Study of Dry Sliding Wear Behavior of Different Material with EN31 Steel on Wear and Friction Monitor Machine

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Abstract— In this study, encompasses the properties of the brass, gun metal, aluminium and the assessment of their tribological response when subjected to Pin-on-Disc wear test, which will perform on wear and friction monitor machine. The EN31 steel disc will attach with motor of machine and varying the speed. The Pin of Gun metal, brass, aluminium will fit in the pin holder of wear and friction monitor machine. An attempt has been made to study the influence of wear parameters like sliding speed in rpm, time in second, load in N and also study friction force and temperature. A plan of experiments, based on the techniques of Taguchi, will perform to acquire data in controlled way. An orthogonal array and the analysis of variance (ANOVA) will employee to investigate the wear behaviour.

Key words: EN31 Steel, Dry Sliding Wear Behavior

I. INTRODUCTION

The word 'tribology' is derived from the Greek word tribos which means rubbing. So, the literal translation of the word is 'the science of rubbing'. Tribology is defined as the science and technology of interacting surfaces in relative motions and of related subjects and practices. The subject 'tribology' generally deals with the technology of lubrication, control of friction and prevention of wear of surfaces having relative motion under load. Tribology is the art of providing operational analysis to problems of great economic significance, namely, maintenance, reliability and wear of equipment starting from household appliances to spacecraft. To have a thorough understanding of the subject and its application to machine elements, it is necessary to have an in-depth knowledge in many areas such as chemistry of lubricants, Physics of fluid flow, surface topography, contact mechanisms, material science, mathematical engineering. Thus, the subject is truly multi-disciplinary in nature [1].

The removal of material from one or both of two solid surfaces in relative motion (Sliding, rolling) is termed as 'wear'. Surface damage due to material displacement with no net change in volume or weight is also called **'**wear'. It occurs as a natural consequence and mostly through surface interactions at asperities. It is a system response and it is not a material property. Interface wear is strongly dominated by operating conditions. Wear can be either desirable or undesirable. Desirable cases of wear include machining, polishing, shearing and writing with a pencil whereas undesirable cases include almost all machine applications such as bearings, gears, cams and seals. Sometimes it is erroneously assumed that high friction means high wear rates. But this is not true. Interfaces with solid lubricants and polymers shows relatively low friction but high wear, which ceramics show moderate friction with extremely low wear. In some isolated cases, friction and wear may be correlated. But, in general, friction and wear are two distinct system responses [1].

Friction and wear occur at machinery components which run together. The researchers investigate friction and wear behaviour of materials because of the adverse effect observed in the performance and life of machinery components. Much of the research reported in the literature was carried out under the atmospheric conditions. At present, there is a steadily rising industrial need for materials to be used in applications such as machining, metal forming, bearings and gears, where friction and wear play an important part. New materials or improved existing materials are called for, in order to extend the lifetime of existing devices and components. Gun metal, aluminium, brass have inherent advantages of having high specific strength and good heat transfer ability, which makes them suitable alternative to replace components made of ferrous alloys. In the present investigation gun metal has strength, ductility, excellent machinibility and good bearing and wears properties [2].

A. *Methods used for Evaluation of Wear*

The most common methods of studying the wear consists of examination of sliding material before and after the test, any difference in material is attributed to wear. The detection of wear generally uses one or the other techniques of weighing, mechanical gauging and examination of surface and sub-surface features and wear debris [7].

B. *Weighing*

This is the simplest way of detecting the wear in which specimen is weighed before and after running, using sensitive weighing balances (accurate >0.1 mg) and weight loss is calculated to get wear rate [7].

C. *Gauging*

In this method, the wear is measured by decrease in dimensions, using mechanical (dial gauge).

D. *Optical*

There are number of methods for measuring wear using the optical technique. One way is to make small micro-hardness indentation on a surface and to study how its size is reduced during the sliding. The horizontal limit of resolution this method is about 10^{-5} m [7

E. *Why Material Used*

Wear is one of the most commonly encountered industrial problems leading to the replacement of components and assemblies in engineering. Therefore, many efforts have been made to produce more durable materials and techniques to reduce the wear of tools and engineering components.

