Optimization of Testing Parameters in Immersion Corrosion Testing of Aluminium Alloy (Al6061) – Alumina (Al_2O_3) Composites Fabricated by Stir Casting

P. V. Rajesh
Assistant Professor,
Department of Mechanical Engineering,
Saranathan College of Engineering

P. Jothi Palavesan
Assistant Professor,
Department of Mechanical Engineering,
Saranathan College of Engineering

K. Vimal Raj
U.G. Scholars,
Saranathan College of Engineering,
Trichy, India.

S. Vijayaragavan
U.G. Scholars,
Saranathan College of Engineering,
Trichy, India.

***Abstract*: -The present study deals with the Optimization of testing parameters in Immersion Corrosion Testing of Aluminium alloy (Al6061) – Alumina (Al_2O_3) Composites fabricated by Stir casting used in Ship hulls. The sample specimens are made by varying the percentage of reinforcements with respect to aluminium alloy. Aluminium is compared with the Al6061- Al_2O_3 composites because the composite samples have improved corrosion resistance than the individual aluminium alloy. Finally, the most suitable composite that is having the best corrosion resistance is optimized using Box Behnken technique in Response Surface Methodology.**

Keywords- Aluminium; alumina; stir casting; box behnken; response surface methodology; composites; ship hulls

I. INTRODUCTION

Composite is a material composed of two or more distinct phases (matrix phase and dispersed phase) and having bulk properties significantly different form those of any of the constituents. Metal Matrix Composite (MMC) is a material consisting of a metallic matrix combined with a ceramic (oxides, carbides) or metallic (lead, tungsten, molybdenum) dispersed phase.

Aluminum Matrix Composites (AMC) is the widest group of Metal Matrix Composites. Matrices of Aluminum Matrix Composites are usually based on aluminum-silicon (Al-Si) alloys and on the alloys of 2xxx and 6xxx series. Aluminum Matrix Composites (AMC) are reinforced by: Alumina (Al2O3) or silicon carbide (SiC) particles (particulate Composites) in amounts 15-70 vol%; Continuous fibers of alumina, silicon carbide, Graphite (long-fiber reinforced composites); Discontinuous fibers of alumina (short-fiber reinforced composites).

Aluminum Matrix Composites can be manufactured by Powder metallurgy(sintering), Stir casting and Infiltration methods. The following properties are typical for Aluminum Matrix Composites, High strength even at elevated temperatures, High stiffness (modulus of elasticity), Low density, High thermal conductivity and Excellent abrasion resistance.

II. MATERIALS AND METHODS

A. Selection of Materials.

Matrix

The matrix material to be used was chosen as Al6061 which is a precipitation hardened aluminium alloy, containing iron, silicon and chromium as its major alloying elements as indicated in Table I. It has good mechanical properties and exhibits good weldability, good formability and high corrosion.

TABLE I. CHEMICAL COMPOSITION OF ALUMINIUM

Constituents	Percentage
Manganese (Mn)	0.108%
Iron (Fe)	0.125%
Copper (Cu)	0.392%
Magnesium (Mg)	0.970%
Silicon (Si)	0.620%
Chromium (Cr)	0.079%
Others (Total)	0.04%
Aluminium (Al)	97.7%

TABLE II. PHYSICAL PROPERTIES OF Al6061

Properties	Value	Unit
Density	2.7	g/cm^3
Melting point	582-652	°C
Brinell Hardness	45	
Ultimate Tensile Strength	130	MPa
Yield Strength	276	MPa
Modulus of Elasticity	68.9	MPa
Thermal conductivity	167	W/m-K
Coefficient of Thermal Expansion	23.6×10^{-6}	m/°C

Reinforcement:

The materials selected to be reinforced into the metallic matrix is Alumina. Aluminium oxide is a chemical compound of aluminium and oxygen with the chemical formula Al2O3. Alumina is significant in its use to produce aluminium metal, as an abrasive owing to its hardness, and as a refractory material owing to its high melting point. It is reinforced in the Al6061 matrix to increase strength, hardness, stiffness, wear resistance and impact strength. Its attractive properties are listed in Table III.

