The Influence of Sand Additives on Slip Resistance of Wood

Jonathan S. Lee-Confer[1]*, Lila T. Wayman[1] and Kristen E. Renner[2]

1 Department of Physical Therapy, University of Arizona, Tucson, Arizona, USA

2 Biomechanics Practice, Exponent, Tampa, Florida, USA

* Correspondence: leeconfer@arizona.edu

Abstract: Introduction: Slips and falls are known to cause serious injuries in the workplace and home. To reduce the likelihood of slipping, sand additives have been recommended to be added into stains placed onto wood flooring. It is unknown which layer (first coat or topcoat), nor which application method (paint brush or roller brush) is best for producing a slip resistant result. Therefore, the purpose of this study was to determine the effects of sand additives on the coefficient of friction with douglas wood fir. Methods: 6 pieces of douglas fir wood was placed into 6 treatments. A Mark IIIb tribometer was used to measure the coefficient of friction at baseline after sanding, and lastly when wet after 2 sealing and staining coats. Results: Paint brush applications exhibited significant increased COF compared to roller brush applications across all conditions ($p < 0.001$) with a large effect size ($\eta^2 = .545$). Lastly, there were no significant effects of applying the sand additive in the first coat or topcoat on COF ($p = 0.59$). These findings demonstrate that the use of sand additives and paint brush application techniques enhance slip resistance, offering valuable insights for improving safety in residential and commercial wood flooring installations. Further research is recommended to explore the long-term durability and environmental resilience of these treatments.

1. Introduction

Slips and falls are known to cause serious injuries in the workplace and at home [1,2]. In fact, money spent on falls are one of the highest personal health care costs in the United States [3]. Slip incidents result from a lack of traction at the foot-floor interface [4] where a person requires more friction than what the floor offers. Furthermore, prior studies have shown that the type of flooring will affect slip resistance, with smoother floors exhibiting less slip resistance and rougher textured floors exhibiting increased slip resistance [5,6]. Adding slip resistance to outside decks as part of a large-scale fall-prevention home modification project was shown to decrease the incidence of falls [7]. A commonly accepted method to increase slip resistance to floors, such as exterior decks or porches, is to combine sand additives into stains and sealers. Sand-additives mixed into the stains and sealers for wood surfaces theoretically reduce the likelihood of individuals slipping when the flooring is wet. However, there is no research that confirms that the addition of sand-additives increases slip resistance, and furthermore, it is currently unknown if the layer sand-additives are placed in (first coat or topcoat), or their application method (paint brush or roller), impacts the resultant slip resistance of wood decks. Understanding the methodology that improves slip resistance may inform best construction practices on how to develop safer flooring for home and commercial properties that implement wood porches and decks.

Sand additives mixed into the first and topcoat of stains and sealers for wood treatments may increase the slip resistance of the floor compared to using no sand-additives. Aside from sand additives, a study reported that adding paint to wood flooring did not affect the coefficient of friction [8]. While the paint did not affect the coefficient of friction of the wood, it could be expected that a sand additive which changes the roughness of the flooring surface would alter slip resistance. A separate study reported that an addition of nanoparticles and sand additives into an epoxy solution increased coefficient of friction when applied to stainless steel sheets [9]. As such, it is likely that sand additives mixed into stains and sealers on wood would increase the coefficient of friction. While increasing the coefficient of friction with sand additives is likely, the methodological effect of applying the sand additive on the coefficient of friction remains unknown.

There are conflicting results as to whether the sand-additive being placed into the first layer or the topcoat results in comparatively better performance of slip resistance. There are numerous conflicting opinions into which layer (first coat or topcoat) best increases slip resistance upon a google search of “do you add sand additive to topcoat or first layer?”. It is posited that sand-additive placed into the topcoat is more successful at producing slip-resistant results, but it produces less pleasing aesthetics. The idea behind sand additive in the topcoat is that the roughness of the sand is on top and the sand will have more contact with the sole of the shoes for traction. Opposingly, sand-additive placed into the first layer also has potential slip-resistant properties as the topcoat stain and sealer contours to the sand-additive in the first layer and becomes more aesthetically pleasing as the sheen of the stain and sealer becomes more evident. Currently, there are no studies determining the effect of what layer the sand-additives are placed in for slip resistance. However, Behr’s premium sand additive directs users to place the sand additive into the topcoat of the stain and sealer. Determining what layer sand-additive is most effective at producing slip resistance may inform home construction on best practices to reduce slip and falls in the general population, however, the effect of paint application on the coefficient of friction also remains unknown.

