Evaluation of Friction and Wear Rate for Hard Chrome Coated Steel 080M40(EN8)

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Abstract— As far as when we talk about the mechanical properties and to make better objects, we cannot forget about tribological properties. It is a very important and vast field to study about. Here in this work, more focus is on tribological properties especially friction force and wear rate. The focus was to analyse these two properties especially for coated material, Alloy Steel 20mncr5 can be coated with Hard Chrome. The coating can be done with Electroplating Process. The thin but micro coating can be applied on the material and can be sent to analyse the tribological testing with help of Pin on Disc meter. Here in this work, the Load on Pin and RPM are selected as input parameters and coefficient of friction and wear rate is selected as output parameters. The expected outcomes for this work are reduction in coefficient of friction value and wear rate.

Key words: Hard Chrome Coated Steel 080M40(EN8), Friction & Wear Rate for Hard Chrome Coated Steel 080M40 (EN8)

I. INTRODUCTION

A. *Friction and Wear*

1) *Friction*

According to Wikipedia, Friction [1.4] is the force resisting the relative motion of solid surfaces, fluid layers, and material elements. It is sub divided in Kinetic friction and Static friction.

Kinetic friction occurs when two objects are moving relative to each other and under rubbing action.

Static friction is when two or more solid objects are not moving relative to each other. In general static friction always has higher value than kinetic friction. As the object needs to break the beerier between relative surfaces.

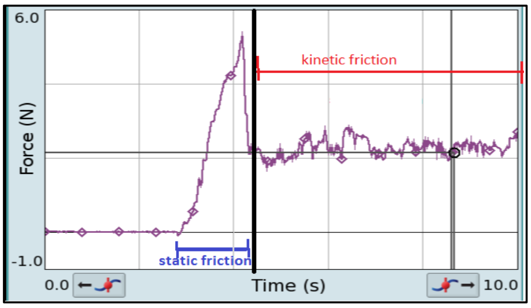

Fig. 1: Static friction and kinetic friction comparison [2]

Here is the figure shows the graph between friction force and time and it clearly indicates that static friction value is higher than kinetic friction.

2) *Wear*

Wear is generally defined as a rate of removing material automatically under the influence of friction forces.

These terms are related to material science, and according to it wear is erosion or sideways displacement of material from the derivative and original position on a solid surface performed by the action of another surface.

Generally there are three stages of wear in any material.

First stage or primary stage or early run period, where surfaces adapt to each other and wear rate might vary between high and low.

Secondary stage or mid age process, where a steady rate of ageing is in motion. Life of components comprised in this stage.

Tertiary stage or old age period, where the components are subjected to rapid failure due to high rate of ageing.

B. *Measurement of Friction and Wear*

The measurement of friction can be done theoretically with the equation F=μN. Where μ is defined as the coefficient of friction or friction coefficient. The equation may be F=μkN for kinetic friction and F=μsN for static friction. Here N is defined as the normal force acting on the body in upward direction.

It is also possible to measure coefficient of friction with Tribometer [1.7] like Pin on Disc meter, Block on ring meter, Fretting test machine, Twin disc machine etc. Here we will discuss all of them in details. Before it we will see the principles of Tribometer and working of it.

1) *Tribometer*

Tribometer is the device that measures tribological entities like coefficient of friction, friction force, and wear volume, between two surfaces in contact. The simple Tribometer works on principle of friction force equation. If we want to measure coefficient of friction between two surfaces, what we need is the force applied to that material to move in a direction and a normal force applied to that object.

By this principle we can be make a ratio of them and able to find the coefficient of friction. The surfaces may be any. This was pure traditional way to measure it, which was invented by Dutch scientist Musschenbroke. The simple schematic diagram of simple Tribometer principle is shown here.

