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Optimization and Prediction of Mechanical Properties of ZA-27/Al_2O_3 MMC Processed By Centrifugal Casting Using Multiple Regression Analysis

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ABSTRACT:

In the present investigation ZA-27/Al_2O_3 MMC are processed by Centrifugal casting. The Hardness and Ductilityproperty of the MMC wasstudied using Brinell hardness tester and Universal testing Machine. Experiments were done based on the Design of Experiments generated through Taguchi's technique. A L25 Orthogonal array was chosen for analysis of data. Study was done to find the influence of melt temperature, rotational speed of the mold, Wt. % of particulate, the size of the particulate and distance from the center of the ingot on hardness and Ductility. Analysis was done by ANOVA and Regression Equation for each response were developed for ZA-27/Al_2O_3 MMC. The parameter"larger the better" was used to analyze the mechanical properties. Results show that melt temperate and Wt. % of particulate have highest significant effect followed by rotational speed,particulate size and distance from the center. Final experimental values were compared with predicted values.

Key words: ZA-27; Al_2O_3; Centrifugal casting; Taguchi's technique; Analysis of Variance; Multiple Regression analysis.

1. INTRODUCTION

From past many years Zinc based alloys are widely used for diecasting commercial components.By varying the aluminium percentage (Typical8,12&27 %) excellent bearing properties can be achieved.These alloys have good castability, high fluidity, and excellent Mechanical properties.In addition,they also possess good physical and technological properties with lower manufacturing cost [1]. These alloys are manufactured using sand, permanent mold, shell mold and high-pressure die casting methods. They can be castinthin sections and does not require any flux. [2]. The properties tend to deteriorate at temperature above 100^0C [3, 4]. This disadvantage can be overcome by reinforcing these alloys with hard ceramic particles.These reinforcement contributes to a higher hardness, superior elastic modulus and lower coefficient of thermal expansion of the matrix alloy at high temperature [5]. Among high aluminum content Zinc based alloys, ZA-27 alloys have excellent fluidity, low density, high mechanical properties excellent bearing and wear resistance properties. In the present work, ZA-27 alloy was reinforced with Al_2O_3 particulate. Mechanical properties like hardness and ductility were studied for different Melt temperature (^{o}C), Rotational speed (rpm), Wt.% of Al_2O_3 ,Size of the particulate (µm), and Distance from the center (mm). These parameters are optimized by using Taguchi technique and prediction was carried out for comparison of experimental and theoretical values using the multiple Regression analysis technique.

DESIGN OF EXPERIMENTS

To study the effect of multiple variables Design of Experiment is one of the powerful statistical techniques, which involve a series of experiments to yield an improved performance of process parameters. [6]. Design of Experiments requires a set of factors and levels be tested in order to observe the results of those test conditions. Taguchi approach is one of the techniques which rely on the assignment of factors in a specific orthogonal array to know the testing combinations. This processhas three main phases, i.e.the planning phase, the conducting phase, and the Analysis phase. The important step in the DOE is the determination of the combination of factors and levels which willprovide the desired output [7]. The experimental result from the analysis uses a signal to noise ratio in order to determine the best process designs. To investigate hardness and ductility this technique has been successfully used. In the present work, DOE was generated by the Taguchi method using orthogonal arrays for improving the design of the manufacturing process. This method yields optimized parameters with the level of significance of the influence of factors on a particular output response.

2. EXPERIMENTAL DETAILS

In the present work, ZA-27 alloy with the chemical composition as per ASTM B669-82 ingot specification, are used as the basic matrix alloy and Al_2O_3 as reinforcement with different size. The alloy was melted usingelectric resistance furnace and 200 °C super heat is maintained as teeming temperature for all the cast tubes. A horizontal centrifugal casting machine used to cast ZA-27 alloyspecimen. The mold was preheated to 500 °C and pouring temperature of the ZA-27/Al2O3 composite slurry and the rotation speed of the moldsare given in Table 1. The dimension of the cylinder is 100 mm outer diameter and 150 mm length. Samples were sectioned from the cylinder along the radial direction in different distance from the center given in Table 1. All tests were conducted in as per ASTM standards. Ductility tests were conducted at room temperature using Universal Testing Machine (UTM). The tensile specimens of diameter 8.9mm and gauge length 76mm were machined from the cast composites. The hardness tests were conducted in accordance with ASTM E10 standard using standard Brinell hardness testing machine with a ball indentor of diameter 2.5mm and load of 31.25 kg. The load was applied for 30 seconds.