The application method, whether paint brush or roller brush, of applying a stain and sealer may potentially affect the direction of streaks and the roughness of the floor. Roller applications are a common method for applying paint to surfaces [10] and are generally considered to result in a more smooth application compared to a paint brush. Paint brushed surfaces are known to have visible brush strokes or streaks that are associated with the bristles of the brush. The visible strokes from the paint brush could potentially alter the foot-floor interface by introducing microgrooves in different directions to increase the roughness of the surface as a result. However, there are no current studies examining the effect of stain and sealer application on the slip resistance of wood. Aside from painting applications, a study suggested that silica sand is tossed on top of the second layer topcoat in some applications [9], however this may result in an uneven application. As such, this study will focus on the uncertainties of painting applications (paint or roller brush) as these will produce a more even application of the sand additive to the wood compared to hand tossing the sand.

As there are several unknowns about sand additives and their application methods on slip resistance when mixed into stains and sealers, the purpose of this study is bi-fold: 1) to determine if the application method (paint or roller brush) affects the slip resistance, and 2) to determine if the order of sand additive layer affects slip resistance. We hypothesized that 1) the paint brush application would exhibit an increased coefficient of friction compared to the roller application, and 2) the sand additive placed in the topcoat would result in a higher coefficient of friction compared to sand additive mixed into the first coat. The findings from this study have the applicability of providing knowledge to the general population and construction companies on how to best finish wood decks and porches to reduce injuries on properties.

2. Materials and Methods

Lumber Selection

A 0.61 x 2.44 meter (2 x 8 foot) plank of prime douglas fir dimensional lumber was purchased from Home Depot and cut into 6 equal dimensions of 0.61 x 0.41 meter using a laser guided circular saw. Douglas fir lumber was selected for this study as it is a commonly used material for construction such as exterior porches and decks (Forest Products Laboratory (US). (1955). *Wood Handbook; Basic Information on Wood as a Material of Construction with Data for Its Use in Design and Specification* (No. 72). US Government Printing Office.).

Lumber Preparation

All wood preparation was conducted at the University of Arizona Health Sciences Innovation Building. Each 0.61 x 0.41 meter wood board was sanded 5 times in the north, east, south and west directions with a new sheet of 80 grit sand paper applied at an even pressure. The sanding was performed minimally as required to ensure optimal stain adherence. Each of the 6 pieces of wood were labeled #1-6 to be coded for respective application methods described in future sections.

Tribometer testing

All tribometer testing was conducted at the University of Arizona's Health Sciences Innovation Building. Tribometer testing was conducted by one independent and trained individual with their own validated and calibrated Mark IIIb tribometer (Slip-Test, Philadelphia, PA, USA). All wood pieces were tested with a tribometer in dry conditions to ensure the wood pieces were similar in coefficient of friction prior to application of stains. Tribometer testing pre- and post- staining occurred in four directions (north, east, south and west) along the length of the wood, and the friction was assessed and recorded 1 time in each direction. Wet testing of the frictional properties of the wood were completed accordingly with the Mark IIIb tribometer manufacturer's suggestions 1 time for each direction. Distilled water was poured onto the wood surface beneath the test foot until a complete unbroken pool of water was present. The water underneath the test-foot of the tribometer was checked after each test strike of the tribometer and water was added to ensure the unbroken pool of water if necessary.

