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Optimization of Wear Parameters for Medical Implant Applications

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RESEARCH ARTICLE

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Abstract

The purpose of the present research is to check the capability of SS 304 for the application of medical implants and describe the influence of sandblasting process, applied load, frequency, sliding distance on the coefficient of friction of SS 304. In this research, attempts have been made to study the wear behavior of SS 304 at various conditions. In the tribology lab wear test was carried out in accordance with the scheme of experiments developed using the Taguchi technique. The robust design of L18 orthogonal array was preferred to investigate the empirical data acquired from the pin on disc tribometer. The optimal conditions for a minimum coefficient of friction are sand blasted plate, frequency (25 HZ), sliding distance (30 mm), load (15 N). It is observed that after sand blasting hardness of SS 304 increases. This research will be helpful for the medical practitioners and researchers working in the area of bio tribology and indirectly will benefit the patients.

Keyword: SS 304, L18 orthogonal array, Wear, Hardness, Sand blasting,

1. Introduction

Stainless steel has excellent toughness, ductility and corrosion resistance and has numerous applications in the field of automotive, aerospace, architecture, surgical tools and medical equipment's, etc. [1]. Particularly in the medical field, **the** demand for medical implants is growing significantly. Common properties required for medical implants are high mechanical strength, high hardness, wear-resistance and biocompatibility for better productivity of the medical implants without any failure [2]. Stainless steel is an iron-based alloy that consists high percentage of chromium and nickel and both chromium and nickel are less toxic for the human body. In the market, basically four types of stainless steel are available that is ferritic, austenitic martensitic and duplex. Out of these, austenitic, ferritic and martensitic stainless steels are widely used for applications in medical devices [14]. Austenitic stainless steel has become the most widely accepted material for the implant usage by cause of their low cost, biocompatibility, high resistance to corrosion and toughness. Over a period, various researchers have also proved that austenitic steel is a less toxic material that can be easily accepted by the human body

[3, 15]. Austenitic stainless steel has low wear resistance [5]. There can be an allergic infection in the surrounding tissue due to wear debris. Thus limitation of austenitic Stainless steel is that only temporary implants can be used [8, 15].

Medical implants are challenging to replace or in some cases, implants are impossible to replace. If there is wear, it can deteriorate the surface properties, thus can lead to an increment of maintenance cost [13]. Austenitic Stainless steel has poor wear resistance, which is an obstacle for its wider application where chances of wear failure are more. Thus, researchers have consistently given attention to the enhancement of wear resistance of Austenitic stainless steel for over a year now without compromising the excellent characteristics of stainless steel [10]. The intention of the present research is to increase the wear resistance, hardness of SS 304. The wear resistance of SS304 can be increased by sand blasting process, but it is time-dependent and the optimal time duration is 15 min [4]. Various surface treatment processes such as sand blasting, etc., which are beneficial for achieving biocompatibility of medical implants, can be improved by sand blasting process [6]. Wear resistance depends on various factors like material, load, sliding speed and sliding distance. By optimization technique, S.Ananth et al. found that, In the case of Gray cast iron, wear rate is most influenced by load followed by sliding speed and sliding distance has least impact on wear rate [11]. J. L Lawen et al. found that Wear resistance also depends upon temperature, friction levels, oxide formation and hardness and oxide formation is the most dominant factor on wear rate [12]. Chowdhury et al. concluded that the coefficient of friction relies on various miscellaneous parameters such as duration of rubbing, sliding velocity, normal load. Distinct Values of friction coefficient are obtained for distinctive sliding pairs; hence by selecting a unique level of normal load, sliding velocity and suitable election of sliding pair, the lower amount of friction can be achieved [16].

2. Experimental Procedures

2.1 Material Selection

Substrate material for this research is AISI 304 austenitic stainless steel. The material was cut by wire EDM process in the form of plate 30mm × 30mm × 5 mm. Then some samples were ground using sic grinding papers to attain a finer finish and remaining samples were sand blasted. Dry sliding wear test was conducted on both types of samples bare metal as well as sand blasted samples by a pin on disc tribometer at tribology lab in Delhi technological university at room temperature microhardness test was conducted at metal cutting lab in Delhi technological university. Table 1 and 2

