Journal of NAMP 66 (2024) 107 - 114

Journal of
The Nigerian Association of
Mathematical Physics
Journal homepage: https://nampjournals.org.ng

OPTIMIZATION OF PIN ON DISC WEAR TEST PROCESS PARAMETERS USING TAGUCHI DESIGN AND GENETIC ALGORITHM

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ARTICLE INFO

Article history:
Received xxxxx
Revised xxxxx
Accepted xxxxx
Available online xxxxx

Keywords:
Taguchi Design, Genetic Algorithm, Optimal values and wear rate.

ABSTRACT

A careful selection and combination of process parameters and its conditions could result in enhanced mechanical properties of automobile engine components. The rate of material wear must be put into perspective before designing and developing a machine so as to ascertain durability and magnitude of resistance offered by components during engine engagement and operation. In determining the optimal values that could control the rate at which ferrous and non ferrous material wear occurs, a Pin on disc wear test machine was used to carry out experiment to ascertain the effect of process parameters on wear rate. To successfully predict the wear rate of aluminium alloy, a mathematical model having a statistical R^2 *(adj) and regression p-value of 92.7% and 0.016 respectively was developed. A developed normal probability plot showed that residual points were closely distributed within the diagonal line. The optimal values of the test parameters were determined by using Taguchi design and genetic algorithm. The validation test conducted showed that the experimented value and the predicted value for the wear rate were 0.0101 kg/m and 0.0103kg/m respectively. The optimal values were successfully predicted.*

1. Introduction

Wear is an adverse effect experienced by components during working condition. It can be seen as a process were bounding surface of materials interact with its working environment resulting in quantitative dimension loss [1]. It is a property if not checked might impede the smooth working condition of a mechanical system. Materials that have high wear resistance produces notable influence on automobile engine system. In the past steel and aluminium silicon alloys were employed in the fabrication of components because of their good wear resistance tendency [2]. But, these days that idea of too much dependence on aluminium alloys have been overtaken by the advent of aluminium matrix composite [3]. The composite materials are known for displaying excellent mechanical properties such as wear resistance, hardness, tensile strength, fluidity, fatigue strength, corrosion resistant, weldability and high conductivity [4].

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To ascertain the rate of wear of metallic materials, a pin on disc wear testing machine is employed. The machine utilizes certain parameters to achieve its wear rate determination [5]. Wear rate could be mathematically determined to be the ratio of the mass of material lost in mg during the friction test to the time taken [6]. This necessitates the wear behavior of metallic materials with varying speed, time, contact pressure, temperature and lubricity.

Research work abounds on the influence of mechanical parameters on the wear rate of engine components. A parametric optimization of the pin on disc wear test on the various grade of aluminum alloy was conducted by [7]. It determined the rate of wear by optimizing track diameter, speed of disc, time and load applied in a pin on disc experiment. Taguchi design and Response surface Methodology were used as optimization tools in achieving optimal levels of the parameters. The result obtained indicates that the disc speed was the most influential parameter in the developed mathematical model [8].

Optimization tools such as Taguchi design, Genetic algorithm, Particle Swarm and Artificial Neural network have been very useful in determining optimal values of process parameters. It has contributed immensely to efficiency of products and production processes across every discipline. This is necessary in targeting goals that could promote viability and competition among production firms [9].

This study is geared towards determining optimal values of the pin on disc wear test parameters process.

2. Materials and Methods

2.1 Materials

The materials used for the study are Pin on disc wear test machine, aluminuim alloy specimen pin and variable loads. The wear rate testing machine used for the experiment is shown in Figure 1.

Figure 1: Wear rate testing machine

1.2 Methods

The methods applied in the optimization of pin on disc wear test parameters are Taguchi Design,

Signal to noise ratio, Genetic Algorithm, Multiple Linear regression and statistical ANOVA

1.2.1 Taguchi Design

Taguchi design is a foremost optimization tool employed in determining the maximum and minimum value of a process parameter. Its main objective is to produce quality product at a considerable low cost to the manufacturer and can be seen as a robust technique for determination of optimal values for process parameters[10]. The robust method is aimed at producing high quality product at a few number of trials. It utilizes the Design of experiment tool in developing a platform for the experimental conditions. The experimental table also known as Taguchi orthogonal array is determined by the number of process parameters and factor levels expected to be investigated. This study investigated four process parameters and three levels each as such an L_9 Taguchi orthogonal array of nine experimental runs was employed. The process parameters are track diameter, speed in rpm, time of wear and load. The number of experimental runs and stipulated levels are represented on the DOE as shown on Table 2. Also, the Signal to noise ratio was used to determine the optimal levels of the process parameters.

