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Optimization of Mechanical Behaviour of AA 5083 Nano Sic Composites Using Design of Experiment

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Abstract

Composites with aluminium alloy matrix and ceramic reinforcements are popular candidates in automotive, aerospace, defense and other industries because of their high strength-toweight ratio, stiffness, impact strength, wear resistance, etc. In the present study AA 5083/Nano SiC composite were fabricated by stir casting. A 2-level Full Factorial design of experiments (DOE) was used to study the influence of process parameters like casting temperature, stirrer speed, and weight percent of reinforcement on hardness of composites. Mathematical model was developed to investigate which parameters significantly affect the hardness of composites. The effect of parameters on the response and adequacy of hardness model developed were tested by employing ANOVA and Fisher's F-test. This model can be used to select the optimum process parameters for obtaining the composites hardness within the range of experimental frame work.

Keywords: DOE; ANOVA; Factorial design; Fisher's F-test; Stir casting; Nano composites

Introduction

Aluminium matrix composites have drawn immense interest for various applications in making aerospace and automobile components due to their light weight, high strength to weight ratio, high stiffness, lower cost, easy of fabrication and high dimensional stability. Particulate–reinforced Aluminum matrix composites (AMCs) are of particular interest due to their ease of fabrication, lower costs, recyclability and isotropic properties [1]. Reinforcement of micron or nano-sized range particles with aluminium matrix yields improved mechanical and physical properties in composite materials. The distribution of nano sized reinforcing particles also changes morphology and interfacial characteristics of nanocomposites [2]. Ali Mazahery characterized cast A356 alloy reinforced with nano SiCp composites and reported that hardness of the composites is higher than that of the un-reinforced alloy [3]. The higher hardness of the composites could be attributed to the fact that SiCp particles act as obstacles to the motion of dislocation. The hardness increment can also be attributed to the reduced grain size. Sajjadi Used, compo-casting method to fabricate aluminum–matrix composite reinforced with micro and nano-alumina particles with [4]. Different weight fractions the result revealed that the hardness of the composites increased with increasing particle weight fraction and decreasing particles size. Also, the hardness distribution becomes more uniform with increasing stirring speed and time. Mazahery Reported that incorporation of nano-particles into the aluminum matrix could enhance the hardness, considerably, while the ductility is retained Mohammed. K. Hassan Investigate the effect of casting processing parameter on the hardness properties of Aluminum alloy 6061 companied with Al_2O_3 and SiCP [5,6]. The specimens were poured in two different mold types one of steel and the other of graphite. The results showed that hardness increase in case of specimen poured in steel mold. This increasing due to fast cooling rate which make refining of the grain size of aluminum alloys. Whereas, their mechanical properties decreased when using graphite molds. In contrast of this result, ductility is increased. Ali Mazahery Aluminium alloy (A356) nanocomposites (SiC) was prepared by casting process [7]. Experimental and modeling investigations were carried out on varies properties of these nano-composites. Result revealed that hardness of the composites was greater than aluminium alloy. The higher hardness of the composite samples relative to that of the matrix Al-alloy could be attributed to the reducing grain size and existing of nanohard particles acting as obstacles to the motion of dislocation. Although a number of mechanical properties of particulate reinforced aluminium matrix composites have been examined and reported, there is no information regarding the casting of AA5083 nano SiC composites by two step mixing (Manual mixing and stirrer Mixing). Recently, factorial design of experiments (DOE) has emerged as an important tool to analyze multi-parameter, complex processes [8-12]. A number of researchers have employed this methodology and developed mathematical models for various properties of MMCs [12-14]. Huda have developed a mathematical model for predicting hardness of an Al/Al_2O_3 composite, using response surface methodology and observed that the effect of volume fraction of reinforcement was very dominant [14]. Indumati and Purohit have used four factors, five levels factorial design to develop the micro-hardness model for Al7075 matrix, Al_2O_3 reinforced metal matrix composite fabricated by stir-casting [15]. Reinforcement size and weight fraction of reinforcement, among other factors, are observed to affect the hardness more severely. Knowledge of hardness of composites is essential from the stand point of wear resistance, crack initiation and growth, scratch resistance, etc. However, it is noticed from the literature that there is no systematic approach to model the hardness of aluminium based, alumina reinforced composites. This paper presents the details of modelling the hardness composites Al-5083 matrix, reinforced with Nano SiC particulates produced by Stir-casting process. Factorial DOE (MINITAB14) is used to develop the mathematical model to predict the influence of three process parameters, viz., casting temperature, stirrer speed, weight fraction of reinforcement on hardness of composites keeping stirring time constant. Analysis of Variance (ANOVA) was performed to determine