Table 1. Chemical analysis of 304 SS [9]

| Element | Percent, | Element | Percent, | Element | Percent, |
|---------|----------|---------|----------|---------|----------|
| Fe | 70.99 | C | 0.08 | N | 0.10 |
| Cr | 18.00 | Si | 0.75 | S | 0.03 |
| Ni | 8.00 | Mn | 2.00 | P | 0.05 |

Table 2: chemical analysis of EN 31 carbon steel pin [11]

| Material | C | Si | Mn | W/V (max) | Cr | Fe |
|-------------|-----------|-----------|-----------|------------------|-----------|-----------|
| Weight % | 0.95/1.20 | 0.10/3.35 | 0.30/0.75 | S&P each0.025 | 1.00/1.60 | Remainder |

2.2 Micro Hardness test

Bare and sand blasted SS 304 samples of dimension 30mm x 30 mm x 5mm were developed. Test was conducted under $F = 300.000\text{mN}/20\text{s}$. Table 3

Table 3: Microhardness

| Plate | Hardness (N/mm ²) |
|--------------|----------------------------------|
| Bare | 1024 |
| Sand blasted | 3011 |

2.3 Wear test

Bare and sand blasted SS 304 samples of dimension 30mm x 30 mm x 5mm were developed. The counter sample of a pin as 6mm diameter and 25mm height was machined from EN31 carbon steels. Fig 1

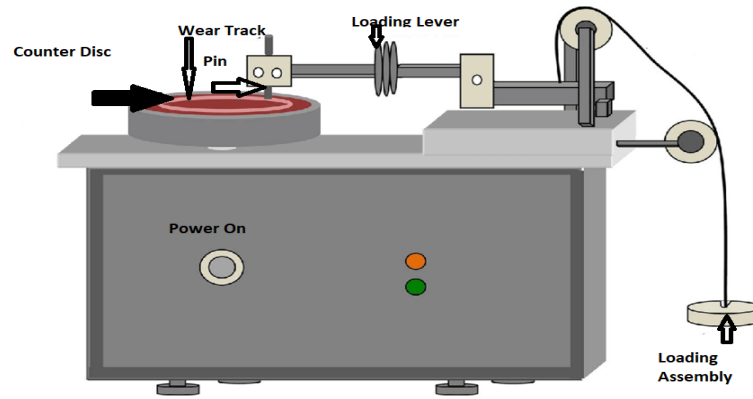


Fig 1. Pin on disc tribometer machine

2.4 Design of experiment

L18 orthogonal array was preferred in the design of experiments. The parameters selected for the experiments were plate, normal load, sliding frequency and sliding distance, as shown in Table 3. ANOVA is used to describe the effect of every input variable and to rule out the impact of every empirical parameter. Taguchi characteristics smaller is better is defined below.

$$S/N = -10 \log \frac{1}{n} \sum y_i^2$$

Where S/N is the signal to noise ratio of the coefficient of friction, n is the repetition number for every trial and y_i is the result of the i^{th} experiment for every trial. Table 4

Table 4. Wear parameters

| S.NO. | Plate | Bare, SB |
|-------|------------------|----------------|
| 1. | Frequency | 5Hz,15Hz,25Hz |
| 2. | Sliding distance | 10mm,20mm,30mm |
| 3. | Load | 5N, 10N, 15N |

SN ratio Smaller is better is preferred for the coefficient of friction.

3. Results and Discussion

3.1 Analysis of control factor

This research determined coefficient of friction with smaller is better S/N quality characteristics to obtain the desired goal that is minimum coefficient of friction. From Table 6, according to ranking most influencing variable might be ruled out. In Table 5 SN response for the signal to noise ratio are depicted from where it can be seen that frequency is the most controlling parameter followed by load and sliding distance for the coefficient of friction in case of wear test. In fig 2, the effect of four factors for SN ratio for the coefficient of friction are shown. table 7

