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Modelling Tensile Behaviour of Stir-cast Aluminium Matrix Composites (AMCs) Using Factorial Design of Experiments

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Abstract

Aluminium based metal matrix composites (MMCs) with ceramic reinforcement are finding extensive applications in aerospace, automobile, agricultural farm machinery and other areas which demand combination of properties such as high strength, stiffness, wear resistance, high temperature resistance, etc. In particular, components comprising Al7075 alloy matrix, reinforced with alumina (Al_2O_3) particulates, are reported to excel their monolithic counterparts. Liquid metal route and powder metallurgy are the most widely used fabrication techniques to produce these MMCs. The former has advantages such as easy adaptability, low cost and possibility of subjecting the cast components to secondary processes like forging, rolling and extrusion for producing the final components. This paper presents the details of developing a mathematical model to predict the tensile behavior like ultimate tensile strength (UTS) and percentage elongation of the as-cast Al7075/Al_2O_3 in terms of size and % fraction of Al_2O_3, holding temperature and holding time; using factorial design of experiments (DoE). Adequacy of the models was tested using Fisher's F-test. UTS of the composite was increased by 20%compared to that of matrix and % elongation was reduced by around 30%.

Keywords: MMC, UTS, % elongation, Design of experiments, Modelling**.**

1. Introduction

Aluminium metal matrix composites (MMCs) with 7xxx alloy as matrix reinforced with ceramic particles are finding application in aerospace, automobile and farm machinery equipment because of their improved mechanical and tribological properties [1-6]. In particular, Al_2O_3 particles mixed with Al7075 matrix in appropriate proportions are reported to exhibit improved tensile properties because of the higher modulus of elasticity and strength of the alumina [7]. Out of the available methods of producing these composites, stir casting route is most promising and economical for synthesizing the particle reinforced AMCs and is not only simple, but is easy to obtain shape castings [8,9]. It is important to understand the process parameters that bring about the enhancement in their behaviour. However, conventionally, this requires conducting costly and time consuming experiments. Alternately, we can predict the influence of process parameters accurately, and to develop composites possessing desirable mechanical properties various modelling methods are available [10-13]. This paper presents one such methodology called rotatable central composite design (CCD), which is a multi-parameter based, multiple response analysis modelling technique [14]. It is not only fast, economical and very effective in assessing the effect of individual parameters, but also helps in predicting the interaction effects of the parameters. Hence, in this work an attempt is made to predict the effect of reinforcement size, %weight fraction of reinforcement, holding temperature and holding time on the ultimate tensile strength and %elongation of a stir-cast Al7075/Al_2O_3 composite system using CCD. The adequacy of the models is checked by Fisher's-F ratio and the analysis of variance is employed to evaluate the effect of parameters.

2. Materials

Al7075 matrix reinforced with varying sizes of Al_2O_3 particles were used to produce composites using stir casting. Tables 1 and 2 present the important properties of the matrix material. Table 3 gives the range of the four most influential process parameters, viz. size of reinforcement particles (D), weight fraction of reinforcement (W), holding temperature (T) and holding time (t).

3. Experimental Program

Rotatable central composite design was used to produce the castings [15-17]. Figs. 1 and 2 show the schematic diagram and close-up view of stir casting process. The details of the process are explained elsewhere [18]. A total of 31 castings comprising 16 (=2^4) factorial points, 8 star points and 7 central points were produced by adapting the CCD as per Table 4. The castings were produced using randomness to avoid the entry of systematic errors in experimentation. Tensile tests were performed on samples extracted from defect-free regions of the castings at a rate of 8.33×10^{-4} s^{-1} as per [19] and a minimum of 3 specimens were tested in each case. The average values of UTS and %E are presented in Table 4.