TABLE III PROPERTIES OF ALUMINA

Properties	Alumina (Al_2O_3)	Units
Density	3.98	g/cm^3
Melting point	2300	°C
Vickers Hardness	1560	
Fracture toughness	4.9	MPa√m
Elastic Modulus	300	GPa
Tensile Strength	210	MPa
Thermal conductivity	21	W/mK
Coefficient of thermal Expansion	9	m/°C

A. Fabrication process

Stir casting is the most popular commercial method of producing aluminium based composites. In this method, pre heated ceramic particulates are incorporated into the vortex of the molten matrix created by a rotating impeller. In principle, it allows a conventional metal processing route to be used, and hence minimizes the final production cost of the product. This conventional method is also called as vortex method and liquid metallurgy route shown in fig. 1.

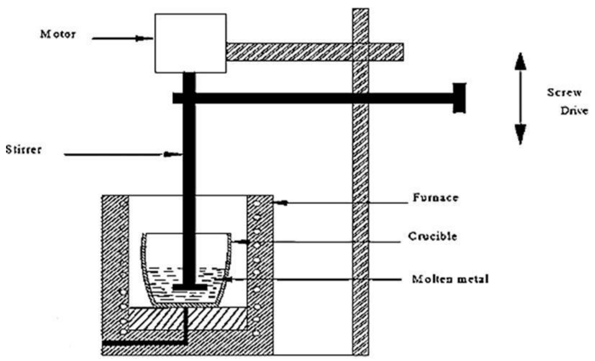


FIG 1. STIR CASTING DIAGRAM

The stir casting process starts with the preheating of graphite crucible in a gas-fired furnace for 20 minutes. The Alumina was initially preheated separately at a temperature of 250°C to remove moisture and to help even distribution within Al6061 alloy. The Al6061 alloy billets were charged into the furnace, fitted with a temperature probe and heated to a temperature of 750 ± 30°C (i.e) above the liquidus temperature of the alloy to ensure that the alloy melts completely. The liquid alloy was then allowed to cool in the furnace to a semi solid state at a temperature of about 600°C. Slag is removed using scum powder. Now with the help of electrical stirrer, the molten alloy is stirred at a constant speed of 450 rpm to create vortex. The preheated Alumina is then charged into the melt at constant pour rate and stirring of the slurry was performed manually for 5-10 minutes. Magnesium about 1% of weight is added to ensure good wettability for all proportions of the reinforcements.

The composite slurry was superheated to 800°C and a second stirring performed using a mechanical stirrer. The stirring operation was performed at a speed of 400 rpm for 10 minutes before casting into prepared sand moulds. Meanwhile the mould is preheated to avoid shrinkage of casting material. Then the melted matrix and reinforced particles are poured into the preheated mould and the pouring temperature should be maintained at 680°C. The entire process is done with either nitrogen gas or inert gas surrounding it to avoid contamination from atmosphere. The final shape of the composite may be a bar, rod or plate whatsoever the shape of the mould.

III. IMMERSION CORROSION TEST

CORROSION TEST

The corrosion behaviour of the composites is studied by weight loss method using mass loss and corrosion rate measurements in both acidic and basic environments. The corrosion test will be carried out by immersion of the test specimens in 1N HCl (3.6ml in 100ml of distilled water) and 1N NaOH (4g in 100ml of distilled water) solutions which will be prepared following standard procedures. The specimens for the test are cut to size 10×10×10 mm and then mechanically polished with emery papers from 150 down to 600 grit sizes to produce a smooth surface. The samples are de-greased with acetone, rinsed in distilled water, and then dried in air before immersion in still solutions at room temperature (25°C). The solution-to-specimen surface area ratio will be about 150 ml cm^{-2}, and the corrosion setups are exposed to atmospheric air for the duration of the immersion test. The weight loss readings will be monitored for a period of 24 hours.

$$\text{Corrosion rate} = \frac{87500 \times (mi - mf)}{\rho \times A \times t} \quad \text{(mmpy)}$$

where

m_i - Initial weight (g)
m_f - Final weight (g)
ρ - Density (g/cm^3)
A - Area (cm^2)
t - Time (hrs)

