A Sticky Situation: Comparing the Adhesive Strength of Pine Resin to Commercial Glues

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Abstract

For hundreds of years, Indigenous people of British Columbia have taken advantage of the adhesive and waterproof properties of resin, a natural excretion of many conifers, to strengthen and waterproof their tools, vessels, and buildings. The study we conducted examined the adhesive strengths of unpurified pine resin and an approximate 50:50 ratio mixture of pine resin and beeswax on wood surfaces. We aimed to evaluate pine resin as a natural alternative to certain commercially marketed glues by comparing their respective adhesive strengths. Specifically, a comparison was made to the adhesive abilities of Elmer's all-purpose craft glue, fish glue, and hot glue from a glue gun. It was predicted that the pine resin would show significant adhesive strength comparable to certain commercial glues, and it was indeed found to have a mean adhesive strength statistically similar to that of commercially sold fish glue, but dissimilar to Elmer's glue and glue from a glue gun. However, large standard deviations were present in the mean forces of separation for the adhesives, indicating that similarities likely exist even between Elmer's glue and pine resin. This implicates the potential for pine resin to function as an adhesive for casual usages on wood surfaces and as an alternative to chemical-based glues and commercially sold fish glue.

Introduction

Resin is a highly viscous substance secreted by many plants. Plant resin, specifically pine resin, has properties which were traditionally used by First Nations people of British Columbia for hundreds of years ("Eastern White Pine (*Pinus strobus*)", n.d.). One of these properties include its adhesive abilities. Pine resin was used as a component in gluing tools and as a sealant to waterproof cracks in the roofs of buildings and in canoes ("Eastern White Pine (*Pinus strobus*)", n.d.). This traditional exploitation of the natural sealant and adhesive properties of pine resin has largely been lost in recent years. However, there has been a growing rise in the popularity of partaking in a more naturalistic lifestyle and adopting environmentally friendly behaviours. This research proposes that the use of pine resin as an adhesive can be revived as an environmentally friendly and sustainable alternative to commercial glues that contain synthetically created chemicals.

Previous studies on the adhesive properties of pine resin have examined its ability to enhance the binding strength of materials. The mechanical strength of particleboard has been shown to be enhanced with the addition of tannins derived from pine resin (*Pinus pinaster* L.) and cellulose nanofibres (Cui et al., 2015). The pitch produced by pine and birch has also been tested for their shear strengths, or ability to withstand a shearing force, at varying temperatures (Kozowyk, Poulis, & Langejans, 2017). The addition of charcoal to pure pine and birch resin was found to increase the adhesive abilities of the resin until a certain threshold of force was applied; boiling of resin also produced this effect (Kozowyk, Poulis, & Langejans, 2017). However, an increase in resin temperature decreased the shear strength of pitch (Kozowyk, Poulis, & Langejans, 2017). In another study, the tensile strength and shear strength of white pitch obtained from a common South American plant, *Protium heptaphyllum*, was compared to commercial adhesives (Vieira, Vieira, Kim, & Netravali, 2014). The tensile strength was considered to be the ability of the adhesive in adhering objects so as to withstand direct pulling force (“Tensile Strength”, n.d.). The testing of tensile strength is a popular method of evaluating strength of an adhesive (“Tensile Strength”, n.d.), a method which we adopted and modified for our study. The study using the pitch of *Protium heptaphyllum* found that the strength of the pitch was overall lower than that of commercial adhesives, but the pitch did have a higher shear strength than tensile strength (Vieira, Vieira, Kim, & Netravali, 2014).

While previous studies have examined the adhesive properties of other plant resins, the adhesive strength of pine resin alone has not been explicitly studied. The aim of our study was to determine whether pine resin's adhesive strength would be comparable to the adhesive strength of certain commercial glues. In addition to natural unpurified pine resin and a 50:50 pine resin/beeswax mixture, the commercial glues selected for use in this study were Elmer's all-purpose craft glue, fish glue, and glue from a standard hot glue gun. These glues were selected since they represent a variety of commercial glues that might be used in a standard household or workshop. In addition, fish glue was chosen because it represents a natural, non-toxic glue that individuals in need of a non-chemical based adhesive may choose. It is to be noted that in this particular study, adhesive strength was measured as the ability of an adhesive to bind objects so that they could resist consistently applied directional force. This most closely mimics tests on tensile force performed in previous studies.

