TRIBOLOGY UNDER REFINING CONDITIONS – INITIAL STUDIES

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ABSTRACT

The refining process is not yet fully understood and more fundamental knowledge is a key to improvements in the future. A tribological view on refining could give new understanding and ideas for improvement of the process efficiency. This paper presents a new apparatus for studying the frictional properties of wood – under refining conditions. A laboratory scale friction tester has been constructed where friction tests can be carried out in a steam atmosphere under high temperature/pressure and with maximum sliding velocity as high as 200 m/s. Initial studies in room temperature show that the coefficient of friction is proportional to the moisture content of wood at a sliding velocity of 24 m/s and with a normal load of 8 N. Wood extractives lowered the friction on dry surfaces and especially at high sliding velocity. The lubricating capacity of a variety of different resin model components among the extractives was also examined, but no significant effects has been found on wood specimens of 30 and 70 % in moisture contents.

INTRODUCTION

The refining process where wood chips are transformed into single fibres and fibre fragments is described by the laws of fracture mechanics. It is well known how the position of the fracture zone shifts due to thermal or chemical softening. Calculations based on fracture mechanical data show that one could expect that only a fraction of the actual energy consumption is needed to create desirable fracture surfaces [1] [2].

A large part of the supplied energy is consumed in developing fibre properties by internal delamination, external fibrillation, generating fines, cutting fibres and in viscoelastic losses. In refining, wood is loaded mechanically, mainly in shear, and fibres or fibre bunches are rubbed against each other in a narrow plate gap. These processes may to a large extent be described as friction processes. Since wood is a viscoelastic/plastic, natural polymeric material, its response to mechanical treatment is greatly affected by temperature, moisture, and time under load. Therefore, it is reasonable to assume that the friction properties of wood and fibre material also are strongly affected by the refining conditions.

The basics of sliding friction between macroscopic surfaces in dry contact was described in the early work of Coulomb in the 18th-19th centuries. Friction is caused by shearing of asperity junctions where asperities are in adhesive contact, by asperity interlocking between two surfaces and by plastic (or viscoelastic plastic) deformation of the surface region of one or both of the contacting solids.

Even though wood is a material that is widely used, surprisingly little research has been done lately concerning the frictional properties of wood. Extensive investigations on the friction of wood were made in the 1950s and 60s by Atack and Tabor [3], McKenzie and Karpovich [4] among others, but when it comes to friction at refining conditions there is still much to investigate.

The coefficient of sliding friction between two polymeric materials, or between one steel surface and a polymer, usually ranges from 0.1 to 0.5, but since the friction properties of polymeric materials diverge from the classical laws of friction by a strong dependence on the surrounding conditions, data tables are not meaningful [5].

The main purpose of this work is to investigate the fundamentals of wood-friction as functions of temperature/pressure, moisture content and sliding velocity. But it is also of great interest to learn how chemistry effects the coefficient of friction (for example extractives, pH, additives, etc.). In existing refining theories, the coefficient of friction is kept constant - probably due to lack of proper data [6]. As frictional forces are of great importance for the mechanical treatment of wood fibres [7], a tribological view of refining could give new understanding and ideas for improvement of the process efficiency.

METHODS AND MATERIALS

To simulate the TMP refining conditions a laboratory scale friction tester, a type of wear-rig, (TT2000) has been designed, built and implemented, allowing control of the testing environment, sliding velocity and normal load. The overall layout is shown in Fig. 1.

Apparatus

The friction tester has a stainless steel climate chamber. By leading steam into the chamber, a hot, pressurised steam environment can be achieved. The active parts of the wear-rig are a 269 mm diameter flat steel disc (3 mm thick) and a 12 ×12 × 12 mm^3 wood cube.