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the effectiveness of parameters on their hardness. Fisher's F-test was carried out to arrive at the adequate model that can be used to produce the composites of desired hardness within the range of parameters selected for this study and also predict the combination of input-parameters that give composites of desired hardness within the framework of the experimental values studied.

Experimental Procedure

Materials

Aluminum alloy 5083 was selected as matrix alloy for synthesis of AMCs. The chemical compositions are shown in Table 1. Nano size Silicon Carbide particulates were used as reinforcement material and average particle size was 40 nm (SiCp-β, 99+%pure) (Figure 1).

Plan of investigation

The research work was planned to be carried out in the following steps:

- Identifying the important controllable process parameters.
- Finding the range of identified parameters viz. weight fraction of reinforcement, casting temperature and stirrer speed.
- Developing the composite design matrix.
- Producing the stir-cast specimen as per design matrix.
- Conducting hardness test and recording the values HRB.
- Developing the hardness model and checking the adequacy.
- Results and discussion.

The experimental plan was formulated considering three parameters (variables) and two levels based on the Factorial Design technique. The levels of these variables chosen for experimentation are given in Table 2.

Synthesis of aluminum alloy sicp composites

Casting was done according to composite design matrix. Four samples each with 1% and 2% weight fraction of Nano SiC of composites were fabricated by two step stir casting. In this process

Element	Zn	Fe	Ti	Cu	Si	Pb	Mn	Mg	Cr	Al
Percent	0.03	0.173	0.04	0.0181	0.16	0.014	0.526	5.13	0.097	Balance

Table 1: Composition of AA 5083 Al alloy.

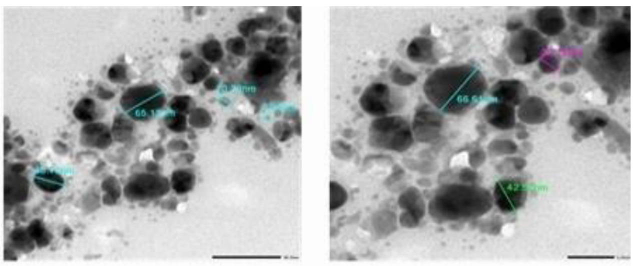

Figure 1: TEM analysis of Nano SiC_p particles.

Level	Weight % of Nato SiC.(W)	Stirring speed. S (RPM)	Casting Temperature. T (°C)
-1	I	450	760
I	2	550	800

Table 2: Parameters and their levels.

Experiment no	W	S	T
1	-1	-1	-1
2	-1	1	-1
3	-1	-1	1
4	-1	1	1
5	1	1	-1
6	1	1	1
7	1	-1	-1
8	1	-1	1

Table 3: Design Matrix.

