International Journal of ChemTech Research
CODEN (USA): IJCRGG, ISSN: 0974-4290, ISSN(Online):2455-9555
Vol.9, No.06 pp 260-269, 2016

Optimization on Stir Casting Process Parameters of Aluminium Alloy (AL6061) Nickel Coated Graphite (NCG) Metal Matrix Composite using Taguchi Based Rsm

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Abstract : The investigation presents the results of experimental investigations on mechanical property and optimization of stir casting process parameters of aluminium 6061 nickel coated graphite metal matrix composite using Taguchi based Response surface methodology (RSM). The investigation has been made the effect of casting parameters such as percentage of reinforcement, stirring time, stirring speed and casting temperature of Al6061-NCG metal matrix composite manufactured by pellet method. The responses considered for the analysis are Hardness and tensile strength. An empirical model has been developed for predicting the Hardness and tensile strength of aluminium 6061 nickel coated graphite metal matrix composite. Response surface model and analysis of variance (ANOVA) are used in order to study the effects of casting parameters. Optimum result in maximizing the Hardness and tensile strength are determined using desirability function approach. The influences of different casting parameters of Al6061-NCGparticulate composite have been analyzed in detail.
Keywords : Al6061, Nickel coated graphite, stir casting, Anova, RSM.

1. Introduction

The Metal matrix composites have potential advantages than monolithic alloys and this has activated considerable attention in the past years. These composites give the solution of increasing problems in service requirements for various Engineering and structural applications by adding reinforcement of metal matrix by metallic or non-metallic materials. Generally Metal matrix composites (MMCs) are reinforced with low density, high strength and high modulus ceramic phases in the form of fibre, whiskers or particulates. The adding of ceramic reinforcement to metal matrix improves strength and stiffness while ductility is compromised[1]. Considerable research in the material science has been directed toward the development of new engineering materials and structural application which possessing high strength, high specific strength, good creep, and fatigue and wear resistance.

Properties of composites are mainly depends on the properties of their basic materials, their distribution and the interaction between the material. Apart from the nature of the parent materials, the geometry of the reinforcement such as size, shape, concentration, distribution and orientation of the reinforcement influences the properties of the composite. The most commonly used reinforcements are Silicon Carbide (SiC), Graphite, Zirconia and Aluminium Oxide (Al2O3). Graphite, in the form of fibers or particulates, has long been recognized as a reinforcement material because of its low co-efficient of friction, low specific gravity, good conductor of heat and electricity[2]. The aluminium alloy and its composites have been used in many engineering applications (for example automotive components, bushes and bearings) because of its low density, more specific strength, corrosion resistance, etc.[3]. The previous attempts made of introduction of nickel-coated graphite, alumina and SiC in aluminium and Zn based alloys, by using stream of nitrogen gas reinforcement particles are injecting into the melt. A later method vortex is used to produce the composite, here stirring is carried out by using impeller and then reinforcement material such as copper coated graphite, nickel coated graphite nickel-coated alumina particles etc. Introducing to Centre of the vortex produced by stirring[4].

Hsiao YehChu[5] Investigated nickel coated metal matrix composite, from the experimental study, nickel coating on graphite particles allows contact between matrix and reinforcement phase (metal to metal contact), thus producing a large surface-to hardness ratio. Material bond can protect the specimen from severe wear.Lakshmikanthan.P[6] also investigated characterisation of nickel coated graphite aluminium composite, from the analysis at the lowest percentage of reinforcement having better hardness and tensile strength due to lubricant properties of graphite.

Response surface methodology (RSM) is used to find the relationships between several explanatory variables and one or more response variables, it is a well-known approach on optimization of the input parameters models based on physical, simulation and experimental observations. These models need to be calculated statistically for their suitability, and then they can be utilised for an optimisation of the initial model. It is also measures the relationships between the controllable input parameters and the obtained response surfaces. The input parameters are sometimes called independent variables, and the performance measure is the response. By using the results of a numerical experiment in the points of orthogonal experimental design, response surface methodology analysis is computationally much less expensive than a solution using the traditional method. By using the analytical model, the objective function problem can be easily solved and time in the calculation can be saved[7].

In the present work, an attempt is made to study experimental investigation on mechanical property and optimization of stir casting process parameters of aluminium 6061 nickel coated graphite metal matrix composite using taguchi and Response surface methodology (RSM), metal matrix composite are synthesized using stir casting technique by “PELLET METHOD”. By using these techniques of producing nickel coated graphite aluminium alloy composites are more attractive and controls the composition using this technique is better than using either method. The cast composites were tested for hardness, tensile strength and microstructure[8].

