# Study of wear behavior of $B_4C$ nanoparticles mixed with polyester powder coating on MS material

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***Abstract:*** *To improve the wear resistance of the polyester powder coating, $B_4C$ nanoparticles was hot mixed to form a homogenous mixture with the powder in the range varying wt. dry sliding wear test was conducted to determine the wear resistance. The experiments were design according to Taguchi L9 array to find the optimum nanoparticles content required to minimize the wear rate of the coating. ANOVA was used to determine the influence of the parameters on the wear rate. It showed that reinforcement has the maximum contribution on the wear rate of the coating as compared to load and frequency. From the graph of means optimum parametric values was obtained at 4 % wt of reinforcement, 15 N load and 3 Hz frequency. The wear rate decrease with the increase in reinforcement.*

***Keywords:*** *Taguchi Method, tribometer Polyester powder, $B_4C$, Wear Rate.*

## I. INTRODUCTION

Powder coating includes depositing a finely ground pitch (powder) on a substrate and heating the coat in the oven. During the curing process, the powder melts and makes a uniform, consistent coating. Powder coatings give incredible erosion, effect, and scratch resistance, and gloss. Manufacturers utilize powder coating measures in a wide range of uses as they cheap in labor, materials, and energy are adaptable and present cost, and in light of the fact that powder coats are durable.

Initially the coating was applied by flame spraying on the metallic surface to protect from weathering and scratch. And after the evolving of the process, most powder-coating applications required dipping a hot part into a powder bed which is fluidized. But this method caused in uneven thickness of film. Electrostatic spray equipment provided a wayto coat cold substrate which helped in forming of uniform, thinner coating resulting in saving of raw material.

Powder-coating methods are used in most production related field for forming protective finishes. Powder can be formed to provide protective surface, and endurance characteristics, and to obtain higher hardness, chemical resistance, and gloss persisting surface. With the help of automation the powder coating can be applied on hot and cold substrate where the environment is of corrosive and have high pressure. Automobile industries uses powder coating, for example, to shield under-hood parts from high temperature environment and pressure. The surface finish provided by powder coating is also good and improves the quality of the wheel, mirror frame, oil filter, and coil spring. Automakers are using powder coatings not only as primers for topcoats, but for the topcoats, with improved durability. Some appliance manufacturers change the energy consuming procedure of applying a porcelain surface on washing machine tops with specially framed scratch-resistant powder coatings. Appliance parts, such as range dryer drums, housings, and microwave oven inside and frame, are now powder coated

## II. EXPERIMENTATION

### A. Methodology of Experiment

There are several optimization techniques to develop product, process or operation. Various techniques can be applied to optimize curing process. Sometimes different techniques are required integrate to get statistically significant results, which can lead to better conclusions and recommendations. Some extensively used methods in developing a process or a product are Build Test Fix (BTF), Design of Experiment (DOE) and One Variable at a Time (OVAT); BTF is very primitive and unorganized approach. It is iterative method of developing a process focused on improvement from last experiment. DOE is highly efficient method of investigating the effect of parameters as it varies multiple parameters at once. As more parameters are investigated, more number of new combinations is required. DOE cannot control individual parameters and more relies on statistical data. In one variable at a time (OVAT) approach, variation is done with one variable at a time and other parameters are kept constant until the effect of one parameter is studied.

It is highly precise method to study effect of each parameter at different levels. Reinforcement, load and frequency were identified as most predominant parameters affecting on wear rate. Based on the observation, Taguchi method has been used to optimize the process parameters. OVAT analysis has been conducted to find out effective range of parameters for optimization study. L9 orthogonal array (OA) has been selected from available designs. Standard notation for OA is given below

OA = Ln (Xm)

Where n= number of experiments, X= number of levels and m= number of parameters under study. From available designs for 3 levels 3 parameters, OA with least number of experiments required to conduct (L9) has been selected. ANOVA has been conducted to find out contribution of each parameter in the output. Minitab 19 software has been used for analysis.

**B. Experimental Machine Selection**

Table 1 states the specification of the Tribometer setup used in this study. All the experiments were conducted Government College of engineering, Aurangabad, M.S, India.


***Figure 1.*** *Tribometer Setup*

***Table 1***. *Tribometer Specification.*

| **Make Model** | **Ducom Ltd., Banglore, India** |
|---|---|
| Upper Specification | Pin(dia. × 1)- Φ4×15mm, Φ6×15mm, Φ8×15mm, Φ10×15mm.<br>Pin Rectangular (lxbxh)-4x6x15<br>Pin Square (lxbxh)- 4x4x15mm, 6x6x15mm, 8x8x15mm.<br>Ball- Φ10mm |
| Lower Specification | Rectangular Block (lxbxh)- 40x40x5, 30x30x5, 20x20x5mm |
| Lower Specification | EN-31 Steel |
| Lower Specification Hardness | 60 HRC |
| Stroke Length Range | 10, 20 30 fixed. |
| Load Range | 5 to 100 N (In step of 5N) |
| Temperature Range | Ambient 200 to 200$^{o}$ C, Ambient 200 to 200$^{o}$ C (For Both |

| | |
|---|---|
| | Lubrication).<br>Least count..-0.21°C, Sensor: PT-100 |
| Frequency (Speed) Range1 | 1-20Hz(1200rpm)<br>Least count: 1rpm, Sensor, Proximity Sensor |
| Power | 230 V× 1 Φ×50Hz,8A(For Tester) |