Procedures

All boards were kept in a temperature-controlled room at 70 degrees in a private laboratory space in the Health Sciences Innovation Building at the University of Arizona. All 6 wood boards underwent friction testing in four directions after sanding to determine if there were any differences in friction prior to applying the stain and sealer. A total of two coats were applied to each of the wood boards with 15 milliliters (0.5 ounces) of Behr premium topcoat stain and sealer. 0.33 grams of Behr's premium sand additive non-slip powder was added into the stain and sealer if the coat required sand additive. This amount of sand additive is proportional to the manufacturer's guidelines. A summary of the protocol for the applications of stains and sealers and the sand additive conditions may be found in Figure 1.

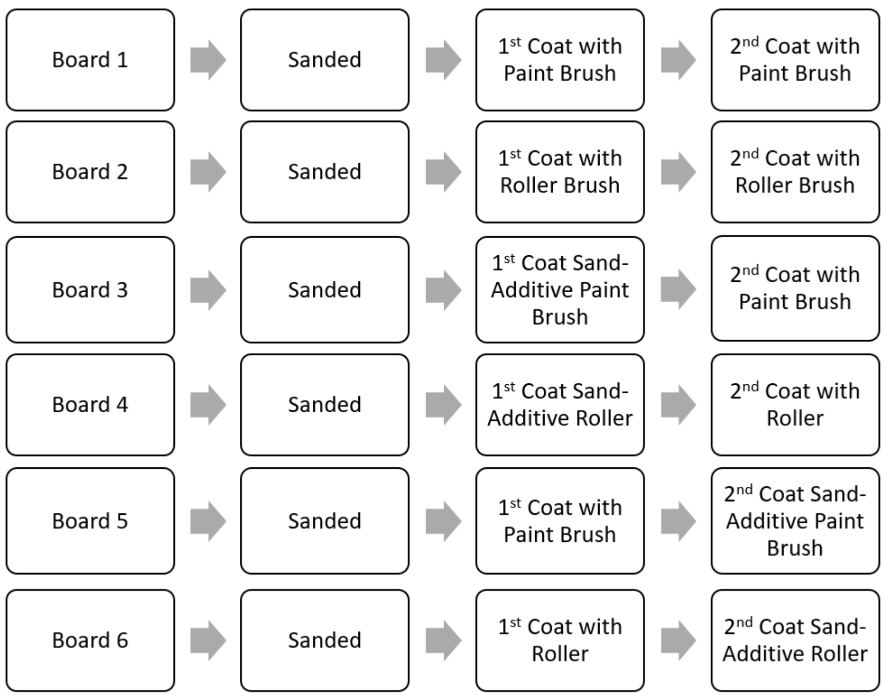

Figure 1. A schematic depicting the methodological design of the 6 wood pieces and 1) the order of the sand additive mixed into the coat (1st or topcoat), and 2) the application style (roller or paint brush).

Board #1's first coat was applied with a paint brush and a stain and sealer with no sand additives. The topcoat for Board #1 was applied with a paint brush and a stain and sealer with no sand additives. Board #2's first coat was applied with a roller brush and a stain and sealer with no sand additives. The topcoat for Board #2 was applied with a roller brush and a stain and sealer with no sand additives. As such, boards #1 and #2 served as the baseline control boards with no sand additives. Board #3's first coat was applied with a paint brush and a stain and sealer with sand additives. The topcoat for Board #3 was applied with a paint brush and a stain and sealer with no sand additives. Board #4's first coat was applied with a roller brush and a stain and sealer with sand additives. The topcoat for Board #4 was applied with a roller brush and a stain and sealer with no sand additives. Board #5's first coat was applied with a paint brush and a stain and sealer with no sand additives. The topcoat for Board #5 was applied with a paint brush and a stain and sealer mixed with sand additives. Lastly, board #6's first coat was applied with a roller brush and a stain and sealer with no sand additives. The topcoat for Board #6 was applied with a roller brush and a stain and sealer mixed with sand additives. An example of the surface of two wood pieces after their topcoat can be found in Figure 2.

Figure 2. A photograph exhibiting the difference between a wood piece with 2 coats of stain and sealer with no sand additive (A) compared to a wood piece with sand additive mixed into the first coat and covered with a 2^{nd} coat of stain and sealer (B).

