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# ANALYSIS AND PREDICTION OF SURFACE ROUGHNESS INFLUENCE IN FATIGUE LIFE

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*Abstract* — **Surface integrity is the key for process selection of grinding in industry. This study identifies the fundamental differences in the integrity of ground surfaces and the subsequent impact on fatigue life in both bending and twisting. In this present work surface roughness of different values are obtained by surface grinding process and the same were optimized by L9 orthogonal array of Taguchi method. Then the work pieces were subjected to fatigue bend test to study the influence of surface roughness on their fatigue life. From S-N curve it has been proved that the fatigue life of stainless steel has been increased from 1250000 cycles to 1500000.**

*Key words*— Fatigue life, Roughness, Optimization, and contour

## I. INTRODUCTION

The heat formation control in grinding is most valuable for assured part quality and thermal internal consistency. Currently this is achieved by delivering fluid into the grinding area to reduce heat conduction to the work piece through lubrication and convective cooling. The efficiency of the fluid delivery system used has a strong bearing on grinding performance. Fluid also provides flushing to the grinding zone and a cleaning action for the wheel. There we have large range of fluid delivery methods but the common is conventional low velocity high-volume flood delivery.

And finally we get the result of use and time fluid loses its properties to become a waste. It has been found that cooling costs can be as high as 17% of a total part manufacturing cost, whereas depreciation and waste disposal contributes for around 54% of cooling costs. Hence, there are more valuable economic benefits to be gained from reducing fluid usage

Most common two trends that lead to fluid reduction: dry machining (DM), near dry machining (NDM). DM may be successfully bring out with solid lubricants and is used in applications with the presence of fluid is detrimental. These methods have been reported to show benefits compared with un-lubricated dry grinding and with conventional wet grinding. However, difficulties have been experienced in the grinding of ductile materials due to wheel loading. NDM, also known as minimum quantity lubrication (MQL) is common in drilling, turning and milling but remains unproven in grinding, where it may also be referred to as near dry grinding (NDG). Minimum quantity lubrication (MQL) refers to the delivery of small volumes of fluid via an aerosol to the cutting region.

## II. TOOL AND WORK PIECE

### A- Work piece materials

Typical work piece materials include aluminum, brass, plastics, cast iron, mild steel, and stainless steel. Aluminum, brass and plastics have poor to just machinability feature for cylindrical grinding. Cast Iron and mild steel have very good features for cylindrical grinding. Stainless steel is very dense to grind due to its toughness and inherent to work harden, but can be labored with the perfect grade of grinding wheels.

### B- Work piece geometry

The resulted shape of a work piece is the similar image of the grinding wheel, with cylindrical wheels creating cylindrical pieces and devise wheels creating devised pieces. Typical sizes on work pieces range from 0.75 inch. To 20 inch. (metric: 18mm to 1 m) and 0.80 inch. To 75 inch. Inch length (metric: 2 cm to 4 m), although pieces between .25 inch. And 60 inch. in diameter (metric: 6 mm to 1.5 m) and 30 inch. and 100 inch. in length (metric: 8 mm to 2.5 m) can be earth. Resulting shapes can vary from linear cylinders, linear edged conical shapes, or even crankshafts for engines that encounter relatively low torque.

### C- System Analysis

The grinding wheel is one element in an engineered system having wheel, machine tool, work material and functioning factors. Each factor affects all the others. Accordingly, the shop that wants to optimize grinding performance will choose the grinding wheel more suited to all of these other elements of the process.

## III. EXPERIMENTAL WORK

### A- Methodology

The objective of the experimental work is to investigate the effect of surface finish generated by grinding process on the fatigue life of the material. Three parameters considered in this study are as follows:

- Feed rate (FR),
- Depth of cut (DOC)
- Cutting speed (CS).

### B- Experimental Set Up

Based on observation, figure 1 shows the surface grinding process that consist of a grinding wheel, lubrication system, work piece fixture and work piece.