These include modification of bulk properties of the materials, surface treatments and application of coating etc. Over the last few years, many efforts have been made to understand the wear behaviour of the surfaces in sliding contact and the mechanism, which leads to wear. The application of gun metal, brass, aluminium and its alloys for the machine parts are increasing day to day in the industry

However limited work has been reported on the wear behaviour of gun metal, brass, aluminium and its alloys with the application of grain refiner and modifier. The commercial gun metal casting alloys are the most common particularly due to some very attractive characteristics such as good appearance, excellent cast ability and pressure tightness, low coefficient of thermal expansion, good thermal conductivity, good mechanical properties and corrosion resistance. [8].

II. MATERIAL SELECTION

After the literature reviewed gun metal, brass, aluminium material is selected because of in the present investigation, there is a steadily rising industrial need for materials to be used in applications such as machining, metal forming, gears, where friction and wear play an important part. New materials or improved existing materials are called for, in order to extend the lifetime of existing devices and components. Gun metal, brass, aluminium have inherent advantages of having high specific strength, good mechanical properties, good corrosion resistance and good heat transfer ability, good appearance and easy of working and joining which make them suitable alternatives to replace components made of ferrous alloys. In the present investigation, gun metal, brass, aluminium has strength, ductility, excellent machinability and wears properties [5].

A. Wear and Friction Monitor Machine

Fig. 1: Wear and friction monitor machine [16].

The pin-on-disc test apparatus will apply to the wear and friction monitor machine. It is shown in figure 3.1, which was used to investigate the dry sliding wear characteristics of the gun metal, brass, aluminium. The setup consists of a stationary pin, which was direct contact on a rotating disk [16].

B. Pin on Disc Set Up

Fig. 2: Pin on Disc Set Up

C. Wear and Friction Monitor Machine Specification

Wear disk diameter	Diameter : 165mm
	Thickness : 8mm
	Material : EN 31, hardened to 60 HRc.
Pin diameter & length	Diameter : 3,4,6,8,10&12mm
	Length : 20mm to 30mm
	Material : MS & Al
Disk speed	Minimum : 200rpm
	Maximum : 2000rpm
Normal load	Minimum : 5N
	Maximum : 200N
Frictional force	maximum 200N, resolution of 1N
Wear	0 to 2000 micron

Table 1: Wear and Friction Monitor Machine Specification

D. Manufacturing of Pin

The material of Brass, Gun metal, aluminium purchase from the metal shop whose diameter is 12 mm and length is 300 mm.

But the material required for my experiment work is 8 mm diameter and 25 mm length. For this purpose I made fabrication of Brass, Gun metal, aluminium pin on the lathe machine in workshop at Ahmedabad institute of technology.

E. Fabrication of Pin

Fig. 3: fabrication of brass, gun metal, aluminium

After material selection, cylindrical road fitted in three jaw chuck of lathe machine for turning operation. Final specimen for wear measurement generated with 8mm diameter and 25mm length.

F. Input Parameter

- Sliding speed (rpm)
- Load (N)
- Contact time (Second) [16].

G. Output Parameter

- Friction force (N)
- Wear (micron) [16].

H. Application of Gun Metal

- Valve bodies
- Jewelry
- Door handles
- Clock components
- Pump bodies
- Marine engines
- Pump casting
- Bushings

I. Application of Brass

- Fabrication of Nuts, bolts, and threaded parts.
- Valve bodies.
- Pipe/water fittings.
- Ornamental trim.
- Jewelry.
- Door handles.
- Clock components.
- Heat exchangers.
- Marine engines.
- Pump casting.
- Bushes bearings.

J. Application of Aluminum

- Aircraft fittings
- Marine fitting and hardware
- Electrical fittings
- Magneto parts
- Brake pistons
- Valve and valve parts
- Cycle ring

K. Summary

In this chapter to detail in wear and friction force for different type of wear mechanism like Abrasive wear, Adhesive wear, Erosive wear, Surface fatigue wear, Corrosive wear and calculate the wear testing method and different method used for the gaughing, optical, weighing.

Wear is one of the most commonly encountered industrial problems leading to the replacement of components and assemblies in engineering. Therefore, many efforts have been made to produce more durable materials and techniques to reduce the wear of tools and engineering components

III. DESIGN OF EXPERIMENT

A. Introduction

The word experiment is used in a quite precise sense to mean an investigation, where the system under study is under the control of the investigator. This means that experiment is the process in which purposeful changes are made to the input variables of process or systems so that we may observe and identify the reasons for changes that may be observed in the output response. For investigate or discovers something about any process there are number of experiments are required for finding response of desire output in condition of large input. Therefore to reduce the number of Experiments and to obtain good quality of investigation the term named Design of Experiments (DOE) is highly useable method in all over the world [10].