Data Analysis

4 directional tribometer readings of the coefficient of friction, for each stain application and additive condition, was compiled and averaged. Coefficient of tribometer readings were performed after sanding the boards for baseline readings and after the 2^{nd} application of stains and sealers under wet conditions.

Statistical Treatment

A two-way repeated measures ANOVA with a Greenhouse-Geisser correction was conducted to determine if the stain application (paint or roller brush) and coating application (no sand, sand in 1^{st} coat, or sand in topcoat) had any significant differences in coefficient of friction between the wood flooring boards after sanding, and when wet after the 2 coats of stains were applied.

Post-hoc analysis pairwise comparisons were conducted for main effects of stain application (paint versus roller brush) and differences in order of application in sand additives (no sand, first coat, or topcoat). Significance was set at an alpha of $\alpha < 0.05$.

3. Results

A summary of the friction results after each stage of prepping the boards may be found in Table 1. A repeated measures ANOVA with a Greenhouse-Geisser Correction determined that coefficient of friction was significant different between time points ($F(1.910, 34.382) = 26.275$, $p < 0.001$). Post hoc analysis with a Bonferroni adjustment determined that coefficient of friction was significantly decreased when stains were applied with roller brush compared to a paint brush (0.069 (95% CI, 0.043 to 0.094, $p < 0.001$). Post hoc analysis with a Bonferroni adjustment determined that coefficient of friction was not significantly different between order of applications of the sand additive (0.012 (95% CI, 0.027 to 0.051, $p = 0.99$).

#	Brush	COF-Sanded	1st Coat	2nd Coat	Wet COF
1	PB	0.63 ± 0.03	Stain	Stain	0.57 ± 0.01
2	RB	0.62 ± 0.07	Stain	Stain	0.49 ± 0.01
3	PB	0.63 ± 0.04	Sand Add	Stain	0.58 ± 0.04
4	RB	0.59 ± 0.08	Sand Add	Stain	0.50 ± 0.04
5	PB	0.58 ± 0.10	Stain	Sand Add	0.54 ± 0.04
6	RB	0.62 ± 0.05	Stain	Sand Add	0.53 ± 0.02

Table 1. A table reporting the coefficient of friction after sanding and when wet after the two coats. Furthermore, the brush application method for each board is listed and identified as PB = Paint Brush, and RB = Roller Brush. The treatment is "Stain" = no sand additive, and "Sand Add" is treatment with sand additive mixed in.

There was a significant effect of brush type application on friction ($F(1, 18) = 21.543$, $p < 0.001$, $\eta^2 = .545$). There was no significant effect of order of application of the sand additive into the stains and sealers ($F(2,18) = 0.584$, $p = 0.568$, $\eta^2 = .061$). The average coefficient of friction of the sanded pieces of wood, prior to any staining and sealing, was 0.73 ± 0.03. The coefficient of friction when wet of all the wood pieces was 0.53 ± 0.09. The coefficient of friction of the wet boards were significantly higher when the stain and sealer were applied with a paint brush compared to a roller brush (0.57 ± 0.04 vs. 0.51 ± 0.03, $p < 0.001$, Fig. 3). The large effect size shows that applying the stain and sealer with a paint brush has a large role in determining the friction. Placing the sand additive in the 1st coat had no effect on efficient of friction when compared to placing the sand additive in the topcoat when the wood was wet (0.55 ± 0.06 vs. 0.54 ± 0.03, $p = 0.59$, Fig. 4). Results are visualized and can be found in Table 1 and Figure 3 & 4.