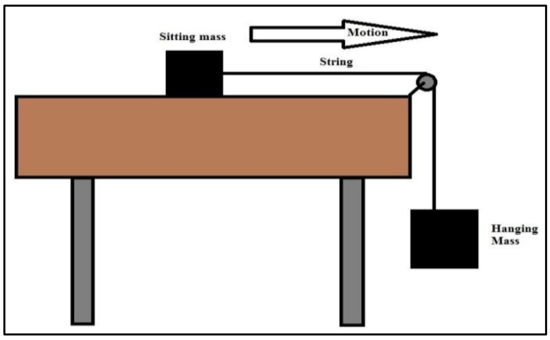

Fig. 2: Simple Tribometer principle [6]

The coefficient of friction can be measured with this formula. μ= Fh/Ft Where Fh = Force applied by hanging mass and Ft = Force applied due to tension of string which is totally equal to the friction force.

C. Pin on Disc / Ball on Disc Tribometer

Pin on disc or ball on disc meter is very unique arrangement and a modern one to measure these tribological properties. As name implies itself as it contains a Pin or ball and a Disc to measure the properties.

- Principle: The material for which we need to measure the coefficient of friction can be made in form of Pin or a Ball form, and the plate usually made of steel. The motion of disc can be applied by motor with specified range of RPM.

Here the schematic diagram of one Pin on disc Tribometer is shown below.

II. Literature Review

R.Venkatesha and others (2015-India) studies wear analysis on HSS Pin tool on stainless steel disc. The tool was coated with SiC. It was influence on SiC nano coating on HSS tool material. The performance parameters like wear rate, volume loss, stress developed, and temperature rise were compared between coated HSS pin and non-coated SS disc. The coefficient of friction test was carried with Pin on Disc test. By this the coefficient of friction between two surfaces can be measured and result was like coated pin was having less volume loss rather than non-coated. [9]

R.J. Talib and others (2013-Malaysia) studied friction and wear characteristics of WC and TiCN (Titanium Carbo-Nitride) coated inserted in turning carbon steel work piece. In this, the turning performance was conducted at cutting speed of 60 mm/min, feed rate of 0.06 mm/rev and 1.0 mm depth of cut, on carbon steel work piece. The investigation of wear rate was measured by field emission scanning electron equipped with energy dispersive X-ray analyser. Tribological characteristic was measured on Pin on Disc meter. TiCN-coated cutting tool were subjected to turning of hardened carbon steel at 50 mm/min with depth of cut at 0.5 mm and feed rate at 0.06 mm/rev under dry turning condition. The results were like TiCN coating thin film have reduced the coefficient of friction. It was also helpful to increase micro hardness and subsequently improved cutting tool life as compared to non-coated turning parts. [10]

U.S. Mbamara et al. (2016-Nigeria) studied on Friction and wear behaviour of nitrogen-doped ZnO thin films deposited via MOCVD under dry contact. Here nitrogen-doped ZnO coating with good stoichiometric composition, thickness and microstructure, in addition to good adhesive property but low tribological properties. Nitrogen doped ZnO thin films were deposited on 304 L stainless steel substrate from a combination of zinc acetate and ammonium acetate precursor by MOCVD technique. Compositional and structural studies of the films were done using Rutherford Backscattering Spectroscopy (RBS) and X-ray Diffraction (XRD). The frictional behaviour of the thin film coatings was evaluated using a ball-on-flat configuration in reciprocating sliding under dry contact condition. The load was of 10 N, which imposes a nominal Hertzian contact pressure of 0.35 GPa, and the stroke length was set to 20 mm. The reciprocating speed was 60 rpm for a test time of 10 minutes. Friction force was taken as output parameters. Both friction behaviour and wear (in the ball counter-face) were observed to be dependent on the crystallinity and thickness of the thin film coatings. [17]

Ana Gasco Owens et al. (2015-Argentina) also made comparisons of tribological properties of stainless steel with hard and soft DLC (Diamond like Carbon) coating. The films have shown their outstanding mechanical and tribological properties but have a major drawback that is their high internal stresses and low thermal stability. They have worked on different stainless steels (EN14301, EN14435 and EN12316) samples coated with DLC with help of Plasma Assisted Chemical Vapour Deposition (PACVD). In results hard and soft both a-C: H: Si (silicon containing amorphous hydrogenated carbon) films were made. Tested tribological properties with help of Pin on Disc meter, and can produce results mentioning that soft DLC films tend to develop better tribological behaviour than hard DLC films and it is not influenced by film thickness and type of steel plate substrate. Parameters were decided as slide velocity and load varies with coating type. [13]

