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*Full Length Research Paper*

# Optimizing friction behavior of clutch facings using pin-on-disk test

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**In this work, a rational approach based on Taguchi technique and Pin-on-disk test is used in order to study the friction coefficient behavior of clutch facings as function of material formulation. Experiments were designed according to the orthogonal array L8 where the chosen factors are temperature and sliding speed. A complex interaction exists between the surface texture of the produced clutch facings and the used manufacturing process parameters, particularly those associated to molding and grinding operations. Since it is not straightforward to render this effect in terms of explicit factors, it is roughly considered here as noise affecting a chosen wear path during Pin-on-disk testing. Signal over noise ratio should be sufficiently high in order that qualification of test results obtained for a given material formulation could be possible. For the set of parameters considered during the actual experiment, the friction coefficient behavior of clutch facings was shown to be mainly controlled by the sliding speed or by the interaction between the sliding speed and temperature.**

**Key words:** Friction coefficient, clutch facings, pin-on-disk, Taguchi method.

## INTRODUCTION

An important issue in the research and development process of clutch facings consists in obtaining a sufficiently high and stable friction coefficient during the whole product servicing life. This could be reached by finding an adequate material formulation. One should notice that the manufacturing process used could also have a drastic influence on the final product performances. In case of important sensitivity to the manufacturing process, the friction coefficient is expected to be irregular. It is necessary therefore, that results of investigation on friction behavior should take into account both the actual material composition and the manufacturing process parameters.

Friction coefficient must also be studied as function of the general rubbing surface parameters which could be idealized to include temperature, the sliding speed, the normal contact pressure, surface roughness and surface state specifications of the counter material. Since in common applications of clutch facings the last three parameters are likely to remain constant, only behavior of the friction coefficient as function of temperature and the sliding speed will be investigated by means of the pin-on-disk test system. A clutch-facing sample having the form of a disk is used and a pin, made from steel, is chosen as the counter material (Bezzazi et al., 2007). Using Pin-on-disc experiment to imitate the contact conditions in the clutch system needs some discussion. A metal pin sliding against a semi-infinite solid introduces a pressure distribution with edge effects. This phenomenon is well known, and does not appear when two nominally flat rough semi-infinite bodies contact each other, where the pressure tends to be uniformity distributed under ideal conditions without any edge effect (Williams, 1994). However, since the aim of investigation is mainly to perform stability analysis of the friction coefficient by doing comparisons between several material formulations, the Pin-on-disk configuration would provide such a fast and sufficiently reliable way of doing tests. It was shown in fact (Bezzazi et al., 2007) that this way of testing friction products could yield the essential features of the friction coefficient behavior. Additional precaution must be considered in deal-

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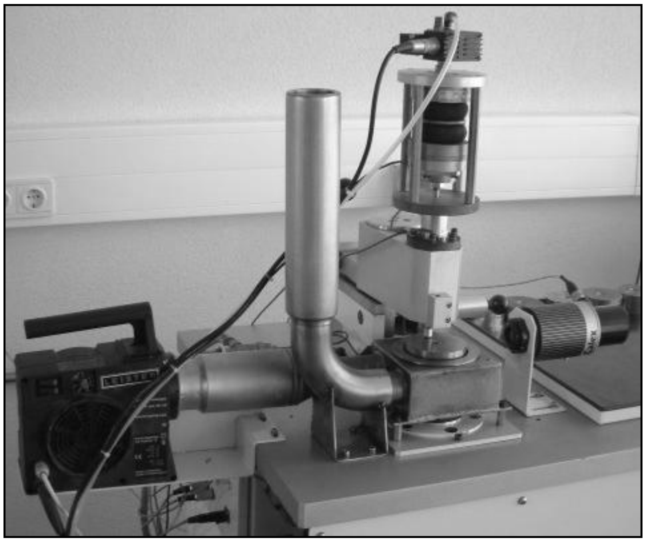

**Figure 1.** Disk of friction product tested on Pin-on-disk apparatus.

dealing with temperature effect using Pin-on-disk testing, since interpretation of the obtained results could only be performed if temperature is allowed to reach a steady state by using extra heat flux (So, 1995).