4. Results and Discussion

The maximum value of UTS obtained was 289MPa; minimum was 262MPa and the mean was at 273MPa, whereas %E obtained was in the range of 14.8% to 9.25% with the average at 11.3%. It is noticed that introduction of Al_2O_3 particulates could result in 20% increase in matrix UTS and decreased the %E by around 30%; implying that composites with enhanced strength can be produced by stir-casting. However, one has to sacrifice the ductility. Similar observations have been made by many researchers [9,19-20]. Second order relations were obtained by regression analysis and are presented in equations (1) and (2) for UTS and %E, respectively.

$$\begin{aligned}UTS&=270.29-3.63D+3.21W+2.36T+3.126t+0.768D^2+2.643W^2+0.518T^2-0.106t^2-0.437DW-0.313DT+\\&\quad 0.563Dt-0.063Wt+0.937Tt\end{aligned} \tag{1}$$

$$\begin{aligned}\%E&=10.508+0.396D-0.421W-0.0413T-0.453t+0.386D^2+0.220W^2+0.126T^2+0.301t^2-0.049DW-0.093DT\\&\quad +0.056Dt-0.21WT+0.363Wt+0.277Tt\end{aligned} \tag{2}$$

Table 5 shows the result of the analyses of variance and it is noticed that, in both the cases, experimental values of F-ratios are higher than that from the table; indicating that the two models are adequate. Also, R^2 and R_{adj}^2 values indicate that the models can be used to predict the responses with 99% confidence level. Hence, the models can be effectively used in predicting the UTS and %E, knowing the composition of Al7075/Al_2O_3 MMCs.

It is observed from equation (1) that as the size of reinforcement (D) increases UTS decreases. D affects UTS independently as well as in combination with weight% and holding temperature. On the other hand, W, T and t contribute positively. Interestingly, the effect of these parameters on elongation is exactly reversed as shown in equation (2). Thus UTS of composites is observed to be 20% enhanced and elongation reduced by nearly 30% compared to the matrix material. Similar observations are recorded by many researchers [19-22]. Leisk and Saigal [23] have shown that further enhancement in tensile strength is possible by subjecting the composites to heat treatment. However, this claim is to be confirmed for Al7075/Al_2O_3 composites. All these aspects can be systematically exploited in developing the AMCs possessing desired tensile strength and %elongation.

5. Conclusion

Based on the experimental work, following conclusions are drawn.

1. Rotatable, central composite design can be successfully used to model the tensile behaviour of AMCs
2. Mathematical models for UTS and %elongation are adequate and will predict the values with 99% confidence.
3. UTS and %elongation show reverse trends as far as influence of the process parameters are concerned.
4. UTS of the Al7075/Al_2O_3 MMCs increased by 20%compared to that of matrix and % elongation was reduced by around 30%.

6. References

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

[2] Ibrahim I.A, Mohamed F.A, Lavernia E.J. (1991). Particulate reinforced metal matrix composites- a review. *Journal of Material Science*, 26, 1137-1156.

[3] Nikhilesh Chawla, Yu-Lin Shen. (2001). Mechanical behaviour of particulate reinforced metal matrix composites. *Advanced Engineering Materials*, 3, 6, 357-370.

[4] Daoud A, Reif W, Rohatgi P. (2003). Microstructure and tensile properties of extruded 7475 AL-Al_2O_3 particulate composites. ECCM13, Sweden, 1201.

[5] Ceschini L, Minak G, Morri A. (2009). Forging of the AA2618/20 Vol. % Al_2O_{3p} composite: Effects on microstructure and tensile properties. *Composites Science and Technology*, 69, 1783-1789.

[6] Mallik, B., et al (2006). Effect of particle content on the mechanical behaviour of aluminium-based metal matrix composites (AMMC). *Indian Foundry Journal*, 52, 35-42.

[7] Hashim J, Looney L, Hashmi M. S. J. (1999). Metal matrix composites: production by the stir casting method. *Journal of Materials Processing Technology*, 92-93, 1- 7.