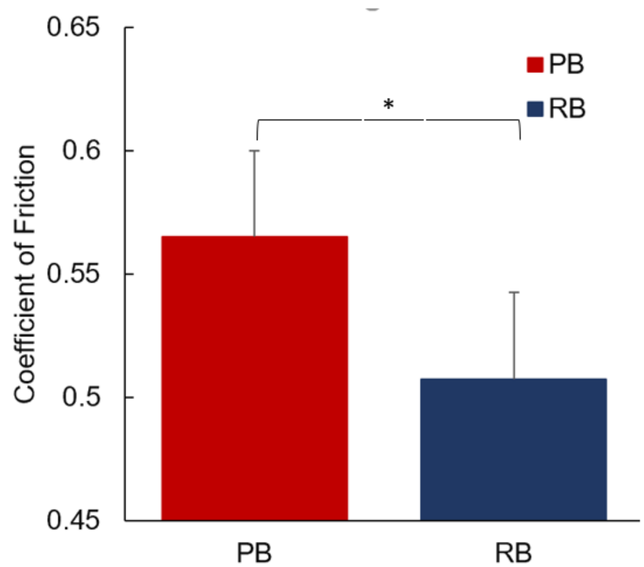

Figure 3. Bar charts comparing the wet coefficient of friction when stained with the paint brush (red) versus the roller brush (blue). * denotes significant differences at $p < 0.001$. N.S. denotes Not Significant.

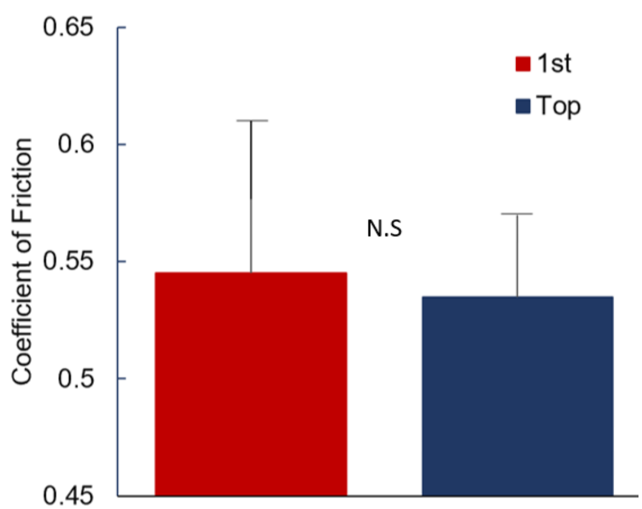

Figure 4. Bar charts comparing the wet coefficient of friction between sand additives mixed into the 1st coat (red) compared to sand additives mixed into the topcoat (blue). * denotes significant differences at $p < 0.05$. N.S. denotes Not Significant.

4. Discussion

This study investigated the impact of sand additives in stains and sealers applied to Douglas fir lumber, with a particular focus on the applications' effects on slip resistance. The importance of this research is its potential application in promoting the safety and slip resistance of wood flooring surfaces, especially in environments where slips and falls are a concern. Prior to this study, the specific influence of sand additives on the coefficient of friction (COF) had not been empirically measured, marking our research as an initial study for measuring the efficacy of application techniques of sand additives and stains and sealers on wood walkway surfaces. In support of our hypothesis, the coefficient of friction was significantly higher in wood boards stained with a paint brush compared to a roller brush. Lastly, in disagreement with our hypothesis, the coefficient of friction was not significantly different in wood floors treated with sand additives in the first coat compared to the topcoat.

The experimental protocol ensured the uniformity of the coefficient of friction across all Douglas fir lumber samples. The sanding and measurement of the coefficient of friction prior to application of any stains or sealers exhibited homogeneity (no significant differences) between board samples and established a controlled baseline for assessing the impact of different staining treatments and techniques. The absence of significant differences in the initial COF measurements across samples provided a foundation for the comparative analysis that followed. As such, any significant differences in friction after stain and sealer treatments were likely due to the techniques or application coating.

The application technique of the stain and sealer appears to affect the slip resistance of wood floors. In support of our hypothesis, there were significant differences in the coefficient of friction between the stain and sealer applied with the paint brush compared to the roller brush. The paint brush likely introduced microgrooves within the stain and sealer that added texture and roughness to the surface of the wood finish increasing the friction and roughness compared to the roller brush. A higher coefficient of friction was observed across each application phase of the project from the first coat, topcoat and testing friction when wet. As such, it is recommended that a paint brush application be used to apply stain and sealer to douglas fir lumbar as the tribometer used in this study is correlated to human slip propensity and a higher coefficient of friction results in a lower likelihood of slipping.