Methods

We collected the raw natural pine resin on December 24, 2018 in the Chilcotin Plateau region of interior British Columbia. All pine resin was harvested directly from the solidified, excreted liquid resin of Lodgepole Pine, *Pinus contorta* var. *latifolia* (*Figure 1*), by gently scraping the solid clumps of resin from the bark of the tree. Pine resin from over 30 trees were collected for use in this study.

Figure 1. Pine resin from the *Pinus contorta*.

The apparatus built in order to separate the homogenous wood surfaces was constructed using a solid 3x4 inch and approximately three feet long central bar. A metal plate was

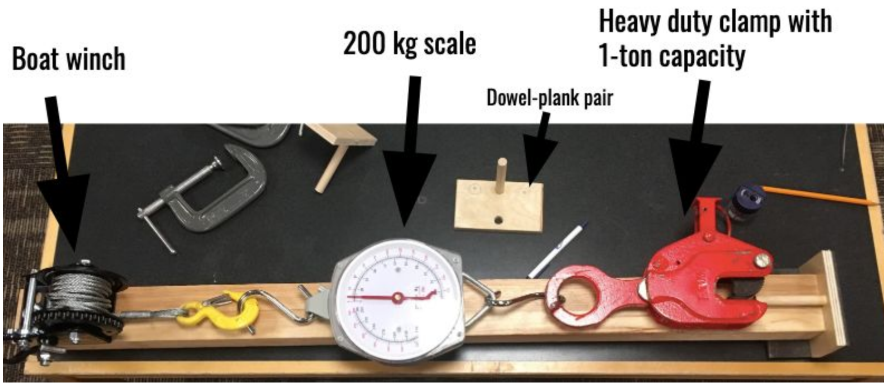

Figure 2. From left to right: the boat winch is connected to a 200 kg pound scale, which is attached to a heavy duty clamp with 1-ton capacity. One end of the clamp holds the wooden dowel while the connected wooden plank rests on the metal plate.

screwed onto one end of the central bar, with half an inch of spacing left between the metal plate and the wooden bar. A small boat winch was then bolted onto the wooden bar on the remaining end, which was used to apply the constant force necessary for this study. A 1-ton capacity heavy duty clamp and a 200 kilogram scale were arranged in a linear fashion along the central bar (*Figure 2)*. This apparatus was used to separate the identical 4-inch long and ½ inch wide wooden dowels from the ½ inch holes in the 3x4 wooden planks they were inserted into. In order to minimize uncertainty caused by differences in how the apparatus was set up for each trial, lines were drawn on the central bar to ensure the hook on the winch was extended the same distance for every trial.

Preparation was required in order to transform the crude original pine resin into a liquid form which could then be applied as an adhesive. Initial attempts to purify the resin by boiling and straining it were unsuccessful due to the excessively sticky nature of the resin. Instead, the unpurified resin was prepared by melting the solid chunks of unpurified resin in a metal pot over a hot plate which separated most of the residual wood chunks from the resin, resulting in a liquid with minimal debris remaining in it (*Figure 3*). The 50:50 pitch/beeswax was prepared by combining approximately similar amounts of solid resin and beeswax in the metal pot and then

Figure 3. Unpurified pine resin melted in a pot over a hot plate.

melting them together over a hot plate. Continuous stirring during the melting process ensured that the two substances formed a relatively homogeneous substance.

Once the resin or 50:50 pitch/beeswax mixture was melted and prepared, it was necessary to apply it immediately to the respective area of the wooden dowel and plank before it hardened. Application of the pine resin and the 50:50 mixture of pine resin and beeswax was done by dipping a Q-tip into the liquid and then liberally applying it to one end of a wooden dowel as well as the inner surface of the hole drilled into a wooden plank. The end of the wooden dowel which had the adhesive liquid applied to it was then immediately inserted into the hole. The ½ inch diameter dowel was inserted into the ½ inch diameter hole drilled into the wooden plank until the end of the dowel was flush with the wooden plank. Therefore, by fitting the dowel exactly into the hole, any excess liquid was forced out of the hole and wiped off. This process minimized uncertainty by ensuring that the same amount of adhesive was applied to each dowel/plank pair for each replicate. This same process was used to apply the commercial glues to the dowel/plank pairs.

The dowel/wood plank pairs were glued together and allowed to set for a minimum of twelve hours to ensure the solidification of the adhesive. For the separation process, the flat side of the wooden plank was inserted into the gap between the metal plate and the central bar, while the free end of the dowel was secured into a clamp of 1-ton capacity. Two G clamps were also used to secure the wooden plank tightly to the metal plate. The 1-ton heavy duty clamp was connected to a scale while the other end of the scale was attached to a boat winch, which allowed us to slowly separate the dowel from the plank using a constant applied force (*Figure 2*). To identify the maximum force reached before the glue pieces of wood separated, the scale was filmed with a camera on a tripod as the crank was pulled back. A slow motion analysis of the video determined the exact moment the maximum force was applied before the dowel separated from the plank and the scale reverted back to zero.

