Parametric Optimization of Wear Behavior of Friction Stir Welded Dissimilar Joints Aluminum Alloys (AA6061 – AA6082)

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Abstract- *The aim of this project is optimization of wear parameter of FSW (friction stir weld) dissimilar aluminium alloys i.e. (AA6061-AA6082 under T6 condition) with the help of statistical analysis. Wear is the progressive removal of material from a surface in sliding or rolling contact against a counter surface. Wear out is found with the use of PIN ON DISC method. Multiple regression equation has been developed for minimizing the wear rate for different aluminium samples. A SPSS software is used to calculate the coefficients of regression equation to predict the wear parameters like wear rate through varying load, track diameter are considered as inputs. An analysis of variance (ANOVA) was used to determine the significant parameter affecting the wear rate.*

Keywords- FSW, PIN ON DISC, MULTIPLE REGRESSION, ANOVA

I. INTRODUCTION

Friction stir welding (FSW) is a solid-state welding process that gained much attention in research areas as well as manufacturing industry since its introduction in 1991[1,2]. For almost 20 years, FSW has been used in high technology applications such as aerospace to automotive till high precision application such as micro welding. The main feature of a solid-state welding process is the non-melting of the work material which allows a lower temperature and a lower heat input welding process relative to the melting point of materials being joined.

This is advantageous over the conventional fusion welding where excessive high heat input is required to melt the work material. Much less heat input required for FSW translates into economic benefits, safer and less complicated welding procedures. The friction stir welding make it possible to join light weight materials such as aluminium alloy, magnesium alloy, copper and titanium alloys which are very difficult to weld by conventional welding. These clear advantages have greatly increased the usage of these materials in structural applications [3]. FSW process provides proven good quality and strong weldment with inexpensive and lesser number of equipment, eliminates the use of filler metal and improved weldability. Due to these factors FSW has successfully been employed in aerospace, automobile and ship building industries.

FSW is done on to aluminium alloys AA6061-AA6082 .On this friction stir welded alloy is taken as specimen for wear behavior of alloy for Corrosion wear out of alloy if found at different loading and at different track diameter. Wear out is displayed LVDT. This wear out is optimized through the multiple regression equation with the help of SPSS software.

Aluminium has a good thermal conductivity, less density and a high strengthto weight ratio. In addition, the aluminium matrix can also be shaped such that it allows for a wide range of materials to be added to it. Upon adding the material,the strength, stiffness, density and thermal/electrical conductivity of the composites improve considerably [4, 5,6]. Of the many reinforcements, graphite is a popular material since it acts a solid lubricant and reduces the wear of the composite [7-9]. Addition of graphite in the aluminium matrix makes it considerably soft, so a harder material is usually added to compensate. Alumina is one such material that is very hard and when added to the matrix, it increases the strength and stiffness of the composite. These composites despite its advantages need to be tested thoroughly before implementing it in industries. In the case of applications that involve physical contact between materials, there is considerable dry sliding wear that occurs even with the availability of lubricants. Hence dry sliding wear study becomes crucial in the evaluation of such materials. Various dry sliding wear studies have been done for a variety of MMC's. A study on the sliding wear behaviour of Al6016-garnet particulate composite shows that the wear resistance is better when compared to the base material [10]. Another study of thermal and wear behaviour of Al6061/alumina metal matrix composites shows that the increase in alumina volume percentage decreased both thermal conductivity and friction coefficient and hence increased the transition temperature from mild to severe wear during dry sliding wear test [11].

From the various studies on dry sliding wear of aluminium composites,effects of reinforcement size, volume fractions and morphology on the wear rate can be observed [12]. Similarly, effects of various operation parameters on the dry sliding wear have been discussed in previous studies. One such analysis of the influence of load and temperature on the dry sliding wear behaviour of Aluminium–Ni_3Al composite shows that the wear resistance decreased withincreasing load and with an increasing fraction of reinforcement Ni_3Al particles [13]. Hence optimizing the input process parameters becomes crucial in reducing the wear rate. There are various methods such as the Fuzzy logic, the Taguchi optimisation, Ant-colony optimisation, Hill climbing algorithm, Genetic Algorithm, etc. that can be employed for optimisation. But very few optimisation techniques use evolving algorithms that provide optimal solutions within a range of data. GA optimisation is one such technique that involves extensive mutation and recombination to arrive at the global minimum value [14]. GA requires an optimisation function that represents the empirical data in the form of a relation between the input parameters and the responses [15]. Among the techniques that can be used to derive a linear relationship among the empirical data, Artificial Neural Networks is found to be most effective in solving real life problems [16]. The ANN relation when used in combination with GA for optimisation produces well refined solutions [17, 18].

