The Effect of Waxes and Adhesives on the Static Coefficient of Friction of Wood Strands

SPENCER A. PERRY[1], STEPHEN M. SHALER[2], DOUGLAS J. GARDNER[2], & WILLIAM A. HALTEMAN[3]
[1]Graduate Assistant, Wood Based Composites Center Fellow, Wood Science and Technology, University of Maine, Orono, ME 04469 (spencer.perry@umit.maine.edu)
[2]Ph.D., Wood Science and Technology, University of Maine, Orono, ME 04469
[3]Ph.D., Mathematics, University of Maine, Orono, ME 04469

INTRODUCTION

While the macro-surface characteristics of the wood strands may have the greatest effect on frictional forces, visual evidence of an effect of wax on strand movement through the manufacturing process has been seen while conducting experiments on the AEWC OSB/OSL pilot forming line. It was noted during an experiment that strand flow increased when wax was added to strands, which may be attributed to a reduction in friction, but it has never been quantified. The broad hypothesis is that strand additives, such as adhesives and waxes may have an effect on strand movement because of changes in the frictional forces between strands themselves and between the strands and equipment. These changes could be due to changes in surface tack or surface energies, which would theoretically make the strands adhere more or less to each other, thus, affecting the frictional forces. In addition, mechanical interlocking may have an effect on frictional forces between the strands.

HYPOTHESES

- Applying wax will lower the static COF of wood strands
- Applying adhesives will increase the static COF of wood strands

LITERATURE REVIEW

Basics of Friction

- Static Friction Force (F_s) - The resistance force opposing the start of the object sliding along a surface [6]
- Kinetic friction force (F_K) - The resistance force to continuous sliding along a surface [6]
- $F_s > F_K$, in general [6]
- COF values for a single material have VERY HIGH VARIABILITY
  - During the formulation of ASTM standards for COF testing, professional testing labs got values UP TO 25% DEVIATION from each other using very similar techniques [3]

Equation 1: Static Frictional Force - COF Relationship [6]

$$F_s \leq \mu_s \times N$$

F_s = Static Frictional Force
μ_s = Static COF
N = Normal Force

Equation 2: Static COF [6]

$$\mu_s = \tan(\theta)$$

μ_s = Static COF
θ = Angle of repose of inclined plane (Figure 3)

Theories of Friction

- Mechanical Interlocking Theory
  - INCREASED Surface Roughness = INCREASED COF [3]
  - Does not take into account adhesion
  - Friction increases when surface roughness is above 100 micro inches (Industrial "Rule of Thumb"-No reliable data to prove this) [3]
- Adhesion Theory
  - INCREASED molecular interactions (Surface Energy) between surfaces= INCREASED COF [3]
  - Does not take into account mechanical interlocking

Wax-Adhesive-Friction Relationship

- Wax
  - Forms weak boundary layer = LOWER surface energy [4]
- Adhesive
  - INCREASED surface energy = INCREASED adhesion [4]

Wood-Friction Relationship

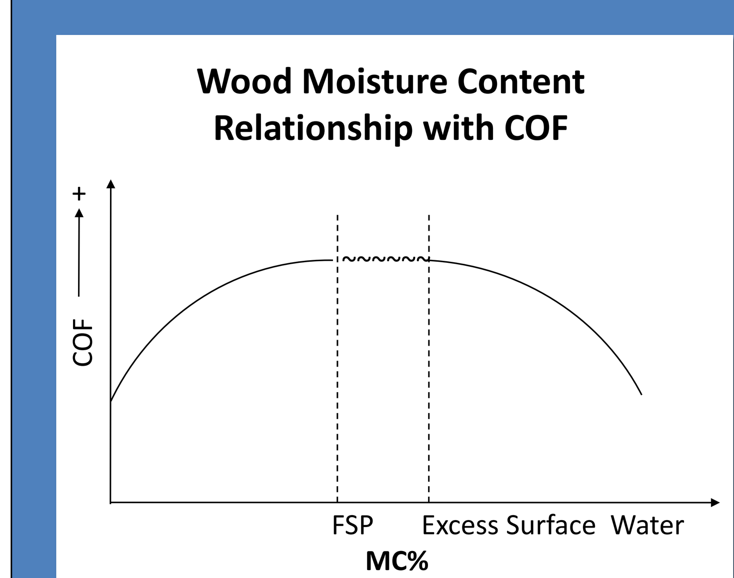

Figure 1: Wood Moisture Content Relationship with COF [5]

