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OPTIMIZATION OF WEAR RESISTANCE OF ALUMINUM MATRIX COMPOSITE (AL-7050/10WT% EGGSHELL) BY STUDY OF EFFECT STIRRING SPEED AND STIRRING TIME

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ABSTRACT

This study investigates the impact of stirring speed (X1) and stirring time (X2) composite materials (Al-7050/10 wt. %eggshell) renforcemented by eggshell particles of the on wear resistance by using the MINITAB 16 program. A composite material was produced by the stir casting method; the ingot was melted, and a molten metal vortex was produced by varying the stirring speed (200, 300, 400, 500, 600 rpm) and stirring duration (10, 20, 30, 40, and 50 minutes). Eggshell particles with a fixed weight fraction of (10% wt.) and sizes (21–30 µm) were used. It was concluded if the variables (X1 = 543.4343 rpm) and (X2 = 48.1818 min.) wear loss of (0.0061 g) could be achieved. In practice, wear loss (0.0063 g) was obtained using the values of X1 and X2, which were obtained using the programs. Was wear loss is almost identical to the value obtained by the program. Additionally, the results manifested that the stirring time (X2) and stirring speed (X1) have a significant impact on the wear loss, where increase in stirring speed and time leading to an increase in wear strength. Furthermore, the effect of stirring speed (X1) on the wear loss is larger than that of stirring time (X2).

KEYWORDS

Stir casting, Stirring speed, Stirring time, Wear resistance, Aluminum alloy, Egg shell, Composite materials.

1. INTRODUCTION

Because of their high specific strength, high specific modulus, and good wear resistance, aluminum matrix composites are being used more and more in the fields of sports, aerospace, marine, and structural applications, compared to traditional metals and alloys. The aluminum matrix, that including ceramic particles in the ductile matrix, resulted in a rise in desirable qualities, such as strength, elastic modulus, wear resistance, a decrease in component weight, low thermal shock, and a low coefficient of thermal expansion (Venkatesh, B.N.,et al 2022).

An Al-7075 alloy requires further reinforcement because of its wide range of applications. Adding desirable single and multiple reinforcement particulates such as SiC, Al_2O_3, Gr, TiO2, B4C, fly ash, etc. as composites, which depict higher strength than the base alloy material, allows the aluminum alloy to be used as a matrix material (Ambali, A. O., et al 2023). This progress in alloy material was necessary for rapidly expanding technologies across various application domains. The ability of Metal Matrix Composites (MMCs) to modify the physical properties (such as density and thermal expansion), mechanical properties (such as tensile and compressive behavior), tribological properties, etc. by varying the constituent or filler material phases has drawn attention in the recent studies (Ambali, A. O., et al 2023). Used an aluminum alloy as a matrix, this material is referred to as aluminum matrix composite (AMC) (Karakoc, H., 2023). Aluminum alloys serve as the matrix in AMC, a form of metal composite material; whereas the ceramic elements, like SiO_2 and Al_2O_3 serve as reinforcement particles (Arumugam, G., et al 2023). Combining aluminum with several kinds of particulate fortifications, including Al_2O_3, B_4C, fly ash, ZrO_2, and so forth, yields wear resistance, stiffness, and suggested strength (Bharath, V., et al 2021). Because of its positive attributes, namely its great strength , hardness, high modulus and heat stress resistance AMC has a hopeful future (Boppana, S.B., et al 2021). MMC fabrication techniques are generally divided into two categories: Liquid and solid state. Squeeze casting, compo casting, stir casting, and infiltration are examples of liquid processing techniques, while friction stir processing, diffusion bonding, and spray deposition are examples of solid-state processing techniques. The stir casting method's simplicity and mass production suitability make it the most valuable. Additionally, stir casting, a popular casting technique, can be used to create parts with a near-net shape (Singh, L., et al 2021). Significant variables in stir casting include the length of the stirring process, the temperature at which the pouring is completed, the mixing time, the speed of the blade, and the composition of the reinforcing particles (Kumar, R., et al 2021).

