Experimental Analysis of the co-efficient of static friction between different pairs of surfaces using Horizontal Plane Apparatus

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Abstract. This study is based on a quick, simple and reliable Engineering Mechanics laboratory experiment for determining the coefficient of static friction between common as well as different materials. First of all, author determines the performance of the Horizontal plane Apparatus to understand facts and concepts of development of frictional force with respect to applied external force causing motion or tends to cause the motion. The average value of coefficient of friction between wood-wood surface, wood-glass surface and wood-leather surface, using simple plane horizontal apparatus obtained by the author are 0.79, 0.49 and 0.61 respectively. Author compares the same with the available values of coefficient of friction in the literature. The work is extremely useful for B.Tech./M.Tech. Students and research scholars for their project/thesis work.

Key words: Coefficient of Friction, Normal Reaction, Effort

1. Introduction

It was the French Physicist Charles de Coulomb in 1781, who investigated that the limiting force of friction is independent with the area of contact between two mating surfaces. He demonstrated that friction depends on the materials of the mating surfaces as well as the normal reaction between them. He defined the friction as the force that opposes the relative motion between the mating sliding surfaces. There are three types of important friction namely Dry friction, liquid friction and internal friction. Presently, we are considering dry or solid friction in our experimental work. Solid friction is considered when dry mating surfaces are in sliding motion. This dry friction again may be classified as static friction as well as kinetic friction. When the applied force exceeds the static force and the body begins to move, a kinetic friction force acts on the body. Kinetic friction coefficient is commonly less than the static friction coefficient. The frictional force is proportion to normal reaction between the mating surfaces, \( F = \mu N \). Here \( \mu \) is a coefficient of static friction, a term used by Coulomb. When a body slides on the other body, a force acts between the two surfaces which opposes the motion, is called friction.

Arnoux et.al.[1] presented an experimental study to investigate dry friction phenomenon in a wide range of sliding speeds for the steel-on-steel contact. Their ballistic setup with an air gun launch, allows estimating the friction coefficient between 20 m/s and 80 m/s. Tests were completed by an adoption of the sensor on a hydraulic tensile machine (0.01 m/s to 3 m/s) and a pin-on-disk tribometer on a CNC lathe. The interactions at the asperity scale were characterized by a white light interferometer surface analysis. Friction coefficient is a function of the sliding speed for different contact pressures. It was observed that high sliding velocity and great pressure can generate conditions leading to interfacial temperatures showing the melt and fully melt temperature regime [2-4]. Alexander Hu and Bruce Peachey [5] showed that the experiments at high school level in physics laboratory to find out the coefficient of friction, a constant velocity (net zero force) is required to make sure that the measured force is only the friction force. Experiment configuration is simple but
having constant velocity is difficult task that is the main reason in large errors. They designed a new friction coefficient experiment involving the static measurements. The standard deviation from their experiment is 3 times smaller than that of ordinary experiment. A Santos et.al.[6] presented their work for determination of dynamic friction between micrometric size coatings of alumina and metallic materials. Friction may be defined as the resistance to relative displacement between two surfaces that are in contact. The coefficient of friction is a dimensionless parameter and is characteristic of every pair of materials which are in contact along with many other factors like temperature, roughness, relative speed between surfaces, etc. [7]. Yadon et.al.[8] summarized the existing friction measurement methods. They proposed a multi-sensor information fusion scheme for coefficient of friction determination between the tire and runway. They used acoustic sensors, optical sensors, tread sensors and other physical sensors for friction related parameters measurement. Their developed model includes the international runway friction index and other fitting models. This paper also correlates the neural network output with the model of correlation for predicting the friction coefficient between tire and runway when the aircraft brakes. Because of human causalities and economic losses, most of the countries devoted researches to develop methods for measuring runway friction in all weather conditions [9]. These developed methods are divided into two categories: the cause-based method experimental method and the effect-based method [10].

