Tribology Letters, Vol. 18, No. 3, March 2005 (© 2005)
DOI: 10.1007/s11249-004-2767-2

In situ examinations of the friction properties of chromium coated tools in contact with wet wood

P. Beer*

Christian-Doppler-Laboratory for Fundamentals of Wood Machining, University of Natural Resources and Applied Life Sciences, Tuerkenschanzstr. 18, 1180 Vienna, Austria
Faculty of Wood Technology, Agricultural University of Poznan, Wojska Polskiego 28, 60-637 Poznan, Poland

Received 4 May 2004; accepted 31 October 2004

The study is concerned with *in situ* examinations of the friction coefficient (μ) of various kinds of wet wood in contact with the active faces of a low-alloy steel cutting tools non-modified and covered with a chromium coating. The variable parameters were: the sliding speed (V) and the normal force (F_N). In all the material pairs examined in friction, the coefficient μ appeared to decrease with increasing V and increasing F_N. Its variation is described by an exponential function. The Cr coating reduces apparently the friction coefficient compared with that of uncoated steel, especially in static friction. The advantageous tribological properties of chromium coating covered with native chromium oxide can be attributed to its weak water wettability and high hardness.

KEY WORDS: chromium, steel, coating, friction, wet wood, tool

1. Introduction

Tools modified by coating their surface with a thin (in the range of 5 μm) chromium layer are used for the first transformation of wood, i.e. for machining wet wood. The chromium coated tools are e.g. frame saw tools, which during machining move in a reciprocal way. According to the observations made by tool manufacturers, chromium coatings prolong the service life of tools by a factor of 2 to 3, and improve the quality of the machined surface. This result has been confirmed by laboratory examinations [1], which have shown that chromium coated tools are capable of self-sharpening. The effect of the chromium coatings on the tribological properties of the chromium-modified tools when used for cutting wet wood has not yet been examined. It is worth specifying that the Cr coating in reality is Cr covered with a native thin chromium oxide film.

The aim of the present study was to find how the tribological properties of the tool surface are improved by coating it with chromium; the value of the friction coefficient (μ), measured under the varying conditions of the machining process, was taken to be the measure of these properties. The variable parameters of the machining process were: the cutting speed (V) and the loading force (F_N). The friction coefficient is a valuable indicator in estimating the cutting properties of tools [2] and in selecting the machining process parameters [3].

Friction between wet wood and steel was examined by McKenzie [4]. In his experiments, the character of the relationship between μ and V appeared to be strongly varied and the results are difficult to generalize. The results obtained by the standard laboratory methods for measuring the friction coefficient cannot be directly transferred to the measurements during wood machining, chiefly because there is no "replacement" of the surfaces in friction, i.e. the same surfaces remain continuously in tribological contact, whereas during the machining process, the active surfaces of the tool meet still new surfaces of the material being cut. Therefore, in the present experiments, the measurements of μ were performed *in situ* during the wood machining process.

2. *In situ* friction tests

The apparatus for the *in situ* measurements of the friction coefficient during the wood machining process was designed and constructed in the ENSAM, Cluny, France [5]. In this apparatus, a wood sample is rotated at a constant linear speed (V) and is acted upon by a specified normal force (F_N) exerted by a friction plate made of metal (figure 1). The friction plate is fixed on a piezo-electric sensor, which measures the friction force (F_F). The plate enters in contact with the wood directly after the cutting knife. As a result, during the measurement of the friction coefficient, the wood surface is in the same condition as that when it is in

*E-mail: piotr.beer@boku.ac.at

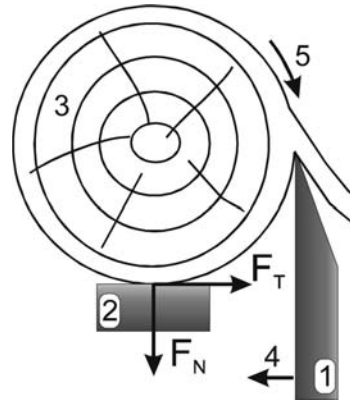

Figure 1. Method of measuring the friction coefficient: 1—cutting knife, 2—friction plate, 3—cut wood, 4—direction of the knife movement, 5—direction of wood movement, 6—chip obtained, F_N—normal force, F_T—friction force.

contact with the active tool surfaces. The values of the normal and friction forces are expressed in Newtons (N) per 1 cm (cm) of the width of the sample examined [N cm^{-1}]. The variation of μ as a function of the cutting speed was examined at a constant value of the normal force equal to 30 N cm^{-1}, whereas μ versus normal force—at a constant cutting speed of 1.0 m s^{-1}.

3. Materials

The friction plates examined in the experiments were made of low-alloy steel popular in the manufacture of the cutting tools intended for the first stage transformation of wood. The steel composition was: C-0.6, Si-1.8, Mn-0.7, Cr-0.3, Mo-0.5, V-0.2. The steel was surface modified by coating it galvanochemically with a Cr layer 5 μm thick. The process temperature was 70 °C. Surfaces roughness—R_Z—before and after modification was in the range of 1 μm.