The comprehensive method of Taguchi, (Davim, 2000) and (Fujmoto, 2003), used throughout this work is largely recognized as a robust and cost effective method of engineering development. Many successful results have been reported in the literature about applications of this method such as reduction in cost and development time, as well as a dramatic improvement in production efficiency.

Taguchi's method differs greatly from the conventional experiment design in that the performance is evaluated within the framework of a scale of signal over noise ratio (S/N). In our case, if the S/N ratio is relatively high, friction performances will be stable. A stable coefficient of friction means that the clutch facing has a reduced sensitivity to the manufacturing process parameters. A particular choice for the wear path in Pin-on-disk testing is expected then to not have significant effect on the friction coefficient behavior. The process parameters could be acknowledged in this case to be robust with regards to the specific material formulation.

Noise could result for clutch facings case from production errors, material heterogeneities, variations of surface characteristics during the manufacturing operations of molding and grinding (Nicholson, 1995), and variations affecting testing conditions.

Since it is not an easy task to consider friction performances characterizing the finished product as function of all these various factors, which in reality could not be known exactly, their effect is roughly idealized as the noise resulting from choosing a particular wear path during Pin-on-disk testing. This will be examined here by performing, for each pair of temperature and sliding speed factors, two separate tests. One on the direct side of the clutch facing sample and the other on the Rear side of this sample. In this way, the error factor is made the friction product side: Direct (a) or Rear (b).

In the actual design of experiment, the distance of wear is made as an input signal and the measured friction coefficient is made a response factor. Two test parameters are investigated as control factors: the sliding speed and temperature.

## Clutch facing materials

Clutch facings investigated in this study are of non asbestos organic type. They contain usually more than fifteen different raw materials, (Nicholson, 1995) and (Khamlichi et al., 2003). The main raw materials used are: binder resin, continuous glass fibrous yarn, friction modifiers and cashew fillers.

The organic yarn clutch facings are obtained through the usual scatter wound procedure, which consists of the following operations: impregnating or coating yarn, drying, winding, press curing baking and grinding.

## Pin-on-disk tests

Friction tests, on friction products under unlubricated conditions, were performed on a Pin-on-disk tribometer PLINT TE67HT, (Breaux et al., 2002) and (Davim and Cardoso, 2006). The objective was to evaluate the behaviour of friction product/steel pair under the effect of sliding velocity and temperature. The normal load pressure was kept constant. The sliding distance was fixed at 1000 m.

The tribometer consists of a loading stationary pin sliding against a rotating disk with its axis perpendicular to the disk, figure 1. The normal load applied on the pin is provided by a pneumatic system with a compression load cell. A motor with a tachogenerator feedback ensured the stable running speeds. An indication of wear process in the pin/disk contact was given by a linear potentiometer mounted in the pneumatic pin-loading piston.

Special DIN Ck45K steel pins (Flat-ended) with a diameter of 8 mm and a length of 67.8 mm were machined. All pins have the following chemical composition (wt.%): 0.45% C, 0.25% Si, 0.65% Mn and present a hardness value of 230 HB. Before testing the pins were ultrasonically cleaned in an acetone bath.

Real clutch facing dimensions are bigger than it is necessary for the pin-on-disk apparatus. So, special samples were manufactured to perform Pin-on-disk wear testing. These samples are discs with 8 mm thickness and 76 mm of diameter. Figure 2 recalls the main characteristics of the tested clutch facing samples. The tribological conditions used on tests to evaluate the behaviour of clutch facing/steel pair were the sliding velocities 1 m/s and 3 m/s and temperatures 100 and 200℃. Temperature is stabilized by a controlled heating system. All the experiments were performed under dry sliding condi-

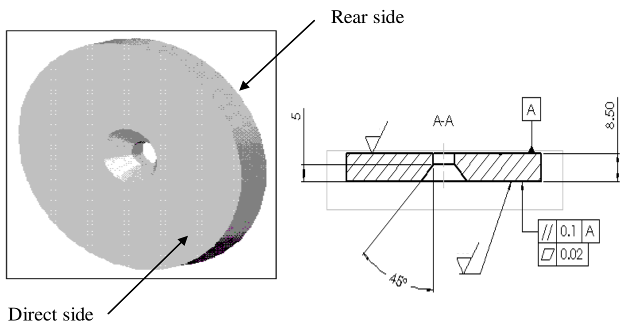

Figure 2. Characteristics of tested clutch facing samples.