Khaleghian et.al. [11] worked on the vehicle crashes due to drivers less knowledge about the friction and performance of stability of the vehicle. Their focus was on both the parameters experimentally as well as model-based approaches. Manuel et.al. [12] presented a review paper for road friction. They concentrated on the potential road grip under regular driving conditions like tyre slip, tyre vibration, and tyre noise. Paul et.al.[13] developed a rules-based estimation algorithm to determine the coefficient of friction between type and road, which is independent with braking control system of the vehicle. SUN et.al.[14] developed aircraft antiskid braking system to eliminate the tire bursts and for safe take-off landing. They suggested a new approach utilizing an on-off valve array in place of the servo valve for pressure control. Jiao et.al.[15] proposed an algorithm for identification of maximum friction force by analyzing the runway and tire friction characteristics that improved the braking efficiency. Huang et.al.[16] used extended Kalman Filter for measuring the coefficient of friction between tire and road. They conducted joint simulation for the suggested algorithm with Matlab/Simulink. Liu et.al.[17] suggested an iteration algorithm method for estimation tire-road friction coefficient based on self-aligning torque of the front tires in real time. It is easy to define the coefficient of friction as it is the ration of perpendicular force and parallel force to an interface between two bodies under impending relative motion but not easy to understand fundamentally. Inspite of the fact that the two static and kinetic coefficients of friction are measured with some difficulty on laboratory conditions. Peter [18] reviewed the measurement and use of static and kinetic friction coefficients and listed the sources of frictional resistance in terms of shear localization. Stahl et.al. [19] gave a fundamental contribution for the explanation of contact mechanics of partially lubricated contact surfaces. They used a unique experimental setup with macroscopic asperities for the study of lubricant flow. Guo et.al. [20] worked on prefabricated composite beam behavior. They performed several tests to measure the friction coefficient and slip stiffness. They showed a positive correlation between concrete strength and friction coefficient and better performance of shot blasted steel. Demarch et.al.[21] worked on important properties of ceramic floor tiles roughness measurements methods. Their method shows very different results using different experimental equipments for the same type of surface. Hasan A. [22] determined the Mechanical Advantage, velocity ratios using experimental data and theoretical data provided by the manufacturer of the apparatus, theoretical and experimental efficiency. Hasan A.[23] determined the double purchase winch crab performance and friction losses in engineering mechanics laboratory. Hasan A. [24] determined the coefficient of friction between various pairs of surfaces and compared the same with the available values of coefficient of friction in the literature. Hasan A. [25] verified and determined in error in the law of moments using bell crank lever apparatus in the engineering mechanics laboratory. Hasan A. [26] worked on comparison of support reactions experimentally as well as theoretically using simple supported beam in the mechanics laboratory.Hasan A.[27] verified and determined the percentage error in the verification of law of Parallelogram of Coplanar Concurrent Forces. Hasan A. [28] calibrated the combined coil and belt friction apparatus on the basis of measurement of the coefficient of friction. Hasan A. [29] calibrated the worm and worm wheel
apparatus in engineering mechanics laboratory on the basis of Measurement of the coefficient of friction. Patil et. al. [30] proposed the technique to minimize the human labour by the application of a screw jack. Tarachand [31] presented the way for getting the optimum efficiency of a screw jack. Hashiguchi et.al.[32] proposed the theory of unconventional friction. Kartal [33] worked on the idea of tensional contact between elastically similar flat-ended cylinders. Eriten et. al.[34] explained the behavior of flat rough surfaces. Kostas et.al[35] presented the coefficient of friction between the inter particles. Chiew et .al.[36] defined the friction model identification. Piatkowski et.al. [37] worked on dynamic friction models. Kostas [38] investigated micro mechanical inter particle loading apparatus. Dong et.al[39] worked on wear reduction model. Deepak et. al. [40] worked on the effect of roughness on coefficient of friction. Cura et. al. [41] gave the wear formulation approach. Saha et.al. [42] proposed modified friction model. Aita et.al. [43] presented their work on nonlinear friction models. Putelat et. al.[44] worked on frictional waves and Tsampras et. al. [45] suggested an experimental study of friction devices and rubber bearings. Author has consulted a no. of text books [46-56] and extracted some data for research purposes. Standard Range of Coefficient of friction for dry surfaces is given in Table 1.

| S.N. | Name of Surfaces | Standard Range of Coefficient of Friction (μ) |
|------|------------------|---------------------------------------------|
| 1    | Metal on Metal   | 0.15 - 0.6                                  |
| 2    | Metal on Wood    | 0.2 – 0.6                                   |
| 3    | Metal on Stone   | 0.3 - 0.7                                   |
| 4    | Metal on Leather | 0.3 - 0.6                                   |
| 5    | Stone on Stone   | 0.4 - 0.7                                   |
| 6    | Earth on Earth   | 0.2 - 1.0                                   |
| 7    | Rubber on Concrete | 0.6 - 0.9                                  |

2. Materials and Methodology

The experimental setup of Friction horizontal inclined plane apparatus available in the Engineering Mechanics laboratory is shown in Figure1. The apparatus is ensured horizontal with the help of sprit level or by other means in the beginning of the experimental observations. Now, Place the slider on the plane horizontal apparatus. Now, tie the slider to the pan with the help of a weightless string passing over the smooth pulley. Now, we placed the weights in the pan till the slider just is about to start moving. Note down the weights and determine the value of coefficient of friction. The same procedure is repeated every time for the impending condition. Then, we calculate mechanical advantage, velocity ratio and efficiency also.