(Sharma, S., and Dwivedi, S.P., 2017), An aluminum-eggshell silicon carbide (SiC) metal matrix composite was evaluated in terms of microstructural, physical, and mechanical properties. Their results suggested that the carbonized eggshell sample with Al-2.5% SiC-7.5% had lower porosity and higher specific strength. (Balan, G. S., et al., 2020), Tensile strength and corrosion resistance were assessed for an Al7075-glass fiber and eggshell composite made by stir casting. The addition of eggshell improved the composite's corrosion resistance because it acts as a corrosion inhibitor. Furthermore, the use of glass fiber boosted tensile strength. (Rashid, W. T., Rashid, and Rashid, K.T. 2021), performed a comparison investigation to determine the effect of eggshell size and addition % on the hardness of the aluminum matrix. 0-12% eggshell fragments varying in size from 100 to 679 µm were mixed. Their study showed that the addition of a large weight percentage of fine powder resulted in increased hardness. Maximum egg thickness (100 µm) was reached at 12% by weight. (Jannet, S., et al., 2021), researchers fabricated an aluminum-ceramic composite by incorporating 2-12% $CaCO_3$ with diameters of 100 µm and 150 µm in an aluminum matrix. They assessed the microstructure and mechanical characteristics of the final composite. Results showed that samples with 100 µm eggshells outperformed those with 150 µm $CaCO_3$. The aim of this study was to develop an aluminum matrix composite (AMC), and investigated the effect of stirring time, speed, and additives eggshell on the corrosion resistance of AMC, the mechanical properties and microstructure of AMC were investigated analyzed using Minitab 16.

2. EXPERIMENTAL WORK

2.1. Composite preparations

In this research, aluminum matrix composites were prepared with the help of stir casting; the interference involves pouring the molten material directly into the well mold, continually mixing the blade as it melts. The stirring method is used to prevent the reinforcement particles from aggregating together during processing. They are also relied upon to enhance the uniform distribution of reinforcing particles in the matrix (Arifin, G.A., et al 2020). The parameters for the stir casting process included mixing time and mixing speed, which were set at 200, 300, 400, 500, and 600 rpm and 10, 20, 30, 40, and 50 minutes respectively. Particle weight, size, and temperature remained constant at 10 wt. %, 21-30 µm, and 750°C, respectively. Table 1 shows the chemical composition of Al-7050. A Fig. 1 and 2 evinces the stir casting process and the cast samples, respectively. Fig.3 manifests the eggshell powder.

Table 1. Chemical composition of Al-7050 (wt.%).

Elements	Cu	Zr	Mg	Mn	Zn	Fe	Al
Concentration %	2.3	0.1	2.8	0.52	4.2	0.08	BAL

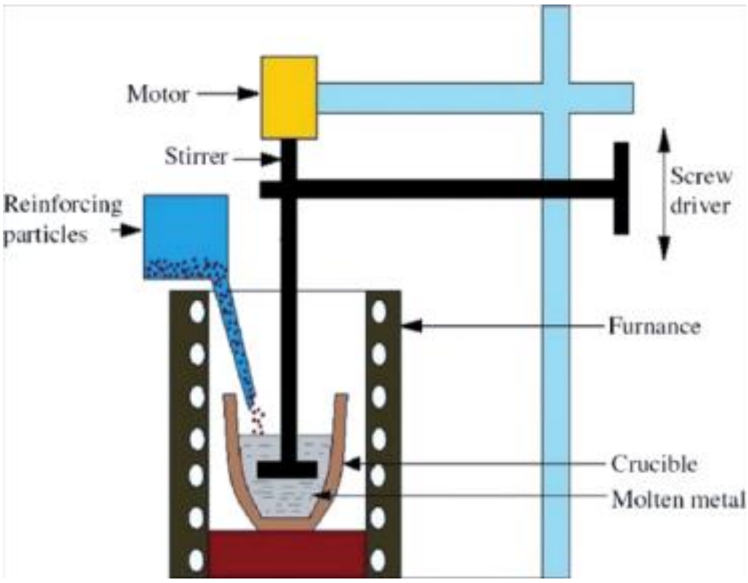

Fig. 1. Stir Casting Process (Mohammad, A. A., Hamdan, B. Y et al 2023).