Run	Composition of Alumina	Stirring speed	Stirring time	Before weight m_i	After weight mf	Time	Volume	Density	Corrosion rate
	Wt. %	rpm	min.	g	g	hrs.	cm^3	g/cc	mmpy
1	10.00	200.00	2.00	20.1	19.7	24	7.20	2.792	362.72
2	5.00	200.00	4.00	20.6	20.2	24	7.20	2.861	353.97
3	5.00	600.00	4.00	22.4	22.0	24	7.20	3.111	325.53
4	10.00	600.00	2.00	20.2	19.8	24	7.20	2.805	361.05
5	5.00	400.00	2.00	20.4	20.1	24	7.20	2.833	268.10
6	15.00	600.00	4.00	9.3	8.8	28	4.32	2.153	503.98
7	10.00	400.00	4.00	4.7	4.2	28	1.44	3.263	332.53
8	10.00	400.00	4.00	4.7	4.2	28	1.44	3.263	332.53
9	10.00	600.00	6.00	12.5	12.3	28	5.76	2.170	200.01
10	10.00	400.00	4.00	4.7	4.2	28	1.44	3.263	332.53
11	15.00	400.00	6.00	8.7	8.3	28	4.32	2.014	431.01
12	10.00	400.00	4.00	4.7	4.2	28	1.44	3.263	332.53
13	10.00	200.00	6.00	5.4	5.1	28	1.44	3.750	173.61
14	15.00	200.00	4.00	21.5	21.2	28	7.20	2.986	218.03
15	5.00	400.00	6.00	21.3	20.9	24	7.20	2.958	342.37
16	15.00	400.00	2.00	21.3	21.0	28	7.20	2.958	220.09
17	10.00	400.00	4.00	4.7	4.2	28	7.20	3.263	332.53

Acidic corrosion rate of cast Al6061 is 1860.1 mmpy

Table IV Acidic corrosion rate results

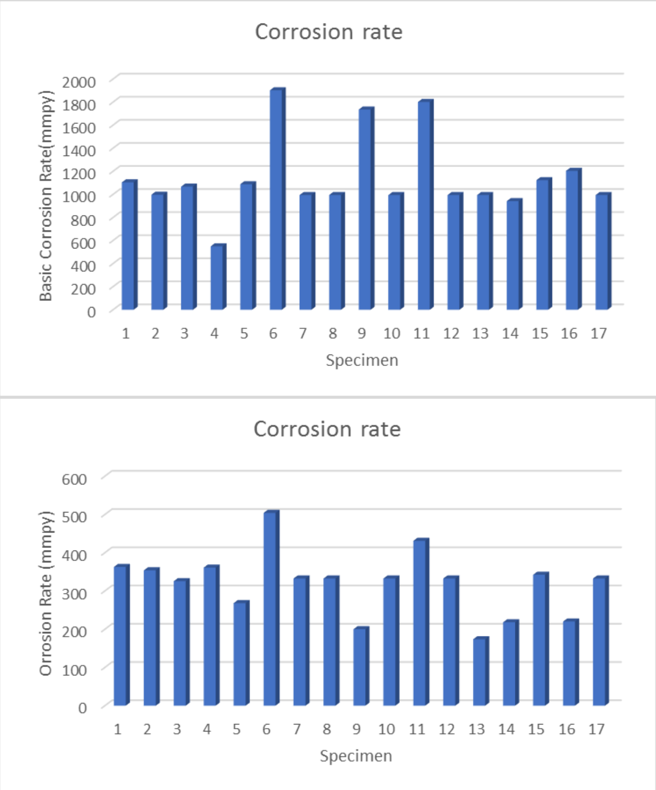


Figure 2 Acidic Corrosion Rate Result & Basic Corrosion Rate Result

IV. EXPERIMENTAL PROCEDURE

Response Surface Methodology

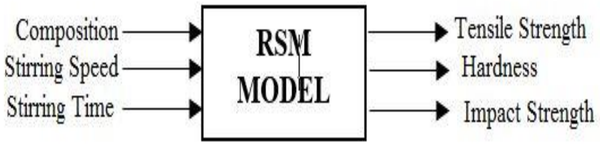
Response Surface Methodology is a collection of mathematical and statistical procedures used for analyzing of problems in which a particular response is influenced by multiple variables. A standard RSM Technique called Box-Behnken Design Technique (BBD) was selected to study hardness, impact test and tensile test. BBD for three parameters composition, stirring speed and stirring time each with two levels was used as experimental design model.