1.2.2 Multiple Linear Regression

The multiple linear regression technique was applied to the values obtained from the Taguchi design. It allowed for the modeling of mathematical model for the wear rate of the aluminium alloy pin specimen. The developed mathematical model contained dependent and independent variables[10]. The dependent and independent variables in this study are wear rate and wear parameters respectively. The wear parameters investigated in this study are track diameter, speed in rpm, time of wear and variable loads [11]. The developed mathematical equation having 4 independent variables was in the similitude of a general multiple linear regression model given in equation (1)

$$WR = \beta o + \beta_1 A + \beta_2 B + \beta_3 C + \beta_4 D \dots\dots\dots\dots\dots\dots\dots\dots. \beta_k Z + \varepsilon \qquad (1)$$

Where β_o is intercept, and β_1, β_2, β_3, β_4, β_k are regression coefficients for the independent variables. Also the independent variables A, B, C and D are Track diameter, speed in rpm, time for wear and variable loads respectively. The error term is represented by ε.

1.2.3 Genetic Algorithm

Genetic algorithm is an evolutionary tool process applied in the optimization problems. It makes use of biological processes such as mutation, selection, reproduction and crossover in determining optimal solutions of complex mathematical systems. A set of chromosome is made to pass through a fitness test to ascertain their level of survival in a process. In this study the developed mathematical model was made to pass the survival test to determine the optimal levels. This was done by introducing the developed mathematical model into the toolbox of the MATLAB Genetic algorithm with affixed boundary limits to promote utmost pattern search through the processes of mutation, selection and crossover [12].

2. Results and discussions

The Pin on disc wear test parameters and the their levels are shown in Table 1.

3.1 Taguchi Design analysis

Table 1: Process parameters and their level

Process parameters	**LEVELS**		
	L_1	**L_2**	**L_3**
Track diameter, A (mm)	50	70	90
Speed, B (rpm)	1100	1300	1500
Time, C (seconds)	180	300	420
Load D (grams)	1000	2000	3000

The Design of Experiment (DOE) table is shown in Table 2.

Table 2: Design of Experiment table

S/N	Track diameter, A(mm)	Speed, B (rpm)	Time, C (s)	Loads, D(kg)	Wear rate (kg/mm
1	50	1100	180	1	0.00579
2	50	1300	300	2	0.00720
3	50	1500	420	3	0.00800
4	70	1100	300	3	0.00700
5	70	1300	420	1	0.00680
6	70	1500	180	2	0.00550
7	90	1100	420	2	0.00510
8	90	1300	180	3	0.00450
9	90	1500	300	1	0.00410

Also, the obtained values of the wear experiment are shown in Table 3.The wear rate was determined by equation (2)

$$wear\ rate = \frac{M_1 - M_2}{Sliding\ distance} \qquad (2)$$

Where M_1=mass before experiment

M_2=mass after experiment

The sliding distance is the product between angular speed in radians and time taken.

Table 3: Experimental values for the pin on disc wear test parameters

S/N	Time, T (s)	Track diameter (mm)	Speed in rpm	Sliding distance (mm), S_d	Mass before experiment, M_1	Mass after experiment, M_2	Mass difference	Wear rate $(M_1-M_2)/S_d$ (g/mm)
1	180	50	1100	518.43	130	127	3	0.00579
2	210	55	1150	695.54	127	122	5	0.0071
3	240	60	1200	904.9	122	115	7	0.0077
4	270	65	1250	1325.5	115	106	9	0.0068
5	300	70	1300	1430.0	106	96	10	0.007
6	330	75	1350	1749.7	96	87	9	0.0051
7	360	80	1400	2111.4	87	76	11	0.0052
8	390	85	1450	2813.3	76	65	11	0.0039
9	420	90	1500	2969.2	65	53	12	0.004