Fig. 2. Sample after the casting process

Fig. 3. Eggshell powder

2.2. Wear test

With a pin-on-disc machine that is displayed in Fig. 4, the wear rate of the reinforcing alloys was examined. The wear samples were polished prior to testing, and they measured 10 mm in diameter and 20 mm in height. Every test was carried out at the room temperature. A carbon steel disc having a (60 HRc) hardness was utilized. The disc rotated at 400 revolutions per minute. Wear tests were conducted using a load of 15 N, and the loading duration of 30 min was utilized to calculate the wear rate. The sliding speed of 4 m/sec was also used to measure the wear rate. A single-pan electronic balance was used to determine the starting weight of the samples with an accuracy of 0.0001 g. Each specimen made in this study was tested for wear resistance in accordance with ASTM G99 criteria. The wear rate was calculated using the formula below (Rashid, W. T., et al 2019) and (Karrar, A., et al 2023):

$$\boldsymbol{Wear\ rat = W1 - W2} \qquad \text{.......} (1)$$

Where: -

W1: Weight before wear test (gm).

W2: Weight after the wear test (gm).

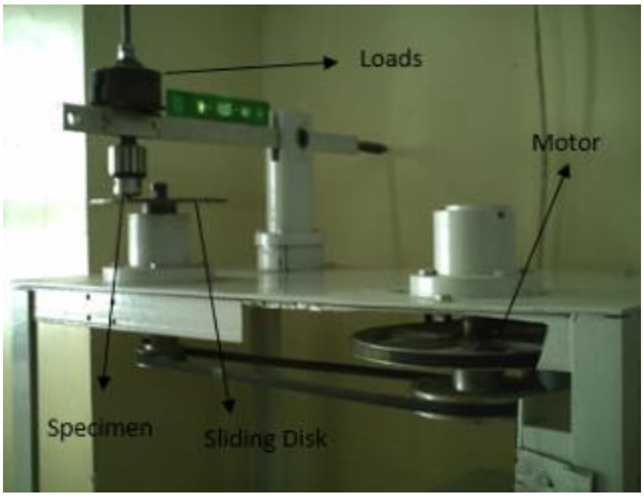

Fig. 4. The wear test device.

3. DESIGN OF EXPERIMENTAL

Optimal results can be obtained by using the number of variables, factors and combinations, and experimental design is a learning method to examine these combinations .It is a practical approach using sophisticated analytical and statistical options to solve engineering design Problems (Verran, G., et al. 2008). The aim of the study is to conduct an analytical study, so the Design of Experiments (DOE) Central Composites create (CCD) program is used .When doing investigations with a lot of variables, CCD is a very useful experimental method. A collection of experimental designs that can investigate (k) factors in (n) observations, with each component at two levels, is known as a two-level factorial design. (Agyemang, A. A., et al 2022). This type of design can be effective when a linear relationship between the response and the factors is observed. Five levels of factors can be studied using CCD, requiring fewer tests. CCD for two variables (stirring time and speed), with five replicates in the middle, yielding a total of (2^2+2^2+5 = 13 runs), as shown in Fig. 5. The CCD can be rotated by selecting a value for ($\alpha = [2k]^{1/4}$). This study makes use of K2 factors, so α becomes 1.414 (Trinh, T. K., and Kang, L. S., 2010). The factors that affect the wear resistance of the composite material are stirring speed and stirring time; the factors and their respective levels used in the trials are listed in Table 2. Wear resistance is assessed, and the answers are utilized to assess the mechanical behavior of the Al7050/eggshell composite material. The experimental setup and results are shown in Table 3.

