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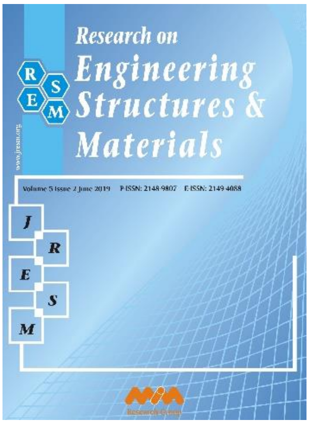


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*Research Article*

# Comparison of wood and knot on wear behaviour of pine timber

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**Abstract**

The wear behaviour of the wood and knot of pine timber is evaluated at ambient conditions. The experiment is carried out under dry sliding conditions using a pin-on-disc apparatus. Wear testing parameters are chosen as 20N load, sliding velocity of 0.64 $ms^{-1}$ and sliding distance ranging from 200m-4500m. The worn surfaces are characterized by optical microscope and scanning electron microscopy. Hardness of wood and knot samples is measured in Durometer hardness tester, tensile testing by an Instron testing machine and density of the samples is calculate from the data of volume and weight. The results of the wear test reveal that the knot shows the better wear properties due to higher strength and density. SEM study of the knot and wood disclose that the knot contents compact cell wall than that of wood.



## 1. Introduction

A knot is a particular type of imperfection in a piece of wood. It affects the physical and mechanical properties as increase the compression strength, hardness, and shear characteristics of the wood and decrease the tensile and bending strength. It causes uneven wear on the surfaces, give trouble because of the checking with moisture changes, make difficulty in painting and increase for cutting forces [1-4]. In a longitudinally sawn plank, a knot will appear as a roughly circular "solid" piece of wood around which the grain of the rest of the wood "flows". Within a knot, the direction of the wood grain is up to 90 degrees different from the grain direction of the regular wood. Pine is an inexpensive, lightweight wood that can be yellowish or whitish with brown knots [5, 6].

The strength of wood depends on its density. Whet the density increases the strength also increase. When evaluating the density of wood, the level of moisture in which its mass and volume were measured must always be known. Usually the density of wood is specified as dry air density [7, 8]. The strength of the wood is basically affected by the direction in which it is loaded in relation to the grain. Knots are portions of branches that become included into the tree trunk during growth and influence the strength properties of a piece wood. Knots decrease the strength of wood mainly because of interrupting the direction of grain, localized steep slope of grain concentrates around knots. As the proportion of knot

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on the cross section increases, density increases. Shrinkage values are not deferent especially in the specimens containing small knots [9-11].

Development of composite material specifically reinforced plastic composites has made a significant contribution since last few decades. However natural fiber reinforced composite has carved an important place made out of waste of organic materials. In this context composites prepared out of wood waste such as saw dust has been considered to replace artificial fiber reinforced composites owing to its ecofriendly nature and reasonably sound mechanical properties [12, 13]. So the frictional properties of wood may be an important factor in these regards.

The mechanical properties of clear wood are well known while for defects such as knots they are relatively unknown. The aim of this study is to understand the wear as well as the physical and mechanical properties of individually wood and knot of pine timber.

## 2. Experimental Details

The frictional and wear behaviors of the wood and knot were investigated in a pin-on disc type wear apparatus by following ASTM Standard G99-05. The samples of 12 mm length and 5 mm diameter were obtained from the wood and knot of pine timber for this study. Mild steel discs were used as the counter-body material. One of the surfaces of the disc was grinded by surface grinding machine and cleaned with cotton. The hardness and surface roughness of the mild steel discs was RC 50 and 0.31 μm respectively. During the wear tests, the end surfaces of the pin samples were pressed against horizontal rotating mild steel disc. Load of 20N was used throughout the test, which yielded nominal contact pressures of 1.0MPa. The tests were conducted at the sliding speed of 0.64 $ms^{-1}$ with varying sliding distances ranging from 200m-4500m. All the tests were carried out in ambient air (humidity 70%) under dry sliding condition. The experimental photograph of setup is shown in Fig. 1. At least three tests were done for each type of material. The sliding distances were calculated by knowing the track diameter and speed of rotation of the disc. Volume loss was calculated from average values of weight-loss measurements. Wear rate and co-efficient of friction were determined with the help of following equations [14, 15]:

$$\mathrm{WR} = \frac{\Delta \mathrm{V}}{\mathrm{SD} \times \mathrm{L}} \tag{1}$$

$$\mu = \frac{\mathrm{FF}}{\mathrm{L}} \tag{2}$$

Where (WR) is the wear rate of the sample, (ΔV) is the volume loss by sample after each wear test, (SD) is the sliding distance, L is the load applied on sample, μ is the friction co-efficient of the sample and FF is the friction factor of the sample.