### C. Selection of material

**Boron Carbide**

Boron carbide has outstanding wear and thermal shock resistance. It has good mechanical properties, especially at high temperatures. It provides corrosion resistance and it is not soluble in water and diluted acids

***Figure 2*** *Bronze*

## III. RESULTS AND DISCUSSION

To get complete understanding of effects of input parameters Reinforcement, load and frequency on output Wear Rate, you usually assess signal to noise ratio or main effects plot for means. For this purpose, Minitab 18 statistical software has been used. Wear rare have been done. ANOVA has been conducted to find out effect of each parameter on the wear rate and linear regression model has been established to predict the values of wear rate.

### A. Experimental Result

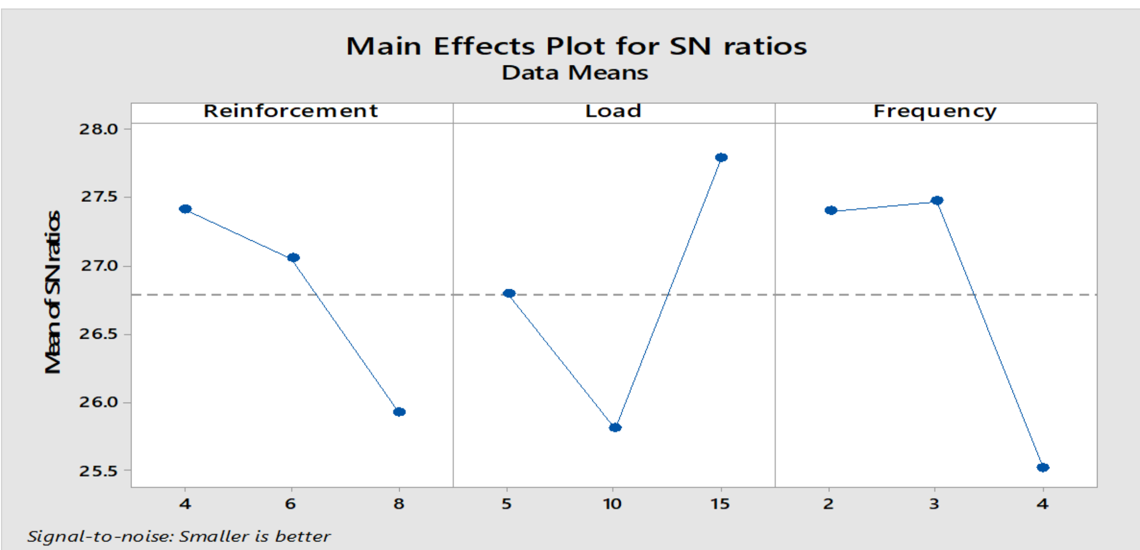
Table 3 shows the L9 orthogonal array with measurement of wear rate for runs one to nine. It also shows S/N ratio for all nine experiments.

***Table 3** L9 orthogonal array with response characteristic.*

| Experiments | Input Factors | | | Output Responses | |
|---|---|---|---|---|---|
| **Trial No.** | **Reinforcement (%)** | **Load (N)** | **Frequency (Hz)** | **Wear rate ($mm^3$/Nm)** | **S/N Ratio** |
| **1** | 4 | 5 | 2 | 0.040 | 27.9588 |
| **2** | 4 | 10 | 3 | 0.043 | 27.3306 |
| **3** | 4 | 15 | 4 | 0.045 | 26.9357 |
| **4** | 6 | 5 | 3 | 0.042 | 27.5350 |
| **5** | 6 | 10 | 4 | 0.058 | 24.7314 |
| **6** | 6 | 15 | 2 | 0.037 | 28.8739 |
| **7** | 8 | 5 | 4 | 0.057 | 24.8825 |
| **8** | 8 | 10 | 2 | 0.054 | 25.3521 |
| **9** | 8 | 15 | 3 | 0.042 | 27.5350 |

The S/N ratio values are calculated with help of Minitab 18 software. It can be seen that variation in S/N ratio is minimum for all experiment.

**B. Main Effects of Wear Rate**




***Graph 1** Main Effects Plot for S/N Ratio*

From main effects plot for S/N ratio, parametric effect on response characteristic i.e The optimal input parameters were Reinforcement 4% (level 1), Load 15 N (level 3) and Frequency 3 Hz (level 2). The graph shows the effect of the control factors on Bronze material