Design of experiment (DOE) is one of the most important statistical tools of TQM for designing high quality experiment at reduced cost. Design of Experiments (DOE) methods provides an efficient and systematic way to optimize designs for performance, quality, and cost. This method was developed in the early 1920s by Sir Ronald Fisher at the Roth Amsted Agricultural Field Research Station in London, England. He was implementing this method for determining the effect of various fertilizers on different plots of land. The purpose of Design of experiment is to plan, design and analyze the experiment so that the valid and objective conclusions can be drawn effectively and efficiently [10].

B. Methods

- Factorial design.
- Taguchi method.
- Response surface method [9].

The techniques are applied in different steps:

1) Brainstorm the quality characteristics and design parameters.
2) Design the experiments using suitable method and software.
3) Conduct the experiments.
4) Analyze the results to determine the optimum condition [13].

C. Taguchi Approach

1) Introduction

Taguchi method provides a systemic and efficient approach for conducting experimentation to determine near optimum setting of design parameter for performance and cost. The method pushes quality back to design stage, seeking to design a process, which incentive to quality problems. The Taguchi method utilizes the orthogonal arrays to study a large number of variables with a small number of experiments. It can reduce research and development cost by simultaneously studying a large number of parameters. Using orthogonal array the method can significantly reduce the number of experimental configurations. The conclusion drawn from small scale experiments are valid over the entire experimental region spanned by the control factor and their setting. In order to analyze the result, the Taguchi method uses a statistical measure of performance called ‘signal-to-noise’ ratio(S/N), where S is the standard deviation of performance parameters for each array experiment and N is the total number of experiment in the orthogonal array. After performing the statistical analysis of S/N ratio, an analysis of variance (ANOVA) needs to be employed for estimating error variance and determining the relative importance of various factors. From their relative importance and from the S/N ratio, the optimum condition of factors is selected [9].

IV. ANOVA ANALYSIS

A. Analysis of Results

In design of experiment the results are analyzed to achieve one or more of the following objectives:

1) To establish the best or the optimum condition for a product or a process,
2) To estimate the contribution of individual factors.
3) To estimate the response under the optimum conditions.

The optimum condition is identified by studying the main effects of each of the factors. The process involves minor arithmetic manipulation of the numerical results. The main effects indicate the general trends of the influence of the factors. Knowing the characteristics, i.e., whether a higher or lower value produces the preferred results, the level of the factors which are expected to produce the best results can be predicted. The knowledge of the contribution of individual factors is a key to deciding the nature of the control to be established on a production process.

B. Analysis of Variance (ANOVA)

The Analysis of variance is the statistical treatment most commonly applied to the results of the experiment to determine the percent contribution of each factors. Study of ANOVA table for a given analysis helps to determine which of the factors need control and which do not. Once the optimum condition is determined, it is usually good practice to run a confirmation experiment. In case of fractional factorial only some of the tests of full factorial are conducted. The analysis of the partial experiment must include an analysis of confidence that can be placed in the results. So analysis of variance is used to provide a measure of confidence. The technique does not directly analyze the data, but rather determines the variability (variance) of the data. Analysis provides the variance of controllable and noise factors. By understanding the source and magnitude of variance, robust operating conditions can be predicted.

1) Analysis of variance (ANOVA) Terms & Notations

In the analysis of variance many quantities such as degrees of freedom, sums of squares, mean squares, etc., are computed and organized in a standard tabular format.

