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*Research Article*

# Experimental Analysis of Effect of Coating on Wear Behavior of Disc Brake

**Ganesh Chandane[1] and Sham Kulkarni[2]**

[1,2]Department of Mechanical Engineering SKNSCOE Pandharpur, PAHS University Solapur, Pandharpur, India

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### *Abstract*

*Brake pad & disc are most important component of an automobile braking system. For smooth retardation of vehicle it converts kinetic energy into heat energy. Due to hard or repetitive braking in steep gradient COF & wear rate, effectiveness between brake pad and disc is decreases. In this work uncoated and Aluminum titanium nitride material coated disc are used. The impact of uncoated and coated disc surface on tribological behavior of braking system are investigated by using pin on disc machine under dry condition. The Aluminum Titanium Nitride (ALTIN) coating on disc done by physical vapor deposition (PVD) process. Low metallic & grey cast iron material considered for pin & disc. The input parameters considered for this test are load, sliding speed & time. Using Taguchi analysis the impact of each parameter are studied using L27 orthogonal array design. ANOVA is a statistical technique used to predict the process parameter and their interactions significantly affect the quality characteristics. The result showed that at minimum load and sliding velocity wear of friction material decreased. The COF & frictional force were stable at different load conditions.*

***Keywords:*** *Aluminum Titanium Nitride (ALTIN), COF, ANOVA, PVD, Taguchi Analysis, Retardation, Sliding Velocity.*

## 1. Introduction

The speed, mileage, and safety features of a car are important considerations in the current market. The car of today needed an engine with a high speed. Thus, regulating the vehicle's speed is a safety feature found in cars. The most crucial safety feature in a car is the brake system. The purpose of the brakes is to convert kinetic energy into thermal energy, which is then released into the atmosphere to bring the vehicle to a stop as quickly as feasible. Modern brakes use a flat metal disc or rotor with rubbing surfaces on both sides to replace the drum brake. The car is slowed down by a braking torque applied to the rotor by the frictional impact between the brake pad and disc. Therefore, the rotor's and the brake pad's sliding interfaces determine how effective a disc brake is. The industry is interested in using lighter materials for the disc in order to lower the vehicle's overall weight and eventually increase fuel efficiency (Federici, et al, 2017).Rotors in disc brake systems can be composed of a number of materials, including composite or aluminum, cast iron, and cast steel combined. The several basic components that make up a brake pad are categorized as reinforcement fibers, binders, fillers, and additives.

These friction compounds are all used to increase strength and rigidity, decrease porosity, minimize noise, and improve friction properties at both high and low temperatures. In brake pad material, lubricants, fillers, reinforcement fiber for mechanical strength, additives for wear resistance and an improved coefficient of friction, and binder for holding friction material are all employed. Stabilize the coefficients of friction at elevated temperature (Cho, et al, 2005). The material's microstructure and composition determine how well a brake pad performs. The demand for cars in urban areas has recently increased due to heavy load hauling, diverse traffic conditions, and accidents. The brakes are rarely used in traffic, with a large load, and under downhill mountain conditions, causing the vehicle's speed to drop to zero in a matter of seconds. This could result in nearly all of the frictional heat produced at the disc pad's contact interface being absorbed by the brake. The characteristics of the frictional material are disturbed by the rising temperature at the point of contact between the brake pad and disc. The result is an exponential increase in wear rate and coefficient of friction decrease. As the temperature rises, the friction coefficient between the pad and the disc decreases. We refer to this phenomenon as brake fade. As a result of the brake

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*Corresponding author's ORCID ID: 0000-0000-0000-0000

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fading, the driver must exert greater effort to stop the car. Both the pad and the rotor wear during this process, and some of that wear will result in particle emissions into the environment that are hazardous to human health. Cast iron now makes up the majority of discs. Up to 50%of all disc emissions are caused by airborne disc wear. The environmental issues brought on by the brake wear's fine particle emission have received special attention lately. It has previously been demonstrated that altering the chemical makeup of cast iron and friction material can reduce the rate at which brake pads and discs wear out. Another strategy to reduce brake rate of wear or airborne emissions is to coat the friction layer of the disc with a strong, wear-resistant coating (Wahlström, et al, 2017), (Belhocine, et al, 2012).Using the phosphate solution dipping method, they created antioxidation phosphate coating on c/c & carbon/silicon carbide discs. Finally, investigated whether friction surface coating improved the friction performance of c/sic while significantly lowering the average COF of c/c (Fan, et al, 2018). Studied how commercial friction material behaves tribologically when it slides against a cast iron disc.

