Taguchi Technique for Effect of Aluminum Titanium Nitride Coating on Friction Performance of Disc Brake

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Abstract: The present study shows the tribological behavior of disc brake under an ALTIN coating on base material cast iron. The experiment is carried out in dry condition on pin on disc machine at room temperature based on Taguchi L27 orthogonal array. The load, sliding velocity and time are considered design parameters & coefficient of friction & wear rate considered as responses. The coefficient of friction & wear rate is determined by using optimal combinations of Taguchi technique. To establish relative significance of each factor on wear performance analysis of variance has been carried out. The result shows that wear rate & coefficient of friction are significantly influenced by increase load, sliding velocity & time. The most efficient factor which affects the tribological properties is sliding velocity & load. The coefficient of friction between pin on disc is stable at different load conditions.

Keywords: **Taguchi Technique; Wear; ALTIN; Coefficient of friction.**

1. INTRODUCTION

In today's market the selection of a vehicle is dependent on the speed, mileage & safety system. The modern vehicle which required a high-speed engine. So, controlling the speed of the vehicle a safety system used in automobile vehicles. Brakes are the most important safety system in automobile vehicle. Brakes are converting kinetic energy into thermal energy, which is dissipated into the atmosphere required to stop the vehicle within smallest possible distance. A drum brake replaced by modern design is disc by a flat metal disc or rotor with rubbing surface on each side. The frictional force between brake pad & disc produces a braking torque on the rotor to slow down the vehicle. Hence, the effectiveness of disc brake depends on rotor with brake pad at their sliding interfaces. In industry there is an interest to use lighter material for the disc to reduce overall weight of the vehicle & ultimately improves fuel consumption [1]. In disc brake system rotors are made from variety of materials such as cast iron, cast steel and composite or aluminum composite. A brake pad is composed of different basic elements are classified as additives, fillers, binders & reinforcement fibers. These all friction materials used to improving friction property at low & high temperature, Increase strength & rigidity, prolong life, reduce porosity & reduce noise. In brake pad material binder holds friction material, reinforcing fiber provide mechanical strength, fillers improve manufacturability, additives used to improve the coefficient of friction & wear resistance and lubricants stabilize friction coefficients at high temperature. The performance of brake pad depends on its composition & microstructure of material. Recently increasing the demand of vehicles in metro city, the hauling heavy load, traffic conditions and accidents are varied. In traffic, heavy load and mountain downhill conditions the brakes are applied hardly in which the speed of the vehicle reduced to zero within split of seconds. This may cause frictional heat generated at the contact interface of disc pad is almost absorbed by brake. Due to increasing temperature at contact between brake pad & disc, the properties of frictional material get disrupted. Therefore coefficient of friction decreases and rate of wear increased exponentially. The coefficient of friction between pad and disc drops with excessive temperature. This effect is called as brake fading. The brake fading causes the driver to applied more effort to stop vehicle during this process both pad & rotor are worn & some of the wear will become as particle emissions in the environment which are harmful to human health. Ali Belhocine [2] did study on thermal effects in the structure and contact behavior of disc pad assembly using FEA. He predicted that large deformation occurs at outer radius of disc and temperature affects the structure & contact behavior of disc.

Today most discs are made up of cast iron. Airborne wear from the disc produces up to 50% of total disc emissions [3].A particular attention has been recently focused to the environmental problems due to the release fine particle of the brake wear. It has already been shown that wear rate of brake pad & disc can be decreased by changing the chemical composition of friction material & cast iron. Another way to decrease wear rate or airborne emission of brake is to deposit a wear resistant hard layer on the friction surface of the disc [4].Shangwu fan et al. [5] prepared antioxidation phosphate coating on c/c & c/sic disc by using phosphate solution dipping method. Lastly they examined that friction surface coating decreased the average of COF of c/c seriously however beneficial to friction performance of c/sic. Matteo Federiciet al. [6] examined sliding wear test against friction material with different surface roughness and WC-CO-CR coating on cast iron disc.it was observed that coated disc wear is extremely severe &COF is quite low. A. Daoud et al. [7] studied the effect of load range of 30-100 N& speed range of 3-12 m/s on the wear & friction behavior of A359-20 vol% SIC particles sliding against friction material. It was their conclusion that wear rate of composites increases with high load. Piyush Verma et al. [8] discussed on the tribological behavior of commercial friction material sliding against cast iron disc. The result showed that a mixture of abrasion and wear by brittle fragmentation is active on the pin surface. The Uyyuru et al. [9] investigated tribological behavior of ALSI-SIC particle composites sliding against brake pad has shown that wear rate increases with increase in normal load and decreases with increasing sliding speed.

