Chapter 3 : Experimentation and Results

3.1 : Experimental Materials

Specimen having 39 mm OD and 10-15 mm thickness were used throughout the experiments and cast iron (C.I.) with hardness of 440 BHN was chosen as a counter material. Teflon is filled with copper in varying percentage of copper as mentioned in Table 3.1.1.

Table 3.1.1

<table>
<thead>
<tr>
<th>Material</th>
<th>Percentage (Filled)</th>
</tr>
</thead>
<tbody>
<tr>
<td>i) Teflon</td>
<td>100 %</td>
</tr>
<tr>
<td>ii) Teflon and Copper</td>
<td>50 % - 50 %</td>
</tr>
<tr>
<td>iii) Teflon and Copper</td>
<td>60 % - 40 %</td>
</tr>
<tr>
<td>iv) Teflon and Copper</td>
<td>70 % - 30 %</td>
</tr>
</tbody>
</table>

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3.2.1 : Experimental set-up

Experiments were carried out in the universal friction and wear test rig as shown in fig. The test piece here acts as a pin over the disc made of C.I. The CI disc is driven by a suitable coupling attached with a reduction gear box which in turn is driven by a motor through belt pulley connection.

The specimen is kept in a suitable specimen holder and the loading is done through an arm provided with pivot fulcrum at one end and loading hook on the other end. Specimen holder is attached with a specially designed precalibrated proving ring. The top CI disc is having a ball type anti friction guide for smooth running with negligible friction.
Fig 3.13.1

UNIVERSAL FRICTION & WEAR TEST-RIG
3.2.2 : Experimental procedure

The experiments are carried out on Teflon and filled Teflon samples varying sliding speed from 10 cm/sec. to 40 cm/sec., specific pressure from 0.5 to 2.5 kg/sq. cm and time from 0.5 hr to 2.0 hr under dry condition. The CI disc is rotated against the sample and the frictional force is monitored using dial gauge fitted to the precalibrated proving ring, attached tangentially to the loading arrangement. Each time the wear on the sample is measured by loss in weight in mg., with the help of electronic balance. The velocity of sliding can be changed either by adjusting the pulley drive between the motor and the gear box or by changing the distance of the sample from the center of the CI disc. The wear measurement are done with varying sliding speed, specific pressure, time and temperature. The temp. is measured by mean of a thermocouple inserted in the specimen holder. The entire plan of the experiment has been done by statistical design and the experimental results processed through analysis of variance within resonable level of confidence.
3.3 : DESIGN OF EXPERIMENT

Experiment is a test. Designed experiment is a test or series of tests conducted in a systematic way by changing various controllable factors at the same time. Statistical Design of experiments are useful to separate the effects of various controllable factors and the effect due to experimental error.

Statistical design of experiments are based on three principles.

Repetition : Replication is the repetition of the same treatment or treatment combinations of controllable factors. This is useful to estimate the error factor in the experiment. This estimate of error is useful to separate the effect of various controllable factors.

Randomisation : randomisation is necessary to make the assumption of independently distributed random variables. In the experimental design, treatments are applied in randomised manner to validate the above assumption.

Blocking is the technique to increase the precision of an experiment. The experimental field is divided into homogenous blocks so as to minimise the experimental error.

In Latin Square Design, the randomisation is restricted in two ways. That is by column as well as row wise. The important advantage of Latin square design is that the experiment gives the same information by carrying 'n 2' number of experiments, instead of 'n 3' number of experiment. The author has used 4x4 Latin square design, and sixteen treatment combination of pressure, velocity and time (all at four levels).

The limitation of Latin square design is that it does not gives the effect of interactions of two different treatments. For the same purpose factorial designs are used. The author has used 2^3 - Factorial Design to find out the effect of pressure, velocity and time (all parameters at two levels) on wear. Author had also carried out 2^4 - experiment to relate the variables.
While conducting Factorial experiments, four extra observations are taken at the mean position of all the related parameters. This is to establish the functional dependence between the controllable factors and response. The replication at the centre helps to estimate the error.