1.1 Experimental Setup of Wear Test

Dry sliding wear tests for different number of specimens was conducted by using a pin-on-disc machine (Model: Wear & Friction Monitor TR-20) supplied by DUCOM is shown in Figure 1

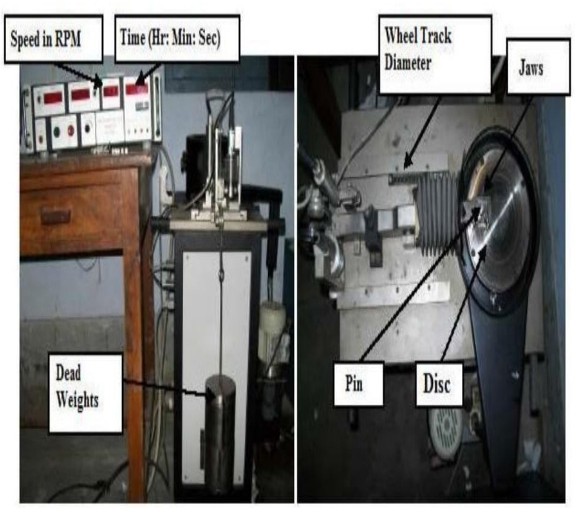

Fig-1wear testing machine

The pin was held against the counter face of a rotating disc (EN31 steel disc) with wear track diameter. The pin was loaded against the disc through a dead weight loading system. The wear test for all specimens was conducted under the normal loads with certain time and speed. Wear tests were carried out to find wear and frictional force

The pin samples were 30 mm in length and 5x5mm in thickness & breadth [19]. The surfaces of the pin samples were slides using emery paper (80 grit size) prior to test in order to ensure effective contact of fresh and flat surface with the steel disc. The samples and wear track were cleaned with acetone and weighed (up to an accuracy of 0.0001 gm using microbalance) prior to and after each test. The wear rate was calculated from the height loss technique and expressed in terms of wear volume loss per unit sliding distance.

1.2 PIN-ON-DISC Test

In this study, Pin-on-Disc testing method was used for tribological characterization. The test procedure is as follows:

- Initially, pin surface was made flat such that it will support the load over its entire cross-section called first stage. This was achieved by the surfaces of the pin sample ground using emery paper (80 grit size) prior to testing.
- Run-in-wear was performed in the next stage/ second stage. This stage avoids initial turbulent period associated with friction and wear curves
- Final stage/ third stage is the actual testing called constant/steady state wear.

This stage is the dynamic competition between material transfer processes (transfer of material from pin onto the disc and formation of wear debris and their subsequent removal). Before the test, both the pin and disc were cleaned with ethanol soaked cotton

Before the start of each experiment, precautionary steps were taken to make sure that the load was applied in normal direction. Figure 2 represents a schematic view of Pin-on-Disc setup.

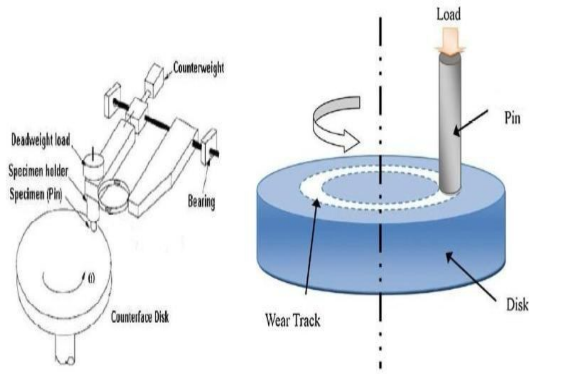

Fig-2 Schematic views of the pin-on-disk apparatus

1.3 Regression:

The method of simple linear regression is applied when we wish to fit a linear model relating the value of a dependent variable *y* to the value of a single independent variable *x*. There are many situations, however, in which a single independent variable is not enough. For example, the degree of wear on a lubricated bearing in a machine may depend both on the load on the bearing and on the physical properties of the lubricant. An equation that expressed wear as a function of load alone or of lubricant properties alone would fail as a predictor. In situations like this, there are several independent variables, $x1, x2, \ldots, xp$, that are related to a dependent variable *y*. If the relationship between the dependent and independent variables is linear, the technique of multiple regressions can be used.

We describe the multiple regression model. Assume that we have a sample of *n* items, and that on each item we have measured a dependent variable *y* and *p* independent variables $x1, \ldots, xp$. The *i*th sample item thus gives rise to the ordered set $(yi, x1i, \ldots, xpi)$. We can then fit the multiple regression model

$$y_i = \beta_0 + \beta_1 x_{1_i} + \cdots\cdots\cdots + \beta_p x_{p_i} + \varepsilon_i \text{ --- } 1$$

1.4 SPSS Software

SPSS Statistics is a software package used for statistical analysis Long produced by SPSS Inc., it was acquired by IBM in 2009. The current versions (2015) are officially named IBM SPSS Statistics.