Such aluminum materials coatings are expected reduce wear & improve high temperature wear resistance as well as thermal fatigue resistance of braking system. The aluminum material coating would be better choice of coating with its processing technique & characteristic advantage such as high temperature conductivity, high heat dissipation rate which minimizes thermal elastic instability, brake fluid vaporization & thermally excited vibrations.

In this present study pin on disc test have been conducted using low metallic friction material cylindrical pin sliding against cast iron disc coated with ALTIN material layer deposited by PVD technology. In order to understand the effect of load range 50-100 N & sliding velocity 3-5 m/s on tribological behavior of coated disc with friction material. Finally, study on wear resistance and COF of pin with ALTIN coated disc was conducted. The section 1 describes the information about research work done on the disc brake system. The section 2 & 3 gives configuration of material and result of testing. Finally section 4 & 5 represents the regression analysis equation and conclusion of testing.

2. EXPERIMENTAL DETAILS

2.1. Material Details

The pin material used for this test was low metallic friction material. To improve wear resistance and hardness an Epoxy resin were selected. The compositions of material are listed in Table 1. All the material were available in the form of sheet from which powder were produced. The pins were made in cylindrical form with a diameter 10 mm and length 25 mm. The materials were selected for disc cast iron with thickness of 8 mm & outer diameter 165 mm. The material selected for coating was ALTIN & thickness of coating 4 µm. The pin materials were tested against coated ALTIN disc.

Table 1. Material Composition of Friction Material [3].

Constituents in Percentage (wt. %)							
Ferrous Metal	Non Ferrous Metal	Abrasive	Lubricant	Fibres	Fillers	Carbon	Epoxy Resin
7	10	12.5	7	3.5	12	28.6	19.4

2.2. Test set up and wear runs

Tribological tests for coefficient of friction & wear of low metallic friction material with coated disc were carried out on multi tribometer block TR-20 [DUCOM, India] under dry condition. This test set up commonly used to evaluate tribological properties in the laboratories. The coated disc used is ALTIN hardened to 255 HBN with thickness 8 mm, outer diameter of 165 mm. The tests were conducted by selecting operating parameters such as sliding velocity, load and test duration and track radius of 80 mm. The surface of cylindrical pin of friction material makes contact to rotating disc. The surface of specimen and disc are cleaned before starting the test. The setup of pin on disc test apparatus is shown in Fig.1.

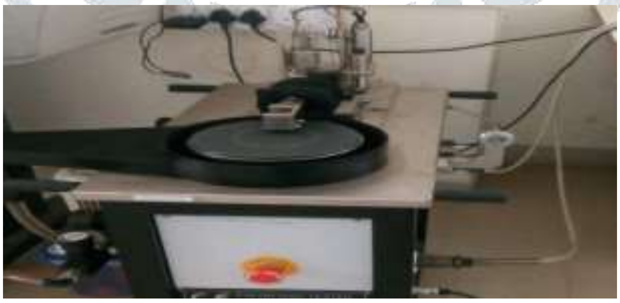

Fig.1. Pin-On-Disc set up.

The initial weight of each pin was measured using an electronic weighing machine. During the experiment pin specimen was pressed against the coated rotating disc by applying load. The tests were conducted under varied levels of process parameters. After each experiment, the pin weighed to calculate wear rate in terms of weight loss. The wear & COF test were carried out with variable load, sliding velocity and test duration. The levels of process parameter are shown in Table 2. The experiment were conducted as per orthogonal array L_{27} having 27 rows in which first column was assigned to load, second column to sliding velocity and third column to test duration.