Table.1 Control factors and their levels used in the experiment

Level	Melt temperature(°C) (a)	Rotational speed (RPM) (b)	Wt. % of Al_2O_3 (C)	Size of the particulate (µm) (d)	Distance from the center (mm) (e)
1	450	400	5	20	0
2	500	500	10	40	10
3	550	600	15	60	20
4	600	700	20	80	30
5	650	800	25	100	40

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3. RESULTS AND DISCUSSIONS

I. Statistical Analysis of Experiments:

As per the orthogonal array the experiments were conducted based upon the various combinations of parameters. The measured results were analyzed using the user friendly software, i.e. MINITAB 14 specifically used for DOE. Table 2 shows the experimental results for hardness and ductility.

Table 2 Experimental results

Sl. No.	Melt temperature(^oC)	Rotational speed (RPM)	Wt. % of Al_2O_3	Size of the particulate(μm)	Distance from the center (mm)	Hardness, BHN	Ductility, %
01	450	400	5	20	0	86.6	3.010
02	450	500	10	40	10	96.7	2.861
03	450	600	15	60	20	105.1	2.723
04	450	700	20	80	30	107.6	2.585
05	450	800	25	100	40	100.1	2.437
06	500	400	10	60	30	99.9	2.723
07	500	500	15	80	40	101.0	2.589
08	500	600	20	100	0	100.6	2.733
09	500	700	25	20	10	97.1	2.794
10	500	800	5	40	20	98.2	2.887
11	550	400	15	100	10	98.1	2.741
12	550	500	20	20	20	103.7	2.813
13	550	600	25	40	30	108.6	2.688
14	550	700	5	60	40	100.5	2.782
15	550	800	10	80	0	94.4	2.902
16	600	400	20	40	40	106.9	2.701
17	600	500	25	60	0	100.4	2.853
18	600	600	5	80	10	96.5	2.922
19	600	700	10	100	20	102.9	2.741
20	600	800	15	20	30	105.1	2.810
21	650	400	25	80	20	100.4	2.640
22	650	500	5	100	30	99.9	2.706
23	650	600	10	20	40	99.0	2.761
24	650	700	15	40	0	103.1	2.931
25	650	800	20	60	10	104.2	2.798

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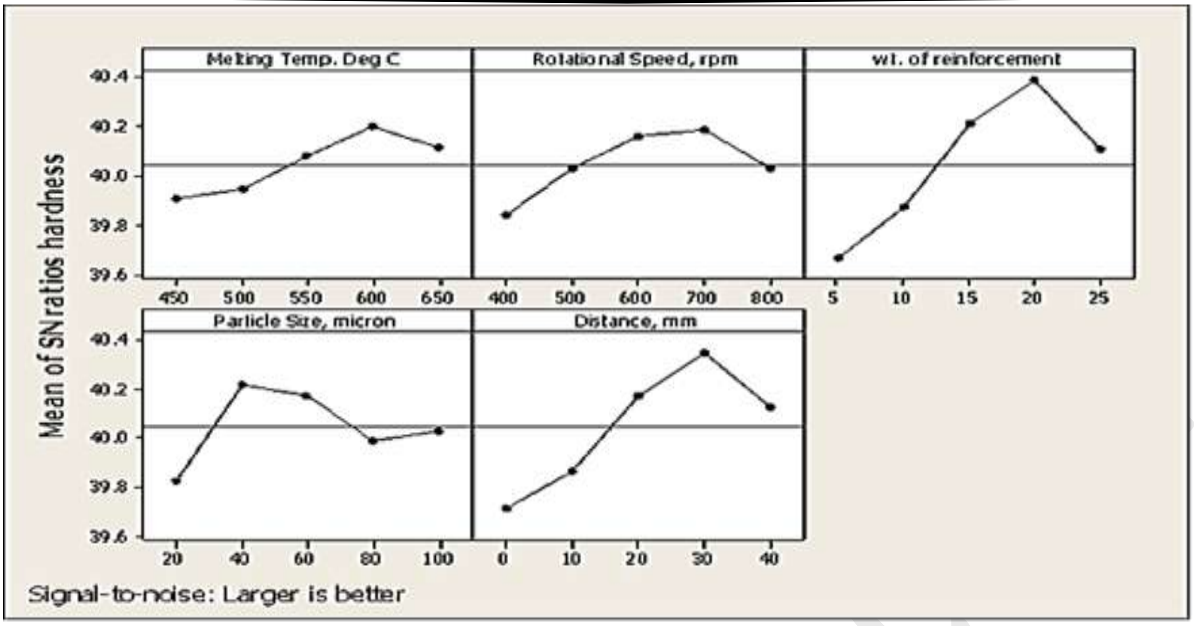

