Impact Strength Table No. 4: Regression statistics of hardness

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	3	116.797	38.932	58.317	8.83824E-06
Residual	8	5.34075	0.6675		
Total	11	122.138			

Table 5: Analysis of variance (ANOVA) hardness

ANOVA	df	SS	MS	F	Significance F
Regression	3	240.193	80.064	100.6344	1.08149E-06
Residual	8	6.3647	0.7955		
Total	11	246.558			

Table 6: Analysis of varianc (ANOVA).impact strength

F- Value for hardness test as per table (3, 11, 0.05) =3.59.

Therefore $F_{Cv} > F_{table}$, Hence model is adequate

	Coefficient	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	38.574	0.235	163.542	0.000	38.030	39.118	38.030	39.118
X VariableA	1.801	0.288	6.235	0.000	1.135	2.467	1.135	2.467
X VariableB	3.333	0.288	11.540	0.000	2.667	3.999	2.667	3.999
X VariableC	0.491	0.288	1.700	0.127	-0.174	1.157	-0.174	1.157

Table No. 7: Regression statistics (P-Value) for hardness test

The p-value calculated indicates the factors A and B are statically significant.

	Coefficient	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	26.479	0.257	102.836	0.000	25.885	27.072	25.885	27.072
X Variable A	1.957	0.315	6.207	0.000	1.230	2.6847	1.230	2.684
X Variable B	5.042	0.315	15.989	0.000	4.315	5.769	4.315	5.769
X Variable C	0.875	0.315	2.774	0.024	0.147	1.602	0.147	1.602

Table No. 8: Regression statistics (P-Value) for Impact Strength test

The p-value calculated indicates the factors A and B are statically significant and

Optimization by simplex method (Big –M Method)

Many designed experiments involve determining optimal conditions that will produce the "best" value for the response. Depending on the design type (factorial, response surface, or mixture), the operating conditions that you can control may include one or more of the following design variables: factors, components, process variables, or amount variables.

LPP (Linear Programming Problem)involves the determination of values of 'n' variables $x_1, x_2, x_3 \ldots x_n$ the linear objective function of this variable assume an optimal values (maximum or minimum). When these variables are subjected to the set of 'm' constraints they are also the linear function of decision variable.

Simplex Method:

When objective functions contain more than two variables, in this case we use simplex method.

1. Slack Variable: A variable is added to the left hand side of less than or equal to constraints to convert the constraints into an equality is called slack variable.
   The slack variables are added only for two reasons:
   1. To convert inequality (≤) to an equality.
   2. To find an initial basic feasible solution.
2. Surplus variables: A variable subtracted from left hand side of a greater than or equal to constraints to convert constraints to equality is as surplus variables.
   The surplus variable are enter only converting in equality (≥) into equality.
3. Artificial variable: Non negative variable are added to left hand side of greater than or equal to constraints are known as a artificial variable, is just to obtained basic feasible solution.

Optimization problem for hardness test

Maximum Y = 38.57 + 1.80 A +3.33 B + 0.491 C

Subject to, 100≤ B ≤ 600
1400 ≤ A ≤ 1900
5 ≤ C ≤ 15

Hear C variable is least significant so we can eliminate it.

Maximum Y = 38.57+ 1.80 A +3.33 B

Subject to, B ≥ 100
B ≤ 600
A ≥ 1400
A ≤ 1900

Maximum Y = 38.57+ 1.80 A +3.33 B + 0S1 +0S2+ OS3+0S4 – MR1- MR2

Subject to, B – S1+ R1= 100
B + S2 = 600
A – S3 + R2 = 1400
A + S4 = 1900

Here (m - n) = (8-4) = 4, where m = number of variables.
n = number of equations

Therefore put A = B = S1 = S3 = 0

The most negative value -2M-1.80, A is entering variable and in constants the minimum value is K= 1400, R1 is releasing variable.

	Cj	1.80	3.33	0	0	0	0	-M	-M		
CB	XB	A	B	S1	S2	S3	S4	R1	R2	K	Ratio
3.33	B	0	1	0	1	0	0	0	0	600	
0	S1	0	0	1	1	0	0	-1	0	500	
1.80	A	1	0	0	0	0	1	0	0	1900	
0	S3	0	0	0	0	1	1	0	-1	500	
	Zj	1.80	3.33	0	3.33	0	1.80	0	0		
	Zj-Cj	0	0	0	3.33	0	1.80	M	M		

Table No. 9: Simplex table 5th iteration (Hardness)

Hear Zj-Cj ≥ 0 that is all the values are positive, so optimal solution is obtained
Therefore solutions are A= 1900 gm = 1.9 Kg
B = 600 gm = 0.6Kg
Therefore the value of Maximum Y = 38.57+ 1.80 A +3.33 B
Maximum Y = 38.57+ 1.80(1.9) +3.33(0.6)
Maximum Y = 38.57+3.42+1.99
Maximum Y = 43.98 which is the optimum solution for hardness test