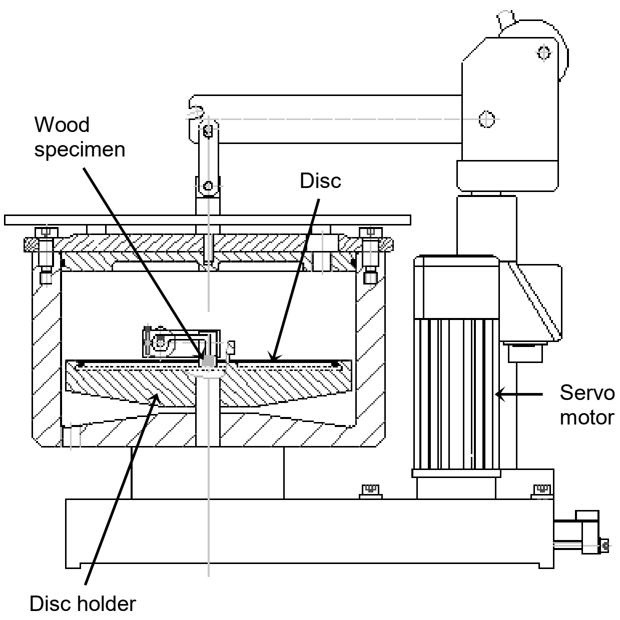

Fig. 1. Sectional view of the tribology tester.

The disc is mounted on a main spindle, which is driven by a servo motor connected to a computer. Rotational velocity can be varied and tuned by the computer and regulated by a servo motor controller. During the disc rotation, one side of the wood specimen (the test surface) slides on a constant diameter wear track of the disc, producing sliding velocities ranging up to over 200 m/s. For comparison, the relative velocity in the grinding zone of a double disc refiner ranges from about 170 m/s to 250 m/s.

Normal load is applied to the cube by a dead weight loading device. The friction force between the surface of the wood specimen and the disc is measured with a piezoresistive load cell, which also restrains the rotational movement of the specimen holder (see Fig. 2). To prevent disturbing influences on the load cell by moisture and high temperature, the load cell is placed outside the chamber. The friction force is transmitted through the chamber wall via a custom made sealed system. The output from the load cell is amplified and passed on to a computer. Since relatively fast data acquisition and processing are required, data can be acquired at 3000 Hz.

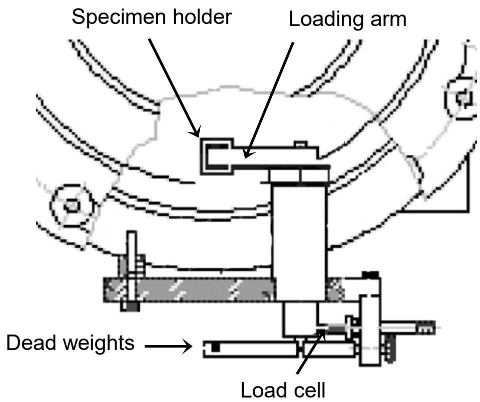

Fig. 2. Loading device with friction force transmission (top view).

Friction measurements

As the refining process consists of a rapid sequence of events, the initial friction directly after the load is applied is of great interest. In this study all measurements were made immediately after loading i.e. after the transient due to loading had faded. When the sliding velocity was varied the time of measurement was adjusted to obtain equal sliding distance. In between measurements the test disc was carefully cleaned with acetone and lint free laboratory tissue. All measurements in this initial study were performed at room temperature (23°C and 50 % RH).

Disc

The steel disc (SS2333 0,07% C stainless steel) was grinded, annealed and then polished at random directions to get between 0,03 and 0,1 µm in surface roughness (R_a). The disc is fastened to a flat disc holder which is connected to the main spindle of the rig.

Wood specimens

The wood specimens used in this study were cubes, 12 ×12 × 12 mm^3, prepared from fresh spruce sapwood (Picea Abies). Smooth sample surfaces of early wood fibres were created with a sledge microtome by cutting off thin sections of wood. Only cubes where the annual rings were close to parallel to the test surface were used. All tests were performed on early wood surfaces sliding parallel to the fibre direction. A SEM image of one test surface is shown in Fig. 3.