The outcome demonstrated that wear caused by brittle fragmentation and abrasion were occurring simultaneously on the pin surface (Verma, et al, 2015). examined how A359–20% SIC particles moving against friction material were affected by a load range of 30N to 100N and a speed range of 3 m/s to 12 m/s in terms of wear and friction behavior. They came to the conclusion that high loads cause composites to wear more quickly (Daoud, et al, 2010). studied the sliding wear test on a cast iron disc using WC- CO-CR coating and friction material with varying surface roughness Coated disc wear was found to be very severe and have a low coefficient of friction (Federici, et al, 2016). The tribological behavior of an ALSI- SIC particle composite sliding against a pad was investigated, and the results showed that the wear rate decreased with increasing sliding speed and increased with an increase in normal load (Uyyuru, et al, 2006). It is anticipated that such coatings made of aluminum materials will increase the brake system's resistance to thermal fatigue and reduce wear at high temperature. With its production method and unique advantages-like high temperature conductivity, rapid heat dissipation that reduces thermal elastic instability, braking fluid evaporation, and thermally excited vibrations. Aluminum would be a preferable possible for a coating. This study's pin-on-disc test was carried out employing cylindrical pin sliding made of low metallic friction material against a cast iron disc covered in a coating of ALTIN material applied using PVD technology. In order to learn how the tribological behavior of a uncoated di sc and coated disc with friction material is affected by the load range of 30N, 60N, 90N and the sliding velocities of 4m/s, 5m/s, and 6m/s. Lastly, research was done on the COF and wear rate of pins with uncoated and ALTIN coated disc.

## 2. Experimental Procedure

### *2.1 Materials*

Low metallic friction material was employed as the pin material in this experiment. An epoxy resin was chosen in order to increase hardness and wear resistance. Table 1 contains a list of the material compositions. Every substance was supplied in sheets, which could be used to make powder. The pins were 24 mm length and a 10 mm diameter when they were produced in a cylindrical shape an outside diameter 164 mm (OD) a thickness of 10 mm (THICK) were used for cast iron disc. The coating substance chosen was ALTIN, with a 5 μm coating thickness. The uncoated and aluminum titanium nitride (ALTIN) material coated disc was used to test the pin materials.

**Table 1.** Composition of Friction Material

| Group | Volume (%) |
|---|---|
| Ferrous metal | 7.0 |
| Non Ferrous Metal | 10.0 |
| abrasive | 12.5 |
| Lubricant | 7.0 |
| Fibers | 3.5 |
| Filers | 12.0 |
| Carbon | 28.6 |
| Epoxy Resin | 19.4 |

### *2.2 Coating Design*

The ALTIN coating on disc is done by PVD technology. In This material transported liquid form to atoms or molecules in the form of vapor through vacuum. The arc causes the atom from the target to transform into gaseous phase. These atoms then deposited into solid form everything on disc surface in vacuum chamber as thin layer of coating. The specifications of coating are; Machine-RTC-850 [Hauzer Technology], Thickness - 4 μm, Coating Structure- Monolayer, Colour-Grey Blue, Operating Temperature-900°c.

### *2.3 Experimental set-up and wear Performance*

On A Pin & Disc Wear Apparatus tribological experiments for wear and coefficient of friction of low metallic friction material with uncoated and coated disc were conducted in a dry environment at room temperature. The test begins, the specimen and discs surfaces are cleaned. This test configuration is frequently used in laboratories to assess tribological qualities. Operating parameters such as load, sliding velocity, time and a 90 mm track radius were chosen in order to execute the experiments. The rotating disc brought into touch with the friction material's cylindrical pin surface. Before the test begins, the specimen and disc surfaces are cleaned. The pin-on-disc test instrument setup is shown in Fig.1.

