Surface process effect on PVAc glued joints

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Abstract

The changes in glueline shear strength on sugar maple, American beech, paper birch wood bonded with polyvinyl acetate (PVAc) adhesive were evaluated. The wood species had different surface properties as the result of across and along to the grain helical planing and sanding with three grit size sandpapers (g.s.p.). The specimens prepared to determine the effect of the variables on bond performance were subjected to shear test in an universal test machine. Surface roughness and wetting properties of wood were measured; microscopic analysis allowed to reveal damages on wood surface. Sugar maple specimens were also subjected to an accelerated aging treatment. The most effective surfacing methods were the helical planing process along and across the grain and sanding process with 150 g.s.p., all able to obtain the best surface for gluing, reaching a peak stress of 22,5 N/mm^2.

Among the different species studied, sugar maple gave the best gluing performance, followed by American beech, and paper birch. Sanding with 60 and 100 g.s.p. produced the roughest surfaces, showing compressed parenchyma rays and torn fibres. Among the studied species paper birch showed the roughest surfaces followed by American beech and sugar maple. Sugar maple sanded with 100 g.s.p. had the highest contact and equilibrium angles, sugar maple sanded with 120 g.s.p. had the lowest.

1. Introduction

This research investigated on how different variables in machining and gluing wood influenced the performance of gluelines. Different wood species and machining processes were evaluated. Wood species have variable behaviours when machined with different processes, because cells on wood surface can be crushed or damaged by these machines, creating a sort of barrier for penetration of liquids into the wood surface and anchor to intact wood material. The machining methods studied are the most common wood machining processes after sawing: planing and sanding.

Gluing is an everyday process in wood industries, and this investigation on surfacing methods may help in creating stronger bonds simply selecting one machine instead of another one.

The gluing shear strength variation was evaluated as a function of machining methods, wood species, and aging treatment. Physical analyses (density, moisture content, wettability, roughness, and microscopic observation) were done in order to better explain the variation in gluing strength.

2. Background

Many reports are available in literature. Davis (1942) found large differences in surface damages caused by sanding 20 wood species. River and Miniutti (1975) reported that damages on surface and subsurface of wood play an important role on the gluing performance. They evaluated two species of wood surfaced with jointer, planer and saw. The jointing process caused less damage. Jokerst and Stewart (1976) found that surfaces sanded with 60 g.s.p. behave better than those machined with 80 g.s.p., 36 g.s.p and by planing. They underlined the importance of aging wood surfaces in order to have a better idea of their long term performance. They observed damages on sanded surfaces whereas knife planed surfaces showed a clean cut. Stewart and Crist (1982) reported how dense latewood crushes into the less dense earlywood during planing and in particular during sanding, causing raised grain. They found that crushes were less severe after planing across the grain than along the grain. They explained the increase of crushes with a decrease of wood density. Murmanis et al. (1983) found no differences in wood cell structure machined with sander and knife planer. Caster et al. (1985) also suggested an aging treatment to detect differences in glueline performance between sanded wood. They also found a different gluing behaviour betweentwo wood species. Hernández (1994) investigated on surfacing methods and wood species showing slight differences between conventional and fixed knife