The layer the sand additive was placed into the stains and sealer appeared to make no difference the slip resistance measurement. The results of our study showed that coefficient of friction was not significantly affected whether sand additive was added into the stain and sealer in first coat or to the topcoat. We initially hypothesized that the sand additive mixed in the stain and sealer in the topcoat would result in an increased coefficient of friction due to the sand creating a raised contact surface relative to the wood, as well as Behr's premium directions that instruct the users to place the additive in the topcoat. As such, Behr's recommendation to place their sand additive in the topcoat may not be the best practice as it increases the coefficient of friction compared to placing sand additives in the first coat and then staining and sealing it. It should be noted, however, that the coefficient of friction was at a value that is considered slip resistant regardless of the layer the sand additive was placed in based on the interpretation of the

Mark IIIb tribometer per the ASTM F2508-23 standard [5,6]. Lastly, this also means that individuals may be encouraged to place the sand additives in the first layer of stains and sealers and then coat it with a non-sand additive stain and sealer to improve the aesthetics of the finish while improving slip resistance.

The findings from this study suggest that incorporating sand additives into stains can enhance the slip resistance of outdoor wood flooring surfaces in both residential and commercial settings. This has potential applications in areas such as decking, porches, and other outdoor wooden structures where slip resistance is critical to maintain to reduce the likelihood of slip-related injuries. Furthermore, this study found specific methods to improve slip resistance by reporting that paint brushes are more effective at increasing coefficient of friction compared to roller brushes when applying stains and sealers.

However, it is important to acknowledge the limitations of our study. One significant limitation is the absence of data on the long-term durability of the enhanced coefficient of friction. In real-world applications, surfaces are subject to various forms of wear and tear, such as people consistently walking over the deck or stairs, which could potentially reduce the effectiveness of the sand additives over time. However, the findings of this study are still important as the presence of sand additive appears to improve the slip resistance from fresh installation. With that, this aspect of the research presents an opportunity for further investigation, as understanding the longevity of the slip-resistant properties is critical for practical applications. Another limitation stems from there only being one user for the tribometer measurements as individual variation has been shown to affect tribometer measurements [11]. Furthermore, this study did not include several different tribometers that may also have different readings of the coefficient of friction. However, the tribometer used in this study is validated and calibrated per ASTM F2508 standards. Additionally, many field users use their single tribometer to determine slip resistance and do not rely on other machines or users to test the same area. Lastly, another limitation from this study involves not studying the effect of dust or dirt remaining on the wood during wet friction testing. Decks and porches can accumulate dust and dirt from the natural environment which can lower the friction of the wood deck when wet. While this study measured the coefficient of friction when the wood flooring was clean, this also opens future investigations into quantifying the effect of dirt levels on slip resistance levels.

5. Conclusions

In summary, our study provides important insights into the enhancement of slip resistance on wooden surfaces using sand additives in stains. The findings highlight the effectiveness of sand additives, particularly when sand additives are mixed into stains and sealers and applied with a paint brush rather than a roller brush. This research contributes valuable knowledge to the field of wood safety treatment, offering practical recommendations for improving slip resistance on wooden surfaces. Nevertheless, further research is needed to explore the long-term durability and environmental resilience of these treatments to fully understand their potential in real-world applications.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "Conceptualization, J.L.C.; methodology, J.L.C; software, J.L.C.; validation, J.L.C., K.T.W, and K.E.R.; formal analysis, J.L.C., and K.E.R.,; investigation, J.L.C. and K.T.W.; resources, J.L.C.; data curation, J.L.C. and K.T.W.; writing—original draft preparation, J.L.C.; writing—review and editing, J.L.C., K.T.W., K.E.R..; visualization, J.L.C..; supervision, J.L.C.; project administration, J.L.C.; funding acquisition, N/A. All authors have read and agreed to the published version of the manuscript." Please turn to the CRediT taxonomy for the term explanation. Authorship must be limited to those who have contributed substantially to the work reported.

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Abbreviations

The following abbreviations are used in this manuscript:

COF	Coefficient of Friction

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