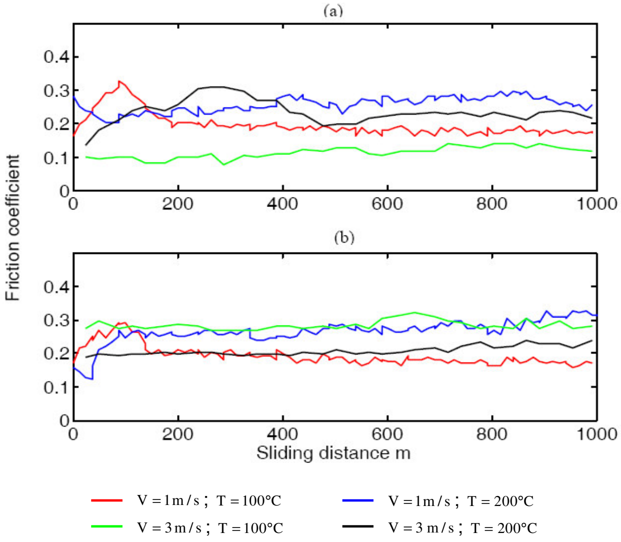

**Figure 3.** Friction coefficient as function of the sliding distance for clutch facing quality C1; (a) Direct side, (b) Rear side.

tions with a relative humidity of about 50%.

The controlled temperature differs from the mean temperature at the apparent contact area between pin and disk which differs in its turn from the flash temperature at the real contact area. Gradients involving these three temperatures have been shown to remain constant during Pin-on-disk testing at least when the steady state is reached (So, 1995). Due to large differences existing between the pin thermal conductivity and those of the friction products being tested, the bulk temperature which is reached at the rubbing surface during the actual Pin-on-disk tests is likely invariable whichever the friction product is. This temperature will only vary depending on the controlled temperature. It should be pointed out here that the reverse pin-on-disk configuration chosen in the actual study has the huge advantage to be free from any glazing effect unlike the direct configuration where the pin is made from a sample of the friction material. In this last situation glazing is likely to occur and friction results would not indicate behavior of the fiction product as it takes place in real conditions of servicing. This variation of behavior between the two configurations has even been observed for a pair arranged from the same material. The results between the rotating pin and the stationnary pin were different under the same testing conditions (So, 1995).

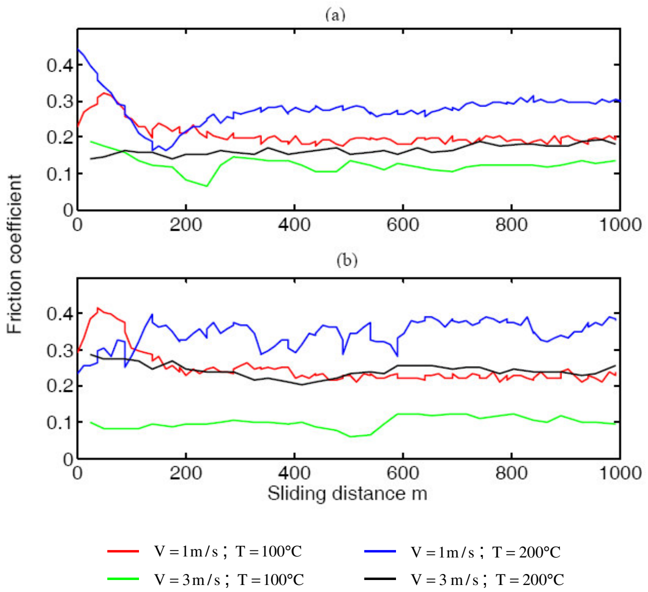

**Figure 4.** Friction coefficient as function of the sliding distance for clutch facing quality C2; (a) Direct side, (b) Rear side.

Experiments carried out in this work intend to investigate friction coefficient behavior following some given modification on raw materials. This is performed in our case by changing a particular raw material in the material formulation.

Three different qualities were tested. They are designnated as C1, C2 and C3. A total number of 24 tests were performed on the 3 qualities. Figures 1 and 2 give respectively the used test configuration and the tested clutch facing sample.