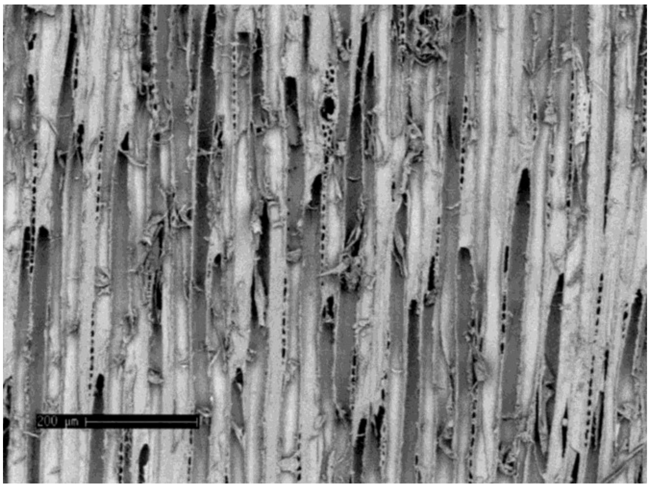

Fig. 3. SEM image of early wood test surface.

Early wood surfaces were chosen because they are smoother and more easy to characterise than mixed surfaces of both early and late wood fibres. The samples used in this study had an average surface roughness of 9 µm (R_a). An illustration of a wood specimen is shown in Fig. 4.

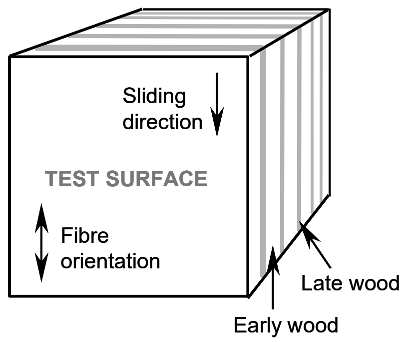

Fig. 4. Illustration of wood sample.

Extraction

In order to get wood specimens free of extractives the wooden cubes were extracted. The extraction was carried out in three steps using a Soxhlet apparatus; 8 hours in acetone, 16 hours in DCM (dichloromethane) and 8 hours in acetone respectively.

Impregnation

When investigating the influence of wood extractives on the friction between wood and steel surfaces the specimens were in a first experiment impregnated with extract from wood chips.

In a later experiment the specimens were impregnated with different resin model compounds representing different component groups among the extractives. The compounds are listed in Table 1.

Each compound was dissolved in acetone to obtain solutions of 50 mM. The specimens were immersed in the solutions over night. The reference specimens were placed in pure acetone during the same time. After the treatment the wood specimens were taken out of their solutions and left to dry and be conditioned in air of controlled humidity.

To evaluate the impregnation of the specimens a surface analysis was made with ATR-FTIR. The study showed that the impregnation method gave extractives deposited onto the wood and that there is a correlation between the concentration of the immersion solution and the surface concentration on the wood, i.e. no saturation of the surface was found.

Conditioning

After the impregnation, the specimens were conditioned for 48 hours at 23°C and 50 % RH, which gave a moisture content of about 8 %. For higher moisture content a climate chamber was used to condition the specimens. To obtain fibre saturation (about 70 % in moisture content) the specimens were placed in water.

Method limitations

Results from measurements of the coefficient of friction, are notorious for their scatter. It is well known that surface topography, contact conditions (sliding velocity, load, temperature, sliding distance and contact geometry) and humidity are sources of scatter. Another source is the dynamic parameters of the friction test apparatus.

As the tribology tester has a soft loading system (a dead weight loaded specimen) the contact load fluctuates. Any small misalignment or distortion in the face of the disc will imply accelerations, giving inertia loads. A stiff system would not be a solution as this would cause similar problems (varying load) [8].