combinations of variables for determining the complex response function. In many experimental conditions, it is possible to represent independent factors in quantitative form as given in Eq.(1).

These factors can be treated as having a functional relationship or response similar to:

$$Y = \Phi\ (x_1, x_2, \ldots\ldots, x_k) \pm e_r \qquad (1)$$

Where, the response Y and x_1, x_2 ,…….., x_k of k quantitative factors, the function is called response surface or response function, the residual e_r measures the experimental errors. When the mathematical form of Φ is not known, it can be approximate satisfactorily within the experimental region by polynomial.



The regression equation of second order polynomial was used to represent the response surface 'Y' is given by equation 2.

Basic corrosion rate of cast Al6061 is 4030.3 mmpy

Table V Basic corrosion rate results

Run	Composition of Alumina	Stirring speed	Stirring time	Before weight	After weight	Time	Volume	Density	Corrosion rate
	Wt. %	**rpm**	**min.**	**g**	**g**	**hrs.**	**cm^3**	**g/cc**	**mmpy**
1	10.00	200.00	2.00	19.8	18.6	24	7.20	2.750	1104.79
2	5.00	200.00	4.00	20.1	19.0	24	7.20	2.792	997.49
3	5.00	600.00	4.00	22.2	20.9	24	7.20	3.083	1067.58
4	10.00	600.00	2.00	19.9	19.3	24	7.20	2.764	549.60
5	5.00	400.00	2.00	20.1	18.9	24	7.20	2.792	1088.17
6	15.00	600.00	4.00	9.2	7.6	24	4.32	2.129	1902.73
7	10.00	400.00	4.00	4.4	3.2	24	1.44	3.056	994.17
8	10.00	400.00	4.00	4.4	3.2	24	1.44	3.056	994.17
9	10.00	600.00	6.00	12.6	11.1	24	5.76	2.188	1735.71
10	10.00	400.00	4.00	4.4	3.2	24	1.44	3.056	994.17
11	15.00	400.00	6.00	8.5	7.1	24	4.32	1.968	1801.09
12	10.00	400.00	4.00	4.4	3.2	24	1.44	3.056	994.17
13	10.00	200.00	6.00	5.5	4.0	24	1.44	3.819	994.43
14	15.00	200.00	4.00	21.3	20.2	24	7.20	2.958	941.52
15	5.00	400.00	6.00	21.1	19.8	24	7.20	2.931	1122.95
16	15.00	400.00	2.00	21.2	19.8	24	7.20	2.944	1203.99
17	10.00	400.00	4.00	4.4	3.2	24	7.20	3.056	994.17

Experimental Design by RSM -Box Behnken Method

All the specimens were prepared according to the experimental runs developed by the DESIGN EXPERT 8. The controlling parameter set for running the design matrix is given Table VI.

Table VI Controlling Parameter and their Levels for the Study

Symbol	Factor	Experimental values	
		Low level (1)	**High level (2)**
A	Composition of Alumina (wt %)	5	15
B	Stirring speed (rpm)	200	600
C	Stirring time (minutes)	2	6

The Model F-value of 10.62 implies the model is not significant relative to the noise. There is a 67.64 % chance that a F-value this large could occur due to noise. "Values of ""Prob > F"" less than 0.0500 indicate model terms are significant. "In this case there is one significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. In this case weight percentage of alumina is process parameter which influences the response (Acidic Corrosion Rate).

