Evaluation of high-temperature tribological behavior of Chromium coating using LRT

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Abstract. This study aimed to investigate the effect of Chromium coating on the tribological performance of the tribopair. The tribological investigation was carried out for different temperature, load and frequency and coefficient of friction and specific wear rate was calculated. The experiments were performed at 3 different levels of loads (10, 20, 30 N), frequency (24, 30, 36 Strokes/sec) and Temperature (40, 80, 120 °C) using a linear reciprocating tribometer. The L9 orthogonal array as per the Taguchi technique was used to analyze the effect of various input parameters and specific wear rate (SWR) and coefficient of friction (COF) were taken as output parameters. The coated surface showed better tribological behavior as compared to cast iron. The temperature had maximum influence on the tribological behavior followed by load and frequency.

Keywords. Chromium coating; Taguchi analysis; Friction; Wear; High-temperature tribology.

1. Introduction

The mechanical, electromechanical and biological systems are used in every engineering application and it has been noted that the substantial amount of energy is consumed in overcoming friction between the mating surfaces of these systems. Wear of parts or components results in resource wastage and unnecessary heat generation. The researches have been working continuously to minimize friction and wear losses. The study of tribological properties (i.e., friction, wear and lubricants) has gained significance in recent years as an effort to reduce the material losses. The recent development of advanced lubricant having various additives has proved to be a big boost for tribological improvement [1-4]. Still there is need to improve the surface of the tribopair to achieve the required tribological performance. Coating of the tribopair has also become an economical and efficient way to improve the tribology in machining technology. The phenomenon of formation of a metallic or composite layer on the metal surface to protect it from corrosion and to enhance the mechanical properties of the metallic substrate by improving its hardness or decreasing the coefficient of friction on its surface is called coating. The coating of suitable material not only improves the wear resistance but enhance the antifriction properties without disturbing the mechanical properties of the bulk material [5]. The Chromium nitride CrN coatings showed better anti-wear characteristic under high load and elevated temperature with moderate residual stress [6-8]. PVD coated bearing materials.
had improved the tribological performance as graphite behaved as a solid lubricant \[9,10\]. The glass fiber reinforced (GFR) and bronze and carbon (C) filled PTFE polymers showed better tribological behavior by reducing friction coefficient up to 17\% \[11\]. The theoretical and experimental analysis of the tribopair showed enhanced tribological performance for the coated surfaces by reducing the power consumption indicating lower friction coefficient \[12,13\]. The coatings had a wide application for several industrial and medical applications to serve various functions such as thermal conductors, antimicrobial materials \[14,15\] and antifriction and wear-resistant materials in bearing applications \[16-18\].

The coating showed a promising and effective mode for improving tribology then the conventional material. The coating of hard material like Chromium has been done and investigated for the tribological behavior on linear reciprocating tribometer.

2. Experimental Setup
The coating of Chromium had been done by the physical vapor deposition method. The micro hardness of the coated and uncoated material was measured. The tribological behavior of the coated specimen was investigated at various temperatures on the linear reciprocating tribometer.

2.1. Linear reciprocation tribometer (LRT)
The tribological investigation was carried out according to ASTM G133 using liner reciprocating tribometer shown in figure 1. The tribometer have load range of 5-50 N, frequency 1-50 Hz, stroke range 1-20 mm, consisted of a reciprocating drive motor attached to the pin holder block, a lever-actuated arm device to connect the motor drive and the pin holder block, and other attachments to allow the pin specimen to be pressed against the stationary plate specimen with a controlled static load. The wear track on the plate was a straight line, resulted due to multiple wear pushes on the same track. The temperature of the plate could be controlled according to the test conditions. The static load was applied to the pin holder. The coefficient of friction measured by the load cell had been shown on the online monitor.

![Linear reciprocating tribometer](image)

**Figure 1.** Linear reciprocating tribometer.
2.2. Test specimens and specimen preparation

The pins were preparing by turning and grinding operation. A casted rod of cast iron was machined and turned to a diameter of 6 mm on a conventional lathe machine. Turning was followed by parting operation, at the required length of 15 mm, which was performed on the conventional lathe machine. Pins were then ground, to ensure a smooth flat circular surface at both ends of the pins. The prepared pins were then coated with Chromium by physical vapor deposition.

Mild steel plates were machined using wire electrical discharge machine or wire-EDM. A sheet of mild steel, having a thickness of 6 mm was casted and sent for grinding operation for smooth flat surface, reducing the thickness to 5 mm. These plates were then processed and cut into squares of 20x20 mm2 dimensions, using a wire-EDM, for high dimensional accuracy.

3. Design of experiment

The experiment was performed under different conditions of load, frequency and temperature given in table 1 for the coated and uncoated pin.

| Sr. No. | Parameter | Range               |
|---------|-----------|---------------------|
| 1       | Load      | 10 N, 20 N, 30 N    |
| 2       | Frequency | 24, 30, 36 Strokes/Sec |
| 3       | Temperature | 40 °C, 80 °C, 120 °C |

To optimize the minimum number of trails, Taguchi L9 orthogonal array was selected. The combination of different parameters according to L9 orthogonal array is given in table 2.

| Experiment Set | Load (N) | Frequency (Strokes/Sec) | Temperature (°C) |
|----------------|----------|-------------------------|------------------|
| A              | 10       | 24                      | 40               |
| B              | 30       | 30                      | 40               |
| C              | 20       | 36                      | 40               |
| D              | 20       | 24                      | 80               |
| E              | 30       | 36                      | 80               |
| F              | 10       | 30                      | 80               |
| G              | 30       | 24                      | 120              |
| H              | 20       | 30                      | 120              |
| I              | 10       | 36                      | 120              |

The output parameters for the experimentation were the coefficient of friction and wear of material. The coefficient of friction and wear should be minimum for improved tribology. The coated and uncoated pins were tested against mild steel plate for tribological investigation.