2. Materials used

The matrix material used in this study is Al 6061, obtained from PMC Corporation, Chennai, as blanks. The reinforcement material used is Nickel coated graphite NCG obtained from Alfa Aesar Ltd, USA in powder form (Powder size: < 150 µm).

3. Experimental Work

All the pellets are compacted to a density of 2.6gm/cm3. The compaction process is carried out at Tenneco Automotive Pvt.ltd, Pondicherry. Pellets are made from the mixture of 65% of nickel coatedgraphite powder and remaining of pure aluminium powder in weight percentage. In order to produce the composites different parameters are selected such as melting temperature, stirring time, stirring speed and percentage of reinforcement. Initially weight percentage of reinforcement such as 2.5%, 5%, 10% produced in form of pellet is pre heated at the temperature of 450^oC, aluminium alloy was melted at defined selected temperature of 700 ^oC,750 ^oC,800 ^oC stirring is carried out for 10 minutes (constant) for all different level of experiment at different selected speed say 400rpm, 450rpm, 500rpm. After adding pellets in the molten aluminium alloy stirring was carriedout at 10, 15, 20 minutes and the resultant slurry was then cast into the metallic mould to form the composite specimens. Fig 3 shows photos of the prepared specimens.

Fig.1:Prepared specimen, clockwise Al6061, Al-NCG 2.5%, Al-NCG 10%,Al-NCG 5%.

Brinell hardness test was performed on the composites with 10 mm ball indenter at a load of 500kgf.for each sample average of the hardness reading was considered. Tensile test was carried out on the prepared specimens as per ASTM standard E8 in order to evaluate the tensile strength of the composites.

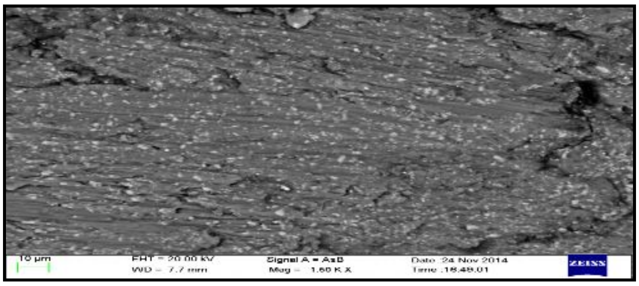

Fig. 2: SEM image at 1500x magnification

The Fig 2. shows the SEM image of thecomposite. From the SEM analysis it is confirmed that the presence of reinforcement in the composite and the particles were distributed uniformly, there is no large pore and particles clustering existed.

3.1 Plan of Experiments

The Taguchi's orthogonal array,which helps in reducing the number of experiments, according to 3-level experiments L27 orthogonal array are conducted. The casting parameters considered for the present investigations are: (1) % weight fraction of NCG (2) stirring speed (3) stirring time (4) stirring temperature. The interactions in the casting parameters may also play constructive role in deciding the Hardness and tensile strength of the composite. After careful investigation,only square effects and two factor are selected ,from this outcome effects are not linearly related, so it is decided to use 3 level tests for each factor[9].

Table 1 Process Parameter and Level

Parameter	Temperature (^{o}C)	Time (sec)	Stirring speed(rpm)	% of Reinforcement
Level 1	700	10	400	2.5
Level 2	750	15	450	5
Level 3	800	20	500	10

3.2 Design of experiment based on Taguchi method and selection of the casting process parameter

Taguchi's design of experiments (DoE) is used for experimentation. Taguchi's approach is a systematic and efficient method provides parameter design to the design engineer for determining optimum design parameters. This method can dramatically reduce the number of experiments required to gather necessary data. In Taguchi's orthogonal array, the most suitable array is L27, which needs 27 runs and has (n-1) 26 degrees of freedoms (DOF)[10]. It can conduct three levels of parameters, for the three level tests, 10 DOFs (5X2) are taken for 5 main factors and the remaining DOFs are taken by interactions. The 3 level L27 orthogonal array is shown in Table 2,