Hardness of wood and knot samples was measured in Durometer Hardness tester. An average of ten concordant readings was taken as the representative hardness of a sample. Tensile testing was carried out in an Instron testing machine, using cross head speed to maintain the strain rate of $10^{-3}$/s. The samples used were according to ASTM specification. Tensile test was determined using five test pieces for each test. Density of the wooden sample at various states was calculated from the data of volume and weight. Microstructural observation of the worn specimens was done by using USB digital microscope and some selected photomicrographs were taken. The SEM investigation was conducted by using a JEOL scanning electron microscope.

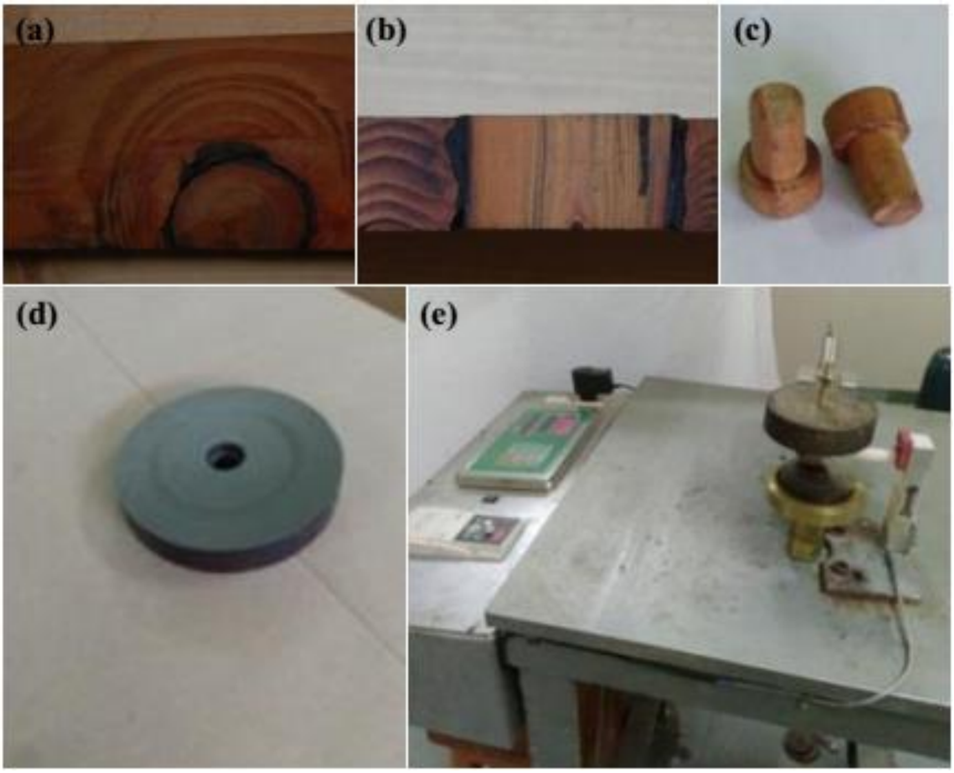


Fig. 1 Experimental pine wood a) top view, b) front view, c) wear sample of wood and knot, d) MS counter disk and e) wear testing machine

## 3. Results and Discussion

### 3.1. Physical and Mechanical Properties

Fig. 2 shows the density, hardness, ultimate tensile strength and elongation of wood and knot of pine timber. The knot shows the higher hardness as well as the tensile strength due to higher compactness of cells present in to the knot. The minimum variation of elongation may be due to the higher bound water into the cell at hand in the knot. Knot itself is different in density usually higher. Its grain orientation is more or less perpendicular to the surrounding wood. So shrinkage is greater across the knot than the surrounding wood [16]. Wood is a heterogeneous, hygroscopic, cellular and anisotropic material. It is composed of cells and the cell walls are composed of micro-fibrils of cellulose and hemicelluloses' impregnated with lignin. The density of wood is an important property to consider since the stiffness, strength and shrinkage properties are all dependent on the density. Lignin and hemicelluloses are material constituents of wood that absorb water and swell, which affects the volume and the weight of a wood sample [17].