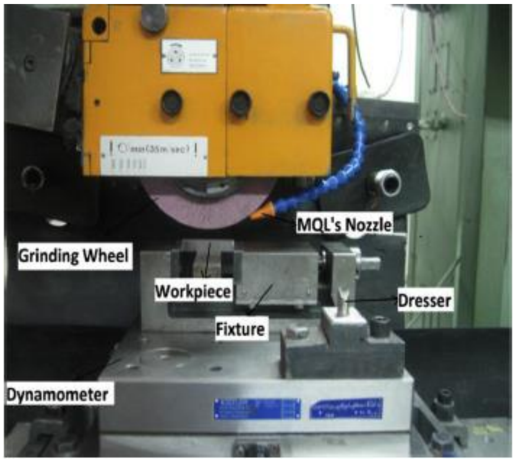


Figure 1 Experimental setup

### C. Design of Experiments

Taguchi Method was recommended by Genichi Taguchi, a Japanese quality management consultant. The method shows the theory of four quality loss function and uses a mathematical measure of performance called signal-to-noise (S/N) ratio, Antony, 2001) the optical setting is the parameter joins, which has the increased S/N ratio. Based on the signal-to-noise (S/N) analysis, the signal-to-noise (S/N) ratio for each level of process data's are calculated. Larger S/N ratio corresponds to better performance feature, regardless of their category of performance. It means that the level of process data's with the increased S/N ratio corresponds to the optimum level of processed data.

The first step before using this method Design of Experiment (DOE) knew how many factors and level to be needed. Table 1 shown the factor and level has been concluded. Literally, method of Taguchi had been used that the factor will have more than two elements. To be Able to reduce the number of process

Table 1 Factors and Levels

| FACTORS | LEVELS | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| CS | 600 | 800 | 1000 |
| DOC | 0.05 | 0.15 | 0.20 |
| FR | 0.1 | 0.2 | 0.3 |

After specifying the number of factors and level, right angle array of methods used for the experiment to knew the whole process. The process should be known in two ways, using a Table or MINITAB software. In this experiment L9 had been used after put forward by orthogonal array based on the three factors and four levels. Table 2 shows the total number experiment has been conducted.

Table 2 Taguchi's L-9 series of Experiments

| Sl.No | CS | DOC | FR |
|---|---|---|---|
| 1 | 600 | 0.6 | 0.2 |
| 2 | 600 | 0.4 | 0.15 |
| 2 | 600 | 0.2 | 0.05 |
| 4 | 800 | 0.6 | 0.25 |
| 5 | 800 | 0.4 | 0.05 |
| 6 | 800 | 0.2 | 0.15 |
| 7 | 1000 | 0.6 | 0.05 |
| 8 | 1000 | 0.4 | 0.25 |
| 9 | 1000 | 0.2 | 0.2 |

## IV. SURFACE ANALYSIS

### A- Surface Analyzer Details

After conducting the Magnetorheological abrasive flow finishing process on the stainless steel work pieces, their final surface finish was analyzed by Talysurf interferometer and its specifications are as follows:

Measuring Technique: Coherence Correlation Interferometry
Vertical Range (Z) : 2.2 mm as standard
Vertical Resolution (max) : 0.01 nm [0.1 A˚]
Repeatability Surface RMS (Z) : < 0.02 nm
Max. Measurement Area (x, y ) : 6.6mm

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Optical Resolution (x, y) : 0.4 – 0.6 µm (SD)
Step height Repeatability : < 0.1 %
Surface Reflectivity : 0.3 % - 100 %
Measurement time : 5 – 40 seconds (typ)

### B. 10 X Interferometry

Table 3 objectives with standard 1024 x 1024 pixel camera

| Mag | FoV | Opt Res | Sam Res(µm) | Slope deg | WD mm | Type | Design | NA |
|---|---|---|---|---|---|---|---|---|
| 10 X | 1.65 x 1.65 | 1.02 | 1.65 | 7.7 | 7.4 | Std | Mirau | 0.3 |

Mag- Magnification power of Objective lens
FoV- Area of the sample measured by a given objective
Opt.Res- Optical Resolution, the ability to distinguish adjacent heights
Sam Res - Sample Resolution, Pixel pitch (Spacial Sampling Resolution)
Slope - Maximum Specular Slope, restricted by the Numerical Aperture
WD- Working distance, distance between Sample and Lens
Type- Lens system, Std – Standard, Uln – ultra low noise
Design- Type of interferometer used, Mirau or Michelson
NA- Numerical Aperture, express the angular aperture

### C. Surface measurements

The aluminum workpieces machined by the end surface grinding process were analyzed by Talysurf interferometer and the surface images obtained are shown below.

### D. CCI Raw Profile

CCI Raw profile shown in figure 2 is the image captured by the interferometer for the area of 3.25 mm x 3 mm and figure 3 shows the levelling profile i.e the datum position of the image captured.