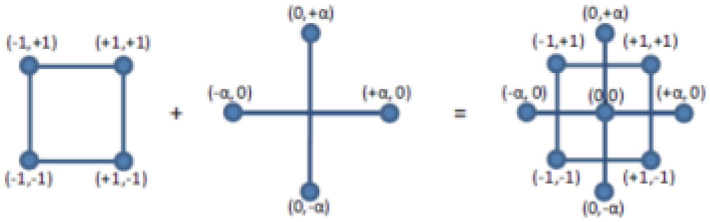

Fig.5. The dimensionless coordinate system for 2 facto

Table 2. The parameters used in the experiments, along with their respective levels

Parameters	**Symbols**	**Unites**	**Levels**				
			-α	-1	0	+1	+α
Stirring Speed	X1	rpm	200	300	400	500	600
Stirring Time	X2	Min.	10	20	30	40	50

Table 3. Values of wear loss and the experimental design matrix.

No	**X1**	**X2**	**Stirring Speed rpm**	**Stirring Time Min.**	**Weight loss (g)**
1	-1	-1	300	20	0.0111
2	+1	-1	500	20	0.0069
3	-1	+1	300	40	0.0089
4	+1	+1	500	40	0.0065
5	-1.414	0	200	30	0.0141
6	+1.414	0	600	30	0.0063
7	0	-1.414	400	10	0.0092
8	0	+1.414	400	50	0.0071
9	0	0	400	30	0.0074
10	0	0	400	30	0.0073
11	0	0	400	30	0.0074
12	0	0	400	30	0.0073
13	0	0	400	30	0.0073

4. RESULT AND DISCUSSION:

4.1. Scanning electron microscopy analysis

Fig.6a elucidates the microstructure of the Al-7050 alloy consolidated without any reinforcement additions. The cast Al-7075 Alloy with eggshell (10wt. %) was analyzed by SEM with a moderate size of 21-30 µm, as shown in Fig. 6b. The SEM image portrays a consistent dispersion of reinforcing particles in the Al matrix.