To ensure that the force we measured was an accurate reflection of the innate adhesiveness of the substance being tested and not a characteristic of how the dowel fit into the wood, the force required to separate every dowel and wood plank pair was pre-measured before applying the adhesive. The total recorded force required to separate any wooden dowel from a plank was determined by subtracting the pre-measured force with no adhesive from the force of separation with adhesive.

The statistical analysis for the collected data was done via an ANOVA test and four individual two-sample t-tests (which assumed unequal variances) performed between pine resin and each of the commercial glues, as well as with the 50:50 beeswax/pine resin mixture. This analysis was performed on Microsoft Excel 2016.

Results

An analysis of the force required to separate a wooden dowel from the wood plank was performed for the pine resin (n=11), 50:50 resin/beeswax (n=5), glue gun (n=5), fish glue (n=5), and Elmer's glue (n=5). The force required to separate the glues was determined by converting kilograms of force into Newtons. The average force, including standard deviation, for the pine resin was 348.67N ± 198.54N. The force required to separate the dowel and wood plank adhered with the 50:50 pitch/beeswax mixture was 223.65N ± 175.39N. The average force of separation when hot glue from a glue gun was used was 117.71N ± 169.47N. The average force of separation when the fish glue was used was 585.60N ± 195.31N. When Elmer's glue was used, the separation of the dowel from the plank required an average force of 786.16N ± 316.43N. *Figure 4* indicates that the mean force required to separate the wood

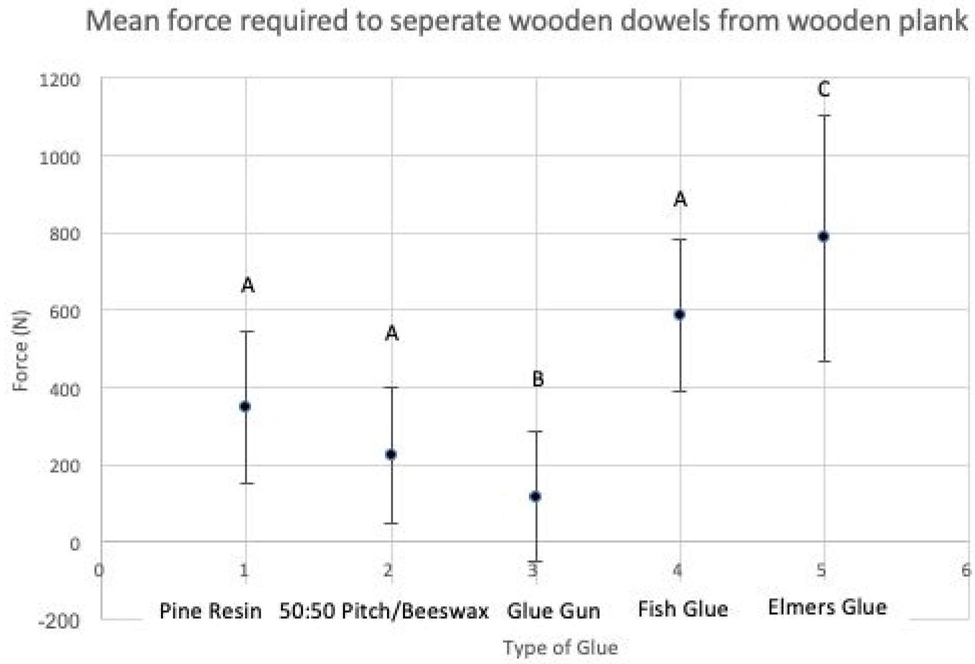

Figure 4. Mean force (N) required to separate wooden dowels from a wood plank bound by resin, natural, or synthetic glues. The standard deviations are ±198.54N for pine resin, ±175.39N for 50:50 pitch/beeswax, ±169.47N for the glue gun, ±195.31N for fish glue, and ±316.43N for Elmer's glue. The P-values between pine resin and the glue gun, and pine resin and Elmer's glue, are <0.05. The P-values between pine resin and the 50:50 pine resin/beeswax mixture, and pine resin and fish glue are >0.05. The same letter denotes adhesives that are statistically similar; different letters denote adhesives that are statistically different.

adhered with pine resin was greater than the 50:50 pitch/beeswax mixture and the glue gun, but less than the fish glue and Elmer's glue.