Table 5: Experiment result for SN ratio by Taguchi method

| S.NO. | Plate | Frequency | sliding distance | Load | COF | SNRA |
|-------|-------|-----------|------------------|------|---------|----------|
| 1. | Bare | 5 | 10 | 5 | 3.66256 | -11.2757 |
| 2 | Bare | 5 | 20 | 10 | 2.70201 | -8.6337 |
| 3 | Bare | 5 | 30 | 15 | 1.82168 | -5.2094 |
| 4 | Bare | 15 | 10 | 5 | 1.32700 | -2.4574 |
| 5 | Bare | 15 | 20 | 10 | 0.68547 | 3.2802 |
| 6 | Bare | 15 | 30 | 15 | 0.44000 | 7.1309 |
| 7 | Bare | 25 | 10 | 10 | 0.41000 | 7.7443 |
| 8 | Bare | 25 | 20 | 15 | 0.40400 | 7.8724 |
| 9 | Bare | 25 | 30 | 5 | 0.81900 | 1.7343 |
| 10 | SB | 5 | 10 | 15 | 1.85397 | -5.3620 |
| 11 | SB | 5 | 20 | 5 | 3.60600 | -11.1405 |
| 12 | SB | 5 | 30 | 10 | 2.85700 | -9.1182 |
| 13 | SB | 15 | 10 | 10 | 0.71600 | 2.9017 |
| 14 | SB | 15 | 20 | 15 | 0.65679 | 3.6514 |
| 15 | SB | 15 | 30 | 5 | 0.53959 | 5.3588 |
| 16 | SB | 25 | 10 | 15 | 0.41600 | 7.6181 |
| 17 | SB | 25 | 20 | 5 | 0.42722 | 7.3870 |
| 18 | SB | 25 | 30 | 10 | 0.46900 | 6.5765 |

Table 6: SN Response Table for Signal to Noise ratio (Smaller is better)

| Symb ol | Paramete r | Mean S/N Ratio (db) | | | Max- min | Ran k |
|------------|---------------|---------------------|-------------|------------|-------------|----------|
| | | Level 1 | Level 2 | Level 3 | | |
| A | Plate | 0.0206 6 | 0.8747 6 | | 0.85410 | 4 |

| | | | | | | |
|---|------------------|----------|---------|---------|----------|---|
| B | Frequency | -8.45660 | 3.31095 | 6.48878 | 14.94538 | 1 |
| C | Sliding distance | -0.13849 | 0.40279 | 1.07883 | 1.21732 | 3 |
| D | Load | -1.73226 | 0.45848 | 2.61690 | 4.34916 | 2 |

Table 7: Response Table for Mean

| Symbol | Parameter | Mean S/N Ratio (db) | | | | Rank |
|--------|------------------|---------------------|---------|---------|---------|------|
| | | Level 1 | Level 2 | Level 3 | Max-min | |
| A | Plate | 1.3635 | 1.2824 | | 0.0811 | 4 |
| B | Frequency | 2.7505 | 0.7275 | 0.4909 | 2.2597 | 1 |
| C | Sliding distance | 1.3976 | 1.4136 | 1.1577 | 0.2559 | 3 |
| D | Load | 1.7302 | 1.3066 | 0.9321 | 0.7982 | 2 |

3.2 Graphs from Taguchi

The mean of SN ratio and means for miscellaneous parameters is depicted in fig 2. As specified by the main effect plot fig 2, the optimal conditions for the minimum coefficient of friction are sand blasted plate, frequency (25 HZ), sliding distance (30 mm), load (15 N).