Table 4: Analysis of Variance values

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	4	0.000003	0.000003	12.49	0.016
A	1	0.000003	0.000009	34.02	0.004
B	1	0.000001	0.000001	0.05	0.828
C	1	0.000003	0.000003	10.81	0.030
D	1	0.000001	0.000001	5.06	0.008
Error	4	0.000001	0.000000		
Total	6	0.000014			

The Coefficient of determination values, R^2 and R^2 (Adj) were 92.59% and 85.17% respectively. While the p-values obtained for the regression model is 0.016 as shown in Table 4. This shows that the developed mathematical model is adequate for a significant level of 0.05. All except speed in rpm, were significant having attained p-values of less than 0.05 as presented in Table 4.

The developed regression model is shown in equation (3)

$$WR = 0.00792 - 0.000061A - 0.000001B + 0.000006C + 0.000468D \quad (3)$$

Where WR= wear rate

A= Track diameter

B=Speed in rpm

C=Time in seconds

D=Load in kg

Furthermore, the adequacy of the model was given more relevance by developing a probability plot. The plot shown in Figure 2 indicates that the residual points are distributed close to the ideal diagonal line which goes to show an ideal distribution that culminates in high model adequacy.

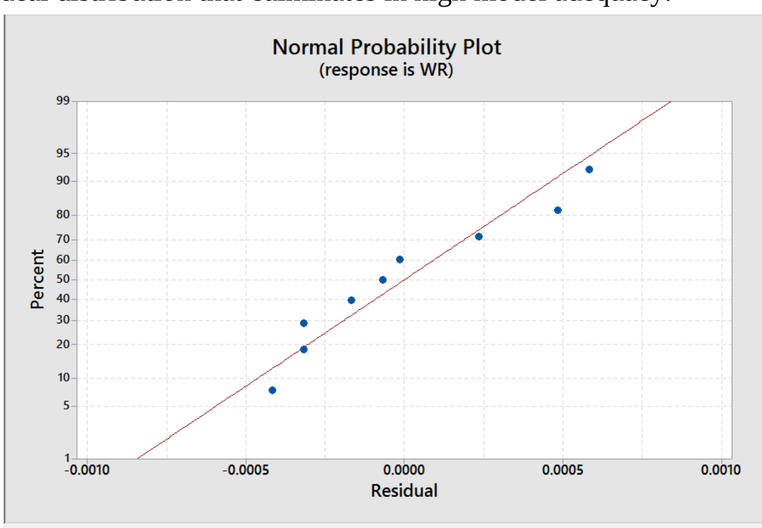

Figure 2: Normal probability Plot

The optimal levels obtained from the application of the developed mathematical model are shown in Table 5. Also, the graphical representation of the optimal values as obtained by the Signal to noise ratio close to values obtained by [13] are shown in Figure 3.

Table 5: Obtained Optimal values

Factor	Process parameters	Taguchi Design
A	Track diameter (m)	90
B	Speed (rpm)	1500
C	Time (s)	180
D	Load (kg)	1
WR	Wear rate	0.006