**Fig. 1.** Pin on disc machine.

Applying load forced the pin up against the uncoated and coated revolving disc. An electronic weighing machine was used to determine each pin's initial weight. Different process parameter levels were used for the tests. The pin was weighed following each experiment to determine the wear rate in terms of weight loss. Test parameters for the wear and COF tests were load, sliding velocity, and test time. An orthogonal array design L27 (3^3) is used to examine the impact of each parameter. The levels assigned for conducting experiments are shown in table 2.

**Table 2.** Levels Assigned for Conducting Experiments

| Levels | Load [N] | Sliding velocity [M/S] | Time [Minute] |
|---|---|---|---|
| 1 | 30 | 4 | 3 |
| 2 | 60 | 5 | 4 |
| 3 | 90 | 6 | 5 |

The experiment data for wear rate and coefficient of friction are shown in table 3.experimental observation are further transformed into signal to noise ratio [S/N] ratio. There are several S/N ratios available depending on the type of performance characteristics. The S/N ratio for wear rate & COF can be expressed as Smaller is better characteristics S/N= -10 log $1/n$ ($\sum y2$), where n is number of observations and y the observed data. The signal to noise ratio measures the sensitivity of the quality characteristics being investigated in a controlled manner to those external influencing factors not under control.

Outcomes displayed on the screen of MINITAB 18 software shown in table 3 and table 4. That gives Taguchi Analysis for coefficient of friction and wear versus Load, sliding velocity & time. It includes response table for signal to noise ratio for specific wear rate and coefficient of friction are shown in table 5 and table 6. Each of the design parameter (N, V, T) and plot for main effect for S/N ratio for specific wear rate and coefficient of fiction are shown in Fig 2 and Fig 3.

**Table 3.** Experiment result of uncoated and coated disc for Specific wear rate and coefficient of friction

| Expt .No. | Load [N] | Sliding Velocity [V] | Time [T] | (Uncoated disc) Specific Wear Rate [mm³/Nm] | (Uncoated disc disc) Coefficient Of Friction [COF] | (Coated disc) Specific Wear Rate [mm³/Nm] | (Coated disc) Coefficient Of Friction [COF] |
|---|---|---|---|---|---|---|---|
| 1 | 30 | 4 | 3 | 0.000910 | 0.2325 | 0.000851 | 0.2365 |
| 2 | 30 | 4 | 4 | 0.001142 | 0.2075 | 0.000940 | 0.2174 |
| 3 | 30 | 4 | 5 | 0.001819 | 0.2556 | 0.001716 | 0.2654 |
| 4 | 30 | 5 | 3 | 0.003511 | 0.3993 | 0.003319 | 0.4142 |
| 5 | 30 | 5 | 4 | 0.001817 | 0.3526 | 0.002059 | 0.3839 |
| 6 | 30 | 5 | 5 | 0.002022 | 0.2887 | 0.001859 | 0.3162 |
| 7 | 30 | 6 | 3 | 0.005858 | 0.2311 | 0.005809 | 0.3178 |
| 8 | 30 | 6 | 4 | 0.003601 | 0.2995 | 0.003589 | 0.3000 |
| 9 | 30 | 6 | 5 | 0.002302 | 0.2552 | 0.002059 | 0.2782 |
| 10 | 60 | 4 | 3 | 0.001910 | 0.1907 | 0.001839 | 0.2180 |
| 11 | 60 | 4 | 4 | 0.002355 | 0.2223 | 0.002059 | 0.2330 |
| 12 | 60 | 4 | 5 | 0.002420 | 0.2777 | 0.002416 | 0.2780 |
| 13 | 60 | 5 | 3 | 0.003003 | 0.3032 | 0.002779 | 0.3820 |
| 14 | 60 | 5 | 4 | 0.002887 | 0.3334 | 0.002809 | 0.3464 |
| 15 | 60 | 5 | 5 | 0.002223 | 0.2700 | 0.002129 | 0.3198 |
| 16 | 60 | 6 | 3 | 0.004202 | 0.2998 | 0.003929 | 0.3001 |
| 17 | 60 | 6 | 4 | 0.002701 | 0.2300 | 0.002409 | 0.2601 |
| 18 | 60 | 6 | 5 | 0.001305 | 0.2332 | 0.001289 | 0.2433 |
| 19 | 90 | 4 | 3 | 0.002878 | 0.3558 | 0.002600 | 0.3740 |
| 20 | 90 | 4 | 4 | 0.003305 | 0.3455 | 0.003329 | 0.3975 |
| 21 | 90 | 4 | 5 | 0.004200 | 0.3775 | 0.004009 | 0.4134 |
| 22 | 90 | 5 | 3 | 0.002304 | 0.4243 | 0.002139 | 0.4359 |
| 23 | 90 | 5 | 4 | 0.002225 | 0.3255 | 0.002029 | 0.4152 |
| 24 | 90 | 5 | 5 | 0.002387 | 0.2627 | 0.002000 | 0.2679 |
| 25 | 90 | 6 | 3 | 0.002102 | 0.3121 | 0.001949 | 0.3142 |
| 26 | 90 | 6 | 4 | 0.001718 | 0.2858 | 0.001519 | 0.2990 |
| 27 | 90 | 6 | 5 | 0.001415 | 0.2324 | 0.001319 | 0.2879 |

