Wood Variables Affecting the Friction Coefficient of Spruce Pine on Steel

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ABSTRACT. Wood of spruce pine, *Pinus glabra* Walt., was factorially segregated by moisture content (0, 10, and 18 percent), specific gravity (less than 0.45 and more than 0.45), and extractive content (unextracted and extractive-free), and the kinetic coefficient of friction on steel (having surface roughness of 9 microinches RMS) determined for tangential earlywood, tangential latewood, radial, and transverse surfaces. Two directions of pull were considered for each surface. The friction coefficient was at maximum for the unextracted transverse surface of high moisture content pulled parallel to the rings (avg. 0.263). It was at minimum for the extractive-free transverse surface of high moisture content pulled perpendicular to the rings (avg. 0.165). Among unextracted samples, it was least for the tangential latewood surface of dense wood having intermediate moisture content and pulled perpendicular to the grain.

CLASSICALLY, the tangential force of kinetic friction between two surfaces sliding past each other is regarded as proportional to the normal force. The proportionality constant or friction coefficient depends on the materials and roughness of the surfaces, but over a wide range it is independent of the contact area and the relative velocity of the sliding surfaces.

In the research reported here, an analysis was made of the sliding coefficient of friction of spruce pine wood on steel. By stratifying wood into three moisture contents and two specific gravities at each of two extractive contents, it was possible to isolate the independent relationships of each of these wood properties with the friction coefficient. The interrelationships between these properties, or factors, and the friction coefficient were considered with respect to two grain orientations and four wood surfaces.

While others have investigated the coefficient of friction of wood on steel, none appears to have stratified the samples to reveal the independent effects of wood variables. For this reason, and because of additional differences in method, it is difficult to compare the present data with those already in the literature.

Procedure

A factorial experiment replicated three times was designed with variables as follows:

Unextracted specific gravity (ovendry weight and green volume)
- Less than 0.45
- More than 0.45

Extractive content (percent of ovendry unextracted weight)
- Extractive-free (0 percent)
- Unextracted (content at test)

Moisture content (percent of ovendry weight)
- 0 percent (low)
- 10 percent (intermediate)
- 18 percent (high)

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Six wood samples, three in each specific-gravity class, were selected from six trees field-identified as spruce pine. This species was chosen because the Southern Forest Experiment Station is attempting to define its properties as an industrial raw material. Each sample was cut into six 1-inch cubes and sanded in order to accurately expose a radial, a transverse, and two tangential surfaces—one of the tangential surfaces was entirely of earlywood and one entirely of latewood (Fig. 1). Getting surfaces of the desired size necessitated taking the samples from the outer portion of large logs.

The 18 cubes in each specific-gravity class were randomly divided into two groups of nine each. One group was extracted in acetone for 24 hours, benzene and ethanol (2 to 1) for 48 hours, and ethanol for 48 hours. The other group was not extracted.

The cubes in each specific gravity and extractive content category were then divided into three groups of three and conditioned to moisture contents of zero percent (ovendried at 105° C.), 10 percent, and 18 percent. Thus, 12 factorial combinations of specific gravity, moisture content, and extractive content were considered.

The horizontal force (F_h) required to slide a 1-square-inch surface subjected to a known vertical force component (F_v) was measured and the coefficient of kinetic friction (μ) calculated by the relationship $\mu = F_h/F_v$.

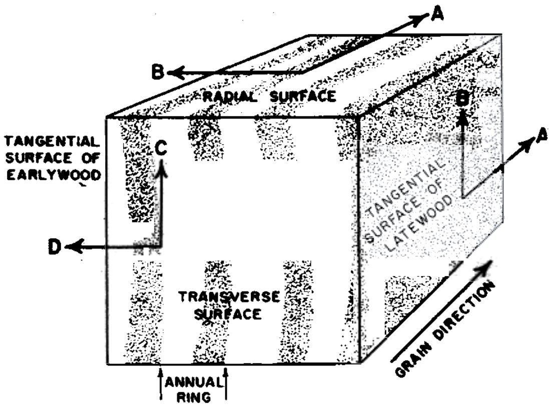

Figure 1. — Method of specimen preparation. The letters A, B, C, and D refer to direction of slide (grain orientation). Direction A is parallel to the wood grain while direction B is perpendicular. Direction C is parallel to the annual rings while direction D is perpendicular.