3.3 Experimental Results

Table 2:Experimental Results

Experimental Run	Temperature (^oC)	Time (sec)	Stirring speed(rpm)	% of Reinforcement	Hardness (BHN)	Tensile (MPa)
1	700	10	400	2.5	62.16	155.62
2	700	10	450	5	55.3	124.2
3	700	10	500	10	50.8	114.73
4	700	15	400	5	54.1	123.24
5	700	15	450	10	50.6	118.43
6	700	15	500	2.5	62.01	142.12
7	700	20	400	10	50.45	122.55
8	700	20	450	2.5	61.95	141.13
9	700	20	500	5	55.8	123.02
10	750	10	400	2.5	62.18	163.62
11	750	10	450	5	56.4	134.20
12	750	10	500	10	51.12	124.73
13	750	15	400	5	55.62	133.24
14	750	15	450	10	51.01	122.43
15	750	15	500	2.5	62.1	154.12
16	750	20	400	10	51.1	124.55
17	750	20	450	2.5	63.12	148.13
18	750	20	500	5	55.15	130.12
19	800	10	400	2.5	61.51	143.48
20	800	10	450	5	55.01	120.52
21	800	10	500	10	50.18	116.43
22	800	15	400	5	54.94	124.23
23	800	15	450	10	50.1	110.48
24	800	15	500	2.5	61.3	135.12
25	800	20	400	10	50.1	113.21
26	800	20	450	2.5	62	137.12
27	800	20	500	5	54.01	112.12

3.4 Modelling and Optimization of Machining Parameters Using Response Surface Methodology

Response surface methodology (RSM) method is used for determining the cause-and-effect relationship between input control variables and true mean responses influencing the responses as a two- or three-dimensional function[11]. Many researchers have applied response surface methodology for modelling and analysis of process parameters in manufacturing. Response surface methodology is one of the simple and easy method to use. In this present work, mathematical model is developed for correlating the interactive and second-order influences of various process parameters on Hardness and tensile strength of Al6061-NCG-MMC composites.

$$y = a_0 + \sum_{k=1}^{i} a_i x_i + \sum_{k=2}^{i} a_{ii} x_i^2 + \sum a_{ii} x_i x_j + \alpha \quad (1)$$

The 'a' coefficients is determined by Higher order model which is obtained by the least square method and controllable parameters for product (process) x values result is obtained using response surface methodology can be satisfying several requirements to find that results in optimization of response. The second-order response surface representing the Hardness (H; BHN) and tensile strength can be expressed as a function of casting parameters such as (1) %volume fraction of NCG (2) stirring speed, (3) stirring time (4) temperature.

ANOVA tables are shown in Tables 3. & 4. for hardness and tensile strength. From the below table , analysis of varience for Hradness and tensile strength model, F value of 318.11 for hardness and F value of 29.88 for Tensile strengthin, it indicates that both model are Significan.The values of probability less than 0.05 imply that models are significant.

Table 3:Analysis of Variance for Hardness

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	13	602.440	46.342	318.11	0.000
Linear	4	336.677	84.169	577.77	0.000
Square	4	52.295	13.074	89.74	0.000
Interaction	5	0.878	0.176	1.21	0.360
Residual Error	13	1.894	0.146		
Total	26	604.334			

Table 4:Analysis of Variance for Tensile strength

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	13	5079.21	390.71	38.92	0.000
Linear	4	2223.64	555.91	55.38	0.000
Square	4	1550.11	387.53	38.60	0.000
Interaction	5	28.11	5.62	0.56	0.729
Residual Error	13	130.50	10.04		
Total	26	5209.71			

ANOVA and F-ratio test are performed to validate the goodness of fit in the developed mathematical models, the developed model can be used to validate the effects of casting parameters on hardness and tensile strength of composite,the t-ratio is used to find the significance value of the individual coefficient factor. The larger and absolute value of the more significant factor will be the t-ratio. The probability value represents the factor coefficient and smaller value are more significant[12]. In this analysis, the origin value selected is 0.05. If the probability value is greater than the selected level, the null hypothesis is accepted and the coefficient is judged not to be significant. Finally, the values of R^2represent the regression confidence. The larger value of $R^2$is always desirable

Regression (R) =a_0 +a Temp1 + a_2 Temp2+ a_3 Temp3 + a_4Time1- a_5TimeE2 + a_6 Time3+ a_7 RPM1 + a_8 RPM2+ a_9 RPM3 + $a_{10}$of Rein1+ a_{11} % of Rein2 + a_{12} % of Rein3 (2)

Table 5:Tests on the Five Factors, Square Effects and Their Interactions for Hardness