**Table 4.** Signal to noise (S/N) ratio for specific wear rate and coefficient of friction

| Sr. No. | Specific Wear Rate [mm³/Nm] | Coefficient Of Friction |
|---|---|---|
| 1 | 61.401 | 12.5334 |
| 2 | 60.537 | 13.2548 |
| 3 | 55.309 | 11.5220 |
| 4 | 49.579 | 7.6558 |
| 5 | 53.726 | 8.3158 |
| 6 | 54.614 | 10.0008 |
| 7 | 44.718 | 9.9569 |
| 8 | 48.900 | 10.4576 |
| 9 | 53.726 | 11.1129 |
| 10 | 54.7084 | 13.2309 |
| 11 | 53.7569 | 12.6529 |
| 12 | 52.3381 | 11.1191 |
| 13 | 51.1222 | 8.3587 |
| 14 | 51.0990 | 9.2084 |
| 15 | 53.4365 | 9.9024 |
| 16 | 48.1144 | 10.4574 |
| 17 | 52.3633 | 11.6972 |
| 18 | 57.7949 | 12.2772 |
| 19 | 51.7005 | 8.5426 |
| 20 | 49.5537 | 8.0133 |
| 21 | 47.9393 | 7.6726 |
| 22 | 53.3958 | 7.2123 |
| 23 | 53.8544 | 7.6349 |
| 24 | 53.9794 | 11.4405 |
| 25 | 54.2038 | 10.0559 |
| 26 | 56.3688 | 10.4866 |
| 27 | 57.5951 | 10.8152 |

**Table 5.** Response Table of S/N ratio for specific Wear rate

| Level | Load(N) | Sliding Velocity (V) | Time(T) |
|---|---|---|---|
| 1 | 53.61* | 54.14* | 52.10 |
| 2 | 52.74 | 52.75 | 53.34 |
| 3 | 53.18 | 52.64 | 54.08* |
| Delta | 0.88 | 1.49 | 1.98 |
| Rank | 3 | 2 | 1 |

Regardless of the performance characteristic category, the highest S/N ratio is associated with the best quality characteristic. The highest S/N ratio determines the optimal level of process parameter. From the main effects plot (Fig.2) and response table of specific wear rate, the optimal combination of design parameters (N1V1T3) is obtained.

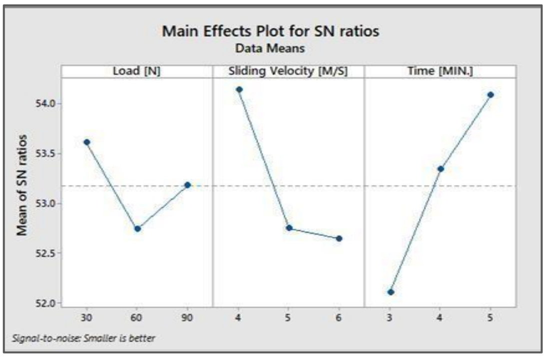

**Fig. 2.** Main Effects Plot for S/N Ratio

The fig. 2. shows that the main effects of signal to noise ratio (S/N ratio) for specific wear rate indicates that at load of 30 N, sliding velocity 4 m/s & time 5 min. has the largest impact on signal to noise ratio. It is observed that at minimum load condition specific wear rate of material is decreased due to low temperature and contact material is pressed up against the disc under conditions of increased load and sliding velocity are raising the temperature at the color interface