TABLE VII Process design layout using box-behnken design and test results

$$y = \beta_0 \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i=1}^{k} \sum_{i \neq j=1}^{k} \beta_{ij} x_i x_j + \varepsilon \quad (5)$$

Run	Composition of Alumina	Stirring speed	Stirring time	Acidic Corrosion rate	Basic Corrosion rate
	Wt. %	**rpm**	**min.**	**mmpy**	**mmpy**
1	10.00	200.00	2.00	362.72	1104.79
2	5.00	200.00	4.00	353.97	997.49
3	5.00	600.00	4.00	325.53	1067.58
4	10.00	600.00	2.00	361.05	549.60
5	5.00	400.00	2.00	268.10	1088.17
6	15.00	600.00	4.00	503.98	1902.73
7	10.00	400.00	4.00	332.53	994.17
8	10.00	400.00	4.00	332.53	994.17
9	10.00	600.00	6.00	200.01	1735.71
10	10.00	400.00	4.00	332.53	994.17
11	15.00	400.00	6.00	431.01	1801.09

12	10.00	400.00	4.00	332.53	994.17
13	10.00	200.00	6.00	173.61	994.43
14	15.00	200.00	4.00	218.03	941.52
15	5.00	400.00	6.00	342.37	1122.95
16	15.00	400.00	2.00	220.09	1203.99
17	10.00	400.00	4.00	332.53	994.17

TABLE VIII ANOVA for Response Surface Quadratic model for Acidic Corrosion Rate

Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**	
Model	53805.42	9	5978.38	10.62	0.0044	Significant
A-Composition	864.03	1	864.03	6.54	0.0146	Predominantly influencing
B-Stirring Speed	9957.43	1	9957.43	1.22	0.3063	
C-Stirring Time	527.48	1	527.48	0.065	0.8068	
AB	24710.27	1	24710.27	3.02	0.1257	
AC	4668.31	1	4668.31	0.57	0.4745	
BC	196.98	1	196.98	0.024	0.8810	
A^2	3650.87	1	3650.87	0.45	0.5254	
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**	
B^2	566.45	1	566.45	0.069	0.8000	
C^2	9137.03	1	9137.03	1.12	0.3256	
Residual	57230.87	7	8175.84			
Lack of Fit	57230.87	3	19076.96			
Pure Error	0.000	4	0.000			
Cor Total	1.110E+005	16				

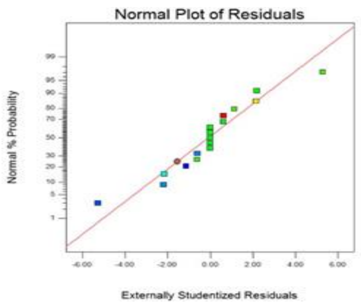
Std. Dev.	90.42	R-Squared	0.7246
Mean	319.01	Adj R-Squared	0.6481
C.V. %	28.34	Pred R-Squared	0.5468
PRESS	9.157E+005	Adeq Precision	13.615
-2 Log Likelihood	186.31	BIC	214.64
		AICc	242.98

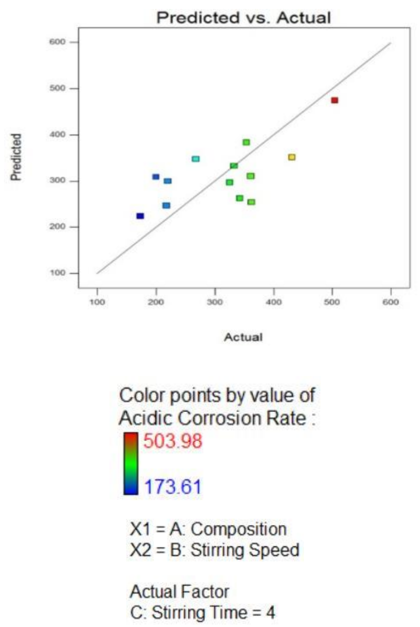
A positive "Pred R-Squared" implies that the overall mean may be a better predictor of your response than the current model. "Adeq Precision" measures the signal to noise ratio. A ratio of 13.615 indicates an inadequate signal and we should not use this model to navigate the design space.