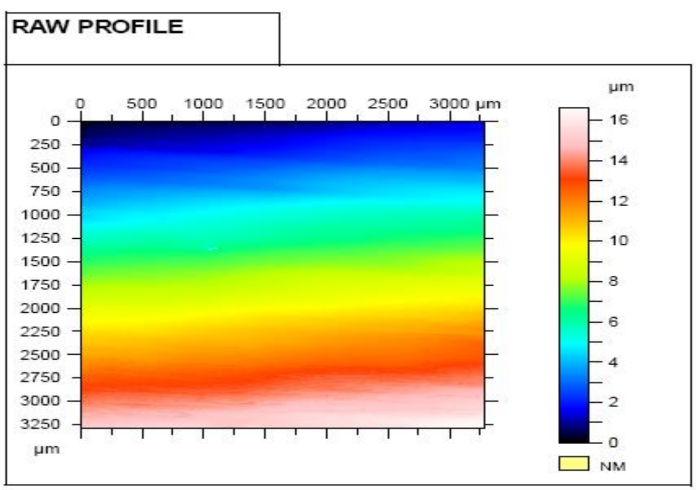


Fig 2. CCI Raw profile

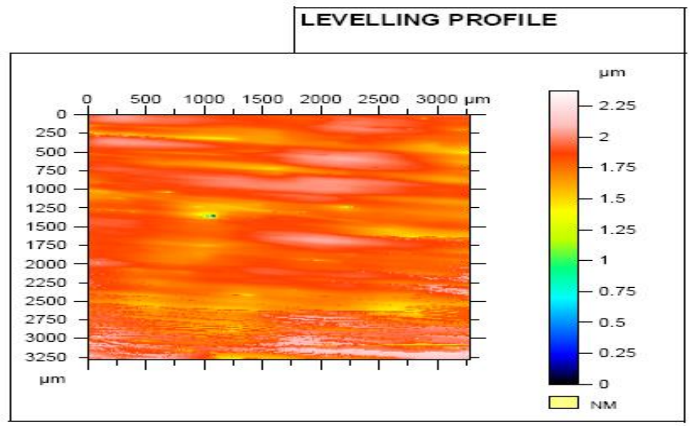


Fig 3 CCI Levelling Profile

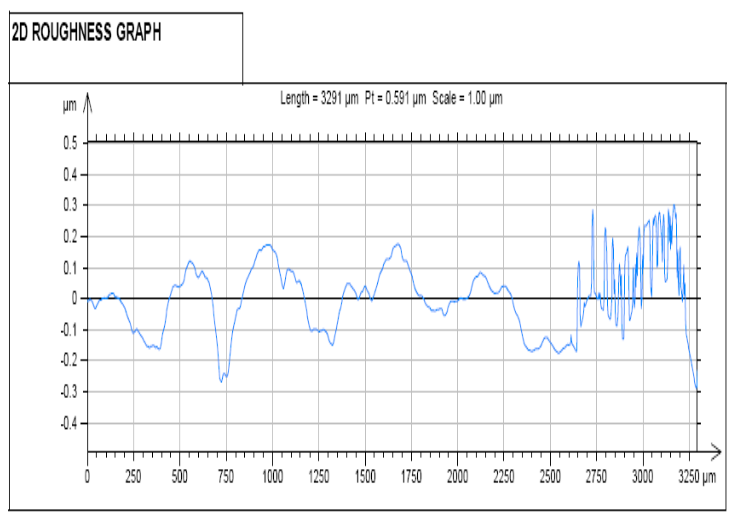


Fig 4 2D Roughness Graph

The figure 4 shows the 2D roughness graph obtained when the object is moved for the length of 3.25 mm to measure the surface quality and figure 5 shows the filtering waviness and roughness graph with the adjustment of optical resolution.

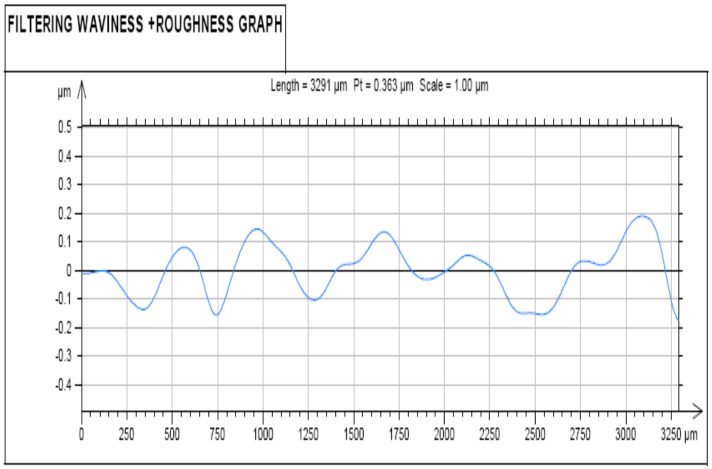


Fig 5 Filtering and waviness Graph

## V. OPTIMIZATION

TAGUCHI METHOD

Every experimenter has to plan and do the experiments to obtain relevant data so that he can infer the science behind the observed concept