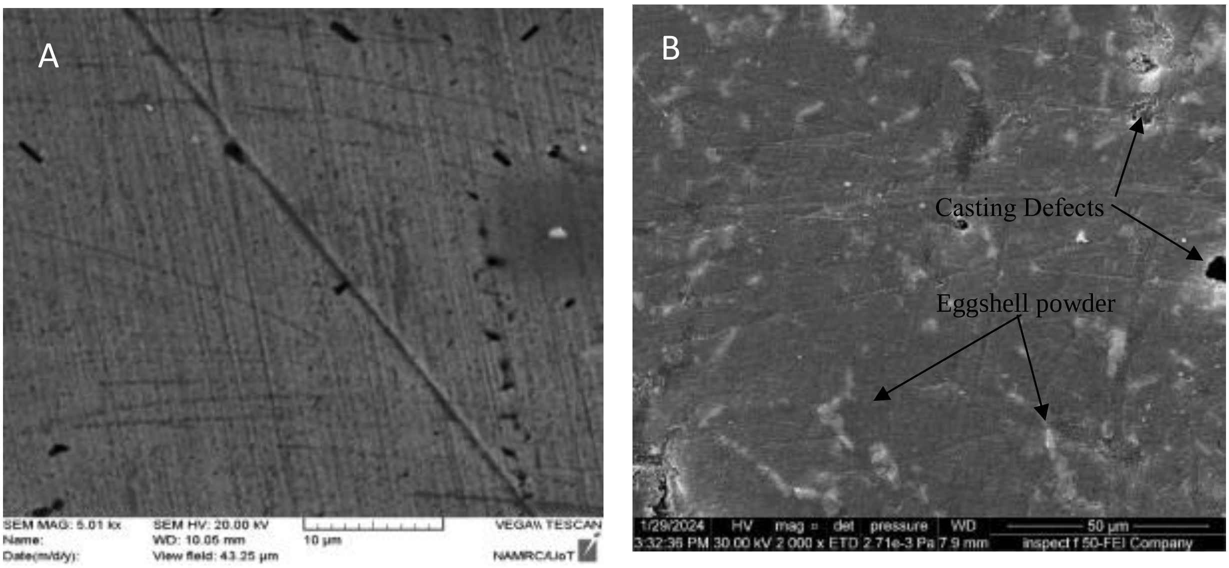

Fig.6. Al-7050 and composite alloys

With a parameter of 10% eggshell, the impact of stirring speed and stirring time on the topography of the worn surfaces of samples was investigated using a scanning electron microscope at constant stirring speeds of 200 and 600 rpm for 30 minutes. The effect of stirring speed is depicted in Figs. 7A and 7B. It was found that the surface experiences severe wear at lower stirring speeds because the deep wear tracks and the distinct wear lines form. Furthermore, there are some surface cracks and signs of abrasive wear. A few wear fragments are separated from the aluminum alloy (Al-7050) surface, which reduces the wear resistance. However, it was observed that the surface experiences less severe wear, and that the wear lines are shallow rather than deep at higher stirring speeds. This is because of the resistance that the sample gains from the high speeds that result in a good distribution of particles within the structure (Wang, W., et al 2017).

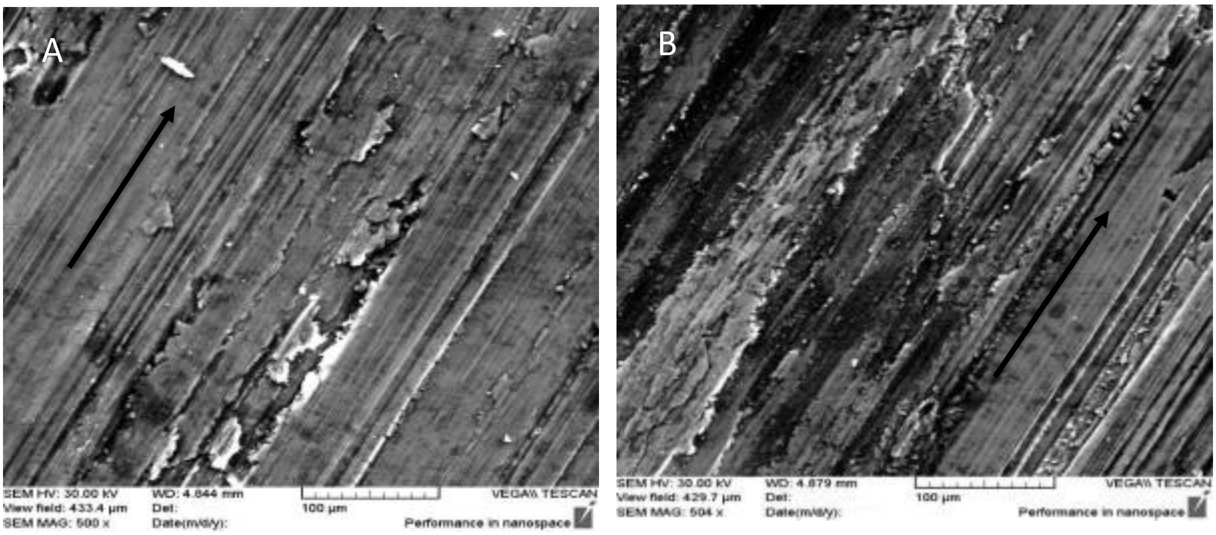

Fig.7. Worn surfaces of (A) specimens No. (5) and (B) specimens No. (6)

4.2. Test of significance

The coefficient that is greater than the value of ($\alpha = 0.05$) is not significant; therefore, it will be deleted from the model. Thus, the wear resistance correlated equation may be written as follows:

$$Y=4.41223+0.83225(X1)+0.06972(X2)+0.00432(X11)+0.00223(X22) \quad \ldots\ldots\ldots\ldots\ldots\ldots 2$$

The wear resistance (weight loss) is represented by (Y), while the variables (X1) and (X2) stand for stirring speed and stirring time, respectively. Equation (1) indicates that the stirring time has a less effect on the weight loss, while the stirring speed (X1) has a greater impact.

