An evaluation of tactile frictional behavior of the wooden material

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Abstract. Skin tribology and contact mechanics have emerged as a recent topic of research, intended to unveil the behavior of human skin. There have been variegated efforts to calculate the coefficient of friction with respect to various parameters such as sliding speed, normal load, and surface roughness. Wood and other timber products have their importance considering the ergonomically designs that have gained importance nowadays. This article shows the relation between normal load, average sliding speed and coefficient of friction (μ) of various types of woods (Rosewood, Sunmica, Teak wood and Pine wood). An experimental investigation is conducted to understand frictional behavior between human skin and different types of woods. Wooden material has been tested with the normal load having the range of 6.5N to 13N. The variation of μ has been remarked as μ_{rosewood} > μ_{pine} > μ_{teak} > μ_{sunmica}. Experimental observation shows that the rosewood has the highest COF which suggests its application where grip and strength of high order are required. With decreasing sliding speed, the relation between normal load and μ become more significant.

1. Introduction:
Friction pertaining to human skin is a recent topic of research in the field of contact mechanics and tribology. It is an interdisciplinary approach to understand the skin friction behavior through the subjects of tribology, contact mechanics, dermatology and physiology.

Human skin is a living material and the exact properties of skin are very difficult to investigate. Human skin is made of three distinct layers dermis, epidermis and subcutis [1,5]. Considering the mechanical behavior of skin, a lot of efforts have been put forward to quantify the mechanical properties of skin [2-3], indentation caused by indenter [4-6], material testing as compression test[7] and measuring the coefficient of friction. Researchers have also investigated the skin friction behavior analytically [8,9] as well as numerically [10-12]. Numerical calculation of stresses, strains and variation of properties of the fluid entrapped between skin and mating materials has been investigated. The models that are implemented to understand the frictional behavior of skin are Adhesion, Hysteresis and Deformation model. The adhesion model is prominently used to model the skin friction behavior.

The pronounced factor that affect the friction in between skin and materials are sliding speed[13-15], skin hydration[13,16], moisture[17], sebum level [18], vibration [19,20], anatomical location [21], hair on skin [22], contact pressure [23,24], temperature [25,26], sliding direction [27], sliding angle[28]. On the counterpart of mating surface effect of parameter such as ridges [29-33], surface roughness [34,35] and contact area [36,37] is investigated.

The skin is the largest organ in the human body and the comfort of skin has become one of the great challenges as an engineering application. In the modern era, considering this fact a lot of research has been
carried out in the various applications as rugby balls [17], glass handling [24,38], polymer and cotton comfort[39,40], metals as stainless steel [38], plastics[34,41].

Various anatomical regions such as forearm [42-44], foot[41], finger[34,37] and palm[39,40] are of practical interest for calculating friction coefficient. These parts of the skin are in contact with the other mating materials mostly.

As finger is used for holding and gripping purpose. A lot of work has been [45,41,47] done for the assessment of the behavior of a finger with reference to materials such as cloth, steel, wood etc. [14,34]. The relation of COF has been investigated in the context with contact pressure [23], with vibration[35], with sliding speed and hydration[48], with skin microstructure[49], with human perception[19], and with a normal load[50]. This depicts that nearly every factor affecting skin friction coefficient has been investigated for finger in addition to other anatomical regions. The present article investigates the interaction of wooden material, with finger skin whose frictional behavior has not been assessed anywhere.

There are various types of woods used in furniture, flooring and decorative purposes etc. Indian rosewood and Teak wood are most popular in the Indian subcontinent. Nowadays Sunmica is used to cover wood for its rust resistant and water-resistant properties. Pine wood is widely used for window paneling and roofing.

There is fever research available in the literature, which comprehensively summaries the tactile friction study of wooden material. In this article, the skin friction behavior with four different woods is discussed and effect of normal load and sliding speed on friction of skin is reported. The effect of normal load, sliding speed on frictional behavior of Indian rosewood, Teak wood, Pine wood and Sunmica with skin is discussed. The range of the load considered is 5 N-12.5 N. The effect of normal load and sliding speed on the coefficient of friction of wooden materials is discussed.

