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Evaluation of the kinetic friction performance of modified wood decking products

Ling Li [a,b,*], Meng Gong [b], Dagang Li [a]

[a] College of Wood Science and Technology, Nanjing Forestry University, Nanjing 210037, Jiangsu, China
[b] Faculty of Forestry and Environmental Management, University of New Brunswick, Fredericton, New Brunswick, Canada E3B 5A3

HIGHLIGHTS

- ▶ Irregular stick-slip motion occurred in the dry wood based specimens tested by a heavy slider at a low sliding speed.
- ▶ Random motion was found in wood plastic composite (WPC) specimens at all conditions.
- ▶ The μ_k of WPC specimens was lower than that of modified/untreated solid wood specimens.
- ▶ The ratio of μ_s to μ_k of wood based specimens ranged from 0.70 to 0.85 but that of WPC specimens ranged from 0.40 to 0.50.

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ABSTRACT

Sliding friction behavior plays a critical role in diverse systems to determine the serviceability of end-used wood products, such as safety. The kinetic or dynamic coefficient of friction (μ_k) is used to describe the relative motion between two objects, which is highly dependent on the material characteristics and surface topology. It has been discovered that the relationship between friction force and sliding time is a kind of regular/chaotic 'stick–slip' or random motion, i.e. nonlinear. However, studies on the nonlinear friction behavior of modified wood products are very limited. This study was aimed at providing a deep understanding of the kinetic friction behavior of wood decking products, including Chromated Copper Arsenate (CCA) treated spruce lumber (CCAS), heat-treated spruce lumber (HTS), wood plastic composite (WPC) lumber and untreated spruce lumber (UTS) as a control group. The authors extended their previous research on the evaluation of slip resistance of modified wood decking products in terms of static coefficient of friction (μ_s). The experimental design included four types of specimens (CCAS, HTS, UTS and WPC), two surface conditions (dry and wet), three sliding speeds (10, 50 and 250 mm/min), and two weights of sliding block (14 and 20 kg). The testing set up was in accordance with ASTM D2394 "Standard methods for simulated service testing of wood and wood-base finish flooring". It was found that (1) 'stick–slip' motion only occurred when a 20 kg sliding block moved at a speed of 10 mm/min on the dry surface of CCAS, HTS, and UTS specimens, while under the rest conditions, a random motion was found. However, only the random motion was observed under all conditions for WPC specimens; (2) the average μ_k values of all types of specimens under wet surface condition were larger than those under dry surface condition. The μ_k values of WPC specimens were the lowest among four types of specimens, followed by UTS, and then HTS and CCAS; (3) the ratios of μ_k to μ_s of CCAS, HTS, and UTS specimens ranged from 0.70 to 0.85, while those of WPC specimens varied between 0.40 and 0.50; and (4) good linear correlations between μ_k and μ_s were found in modified wood products tested.

1. Introduction

With an increasing concern on environment, Chromated Copper Arsenate (CCA) treated lumber has been substituted by environmentally friendly products, such as wood plastic composite (WPC) and heat treated lumber. When these products are used as decking, their slipping behaviors play a critical role in evaluation of safety of pedestrians. A decking or flooring of a low coefficient of friction suggests a high slippery surface, causing pedestrians to easily slip and fall down. A report published by the National Floor Safety Institute showed that the surface property of flooring was a major cause for over 50% of slips and fall accidents and the estimated average cost for defending against a slip and fall lawsuit was around $50,000 per year [1].

The sliding friction behavior of decking can be evaluated in terms of the coefficient of friction, which usually occurs between

* Corresponding author at: Faculty of Forestry and Environmental Management, University of New Brunswick, Fredericton, P.O. Box 4400, 28 Dineen Avenue, New Brunswick, Canada E3B 5A3. Tel.: +1 506 453 4507 (office); fax: +1 506 453 3574.

E-mail addresses: Ling.Li@unb.ca, njfuldg@163.com (L. Li), mgong@unb.ca (M. Gong).

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two moving objects having non-smooth surfaces. There are two coefficients of friction. The first is called the static coefficient of friction (μ_s), which is defined as the friction opposing the initial relative motion/impending motion. μ_s has been employed by the Canadian Construction Materials Centre (CCMC) to evaluate the slip resistance in its Technical Guides [2]. The second is the kinetic coefficient of friction (μ_k), which is defined as the friction opposing the continuance of relative motion once the motion has started. μ_k can be used to simulate the movement between a pedestrian's foot and the underfoot surface (such as decking or flooring) during a sudden slip on the heel [3].

In comparison to μ_k, μ_s of modified wood products has been studied by authors and other researchers [4–6]. The results showed the μ_s values of CCA treated and heat treated lumbers were larger than those of WPC lumber. However, the studies on the behavior of friction force with increasing time during a stable sliding movement, i.e. the kinetic friction behavior, were very limited. It was reported that μ_k was about 25% less than μ_s for solid wood [7]. Nevertheless, due to the diverse characteristics of a material and its surface properties (e.g. smooth or rough, hard or soft, elastic, viscoelastic, or plastic, brittle or ductile, dry (unlubricated) or lubricated, and different chemical components), the multitude of asperities on two individual surfaces either coming into or out of the contact display a nonlinear nature of friction [8]. In other words, in the case of sliding friction, any simple input of a constant driving force or a steady sliding speed applied on a slider can result in a complex spectrum of motions [9]. The relationship between μ_k and μ_s might be different with the changes in material component, surface condition, sliding speed, external load, etc. In addition, Blau [7] pointed out that there were some ambiguities about the definition of terminology on friction testing. One of controversial issues was the term of 'stick–slip' that describes a periodically or chaotically instable motion between two objects [8–10]. As illustrated in Fig. 1 (adapted from Blau [7]), the upward oblique lines labeled 's' mean that no relative motion occurs between two surfaces at these periods but the driving force keeps increasing until it reaches the maximum value. This maximum force is named as static friction force (F_s), which is sufficient to prevent the relative motion between two surfaces. The downward oblique lines labeled '*k*' indicates the occurrence of the relative motion, so that the driving force quickly decreases to a minimum. This minimum force is redeemed as kinetic or dynamic friction force (F_k). Blau [7] indicated that it was not correct to calculate μ_k by averaging the ratios of the driving force and the normal force through all periods. However, this special phenomenon in sliding friction testing for wood-based products has not been discussed.

