CHAPTER 3

PROBLEM FORMULATION

3.1 NEED OF PRESENT WORK

On the basis of literature review it has been observed that the wear studies were conducted on wide varieties of materials/alloys. It has been observed that theoretical calculations differ from experimental results. It is due to some assumptions considered theoretically. The mathematical model discussed above described the various effects regarding friction since it is one of the major causes of wear. But in every theory the surfaces which are kept in contact for wear to take place are in horizontal position or at one particular orientation as stated in the conclusion of the work of Fillet et al., thus there is need to check the wear for one particular set of condition at different orientation, even from prima facie it seems that there will be some wear of material which do takes place and hence can also be one of the cause of the wear, thus orientation of surfaces of material kept in contact must be taken in account. In the existing models the surfaces are kept horizontal and the rates of wear are calculated keeping one fixed orientation. It is also necessity to developed mathematical model which should be based on friction which takes in to account all the relative orientation between the surfaces. The wear rate should vary changing the orientation of surfaces. Keeping this phenomena and sensitivity of the operation which is applied in every simple or complex machine. Generally wear test carried on pin on disc method. In this test the specimen is always at one particular orientation with respect to horizontal position (i.e. no change in orientation of the work piece). However, in practical situation components mating position are at different
orientation. A typical multi orientation pin-on-disc wear test rig has been
designed and fabricated.

The multi orientation rig play a key role for removal of debri. In actual practice
debris wear out from the specimen and exist in between disc and specimen. Therefore two body abrasion is converted in to three body abrasion. The present study is based on said phenomena to evaluate effect of wear behavior and to developed mathematical model which should be based on applied load which takes in to account all the relative orientation of work piece (specimen).

3.1.1 OBJECTIVES OF THE PRESENT WORK

The aim of present work is to check the abrasive wear properties and wear resistance of Al6061, Brass60:40 and Mild steel at different orientation of the specimen and at different applied loads. In this connection the following procedure were aimed to be carried out.

- To fabricate a very new type of multi-orientation-al setup in comparison to single orientation pin on disc setup.
- To select three different materials for the desired test according to availability.
- To study the abrasive wear characteristics of the selected materials at different orientation of the specimen.
- To determine the abrasive wear characteristics at different applied loads.
- To perform statistical analysis and formulate the mathematical model of the results obtained.
3.2 MATHMATICAL MODEL FOR PROBLEM FORMULATION

The problem stated above is based on mathematical model proposed by Fillot et al., according to Fillot et al, the presence of wear particles in the system will act as a dry lubricant. To formulate an analytical model the author first composes a particular definition of the third body concept stating that wear is a process characterized by three distinct phases: material detachment from the surface of a body, the mass of particles within the contact area and finally the ejection of particulate matter from the system; referring to figure 1 these are $Q_s$, $M_i$ and $Q_w$ respectively. As a result the change in mass of particles within the system can be written as a function of the two volume flow rates, as given in equation 12; the author refers to this as the mass equilibrium equation (i.e. it is a mass balance).

$$\frac{dM_i}{dt} = Q_s - Q_w \quad (12)$$

Subsequently the author defined two relationships that were essential in this wear analysis, these are the connection between $Q_s$ and $M_i$ and secondly between $Q_w$ and $M_i$. Fig.1 shows graphical representation of three body concept.
The first relationship ($Q_s - M_i$) is referred to as the source flow activation and represents the particle generation process; as discussed, this was the sole concern of Archard’s wear law. The author considers this in three stages. Firstly he states that the normal pressure applied across the contact will be equally shared by the surfaces and the third body. Furthermore he states that the total sliding distance occurring in the system will be composed of the sliding distance of the two surfaces and the sliding distance of the third body, which represents the shear occurring between particles, and uses this definition to arrive at equation 13.