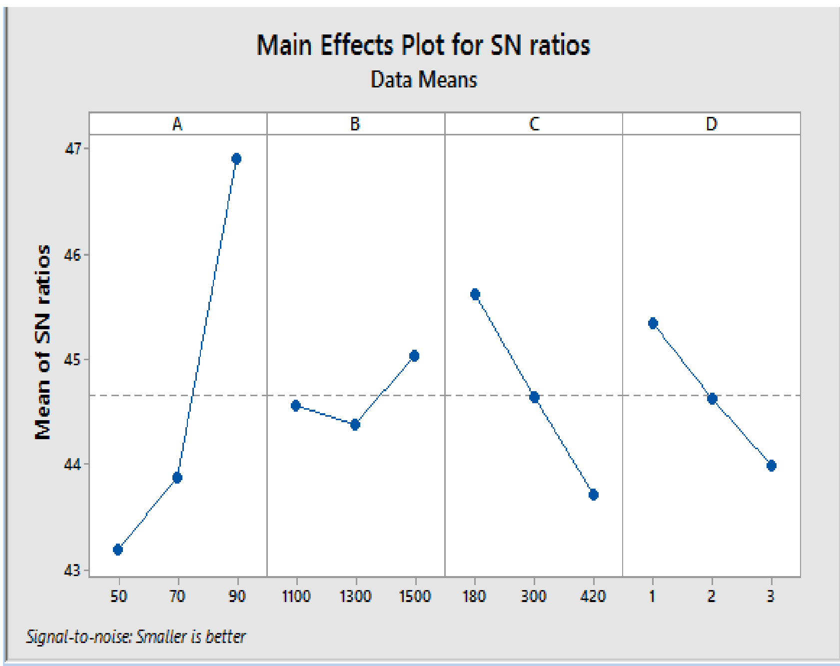

Figure. 3: Signal to noise ratio Plot

2.2 Genetic algorithm analysis

The Genetic algorithm result for 100 generations is shown in Figure 4. The developed mathematical model was used as objective function in the genetic algorithm toolbox to yield 89.98mm, 1479.45rpm, 181.87s, 1.0014N, 0.0103kg/m for Track diameter, speed, time, load and wear rate respectively which is similar to that obtained in [14].

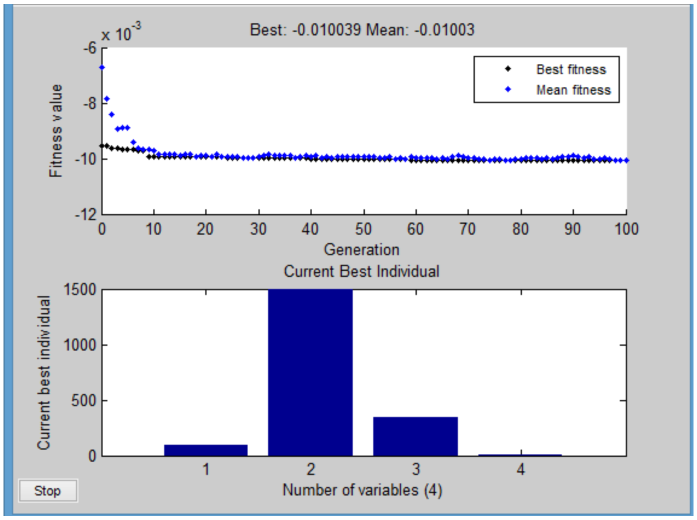

Figure. 4: Fitness value and generation graph

3.3 Comparison between Taguchi result and Genetic algorithm result

The values obtained from Taguchi design were compared with that of Genetic algorithm. It was noticed that the genetic algorithm result predicted to the nearest four decimal points. While the Taguchi design result predicted the process parameters to the nearest unit as shown in Table 6. The obtained values are close to the obtained in [14].

Table 6: Comparison of Taguchi Design result and Genetic algorithm result

Factor	Process parameters	Taguchi Design	Genetic Algorithm
A	Track diameter (m)	90	89.98
B	Speed (rpm)	1500	1479.45
C	Time (s)	180	181.87
D	Load (kg)	1	1.0014
WR	Wear rate	0.006	0.0103

3.4 Validation of the developed model

The optimal values obtained were used to carry out experiment in the Material Engineering laboratory to ascertain the relevance of the obtained model and optimal parameters. The wear rate value obtained from the experiment was 0.0101kg/m which is close to the value obtained in [15]. It was noticed that the predicted and experimented values were very close. The experimented value gave credence to the validation obtained from the ANOVA and R^2(adj) statistical values. The predicted and experimented values are shown in Table 7.

Table 7: Comparison between Experimented and Predicted values

	Track diame	Speed (rpm)	Time(s)	Load (kg)	Wear rate
Predicted value	89.98	1479.45	181.87	1.0014	0.0103
Experimented value	89.98	1479.45	181.87	1.0014	0.0101

3. Conclusion

The reduction of wear leads to increase in life and performance of tools and materials. This study investigated the optimal values that could control the rate at which non ferrous aluminium alloy material wears. To successfully predict the wear rate of materials, a mathematical model having a statistical R^2 (adj) and regression p-value of 92.7% and 0.016 respectively was developed. The adequacy of the developed model was further given credence by the normal probability plot which showed that residual points were closely distributed within the diagonal line [16]. The optimal values of the process parameters were determined by using Taguchi design and genetic algorithm. The validation test carried out showed that the experimented value and the predicted value for the wear rate were 0.0101 kg/m and 0.0103kg/m respectively.

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