**Table 6.** Response Table of S/N ratio for coefficient of friction

| Level | Load (N) | Sliding Velocity (V) | Time(T) |
|---|---|---|---|
| 1 | 10.533 | 10.948* | 9.777 |
| 2 | 10.989* | 8.859 | 10.191 |
| 3 | 9.0.97 | 10.813 | 10.651 |
| Delta | 1.892 | 2.089 | 0.875* |
| Rank | 2 | 1 | 3 |

From the main effects plot (Fig 3) and response table of coefficient of friction, the optimal combination of design parameters (N2V1T3) is obtained. For the best possible combination of a given coefficient of friction.

The fig 3. shows the main effects of signal to noise ratio (S/N ratio) for specific wear rate indicates that at load of 60 N, sliding velocity 4 m/s & time 5 min. has the largest impact on signal to noise ratio. It showed that maximum impact on coefficient of friction. The signal to noise ratio it is observed that at maximum load & minimum time condition coefficient of friction decreases because increase the surface temperature of friction material by maximum load. At maximum braking duration condition loading is uniform contact between pin and disc friction surface. It is clear that increase the coefficient of friction between pin & disc.

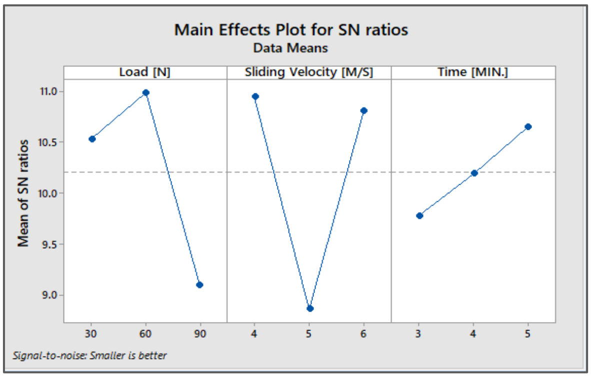

**Fig. 3.** Main Effects Plot for S/N Ratio

## 3. (ANOVA) Analysis of Variance

Analysis of variance (ANOVA) assess the importance of one or more factors by comparing the response variable means at the different factor levels. The statistical technique (ANOVA) is used to predict the process parameter and their interactions significantly affect the quality characteristics. This is done by separating the total variability of S/N ratio. analyze the effects of design parameters on the experimental data at a 95% confidence level. This includes understanding the impact of load (N), sliding velocity (V), and time (T), as well as the interaction of factors. The two tables 8 and 10 exhibit the Anova results for the given wear rate and COF. The F value and the percentage contribution of each interaction factor that affects the performance attributes are displayed in a table. It is shown that the most important factors for both COF and specific wear rate are sliding velocity and the interaction factor between loads and sliding velocity, followed by load and other parameters and interaction terms. The percentages of sliding velocity and the interaction between load and sliding velocity that contribute to COF are about 28.87% and 23.45%, respectively. 49.41% & 3.27% are also the wear rate.

**Table 7.** Factor Information

| Factor | Type | Levels | Values |
|---|---|---|---|
| Load | Fixed | 3 | 30, 60, 90 |
| Sliding Velocity | Fixed | 3 | 4, 5, 6 |
| Time | Fixed | 3 | 3, 4, 5 |

**Table 8.** Analysis for Variance for Specific wear rate

| Source | Degree of freedom | Seq SS | Adj SS | Adj MS | F-value | Contribution (%) |
|---|---|---|---|---|---|---|
| N | 2 | 0.000000 | 0.000000 | 0.000000 | 0.35 | 0.32 |
| V | 2 | 0.000001 | 0.000001 | 0.000000 | 3.60 | 3.27 |
| T | 2 | 0.000002 | 0.000002 | 0.000001 | 8.89 | 8.08 |
| N*V | 4 | 0.000015 | 0.000015 | 0.000004 | 27.22 | 49.41 |
| N*T | 4 | 0.000002 | 0.000002 | 0.000001 | 4.38 | 7.96 |
| V*T | 4 | 0.000008 | 0.000008 | 0.000002 | 15.06 | 27.33 |
| Error | 8 | 0.000001 | 0.000001 | 0.000000 | | 3.63 |
| Total | 26 | 0.000030 | | | | |