[8] Ceschini L, Minak G, Morri A. (2006). Tensile and fatigue properties of the AA6061/20 vol. % Al_2O_{3p} and AA7005/10 Vol. % Al_2O_{3p} composites. *Composites Science and Technology*, Vol. 66, 333-342

[9] Gupta M, Lai M.O, Lim C.Y.H. (2006). Development of a novel hybrid aluminium-based composite with enhanced properties. *Journal Material Processing Technology*, Vol. 176, No. 1-3, 191-199.

[10] Sahin Y. (2003). Wear behavior of aluminium alloy and its composites reinforced by SiC particles using statistical analysis. *Materials and Design*, 24, 95-103.

[11] Yilmaz O, Buytoz S. (2001). Abrasive wear of Al_2O_3-reinforced aluminium-based MMCs. *Composite Science and Technology*, 61, 2381-2392.

[12] Mondal D.P, Das S. (2006). High stress abrasive wear behavior of aluminium hard particle composites: Effect of experimental parameters, particle size and volume fraction. *Tribology International*, 39, 470-478.

[13] Chawla N, Chawla K.K. (2006). Microstructural e-based modeling of the deformation behavior of particle reinforced metal matrix composites. *Journal of Material Science and Technology*, (41) 913-925.

[14] Deshmanya Indumati B, Purohit G.K. (2011). Studies on modelling of aluminium matrix composites (AMCs)-A Review. *ICAM 2011, Joint International Conference on Advanced Materials.* 144-145.

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

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

[17] Adler Y.P, Markov E. V, Granovsky Y.V. (1975). *The design of experiments to find optimal conditions.* MIR Pub., Moscow.

[18] Deshmanya, Indumati B, Purohit G.K. (2011). Modelling of impact strength and hardness of Al_2O_3 – reinforced Al-7075 composites. *International Journal of Industrial Engineering Practice*, Vol. 3, Issue 1, 61-66.

[19] Doel T. J. A, Bowen P. (1996). Tensile properties of particulate-reinforced metal matrix composites. *Composites Part A: Applied Science and Manufacturing*, 27, 655-665.

[20] Srivatsan T.S. (1996). Microstructure tensile properties and fracture behaviour of Al_2O_3 particulate-reinforced aluminium alloy metal matrix composites. *Journal of Materials Science*, 31, 1375.

[21] Seah K. H. W, Sharma S. C, Girish B.M. (2001). Mechanical properties of as- cast and heat-treated ZA-27/graphite particulate composites. *Composite: part A. 28A 251-6 Composites Science and Technology*, 61, 2381.

[22] Abis S. (1989). Characterization of an aluminium alloy/alumina metal matrix composites. *Journal of Composite Science and Technology*, 35, 1-19.

[23] Leisk G, Saigal A. (1995). Taguchi analysis of heat treatment variables on the mechanical behaviour

of alumina /aluminium metal matrix composites. *Composites Engineering*, 5, 2, 129-142.

Table 1: Chemical Composition of Al7075

Cr	Cu	Mg	Zn	Al	Density g/cc at 20°C
0.22	1.60	2.80	5.50	Balance	2.89

Table 2: Details of other important properties of Al7075

UTS MPa	Yield Strength MPa	Elongation %	Hardness VHN	Thermal Conductivity Cal/Cm^2/Cm/°C at 25°C	Elect. Resistivity µΩ-Cm at 20°C
228	103	17	79	0.29	5.74

Table 3: Coded values of as-cast input variables at different levels

Coded values	Input parameters	Notation	Units	Lower level		Middle	Upper level	
				-2	-1	0	+1	+2
X_1	Size of Al_2O_3	D	µm	36	45	54	63	72
X_2	% Wt of Al_2O_3	W	---	5	7.5	10	12.5	15
X_3	Holding Temperature	T	°C	150	237	325	413	500
X_4	Holding Time	t	Hrs	1	2	3	4	5

Table 4: Design matrix for preparation of tensile test samples by stir casting along with responses