Term	Effect	Coef	SE Coef	T-Value	Probability	R^2
Constant	------	53.436	0.240	223.02	0.000	99.54%
Temp	-0.4501	-0.2251	0.0908	-2.48	0.028	
Time	-0.1102	-0.0551	0.0917	-0.60	0.558	
RPM	0.028	0.014	0.127	0.11	0.915	
% of Rein	-11.570	-5.785	0.122	-47.41	0.000	
Temp*Temp	-1.476	-0.738	0.156	-4.73	0.000	
Time*Time	0.531	0.266	0.156	1.70	0.112	
RPM*RPM	-0.702	-0.351	0.165	-2.13	0.053	
% of Rein*% of Rein	6.822	3.411	0.189	18.06	0.000	
Temp*Time	-0.088	-0.044	0.110	-0.40	0.695	
Temp*RPM	-0.493	-0.247	0.110	-2.24	0.043	
Temp*% of Rein	-0.031	-0.016	0.108	-0.14	0.888	
Time*RPM	-0.280	-0.140	0.165	-0.85	0.411	
Time*% of Rein	-0.012	-0.006	0.162	-0.04	0.971	

Regression Equation

Hardness(BHN) = -155.5 + 0.4857 Temp + 0.057 Time + 0.2090 rpm - 4.508 % of reinf. -0.000295 Temp* Temp + 0.01062 Time *Time - 0.000140 rpm *rpm + 0.2426 % of reinf. *% of reinf. - 0.000177 Temp*Time - 0.000099 Temp*RPM -0.000083 Temp*% of rein. - 0.000561 Time *rpm - 0.00032 Time *% of reinf.

Table 6:Tests on the Five Factors, Square Effects and Their Interactions for Tensile strength

Term	Effect	Coef	SE Coef	T-Value	Probability	R^2
Constant	---	123.39	1.99	62.04	0.000	97.50%
Temp	-5.702	-2.851	0.753	-3.78	0.002	
Time	-4.895	-2.448	0.762	-3.21	0.007	
RPM	-4.85	-2.42	1.06	-2.29	0.039	
% of Rein	-26.96	-13.48	1.01	-13.31	0.000	
Temp*Temp	-21.39	-10.70	1.29	-8.27	0.000	
Time*Time	2.52	1.26	1.29	0.97	0.348	
RPM*RPM	4.27	2.13	1.37	1.56	0.143	
% of Rein*% of Rein	28.67	14.34	1.57	9.14	0.000	
Temp*Time	-1.688	-0.844	0.915	-0.92	0.373	
Temp*RPM	0.715	0.358	0.915	0.39	0.702	
Temp*% of Rein	1.009	0.504	0.898	0.56	0.584	
Time*RPM	2.28	1.14	1.37	0.83	0.420	
Time*% of Rein	1.52	0.76	1.34	0.57	0.581	

Tensile Strength(MPa) = -1907 + 6.330 Temp - 1.77 Time- 0.992 (RPM)-18.96 % of Rein -0.004278 Temp * Temp + 0.0504 Time*Time+ 0.000853 (RPM)* (RPM)+ 1.019 % of Rein * % of Rein - 0.00338 Temp *Time+ 0.000143 Temp * (RPM) + 0.00269 Temp*% of Rein + 0.00456 Time* (RPM) + 0.0406 Time(sec)*% of Rein

The casting parameter has been optimization using response optimizer in MINITAB and the result are discussed below.

4 . Result and discussion

In this analysis the objective set for casting process is maximizing the hardness and tensile strength, for optimization MINITAB 17 software is used. The results obtained from the experimental runs carried out,according to the taughi orthogonal array shown in Table 6. The main effects analysis plot is used to analysis the effects of each factors of casting parameter such as weight % of NCG, stirring speed , stirring time & stirring temperature versus Hardness have been shownin Figs. According to main effect plots, average hardness per casting process

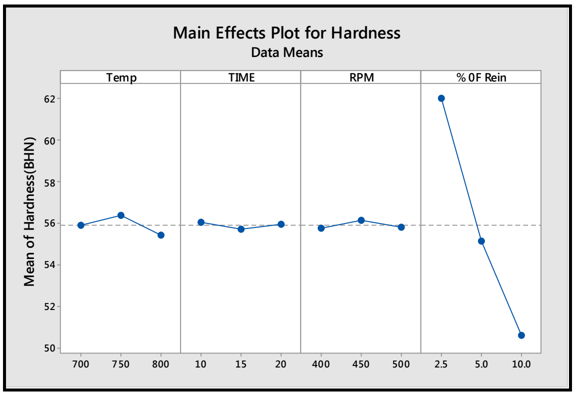

Fig 3: Main effect plot for Hardness(BHN)