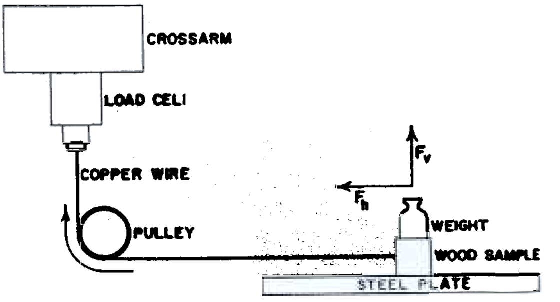

Figure 2. — Experimental setup.

An Instron testing machine was used to maintain a constant sliding velocity of 2 inches per minute as well as to measure the horizontal force (Fig. 2). A thin copper wire was attached to the specimen and to a 1-pound load cell mounted on the movable crossarm of the testing machine. Movement of the crossarm thus provided a constant sliding velocity, while the load cell simultaneously detected the horizontal force component. A 1-pound weight was placed on the upper surface of the cube and it, plus the weight of the sample, was considered the total vertical force component.

An oil-hardened, tool steel plate was used as the stationary surface. Its surface roughness was 9 microinches RMS, and the specimens were pulled parallel to the grinding marks. Prior to each force determination, the plate was cleaned with acetone and a lint-free laboratory tissue. Ordinary paper towels were found to deposit a film that made results erratic.

Each wood surface was sanded in a figure-eight motion with a fresh sheet of 220-grit sandpaper and cleaned with compressed air prior to each run. Each surface was tested in two directions. On the radial and tangential surfaces, specimens were pulled first parallel and then perpendicular to the grain (direction A and direction B in Fig. 1). On the transverse surface they were pulled both parallel and perpendicular to the annual rings (direction C and direction D in Fig. 1). Three observations were made for each surface and direction of pull and the results averaged. Tests were conducted at 24° C.

At the conclusion of the experiment, the moisture content, extractive content, and specific gravity of all specimens were determined by standard methods.

Table 1. — RESULTS OF WOOD PROPERTY AND FRICTION COEFFICIENT DETERMINATIONS.[1]

Moisture content	Specific gravity	Extractive content	Parallel slide				Perpendicular slide			
			Tangential latewood	Tangential earlywood	Transverse	Radial	Tangential latewood	Tangential earlywood	Transverse	Radial
Percent		Percent								
0.00	0.397	0.00	0.192	0.216	0.205	0.182	0.179	0.199	0.198	0.197
.00	.499	.00	.204	.211	.195	.178	.205	.187	.192	.180
.00	.392	1.65	.179	.200	.250	.209	.164	.192	.225	.220
.00	.509	.96	.174	.190	.233	.207	.162	.218	.226	.217
11.78	.386	.00	.188	.223	.228	.213	.183	.212	.229	.199
10.74	.511	.00	.204	.193	.215	.198	.183	.192	.229	.201
11.01	.394	2.13	.191	.213	.247	.196	.208	.207	.269	.216
11.13	.518	1.02	.160	.166	.180	.152	.156	.150	.171	.156
19.95	.392	.00	.223	.194	.172	.214	.222	.177	.164	.208
16.96	.514	.00	.181	.192	.168	.233	.180	.173	.166	.222
18.29	.385	1.63	.165	.203	.273	.218	.162	.199	.255	.198
18.45	.514	1.25	.203	.197	.253	.198	.195	.197	.255	.182

[1]Each numerical value is the average of three replications.

Results

Table 1 summarizes the information on wood properties and coefficients of friction. The values for moisture content ranged from zero to 25.34 percent; specific gravity ranged from 0.350 to 0.530. Extractive contents ranged from zero to 3.1 percent; the average for unextracted wood was low—1.4 percent—because the samples were from the outer portion of old stems.