The wood species selected for the experiments were false acacia (*Robinia pseudoacacia* L.), and beech (*Fagus selvatica* L.) as representatives of two variable hardwoods, and Douglas fir (*Pseudotsuga menziesii* Franco)—as a representative of softwoods. Prior to the examinations, the wood was subjected to a hydrothermal treatment (stored in water of 20 °C), so that its humidity exceeded the saturation point of the wood fibres (above 30%). During the measurements, the temperature of the wood was 20 °C.

According to increasing hardness, the materials can be ordered in the sequence: wood (HB: Douglas = 5, beech = 7, acacia = 18,) <steel ($HV_{0.05} = 850$) < chromium ($HV_{0.05} = 1100$).

4. Results and discussions

The variation of μ with F_N in steel and selected wood species is shown in figure 2(a), and in chromium coated steel—in figure 2(b). This variation can be described by the exponential function

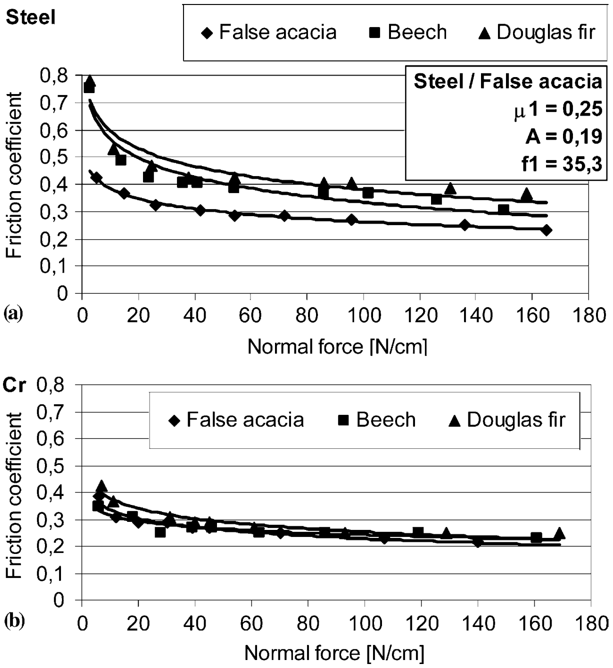

Figure 2. Effect of the normal force on the friction coefficient: (a) steel, and (b) Cr (framed data in figure 2(a) are the values of the parameters that appear in equation (1) for the steel/false acacia pair).

$$\mu = \mu 1 + Ae^{\frac{-F_N}{f1}} \qquad (1)$$

where: $\mu 1$, A and $f1$ are the parameters of the function characteristic of a given pair in friction.

The function (1) may be transformed to take the form:

$$\mu = \mu_{0F} - \mu_F(1 - e^{\frac{-F_N}{f1}}) \qquad (2)$$

where: the member $\mu_{0F} = \mu 1 + A (A = \mu_F)$ is the friction coefficient approximated to its value at $F_N = 0$ N. The second member represents the variation of the friction coefficient with increasing normal force.

The character of the relationship $\mu = f(F_N)$ of wet wood is similar to steel in contact with dry wood [6], which, according to the Kragielsky model [7], suggests that the mechanical state of these contacts is elastic and, hence, friction depends in the first place on the hardness of the mechanically weakest partner in the contact, i.e. in our case on the hardness of wood. With unmodified steel, μ evidently depends on the hardness of the wood, whereas with chromium coated steel, this dependence does not occur, and the values of μ are smaller than those observed with unmodified steel. Friction seems to be mostly affected by the hardness of the tool material, which can evidently be reflected in the wear of the tool used for machining a given

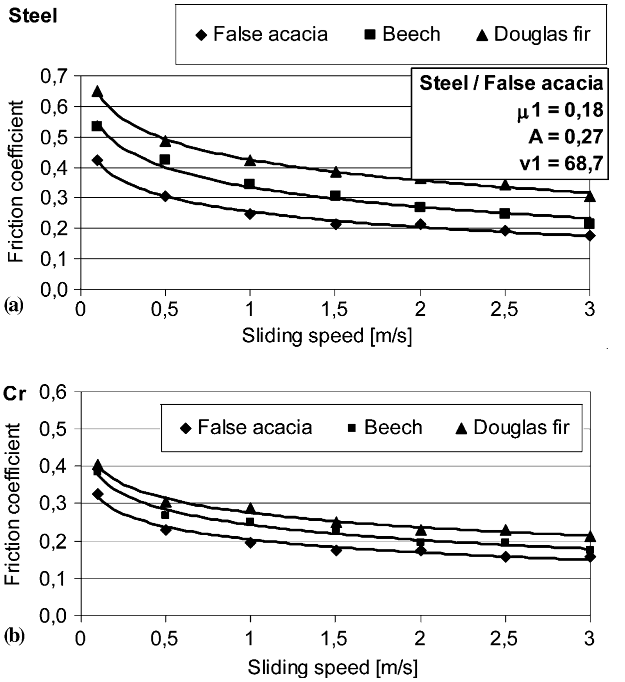

Figure 3. Effect of the sliding speed upon the friction coefficient: (a) steel, and (b) Cr (framed data in figure 3(a) are the values of the parameters in equation (3) for the steel/false acacia pair).

piece of wood. In the case of kinetic friction, the difference between the values of μ of steel and chromium seems however to be too small to explain the observed advantageous effect of frame saw tools coated with chromium.