As mentioned above the coefficient of friction depends strongly on the surrounding conditions and the test apparatus in itself. In this study the intention is therefore to find general relations and trends at certain conditions. We have not strived for absolute numerical values for the coefficient of friction since it is a system parameter, not a material parameter.

TABLE 1. RESIN MODEL COMPOUNDS AMONG THE EXTRACTIVES

Name	Carbon chain length	Structure
Alkanes		
n-Decane	10	$CH_3(CH_2)_8CH_3$
n-Octadecane	18	$CH_3(CH_2)_{16}CH_3$
Fatty alcohols		
n-Decanol	10	$CH_3(CH_2)_8CH_2OH$
n-Octadecanol	18	$CH_3(CH_2)_{16}CH_2OH$
Saturated fatty acids		
n-Decanoic acid	10	$CH_3(CH_2)_8CO_2H$
n-Octadecanoic acids	18	$CH_3(CH_2)_{16}CO_2H$
Unsaturated fatty acids		
cis-9-Octadecanoic acid	18	$CH_3(CH_2)_7CH=CH(CH_2)_7CH_3$
cis, cis-9,12-octadecanoic acid	18	$CH_3(CH_2)_4CH=CHCH_2CH=CH(CH_2)_7CO_2H$
Triglycerid		
Tristearin	18	$CH_3(CH_2)_{16}COO-CH_2$ / $CH_3(CH_2)_{16}COO-CH$ / $CH_3(CH_2)_{16}COO-CH_2$
Resin Acid		
Abietic acid	-	$C_{20}H_{30}O_2$
Sterol		
Sitosterol	-	$C_{19}H_{50}O$

RESULTS

Influence of moisture content

The friction between steel and extracted wood specimens, conditioned to three different moisture contents (8 %, 30 % and 70 %) were measured. The measurements were performed in room temperature, at a sliding velocity of 24 m/s and with a normal load of 8 N. In Fig. 5 the results from 8 measurements of each moisture content are presented. The figure shows a significant increase in the coefficient of friction with increasing moisture content. An AFM study made by Garoff and Zauscher also showed a significant increase of the friction and adhesion of clean cellulose with humidity [9].

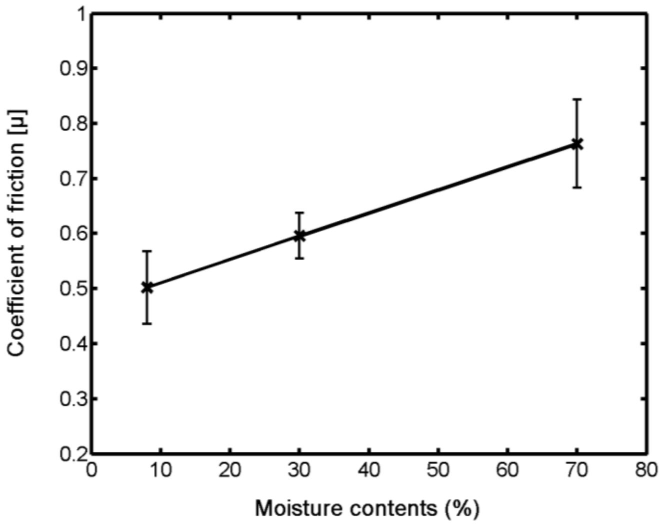

Fig. 5. Influence of moisture content on wood-steel friction.

Atack and Tabor described the friction of wood using two terms; one caused mainly by interfacial adhesion and another related to deformation, which is essentially a bulk phenomenon [3]. The raise in friction due to an increased moisture content could be explained with the help of these terms. As the wood specimens are softened by increasing moisture content [10] energy dissipation due to viscoelastic or plastic deformations give larger contributions to the coefficient of friction. This internal friction is a sort of resistance against movement between the long polymer chains of the material.