Mean values for the friction coefficient by moisture content, specific gravity, and extractive content are listed in Table 2 for each combination of direction of slide and wood surface. Differences between means were tested by analysis of variance at the 0.05 level of significance. Variance analysis was preferred to regression because it more readily separates effects of individual factors.

For samples pulled in the parallel direction and averaged over all moisture contents, specific gravities, and extractive contents, the friction coefficient was significantly lower for the tangential surface of latewood (avg. 0.189) than for the transverse surface (avg. 0.218). No differences were detected between coefficients for the remaining surfaces.

For samples pulled in the perpendicular direction, the friction coefficient was significantly greater (avg. 0.215) for the transverse surface than for the tangential surface of latewood (avg. 0.183) or the tangential surface of earlywood (avg. 0.192). No differences were detected between friction coefficients among the remaining surfaces.

Tangential Surface of Latewood

When averaged over all moisture contents and specific gravities (Table 2), the friction coefficient for tangential latewood was higher in extractive-free wood than in unextracted wood. For samples pulled parallel to the grain the average values were 0.199 for extractive-free wood and 0.179 for unextracted wood. For samples pulled perpendicular to the grain the corresponding values were 0.192 and 0.174. No differences were detected between moisture contents or specific gravities.

When averaged over all study variables, friction coefficient showed no significant difference between directions of slide; averages were 0.189 parallel to the grain and 0.183 perpendicular.

Tangential Surface of Earlywood

Only one primary variable, specific gravity, was significant when tangential earlywood was pulled parallel to the grain. When averaged over all moisture and extractive contents, the friction coefficient (μ) was greater (avg. 0.208) in wood of low gravity than in wood of high gravity (avg. 0.192).

The interaction of specific gravity and moisture content was significant. As the follow-

Table 2. — EFFECT OF STUDY VARIABLES ON THE COEFFICIENT OF FRICTION.[1]

Factor	Parallel slide				Perpendicular slide			
	Tangential latewood	Tangential earlywood	Transverse	Radial	Tangential latewood	Tangential earlywood	Transverse	Radial
Moisture content				*				
Low (0%)	0.187	0.204	0.221	0.194	0.178	0.199	0.210	0.203
Intermediate (avg. 11.2%)	.186	.199	.218	.190	.182	.190	.224	.193
High (avg. 18.4%)	.193	.196	.216	.216	.190	.187	.210	.202
Specific gravity		*	*					*
Less than 0.45 (avg. 0.39)	.190	.208	.229	.205	.186	.198	.223	.206
More than 0.45 (avg. 0.51)	.189	.192	.207	.194	.180	.186	.206	.193
Extractive content	*		*		*		*	
Extractive free (0%)	.199	.205	.197	.203	.192	.190	.196	.201
Unextracted (avg. 1.4%)	.179	.195	.239	.197	.174	.194	.234	.198
Grand mean	.189	.200	.218	.200	.183	.192	.215	.199

[1]All factors were tested at the 0.05 level; significant differences are indicated by an asterisk.

ing tabulation indicates, the friction coefficient decreased with increasing specific gravity when the moisture content was intermediate. At high or low moisture contents, the coefficient remained unchanged with increasing specific gravity. Thus, when a tangential surface of earlywood is pulled parallel to the grain, low coefficients of friction (avg. 0.180) are associated with dense wood of intermediate moisture content:

Specific gravity	Wood moisture contents		
	Low	Intermediate	High
	(μ)	(μ)	(μ)
Less than 0.45	0.208	0.218	0.198
More than 0.45	.201	.180	.194

None of the primary variables proved significant for the tangential surface of earlywood pulled perpendicular to the grain, but the interaction of specific gravity and moisture content was again significant. The coefficient was least for dense wood of intermediate moisture content (avg. 0.171), and no differences were detected between specific gravities when the moisture content was high or low:

Specific gravity	Wood moisture contents		
	Low	Intermediate	High
	(μ)	(μ)	(μ)
Less than 0.45	0.196	0.210	0.188
More than 0.45	.203	.171	.185