Table 2. Levels of operating parameters.

Levels	Load [N]	Sliding Velocity [M/S]	Time [MINUTE]
1	50	3	2
2	75	4	4
3	100	5	6

3. RESULTS AND DISCUSSION

The tribological experiment for COF & Wear rate are conducted as per orthogonal arrays based on design of experiment given in table 2 and experimental data for COF & wear are shown in table 3.The Minitab 18 statistical software used for taguchi analysis. The quality characteristics of process /product defines S/N ratio. The analysis of S/N ratio based on three categories of performance characteristics that is smaller the better, larger the better & nominal is best. For this analysis smaller the better adopted COF & Wear rate for calculating S/N ratio. The S/N ratio for responses is as shown in table 3. The influence of each design parameter (A, B & C) on response variables are obtained from the response table of mean S/N ratio. Response table for specific wear rate & COF are presented in table 4& table 5.

The S/N ratio identified control factors that minimize the variability caused by noise factors. The S/N ratio plot of specific wear rate & COF are as shown in Fig. 2. In plot the line is horizontal there is no main effect & if point near to average horizontal line has less significant effect & highest inclination will have most significant effect on the responses.

Table 3. Experiment data and S/N ratio for COF and Wear rate

Exp. Run	Load (A)	Sliding Velocity (B)	Time (C)	Coefficient of Friction	Specific Wear Rate (mm^3/Nm)	S/N ratio (COF)	S/N ratio Wear Rate
1	50	3	2	0.2401	0.000952	12.3921568	67.91548
2	50	3	4	0.2378	0.001041	12.47576299	56.02686
3	50	3	6	0.2654	0.001817	11.52198163	55.70312
4	50	4	2	0.3012	0.003420	10.42290065	55.34008
5	50	4	4	0.2946	0.002160	10.61534515	54.24397
6	50	4	6	0.2762	0.001960	11.17552652	54.13717
7	50	5	2	0.3417	0.005910	9.327100424	41.09063
8	50	5	4	0.299	0.003690	10.48657623	48.99543
9	50	5	6	0.2682	0.002160	11.43082453	54.56317
10	75	3	2	0.317	0.001940	9.978814756	53.43241
11	75	3	4	0.332	0.002160	9.577238326	53.31092
12	75	3	6	0.3012	0.002517	10.42290065	53.15155
13	75	4	2	0.354	0.002880	9.019934759	50.81215
14	75	4	4	0.3364	0.002910	9.462880257	50.72214
15	75	4	6	0.3098	0.002230	10.17837173	50.66265
16	75	5	2	0.2901	0.004030	10.74904542	53.31092
17	75	5	4	0.3146	0.002510	10.04482563	55.70312
18	75	5	6	0.2601	0.001390	11.69719296	57.1397
19	100	3	2	0.373	0.002700	8.565823364	49.34491
20	100	3	4	0.3875	0.003430	8.234565863	49.29412
21	100	3	6	0.4034	0.004110	7.885282122	49.06915
22	100	4	2	0.3919	0.002240	8.13649473	52.99504
23	100	4	4	0.3817	0.002130	8.365556801	53.43241
24	100	4	6	0.2879	0.002100	10.8151667	53.55561
25	100	5	2	0.3042	0.002050	10.33681581	53.76492
26	100	5	4	0.298	0.001620	10.51567472	55.8097
27	100	5	6	0.2779	0.001420	11.12222906	56.95423

a) b)