Possible Causes

- @ MC > 6% - Monomolecular layer of water is formed on the surface [2]
  - INCREASED cohesive forces between polar water molecules = INCREASED Adhesion= INCREASED COF
- @ FSP - Wood cell wall completely saturated
  - NO CHANGE in cell wall MC% = NO CHANGE in adhesion forces = NO CHANGE in COF
- Excess Surface Water- Water film covers the surface irregularities
  - DECREASED surface roughness = DECREASED COF

METHODS AND MATERIALS

COF Measurements

Inclined Plane Method [1]

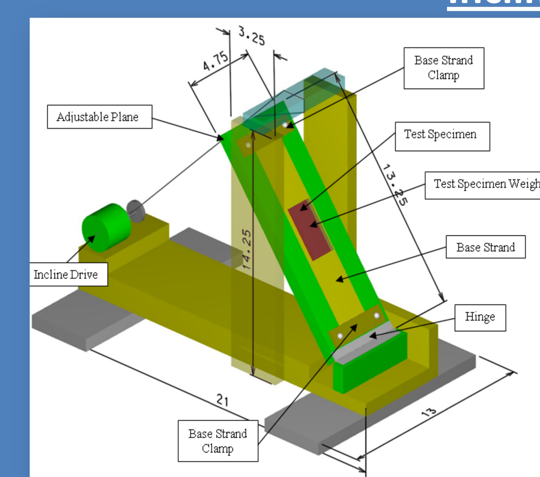
Figure 2: Inclined Plane Apparatus

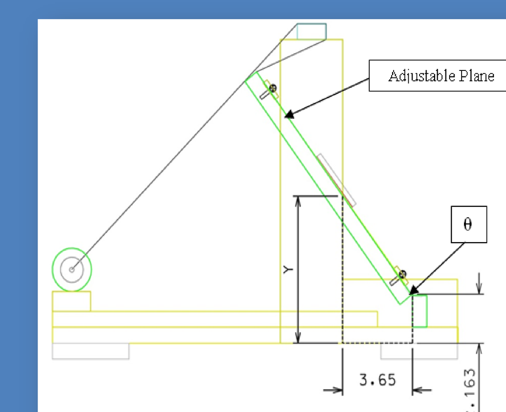

Figure 3: Inclined Plane Apparatus (Side)

1. Blend 30 lbs of dry aspen (*Populus* spp.) strands with E-Wax (1.25% by weight (bw)) or UF adhesives (10% bw) using the AEWC Coil® rotary blender
2. 30 "Test Specimens" of each treatment were selected and cut to 3" x 1.5"
3. Attach "Base Strand" that has the same treatment as the "Test Specimen" on the "Adjustable Plane"
4. Place a 200g "Test Specimen Weight" on the "Test Specimen" [1]
5. Incline the plane at a constant rate of 1.5+/-0.5° [1]
6. Stop inclining the plane when the "Test Specimen" and weight start to slide down the "Adjustable Plane"
7. Measure angle (θ) [1]
8. Repeat for 5 times for each "Test Specimen" and measure θ

Surface Energy Measurements

Sessile Drop Method (w/ Water)

(HIGHER contact angle (θ_{CA})= LOWER surface energy)

1. Select 5 specimens from each treatment group
2. Place 10 drops of probe liquid (Water) on each of the specimens' surfaces
   Note: The sessile drop method is most accurate when at least three probe liquids are used. However, since we are interested in comparative results, only water was used for a probe liquid. Therefore, the surface energies are not "true" values, but the relationship between the treatments is true.
3. Measure the contact angles (Figure 4) using a two camera image acquisition system (Figure 5) and Equation 3

Equation 3: Solid surface free energy equation

$$\gamma_{sv} = \frac{\gamma_{lv}(1 + \cos(\theta_{CA}))}{4\phi^2}$$

γ_{sv} = solid surface free energy
γ_{lv} = liquid surface tension (equals 72.8 mJ/m^2 for water)
θ_{CA}=contact angle
ϕ=interaction parameter (equals 1.0 for Water)

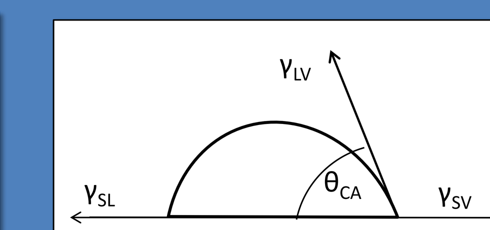

Figure 4: Contact angle

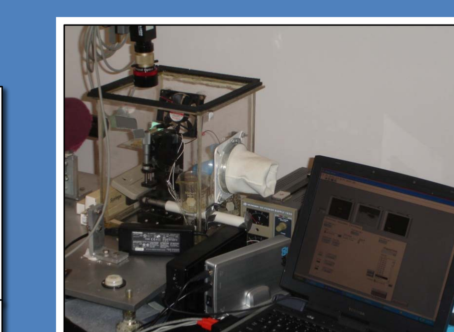
Figure 5: Image acquisition system for contact angle analysis