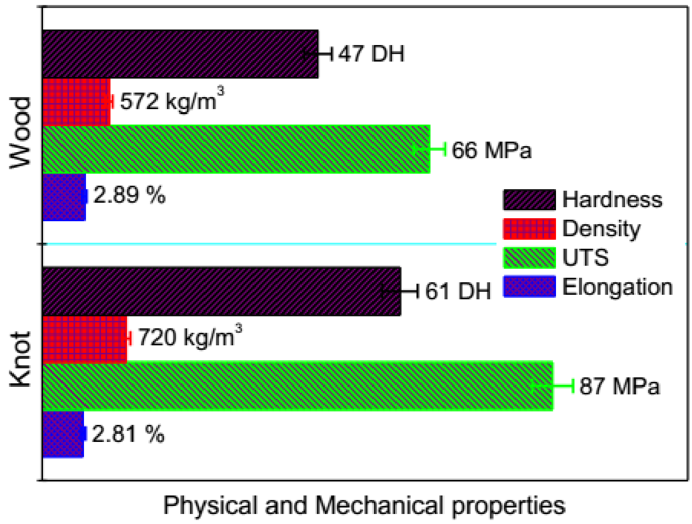


Fig. 2 Experimental result of physical and mechanical properties of the wood and knot of pine timber

### 3.2. Wear Behavior

Fig. 3 shows the volume loss of pine wood and knot as a function of sliding distance at normal load of 20N and sliding speed of 0.64 $ms^{-1}$. It is generally known that with increasing sliding distance, the volume loss increases due to more intimate contact time between the contact surfaces of the specimen with the rotating disc. However, less volume loss was observed in case of the knot compared to the wood at higher sliding distance. With increase in sliding distance causes a rise in interface temperature results in thermal softening of the material causing removal of the thin metal layer from the surface. The continuous fracture of thin layer leads to higher volume loss [18-20].

Fig. 4 presents the wear rate vs. sliding distance plot for wood and knot of pine timber. It can be observed that wear rate increased at a steep rate initially for wood and knot and after a certain point onwards attained a constant value for wood and the decreases trend for the knot. Initially maximum wear rate was observed because abrasive mild steel was fresh. With consecutive runs wear rate decreased gradually because the abrasive grits become smooth and less effective. The wear debris filled the space between the abrasives, which reduced the depth of penetration in the sample. As a tree grows and increases the circumference of its trunk, the growing trunk begins to overtake the branches that grow out from it. Knots form around these branches, building up trunk material as the tree continues to expand. Since the branches are still growing as they are overtaken by the trunk, the knot that forms is solid and contains living wood throughout. The wood of the knot is typically tougher than the surrounding wood and may form a bulge around the branch emerging from its centre. That is why the wear rate of the knot is minimum than that of wood.

The relationships between the coefficient of friction and the sliding distance for the wood and knot on the mild steel counter body is shown in Fig. 5. These differences in the coefficient of friction are considered to be due to both adhesion and deformation components of friction between wood and counter face material. The frictional force is higher for knot sample than that of wood sample. The reason could be due to the presence of fine grain structure in the knot sample and the coarse grain structure in the wood sample. The fine grains have greater surface area per unit volume than the large and irregular grains. The higher bound water increases the moister content of the knot. It is also another reason for higher coefficient of friction [21]. The coefficient of friction decreased linearly with sliding distance. Interface temperature increases with increment in sliding distance that may promote the surface oxidation and reduce the direct contact hence there is slight decline in frictional coefficient [22]. In case of wood the rate of decreases of friction coefficient is relatively higher because of minimum adsorbed water into the cell wall. It softens the cellulose/lignin material of the cell water. Therefore, it reduces all strength and stiffness properties; that weakens the wood [23]

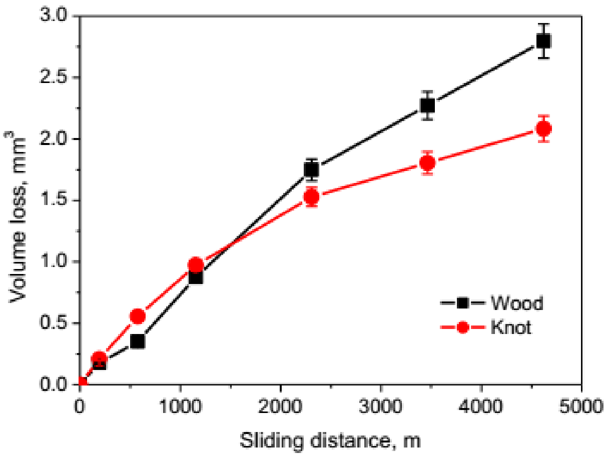


Fig. 3 Variation of volume loss with sliding distance at applied pressure of 1.0MPa and sliding velocity of 0.64 $ms^{-1}$