$$dX_{\text{total}} = dX_{\text{FB}} + dX_{\text{TB}} \quad (13)$$

Where $dX_{\text{total}}$ is the total sliding distance, $dX_{\text{FB}}$ is the sliding distance of the contacting surfaces and $dX_{\text{TB}}$ is the sliding distance of $M_i$. The total velocity of the system is the rate of change of distance with respect to time and therefore can be written as in equation 14.

$$V = \frac{dX_{\text{FB}}}{dt} + \frac{dX_{\text{TB}}}{dt} \quad (14)$$

Where $V$ is the total velocity of the system. The author now considers the occurrence of shear within the system, stating that, as a preference, shear will occur in the third body rather than at the contacting surfaces as long as it is “easier” to do so. This will cease to be the case when the maximum value of shear stress has been obtained within the third body; hence at $\tau_{\text{max}}$. The shear rate can then be expressed as a function of the max shear stress and therefore a function of the velocity within the third body and its thickness as shown in equation 15.

$$\nu = \frac{1}{H_{\text{TB}}} * \frac{dX_{\text{TB}}}{dt} \quad (15)$$
Where $\nu$ is the shear rate, $H_{TB}$ is the height of the third body. If the shear rate of the system is assumed to be a constant then the velocity of the third body is proportional to its height. Therefore the mass of the third body can be related to the sliding velocity:

$$\frac{dX_{TB}}{dt} = aM_i \quad (16)$$

Where ‘$a$’ is a constant of proportionality. The variable $Q_s$ is considered with respect to the sliding velocity of the bodies in contact. Referring to Archard the volume of material removed from the body is proportional to the sliding distance; hence the rate of change of volume produced (volume flow-rate $Q_s$) will be proportional to the rate of change of sliding distance (i.e. velocity)

$$\frac{dX_{FB}}{dt} = bQ_s \quad (17)$$

Where ‘$b$’ is a constant of proportionality. Equations 17, 16 and 14 can now be combined to find a relationship between $Q_s$ and $M_i$ and it is given as:

$$Q_s = C_s (M_i^{\text{max}} - M_i) \quad (18)$$

From this last equation (eq. no. 18) it can be seen that the flow of material from the contact surfaces is proportional to the mass of material already trapped in the contact area. The author does not examine the process of material removal from the surfaces in great detail but he proposes that material removal will occur when the energy present in the system cannot be absorbed by the third body.

To conclude the author restates that the aim of this work was not to refine or continue existing wear laws and thinking but to look at this problem from a new angle in order to better describe, predict and understand wear. The author also raises the question surrounding the pin on disc test: i.e. why the wear process is dependant on the orientation in which the apparatus is configured. Therefore the
author incorporates the way in which a particle leaves the contact area to try and account for this phenomenon. He suggests that a large amount of time has been spent in defining and investigating the various wear mechanisms but there is a distinct dearth of information on the methods of material expulsion.

With conclusion stated above the problem was picked to check the movement and expulsion of debris particle (third body) during wear of Al6061, Brass6040 and Mild Steel. Later on during the work it was also decided to develop a mathematical equation for the same, to do this Response Surface Methodology (RSM) was used with central composite design (CCD) having 14 runs of experiment. These are the virtual experiment performed by software (Minitab 15), the actual experiments were performed on the setup by taking the mean of 5 trials of each specimen at different orientation. These values were put in central composite design having 14 runs of experiment for statistical analysis and to formulate the mathematical model.
Chapter 4
MATERIALS AND METHODOLOGY

4.1 EXPERIMENTATION

In this chapter details of material used in the present investigation and its preparation has been described and the details of the experimentation on wear studies in the material of present investigation have been given.

In order to carry out the experimental work, the procedure is as follows.