Material	Model	Manufacturer	Characteristics
Emulsified-Wax (E-Wax)	Cascowax EW-58H	Hexion Specialty Chemicals, Inc.	58% solids content
Urea-Formaldehyde (UF)-Adhesive	GP354G51 U/F Board Resin	Georgia-Pacific Chemicals, LLC	High tack, thermosetting amino adhesive used for interior applications

RESULTS

COF Measurements

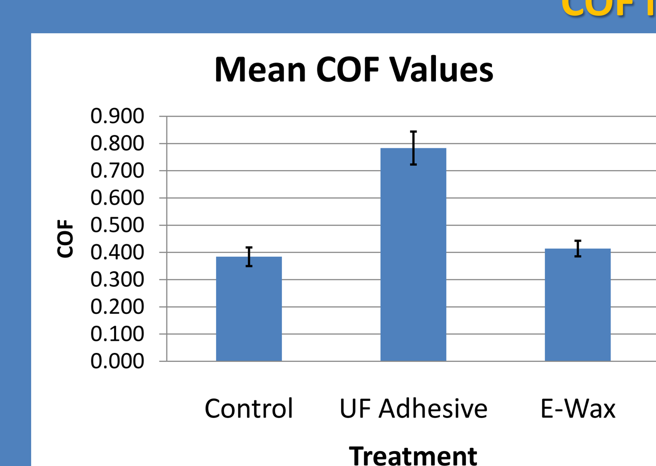

Figure 6: Mean COF values with +/- 1 standard deviation

Tukey's Honestly-Significant-Difference Test –COF (Transformed=Response^0.05--)					
TREATMENT(i)	TREATMENT(j)	Difference	p-value	95.0% Confidence Interval	
				Lower	Upper
Control	Adhesive	-0.035	**0.000**	-0.055	-0.014
Control	Wax	-0.004	**0.909**	-0.024	0.017
Adhesive	Wax	0.031	**0.001**	0.010	0.051

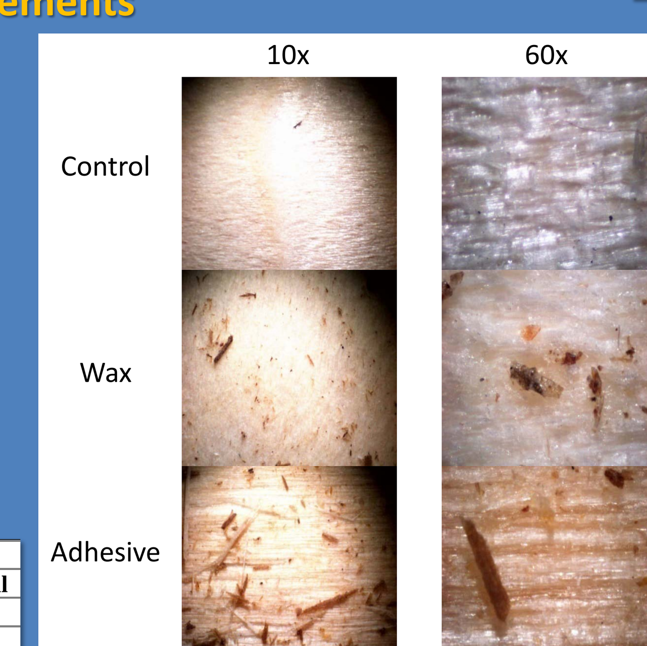

Figure 7: Surface Roughness Comparison

- ✓ UF Adhesive SIGNIFICANTLY INCREASES COF over the control
- ✗ Wax does not significantly decrease COF over the control
  - WHY??? INCREASED SURFACE ROUGHNESS through blending process (Figure 7)