C.F = Correction factor
n= Number of trials
r = Number of repetition
e = Error
P = Percent contribution
F = Variance ratio
T = Total of results
f = Degree of freedom
S = Sum of squares
F_e = Degree of freedom of error
S’= Pure sum of squares
f_T = Total degree of freedom
V = Mean squares (variance)

- Total number of trials: The total number of trials is the sum of trials at each level.
- Degree of freedom: It is a measure of the amount of information that can be uniquely determined from a given set of data. DOF for data concerning a factor equals one less than the number of levels.
- Sum of squares: The sum of squares is a measure of the deviation of the experimental data from the mean value of the data.
- Variance: Variance measures the distribution of the data about the mean of the data.
- Variance ratio: Variance ratio is the ratio of variance due to effect of a factor and variance due to the error term. This ratio is used to measure the significance of the factor under investigation with respect to the variance of all the factors included in the error term. The F value obtained in the analysis is compared with a value from standard F-tables for a given level of significance. When the computed F value is less than the value determined from the F tables at the selected level of significance, the factor does not contribute to the sum of squares within the confidence level.

C. Result Table of Aluminum Wear

Sr. No	**Rotating Speed**	**Load**	**Contact Time**	**Wear**
1	600	10	180	14
2	600	10	300	17
3	600	10	420	21
4	600	20	180	16
5	600	20	300	19
6	600	20	420	23
7	600	30	180	21
8	600	30	300	23
9	600	30	420	28
10	800	10	180	15
11	800	10	300	19
12	800	10	420	24
13	800	20	180	19
14	800	20	300	21
15	800	20	420	27
16	800	30	180	24
17	800	30	300	27
18	800	30	420	32
19	1000	10	180	18
20	1000	10	300	23
21	1000	10	420	28
22	1000	20	180	21
23	1000	20	300	25
24	1000	20	420	29
25	1000	30	180	28
26	1000	30	300	32
27	1000	30	420	35

Table 1: Aluminum wear

D. Analysis of variance (ANOVA) For Wear

Total number of runs, n = 27
Total degree of freedom f_T = n-1 = 26

1) Three Factors and their Levels

Rotating Speed (rpm), A = A1, A2, A3
Load (kg), B = B1, B2, B3
Contact Time (min), C = C1, C2, C3

2) Degree of Freedom

- Factor A – Number of level of factors, f_A = A-1 = 2
- Factor B – Number of level of factors, f_B = B-1 = 2
- Factor C – Number of level of factors, f_C = C-1 = 2

For error, Fe = $f_T - f_A - f_B - f_C = 26 - 2 - 2 - 2 = 20$
T = Totals of all results = 629

Correction factor C.F. = $\frac{T^2}{n} = \frac{(629)^2}{27}$ = 14653.37

3) Total Sum of Squares

$$S_T = \sum_{i=1}^{n} y_i^2 - \text{C.F.} = 15425 - 14653.37 = 771.6296$$

4) Total Contribution of each Factor Level

A1 = 14+17+21+16+19+23+21+23+28 = 182
A2 = 15+19+24+19+21+27+24+27+32 = 208
A3 = 18+23+28+21+25+29+28+32+35 = 23
B1 = 14+17+21+15+19+24+18+23+28 = 179
B2 = 16+19+23+19+21+27+21+25+29 = 200
B3 = 21+23+28+24+27+32+28+32+35 = 250
C1 = 14+16+21+15+19+24+18+21+28 = 176
C2 = 17+19+23+19+21+27+23+25+32 = 206

C3 =21+23+28+24+27+32+28+29+35 = 247

E. Factor Sum of Squares

$$S_A = \left(\frac{A_1^2}{N_{A1}} + \frac{A_2^2}{N_{A2}} + \frac{A_3^2}{N_{A3}}\right) - C.F.$$

$$= \left(\frac{(182)^2}{9} + \frac{(208)^2}{9} + \frac{(239)^2}{9}\right) - 14653.37$$

$$= 180.963$$

$$S_B = \left(\frac{B_1^2}{N_{B1}} + \frac{B_2^2}{N_{B2}} + \frac{B_3^2}{N_{B3}}\right) - C.F.$$

$$= \left(\frac{(179)^2}{9} + \frac{(200)^2}{9} + \frac{(250)^2}{9}\right) - 14653.37$$

$$= 295.629$$

$$S_C = \left(\frac{C_1^2}{N_{C1}} + \frac{C_2^2}{N_{C2}} + \frac{C_3^2}{N_{C3}}\right) - C.F.$$

$$= \left(\frac{(176)^2}{9} + \frac{(206)^2}{9} + \frac{(247)^2}{9}\right) - 14653.37$$