Javier Fernandez et al. (2010-Spain) have made comparison of mechanical and tribological properties of TiC-NiTi and TiC-TiB2-NiTi coatings on steel in form of powder by using Thermal Sprayer and tried to measure Mechanical Adherence, Tribological Properties and Corrosion Properties using Ball on Disk meter, in results they were able to get substantial resistance in wear for TiC coating. It shows that carbon has much more efficiency to prove itself as a best wear resistant. Also the friction coefficient of the coating containing di boride (B2) is higher than the friction coefficient of TiC-NiTi matrix. The corrosion potential for TiC-TiB2-NiTi and TiC-NiTi coatings results very close to that of the steel substrate because of the porosity and small crack presents. [14]

Javier Fernandez et al. (2010-Spain) analysed the Wear and corrosion of metal matrix (stainless steel or NiTi)-TiC coatings. The TiC-NiTi and TiC-stainless steel which was used as coating materials powders were prepared using the SHS method. Plasma and High Velocity Oxi-Fuel methods used for coating. Tension tests were also carried out following the ASTM C-633 standard. The coatings were tested by dry sand rubber wheel abrasion test following ASTM G65-00. The normal force used was 50 N. Friction tests were done using ball-on-disk equipment according to ASTM G99-03. Specimens were pressed against a WC-Co, 16 mm ball under 10 N of load. Current (A) -550-630, Ar flow (l/min) – 38-42, H2 flow (l/min) -10-15, Spray distance (mm) – 120, Feed rate (g/min) -15 taken as input parameters for plasma. Carrier gas (air) flow (l/min)-370-380, Propylene flow (l/min)-70-80, O2 flow (l/min)-250-260, Spray distance (mm)-225, Feed rate (g/min)-30 taken as input parameters for HVOF. Adherence (MPa), Friction coefficient, Wear loss (mg/min), Corrosion potential (mV), Porosity (%) taken as output parameters. [18]

Prasanna Gadhari et al. (2014-India) [15] studied influence of process parameters on multiple roughness characteristics on Ni-P-TiO2 composite coating. In the study, attempts are made to investigate the influence of process parameters on the surface roughness of Ni–P–TiO2 composite coatings with the help of Grey analysis and the Taguchi method. It is observed that the concentration of the second phase particles, i.e. titanium particles has significant influence and amount of reducing agent has moderate influence in controlling roughness parameters of composite coatings. Composite coating were annualized by SEM (scanning electron microscope) EDAX, and XRD (X-Ray diffraction analysis). [15]

P. Shrinivas Rao et al. (2014-India) have investigated study of tribological behaviour of alternate WC (Tungsten Carbide) coated bearing surfaces. In which they have coated the Mild Steel plate (2% C, 1.65% Mn, 0.6%Cu, and 0.6% Si) with alternate WC coating has been developed with plasma spray technique and experiments are designed using full factorial design methodology. Tribological properties like wear, coefficient of friction and frictional force were found by experiments on both non coated and coated plates. Used Pin on Disk, method to analyse and getting results. Significant factors were identified and models are developed by using regression analysis and ANOVA is used for analysing results. They were able to get the conclusion that tribological properties can be enhanced by alternate coatings. Also the amount of wear was reduced by 2to3 times of the wear than uncoated disk. Also shown that load becomes significant factor to response frictional of an alternate coated disk or plate, but not for non-coated disk. [12]

A.P.I. Popoola et al. (2016-Nigeria) studied Corrosion and wear properties of Ni-Sn-P ternary deposits on mild steel via electrolysis method. Hear Ni-P and Ni-Sn-P used as a coating materials and mild steel as a subtract material. Microstructural examination using scanning electron microscopy (SEM) analysis. Binary and ternary electrolysis depositions method used for coating. Bath components and composition used were Nickel chloride (40 g/l), Tin oxide (20 g/l), Sodium hypophosphite (30 g/l), Trisodium citrate (20 g/l), Ammonium chloride (35g/l), Ph (4-5), Temperature (80-90^{0}C), Plating time (30 min). The integration of metals with good corrosion and wear properties on the electroless bath produces deposits with striking qualities consequently improving the electrochemical and physical properties of the mild steel. This consequently fosters manufacturing processes involving the application of mild steel. [19]