Surface Energy Measurements

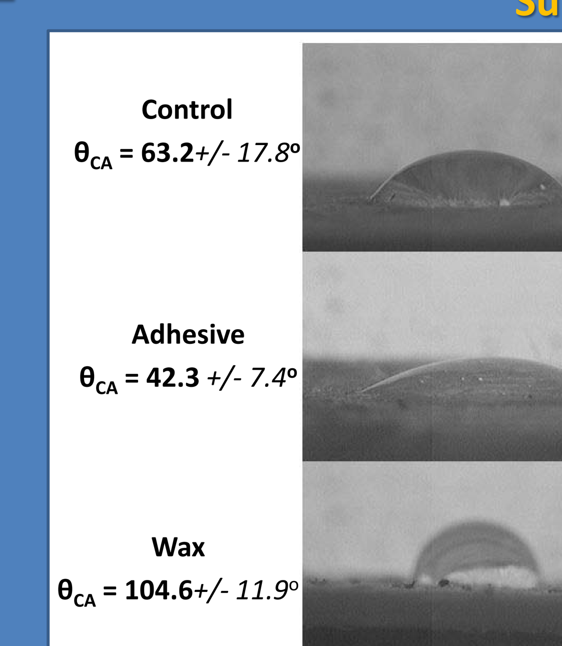

Figure 8: Images from contact angle analysis

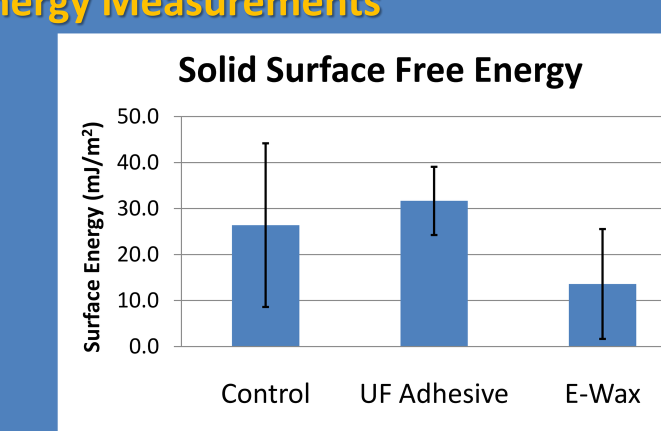

Figure 9: Mean Solid Surface Free Energy values with +/- 1 standard deviation

Tukey's Honestly-Significant-Difference Test- Contact Angle					
TREATMENT(i)	TREATMENT(j)	Difference	p-value	95.0% Confidence Interval	
				Lower	Upper
Control	Adhesive	20.946	**0.000**	13.634	28.257
Control	Wax	-41.385	**0.000**	-47.547	-35.224
Adhesive	Wax	-62.331	**0.000**	-69.534	-55.128

- ✓ UF Adhesive SIGNIFICANTLY INCREASES surface energy over the control and wax treatments
- ✓ Wax SIGNIFICANTLY DECREASES surface energy over the control and adhesive treatments

CONCLUSIONS

- UF adhesive significant increases the COF due to several reasons
  - Increased surface energy in accordance with Adhesion Frictional Theory
  - Increased Surface roughness in accordance with Mechanical Interlocking Frictional Theory
- Wax does not significantly decrease COF because the effects of the decreased surface energy are cancelled out by the significant increase in surface roughness

FUTURE WORK

- In the future, we hope to use this and future data to understand how the changes in COF by adhesive and wax types and loadings affect the OSC manufacturing process, such as strand dynamics in storage, conveying, and forming.

ACKNOWLEDGMENTS

- This study was funded by the Wood Based Composites Center & United States Department of Agriculture's Wood Utilization Research Grant. Special thanks to Mr. Jeffrey Balogh of Georgia-Pacific Chemicals, LLC, Mr. Earl Phillips of Hexion, Inc., and AEWC Faculty & Staff.

LITERATURE CITED

1. American Society for Testing and Materials (ASTM). (2002). Standard Test Methods for Coefficient of Static Friction of Uncoated Writing and Printing Paper by Use of the Inclined Plane Method. ASTM D-4918-97 (2002).
2. Bowyer, J. L., Shmulsky, R., and Haygreen, J. G. (2003). Forest Products and Wood Science: An Introduction. 4th Ed. Ames, Iowa: Iowa State University Press. 554p.
3. Ludema, K. C. (1996). Friction, Wear, Lubrication: A textbook in Tribology. CRC Press, Inc. 257p
4. Pocius, A.V. (2002). Adhesion and Adhesives Technology: An Introduction. 2nd Ed. Munich, Germany: Hanser Publishing. 319p.
5. Wood Handbook. (1999). Wood as an engineering material. Gen. Tech. Rep. FPL-GTR-113 USDA Forest Prod. Lab., Madison, WI.
6. Young, H. D. and Freedman, R.A. (2004). University Physics with Modern Physics. 11th Ed. San Francisco, CA: Pearson Education, Inc. 1714p.