pressure-bar planing. Sinn et al. (2004) made a deep analysis of sanded surfaces using four grit size papers and two wood species. Density and pH affected surface roughness. Nordin et al. (1998) reported that wood density influences glue bond shear strength and wood failure percentage. Medium density wood species had better behaviours than high and low density species. Özçifçi et al. (2008) found an increase of peak stress with decrease of roughness, or increase of wood density. Burdurlu et al. (2006) found that 60 grit size paper sanded surfaces had better gluing results than planed surfaces.
The tool wear strongly influences gluing performance (Chladil 2007; Hernández and de Moura 2002a; Hernández and Rojas 2002b). Hernández and Rojas (2002b) reported that best performances of gluelines in sugar paple are possible within the first 500 metres of planing with freshly sharpened knives. Hernández and Naderi (2001) showed how surface damages prevent glue to penetrate sufficiently deep to reach undamaged cells. Hernández and de Moura (2002a) have reported that the increasing roughness caused by a slight wear of knives will create stronger gluelines. However, this positive effect of a slight wear was observed for red oak but not for sugar maple wood. Kilic et al. (2006) indicated that wood species with higher density had the higher roughness. de Moura and Hernández (2006a) found differences in roughness and wood cells damages analysing the surface obtained by helical planing along and across the grain. de Moura and Hernández (2006b) found that sanded surfaces presented the highest roughness and the best wetting properties than helical planed ones. Gurau et al. (2005) and (2006) reported the necessity of filtering data from measures of roughness on sanded surfaces. Gindl (2001) showed that glue predominantly penetrate through cut open tracheids and rays of wood. Stehr et al. (2000a) evaluated the changes in contact angle with time on sanded and razor blade cut surfaces. Stehr et al. (2000b) and Stehr et al. (2000c) discussed possible causes of poor bonds strength proposing a chemical and a mechanical boundary layer, and finding cracks originated by machining.

3. Method

3.1 Testing material

144 air dried flat-sawn boards of sugar maple *(Acer saccharum* Marsh.), 17 air dried flat-sawn boards of paper birch (*Betula papyrifera* Marsh.) and 14 air dried flat-sawn boards of American beech (*Fagus grandifolia* Ehrhart) were selected for this study. The average and standard deviation of density for sugar maple were 759 and 41 kg/m^3, for paper birch were 570 and 29 kg/m^3 and for American beech were 729 and 59 kg/m^3, all conditioned at 20°C ± 2°C and 60% ± 3% relative air humidity (RH) up to 11% equilibrium moisture content (EMC). All the specimens were visually selected as homogeneous as possible.
The boards were shaped with a jointer and a knife planer. Each board was then crosscut and labelled. After these treatments dimensions were 600 x 51,3 x 17,9 mm. Each board underwent the appropriate surfacing method and was re-sectioned in four parts: two 275 x 51,3 x 17,6 mm parts to constitute the laminated board, two 25 x 51,3 x 17,6 mm specimens for measuring wettability and roughness.

2.2 Machining treatments: sanding

The variables influencing sanding process results were considered according to Caster et al. (1985). Specimens were sanded with a Costa Levigatrici 36 CCK 1150 sander, with 4 different grit size sandpapers (60, 100, 120, 150) and the same belt type (Siawood 1939 open coating corundum/aluminium oxide belt for grit size 100, 120, 150, Nanomax F semi open coating corundum/aluminium oxide belt for grit size 60). All belts were new. The sanding process was done with a feed speed of 5,5 m/min (equal to the feed speed of the helical planer), and for each grit size were removed 0,30 mm (±0,03 mm) of thickness. Each sanding paper was mounted on the same drums set; only one drum was used in sanding action, with a speed of 21 m/s. The direction of sanding was parallel to the lumber grain.

2.3 Machining treatments: helical planing

The helical planing was performed with a Casadei R63H3 24” surface planer provided with two freshly sharpened flexible knives. An accurate selection permitted to plane with new defect-free knives. Feed speed was set at 5,5 m/min and deep of cut at 1 mm. The rake and helix angle were 30° and 14°, respectively. Specimens were planed along and across the grain. For this, the specimens were fixed side to side into a jig, and fed with the grain perpendicular and parallel to the cutting helix angle of the planer. Fig. 1 shows the jigs used for planing across and along the grain, respectively.