**A- Design of Experiments:**

A well-organized set of process, in which all data of interest are varied over a particular range, is better suggestion to obtain systematic data. Mathematically speaking, such a whole set of process ought to give expected results. Usually the number of process and scheme (materials and time) required are restrict large. Often the experimenter advised to perform a subset of the whole set of process to save time and money. It does not easily grant itself to understanding of science behind the concept. The analysis is such a difficult task to perform and thus effects of various parameters on the observed data are not readily apparent.

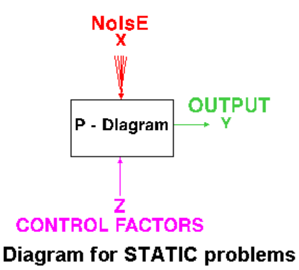


Fig 6 S-N Diagram - Static

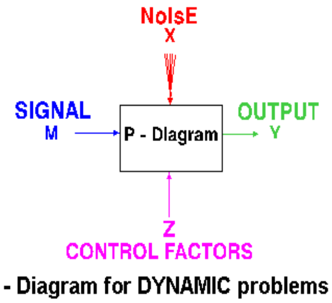


Fig 7 S-N Diagram – Dynamic

**B- Optimization of Surface grinding Process**

In order to optimize the process parameters of end surface grinding process on stainless steel work pieces by Taguchi technique, L-9 series of experiments were conducted and optimization was carried out by Minitab 16.0, optimization software. Table 4 shows the results MQL Technique.

Table 4 Results of Taguchi's L-9 series of Experiments

| Sl.No | CS (rpm) | DOC (mm) | FR (mm/min) | Surface Roughness (Ra) |
|---|---|---|---|---|
| 1 | 600 | 0.6 | 0.2 | 0.752 |
| 2 | 600 | 0.4 | 0.15 | 0.804 |
| 2 | 600 | 0.2 | 0.05 | 0.359 |
| 4 | 800 | 0.6 | 0.25 | 2.242 |
| 5 | 800 | 0.4 | 0.05 | 0.238 |
| 6 | 800 | 0.2 | 0.15 | 0.572 |
| 7 | 1000 | 0.6 | 0.05 | 0.354 |
| 8 | 1000 | 0.4 | 0.25 | 1.907 |
| 9 | 1000 | 0.2 | 0.2 | 1.152 |

**C. Contour plots**

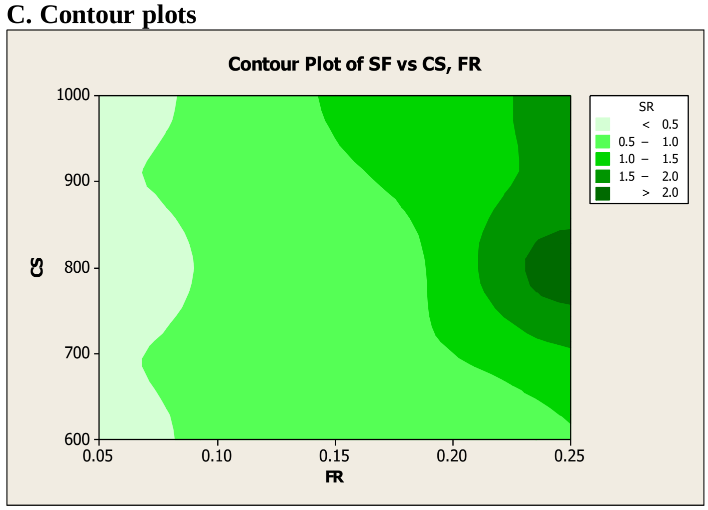

Fig 8 Contour Plot of Surface finish Vs Cutting speed and Feed Rate

The contour plot of surface finish Vs cutting speed and feed rate shown in figure 8 reveals that the surface quality moves towards the better surface finish when the cutting speed is increasing and feed rate up to a certain level
.