4.3. Analysis of variance (ANOVA):

ANOVA is an abbreviation for the term (Analysis of Variance. This method of statistical analysis is based on the F-test, which is mainly based on the analysis of variance. Where the variance is the average of the squares of the deviation of values from their arithmetic mean. In it, the value of F is compared with the value of P, which is significant , i.e., equal to 0.05 or not. The design parameters that significantly influenced the weight loss were identified using the ANOVA test. Based on the significance level (%5) and utilizing the F-test of the regression model, the probability (P-value) in Table 4 is less than 5%, indicating the significance of the regression model (Salih, H. A., 2023.) and (Wang, X., et al 2021).

This is a good enough outcome. R-sq adjusted is equal to (98.78%), which indicates that the other factors, like the random error, account for the remaining percentage. 98.78% of the variables that occur in the variable (Y) are explained by the independent variables (X1, X2). When one of the best coefficients of determination is closed, the outcomes may be satisfactory.

Table 4. Analysis of variance for Y

Source	DF	SS	MS	F-value	P-value
Regression	5	0.000058	0.000012	194.74	0.000
Residual Error	10	0.000006	0.000001		
Total	15	0.000064			
R-Sq=99.29%		S = 0.0244488		R-Sq(adj)=98.78%	

4.4. The main effect plot of hardening

Fig.8 illustrates how the weight loss and individual form are affected by stirring speed and stirring time for values in the range of (1.414, -1.414). Due to the uniform dispersion of eggshell particles in the matrix alloy, it is observed that the wear resistance progressively increases as stirring speed and time increase. This results in weight loss that is reduced. This ultimately improved the composite's strength by increasing the wear resistance and creating a strong bond between the soft and reinforced aluminum matrix. This outcome is acceptable and consistent with the research (Madhu, K. S., et al 2021) and (Mydur, K., et al 2023). It has been shown that the wear resistance increases when the stirring speed is increased between 100 and 500 rpm. These findings clarified why increasing the stirring speed promoted the diffusion of reinforcement particles into the matrix. Moreover, increasing the stirring time values would allow the particles ample time to disperse throughout the matrix.

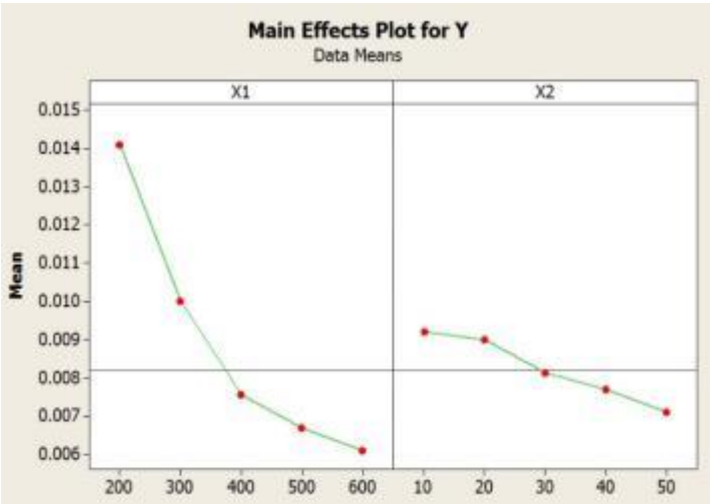

Fig.8. Main effect plot of residuals of wear resistance

4.5. Normal probability plot

Fig.9 reveals the residuals' normal probability plot. Plots of normal probability were made using the computer program MINITAB. When the data is shown, the almost straight line formed by the total points indicates that the all residuals are about normally distributed. Additionally, Fig.10 exhibits how the distribution becomes random on both sides of the zero line, which divides the residuals into positive and negative values. This is due to the random nature of the error result, which makes it impossible to track in a particular way because it is neither present on one side nor rising or falling. Consequently, the variance of these residuals is typically not constant.