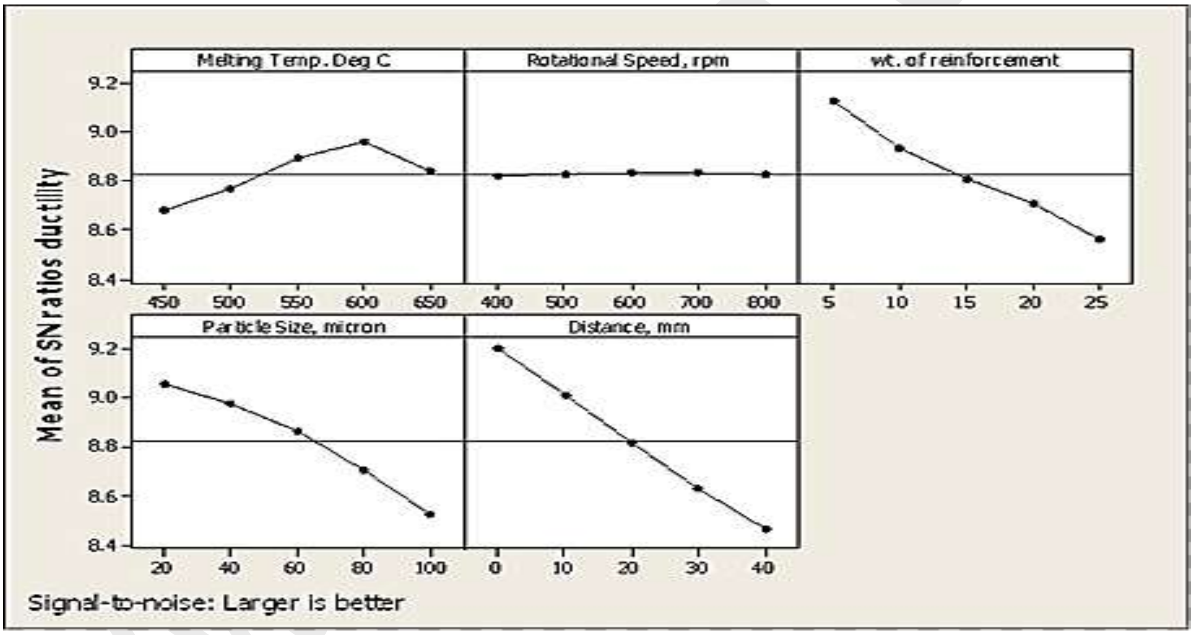

Figure 1 shows the influence of process parameters on hardness and ductility graphically.

The analysis of these experimental results using S/N ratio gives the optimum conditions resulting in maximum hardness and minimum ductility. Table 3 shows the optimum level parameters for hardness and ductility.

Table 3 optimum level process parameters for Hardness and Ductility.

Mechanical properties	Melt temperature(°C)	Rotational speed (RPM)	Wt.% of Al_2O_3	Size of the particulate(µm)	Distance from the center (mm)
Hardness	600	700	20	40	30

Ductility	600	-	5	20	0

II. ANOVA RESULTS

The analysis of variance is used to analyze the experimental results and to investigate the influence of the control parameter that significantly affects the performance measures. By the analysis of variance it can be decided that which independent factor dominates over the other independent variable with their particular contribution.

Table 4 (a) Analysis of Variance for Hardness, BHN, using Adjusted SS for Tests, Analysis of Variance for Hardness(BHN) using Adjusted SS for Tests

Source	DF	Seq SS	Adj MS	% P
Melting Temp °C	4	36.432	9.108	6.94
Rotational Speed, RPM	4	47.311	11.828	9.01
Wt. of reinforcement	4	211.018	52.755	40.17
Particle Size, µm	4	60.321	15.080	11.48
Distance, mm	4	166.181	41.545	31.64
Error	4	4.00	1.00	0.76
Total	24	525.263		
(b) Analysis of Variance for Ductility, %, using Adjusted SS for Tests				
Melting Temp °C	4	0.020839	0.005210	5.55
Rotational Speed, RPM	4	0.000051	0.000013	0.01
Wt. of reinforcement	4	0.093609	0.023402	24.94
Particle Size, µm	4	0.089335	0.022334	23.80
Distance, mm	4	0.171158	0.042789	45.59
Error	4	0.0004	0.00001	0.11
Total	24	0.374992		5.55

Table 4(a) and 4(b) shows the ANOVA results for hardness and Ductility for five factors varied at five levels and interaction of those factors. This analysis is carried out for a confidence level of 95%. Sources with the P value less than 0.05 were considered to have a statically significant contribution to the performance measure.