The P-value we obtained from comparing all five adhesive samples in the ANOVA test (P=0.000199, F=8.23) statistically demonstrates that there is a difference present somewhere in the data, but does not provide us any information about where this difference lies or what the magnitude of this difference is. Two-tailed t-tests were then performed to identify where these differences lay. The results of two individual two-tailed t-tests (assuming unequal variance) between pine resin and the glue gun (t=2.26, P=0.0405; *Figure 4*), and pine resin and Elmer's glue (t=2.57, P=0.0359; *Figure 4*), generated P-values of <0.05, thus demonstrating that these adhesives have statistically different strengths from pine resin. However, the t-tests performed between pine resin and fish glue (t=2.36, P=0.0556; *Figure 4*), and pine resin and the 50:50 mixture of beeswax/pine resin (t=2.26, P=0.237; *Figure 4*) yielded P-values >0.05, indicating that they have an adhesive strength statistically similar to pine resin.

Discussion

The results of this study indicate that unpurified pine resin has a greater adhesive strength than the 50:50 pitch/beeswax mixture and the glue gun, but lower than that of the fish glue and Elmer's glue. An individual t-test done between the pine resin and fish glue yielded a P-value greater than 0.05, indicating that there is no statistical difference between their adhesive strengths. Hence, we can state that the pine resin has an adhesive strength comparable to fish glue. We can also observe from the spread in standard deviation and the large overlap in the data points themselves that there is likely a similarity in the adhesives strengths of the pine resin and Elmer's glue as well. Elmer's glue, in particular, had the largest standard deviation of ± 316.43N, and therefore even though its mean force of separation was larger than both fish glue and pine resin, it could still be considered to have a similar adhesive ability to pine resin due to the sizable overlap in data points. Furthermore, the difference in the data, which is detected by the statistical tests, may be due to the limited number of replicates (n=5 for all adhesives besides pine resin, which had n=11). Future studies could be done to determine the extent of the difference between the Elmer's glue and the pine resin, as well as the pine resin and the glue gun.

The average force required to separate the wooden components adhered using pine resin was 348.67 N, which demonstrates that it maintains an adhesive strength large enough to function as an adhesive for casual usages. This implies that pine resin could be utilized as an environmentally friendly option to commercial adhesives, which are often produced in a non-environmentally friendly or unsustainable manner. Elmer's all-purpose glue, for example, is made from artificially synthesized chemicals. Fish glue is made from extractions of fish bone and/or skin, and therefore is dependent on fishing practices which may not always be environmentally sustainable (Petukhova, 2000). On the other hand, pine resin can be harvested from the surface of tree bark without causing any damage to the trees, due to the fact that the resin solidifies on the surface of the tree and is easily dislodged. Therefore, while these chemical-based glues may be stronger alternatives than pine resin, unpurified pine resin could potentially still satisfy many of the same purposes fulfilled by commercial glues. If harvested and processed in the manner done in this study, pine resin can be collected with little to no ecological impact, and the raw product can then be immediately transformed into a bonding adhesive. As demonstrated in this study, resin can be semi-purified by melting it to a liquid state, which naturally separates the wooden debris from the liquid resin. The liquid resin which separates from the debris can be resolidified, and this solid resin can then be transformed into blocks to be melted down later for consumer use. Not only does this process require no release or use of toxic chemicals, but it also minimizes cost and utilizes easily obtainable materials. Furthermore, pine resin is readily available in North America, as pine trees are a primary tree species in boreal forests, which cover around 55% of Canada's land mass (La Roi, 2013). It therefore contains commercial potential as an ecologically friendly and low cost adhesive for casual usage.

Future studies should examine whether purification of pine resin would increase or decrease its adhesive strength. This study determined that mixing pine resin with beeswax weakened its adhesive abilities, but it would be of interest to examine if mixing it with other substances would in fact strengthen its adhesive abilities.

Conclusion

Based on the results of our study, we propose the potential for pine resin to be used as an environmentally friendly and non-toxic alternative to commercial glues, suitable for casual usages. For individuals seeking to use a natural and eco-friendly adhesive, pine resin may be the solution.