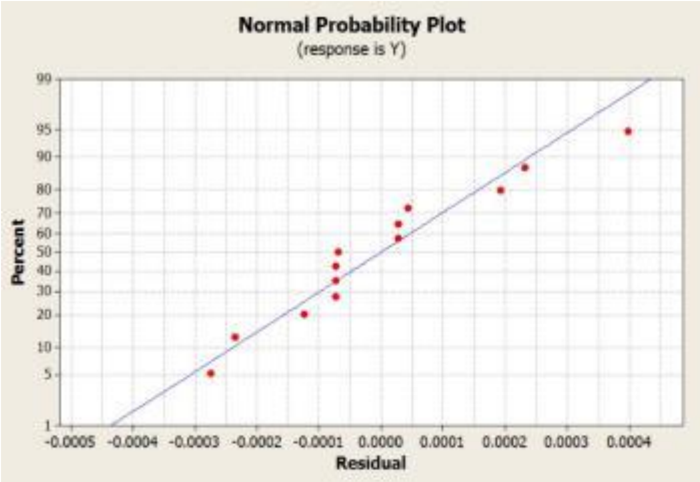

Fig.9. Residuals' normal probability plot

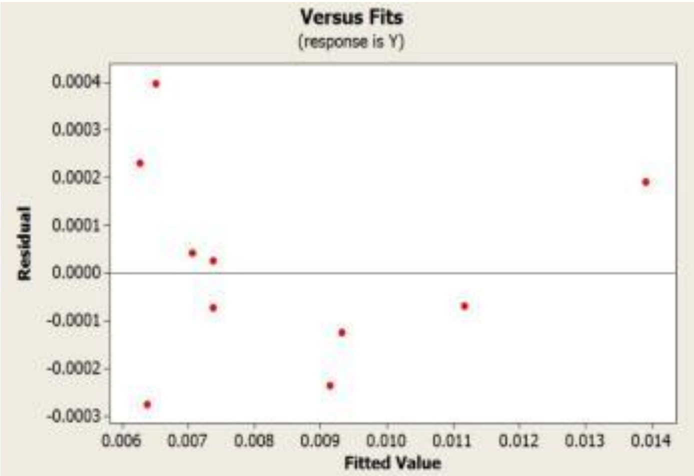

Fig.10. The plot of fitted values versus the residuals.

4.6. Analysis of Response Surface

Fig.11A and B depict a three-dimensional and contour plot that explains how the factors (X1, X2) affect a response (Y). Wear resistance is influenced by the speed and time of stirring, as indicated by the three-dimensional plots; the contour plots and three-dimensional data demonstrate an increase in wear resistance as the speed and duration of stirring increase. However, as the mixing time increases, there is a very slight decrease in wear resistance, which could be related to some particle agglomeration brought on by prolonged stirring. But there was no discernible drop in wear resistance. This result is some extent consistent with (Nagpal, Y., et al 2023).