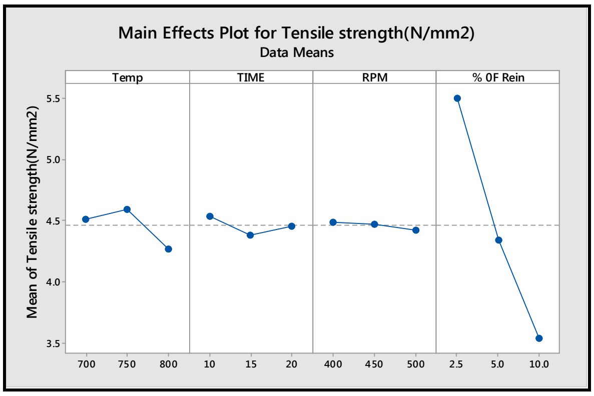

Fig 4: Main effect plot for Tensile strength(N/mm^2)

Analysis of Variance (ANOVA) technique is used to check the validity of the developed model and Student's *t*-test was utilised to find the significance of factors Analysis of Variance (ANOVA) and F test were analysis to find the significance level of each factor(confidence level of more than 95%). If the F value of a factor exceeds the F0.05 the factor is insignificant. ANOVA tables for all the four are presented in Tables 3 & 4.

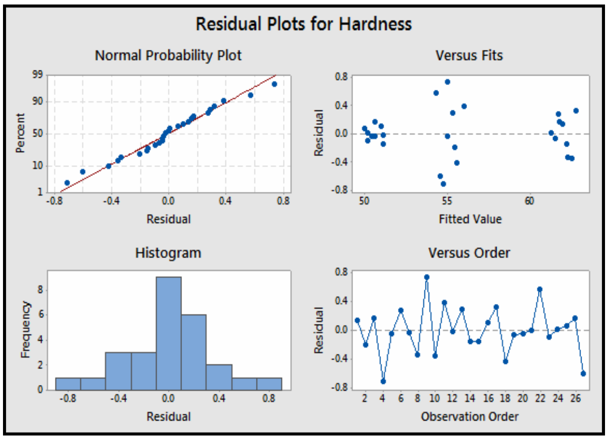

Fig. 5:Residual plot for Hardness(BHN)

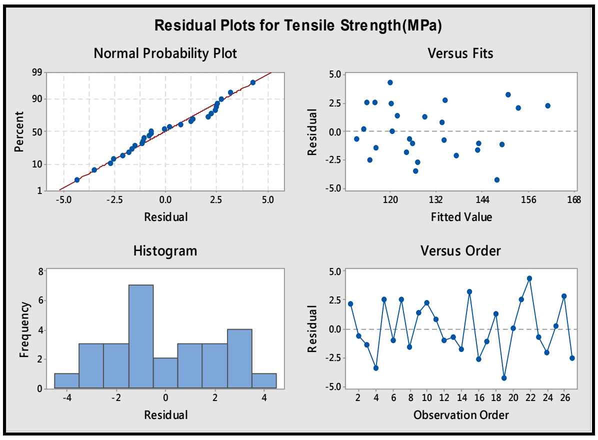

Fig.6: Residual plot for Tensile strength(N/mm^2)

From ANOVA of Hardness and tensile in Table 3 & 4, it can be observed that the influence of % reinforecement on hardness as well as tensile strength is more when compared to the other parameters. Hence, of % reinforecement is the most significant input parameter affecting Hardness and tensile, followed by stirring Temperature, stirring time and stirring speed. Consequently, it can be concluded that Hardness and tensile strength of Al6061–NCG are found to be more sensitive to percentage of reinforcement and stirring time than other two parametrs. Fig. 5 & 6.Shows the normal probabilities plot of residuals between predicted values and experimental value, from the figure it is clear that the residuals are spread closer to the straight line for both hardness and as well as tensile strength the residuals are fitted accurately so this entailed that the errors are distributed normally with respect to the predicted values. The residuals are distributed both in positive and a negative direction. This implies that the model is adequate.