![Figure 1. Friction Horizontal Plane Apparatus](image-url)
3. Observations
Observations and calculations are recorded in Table 2. Constant Observations: \( M_1 = 115 \) gm, \( m_1 = 25 \) gm.

| S.N. | Combination of surfaces | \( M_2 \) (gm) | \( m_2 \) (gm) | \( W = (M_1+M_2)(gm) \) | \( P = (m_1+m_2)(gm) \) | \( \mu = \frac{(m_1+m_2)}{(M_1+M_2)} \) | Average \( \mu \) |
|------|------------------------|----------------|----------------|------------------------|------------------------|------------------------|----------------------|
| 1    | Wood-Wood              | 0              | 0              | 0                      | 0                      | 0                      | 0.00                 |
| 2    | 10                     | 75             | 125            | 100                    | 0.80                  |
| 3    | 50                     | 117            | 165            | 142                    | 0.86                  |
| 4    | 70                     | 120            | 185            | 145                    | 0.78                  |
| 5    | 100                    | 130            | 215            | 155                    | 0.72                  |
| 6    | 250                    | 260            | 365            | 285                    | 0.78                  |
| 7    | Wood-Glass             | 0              | 0              | 0                      | 0.00                  |
| 8    | 10                     | 20             | 125            | 45                     | 0.48                  |
| 9    | 50                     | 47             | 165            | 72                     | 0.44                  |
| 10   | 70                     | 67             | 185            | 92                     | 0.50                  |
| 11   | 100                    | 90             | 215            | 115                    | 0.53                  |
| 12   | 250                    | 150            | 365            | 175                    | 0.48                  |
| 13   | Wood-Leather           | 0              | 0              | 0                      | 0.00                  |
| 14   | 10                     | 20             | 125            | 45                     | 0.68                  |
| 15   | 50                     | 55             | 165            | 80                     | 0.61                  |
| 16   | 70                     | 65             | 185            | 90                     | 0.59                  |
| 17   | 100                    | 70             | 215            | 95                     | 0.53                  |
| 18   | 250                    | 200            | 365            | 225                    | 0.62                  |

Where:
\( W = \) Weight of the block placed on horizontal surface = \((M_1+M_2)\) g N,
\( M_1 = \) Mass of block in kg,
\( M_2 = \) Mass placed on the block in kg,
\( R = N = \) Normal reaction of the surface,
\( P = \) Effort applied to the block = \((m_1+m_2)\) g N,
\( m_1 = \) Mass of Pan in kg,
\( m_2 = \) Mass placed on the Pan in kg.
\( F = \) Static force of friction,
\( F_m = \) Maximum limiting force of static friction,
\( \mu_s = \) Coefficient of static friction,
M.A. = Mechanical Advantage = W/P.

4. Results
The average value of coefficient of friction between wood-wood surface, wood-glass surface and wood-leather surface, using simple plane horizontal apparatus, are 0.79, 0.49 and 0.61 respectively. Our results are within limits and in completely agreement with the results already available in Table 1 of the literature [46-56].

5. Conclusions
Figure 2 shows the relationship between friction force \( F \) and Normal Reaction \( R \), which is a straight line. The slope of wood-wood line, wood-glass line and wood-leather line gives the coefficient of friction between the contact Surface pair of wood-wood surface, wood-glass surface and wood-leather respectively. From Table 2, we see that the coefficient of friction between wood and wood surfaces is higher than between the wood-leather and wood and glass surfaces. We should take care that pulley should be frictionless and any knot in the string should be avoided. Weight in the pan must be placed gently and keep string parallel to the smooth and cleaned inclined plane. Sufficient lubrication must be done on the pulley to optimize the friction. The friction analysis needs knowledge of precise
experimental data showing the mechanical phenomenon that happen in contact mechanisms. The author has taken a set of six measurement observations for wood-wood, wood-glass line and wood-leather contact surfaces. The study further can be extended for friction coefficient measurement for other pairs of different contacting surfaces.

In Figure 2, Normal reaction is equal to the total weight placed on the solid surface which is about to move against its mating surface having same or different material. The frictional force is the friction coefficient times the normal reaction. In other words, it the effort applied. Frictional force is directly proportional to the normal reaction and the ratio of frictional force and normal reaction is friction coefficient.

![Frictional Force V/s Normal Reaction](image)

**Figure 2.** Coefficient of Friction in different surfaces using Plane Horizontal Surface Apparatus

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