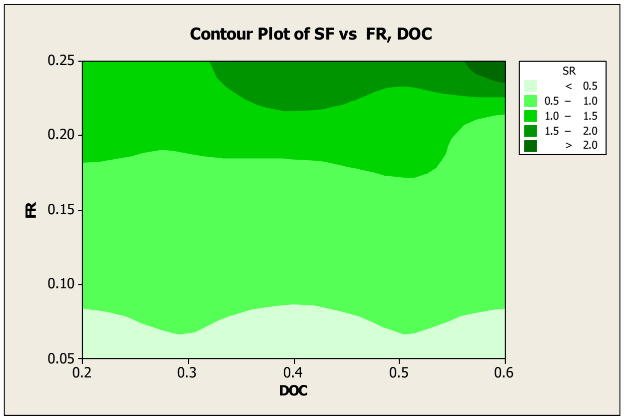


Fig 9 Contour Plot of Surface finish Vs , FR, DOC

The contour plot of surface finish Vs Pressure and number of cycles shown in figure 9 reveals that the surface quality moves towards the better surface finish when DOC increases and feed rate up to a certain level.

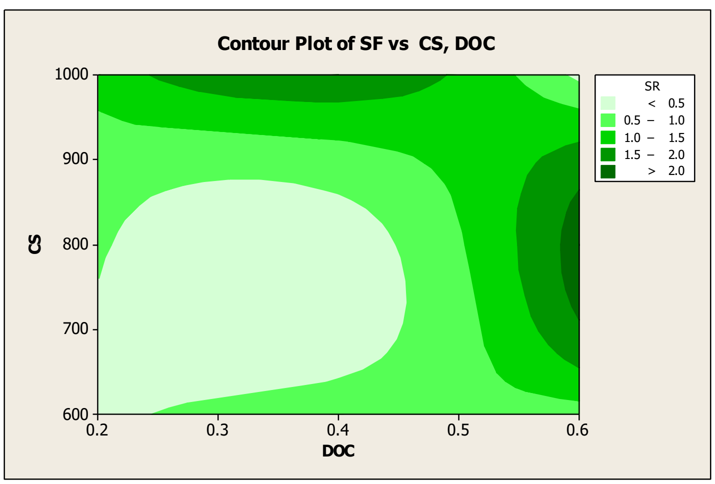


Fig 10 Contour Plot of Surface finish Vs CS, DOC

The contour plot of surface finish Vs Pressure and number of cycles shown in figure 10 reveals that the surface quality moves towards the better surface finish when cutting speed and depth of cut are increased in certain specific regions.

### D. Response Tables

Table 5 Response table for Signal to Noise Ratios Smaller is better

| Level | CS | DOC | FR |
|---|---|---|---|
| 1 | 0.6383 | 0.6943 | 0.317 |
| 2 | 1.0173 | 0.983 | 0.688 |
| 3 | 1.1377 | 1.116 | 0.952 |
| 4 | 1.2143 | 0.3452 | 2.0745 |
| Delta | 0.4993 | 0.4217 | 1.7575 |
| **RANK** | **2** | **3** | **1** |

From the table 5, it has been clearly understood that current is the parameter which influences the surface finish of the stainless steel work piece the most when compared with the other two parameters.

Table 6 Analysis of variance

| **Source** | **DF** | **Seq SS** | **Adj SS** | **Adj MS** | **F** | **P** |
|---|---|---|---|---|---|---|
| CS | 3 | 0.1376 | 0.1376 | 0.0459 | 1.02 | 0.447 |
| DOC | 3 | 0.0872 | 0.0872 | 0.0291 | 0.65 | 0.613 |
| FR | 3 | 6.9542 | 6.9542 | 2.3181 | 51.57 | 0 |
| Error | 6 | 0.2697 | 0.2697 | 0.045 | | |
| Total | 15 | 7.4487 | | | | |

S = 0.212003 R-Sq = 96.38% R-Sq(adj) = 90.95%

## VI. RESULTS AND DISCUSSION

### A. Experimental surface roughness

Table 7 shows the surface roughness values obtained by means of experiments along with S/N ratios.