2. Materials and Methods:
2.1 Subjects and Environmental conditions
The temperature range of 35-40 degree Celsius and humidity 40 % RH of environment is maintained. One subject is taken, and the right-hand index finger is used during the experiment. The angle between finger and surface was maintained at 40 degrees. Before every experiment, the fingertips were washed with alcohol and dried in air for five minutes.

2.2 Experimental setup
As shown in figure 2.1 for measuring force (normal and frictional) Kistler 9272 plate was used, which can measure force in all three directions. It has a measuring range of -20 kN to 20 kN with a least count of 1mN. Since we require only two forces, so other channels were switched off during the experiment. The force in
third direction was very less as compared to forces under concern, so its effect was negligible. The output, Voltage was converted into force signal by a transformer (Kistler make). The force signal was feeded to dynoware software, which shows a continuous variation of forces with respect to time while sliding the finger on force plate. As shown in figure 2.2 the sample rate was chosen 10 Hz and time period chosen varied 5-25 sec. The obtained number of samples from dynoware software per unit cycle time. It was analyzed using MINITAB software for regression and graphical analysis.

2.3 Testing Objects
Tests are conducted on four types of wood: Teakwood, Indian rosewood, Pine wood and Sunmica.

2.4 Method of Experiment
The finger was slide over the sample for the specified period to get different average velocities. The size of wood sample is 42 mm*42 mm as depicted in figure 2.3. The subject was instructed to stand in the stable and natural way.

For investigating the effect of wetness of COF isopropyl alcohol was used. The values of friction coefficient (µ) are calculated as the ratio of friction force to normal force.

![Figure 2.3 Four Wood samples for the experimental investigation.](image_url)

2.5 Statistical Analysis
After importing normal force and friction force sample (at different sliding speed) of woods, COF is calculated at the discrete instant of time (depending on no. of samples/Cycle time). Calculated mean range, standard deviation and variance of the normal load and COF have been shown in table 3.1. To validate the
strength of the relation between COF and normal load at different sliding speeds, Regression Coefficient ($R^2$) is calculated. The Pearson coefficient and p-value to find the significance of the correlation between μ and normal force. A negative value of Pearson coefficient indicates the COF decreasing with normal force. It varies between -1 to 1. The zero value of Pearson coefficient indicates no correlation. Pearson coefficient has a vital role in developing the correlation. It is essential to have the correlation coefficient that is strongly affected by p-value. If the p-value is less than 0.05 then only, the correlation is found to be significant. In current study p-value obtained is less than 0.05.

3. Results and Discussions:

Figure 3.1 depicts the variation of COF with the normal load. Wood has average COF less than 1. Indeed it is vital to note that COF decreases with increasing normal load. The relation is more pronounced at lower sliding speed validated by the $R^2$ value. Indian rosewood has the maximum coefficient of friction followed by Pine wood, Teak wood and Sunmica. With decreasing sliding speed, the relation between normal load and COF becomes even more significant, as prevalent from $R^2$ Values and Pearson coefficient. If p-value is less than 0.05 then a strong correlation exist, it is also found mostly in lower sliding speed.

Figure 3.1 Variation of COF of woods with normal load at various sliding speeds.
Table 3.1 Influence of normal load on COF