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References

Cui, J., Lu, X., Zhou, X., Chrusciel, L., Deng, Y., Zhou, H., … Brosse, N. (2015). Enhancement of mechanical strength of particleboard using environmentally friendly pine (*Pinus pinaster* L.) tannin adhesives with cellulose nanofibers. *Annals of Forest Science, 72(1),* 27-32. doi:10.1007/s13595-014-0392-2

"Eastern White Pine (*Pinus strobus*)". (n.d.). *The Healing Power of Plants.* Retrieved from http://www.virtualmuseum.ca/sgc-cms/expositions-exhibitions/plantes-plants/plant_dir/eastern whitepine.php

Kozowyk, P.R.B., Poulis, J.A., & Langejans, G.H.J. (2017). Laboratory strength testing of pine wood and birch bark adhesives: A first study of the material properties of pitch. *Journal of Archaeological Science: Reports, 13,* 49-59. doi:10.1016/j.jasrep.2017.03.006

La Roi, G.H. (2013). Boreal Zone. *The Canadian Encyclopedia.* Retrieved from https://www.thecanadianencyclopedia.ca/en/article/boreal-forest

Petukhova, T. (2000). "A History of Fish Glue as an Artist's Material: Applications in Paper and Parchment Artifacts". Retrieved from https://cool.conservation-us.org/coolaic/sg/bpg/annual/v19/bp19-29.html

"Tensile Strength". (n.d.). *NTS.* Retrieved from https://www.nts.com/services/testing/mechanical/tensile-strength/

Vieira, R.K., Vieira, A.K., Kim, J.T., & Netravali, A.N. (2014). Characterization of Amazonic White Pitch (*Protium heptaphyllum*) for potential use as 'green' adhesive. *Journal of Adhesion Science and Technology, 28(10),* 963-974. doi:10.1080/016942.2014.880220

Appendix

Table 1: Mean force (N) required to separate wooden dowels from wooden plank

Type of Glue	**Force (N)**	**Standard Deviation (N)**
Pine Resin	348.67N	± 198.54N
50:50 pitch/beeswax mixture	223.65N	± 175.39N
Glue Gun	117.71N	± 169.47N
Fish Glue	585.60N	± 195.31N
Elmer's Glue	786.16N	± 316.43N

Table 2: ANOVA test between the 5 adhesives

Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Column 1	11	3835.319	348.665364	39417.2682		
Column 2	5	1118.226	223.6452	30760.409		
Column 3	5	588.54	117.708	28720.6196		
Column 4	5	2927.9865	585.5973	38145.0239		
Column 5	5	3930.808	786.1616	100129.126		
ANOVA						
irce of Variati	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Grc	1500772.31	4	375193.077	8.2307411	0.00019867	2.74259414
Within Grou|	1185193.4	26	45584.3614			
Total	2685965.7	30				

Table 3: T-test between pine resin and the 50:50 beeswax mixture

t-Test: Two-Sample Assuming Unequal Variances		
	pine resin	*glue gun*
Mean	348.665364	117.708
Variance	39417.2682	28720.6196
Observations	11	5
Hypothesized	0	
df	9	
t Stat	2.39138173	
P(T<=t) one-t	0.02023281	
t Critical one	1.83311293	
P(T<=t) two-t	0.04046562	
t Critical two	2.26215716	

Table 4: T-test between pine resin and the glue gun

t-Test: Two-Sample Assuming Unequal Variances		
	pine resin	*50/50*
Mean	348.665364	223.6452
Variance	39417.2682	30760.409
Observations	11	5
Hypothesized	0	
df	9	
t Stat	1.26707291	
P(T<=t) one-t	0.11846661	
t Critical one	1.83311293	
P(T<=t) two-t	0.23693322	
t Critical two	2.26215716	

Table 5: T-test between pine resin and the fish glue

t-Test: Two-Sample Assuming Unequal Variances		
	pine resin	*fish glue*
Mean	348.665364	585.5973
Variance	39417.2682	38145.0239
Observations	11	5
Hypothesized	0	
df	8	
t Stat	-2.2375588	
P(T<=t) one-t	0.02781848	
t Critical one	1.85954804	
P(T<=t) two-t	0.05563697	
t Critical two	2.30600414	

Table 6: T-test between pine resin and the Elmer's glue

t-Test: Two-Sample Assuming Unequal Variances		
	pine resin	*elmers glue*
Mean	348.665364	786.1616
Variance	39417.2682	100129.126
Observations	11	5
Hypothesized	0	
df	5	
t Stat	-2.8473022	
P(T<=t) one-t	0.01796861	
t Critical one	2.01504837	
P(T<=t) two-t	0.03593723	
t Critical two	2.57058184	