**Table 9.** Factor Information

| Factor | Type | Levels | Values |
|---|---|---|---|
| Load | Fixed | 3 | 30, 60, 90 |
| Sliding Velocity | Fixed | 3 | 4, 5, 6 |
| Time | Fixed | 3 | 3, 4, 5 |

**Table 10.** Analysis for Variance for coefficient of friction.

| Source | Degree of freedom | Seq SS | Adj SS | Adj MS | F-value | Contribution (%) |
|---|---|---|---|---|---|---|
| N | 2 | 0.023627 | 0.023627 | 0.011813 | 26.49 | 20.81 |
| V | 2 | 0.032777 | 0.032777 | 0.016389 | 36.75 | 28.87 |
| T | 2 | 0.005815 | 0.005815 | 0.002907 | 6.52 | 5.12 |
| N*V | 4 | 0.026621 | 0.026621 | 0.006655 | 14.92 | 23.45 |
| N*T | 4 | 0.001926 | 0.001926 | 0.000481 | 1.08 | 1.70 |
| V*T | 4 | 0.019200 | 0.019200 | 0.004800 | 10.76 | 16.91 |
| Error | 8 | 0.003567 | 0.003567 | 0.000446 | | 3.14 |
| Total | 26 | 0.113534 | 0.113534 | | | |

## 4. Regression Analysis

In order to investigate wear and friction performance in dry conditions, regression analysis was performed for the friction material pin sliding against coated disc. It was possible to derive the empirical equation for wear and friction performance in terms of load, sliding velocity, and time. The following is an expression for the linear regression for the friction material pin wear under investigation

**Specific Wear rate =** -0.02122 + 0.000124 Load
[N] 0.005702 Sliding Velocity [M/S]
+ 0.002926 Time [MIN.] - 0.000036
Load [N]*Sliding Velocity [M/S]
+ 0.000014 Load [N]*Time [MIN.] - 0.000823
Sliding Velocity [M/S]*Time [MIN.] (1)

**Coefficient of friction =**
-0.490 + 0.00779 Load [N] + 0.1586 Sliding
Velocity [M/S] + 0.0944 Time [MIN.]
-0.001279 Load [N]*Sliding Velocity [M/S] - 0.000128
Load [N]*Time [MIN.]
-0.0209 Sliding Velocity [M/S]*Time [MIN.] (2)

## 5. Conclusions

Analysis of variance (ANOVA) and the experiment test, along with the Taguchi analysis method, have helped to successfully assess the specific wear rate and coefficient of friction material with ALTIN coated disc. Examined was the effect of variables like load, sliding velocity, and time on a specific wear rate and coefficient of friction. The investigation has led to the following conclusion.

1) The wear of friction material has been found to decrease with applied load & sliding velocity.

2) The wear of friction material sliding against uncoated disc is comparatively higher than ALTIN coated disc.
3) However, Coefficient of friction of coated disc is stable at different load conditions than that of cast iron disc. Hence, which will enhance braking performance.
4) The Taguchi design can be used to predict wear of friction material while sliding against coated disc. Also regression analysis equation can be determined from the selected experiment results & used to determine wear at various input conditions.
5) The optimal condition for Coefficient of friction between pin on disc is found to be 60 N load, 4 m/s sliding velocity and 5 minute time. In case of specific wear rate it is found to be 30 N load, 4 m/s sliding velocity & 5 minute time.
6) ANOVA for Coefficient of friction & specific wear rate of pin shows that load on pin which further considered as sliding velocity is the most influencing factor where as duration has little significant impact on performance.
7) This study concludes that the tribological properties of friction material pins with ALTIN coated disc increase when the load and sliding velocity are properly combined.

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