$$= 282.296$$

$S_E = S_T - (S_A + S_B + S_C)$
$=771.6296 - (180.963 + 295.629 + 282.296)$
$= 12.74074$

F. Mean Square (Variance)

$$V_A = \frac{S_A}{f_A} = \frac{180.963}{2} = 90.48148$$

$$V_B = \frac{S_B}{f_B} = \frac{295.629}{2} = 147.8148$$

$$V_C = \frac{S_C}{f_C} = \frac{282.296}{2} = 141.1481$$

$$V_E = \frac{S_E}{f_E} = \frac{12.74074}{20} = 0.637037$$

G. Variance Ratio

$$F_A = \frac{V_A}{V_E} = \frac{90.48148}{0.637037} = 142.0349$$

$$F_B = \frac{VB}{V_E} = \frac{147.8148}{0.637037} = 232.0349$$

$$F_C = \frac{V_C}{V_E} = \frac{141.1481}{0.637037} = 221.5698$$

$$F_E = \frac{V_E}{V_E} = \frac{0.637037}{0.637037} = 1$$

Here computed F value for all the factors is higher than the value determined from the standard F tables at the selected level of significance, so the factors contribute to the sum of squares within the confidence level and cannot be pooled.

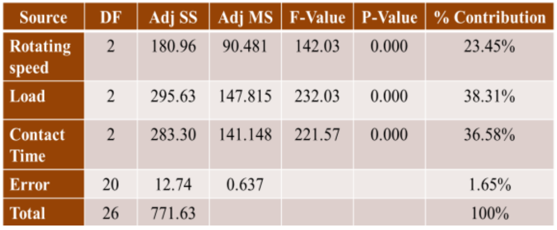
H. Percentage Contribution

$$P_A = \frac{S_A}{ST} = \frac{180.963}{771.6296} = 0.23452 = 23.45\%$$

$$P_B = \frac{S_B}{ST} = \frac{295.6296}{771.6296} = 0.383124 = 38.31\%$$

$$P_C = \frac{S_C}{S_T} = \frac{282.2963}{771.6296} = 0.365844 = 36.58\%$$

$$P_E = \frac{S_E}{S_T} = \frac{12.74074}{771.6296} = 0.016511 = 1.65\%$$



Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Rotating speed	2	180.96	90.481	142.03	0.000	23.45%
Load	2	295.63	147.815	232.03	0.000	38.31%
Contact Time	2	283.30	141.148	221.57	0.000	36.58%
Error	20	12.74	0.637			1.65%
Total	26	771.63				100%

Table 2: Summary of ANOVA calculation for aluminum wear

V. RESULT AND DISCUSSION

This chapter was generally discuss the results obtained throughout the experimental research analysis on wear and friction force on brass-gun metal and aluminium. The main theme of proposed research was centered on the full analysis of tribological properties of brass-gun metal and aluminium when subjected to pin on disk test. Wear and friction force we get that depends on different process parameter like rotating speed, load and contact time. Here the number of experiments depends on the design of experiments carried out and results in the terms of output parameters (wear, friction force).

A. Experiment Result Table for Aluminum Wear

The Full observation Table of different parameters of wear is shown in Table 3.

Sr. No	Rotating Speed	Load	Contact Time	Wear
1	600	10	180	14
2	600	10	300	17
3	600	10	420	21
4	600	20	180	16
5	600	20	300	19
6	600	20	420	23
7	600	30	180	21
8	600	30	300	23
9	600	30	420	28
10	800	10	180	15
11	800	10	300	19
12	800	10	420	24
13	800	20	180	19
14	800	20	300	21
15	800	20	420	27
16	800	30	180	24
17	800	30	300	27
18	800	30	420	32
19	1000	10	180	18
20	1000	10	300	23
21	1000	10	420	28
22	1000	20	180	21
23	1000	20	300	25
24	1000	20	420	29
25	1000	30	180	28
26	1000	30	300	32
27	1000	30	420	35

Table 3: Experiment result table for aluminium wear

B. Main Effect Plots for Aluminum Wear

The relation between all the process parameters of wear like rotating speed, load and contact time are shown in Fig. 4.

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.

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 600 rpm to 1000 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 420 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.