From ANOVA and Signal /Noise ratio, it is concluded that Wt. of reinforcement has the highest contribution on hardness and ductility is followed by distance from the center of the ingot.

4. MULTIPLE REGRESSION MODEL

Using statistical software "MINITAB 14", a Multiple Regression analysis is developed. This model gives the relationship between an experimental values verses predicted values and the response variable is obtained by fitting a linear equation bygiving data. The generated regression equation establishes the correlation between the significant terms obtained from ANOVA analysis for the control factors.

The Regression equation developed for ZA-27/Al_2O_3 MMC for hardness and ductility as follows.

Hardness = 130.839 - 0.0861877 A - 0.176718 B + 0.803639 C - 0.0491628 D + 4.72042 E + 0.000349566 A*B + 0.00307473 B*C + 0.00207902 C*D - 0.053039 D*E - 0.00732791 E*A - 8.38288e-6 A*B*C + 1.11121e-5 B*C*D + 2.95709e-5 C*D*E + 8.2839e-5 D*E*A **(1)**

Ductility = 2.68271 + 0.000573373 A + 0.000765348 B + 0.00433615 C - 0.000483626 D - 0.011796 E - 1.2394e-6 A*B - 4.09065e-005 B*C - 0.000164073 C*D + 0.00014098 D*E + 1.09698e-5 E*A + 5.07891e-8 A*B*C + 1.22781e-7 B*C*D - 4.20913e-7 C*D*E - 2.55507e-7 D*E*A **(2)**

PREDICTED VALUES

The experimental values will be fed into the MINITAB along with the control parameter. The Table 5 showsthe values of hardness and ductility for various control factors at different levels obtained from from Regression Analysis technique,Fig 2 and 3 shows the variation in experimental and predicted values for hardness and ductility.

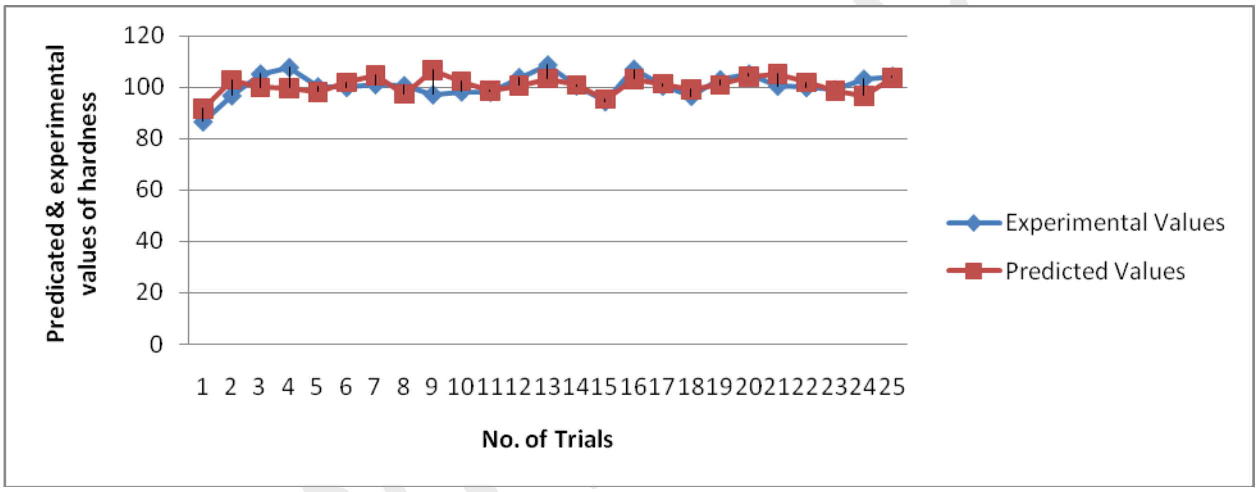

Figure 2 EstimatedValue of Hardness

Table 5 Predicted Values for Hardness and Ductility

Sl. No.	Melt temperature(°C)	Rotational speed (RPM)	Wt.% of Al_2O_3	Size of the particulate(μm)	Distance from the center (mm)	Predicted Hardness	Predicted values of Ductility
01	450	400	5	20	0	91.644	2.81232
02	450	500	10	40	10	103.014	2.80718
03	450	600	15	60	20	100.044	2.74074
04	450	700	20	80	30	99.634	2.87782
05	450	800	25	100	40	98.274	2.538763
06	500	400	10	60	30	102.004	2.80752