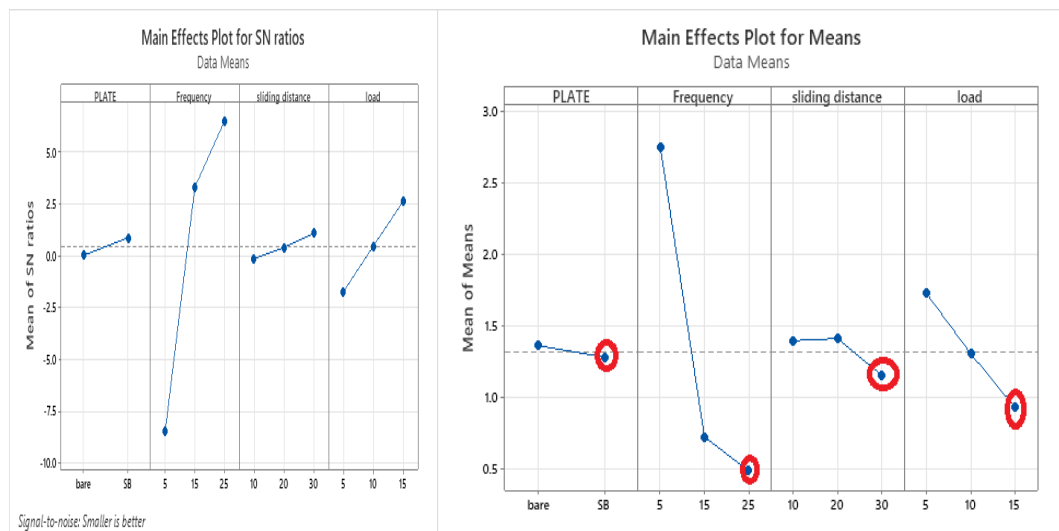


Fig 2. Main effect plot (a) for SN ratios and (b) for mean

3.3 Analysis of Variance

ANOVA is used for finding variable combinations that have an impact on output response. The level of confidence 95 % is taken for this analysis. The result of variance analysis for the coefficient of friction are shown in Table 8 and Table 9. The percentage contribution of each parameter is calculated as shown in Table 8 and Table 9. In accordance with the analysis of variance, it can be ensured that frequency is the most dominating factor with 86.48% contribution, which control the coefficient of friction. After this load with 6.5% contribution followed by sliding distance and type of plate.

Table 8: Analysis of Variance for SN ratio

| Source | DF | Seq SS | Adj SS | Adj MS | F | P | Contribution (%) | Remark |
|------------------|----|---------|---------|---------|-------|------|------------------|-------------|
| Plate | 1 | 3.283 | 3.283 | 3.283 | 0.63 | 0.44 | 0.38167 | Significant |
| Frequency | 2 | 743.877 | 743.877 | 371.938 | 71.83 | 0.00 | 86.4825 | Significant |
| Sliding distance | 2 | 4.464 | 4.464 | 2.232 | 0.43 | 0.66 | 0.5189 | Significant |
| Load | 2 | 56.747 | 56.747 | 28.373 | 5.48 | 0.02 | 6.597 | Significant |
| Residual error | 10 | 51.777 | 51.777 | 5.178 | | | 6.019 | |
| Total | 17 | 860.147 | | | | | | |

Table 9: Analysis of Variance for Means

| Source | DF | Seq SS | Adj SS | Adj MS | F | P | Contribution(%) | Remark |
|------------------|----|---------|---------|--------|-------|------|-----------------|-------------|
| Plate | 1 | 0.0296 | 0.0296 | 0.0296 | 0.18 | 0.68 | 0.1323 | Significant |
| Frequency | 2 | 18.5097 | 18.5097 | 9.2548 | 55.41 | 0.00 | 82.7441 | Significant |
| sliding distance | 2 | 0.2465 | 0.2465 | 0.1232 | 0.74 | 0.50 | 1.1019 | Significant |
| load | 2 | 1.9136 | 1.9136 | 0.9567 | 5.73 | 0.02 | 8.5543 | Significant |
| Residual Error | 10 | 1.6703 | 1.6703 | 0.1670 | | | 7.46676 | |
| Total | 17 | 22.3698 | | | | | | |

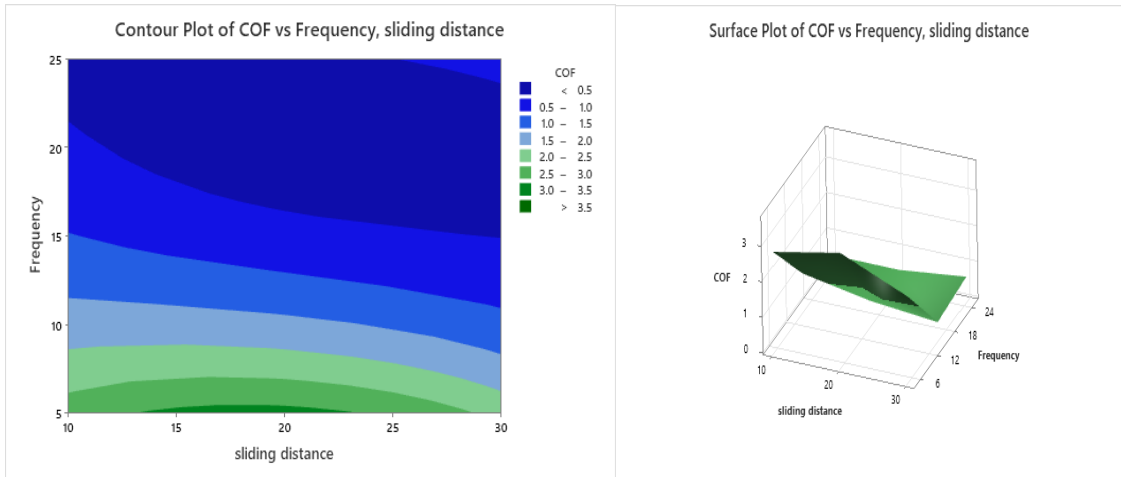


Fig 3. Relation between coefficient of friction vs frequency and sliding distance (a) contour plot and (b) surface plot