Final Equation in Terms of Actual Factors:

Acidic Corrosion Rate = +621.59 -66.5825 * Composition -0.4477* Stirring Speed +47.9274 * Stirring Time +0.07859 * Composition * Stirring Speed +3.4162 * Composition * Stirring Time
+0.017543* Stirring Speed * Stirring Time +1.1778 * Composition^2 -2.89961E-004 *
Stirring Speed^2 -11.645 * Stirring Time^2

The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space.





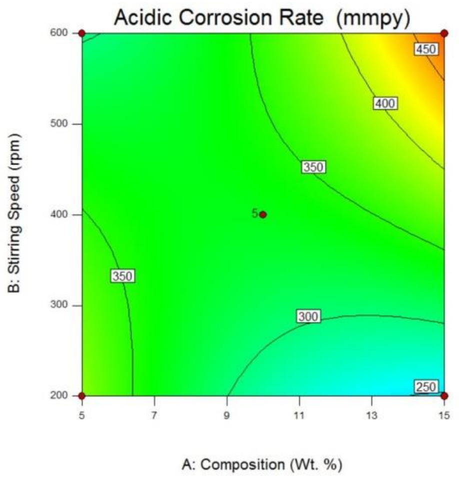


TABLE IX ANOVA for Response Surface Quadratic model for The Model F-value of 12.34 implies the model is significant. There is only a 0.16% chance that an F-value this large could occur due to noise. "Values of ""Prob > F"" less than 0.0500 indicate model terms are significant. " In this case A, B, C, AB, BC, A^2- are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. In this case weight percentage of alumina is process parameter which influences the response (Basic Corrosion Rate).

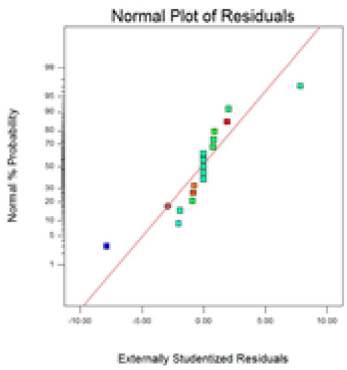
"The ""Pred R-Squared"" of 0.0516 is not as close to the ""Adj R-Squared"" of 0.8645 as one might" normally expect; i.e. the difference is more than 0.2. This may indicate a large block effect or a possible problem with your model and/or data. Things to consider are model reduction, response transformation, outliers, etc. All empirical models should be tested by doing confirmation runs. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 11.691 indicates an adequate signal. This model can be used to navigate the design space.

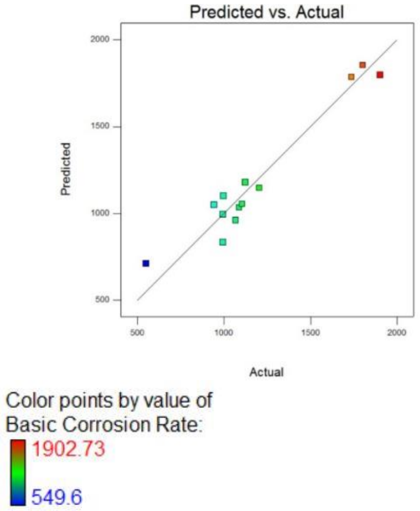
Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	1.808E+006	9	2.009E+005	12.34	0.0016	Significant
A-Composition	3.093E+005	1	3.093E+005	25.81	0.0014	Most influencing
B-Stirring Speed	1.853E+005	1	1.853E+005	11.38	0.0119	
C-Stirring Time	3.645E+005	1	3.645E+005	22.39	0.0021	
AB	1.985E+005	1	1.985E+005	12.20	0.0101	
AC	79050.95	1	79050.95	4.86	0.0634	
BC	4.202E+005	1	4.202E+005	19.00	0.0033	
A^2	2.048E+005	1	2.048E+005	12.58	0.0094	
B^2	670.72	1	670.72	0.041	0.8449	
C^2	33607.83	1	33607.83	2.06	0.1939	
Residual	1.140E+005	7	16278.91			
Lack of Fit	1.140E+005	3	37984.12			
Pure Error	0.000	4	0.000			
Cor Total	1.922E+006	16				