Sandeep S Kadam et al. (2014-India) studied Dry Sliding Wear Behaviour of Carburized 20mncr5 Alloy Steel. Here the Carburized Heat Treatment process was use to improve the tribological property of the substance. 20mncr5 was used as a base material. The abrasive wear study is performed on pin-on-disc tribotester. Sequence of the Heat treatment done on 20MnCr5 was Carburizing (900 ^{0}C, 2hr), Quenching (680 ^{o} C, Oil quenched), Tempering (160 ^{o} C, 1.5hr). Load (3-4-5 kg), Sliding Velocity (0.8-1.6-2.4 m/s), Sliding Distance (1200-1400-1600m) taken as input parameters and wear rates as output parameters. Carburized heat treatment improves the microstructure and wear property of the material as amount of free ferrite observed in carburized heat treatment is less as compared to raw material. [20]

Mika Mäkinen et al. (2015-Finland) studied Preliminary comparison of properties between Ni-electroplated stainless steel parts fabricated with laser additive manufacturing and conventional machining. Here the Nickel and Chromium used as a coating materials and ss316L as a base material. The electroplating process is used coating process. Electroplating was done in matrix cell and electro less was done in plastic sink properties of plated parts were tested within acetic acid salt spray corrosion chamber. Adhesion of coating, friction and wearing properties were tested with Pin-On-Rod machine. Electroplating with bright nickel and chromium will increase both friction force and friction coefficient. [21]

Divyesh P. Dave et al. (2015-India) studied Study of tribological behaviour for chromium based coatings deposited on conventional materials. Hear the RF reactive magnetron sputtering process was used for coating purpose. Chromium is used as a coating material and Aluminium, Brass, Mild Steel used as base material. The tribological properties of uncoated pins of aluminium, brass and mild steel with same diameters and after applying chromium based coatings were measured by pin on disc tribometer. Load and speed was taken as input parameters and coefficient of friction as output parameters. It was observed that application of chromium based coating prolongs the reliability and service lifespan of these conventional materials by enhancing their wear resistance. [22]

A.M. Rashidi et al. (2015-Iran) studied Effect of Electroplating Parameters on Microstructure of Nano crystalline Nickel Coatings. Here nickel was used as a coating materials and copper as base material. The process parameters namely, bath temperature, current density, and saccharin addition on grain size and texture coefficient (TC= I (200)/I (111)) taken as input parameters. The grain size of nickel particles taken as output parameters. The results showed that in a bath containing 5 g/L saccharin, by increasing the bath temperature from 45 ^{0}C to 55 ^{0}C, the grain size decreased, whereas further increase of bath temperature resulted in a contrary effect. By increasing the current density from 10 to 75 mA/cm^{2}, the grain size decreased, while further increase in current density had no significant effect on the grain size. [23]

Mohan Kumar S et al. (2014-India) Evaluation of Fracture Toughness and Mechanical Properties of Aluminium Alloy 7075, T6 with Nickel Coating. Mechanical and fracture properties, through the experimentation techniques has been carried out on a Al 7075-T6 and it coated with an Electroless Nickel deposits of 10 – 20 µm in coating thickness. Ni2+ (5 mg/l), Sodium Potassium Tartarate (65 mg/l), Sodium Hydroxide (40 mg/l), Composition of Electroless Nickel Plating Solution were Ammonium Hydroxide (28%) (120 mg/l), Sodium Borohydride (0.75 mg/l), $TINO_2$ (50 mg/l), Pb $(NO3)_2$ (10 mg/l), pH (5), Temperature (80 - 90º C). The EN coating can give rise to a significant improvement in the fracture behaviour (performance) of the substrate and also it has shown that EN coating exhibit a very good adhesive property to the alloy material when the tensile stresses exceeding the yield strength are applied to the system and performance of these pre-treatments was studied by SEM analysis. [24]