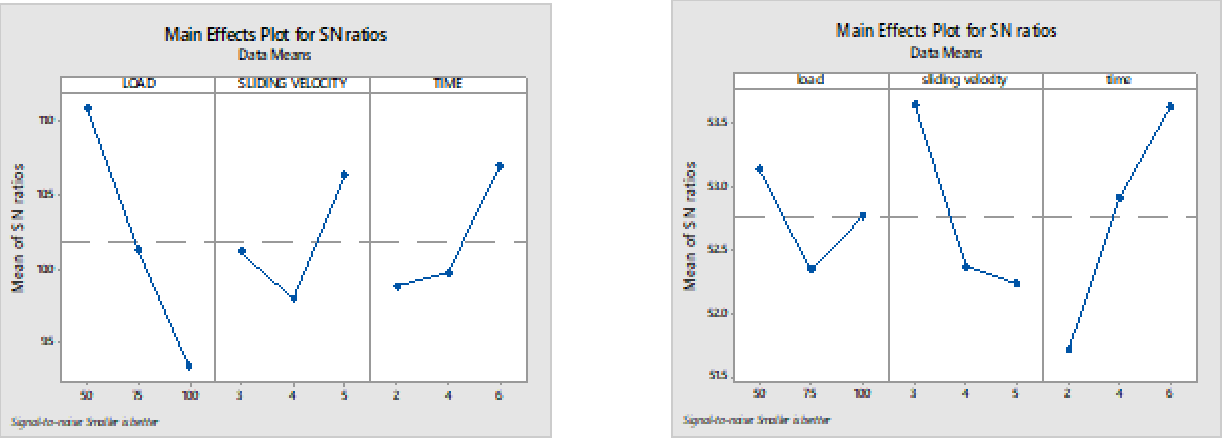

Fig. 2 S/N ratio plot for a) COF b) Wear Rate

Table 4. Response table for each factor level of COF

Levels	Load	Sliding Velocity	Time
1	11.094*	10.117	9.881
2	10.126	9.799	9.975
3	9.331	10.634*	10.694*
Delta	1.763	0.835	0.813
Rank	1	2	3

‘*’ indicates optimal process level

Table 5. Response table for each factor level of Wear rate

Levels	Load	Sliding Velocity	Time
1	53.14*	53.65*	51.71
2	52.35	52.37	52.35
3	52.77	52.23	52.63*
Delta	0.79	1.41	1.92
Rank	3	2	1

‘*’ indicates optimal process level

The highest S/N ratio corresponds to best quality characteristics regardless of the category of the performance characteristics. The optimal level of process parameter decides by highest S/N ratio. From response table of COF & main effects plot (Fig.2) the optimum combination of design parameters (A1B3C3). For optimum combination of specific wear rate is (A1B1C3).

From Fig.2 shows that the main effect plot of S/N ratio for specific wear rate indicates that at load of 50 N, sliding velocity 3 m/s & time 6 min. has the largest effect on signal to noise ratio. It shows that maximum effect on wear rate of pin. From the S/N ratio it is observed that at minimum load condition the specific wear rate of material is decreased due to temperature & contact plateaus rise are low. At condition of higher load & sliding velocity the friction material is forced against the disc resulting in higher temperature at the interface. There by destroying the transfer film at faster rate causing more wear of friction material.

In case of COF, it is clear that at high load & minimum time the COF decreases because surface temperature of friction material increases with high load & epoxy resin in friction material is soft caused by frictional heat at the interface. Thus reduction of COF occurs. At maximum duration of braking thermal loading between pin & disc is homogeneous & uniform contact conditions on pin and disc friction surface.so, it leads to increase COF between pin & disc.

3.1. Analysis of Variance

To understand the effect of design factors like load (P), sliding velocity (V) & speed (T) & interaction of factors on the experimental data analysis is of variance (ANOVA) is studied at 95% level of confidence. The results of anova for specific wear rate & COF are presented in table 6& table 7. In a table F ratio & percentage of contribution of each & interaction factor which affect the performance characteristics. It is seen that sliding velocity & interaction factor between loads& sliding velocity is the most significant factor followed by load & other parameters & interaction terms both for COF & specific wear rate. The percentage of contribution for COF of sliding velocity & interaction between load & sliding velocity are about 8.52 % & 31.64 % for COF. Also for wear rate are about 3.44 % & 51.72 %.