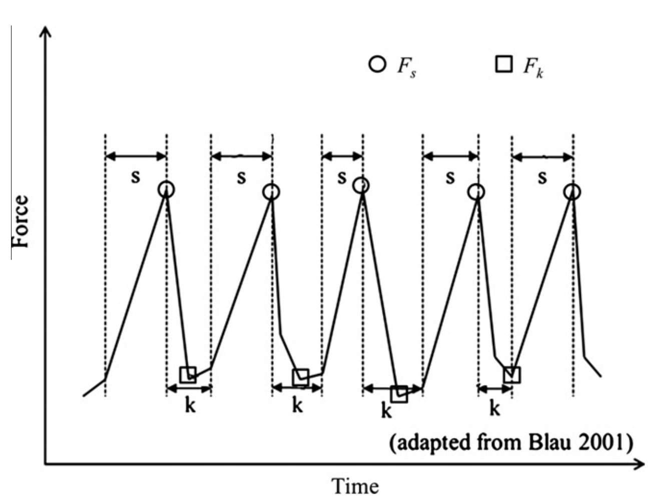

Fig. 1. Illustration of 'stick–slip' motion and definition of F_s and F_k.

Therefore, the authors extended their previous discussion on the evaluation of slip resistance of modified wood decking products in terms of static coefficient of friction (μ_s) in this paper with an aim at providing a deep understanding of the kinetic friction behavior occurring in a sliding movement between a piece of leather and different wood-based decking products. To reach this goal, the μ_k of all specimens under two surface conditions (i.e. dry and wet), three sliding speeds (i.e. 10, 50 and 250 mm/min), and two weights of sliding block (i.e. 14 and 20 kg) was measured and analyzed.

2. Materials and method

The preparation of materials and friction testing method used in this study were exactly the same as those described in a previous paper by authors [6], and briefly summarized as follows.

2.1. Materials

Four groups of specimens were purchased from market, including three groups of planed lumbers: Chromated Copper Arsenate (CCA) treated spruce lumber (CCAS), heat treated spruce lumber (HTS), untreated spruce lumber (UTS) used as a control group, and one group of wood plastic composite (WPC) lumber. The surfaces of these products were not coated with lacquer or other materials. The dimensions of CCAS, HTS and UTS specimens were 50 mm (thickness) by 102 mm (width) by 300 mm (length), while WPC specimens had the dimensions of 25 mm (thickness) by 152 mm (width) by 300 mm (length). 18 specimens for each group were prepared, giving a total of 72 specimens. One side of a specimen was tested under dry surface condition and the other side was tested under wet surface condition. Before testing, all specimens were placed in a conditioning chamber at 20 ± 2 °C and 65 ± 5% relative humidity until they reached their own stable moisture contents.

2.2. Method

Sliding friction tests were conducted at room temperature according to ASTM D2394 [11]. An Instron universal testing machine with 1 kN load cell was used to perform the sliding friction tests. The wet surface condition was created by evenly spraying about 5 ml amount of water on the surfaces of a specimen and a piece of leather, ensuring that no large water droplets could be observed on two surfaces. Before each test, the surface of the leather was slightly sanded by a 1/2-grit garnet paper. The moving direction of a sliding block was along the wood grain direction, i.e., longitudinal direction. A nominal contact area of the leather was 11,628 mm^2, which was roughly equal to the half area of one sole for footwear. Therefore, the pressures given by a 14 kg *WSB* and a 20 kg *WSB* were about 1.21 MPa and 1.72 MPa, respectively, which could be redeemed as a 56 kg person and an 80 kg person stand on the floors. Table 1 shows a full factorial design of experiment including four factors at various levels using Minitab®16 Software [12], totally generating 144 surfaces for testing.

3. Results and discussion

3.1. Kinetic friction behavior during a stable sliding movement

When a sliding block steadily moved on the surface of a specimen, the behavior of driving force with increasing time displayed either an irregular (erratic or intermittent) periodic 'stick–slip' motion or a random motion. For CCAS, HTS and UTS specimens, the irregular 'stick–slip' motion only occurred when a 20 kg *WSB* moved at the *SS* of 10 mm/min under dry *SC*, while under the rest conditions, a random motion was found. However, no irregular 'stick–slip' motion was observed in WPC specimens but the random motion appeared under any condition. Two typical

Table 1
Design of experiment (DOE).

Factor	Level				Replicates
Type of specimen (*TS*)	CCAS	HTS	UTS	WPC	3
Surface condition (*SC*)	Dry	Wet			
Weigh of sliding block (*WSB*) (kg)	14	20			
Sliding speed (*SS*) (mm/min)	10	50	250		