**C. ANOVA Result**

ANOVA, the ratio between the variance of the welding parameter and the error variance is called Fisher's ratio (F). It is used to determine whether the parameter has a significant effect on the quality characteristic by comparing the F test value of the parameter with the standard F table value at the P significance level. If the F test value is greater than P test the operating parameter is considered significant. Relevance of the models is tested by analysis of variance (ANOVA). It is a statistical tool for testing the null hypothesis for planned experiments, in which several different variables are studied simultaneously. ANOVA is used to quickly analyze the variances in the experiment using the Fisher test (F test). ANOVA table shown the result of the ANOVA analysis. ANOVA analysis makes it possible to observe that the value of P is less than 0.05 in the three parametric sources. It is therefore clear that rotational speed, welding speed and tool tilt angle of the material have an influence on the bronze material. The last column of cumulative ANOVA showed the percentage of each factor in the total variance that indicates the degree of impact on the outcome. Table 4 shows results obtained from analysis of variance

***Table 4** ANOVA Result.*

| Source | DF | Adj SS | Adj MS | F-Value | P-Value | % Contribution |
|---|---|---|---|---|---|---|
| Reinforcement | 2 | 0.000109 | 0.000054 | 23.29 | 0.041 | 21.54 |
| Load | 2 | 0.000171 | 0.000085 | 36.57 | 0.027 | 33.79 |
| Frequency | 2 | 0.000222 | 0.000111 | 47.57 | 0.021 | 43.87 |
| Error | 2 | 0.000005 | 0.000002 | | | |
| Total | 8 | 0.000506 | | | | |

It shows table 4 that the Reinforcement (21.54%), the Load (33.79%) and the Frequency (43.87%) have major influence on the Wear Rate. Contribution of Frequency (46.60%) is highest among all three parameters hence it is most dominating parameter while Reinforcement is least affecting parameter.

**D. Development of Regression Model for Wear Rate**

Regression model has been developed using Minitab software. Substituting the experimental values of the parameters in regression equation, values for Wear rate have been predicted for all levels of study parameters. Graphical representation also shows that a predicted and experimental value of Wear rate correlates with each other.

Regression Equation –

Wear Rate = 0.0242 + 0.00208 Reinforcement - 0.000533 Load + 0.00500 Frequency

Table number 5 gives comparison between experimentally measured and predicted wear rate by developed mathematical equation

***Table 5** Experimental and Predicted Values of Wear rate*

| Sr. No. | Experimental value | Predicted value | Error % |
|---|---|---|---|
| 1 | 0.040 | 0.039 | 2.54 |
| 2 | 0.043 | 0.042 | 3.38 |
| 3 | 0.045 | 0.044 | 2.27 |
| 4 | 0.045 | 0.049 | 8.16 |
| 5 | 0.056 | 0.051 | 9.80 |
| 6 | 0.037 | 0.038 | 5.26 |
| 7 | 0.057 | 0.058 | 1.72 |
| 8 | 0.049 | 0.045 | 8.88 |
| 9 | 0.047 | 0.052 | 9.61 |

Difference between wear rate values calculated using regression equation and experimental values for each experience found less than 10%. Hence, we can say that the regression equation developed is valid.

**E. Confirmation Experiment Result**

Table 5 shows the difference between value of Wear rate of confirmation experiment and value predicted from regression model developed.

**Table 6** Confirmation Experiment Result

| Parameter | Predicted value | Experimental value | Error % |
|---|---|---|---|
| Wear Rate ($mm^3$/Nm) | 0.038 | 0.036 | 5.26 |

Confirmation experiment is conducted by keeping parameters at optimum levels suggested by Taguchi method and the wear rate value obtained has been compared with value predicted by the regression model keeping the parameters at same levels. It can be seen that the difference between experimental result and the predicted result is 5.26%. This indicates that the experimental value correlates to the estimated value.

## IV. CONCLUSIONS

In this study the influence of operating parameters such as Reinforcement, Load, and Frequency and their optimization and ANOVA tool were used to find the significant quantity of nanoparticles which can be added to the polyester powder coating to improve its wear resistance. Following conclusions are drawn.

- From experimentation the optimum value was found to be 4 % weight reinforcement, 15 N load and 3 Hz frequency. But the most important result was that 4% weight of reinforcement shows better wear resistance than the polyester powder and 10% weight reinforcement powder. And ANOVA analysis for wear resistance shows the percentage contribution and for reinforcement it was 21.54 %.
- ANOVA results indicate that frequency plays prominent role in determining the Wear Rate. The contribution of Reinforcement, Load and Frequency to the quality characteristics Wear Rate is 21.54%, 33.79% and 43.77% respectively.
- There was a great improvement in the wear resistance of the 4 % weight of $B_4C$ coating compared to the others coatings. The boron carbide reduces the contact area between the coating and the sliding pin which helps to delays the onset of wear during reciprocating abrasion test and also decreases the wear rate.
- The addition of nanoparticles above 4 % hinders the electrostatic charging process of the powder. Due to which it affects the mechanical properties of the coating
- Hot mixing of the powder with $B_4C$ helped in homogenous mixing of nanoparticles. Mixing of nanoparticles does not affect the adhesiveness of the coating
- Value of Wear Rate is lower obtained in confirmation experiment. Hence, good quality of polyester coating with B4C can be achieved using suggested level of parameters by Taguchi method.
- Values of Wear Rate calculated using regression model correlates with experimental values with error less than 10%. Hence the model developed is valid and experimental results of Wear Rate with any combination of operating parameters can be estimated within selected levels.

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