Samples were manufactured under the same conditions during molding, baking and grinding. For instance, cycles of ventilation during molding are exactly the same for all the 3 qualities and no extra process adjustment were considered to take into account the particular material formulation.

## Testing results

Figures 3 to 5 give the friction coefficient as function of the sliding distance. In all cases a stable friction coefficient is obtained when bedding in phase has been achieved. This occurs approximately after running 100 m from the beginning of the test. Figures 3 to 5 show also that there are some discrepancies between the friction coefficient results associated to direct side (a) of the tested samples and those associate to their rear side (b).

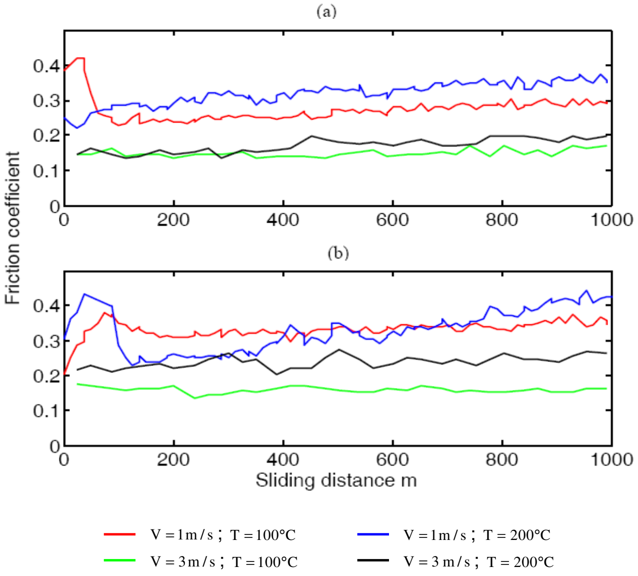

**Figure 5.** Friction coefficient as function of the sliding distance for clutch facing quality C3; (a) Direct side, (b) Rear side.

**Table 1.** Average friction coefficient results for clutch facings C1, C2 and C3, (a) Direct side, (b) Rear side.

| Quality | Texture | Speed m/s | Temperature °C | Average µ |
|---|---|---|---|---|
| C1 | (a) | 1 | 100 | 0.27 |
| | | | 200 | 0.32 |
| | | 3 | 100 | 0.15 |
| | | | 200 | 0.17 |
| | (b) | 1 | 100 | 0.33 |
| | | | 200 | 0.37 |
| | | 3 | 100 | 0.16 |
| | | | 200 | 0.24 |
| C2 | (a) | 1 | 100 | 0.21 |
| | | | 200 | 0.28 |
| | | 3 | 100 | 0.12 |
| | | | 200 | 0.16 |
| | (b) | 1 | 100 | 0.25 |
| | | | 200 | 0.34 |
| | | 3 | 100 | 0.10 |
| | | | 200 | 0.24 |
| C3 | (a) | 1 | 100 | 0.20 |
| | | | 200 | 0.26 |
| | | 3 | 100 | 0.11 |
| | | | 200 | 0.23 |
| | (b) | 1 | 100 | 0.19 |
| | | | 200 | 0.27 |
| | | 3 | 100 | 0.28 |
| | | | 200 | 0.21 |

This indicates that the manufacturing process parameters have some influence on the friction performance.

Table 1 presents the obtained results in terms of the average friction coefficient as function of the control parameters and the wear path used during the test.

Tables 2 to 4 give the ANOVA tables for all the performed tests. Noise is assumed here to result from the factor designed as wear path texture (text.) and its different interactions with speed and temperature (temp.).

From comparisons between results obtained for clutch facing materials C1, C2 and C3, it is shown that stability of the friction coefficient is only obtained in case of qualities C1 and C2. Comparing the friction coefficient values given in table 2, one could notice that there is only small variations between qualities C1 and C2. Both of these last qualities are found to fit the friction performance as to stability requirements with some advantage for material quality C1.

The p-values in the ANOVA tables 2 and 3 show that, for qualities C1 and C2, the friction coefficient variations are largely influenced by the interaction between the sliding speed and temperature. As for clutch facing material C3, the p-values in the ANOVA table 4 shows that speed is the main factor responsible for friction performance variability. Since, in real driving situations, extreme sensitivity of friction material to the sliding speed may yield Judder instability phenomenon, material quality C3 must be discarded.