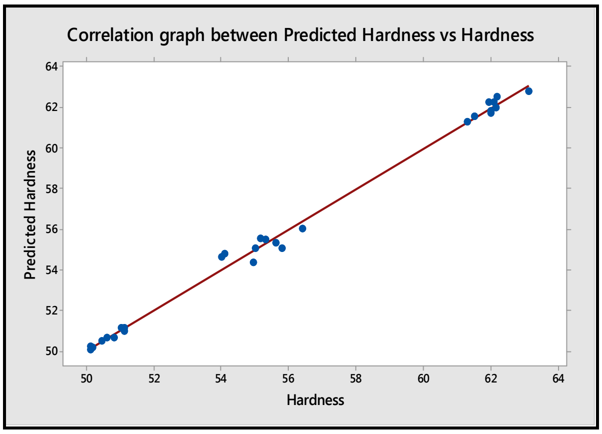

Fig 7: correlation graph for Hardness(BHN

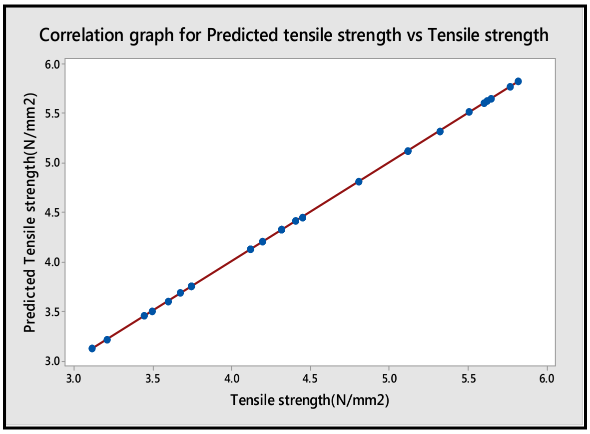

Fig 8: correlation graph for Tensile strength(N/mm^2)

From Fig. 7&8. it is declared that the predicted results are very close to the experimental results and hence the response surface models are suitable for predicting Hardness and tensile strength of the aluminium nickel coated graphite composites.

Minitab's response optimizer provide optimize set of response by combination a set input variable that satisfying the requirements..

1. Attain individual desirability (d) for every response
2. Combining the individual desirabilities to obtain the composite desirability (D)
3. Maximizing the composite desirability and identifying the optimal input variable settings.

The optimization graph obtained, the parameters used, its goal set and other information are given in Figure 9. Using the above the global statement

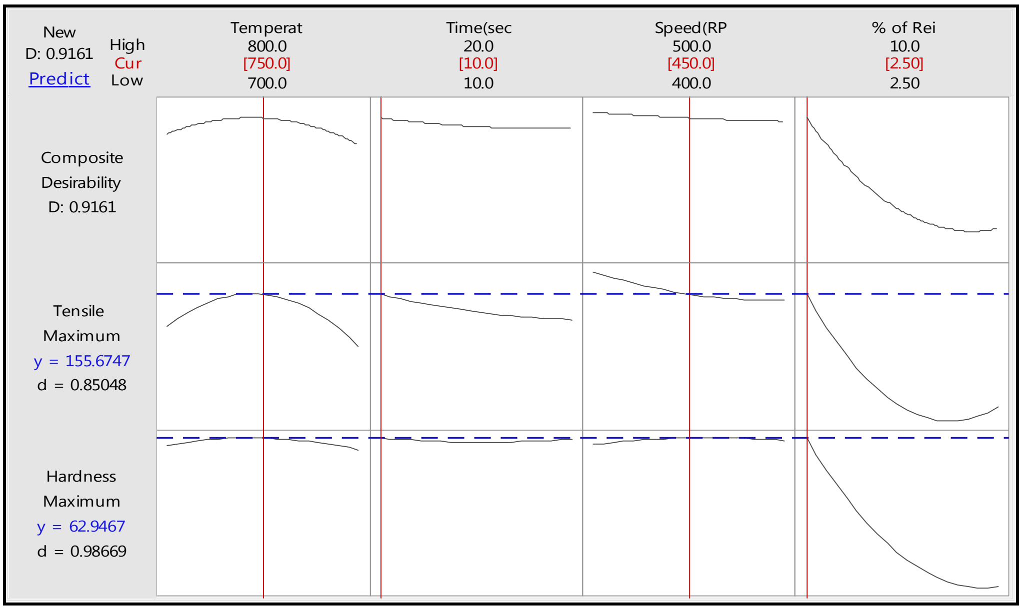

Fig 9.Optimization plot for Hardness (BHN) and tensile strength (MPa)

From the optimization graph obtained, using the above the global obtained for maximization of Hardness and tensile strength are below shown.