Johny James.S et al. (2014-India) have studied the mechanical and machining properties of hybrid aluminium metal matrix composite. They have reinforced the SiC (Silicon Carbide) and TiB2 (Titanium di boride). They studies morphology and micro structure in details with help of optical microscopy. Hardness test has been carried out to determine the hardness of the cast composite using Vickers hardness testing instrument. Shown that SiC and TiB2 were able to increase the hardness values. Also done tensile test for different specimen made by this reinforcing. Wear test analysis proved that addition of TiB2 increased the wear resistance behaviour of composite. Results proved that the quantity of wear of Sic 10% - TiB2 0% is 20% more than SiC 10% - TiB2 2.5% specimen. [16]

Pardeep Sharma et al. (2015-India) studied dry sliding wear investigation of Al6082/Gr metal matrix composites by response surface methodology. They have used graphite particles on Al6082 alloy composites produced by conventional stir casting method. The tribological behaviour of composites was investigated by pin on disc apparatus. Percentage reinforcement, load, sliding speed and sliding distance were taken as the input variables. Response surface methodology has been used to analyse the experiment. In the results it was observed that the most influencing factor is sliding distance and load which affects the wear test. The wear resistance of developed composites was lower than that of cast AA6082 at all combination of reinforcement, load, sliding speed and sliding distance. [11]

Guojia Ma et al. (2014-Chaina) evaluated the friction coefficient of a TiN coated contact during sliding wear. Hard TiN coating was prepared on a bearing steel (GCr15) substrate by applying the composite method of cathode arc and magnetron sputtering. The microstructure, micro scratch, micro hardness, and tribological behavior of this coating were studied to get friction coefficient and other related coating properties. They have proved that coating friction and wear should me input parameters which influence each other's so need to evaluate separately. A novel friction-wear interactive friction model was developed by them to represent the evolution of friction coefficient and to predict coating breakdown. They have also used Pin on Disc meter to measure the tribological properties. [25]

M. Pazderova et al. (2011-Czech Republic) made analysis of tribological properties of composite coating. They have applied PTFE (poly tetra floro ethylene) based with Zn (Zinc). The numbers of analysis methods were chosen to characterize all the parameters like friction coefficient measurement, optical microscopy, infrared spectroscopy, etc. Result shown that incorporation of PTFE particles in to Zn coating positively affects the friction coefficient, self-lubrication and other best results. They applied this coating on sheet of steel (plate) with dimension of 135 x 40 x 8 mm and the other was sample (tablet) with diameter of 20 x 8 mm. analyzed the results with tribometer TOP3. The result shown that friction coefficient measurement showed that implementation of PTFE particles into the Zinc coating improved the tribological behaviors and wear resistance of the coating. Resulted in reduction in coefficient of friction and wear rate. [26]

J Sudeepan et al. (2014-India) studied friction and wear of ABS/ZnO polymer composite using Taguchi technique. They have selected ABS (acrylonitrile butadiene styrene) as a base material and applied micron-sized zinc oxide (ZnO) as a coating material. The experiment was carried out in dry condition on block on roller multi tribometer in room temperature. Filler content, normal load and sliding speed were considered as the input parameter and coefficient of friction and specific wear rate are considered as the output parameters. The result shows that the friction of coefficient and wear rate is influenced by increase in filler content, load and speed. The most influencing factor is normal load which affects the tribological properties. Scanning electron microscopy also carried out to identify the wear mechanism, for the worn surfaces and optical parameter combination. The results were like the addition of filler the friction coefficient and wear rate decrease with an increase in load and speed. Also be concluded that the design factor, applied load has the major contribution on tribological property followed by filler content and speed. The tribological properties get improved with the addition of micron-sized ZnO filler with the ABS matrix at the right combination of load and speed. [27]

H.L. Tian et al. (2013-China) analyzed the wear behavior of high velocity arc spraying FeNiCrAlBRE/Ni95Al composite coating. The base metal was chosen as carbon steel plate. Scanning electron microscopy and Vickers hardness test were used to evaluate coatings structure and mechanical properties. The result shown that coating had relatively high average hardness about 550 HV0.1 and adhesive strength was 47 MPa. These kinds of composite coatings can change the properties of materials and help us to improve it. [28]