(i) Fabrication of Test Rig

(ii) Specimen’s Materials

(iii) Wear characterization

4.2 FABRICATION OF TEST RIG

Numerous researches have been done in the field of abrasive wear. This work is also an experimental design in the field of abrasive wear evaluation via a newly designed wear test rig. In view of the objective a set-up was needed to be designed which can calculate wear rate at different angular positions (0°, 30°, 45°, 60°, 90°) of work piece with respect to the main frame (horizontal position).
The wear machine used for evaluating wear properties was designed by Prof. (Dr.) Zahir Hasan and fabricated by Er. MohdShadab Khan with help of Er. Hasan Mehdi and ErFarhan. A pin on disc wear test technique was adopted to test the wear behavior of specimens. Wear rate and wear mass were evaluated at different orientation of the specimen. The tests were conducted for five different orientations namely 0°, 30°, 45°, 60°, and 90°. The wear mass of above said specimen evaluated at four different applied loads i.e. 5N to 20N with a variation of 5N.

The set up has following different parts


The designed setup is shown in the fig. 4.1 and 4.2.

4.2.1 Experimental Setup Of Wear Test Rig

Fig. 4.1 Experimental Setup (Front View)
4.2 WORKING OF SET-UP

DC motor is connected to regulator through a suitable electrical wiring. Further, flange coupling connects D.C motor to a shaft. A key is provided for connecting DC motor and shaft. Grinding disc is connected to one end of the shaft which is supported by two bearings. The specimen is fitted in specimen holder. The specimen holder is made of wood; a slot equal to the size of cross-section of specimen is made in it, to properly hold the same. The samples are fastened with the fixture in these slots, one at a time and the wear test is performed. The fixture is fitted in acrylic sheet having multiple holes along the radius of the sheet. These holes are made in such a way to get fresh surface along grinding disc. At the end of the acrylic sheet there is attachment to apply a load. The load is
applied with help of screw jack, as the screw jack moves forward it pushes the acrylic sheet with help of shaft which connects screw jack and acrylic sheet. The applied load is measure with the help of load cell, for this a special fixture is made and fitted on the connecting shaft to give correct value of applied load.

To change the orientation of set-up an arrangement is made to lift the setup at different angular positions. The whole arrangement of attachment, different parts and assemblies is discussed and shown in the figures later in chapter.

4.2.3 DESCRIPTION OF THE PARTS OF THE WEAR TEST RIG

4.2.3.1 DC Motor

The D.C. Motor having following specifications:

Power – 1 H.P., Rotation – 1 rpm to 3000 rpm

4.2.3.2 REGULATOR

Regulator of a direct current motor is used to regulate and control the speed of motor. It has ammeter to measure current and voltmeter to measure volt attached to it. The characteristic features of regulator are:

Regulated Voltage – 0-260 V, Least Count – 2 V

The technical parameters of Ammeter are:

Current Range: 0 – 10 ampere

Least Count: 0.4 ampere

The technical parameters of Voltmeter are:

Voltage Range : 0 – 300 V, Least Count: 20 V
4.2.3.3 FRAME

The main frame is just like chassis to the engine , it hold all the parts such as motor , shaft , coupling , load cell , screw jack and all its related attachment. The main frame used in the design is shown in the fig. 4.8. The dimensions of the main frame are as follows:

Length – 105 cm , Width – 21 cm

Dimensions of angular frame are as follows:

Length – 115 cm

Width – 35 cm

4.2.3.4 ACRYLIC DISC

The acrylic disc is used as a fixture of specimen holder. The disc is drilled with multiple holes at different radius. This is done so that every specimen gets fresh abrasive surface. This makes synchronization in the calculation of wear rate of the entire specimen. The dimensions of the acrylic disc are as follows:

Diameter – 26 cm

Radius of the first hole \( r_1 \) = 8 cm

Radius of the second hole \( r_2 \) = 16 cm

Radius of the third hole \( r_3 \) = 24 cm
4.2.3.5 GRINDING WHEEL

A grinding wheel used in the design as an abrasive media to produce abrasive wear on the specimen selected. The dimensions of the grinding disc are as follows:

Diameter – 20 cm

4.2.3.6 SPEED OF GRINDING WHEEL

Generally all the abrasive processes are performed with the wheel speed in between the range of 1500 to 2000 rpm with the maximum work speed from 0 to 60 m/min.