Table 7 Surface Roughness and S/N ratio

| **Sl.No** | **Ra** | **S/N ratio** |
|---|---|---|
| 1 | 0.752 | -5.0522 |
| 2 | 0.804 | 1.7822 |
| 3 | 0.359 | 12.803 |
| 4 | 2.242 | -7.10231 |
| 5 | 0.238 | 13.1921 |
| 6 | 0.572 | 4.7231 |
| 7 | 0.354 | 8.9324 |
| 8 | 1.907 | -5.6453 |
| 9 | 1.152 | -1.3042 |

### B. Regression Analysis

The regression equation obtained is
SR = - 0.846 + 0.000653 CS + 0.459 DOC + 7.14 FR

The experimental results shows that the exp.no 3 gives the minimum surface roughness value (0.238µm). Therefore substituting the respective parameters in the above equation we can check its predicting capability.
SR = - 0.846 + 0.000653 800 + 0.459 0.4 + 7.14 0.05
SR = - 0.846 + 0.5224 + 0.1836 + 0.357
= 0.217 µm
Depending on these predictions, it can be inferred that calculated surface roughness is 0.2924 µm, which is smaller than 0.387µm from experiments.

Depending on these calculations, it can be deduce that calculated surface roughness is 0.2523 µm, which is smaller than 0.2546 µm from experiments.

### C. Load Variation With Bending Moment

| SAMPLES | STRESS (MPa) | LOAD (Kg) | BENDING MOMENT Nm |
|---|---|---|---|
| SAMPLE 1 | 230 | 1056.12 | 5.175 |
| SAMPLE 2 | 210 | 964.29 | 4.725 |
| SAMPLE 3 | 190 | 872.45 | 4.275 |
| SAMPLE 4 | 170 | 780.61 | 3.825 |
| SAMPLE 5 | 150 | 688.18 | 3.375 |

Fig 11 Load Variations with Bending Moments

### D. Specimen After Bending Fatigue Testing

Fig 12 Specimens after bending fatigue testing

**PLOTTING OF S-N CURVE**

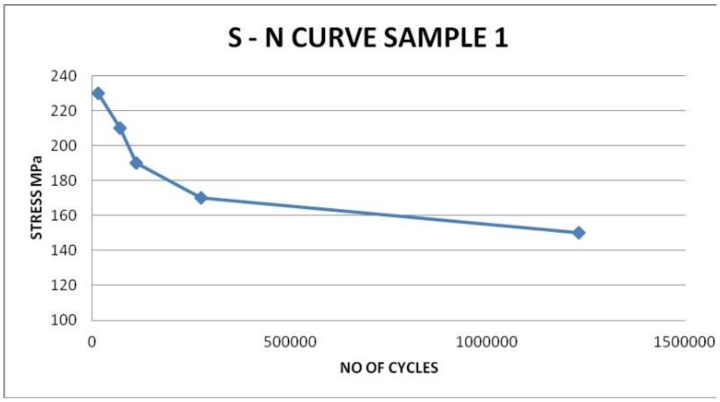


Fig 13 S-N Curve for Specimens before finishing

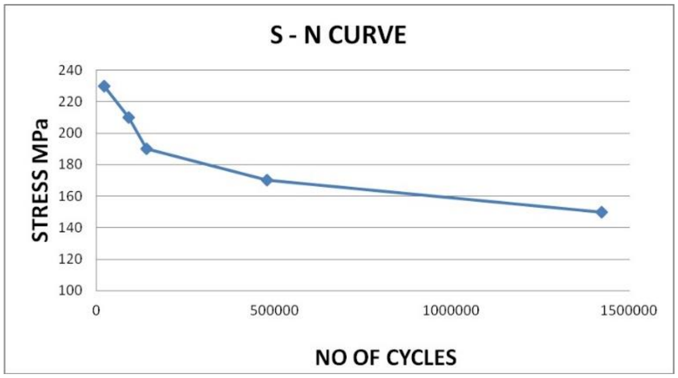


Fig 14 S-N Curve for Specimens after finishing

From S-N curve shows that the fatigue life of stainless steel has been increased from 1250000 cycles to 1500000.

## VII. CONCLUSION

According to the experiment result, the fatigue lives of the stainless steel 316L specimens are significantly influenced by the surface roughness values generated by the surface grinding process. Taguchi's orthogonal array of L9 was used to optimize the process parameters. S/N noise ratio and Analysis of Variance (ANOVA) permitted data more noteworthy with an effect of surface roughness is given rate follow by cutting speed and depth of cut. Almost the connection between dependent variable with independent variable very close and strong, which is approval by using multiple developed analysis. The value experiment with calculated almost closed. It shows that the Taguchi method give more exact calculated value. For the surface roughness, the result calculated by using regression equation is 0.217 µm. Then the experiment result has shown 0.238 µm. The percentage error occurs between calculated and experiment is 8.8 From the S-N Curve, the Specimen with low Roughness ($R_a$) value lasts for greater Number of cycles.

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