III. Conclusion

From this review, it conclude that

- Implementation of PTFE particles into the Zinc coating improved the tribological behaviors and wear resistance of the coating. Resulted in reduction in coefficient of friction and wear rate.
- The tribological properties get improved with the addition of micron-sized ZnO filler with the ABS matrix at the right combination of load and speed.
- It was observed that application of chromium based coating prolongs the reliability and service lifespan of these conventional materials by enhancing their wear resistance.
- Electroplating with bright nickel and chromium will increase both friction force and friction coefficient.
- EN coating exhibit a very good adhesive property to the alloy material when the tensile stresses exceeding the yield strength are applied to the system and performance of these pre-treatments.
- Carburized heat treatment improves the microstructure and wear property of the material as amount of free ferrite observed in carburized heat treatment is less as compared to raw material.
- Titanium particles has significant influence and amount of reducing agent has moderate influence in controlling roughness parameters of composite coatings.
- The integration of metals with good corrosion and wear properties on the electroless bath produces deposits with striking qualities consequently improving the electrochemical and physical properties of the mild steel.
- Tribological properties can be enhanced by alternate coatings. Also the amount of wear was reduced by 2to3 times of the wear than uncoated disk. Also shown that load becomes significant factor to response frictional of an alternate coated disk or plate, but not for non-coated disk.
- Both friction behaviour and wear were observed to be dependent on the crystallinity and thickness of the thin film coatings.

IV. EXPERIMENTAL SETUP

Fig. 3: Pin on Disc (DUCOM/TR-20LE-PHM-200

Fig. 4: Display Monitor of Frictional Force, Wear, Temperature, Speed and Timer

V. EXPERIMENTAL RESULT

Sr. No.	Rotating Speed (rpm)	Load (N)	Contact Time (sec)	Wear (µm)	Friction force (N)
1	20	300	180	3.21	4.02
2	20	300	240	3.52	4.36
3	20	300	300	4.03	4.81
4	20	400	180	3.86	4.26
5	20	400	240	3.65	4.96
6	20	400	300	4.53	5.06
7	20	500	180	3.96	5.10
8	20	500	240	4.96	5.00
9	20	500	300	5.60	6.95
10	40	300	180	4.06	5.88
11	40	300	240	4.66	6.06
12	40	300	300	5.03	6.09
13	40	400	180	4.13	6.32
14	40	400	240	5.83	6.77
15	40	400	300	5.26	7.85
16	40	500	180	4.26	7.26
17	40	500	240	5.96	8.75
18	40	500	300	5.50	8.07
19	60	300	180	4.93	7.72
20	60	300	240	5.43	7.17
21	60	300	300	6.26	7.81
22	60	400	180	5.21	7.24
23	60	400	240	6.02	8.75
24	60	400	300	6.83	8.95
25	60	500	180	5.93	7.82
26	60	500	240	6.23	8.47
27	60	500	300	6.86	8.87

Table 1: Summary of ANOVA calculation for Hard Chrome Coating friction force

Source	Df	Adj SS	Adj MS	F-Value	% Contribution
Load	2	14.95561	7.477804	56.8822997	54.61%
Rotating Speed	2	3.673207	1.836604	13.9707137	13.41%
Contact Time	2	6.125785	3.062893	23.2942797	22.37%
Error	20	2.62923	0.131461	1	9.60%
Total	26	135.71			100%

Table 2: Summary of ANOVA calculation for hard chrome Coating wear

Source	Df	Adj SS	Adj MS	F-Value	% Contribution
Rotating Speed	2	45.82343	22.91171	89.047023	71.79
Load	2	8.495722	4.247861	16.509434	13.31
Contact Time	2	4.358783	2.179391	8.4702661	6.82
Error	20	5.145978	0.257299	1	8.06
Total	26	180.35767			100%

Table 3: Summary of ANOVA calculation for hard chrome Coating wear

A. Main Effect Plots for Aluminium Wear

This analysis was made with the help of a software package MINITAB 17. The main effect plots for SN ratio were shown in Fig. 6.2. These show the variation of individual response with the three parameters i.e. rotating speed, load and contact time separately. In the plots, the x-axis indicates the value of each process parameter at three level and y-axis the response value. Horizontal line indicates the mean value of the response.