Optimization problemfor Impact Strength test

Maximum Y = 26.47+ 1.95 A +5.04 B + 0.875 C
Subject to, 100≤ B ≤ 600
1400 ≤ A ≤ 1900
5 ≤ C ≤ 15
Hear C variable is least significant so we can eliminate it
Maximum Y = 26.47+ 1.95 A +5.04 B
Subject to, B ≥ 100
B ≤ 600
A ≥ 1400
A ≤ 1900
Maximum Y = 26.47+ 1.95 A +5.04 B + 0S1 +0S2+ OS3+0S4 – MR1- MR2
Subject to, B – S1+ R1= 100
B + S2 = 600
A – S3 + R2 = 1400
A + S4 = 1900
Here (m- n) = (8-4) = 4, where m = number of variables.
n = number of equations
Therefore put A = B = S1 = S3 = 0

	Cj	1.95	5.04	0	0	0	0	-M	-M		
CB	XB	A	B	S1	S2	S3	S4	R1	R2	K	Ratio
5.04	B	0	1	0	1	0	0	0	0	600	
0	S1	0	0	1	1	0	0	-1	0	500	
1.95	A	1	0	0	0	0	1	0	0	1900	
0	S3	0	0	0	0	1	1	0	-1	500	
	Zj	1.95	5.04	0	5.04	0	1.95	0	0		
	Zj-Cj	0	0	0	5.04	0	1.95	M	M		

Table No. 10: Simplex table 5th iteration (Impact Strength)

Hear Zj-Cj ≥ 0 that is all the values are positive, so optimal solution is obtained.
Therefore solutions are A= 1900 gm = 1.9 Kg
B= 600 gm = 0.6Kg
Therefore the value of Maximum Y = 26.47+ 1.95 A +5.04 B
Maximum Y = 26.47+ 1.95(1.9) +5.04(0.6)
Maximum Y = 26.47+3.70+3.02
Maximum Y = 33.19 which is the optimum solution for Impact Strength test.

4. CONCLUSION H

1) The results suggest that with increase in composition of SiC, an increase in hardness and Impact Strength has been observed.
2) The best results has been obtained at 25% weight fraction of 320 grit size SiC particles. Maximum Hardness = 43.70 BHN, Maximum Impact Strength = 33.67 Joules
3) 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.

4) Factorial design of experiments can be successfully employed to predict the optimum conditions for producing AlSiC MMCs.
5) The model developed can be used to produce AlSiC composites of desired hardness, Impact Strength and also to predict the hardness and Impact Strength of the composites knowing the proportions of the Same. And percentages of reinforcement (SiC) are most significant parameter affecting hardness, Impact Strength of composite produced by stir casting. Results are verify by all means.

REFERENCES

[1] Composite materials",RSC, Advancing the Chemical Sciences, – page 1 of 3, Index 4.3.1.

[2] Rohatgi, P.K. (1993). Metal–Matrix Composites, Defense Science Journal, Vol.43, No.4, 323-349

[3] Sahin, Y.; Ozdin, K. (2008). A model for the abrasive wear behavior of aluminium basedComposites, Journal of Material Science Vol.29, 728-733

[4] Srivatsan, T.S.; Ibrahim, I.A.; Mohammed, F.A.;
Lavernia, E.J. (1991). Processing techniquesof particulate-reinforced metal aluminium matrix composites, Journal of Material Science,Vol.26, 5965-5978.

[5] Surappa, M.K. (2003). Aluminium matrix composites; Challenges and Opportunities, SadhanaVol.28 Parts 1& 2, 319-344.

[6]Ibrahim, I.A.; Mohamed, F.A.; Lavernia, E.J. (1991).Particulate reinforced metal matrixcomposites- a review. Journal of Material Science, 26, 1137.

[7]DouglusC.Montegomery, "*Design and analysis of experiment*", 7th edition by, Wiley India Edition.

[8] Suresh, et al. (1993). Fundamentals of metal- matrix composites, Butter-worth-HeinemannPublications, (USA).

[09] Sahin, Y. (2003). Wear behavior of aluminium alloy and its composites using statisticalanalysis, Journal of Material Science, Vol.24, 95-103.

[10] Mondal, D.P. et al. (2005). Effect of zinc concentration and experimental parameters on highstress abrasive wear behavior of Al-Zn alloys: A factorial design approach, Material Scienceand Engineering, A406 24-33

[11] Huda, D.; El Baradie, M.A.; Hasmi, M.S.J. (1994). Development of a hardness model ForMMCs (Al/A2O3), Journal Materials Processing Technology, 44, 81

[12] Cochran, W.G.; Cox, G.M. (1992). Experimental Design, John Wiley, New York

[13] Montgomery, D.C. (2009). Design and Analysis of Experiments, John Wiley, New York

[14] Adler, Y.P.; Markov, E.V.; Granovsky, Y.V. (1975). The design of experiments to find Optimalconditions, MIR, Moscow.