The variation of μ with V for selected species of wood in contact with steel is shown in figure 3(a), and in contact with chromium—in figure 3(b). This variation is described by the exponential function:

$$\mu = \mu 1 + Ae^{\frac{-V}{v1}} \tag{3}$$

where: $\mu 1$, A and $v1$ are the parameters of the function characteristic of a given pair in friction.

The function (3) can be transformed into:

$$\mu = \mu_{0V} - \mu_V(1 - e^{\frac{-V}{v1}}) \tag{4}$$

where: the first member $\mu_{0\mathrm{V}} = \mu 1 + A(A = \mu_{\mathrm{V}})$ is the static friction coefficient (at $V = 0\ \mathrm{m\ s^{-1}}$) for a given pair in friction, and the second member describes the decrease of the friction coefficient with increasing sliding speed.

Table 1 gives the values of $\mu_{0\mathrm{V}}$ for the material pairs in friction examined in the present experiments. We can see that with chromium, principally, $\mu_{0\mathrm{V}}$ does not depend on the species of wood and its value is appreciably smaller than $\mu_{0\mathrm{V}}$ of steel (the value of $\mu_{0\mathrm{V}}$ primarily depends on molecular interactions). In the reciprocal movement performed by frame saws, the value of $\mu_{0\mathrm{V}}$ has an enormous significance. It seems that the fact that this tribological property is better in chromium than in steel may contribute considerably to a reduction of tool wear. The stabilized values of μ (μ_{C}), i.e., such that remain constant with the variation of V, do not significantly differ between steel and chromium (table 1).

The functions μ (F_{N}) and μ (V) have a monotonically decreasing character, which suggests that the state of the contact does not undergo violent changes, such as, in the first place, water removal from the contact. This means that a water layer (derived from wood) was continuously present in the contacts examined. The molecular interaction of native chromium oxide film present on the chromium with water is weaker than that of steel, since the latter is better wetted by water. It seems that it is just the molecular interaction with water, which determines the value of $\mu_0(V)$, which would explain the improved anti-abrasive behaviour of chromium-coated frame saw tools in the process of cutting wet wood.

Laboratory examinations of the relationship $\mu = f(V)$ in dry wood in contact with steel [8] have shown that here the process has an entirely different character. The value of μ increases with increasing V, even though the mechanical state of the contact is elastic. A comparison of the behaviours of dry and wet wood clearly indicates the significance of the presence of water in the contact.

5. Conclusions

The *in situ* examinations of the friction process with wet wood machined with the use of a reciprocally moving tool have shown that chromium has good tribological properties and that these properties can be

Table 1.
Values of $\mu_{0\mathrm{V}}$ (the static friction coefficient) and μ_{C} (the stabilized values of friction coefficient) for the various pairs in friction examined in the experiments.

	False acacia		Beech		Douglas fir	
Tool's surface	$\mu_{0\mathrm{V}}$	μ_{C}	$\mu_{0\mathrm{V}}$	μ_{C}	$\mu_{0\mathrm{V}}$	μ_{C}
Steel	0.45	0.18	0.55	0.21	0.69	0.31
Chromium	0.36	0.16	0.40	0.18	0.41	0.21

attributed to the high hardness and poor wettability of native chromium oxide by water.

In the tribological contact of wet wood with the active faces of the cutting tool, the values of the friction coefficient decrease with increasing sliding speed or increasing normal force. The variation of the friction coefficient depending on these two parameters can be described by exponential functions.

Acknowledgments

Author would like to express his appreciation to the university of ENSAM Cluny in France for the possibility of performing tests and to Prof. Aleksandra Sokolowska, Prof. Remy Marchal and DI Gerhard Sinn for valuable discussions about the results obtained.

References

[1] Ch. Kato, J. Jpn. Wood Res. Soc. 39(4) (1993) 406.

[2] M.A. Djouadi, P. Beer, R. Marchal, A. Sokolowska, M. Lambertin, W. Precht and C. Nouveau, Surf. Coat. Technol. 116–119 (1999) 508.

[3] W.M. McKenzie, Wood Sci. Technol. 25 (1991) 397.

[4] W.M. McKenzie, Forest Prod. J. 17(11).

[5] J.C. Butaud, C. Decès-Petit and R. Marchal, *Proc. 12th IWMS, Kyoto, Japan* (1995) p. 479.

[6] P. Beer, S. Miklaszewski, A. Sokolowska, *Proc. 10th Congr. IFHT, Brighton, England* (1999) p. 533.

[7] I.V. Kragielsky, M.N. Dobychin and V.S. Konbalov, Friction and Wear – Calculation Methods. (Pergamon Press Ltd., 1982).

[8] S. Sugiyama, J. Jpn. Wood Res. Soc. 38(2) (1992) 144.