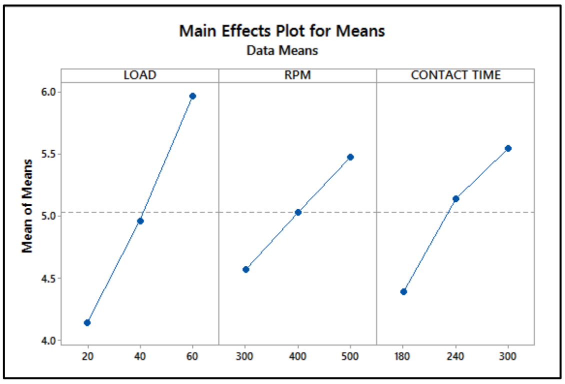

Fig. 5: Main Effect Plots for Aluminium Wear

In the present investigation, from the graph we can say that rate of change of wear was decreasing and wear was increasing as we increase the rotating speed from 300 rpm to 500 rpm. Here rate of change of wear was decreasing because at low rotating speed, more time was available for the formation and growth of micro welds, due to more intimate contact, which increase the force required to shear off the micro welds to maintain the relative motion and this leads to increase the wear. However, at higher rotating speeds, there was less residential time for the growth of micro welds leading to lesser wear rate. For our experiment the variation of load values are much less so it was not having significant effect on wear. As we move contact time from 180 sec to 300 sec, wear was increasing but at the same time rate of change of wear was decreasing. When we compare all three plots, the contact time was having domination on wear as compared to other two parameters.

B. *Main Effect Plots for Aluminium Friction Force*

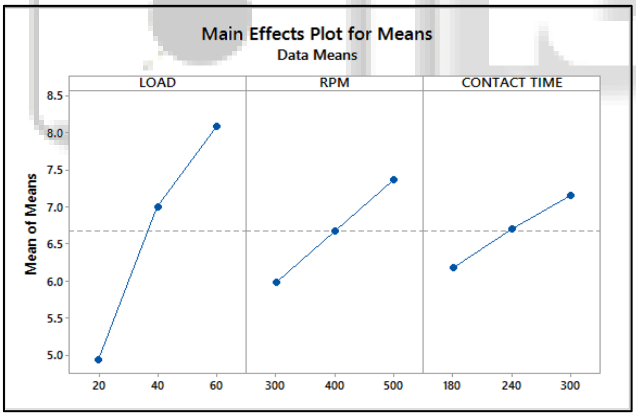

Fig. 6: Main Effect Plots for Aluminium Friction Force

The analysis was made with the help of a software package MINITAB 17. The main effect plots for SN ratio were shown in Fig. 6.3. These show the variation of individual response with the three parameters i.e. rotating speed, load and contact time separately. In the plots, the x-axis indicates the value of each process parameter at three level and y-axis the response value. Horizontal line indicates the mean value of the response.

Here from the graph we can say that friction force was increasing as we increase the rotating speed from 300 rpm to 500 rpm. Friction force was varying almost linearly with load variation from 20 kg to 60 kg. As we move contact time from 180 sec to 300 sec, friction force was increasing. When we compare all three plots, the rotating speed was having major effect on friction force as compared to other two parameters.