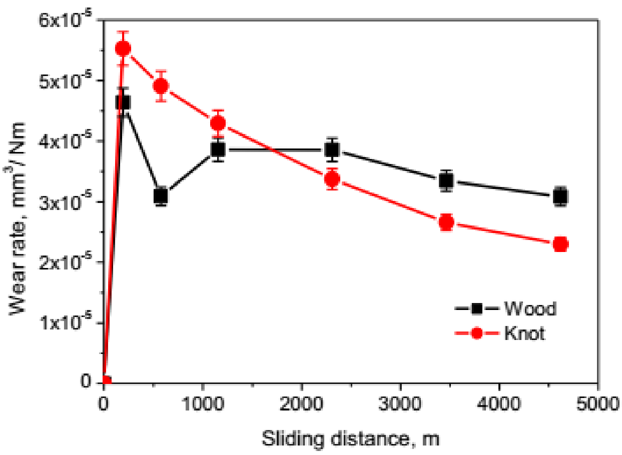


Fig. 4 Variation of wear rate with sliding distance at applied pressure of 1.0MPa and sliding velocity of 0.64 $ms^{-1}$

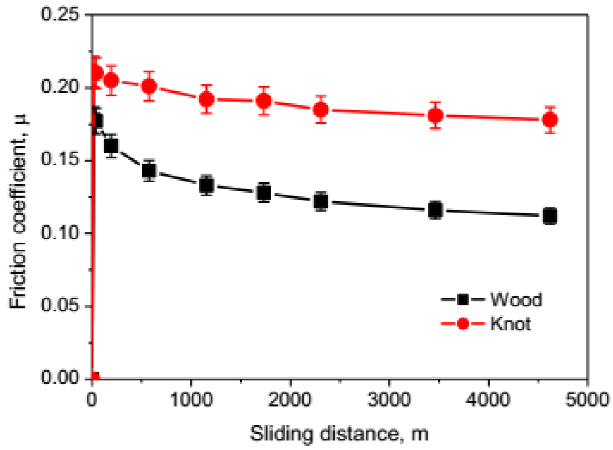


Fig. 5 Variation of friction coefficient with sliding distance at applied pressure of 1.0MPa and sliding velocity of 0.64 $ms^{-1}$

Fig. 6 shows the comparison of the variation of friction coefficient with normal load for wood and knot. These results show that friction coefficient decreases with the increase in normal load. Increased surface roughness and a large quantity of wear debris are believed to be responsible for the decrease in friction with the increase in normal load. Similar behavior is obtained for wood [24-26] i.e. friction coefficient decreases with the increase in normal load.

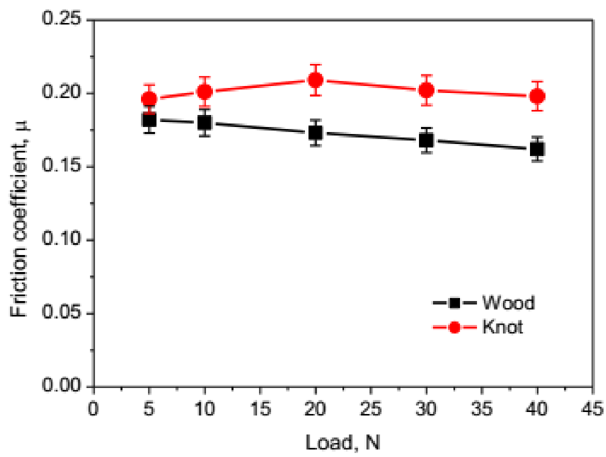


Fig. 6 Variation of friction coefficient with applied load at sliding velocity of 0.64 $ms^{-1}$

### 3.3. Optical Microscopic Observation

In Fig. 7 are presented the worn surfaces for the wood and knot at different sliding distances. Before wear the microstructure of the wood and knot show the smooth cell wall (Fig. 7a and 7b). In case of knot some spots are observed as it contents dead cells [27]. After wear for 200m the wood and knot microstructure show the lines in the direction of weariness (Fig. 7c and 7d). The damaged surface due to the adhesion wear, distortion took place in the surface of the specimen. It can also be observed that the surfaces of wood and knot as the sliding distance increase the wear marks becomes more visible and deep (Fig. 7e and 7f).