From ANOVA tables 2 and 3 one could notice also that the interaction between speed and texture is more important for clutch facing material quality C1 than for quality C2. This indicates that clutch facing quality C2 is more sensitive to manufacturing conditions than C1. Since cost of material quality C1 is lower than that of C2, material C1 yields in our case the optimal design.

## Conclusions

Using Pin-on-disk test in the context of Taguchi design of experiment was performed in order to achieve friction performance of clutch facings. Stable behavior of the friction coefficient was found in case of materials C1 and C2. The other findings could be summarized as follows: -

- The S/N ratio is found to be enough high in case of material formulation C1 indicating that this material has a robust behavior when considering variations of the friction coefficient as function of the wear path used during test. Reduced sensitivity to the manufacturing process parameters is obtained for this material.

- For temperatures and sliding speeds investigated during

**Table 2.** ANOVA analysis for clutch facings quality C1.

| Source | SQA | d.f. | S/N | Test F | F 5% | P (%) |
|---|---|---|---|---|---|---|
| Texture | 0.00451 | 1 | 0.98 | 7.37 | 0.2247 | 8.90 |
| Speed | 0.04061 | 1 | 8.83 | 66.31 | 0.0778 | 80.11 |
| Temperature | 0.00451 | 1 | 0.98 | 7.37 | 0.2247 | 8.90 |
| Text.*Speed | 0.00011 | 1 |  | 0.18 | 0.7422 | 0.22 |
| Text.*Temp. | 0.00031 | 1 |  | 0.51 | 0.6051 | 0.61 |
| Speed*Temp. | 0.00001 | 1 |  | 0.02 | 0.9097 | 0.02 |
| Error | 0.00061 | 1 |  |  |  | 1.20 |
| Noise | 0.00460 | 3 |  |  |  | 9.07 |
| Total | 0.05069 | 7 | 11.02 |  |  |  |

**Table 3**. ANOVA analysis for clutch facings quality C2

| Source | SQA | d.f. | S/N | Test F | F 5% | P (%) |
|---|---|---|---|---|---|---|
| Texture | 0.00320 | 1 |  | 4 | 0.2952 | 6.82 |
| Speed | 0.02645 | 1 | 7.56 | 33.06 | 0.1096 | 56.34 |
| Temperature | 0.01445 | 1 | 4.13 | 18.06 | 0.1471 | 30.78 |
| Text.*Speed | 0.00020 | 1 |  | 0.25 | 0.7048 | 0.43 |
| Text.*Temp. | 0.00180 | 1 |  | 2.25 | 0.3743 | 3.83 |
| Speed*Temp. | 0.00005 | 1 |  | 0.06 | 0.8440 | 0.11 |
| Error | 0.00080 | 1 |  |  |  | 1.70 |
| Noise | 0.00350 | 3 |  |  |  | 7.45 |
| Total | 0.04695 | 7 | 13.41 |  |  |  |

**Table 4.** ANOVA analysis for clutch facings quality C3.

| Source | SQA | d.f. | S/N | Test F | F 5% | P (%) |
|---|---|---|---|---|---|---|
| Texture | 0.00281 | 1 |  | 0.51 | 0.6051 | 13.20 |
| Speed | 0.00101 | 1 |  | 0.18 | 0.7422 | 0.47 |
| Temperature | 0.00451 | 1 |  | 0.82 | 0.5318 | 21.18 |
| Text.*Speed | 0.00281 | 1 |  | 0.51 | 0.6051 | 13.20 |
| Text.*Temp. | 0.00361 | 1 |  | 0.66 | 0.5668 | 16.96 |
| Speed*Temp. | 0.00101 | 1 |  | 0.18 | 0.7422 | 4.74 |
| Error | 0.00551 | 1 |  |  |  | 25.88 |
| Noise | 0.00920 | 3 |  |  |  | 43.21 |
| Total | 0.02129 | 7 | 2.31 |  |  |  |

experiment, friction coefficient of clutch facing materials C1 and C2 is found to be very sensitive to the interaction between the sliding speed and temperature indicating that a linear model is insufficient to model their friction behavior.

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