VI. REGRESSION ANALYSIS

A. *Regression analysis for hard chrome coating wear*

The regression equation is

$$W = -0.900 + 0.04550 (L) + 0.004517 (R) + 0.00958 (C)$$

Where W = Wear, R = Rotating Speed, L = Load, C = Contact Time

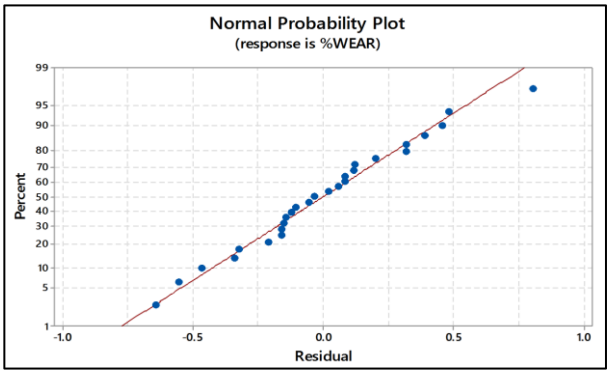

Fig. 7: Main effect residual plot for hard chrome coating wear

B. *Regression analysis for hard chrome coating friction force*

The regression equation was…

$$F = -1.176 + 0.07852 (L) + 0.00687 (R) + 0.00820 (C)$$

Where W = wear, R = rotating speed, L = load, C = contact time

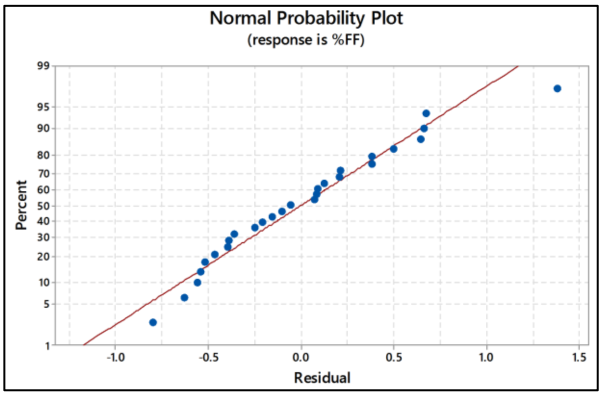

Fig. 8: Main effect residual plot for aluminium friction force

VII. OPTIMIZATION

A. *Calculation of Hard Chrome coating wear and friction force GRC and GRG*

Run Order	GRC for Hard Chrome coating Wear	GRC for Hard Chrome coating Friction force	GRG For Hard Chrome coating	Grade No
1	1	1	1	1
2	0.85480093	0.87878787	0.86679440	2
3	0.68998109	0.75729646	0.72363878	5
4	0.73737373	0.91127541	0.82432457	3
5	0.80573951	0.72393538	0.76483745	4

6	0.58028616	0.70328102	0.64178359	7
7	0.70873786	0.69534555	0.70204171	6
8	0.51048951	0.71552975	0.61300963	9
9	0.43297746	0.45690454	0.44494100	17
10	0.68224299	0.56994219	0.62609259	8
11	0.55725190	0.54716981	0.55221086	11
12	0.50068587	0.54355016	0.52211801	13
13	0.66484517	0.51731374	0.59107946	10
14	0.41057367	0.47267497	0.44162432	18
15	0.47096774	0.39158062	0.43127418	19
16	0.63478260	0.43207712	0.53342986	12
17	0.39890710	0.34259902	0.37075306	23
18	0.44349939	0.37835763	0.41092851	20
19	0.51480959	0.39983779	0.45732369	14
20	0.45117428	0.439002671	0.44508848	16
21	0.37435897	0.394084732	0.384221853	22
22	0.47712418	0.433597186	0.455360684	15
23	0.39374325	0.342599027	0.368171142	29
24	0.33516988	0.333333333	0.334251607	26
25	0.40154015	0.393455706	0.39749793	21
26	0.37667698	0.356471439	0.366574213	25
27	0.33333333	0.336978811	0.335156072	27

Table 4: Calculation of Hard Chrome coating wear and friction force GRC and GRG

From the table it is found that experiment no.1 has the best multiple performance characteristic among 27 experiments

Because it has the highest grey relational grade of 1.

VIII. Conclusion

1) In Hard Chrome coating wear, Load, Rotating speed, Contact time is affected respectively 54.61%, 13.41%, 22.37% from this study it shows that load is highly affected on Hard Chrome coating wear. The pooled error associated with the ANOVA of Hard Chrome coating wear was 9.60%.
2) In Hard Chrome coating Friction force, Load, Rotating speed, Contact time is affected respectively 71.79%, 13.31%, 6.82% from this study it shows that Contact time is highly affected on Hard Chrome coating Friction force. The pooled error associated with the ANOVA of Hard Chrome coating Friction force was 8.06%.
3) From Regression analysis, it conclude that Experimental value of Hard Chrome coating is near by the standard value of Hard Chrome coating at 95% confidence level.
4) From this optimization technique of Grey relational analysis it concluded that the best combination set of Hard Chrome coating for wear and friction force is Load 20 N, Rotating speed 300 rpm and Contact time 180 sec.

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