S.No.	W	S	T	Hardness (Rockwell Bscale)
I	I%	760°C	450	22.4
2	1%	800°C	450	22.71
3	1%	760°C	550	20.38
4	1%	800°C	550	24.51
5	2%	800°C	450	25.38
6	2%	800°C	550	19.91
7	2%	760°C	450	20.05
8	2%	760°C	550	21.93

Table 4: Results of hardness test for AA 5083 Nano SiC Composites.

first of all AA 5083 alloy was heated to 7600°C in a graphite crucible in electrical resistance furnace until Aluminum alloy melted completely. Then furnace heater was stopped and melt was hold for 30 minutes. Effect of the holding time helps in the Al-SiCp composites mainly two ways: to distribute the particles in the liquid, and to create perfect interface bond between reinforcement and matrix. Temperature was recorded by thermocouple and it was around 6000°C. At this temperature preheated (3000°C), Nano SiC-β of 40 nm size were added into the melt and composite was mechanically stirrer for 20 minutes. At this stage melt temperature was around 5800°C. Again this material is heated upto 7600°C and vortex created by mechanical stirring by the stir impeller for 20 minutes. Again AA 5083 alloy was heated to 8000°C in a graphite crucible in electrical resistance furnace melt was hold for 30 minutes. Melt was covered with coverall 11 to prevent from atmosphere. Degassing was done by dry N2 grade I for 5 minutes to remove air from the casting. Melt was cleaned and poured in preheated mild steel die.

Sample preparation for hardness test

For performing Rockwell hardness test, test samples were extracted from defect-free regions of the casted composites and a minimum of five indentations were made on the samples at distance 5 mm using Rockwell hardness tester.

Results and Discussion

Hardness results

The experiments were conducted as per Design Matrix given in Table 3 and the average hardness results obtained for various combinations of parameters are shown in Table 4. Variation of hardness at different point on the samples is shown in Figure 2.

Multiple linear regression model

A multiple linear regression model is developed using statistical software "MINITAB 14". This model gives the relationship between an independent/predicted variable and a response variable by fitting a linear equation to observe data. Regression equation thus generated

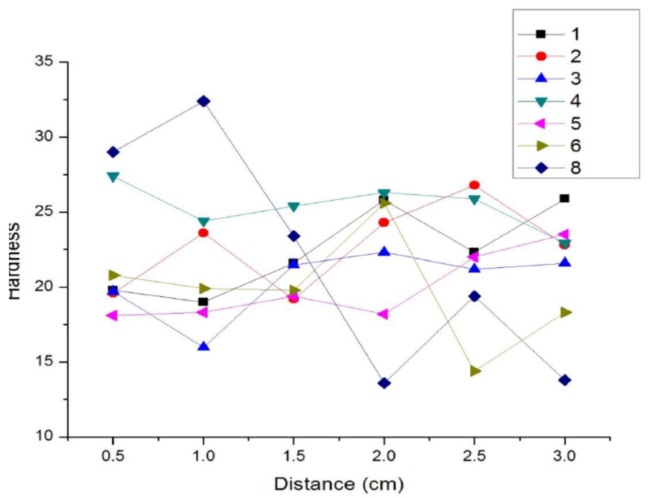

Figure 2: Hardness at Various points on different samples.

Predictor	Codef	SE Coef	T	P
Constant	-4.15	32.84	-0.13	0.906
W	-0.633	1.51	-0.42	0.697
T	0.04719	0.03775	1.25	0.279
S	-0.02005	0.0302	-0.66	0.543

S=2.1359; R-Sq = 85.3%; R-Sq (adj)=91.1%

Table 5: Analysis of Variance (ANOVA).

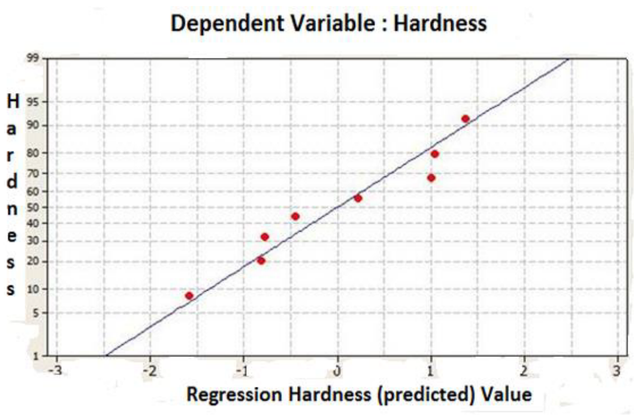

Figure 3: Regression results.