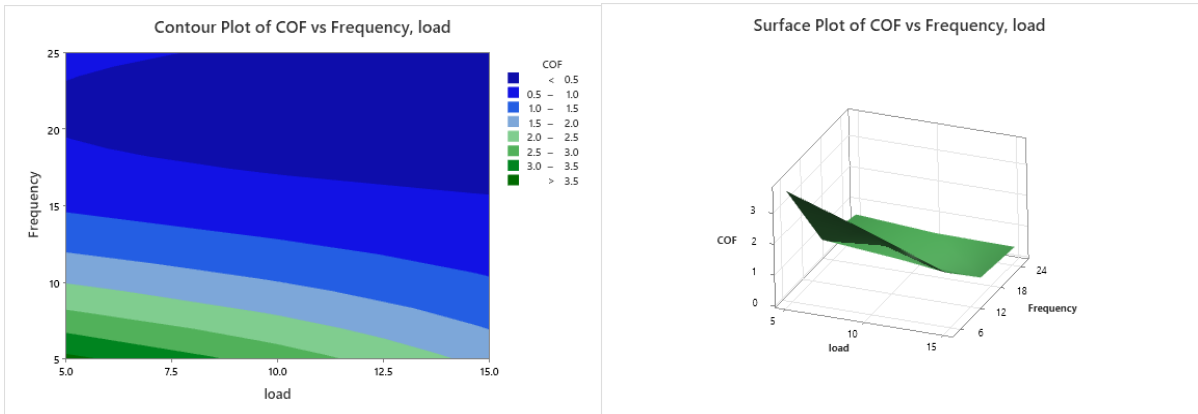


Fig 4. Relation between coefficient of friction vs frequency and load (a) contour plot and (b) surface plot

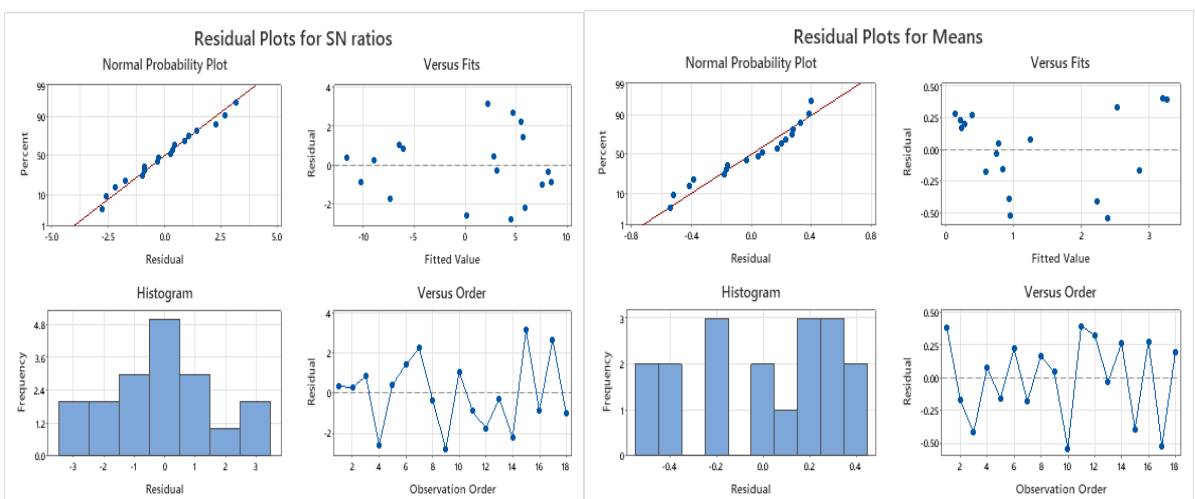


Fig. 5. Residual plot for (a) SN ratio (b) Means

4. Conclusion

For the lowest coefficient of friction, optimal parameters are friction are sand blasted plate, frequency (25 HZ), sliding distance (30 mm), load (15 N). In accordance with the analysis of variance, it can be concluded that frequency is the most dominating factor with 86.48% contribution, which control the coefficient of friction. After this load with 6.5% contribution followed by sliding distance and type of plate.

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