Further, moisture content interacted with extractive content. The friction coefficient decreased with increasing extractive content when the moisture content was intermediate, but increased with increasing extractive content when the moisture content was high. At low moisture contents, the coefficient was unaffected by changes in the level of extractives. The coefficient was lowest for unextracted wood of intermediate moisture content (avg. 0.179) and extractive-free wood of high moisture content (avg. 0.175):

Extractive content	Moisture contents		
	Low	Intermediate	High
	(μ)	(μ)	(μ)
Extractive-free	0.193	0.202	0.175
Unextracted	.205	.179	.198

When averaged over all moisture contents, specific gravities, and extractive contents, the coefficient for tangential earlywood did not differ between directions of slide.

Transverse Surface

When averaged over all moisture and extractive contents, and when pulled parallel to the annual rings, wood of low specific gravity had a higher friction coefficient (avg. 0.229) than wood of high specific gravity (avg. 0.207). Extractive-free wood had a lower friction coefficient (avg. 0.197) than unextracted wood (avg. 0.239). No differences were detected between moisture contents, although the interaction of extractive content and moisture content was significant. The coefficient of friction increased with increasing extractive content at high and low moisture contents but remained relatively constant with increasing extractive content at intermediate moisture. The coefficient was least (avg. 0.170) when the moisture content was high and the wood was extractive-free; it was greatest (avg. 0.263) when the moisture content was high and the wood was unextracted:

Extractive content	Moisture contents		
	Low	Intermediate	High
	(μ)	(μ)	(μ)
Extractive-free	0.200	0.222	0.170
Unextracted	.242	.214	.263

When the transverse surface was pulled perpendicular to the annual rings, extractive-free wood had a lower friction coefficient (avg. 0.196) than unextracted wood (avg. 0.234). The interaction of extractive content and moisture content was also significant; the trends were similar to those observed when the specimen was pulled parallel to the rings. Thus, the coefficient was least (avg. 0.165) when the moisture content was high and the wood extractive-free; it was greatest (avg. 0.255) when the moisture content was high and the wood was unextracted:

Extractive content	Moisture contents		
	Low	Intermediate	High
	(μ)	(μ)	(μ)
Extractive-free	0.195	0.229	0.165
Unextracted	.226	.220	.255

When averaged over all variables, the mean coefficient for the transverse surface was 0.215 for samples pulled perpendicular to the annual rings and 0.218 for samples pulled parallel. The means were not significantly different.

Radial Surface

In radial surfaces pulled parallel to the grain, the coefficient of friction was least when the moisture content was low or intermediate (avg. 0.194 and 0.190, respectively), and greatest when the moisture content was high (avg. 0.216). The interaction of moisture content and extractive content was also significant. When the wood was unextracted, the coefficient was least when the moisture content was intermediate (avg. 0.174). There was no difference in coefficients between high and low moisture contents. In extractive-free wood the coefficient was least when the moisture content was low (avg. 0.180) and greatest when the moisture content was high (avg. 0.224):

Extractive content	Moisture contents		
	Low	Intermediate	High
Extractive-free			
Unextracted			

When a radial surface was pulled perpendicular to the grain, the coefficient decreased with increasing specific gravity. Wood of low gravity averaged 0.206, while wood of high gravity averaged 0.193. The interaction of specific gravity and extractive content was significant. Thus, friction decreased with increasing specific gravity in unextracted wood but remained unchanged in extractive-free wood. The coefficient was least (avg. 0.185) in dense, unextracted wood:

Extractive content	Specific gravities	
	Less than 0.45	More than 0.45
	(μ)	
Extractive-free	0.201	
Unextracted	.211	

The interaction of moisture content and extractive content was also significant. With increasing moisture content friction increased in extractive-free wood but decreased in unextracted wood:

Extractive content	Moisture contents		
	Low	Intermediate	High
	(μ)	(μ)	(μ)
Extractive-free	0.188	0.200	0.215
Unextracted	.218	.186	.190

When averaged over all moisture contents, specific gravities, and extractive contents, the friction coefficient of the radial surface was 0.199 for samples pulled perpendicular to the grain and 0.200 for samples pulled parallel; the means were not significantly different.