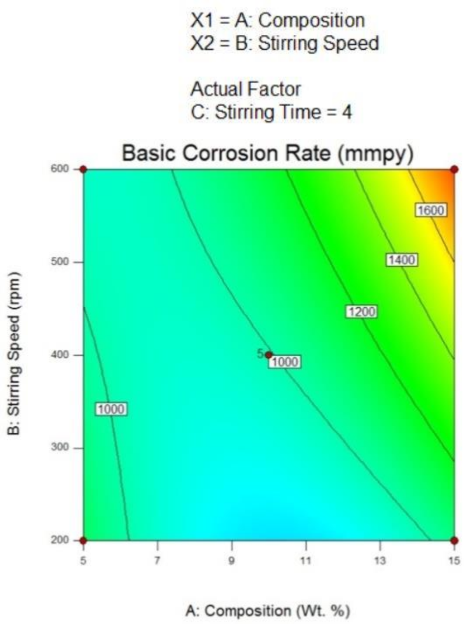
Std. Dev.	127.59	R-Squared	0.9407
Mean	1145.94	Adj R-Squared	0.8645
C.V. %	11.13	Pred R-Squared	0.0516
PRESS	1.823E+006	Adeq Precision	11.691
-2 Log Likelihood	198.02	BIC	226.35
		AICc	254.69

Final Equation in Terms of Actual Factors:

Basic Corrosion Rate = +3909.544 -282.44649 * Composition -4.960* Stirring Speed -536.653 * Stirring Time +0.22278 * Composition * Stirring Speed +14.058 * Composition * Stirring Time +0.810293 * Stirring Speed * Stirring Time +8.82155 * Composition^2 +3.1553124E-004 * Stirring Speed^2 +22.335* Stirring Time^2







OPTIMIZED VALUE

Composition	Stirring Speed	Stirring Time	Acidic Corrosion Rate	Basic Corrosion Rate	Desirability
6.838	600.000	2.000	287.833	622.595	0.946

CONCLUSION

In this study, the aluminium (Al6061) - alumina composites were fabricated by varying the composition of alumina, stirring speed and stirring time. The influence of the three factors were analysed by using Box Behnken design. Also, a quadratic model equation was developed which explains the relationship between the responses and the process parameters. The effects of process parameter levels on the response value were analysed using analysis of variance (ANOVA). From the obtained results, corrosion rate of the aluminium alumina composites were highly influenced by the composition of alumina. Also the optimized values for obtaining the desired properties is found.

REFERENCES

[1] B. Ravi, B. Balu Naik, J. Vdhaya Prakash, “Characterisation of aluminium matrix composites (al 6061 b4c) fabricated by stir casting technique” Materials Today(2015)PG. 2984 – 2990

[2] Dattatraya N Lawate, Shriyash B Shinde, Tussar S Jagtap, “study of process parameters in stir casting method for production particulate composite plate” International Journal of Innovations in Engineering Research and Technolog(2016) volume III issue 1 issn 2394 – 3696

[3] Shubhaam Mathur, Alok Barnawal, “Effect of process parameters of stir casting on metal matrix composite” International Journals of Science and Research(2013) volume II page 395 – 397

[4] G.G. Sochamannan, S. Balasivananda Prahu, “Effect of processing parameters on metal matrix composite stir casting process” Journal of Surface Engineered Materials and Technology (2012) volume II page 11 -15

[5] Mohsen Hussein – Zadh, Mansur Razavi, Omie Mirzaee, Razieh Ghaderi, “Characterization of properties of al-al$_2$o$_3$ nano composite synthesised via milling and subsequent casting” Journal of King Saud University(2013) volume : xxv page : 75-80

[6] Pradeep Sharma, Dinesh Khandiya,Satpal Sharma, “Dry sliding wear investigation of al6082/gr metal matrix composite by response surface methodology” Journal of Materials Research and Technology(2016) volume : 5(1) page : 29-36