4.2.3.7 SHAFT

Two shafts were used, the first shaft connects motor to the abrasive disc and second shaft connects acrylic disc to screw jack. Load is applied with help of second shaft, it pushes the specimen against the rotating abrasive disc. An attachment of load cell is fitted on second shaft to measure the applied load. The dimensions of the shaft are as follows:

Diameter – 25mm

Length (First) – 20 cm

Length (Second) – 30 cm
4.2.3.8 SCREW JACK

The screw jack is used to apply the load gradually turn wise. The screw jack is connected to the shaft, which is further connected to the acrylic disc and specimen fixture. As the screw jack unfolds, it pushes the shaft and acrylic sheet which holds the specimen against the abrasive disc. The push movement of screw jack is measured in terms of applied load with the help load cell.

4.2.3.9 WEIGHING MACHINE

The weighing machine used in the design to calculate mass loss (wear) of the specimen. The weighing machine used had following parameters:

Least Count – 0.001gm

Max. Capacity – 5 Kg

4.2.3.10 LOAD CELL

A digital load cell is used in the design to exactly calculate applied load on the selected specimen against abrasive disc. Load cell is a transducer that converts force into an electrical signal. The strain gauge measures the deformation (strain) as an electrical signal. The load cell used in the design is shown in fig. 4.3 and the whole attachment of the arrangement in the setup is shown in the fig. 4.4. The casing of load cell is welded on the shaft connected to the screw jack. As the screw jack unfolds, it pushes the shaft on which the arrangement of load cell is welded and acrylic sheet which holds the
specimen against the abrasive disc. The push movement of screw jack is measured in terms of applied load with the help load cell. As the strain changes the effective electrical resistance of the wire. The output of the transducer can be scaled to calculate the force applied to the transducer.

The technical parameters are:

Least count – 0.01 N

Max capacity – 100 N

Load type – Tensile & Compressive

Fig 4.3 Strain Gauge Load Cell
Fig 4.4  Arrangement of Load Cell In Wear Test Rig

4.2.3.11 DIAGRAM OF EXPERIMENTAL SET UP

Fig 4.5 Experimental Set Up – With Controller
Fig 4.6  Experimental set up (Front View)

Fig 4.7  Experimental set up (Top View)
Fig 4.8  Experimental set up-Angular Position I

Fig. 4.8 (a) Experimental set up (Close View )
Fig 4.9  Experimental set up-Angular position II
Fig 4.10  Experimental set up-Angular position III
4.3 SPECIMEN’S MATERIALS

As discussed in chapter 3, the idea is to evaluate abrasive wear only. These specimen were selected for present investigation randomly.

(a) Al-alloy 6061 type

(b) Brass 6040

(c) Mild steel

The Chemical composition and Physical Properties of Al6061, Brass6040 and Mild steel Alloys are shown in Table. 4.1, 4.2 and 4.3 respectively

**Table 4.1: Chemical Composition and Physical Properties of Al 6061 Alloy**

<table>
<thead>
<tr>
<th>Elements</th>
<th>Cu</th>
<th>Mn</th>
<th>Mg</th>
<th>Si</th>
<th>Fe</th>
<th>Cr</th>
<th>Ti</th>
<th>Zn</th>
<th>Density</th>
<th>MOE</th>
<th>Poisson’s Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt %</td>
<td>0.15-0.40</td>
<td>0.1-5</td>
<td>0.8-1.2</td>
<td>0.4-0.8</td>
<td>0.7</td>
<td>0.04-0.35</td>
<td>0.15</td>
<td>0.25</td>
<td>2.7 gm/cm³</td>
<td>70-80 GPa</td>
<td>0.33</td>
</tr>
</tbody>
</table>