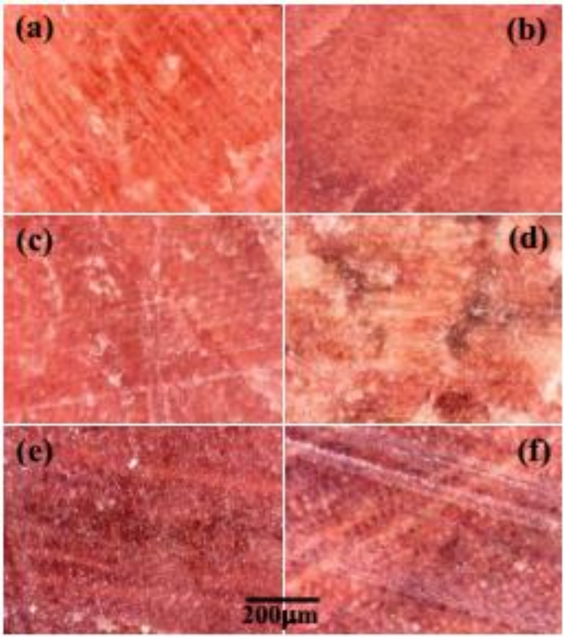


Fig. 7 Optical micrograph of worn surfaces of the wood and knot at different sliding distances at applied pressure of 1.0 MPa and sliding velocity 0.64 $ms^{-1}$

Fig. 8 shows the surfaces of MS counter-body which contents the dust of wood and knot generated during wear experiment at different sliding distances. Fig. 8a and 8b contains the dust of wood and knot after wear for 200m and Fig. 8c and 8d after wear for 4500m respectively. It shows that the higher sliding distance produces the higher amount of dust on the MS counter body. In this study, the dust is generated during the wear experiments from knot, contain higher amounts of large sized particles. This is due to fact that the knot contents compact cell wall. Whereas, the small sized particles produced from wood because of the losses cell wall.

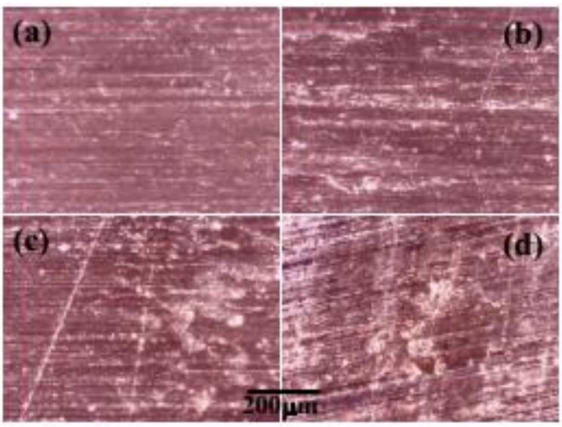


Fig. 8 Optical micrograph of MS disc surfaces for the wood and knot at different sliding distances at applied pressure of 1.0 MPa and sliding velocity 0.64 $ms^{-1}$

### 3.4. Scanning Electron Microscopy

The SEM micrographs of the wood and knot of pine timber are shown in Fig. 9a and 9b respectively. The wood fiber is basically built up of the polymers: cellulose, hemicelluloses, and lignin. Pectin, inorganic compounds, and extractives are also present in wood, although only as minor components. Wood consists of regular cell with larger cavity than that of knot. The higher number of compact cells is observed in the knot structure. The knot stays perpendicular from the grain direction of the regular wood. During growth the tree compresses the knot which results the compact cell [28, 29].

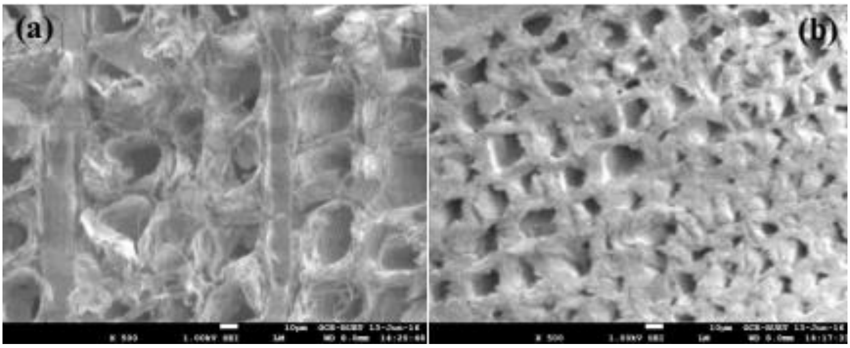


Fig. 9 SEM images of the a) wood and b) knot of pine timber

## 4. Conclusion

The knot itself is harder, denser, often more resinous and shrinks in a manner different from that of the surrounding tissue. Knot itself shows the higher mechanical properties than that of the wood. Wear rate increases to a maximum for wood and knot then attain a plateau for wood and decreases for knot with increasing sliding distance. The superior mechanical property of the knot leads to its better wear resistance. Regular cells with larger cavity are observed in wood structure and the knot contains the compact cell wall in the structure.

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