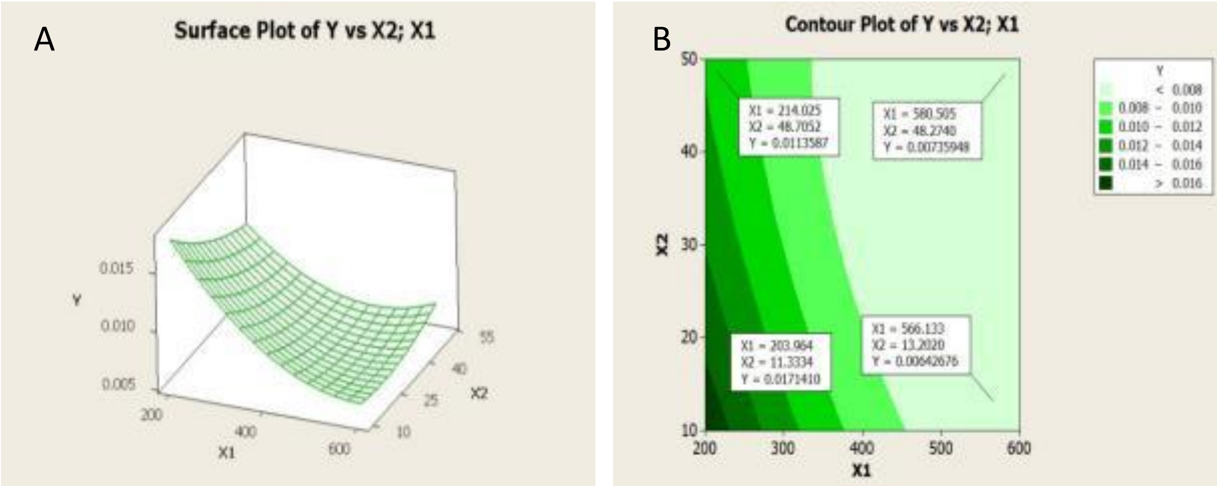

Fig. 11. (A) 3D Surface plots and (B) Contour plots of wear resistance (Y)

4.7. Optimization of wear loss

The wear resistance optimization chart for the two factors (X1, X2) at various levels is displayed in Fig. 12. The result's optimization is presented in the left column, and the middle of the top row shows each parameter's ideal setting. Each factor's behavior curve is displayed below. For the weight loss of 0.0061 g is predicted by the chart for an ideal run at stirring speed (543.4343 rpm) and stirring time (48.1818 min). When the program's light values for stirring speed (X1) and stirring time (X2) were applied, the weight loss (0.0059 g) that resulted was almost exactly the same as what the program had predicted.

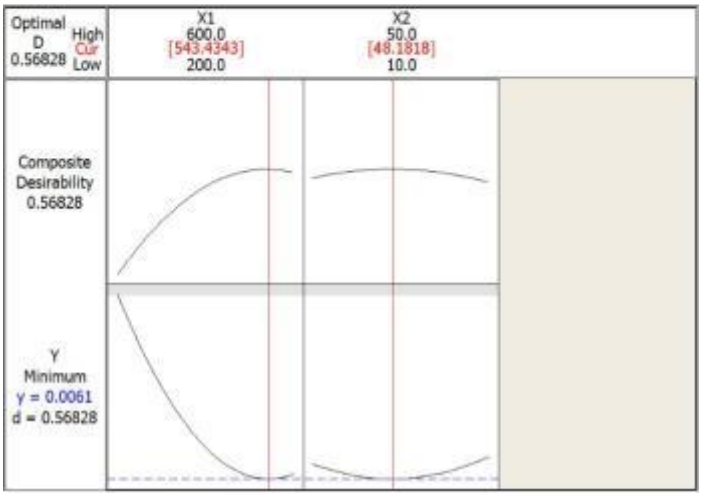

Fig.12. Optimization chart for maximum wear resistance

5. CONCLUSIONS

The present research, which used the MINITAB 16 program to examine the impact of stirring time and speed on the tensile strength of Al-7050/5wt% eggshell, leads to the following conclusion:

1. Wear resistance increased as stirring speed increased (X1); this could be because the eggshell particles were distributed more uniformly throughout the matrix.

2. As the stirring time (X2) increases, the wear resistance rises; however, as the stirring speed increases, the wear resistance starts to fall. There is a very slight decrease in wear resistance as the mixing time increases, which could be explained by some particle agglomeration brought on by the prolonged stirring. But there was no discernible drop in wear resistance.

3. The stirring speed (X1) of 543.4343 rpm and the stirring time (X2) of 48.1818 minutes yield the best wear resistance, where the weight loss (0.0061 g) is recorded. When using these variables, this is the best outcome that can be achieved. Wear loss (0.0059 g) was obtained in practice by using the lower values of X1 and X2, which were obtained using the programs.

4. The following formula can be used to represent the regression models:

$$Y = 4.41223 + 0.83225 (X1) +0.06972 (X2) + 0.00432 (X11) +0.00223(X22).$$

The wear resistance is significantly impacted by both X1 and X2, however it is noted that X1 has a greater influence than X2.

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