**Table 4.2: Chemical Composition and Physical Properties of Brass 60:40 Alloy**

<table>
<thead>
<tr>
<th>Elements</th>
<th>Cu</th>
<th>Zn</th>
<th>Fe</th>
<th>Tensile Strength</th>
<th>Shear Modulus</th>
<th>Melting Point</th>
<th>Density</th>
<th>Modulus of Elasticity (E)</th>
<th>Poison’s Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt %</td>
<td>60 %</td>
<td>39.6 %</td>
<td>0.3</td>
<td>370 MPa</td>
<td>37 GPa</td>
<td>885 - 900 °C</td>
<td>8.49 gm/cm³</td>
<td>97 GPa</td>
<td>0.31</td>
</tr>
</tbody>
</table>
Table 4.3: Chemical Composition and Physical Properties of MildSteel

<table>
<thead>
<tr>
<th>Elements</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Tensile</th>
<th>MP</th>
<th>Density</th>
<th>MOE</th>
<th>PR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt %</td>
<td>0.45 %</td>
<td>0.60 %</td>
<td>0.35 %</td>
<td>500 MPa</td>
<td>1510 °C</td>
<td>7.85 gm/cm³</td>
<td>200 GPa</td>
<td>0.303</td>
</tr>
</tbody>
</table>

4.3.1 SPECIMEN PREPARATION

The specimen for wear studies was cut from the Al alloy bar. The cross section of specimen was 1 cm x 1 cm with a length of 4.5 cm. The top and bottom surfaces of specimen were made planer by polishing against emery papers of appropriate grits. For smooth surface of specimen to be used for wear studies.

Fig 4.11 Specimen-Al6061
Fig 4.12 Specimen-Brass6040

Fig 4.13 Specimen- Mild Steel
4.4 WEAR CHARACTERIZATION

The selection of applied load, selection of orientation and test procedure is according to the problem formulated and also in synch with technical resources available.

4.4.1 SELECTION OF APPLIED LOAD

In view of the problem formulated, it is important to select such a load on the specimen which can withstand the pressure applied on grinding disc as well as the load taken by D. C. motor in rotating the grinding disc. Since D. C. motor used in the setup is of 1 H.P. The applied loads selected are in synch with the same. Thus for wear studies the following loads were selected

(i) 5 N
(ii) 10 N
(iii) 15 N
(iv) 20 N

4.4.2 SELECTION OF POSITION OF THE SPECIMEN

The selection of orientation was according to problem formulated, the problem formulated states that to check abrasive wear at different orientation, initially two orientations were selected viz. 0° and 90°, but owing to the large variation in the result and suggestion by jury members in RDC, it was decided to check wear rate on more than two orientation. This helps in collecting more data of wear rate which further helps in statistical analysis of data as well as forming wear equation later. Thus for each load the following orientation of the specimen were selected respectively:

(i) 0°
(ii) 30°
(iii) 45°
4.4.3 TEST PROCEDURE

The test stated for each specimen of the selected material in order viz. Al6061, Brass6040 and Mild steel respectively. Before each test, the weight of the specimen was taken carefully using an Electronic balance with an accuracy of 0.001g. After a travel time of 05 minutes against the grinding disc, the sample was taken out carefully from the fixture. The debris’s were removed from the valleys of the specimen with help of cotton cloth so that the exact wear of materials can be measured. Once again weight of the grinded test specimen was taken carefully using the above electronic balance and the difference in weight was noted. This was continued for five times with same specimen and at same position. Thus 5 trials were conducted for each specimen and after that next specimen was taken for next test condition i.e. 30° angle and 5 N applied load and wear test was conducted using same procedure as discussed above. A total of 25 readings and five specimens at five different orientation (i.e. 0°, 30°, 45°, 60° and 90°) were consumed for one set experiment. The cumulative effect of weight loss was taken for calculating the wear mass and wear rate.