| Material       | Sliding Speed | Sliding Speed COF (Mean) | Sliding Speed COF (Range) | COF Variance | Normal Load COF (Mean) | Normal Load COF (Range) | Normal Load COF (Variance) | R² Value | Pearson Coefficient | P - Value |
|----------------|---------------|--------------------------|---------------------------|--------------|------------------------|--------------------------|---------------------------|-----------|---------------------|-----------|
| Sunmica        | 4.2           | 0.692                    | 0.654-0.744               | 0.001        | 10.832                 | 9.58-12.18               | 1.21                      | 0.26      | -0.51               | 0.29      |
|                | 2.62          | 0.689                    | 0.353-0.807               | 0.023        | 10.006                 | 9.00-10.90               | 0.48                      | 0.13      | -0.36               | 0.41      |
|                | 1.97          | 0.721                    | 0.453-0.872               | 0.020        | 8.442                  | 6.730-9.62               | 1.07                      | 0.68      | -0.82               | 0.04      |
| Pine Wood      | 4.2           | 0.941                    | 0.677-0.759               | 0.027        | 11.114                 | 9.90-12.50               | 1.14                      | 0.18      | -0.43               | 0.46      |
|                | 2.3           | 0.942                    | 0.590-1.175               | 0.032        | 7.876                  | 6.43-9.60                | 1.61                      | 0.30      | -0.55               | 0.19      |
|                | 1.68          | 1.110                    | 0.943-1.346               | 0.016        | 6.639                  | 5.51-8.26                | 0.90                      | 0.14      | -0.37               | 0.32      |
| Indian R. wood | 4.6           | 1.221                    | 1.162-1.312               | 0.004        | 11.548                 | 10.69-12.30              | 0.40                      | 0.21      | -0.46               | 0.42      |
|                | 2.3           | 0.875                    | 1.058-1.764               | 0.058        | 9.788                  | 4.08-11.77               | 6.66                      | 0.82      | -0.90               | 0.00      |
| Teak Wood      | 4.2           | 0.895                    | 0.722-0.992               | 0.011        | 12.044                 | 11.29-12.39              | 0.19                      | 0.49      | -0.70               | 0.18      |
|                | 2.8           | 0.922                    | 0.747-1.084               | 0.010        | 12.594                 | 11.16-13.60              | 0.58                      | 0.15      | -0.38               | 0.34      |
|                | 1.68          | 0.950                    | 0.797-1.050               | 0.007        | 9.988                  | 8.85-11.53               | 0.77                      | 0.62      | -0.77               | 0.00      |

The friction behavior of human skin has three components adhesion, deformation and hysteresis. Adhesion depends up on the effective contact area, elastic modulus of skin and load applied. The hysteresis component has less significance as compared to adhesive and deformation component in human skin, but it increases with the load due to softening of the skin while adhesion decreases with the load [44]. The friction model consists of adhesion and deformation model reported in [34]i.e:

\[ F_{fr, total} = F_{fr, adh} + F_{fr, def} \]

(1)

\[ F_{fr, adh} = (\tau_0 + \alpha_0)A_{real} \]

(2)

Friction coefficient is the ratio of friction force to normal force.

\[ \mu_{adh} = \frac{F_{adh}}{F_N} = \frac{\tau_0}{A_{real}} \]

(3)

Additional to above the further reason is that the ratio \( \frac{F_N}{A_{real}} \) will increase because \( A_{real} \) will increase more as compared to \( F_N \), ultimately decreasing the adhesion friction coefficient. Also from [52] the effective area between finger and surface can be found, which states that the area depends on many factors such as load, effective radii and effective elastic modulus.

4. Conclusion:
Measurement of COF of right-hand index finger done on Kistler tri-axial-one moment force plate (related accessories) on wooden material with respect to normal load and sliding speed. Range of COF for Sunmica, Pinewood, Rosewood and Teak is found to be 0.353-0.872, 0.5909-1.346, 0.7274-1.764 and 0.7248-1.084 respectively on the basis of varying sliding velocity and normal load.

It is observed that the COF have two components adhesion and deformation, in which adhesion plays a predominant role. The adhesion is dependent upon the asperities contact between skin and mating material, whose effect can be directly seen in abrasive papers. The coefficient of friction decreased with the normal load for all the samples and its effect is more pronounced at lower sliding speed, as the p-value and R² value that indicated the level of correlation between COF and normal load. The velocity dependency of the
Coefficient of friction for the finger pad against a range of materials show rather complex behavior, that still matter of research for various other materials. Factors like vibration and acoustic emission are yet to be investigated. Skin tribology has great scope in material science, in which the research can be started to design and fabricate artificial finger that can mimic the human skin behavior and in robotics.

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