Table 7:Multiple Response Prediction for hardness and tensile strength

Variable Setting	Prediction Optimized Values
Temperature(^{O}C)	750
Time(sec)	10
Stirring Speed(RPM)	450
% of reinforcement	2.5

The response surfaces are plotted for the model established. Figure 11&12. shown below the response surface of Hardness (H) with respect to the Weight fraction of NCG, stirring temperature and stirring time

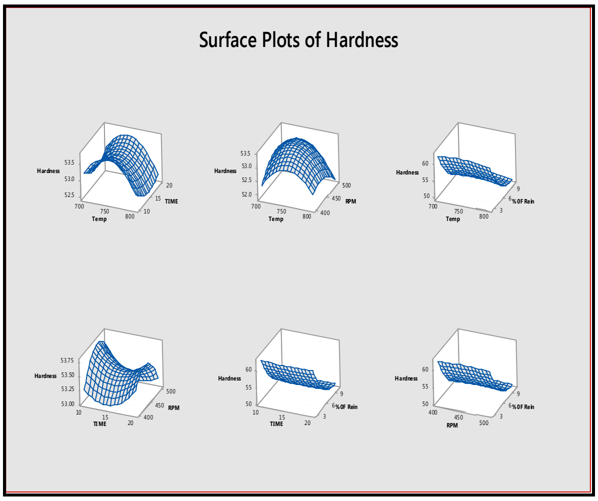

Fig. 10: Surface Plot for Hardness (BHN)

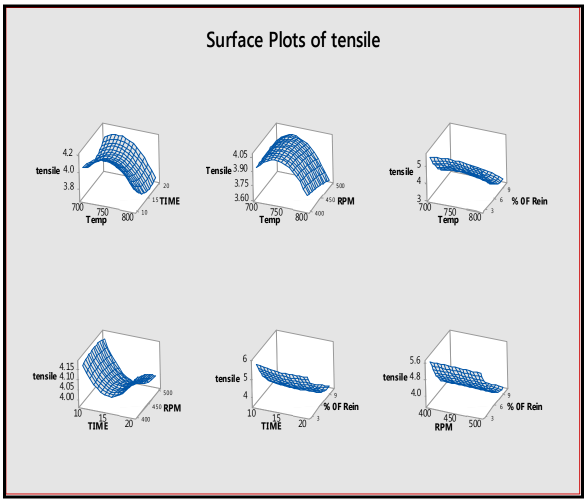

Fig .11:Surface Plot for tensile strength (N/mm^2)

The surface plot shows that the Hardness and tensile strength are maximum at medium stirring temperature, stirring time, stirring speed and lower percentage of reinforcement. It is clear that the change in temperature and speed plays an important role in achieving maximum Hardness. The decreasein percentage of reinforcement leads to an increase strength of the composite material, this is subjected to increase in hardness and tensile strength of the casting process parameter. As a result, the observed hardness becomes higher. The effects of weight fraction NCG, while keeping the other parameters at centre level, are shown in Figure the above fig.10&11. It is evident from the plot that the Hardness of Al– NCG composites increase with a decrease in weight fraction of NCG.This is due to the solid lubrication of Gr particles.

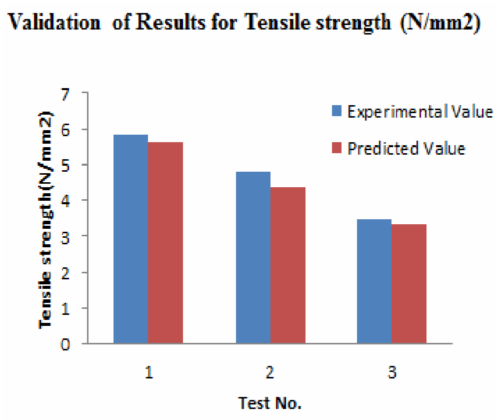

Fig .12:Validation result for tensile strength (MPa)

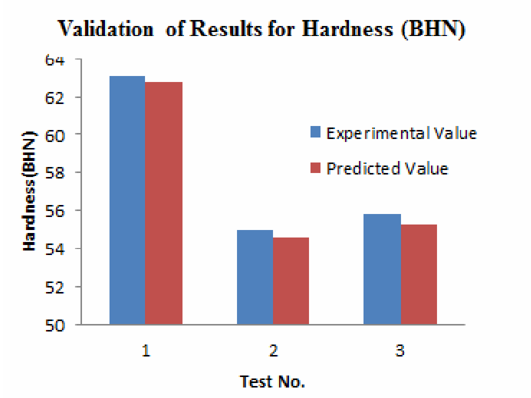

Fig.13:Validation result for Hardness (BHN)

or confirmation of the second-order response surface model, verification tests are conducted at three selected conditions. Figure 12. shows the validation of tensile strength result and Figure 13. shows the validation of hardness result, from this the difference between the predicted Hardness by the second order response surface model and the experiment are very closer, hence the second order response surface surface model is very useful for predicting the Hardness and tensile strength of stir casted Al6061-NCG composites within the selected parameter settings.