Companion products in the same family are used for survey authoring and deployment (IBM SPSS Data Collection), data mining (IBM SPSS Modeler), text analytics, and collaboration and deployment (batch and automated scoring services).The software name originally stood for Statistical Package for the Social Sciences (SPSS), reflecting the original market, although the software is now popular in other fields as well, including the health sciences and marketing.

SPSS is a widely used program for statistical analysis in social science. It is also used by market researchers, health researchers, survey companies, government, education researchers, marketing organizations, data miners, and others. The original SPSS manual (Nie, Bent & Hull, 1970) has been described as one of "sociology's most influential books" for allowing ordinary researchers to do their own statistical analysis. In addition to statistical analysis, data management (case selection, file reshaping, creating derived data) and data documentation (a metadata dictionary was stored in the data file) are features of the base software.

Statistics included in the base software:

- Descriptive statistics: Cross tabulation, Frequencies, Descriptive, Explore, Descriptive Ratio Statistics
- Bivariate statistics: Means, t-test, ANOVA, Correlation (bivariate, partial, distances), Nonparametric tests
- Prediction for numerical outcomes: Linear regression
- Prediction for identifying groups: Factor analysis, cluster analysis (two- step, K-means, hierarchical),

II. METHODOLOGY

In this process on friction stir welded aluminum alloy (AA6061-AA6082) is taken for conducting wear test on pin on disk machine and wear behavior on the specimen is found at varying load and track diameter. Wear out is found at welded and non welded portions of AA6061 and AA6082. The experimental data is taken for comparing the wear behavior of similar and dissimilar welded aluminum alloy [19]. For parametric optimization of wear behavior of friction stir welded dissimilar aluminum alloy (AA6061-AA6082) is determined with the help of SPSS software with multi liner regression analysis.

This experimental data is analyzed with the application of multiple regression equation we have solved the optimal equation. Coefficients to the multiple regression equation have been solved for finding wear behavior for further.

The coefficients of linear regression equation are calculated by using the following equations.

For theoretical calculation the experimental data is taken, from this data using the parameters the following equations are developed.

$$\sum \omega = n\beta_0 + \beta_1 \sum W + \beta_2 \sum D \quad (2)$$
$$\sum(\omega \times W) = \beta_0 \times \sum W + \beta_1 \sum W^2 + \beta_2 \sum(W \times D) \quad (3)$$
$$\sum(\omega \times W^2) = \beta_0 \times \sum W^2 + \beta_1 \sum W^3 + \beta_2 \sum(W^2 \times D) \quad (4)$$

2.1 Experimental Data Of The Specimens:

After friction stir welding is carried out on Aluminum 6061-6082 alloy samples, the specimens extracted from the welded and non welded zone are tested on pin-on-disc machine to calculate the dry sliding wear test are shown in the following tables.

Table-1 Friction stir welding sample, performing wear test

S.No	Samples	Length *Breadth*Thickness
1	I-Al6061W	30*5*5
2	I-Al6082W	30*5*5
3	I-Al6061NW	30*5*5
4	I-Al6082NW	30*5*5

Table-2 1kg load at 60mm wear track diameter

Sample	Applied load(kg)	Track diameter(mm)	Wear (micrometers)
I-6061/6082			
6061 W	1	60	487
6082 W	1	60	168
6061 NW	1	60	35
6082 NW	1	60	40

Table-3 1kg load at 80mm wear track diameter

Sample	Applied load(kg)	Track diameter(mm)	Wear (micrometers)
I-6061/6082			
6061 W	1	80	1208
6082 W	1	80	751
6061 NW	1	80	714
6082 NW	1	80	19

Table -4 2kg load at 80mm wear track diameter

Sample	Applied load(kg)	Track diameter(mm)	Wear (micrometers)
I-6061/6082			
6061 W	2	80	1208
6082 W	2	80	751
6061 NW	2	80	714
6082 NW	2	80	19

Table-5 1kg load at 100mm wear track diameter

Sample	Applied load(kg)	Track diameter(mm)	Wear (micrometers)
I-6061/6082			
6061 W	1	100	1215
6082 W	1	100	221
6061 NW	1	100	650
6082 NW	1	100	53

The above equations 2, 3 & 4 are solved using the SPPS software and the results are explained below

III. RESULTS AND DISCUSSION

The Table-7 of in wear is the Model Summary table, as shown below:

Table-7 Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.354[a]	.125	-.009	.0451366

a. Predictors: (constant), load, track diameter

b. Dependent variable: wear

This table provides the R and R^2 values. The R value represents the simple correlation and is 0.354 (the "**R**" Column), which indicates a high degree of correlation. The R^2 value (the "R Square" column) indicates how much of the total variation in the dependent variable, wear, can be explained by the independent variable, load, track diameter . In this case, 12.5% can be explained, which is very large. Estimate Std. error is obtained as 0.045.