Table 6. ANOVA Table for Specific Wear Rate

Source	Degree of Freedom	Sum of Square	Mean Square	F-Value	Contribution
P	2	0.000000	0.000000	0.36	0.00%
V	2	0.000001	0.000000	3.61	3.44%
T	2	0.000002	0.000001	8.90	6.89%
P*V	4	0.000015	0.000004	27.22	51.72%
P*T	4	0.000002	0.000001	4.38	6.89%
V*T	4	0.000008	0.000002	15.06	27.58%
Error	8	0.000001	0.000000		3.44%
Total	26	0.000029			

Table 7. ANOVA Table for Specific COF

Source	Degree of Freedom	Sum of Square	Mean Square	F-Value	Contribution
P	2	0.018773	0.009386	18.94	34.37%
V	2	0.004653	0.002326	4.69	8.52%
T	2	0.004586	0.002293	4.63	8.39%
P*V	4	0.017282	0.004320	8.72	31.64%
P*T	4	0.000878	0.000220	0.44	1.60%
V*T	4	0.004469	0.001117	2.25	8.18%
Error	8	0.003965	0.000496	18.94	7.26%
Total	26	0.054605			

3.2. Confirmation Test

From taguchi analysis the optimum level of design parameters are selected for COF & specific wear rate .the final step to predict & verify the improvement of the performance. Using optimal level of process parameter the estimated S/N ratio, γ is calculated using equation (1) (J Sudeepan et.al, 2014).

$$\gamma = \gamma_m + \Sigma (\gamma_i - \gamma_m) \quad (1)$$

Where, γ_m is the total mean S/N ratio, $\overline{\gamma_i}$ the mean S/N ratio at the optimal testing parameter level. The table shows the results of the confirmation experiment using optimal parameter good agreement between predicted performance & actual performance. The improvement of S/N ratio from initial to optimal levels are about 9.67% and 5.91% for COF & specific wear rate respectively. Hence friction & wear performance are improved by using taguchi method.

Table 8.Confirmation test for estimated and actual S/N ratio of Wear Rate

Parameter	Initial Optimal	Predicted	Expt.	Improvement in Result
Level	$A_2B_2C_2$	$A_1B_1C_3$	$A_1B_1C_3$	
Wear Rate	0.00104		10.001817	
S/N Ratio (dB)	56.02686	54.08	55.70	5.91%

Table 9.Confirmation test for estimated and actual S/N ratio of COF

Parameter	Initial Optimal	Predicted	Expt.	Improvement in Result
Level	$A_2B_2C_2$	$A_1B_3C_3$	$A_1B_3C_3$	
Wear Rate	0.2378		0.2682	
S/N Ratio (dB)	12.475	10.80	11.430	9.67%

4. Regression Analysis

The regression analysis was done for the friction material pin sliding against coated disc to study the wear & friction performance under dry condition. The empirical equation for wear & friction performance in terms of load, sliding velocity & time were obtained. The linear regression for wear of friction material pin under investigation can be expressed as follows:

$$\text{Wear rate} = -0.01467 + 0.000139\,P\,[N] + 0.005149\,V\,[M/S] + 0.000844\,T\,[MIN.] - 0.000044\,P{*}V\,[M/S] + 0.000008\,P{*}T\,[MIN.] - 0.000411\,V{*}T\,[MIN.]$$

$$COF = -0.286 + 0.00746\,P[N] + 0.1293\,V\,[M/S] + 0.0243\,T\,[MIN.] - 0.001498\,P{*}V\,[M/S] - 0.000045\,P{*}T\,[MIN.] - 0.00707\,V{*}T\,[MIN.]$$

5. Conclusion

Taguchi analysis method has assisted to analyze successfully the friction coefficient & specific wear rate of friction material with ALTIN coated disc under dry condition. The effect of operating parameters such as load, sliding velocity & time on friction coefficient & specific wear rate were examined. The following conclusion drawn from study:

- The optimal condition for COF between pin on disc is found to be 50 N load, 5 m/s sliding velocity and 6 minute time. In case of specific wear rate it is found to be 50 N load, 3 m/s sliding velocity & 6 minute time.
- ANOVA for COF & specific wear rate of pin shows that load on pin which further considered as sliding velocity is the most influencing factor whereas duration has little significant effect on performance.
- The confirmation test show that the improvement of COF (S/N ratio) from initial condition to optimal condition by 9.67% & for specific wear rate (S/N ratio) by 5.91%.
- It can be concluded that from this study that friction material pin with ALTIN coated disc at right combination of load & sliding velocity the braking performance get improved.

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