Softening could also cause the area of the actual contact to increase with moisture, as the surface roughness causes contact to occur only at discrete spots. A larger contact area would increase the contribution from surface interactions dominated by interfacial adhesion, i.e. the coefficient of friction would increase.

Influence of wood extractives

After extraction of the wood specimens, impregnation with extracted resin and conditioning to about 8 % moisture content, the friction properties were tested. In Fig. 6 the friction coefficient of the impregnated specimens are shown as a function of sliding velocity. The friction of extracted wood is included as a reference.

The friction between steel and extracted wood surfaces seem to increase with sliding velocity. This could be a viscoelastic effect since the yield stress of wood increases drastically with the deformation rate [11].

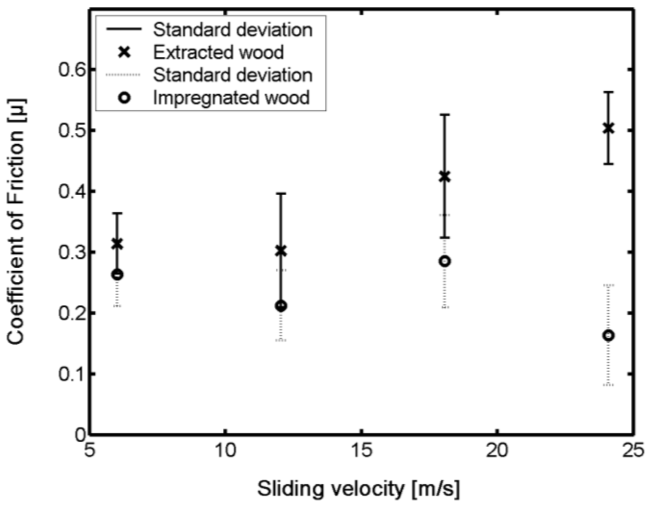

Fig. 6. Influence of wood-extractives on wood-steel friction.

It seems like wood extractives reduces the friction between dry wood and steel surfaces, especially at high sliding velocity. This could be explained by the fact that a thin lubricating layer of extractive substance is introduced between the surfaces. Higher sliding velocity increases the temperature in the contact region, and friction might arise primarily from the shear of a softened or molten layer of extractives with a temperature-dependent viscosity or shear strength [12]. Some components among the extractives have low melting points which decreases the melting point of the mixture.

Influence of model components

After impregnation with the model components listed in Table 1, friction measurements were made at two moisture levels, 30 % and 70 %. However, the differences in the results are not that striking and barely statistically significant. Table 2 shows that the coefficient of friction is not altered by neither abietic acid nor octadecanoic acid at high moisture content. At a moisture content of 8 % the two components tested lower the coefficient of friction considerably. These model components both lowered the friction between impregnated paper surfaces [13]. However, on paper at low sliding velocity octadecanoic acid lowered the friction more than abietic acid. The lack of difference between the components in our data could be an effect of temperature due to much higher sliding velocity.

TABLE 2. EFFECTS OF EXTRACTIVES AND MOISTURE CONTENT

Specimen	8 %	30 %	70 %
Extracted reference	0.50±0.06	0.58±0.06	0.79±0.05
Abietic acid	0.26±0.08	0.59±0.07	0.80±0.10
Octadecanoic acid	0.26±0.06	0.54±0.10	0.80±0.06

CONCLUSIONS

In conclusion, there are still a lot of variables left to examine that can possibly affect the coefficient of friction between wood and steel surfaces at extreme conditions. In this study a new apparatus for friction measurements has been presented. Results from the initial studies show:

- At high sliding velocity, 24 m/s, the coefficient of friction depends linearly on the moisture contents of the wood specimens.
- A friction lowering effect of wood extractive components has been recorded on dry wood at high sliding velocities. However, on wet wood no significant effects of extractive components could be seen.

Further investigations are needed in this field, especially at high temperatures and pressures. In the future, the friction properties of wood at temperatures around lignin softening (T_g of lignin) will be investigated thoroughly.

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