07	500	500	15	80	40	104.594	2.7356
08	500	600	20	100	0	97.454	2.8801
09	500	700	25	20	10	106.804	2.88524
10	500	800	5	40	20	102.414	2.6652
11	550	400	15	100	10	98.624	2.73812
12	550	500	20	20	20	100.644	2.88262
13	550	600	25	40	30	103.424	2.45116
14	550	700	5	60	40	100.994	2.73526
15	550	800	10	80	0	95.434	2.73778
16	600	400	20	40	40	103.174	2.73298
17	600	500	25	60	0	101.404	2.7404
18	600	600	5	80	10	99.224	2.80456
19	600	700	10	100	20	101.054	2.8049
20	600	800	15	20	30	104.244	2.81004
21	650	400	25	80	20	105.194	2.59338
22	650	500	5	100	30	102.004	2.59076
23	650	600	10	20	40	98.874	2.66268
24	650	700	15	40	0	96.854	2.95454
25	650	800	20	60	10	103.774	2.66006

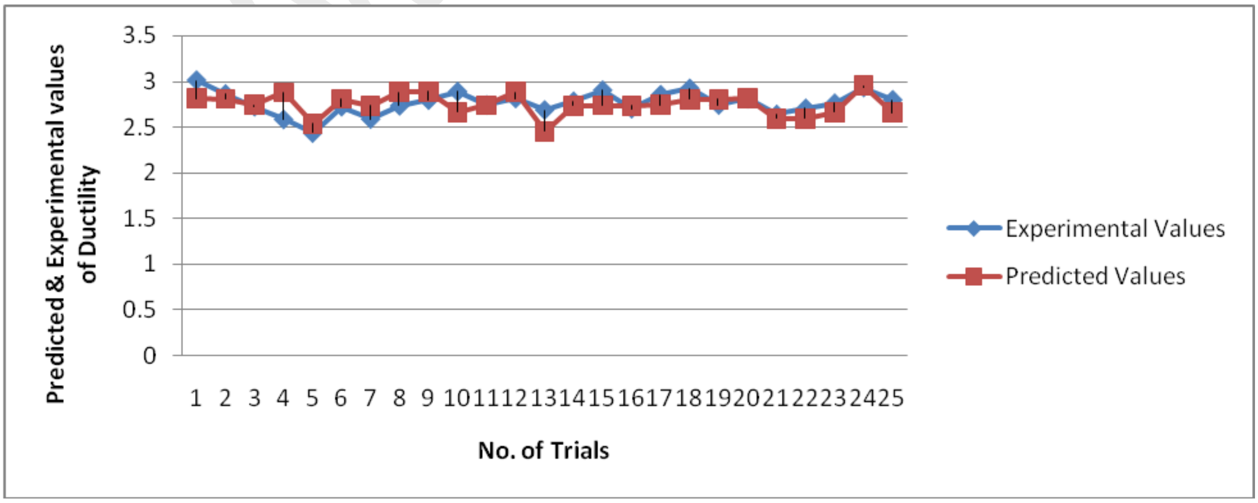

Figure 3 EstimatedValue of Ductility

CONCLUSION

- The experimental results show that the Wt. % of Al_2O_3 has most significant effect on the multiple performance characteristics such as hardness and ductility of the ZA-27/Al_2O_3 composites.
- The position of the specimen from the center axis of spinning is second and is followed by melting temperature, particle size and lastly rotation speed.
- It was observed that optimized parameters have shown good results, the initial hardness of ZA-27/Al_2O_3 MMC is 86.6 BHN to 107.6 BHN and the Ductility is 2.4% to 3%
- The optimized parameters for the hardness of ZA-27/Al_2O_3 MMC is the melt temperature of 600^oC, rotational speed of 700rpm, Wt. % of alumina is 20%,Size of the particulate is 40µm and Distance from the center is 30mm,which gives the hardness of 105.45 BHN
- The optimized parameters for the Ductility of ZA-27/Al_2O_3 MMC is the melt temperature of 600^oC, rotational speed of 400rpm, Wt. % of alumina is 5%,Size of the particulate is 20µm and Distance from the center is 0mm,which gives the ductility of 2.902%
- Finally the prediction of hardness and ductility is being done using the Multiple Regression Analysis which gives the 5% error by comparing the measured data and estimated data of both hardness and ductility.

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