[7] Waleed T.Rashid,Hijran Zinalabiden, “Study the effect of stirring speed and particle size on the tensile strength of the aluminium matrix composites” Diyala journal of engineering sciences(2016) volume : 09 page : 100-112

[8] Bharath V, Mahadev Nagaral, V Auradi, S.A.Kori, “Preparation of al6061-al$_2$o$_3$ mmc’s by stir casting and evaluation of mechanical and wear properties” Proceedia Materials Science(2014) volume : 6 pp : 1658-1667

[9] Praveen Kittali , J.Satheesh, G. Anil Kumar, and T. Madhusudhan, “A review on effects of reinforcements on mechanical and tribological behavior of ammc” International Research Journal of Engineering and Technology (IRJET)(2016) volume : 03 issue : 04

[10] Michael Oluwatosin Bodunrin, Kenneth Kanayo Alaneme, Lesley Heath Chown, “Aluminium matrix hybrid composites: a review of reinforcement philosophies; mechanical, corrosion and tribological characteristics”, Journal of Materials Research and Technology, ELSEVIER 169(2015), pp. 1-12

[11] Vengatesh.D, Chandramohan.V, “Aluminium Alloy Metal Matrix Composite: Survey Paper”, International Journal of Engineering Research and General Science Volume 2, Issue 6(October-November, 2014), ISSN 2091-2730, pp. 792-796

[12] Gowri Shankar M.C., Jayashree P.K., Raviraj Shettya, Achutha Kinia Sharma S.S., “Individual and Combined Effect of Reinforcements on Stir Cast Aluminium Metal Matrix Composites-A Review”, International Journal of Current Engineering and Technology Vol.3, No.3(August 2013), ISSN 2277 – 4106, pp. 922-934

[13] B.Babu, S.K.Karthikeyan, V.Adithya, “Experimental Investigation and Analysis of Corrosion and Hardness using Aluminium Composites”, International Journal of Latest Trends in Engineering and Technology (IJLTET) Vol. 4, Issue 4(November 2014), ISSN: 2278-621X, pp. 37-46

[14] M.P.Navin, R.Deivasigamani, "Material Characterization of Aluminium Hybrid Composite for Clutch Plate", International Journal of Engineering, Research and Science & Technology Vol. 4, No. 1(February 2015), ISSN 2319-5991, pp. 297-305

[15] Oluwagbenga Babajide Fatile, Joshua Ifedayo Akinruli, Anthony Akpofure Amori, "Microstructure and Mechanical Behaviour of Stir-Cast Al-Mg-Sl Alloy Matrix Hybrid Composite Reinforced with Corn Cob Ash and Silicon Carbide", International Journal of Engineering and Technology Innovation Vol. 10, No. 10(2014), pp. 1-9

[16] L.Lancaster, M.H.Lung, D.Sujan, "Utilization of Agro-Industrial Waste in Metal Matrix Composites: Towards Sustainability", International Journal of Environmental, Ecological, Geomatics, Earth Science and Engineering 7 (1) 2013, pp. 25-33.

[17] K.Madheswaran, S.Sugumar, B.Elamvazhudi, "Mechanical Characterization of Aluminium – Boron Carbide Composites with Influence of Calcium Carbide Particles", International Journal of Emerging Technology and Advanced Engineering Volume 5, Issue 7(July 2015), ISSN 2250-2459, pp. 492-496

[18] S.Dhinakaran, T.V.Moorthy, "Fabrication and Characteristic of Boron Carbide Particulate Reinforced Aluminum Metal Matrix Composites", Anna University Newsletter 2014

[19] T.Tirumalai, R.Subramaniam, S.Kumaran, S.Dharmalingam, S.S.Ramakrishnan, "Production and Characterization of Hybrid Aluminium Matrix Composites Reinforced with Boron Carbide and Graphite", Journal of Scientific & Industrial Research Volume 73 (October 2014), pp. 667-670

[20] S. Rama Rao, G. Padmanabhan, " Fabrication and mechanical properties of aluminium-boron carbide composites", International Journal of Materials and Biomaterials Applications 2012 2(3), pp. 15-18