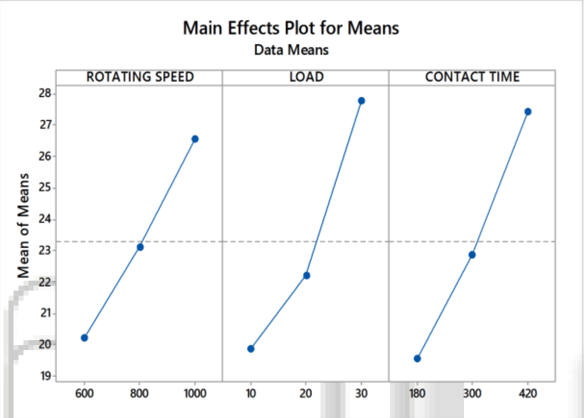


Fig. 4: Effect of rotating speed, load and contact time on aluminium wear

VI. OPTIMIZATION

A. *Grey Relational Analysis*

In grey relational analysis, experimental data i.e. measured features of quality characteristics of the product are first normalized ranging from zero to one. This process is known as grey relational generation. Next, based on normalized experimental data, grey relational coefficient is calculated to represent the correlation between the desired and actual experimental data. Then overall grey relational grade is determined by averaging the grey relational coefficient corresponding to selected responses. The overall performance characteristic of the multiple response process depends on the calculated grey relational grade. This approach converts a multiple- response- process optimization problem into a single response optimization situation, with the objective function is overall grey relational grade. The optimal parametric combination is then evaluated by maximizing the overall grey relational grade. [27]

1) *Data Preprocessing*

In grey relational generation, the normalized data corresponding to Lower-the-Better (LB) criterion can be expressed as:

$$\boldsymbol{Xi\ k} = \frac{\max yi\ k - yi(k)}{\max yi\ k - \min yi(k)} \qquad (8.1)$$

For Higher-the-Better (HB) criterion, the normalized data can be expressed as:

$$\boldsymbol{Xi\ k} = \frac{yi\ k - \min yi\ (k)}{\max yi\ k - \min yi(k)} \qquad (8.2)$$

Where xi (k) is the value after the grey relational generation, min $\boldsymbol{yi\ (k)}$ is the smallest value of $\boldsymbol{yi\ (k)}$ for the k_{th} response, and max $\boldsymbol{yi\ (k)}$ is the largest value of $\boldsymbol{yi\ (k)}$ for the k_{th} response.

An ideal sequence is x_0 (k) for the responses.

However, if there is ‘‘a specific target value’’, then the original sequence is normalized using,

$$\boldsymbol{Xi\ k} = 1 - \frac{|yi\ k - OB|}{\max\{\max yi\ k - OB, OB - \min yi\ (k)\}} \qquad (8.3)$$

Alternatively, the original sequence can be normalized using the simplest methodology that is the values of the original sequence can be divided by the first value of the sequence, $\boldsymbol{yi\ (k)}$

$$\boldsymbol{Xi\ k} = \frac{yi\ (k)}{y1\ (k)} \qquad (8.4)$$

Where, $\boldsymbol{yi\ (k)}$ is the original sequence, $\boldsymbol{Xi\ k}$, the sequence after data preprocessing, max, $\boldsymbol{yi\ (k)}$, the largest value of, $\boldsymbol{yi\ (k)}$ and min, $\boldsymbol{yi\ (k)}$, the smallest value of, $\boldsymbol{yi\ (k)}$.

2) *Grey relational Co-efficient and Grade*

The purpose of Grey relational grade is to reveal the degrees of relation between the sequences say, [x0 (k) and xi (k), i = 1, 2, 3…, n]. The Grey relational coefficient can be calculated using the preprocessed sequences. The Grey relational coefficient $\boldsymbol{\xi i\ k}$ is defined as follows

$$\boldsymbol{\xi i\ k} = \frac{\min\Delta + \theta\max\Delta}{\Delta i\ k + \theta\max\Delta}\ ;\ 0 \le \boldsymbol{\xi i\ k} \le \boldsymbol{1} \qquad (8.5)$$

Where $\Delta\boldsymbol{i} = |x0\ k - xi(k)|$ =difference of the absolute value x0 (k) and xi (k); θ is the distinguishing coefficient 0 ≤ θ ≤ 1; $\boldsymbol{min}\Delta$= ∀j $\boldsymbol{min}$∈i ∀k $\boldsymbol{min}$ $|x0\ k - xj(k)|$ = the smallest value of Δ0i; and $\boldsymbol{max}\Delta$= ∀j $\boldsymbol{max}$∈i ∀k $\boldsymbol{max}$= largest value of Δ0i. After averaging the grey relational coefficients, the grey relational grade γi can be computed as:

$$\boldsymbol{yi} = \frac{1}{n}\sum_{k=1}^{n} \xi i\ (k) \qquad (8.6)$$

Where n = number of process responses. The higher value of grey relational grade corresponds to intense relational degree between the reference sequence x0 (k) and the given sequence xi (k). The reference sequence x0 (k) represents the best process sequence. Therefore, higher grey relational grade means that the corresponding parameter combination is closer to the optimal.