5. Conclusions

The Hardness and tensile strength in the casting process parameter has been investigated according to the Taguchi L27 orthogonal array. Based on the orthogonal array experimental and analytical results, the following conclusions are made:

1. The effect of casting parameters on the Hardness is evaluated with the help of Taguchi method. The % volume fraction of NCG and casting Temperature are dominant parameters for Hardness.
2. Optimal process parameter for maximizing Hardness and Tensile strength are determined.
3. A second order response surface model for Hardness is developed from the observed data. The predicted values and measured values are fairly close to each other, which indicate that the developedmodel can be effectively used to predict the Hardness on the casting parameter of Al6061-NCG composites with 95% confidence intervals. Using such model a remarkable saving in time and cost has been obtained.
4. The results revealed that maximization of Hardness and Tensile strength could be arrived significantly for composite casting.
5. Verification results reveal that the second order response surface model is suitable for predicting Hardness on the casting parameter of Al6061-NCG composite within the ranges of selected casting parameters are studied.

References:

1. M.K. Surapa, "Aluminium matrix composites: Challenges and opportunities". Sadhana Vol. 28, Parts 1 & 2, pp. 319–334, 2003.
2. Chambers AR. The machinability of light alloy MMCs.Composites A 1996;27A:143–7. Becher, P.F.; Wei, G.C. (1984) Toughening behavior in SiC – whisker- reinforced alumina. Journal of American Ceramic Society, 67(12): 267–269.
3. J.S.S. Babu, K.N. Prabhakaran, G. Unnikrishnan, C.G. Kang,"Development of Aluminum-based Hybrid Composites with Graphite Nanofibers/Alumina Short Fibers: Processing and Characterization".Journal of Composite Materials, vol 44, no. 16, pp1929 – 1943, 2010.
4. M.L. Ted Guo, Chi.-Y.A. Tsao , Tribological behavior of aluminum/SiC/nickel-coated graphite hybrid composites, Materials Science and Engineering A333 (2002) 134–145
5. Hsiao Yeh Chu, Jen Fin Lin, Experimental analysis of the tribological behavior of electroless nickel-coated graphite particles in aluminum matrix composites under reciprocating motion, Wear 239 2000. 126–142
6. Lakshmikanthan.P, Kannan.V, Prabu. BSynthesis and Charecterisation of Al 6061 – Nickel Coated Graphite Composite Using Pellet Method, International Journal of Applied Engineering Research • ISSN 0973-4562 Volume 10, Number 3 (2015)
7. Aggarwal, A., Singh, H., Kumar, P., Singh, M., 2008. Optimizing power consumption for CNC turned parts using response surface methodology and Taguchi's technique e a comparative analysis. J. Mater. Process. Technol. 200, 373e384
8. B. C. Pai, P. K. Rohatgi, Production of cast aluminium-graphite particle composites using a pellet method, Journal of Materials Science 13 (1978) 329-335
9. M. Aloufi, T.J. Kazmierski, A response surface modelling approach to performance optimisation of kinetic energy harvesters, IJRRCS Simulation. Benchmarking and Modeling of Systems and Communication Networks (2011) 1–8.
10. A.Srinivasan, R.M. Arunachalam, S. Ramesh and J.S. Senthilkumaar, Machining Performance Study on Metal Matrix Composites-A Response Surface Methodology Approach, American Journal of Applied Sciences 9 (4): 478-483, 2012
11. Ilhan Asiltürk, Süleyman Neseli, Multi response optimisation of CNC turning parameters via Taguchi method-based response surface analysis, Measurement 45 (2012) 785–794.
12. K. Palanikumar a , N. Muthukrishnan b & K. S. Hariprasad c, surface roughness parameters optimization in machining a356/ sic/20p metal matrix composites by pcd tool using response surface Methodology and desirability function, Machining Science and Technology, 12:529–545.

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