The Table-8 is the ANOVA table, which reports how well the regression equation fits the data (i.e., predicts the dependent variable) and is shown below:

Table-8 ANOVA[a]

Model 1	Sum of Squares	df	Mean Square	F	Sig.
Regression	.004	2	.002	.932	.418[b]
Residual	.026	13	.002		
Total	.030	15			

a. Predictors: (constant), load, track diameter

b. Dependent variable: wear

The Table-8 indicates that the regression model predicts the dependent variable significantly well. Look at the "Regression" row and go to the "**Sig.**" column. This indicates the statistical significance of the regression model that was run. Here, p =0.418 which is, the regression model statistically significantly predicts the outcome variable (i.e., it is a good fit for the data).

The Coefficients Table-9 provides us with the necessary information to predict wear from load and track diameter, as well as determine whether load and track diameter contributes statistically significantly to the model (by looking at the "Sig**.**" column). Furthermore, we can use the values in the "B" column under the "Unstandardized Coefficients" column, as shown below:

Table-9 Coefficients[a]

Model 1	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-.045	.073		-.621	.545
Track diameter	.001	.001	.286	1.10 4	.290
load	2.096E-005	.000	.209	.804	.436

a. Dependent variable: wear

The regression equation is given as

$$\omega = -0.45 + 0.001D + 2.096\text{E-}005W$$

Histogram for the given data in SPSS is given as follows

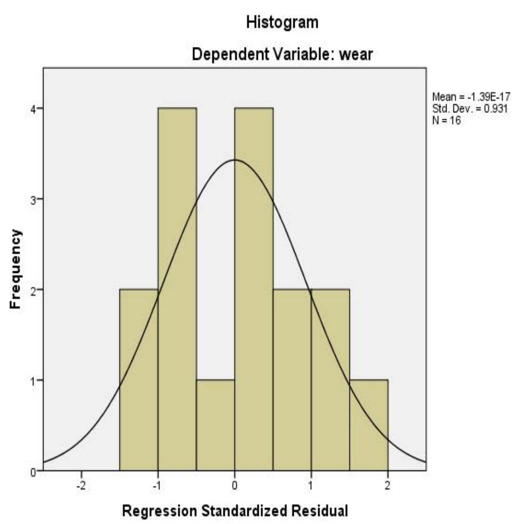

Fig-3 Histogram for wear data

Graphical representation is shown below for observed cumulative probability and to the expected cumulative probability as shown below:

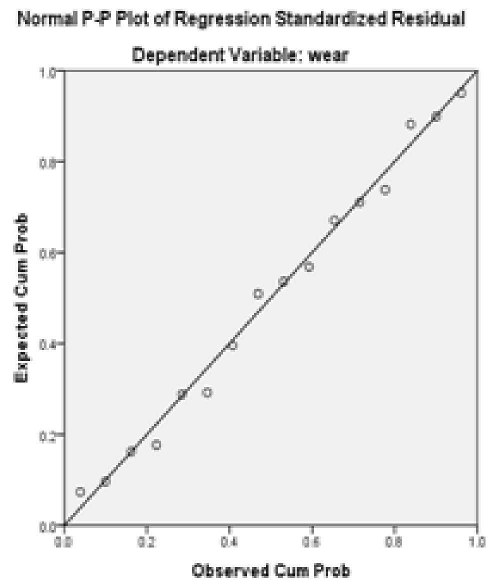

Fig-4 observed cumulative probability and to the expected Cumulative probability

To the give data for predication of wear at varying load and track diameter, regression equation is linear.

IV. CONCLUSIONS

This study presents a prediction, optimization and modeling of the wear behavior of similar joints of aluminum alloys (AA6082-AA6061) based on the Statistical analysis using SPSS software.

- The main wear parameters that affect the wear rate of the aluminum alloys (AA6061-AA6082) were determined as applying load and track diameter among three controllable factors influencing the wear rate using ANOVA.
- A Regression equation was developed for predicting the wear rate. The predicted values were found to be very close to the experimental values.
- The optimum parameter combination for the minimum wear rate was obtained by using the Statistical analysis using SPSS software.
- The confirmation test supports the finding that the wear rate is greatly decreased by using the optimum design parameters. From confirmation test, the error (%) associated with wear rate is 0.0451366% resulting in the conclusions that the statistical method was successful for calculating wear rate from the regression equation.

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