Trial No.	Input Parameters				Responses	
	X_1 Size of Al_2O_3 D (μm)	X_2 Wt. fraction of Al_2O_3 %W	X_3 Holding Temperature, T (°C)	X_4 Holding Time, t (Hrs)	UTS MPa	Elongation %
1	-1	-1	-1	-1	268	13.54
2	+1	-1	-1	-1	264	14.80
3	-1	+1	-1	-1	273	11.35
4	+1	+1	-1	-1	267	13.20
5	-1	-1	+1	-1	275	12.80
6	+1	-1	+1	-1	262	14.50
7	-1	+1	+1	-1	277	10.63
8	+1	+1	+1	-1	275	11.25
9	-1	-1	-1	+1	274	11.54
10	+1	-1	-1	+1	271	13.15
11	-1	+1	-1	+1	278	10.22
12	+1	+1	-1	+1	273	12.12
13	-1	-1	+1	+1	280	11.35
14	+1	-1	+1	+1	276	13.05
15	-1	+1	+1	+1	288	11.12
16	+1	+1	+1	+1	284	12.23
17	-2	0	0	0	285	11.10
18	+2	0	0	0	262	9.98
19	0	-2	0	0	273	9.25
20	0	+2	0	0	289	10.50
21	0	0	-2	0	270	9.00
22	0	0	+2	0	275	10.00
23	0	0	0	-2	267	11.10
24	0	0	0	+2	273	9.30
25	0	0	0	0	270	10.25
26	0	0	0	0	271	10.50
27	0	0	0	0	272	10.55
28	0	0	0	0	270	10.61
29	0	0	0	0	273	10.45
30	0	0	0	0	268	10.70
31	0	0	0	0	268	10.50

Table 5: Analysis of Variance (ANOVA)

Particulars	Source	DF	SS	MS	F	R^2	$Radj^2$
UTS	I & II Order Terms	14	455.438	32.531			
	Lack of Fit	10	885.07	3.571	9.11	98.42	98.18
	Residual Error	6	21.427				
	Total	30	1361.935	36.102	9.11	98.42	98.18
	Source	DF	SS	MS	F	R^2	$Radj^2$
	I & II		23.489	1.677			
% El							99.79
							99.79

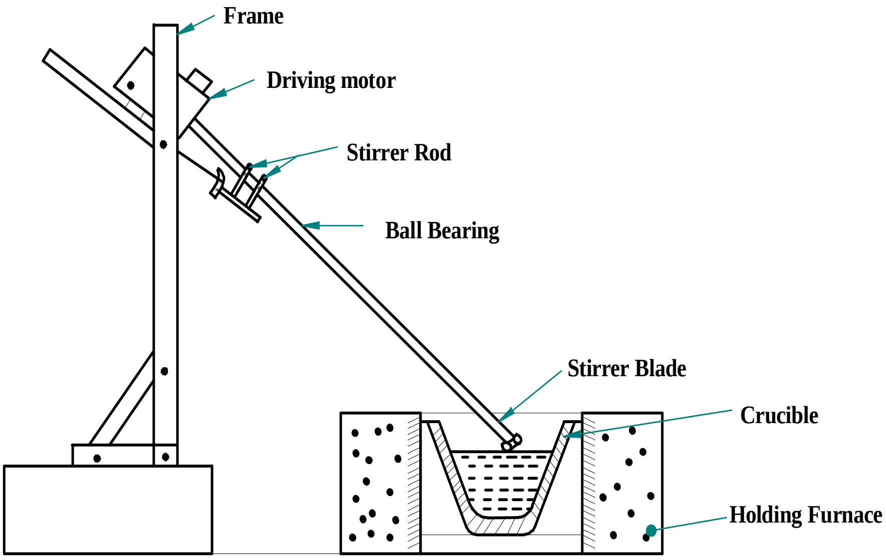

Figure 1: Schematic diagram showing components of stir-casting process.

The stirrer is a servomotor operated ceramic coated stainless steel rod.

Figure 2:Close-up view of the stir-casting set-up. Al_2O_3 particulates of various sizes are added to the melt at 730°C which is continuously stirred using a motorized stirrer made of ceramic coated stainless steel rod.

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