Analysis of variance (ANOVA) technique is used to validate the results from the design of experiments. ANOVA is useful in decomposing the total variation in response into the variation due to different controllable factors and the variation due to chance cause. In ANOVA technique, F-test is the important tool to decide the significant effect of the controllable factors.

Regression analysis is used to establish the functional dependence of controllable factors with the response. In case of factorial regression, the total experiment is divided into two blocks by taking the observations randomly and then the regression model is fitted to each block and total experiment. The model selection criteria are based on the value of regression coefficient and the results from ANOVA analysis. The significance of the co-efficients of different controllable factors is decided using student's t-test.

After selecting the appropriate regression model, 3D response surfaces are plotted to decide various combinations of controllable factors to get the same response. This is helpful to designers to select the proper combination depending on the available setup. Also the ease the selection, contour diagrams are also plotted.

The author had conducted the experiments to study the effect of velocity, pressure, time and also temperature controller on wear as well as on co-efficient of friction. He had studied the effects of these controllable factors on wear and co-efficient of friction on four materials in which the percentage of copper is varying.

The selected regression models are used to find the optimum frictional energy for minimum wear and the respective treatment combination of pressure and velocity.
3.4: Dimensional Analysis:

From the ANOVA and significance analysis, dimensional analysis is used to find out the various non-dimensional groups of independent parameters influencing the output response.

\[ W = k * \rho * \alpha * V * \beta * t * \gamma * \sigma_b \delta * Ra * \mu \eta \]  

\[ M = [ML^{-1}T^{-2}]^\alpha [M]^{1-1} [T]^{1} [L]^{-1} [L]^{-1} [T]^{-2} [L]^{-1} [M]^{-1} [T]^{-1} [L]^{-1} \]

\[ \alpha + \delta + \eta = 1 \]

\[ -\alpha + \beta - \delta + \varepsilon - \eta = 0 \]

\[ -2*\alpha - \beta + \gamma - 2*\delta - \eta = 0 \]

Therefore

\[ \varepsilon = 1 - \beta \]

\[ \eta = 2 + \beta - \gamma \]

\[ \delta = -\alpha - \beta + \delta - 1 \]

By substituting these \( \varepsilon, \delta, \eta \) in equation (5)

\[ W = k * \rho * \alpha * V * \beta * t * \gamma * \sigma_b (-\alpha + \beta + \gamma - 1) * Ra (1 - \beta) * \mu (2 + \beta - \gamma) \]  

**Material: 100% Teflon:**

\[ W = 39.54 * \rho 0.1618 * V 0.1075 * t 0.3050 * \sigma_b 1.0357 * Ra 0.8925 * M 1.8025 \]

Substituting value of \( \sigma_b, Ra \) and \( \mu \), and equating non-dimensional groups, we get

\[ W = 4.7366 * \rho 0.1618 * V 0.1075 * t 0.3050 \]

**50% Teflon and 50% Copper:**

\[ W = 5.72 * \rho 0.2868 * V 0.0502 * t 0.1582 * \sigma_b -1.1788 * Ra 0.9498 * M 1.892 \]

Substituting value of \( \sigma_b, Ra \) and \( \mu \), and equating non-dimensional groups, we get
\[ W = 0.1944 \times p^{0.2868} \times v^{0.0502} \times t^{0.1582} \]

**60% Teflon and 40% Copper:**

\[ W = 3.46 \times p^{0.1261} \times v^{0.0429} \times t^{0.0994} \times \sigma_b^{-1.0696} \times R_a^{0.9571} \times \mu^{-19435} \]

Substituting value of \( \sigma_b, \) \( R_a, \) and \( \mu, \) and equating non-dimensional groups, we get

\[ W = 0.2117 \times p^{0.1261} \times v^{0.0429} \times t^{0.0994} \]

**70% Teflon and 30% Copper:**

\[ W = 5.72 \times p^{0.1786} \times v^{0.0667} \times t^{0.1674} \times \sigma_b^{-1.0779} \times R_a^{0.9333} \times \mu^{1.8993} \]

Substituting value of \( \sigma_b, \) \( R_a, \) and \( \mu, \) and equating non-dimensional groups, we get

\[ W = 0.3380 \times p^{0.1786} \times v^{0.0667} \times t^{0.1674} \]