establishes correlation between the significant terms obtained from ANOVA analysis namely weight% of Nano SiC, Stirring speed and Casting temperature. The regression equation developed for Al Nano SiC Composites for hardness measurement is as follows

$$H=-4.2-0.63\ W+0.0472\ T-0.0200\ S$$

This regression equation was then used to obtain the optimum value for the parameters selected. The optimized value of the parameters to obtain the optimum hardness of the specimen and optimum hardness corresponding to this value of parameters is 19.4 HBN.

ANOVA and Fisher's F-test

The effect of parameters on the response and adequacy of hardness model developed were tested by employing ANOVA and Fishers F-test. The results are shown in Table 5.

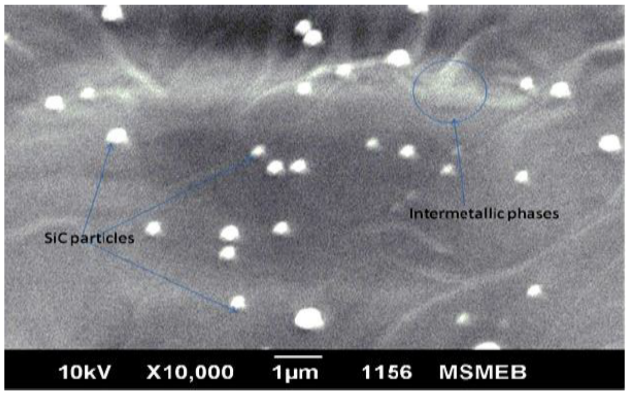

Figure 4: SEM Micrograph of composite with 2% nanoSiC$_p$.

Fisher's F-test: Further, the mathematical model developed is found to be adequate by the fact that Fisher's F-value for the model (35.42) is much higher than the corresponding tabulated value of 4.07 as per Table (14, 6, 0.05). Also, the value of R-Sq (0.991) and R-Sq(adj)=0.989 are the confirmation at 99% confidence level. Hence, the model can be used effectively in producing composite parts by stir casting (Table 5) gives the details of ANOVA (Figure 3).

Microstructure

The microstructure shows two phases one is α- Al and another is Mg_2Si. The microstructure shows α- Al phase and the intermetallic phases. By comparing it with phase diagram the possible inter-metallic compound could be Mg_2Si, Al_3Mg_2 as well as SiCp. The inter-metallic phase is formed to be precipitated on the grain boundaries. Figure 4 shows the micrograph of Al5083-2 wt.% SiCp composites which shows uniform distribution of Nano SiCp particles. At some places intermetallic compounds are visible.

Conclusions

Based on the present work the following conclusions may be drawn. On performing hardness test on eight samples which were fabricated by stir casting process with varying parameters stirrer speed, temperature and %weight of SiC set using DOE. The optimized value of the parameters to obtain the optimum hardness of the specimen is 2% weight of Nano SiC, 7600^{o}C casting Temperature, 550 RPM stirrer Speed. Factorial design of experiments (DOE) can be successfully employed to model the hardness behaviour of casted composites Parts possessing maximum Rockwell-hardness corresponding to this value of parameters is 19.4 and the optimum hardness Rockwell Hardness can be obtained of any specimen whose parameters lie within the limits of our set parameters. As per analysis of variance, the F-values corresponding to the models are greater than the standard F-value as obtained for degrees of freedom (14, 6). Hence the model is validated with 99% significance level. The model developed can be used to produce Al5083 Nano SiC composites of desired hardness and also to predict the hardness of the composites knowing the proportions of the same. Elimination of residual pores and defects formed during casting, more uniform distribution of reinforcing particles, stronger bonding between the matrix and particles, and refinement of grains during working have a greater bearing as far as hardness is concerned. As such, a careful and judicious application of these models is recommended.

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