4. Result and discussions

4.1. Hardness Testing

The micro hardness of the tribopairs of mild steel as plate and cast iron and Chromium coated pins were determined using Vickers’s hardness, the figure 2 represents the depth of indentation of the
indenter in the specimen and the corresponding micro hardness has been calculated as given in table 3. The micro hardness of Chromium coated pin was 280 % more the cast iron pin, moreover, Chromium coating also would also provide protecting shield from the environmental attack.

| Sr. No. | Material                        | Hv Value   |
|---------|---------------------------------|------------|
| 1       | Mild steel plates               | 177.12     |
| 2       | Chromium coated pins            | 616.06     |
| 3       | Pure cast iron pins             | 215.87     |

Table 3. Vicker hardness value of different materials.

![Figure 2. Depth of indentation vs applied load.](image)

4.2. Tribological Testing
The coefficient of friction was measured by the online monitor connected to the tribometer, the specific wear rate was measured by the weight loss technique.

The specific wear rate was calculated as given in equation (1).

\[
Sw = \frac{Vw}{(P*D)}
\]  

Where,
- \(Sw\) = specific wear rate, \(\text{mm}^3 / \text{N-m}\)
- \(Vw\) = Volume of wear loss, in \(\text{mm}^3\)
- \(P\) = Applied load in Newton, \(N\)
- \(D\) = Sliding Distance in meters, \(m\)
The variation in the coefficient of friction for the different set of experiments has been shown in figure 3. The coefficient of friction for the coated pin was lesser as compared to the cast iron pin this may be due to lesser asperity contact of the coated surface with the counter body (mild steel) as the coated surface possess better surface finish. Figure 4 shows the specific wear rate for the different test conditions for cast iron pin and Chromium coated pin. The wear in case of the coated pin is lesser as compared to the cast iron pin. Moreover, the wear at an elevated temperature increased drastically for cast iron pin but it remained almost constant for the coated pin, this may be due to the higher hardness, better surface finish and the ability of the material to sustain elevated temperature.

Figure 3. Variation in coefficient of friction.

Figure 4. Variation in specific wear rate.
4.3 Taguchi Analysis

Taguchi methodology has been utilized to find the importance of each parameter and it also provides the optimum set of parameters which results in lower and lower specific wear rate as well. The values of coefficient of friction and specific wear rate between the tribopairs were observed and recorded for L9 orthogonal array.

![Figure 5](image_url)

**Figure 5.** S/N ratio for cast iron vs mild steel considering smaller is better a) COF b) SWR.

The results were analyzed for “smaller is better” and S/N ratio was obtained. S/N ratio value is used to optimize the process parameters. Figure 5 shows the Taguchi analysis for mild steel vs cast iron tribopairs showed that temperature was the most influencing factor for the COF followed by load and frequency, whereas in case of SWR the frequency was more dominating than the load as shown in table 4 and 5.

**Table 4.** Response for S/N ratio of COF considering smaller is better for cast iron vs mild steel.

| Level | Load | Frequency | Temperature |
|-------|------|-----------|-------------|
| 1     | 6.025| 6.941     | 7.840       |
| 2     | 6.100| 6.758     | 5.970       |
| 3     | 7.303| 5.729     | 5.619       |
| Delta | 1.278| 1.212     | 2.221       |
| Rank  | 2    | 3         | 1           |

**Table 5.** Response for S/N ratio of SWR considering smaller is better for cast iron vs mild steel.

| Level | Load | Frequency | Temperature |
|-------|------|-----------|-------------|
| 1     | 16.51| 15.53     | 17.68       |
| 2     | 15.61| 16.82     | 18.69       |
| 3     | 15.77| 15.55     | 11.52       |
| Delta | 0.90 | 1.29      | 7.17        |
| Rank  | 3    | 2         | 1           |
The results were analyzed for “smaller is better” and S/N ratio was obtained. S/N ratio value is used to optimize the process parameters. Figure 6 shows the Taguchi analysis for mild steel vs chromium coating showed that temperature was the most influencing factor for the COF followed by load and frequency, whereas in case of SWR the frequency was more dominating than the load as shown in table 6 and 7.

Table 6. Response for S/N ratio of COF considering smaller is better for chromium coating vs mild steel.

| Level | Load   | Frequency | Temperature |
|-------|--------|-----------|-------------|
| 1     | 7.393  | 8.204     | 8.799       |
| 2     | 7.831  | 8.061     | 8.032       |
| 3     | 8.123  | 7.082     | 6.516       |
| Delta | 0.729  | 1.122     | 2.283       |
| Rank  | 3      | 3         | 1           |

Table 7. Response for S/N Ratio of SWR considering smaller is better for chromium coating vs mild steel.

| Level | Load   | Frequency | Temperature |
|-------|--------|-----------|-------------|
| 1     | 20.42  | 20.00     | 21.39       |
| 2     | 19.68  | 20.19     | 19.76       |
| 3     | 19.73  | 19.64     | 18.68       |
| Delta | 0.74   | 0.55      | 2.70        |
| Rank  | 2      | 3         | 1           |

5. Conclusion
The coated pin was tested for tribological investigation and to know the contribution of different factors Taguchi analysis was used.

- The hardness of the Chromium coated pin was 280% more the cast iron pin.
- The coating improved the tribological performance at ambient conditions (40°C) as the COF and SWR reduced.
- At elevated temperature and high speed, the coated pin showed significant improvement in the tribological properties.
Taguchi analysis shows that temperature was the most dominating factor followed by the load which affects the tribological properties but in the case of COF for Chromium coated pin load was the most dominating factor followed by temperature. Frequency had very little effect.

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