However, Equation (8.6) assumes that all response features are equally important. But, in practical case, it may not be so. Therefore, different weight ages have been assigned to different response features according to their relative priority. In that case, the equation for calculating overall grey relational grade (with different weight ages for different responses) is modified as shown below

$$\mathbf{yi} = \frac{\sum_{k=1}^{n} wk\ \xi i\ (k)}{\sum_{k=1}^{n} wk} \qquad (8.7)$$

Here, **yi** is the overall grey relational grade for ith experiment. ξ i (k) is the grey relational coefficient of kth response in ith experiment and wk is the weight age assigned to the kth response.[27]

B. *Process Steps for Multi Response Optimization*

The basic processer steps for multi-response optimization are given below.

- Normalization of experimental results for all performance characteristics.
- Calculation of grey relational coefficient (GRC).
- Calculation of grey relational grade (GRG) using weighing factor for performance characteristics.

VII. CONCLUSION

1) In Aluminium wear, Rotating speed, Load, Contact time is affected respectively 23.45%, 38.31%, 36.58% from this we can say that load is highly affected on Aluminium wear. The pooled error associated with the ANOVA of Aluminium wear was 1.65%.
2) In Aluminium Friction force, Rotating speed, Load, Contact time is affected respectively 36.81%, 10.80%, 50.73% from this we can say that Contact time is highly affected on Aluminium Friction force. The pooled error associated with the ANOVA of Aluminium Friction force was 1.64%.
3) In Brass wear, Rotating speed, Load, Contact time is affected respectively 20.56%, 41.94%, 35.70% from this we can say that load is highly affected on Brass wear. The pooled error associated with the ANOVA of Brass wear was 1.77%.
4) In Brass Friction force, Rotating speed, Load, Contact time is affected respectively 33.25%, 12.17%, 53.03% from this we can say that Contact time is highly affected on Brass Friction force. The pooled error associated with the ANOVA of Brass Friction force was 1.54%.
5) In Gun metal wear, Rotating speed, Load, Contact time is affected respectively 20.21%, 40.49%, 37.03% from this we can say that load is highly affected on Gun metal wear. The pooled error associated with the ANOVA of Gun metal wear was 2.25%.
6) In Gun Metal Friction force, Rotating speed, Load, Contact time is affected respectively 33.88%, 13.16, 50.50 from this we can say that Contact time is highly affected on Gun metal Friction force. The pooled error associated with the ANOVA of Gun metal Friction force was 1.54.
7) From Regression analysis, it conclude that Experimental value of Aluminium, brass, gun metal are near by the standard value of aluminium, Brass and Gun metal at 95% confidence level.
8) From this optimization technique of Grey relational analysis it concluded that the best combination set of Aluminium for wear and friction force is Rotating speed 600 rpm, Load 10 kg, and Contact time 180 sec.
9) From this optimization technique of Grey relational analysis it concluded that the best combination set of Brass for wear and friction force is Rotating speed 600 rpm, Load 10 kg, and Contact time 180 sec.
10) From this optimization technique of Grey relational analysis it concluded that the best combination set of Gun metal for wear and friction force is Rotating speed 600 rpm, Load 10 kg, and Contact time 180 sec.

FUTURE SCOPE

- In this study Aluminium, brass and gun metal have been used. This can be changed some other composition of material to study the effect on wear behaviour.
- The heat treatment temperatures are showing better wear resistance value. Therefore at these temperature the soaking time can be increase and further the wear properties can be evaluated
- The present investigation is limited to analysis of variance only. However other available techniques could be tried and Analyzed so that a final conclusion can be drawn there from such as ANN (artificial neural network)
- Generation of software for eliminating the experimental work and saving time and cost of experimentation.

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