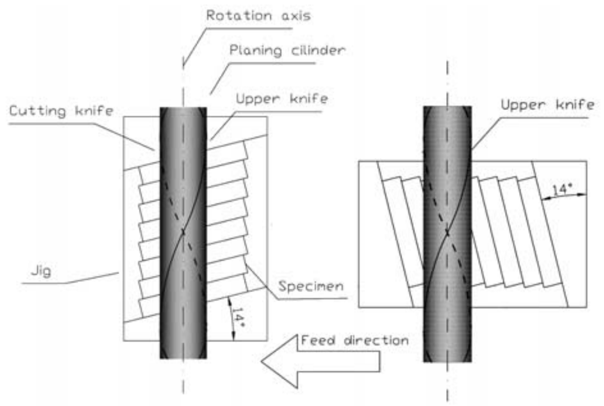

Fig.1: Planing along (left) and across (right) the grain

2.4 Gluing

The PVAc Nacan DURO-LOK TM 42.2150 glue was applied with a spread rate of 230 g/m^2, and a gluing pressure of 3 kg/cm^2. The pressing was conducted with a pre-load of 0,177 kg/cm^2 with a speed of 10 mm/min, and a pressing speed of 1 mm/min. The pressing time was 60 minutes, in a laboratory conditioned at 20° C and 65% RH. It was found useful to add a pigment to the glue in order to facilitate the visual analysis. Safranin was then selected and added in a proportion of 0,1% respect to the glue volume. Glue was applied on the tangential faces of wood specimens, 4 specimens per time, and fixed face to face into a jig. The glued specimens were finally pressed with an MTS Q/Test 5 universal testing machine equipped with a special pressing tool, for an homogeneous distribution of the pressure.

2.5 Specimen preparation

After gluing, the laminated boards were stored at least two weeks in a conditioning chamber at 20°C ± 2°C and 60 % ± 3 % RH. From each board, two shear specimens were obtained in its middle part according to ASTM D905-03. A total of 350 shear specimens were hence prepared. A small specimen for microscopic analysis was also prepared from the remaining part of the laminated board.

2.6 Accelerated aging

An accelerated aging treatment was used in order to facilitate detection of differences between machining treatments, as suggested in previous studies (Caster et al. 1985; Jokerst and Stewart 1976). An aging standard test (ASTM D 3434-00) was found too strong for our purposes, so 144 sugar maple glued specimens conditioned at 11% EMC were immersed for 10 hours in distilled cold (15°C ± 5°C) water until they reached 31±2 % of moisture content (MC), then they were mildly dried in an air oven at 40°C ± 1°C for 6 hours until they reached 15±1 % of MC and finally they were left in a conditioning chamber at 20°C ± 2°C and 60% ± 3% RH for nine days, until they reached 11% of EMC. This aging process forced wood to make only one swelling and one shrinking process, resulting in a mildly aging method.

2.7 Surface topography measurements

Roughness measurements were carried out with a Micromeasure confocal microscope. A surface of 10 mm x 10 mm was analyzed per sample. The data was collected with the Surface Map 2.4.13 software using an acquisition frequency of 300 Hz and a scanning speed of 12,5 mm/s. The average roughness (S_a) was determined by using the Mountain software based upon ISO 4287 (1998). A cut off length of 2,5 mm combined with a Gaussian filter (ISO 11562 1996) were used for calculations.

2.8 Surface wettability test

Contact angle analyses were performed using a FTÅ D200 imaging goniometer at 20°C. The studied glue was used as probe liquid in order to specifically measure the affinity of the surface with glue. A droplet was added to the wood surface within 90 minutes after surfacing treatment with a microsyringe. A frame grabber recorded the changes in contact angle of the droplet during the first two minutes of wetting. The view of the droplet was parallel to the orientation of wood fibers. In this way, the measured contact angles gave an indication of the longitudinal spreading of the tested liquid. Contact angle was calculated as an average of both sides of droplets to compensate for any horizontal variations. An initial contact angle was measured as soon as the drop fell down and became stable (usually after 2-3 seconds). A second value was taken when there were no more significant variation in the angle (usually after 80 – 120 seconds).

2.9 Shear test

The shear test was carried out according to ASTM D 905-03 standard. The quality of bonding is commonly judged by the combination of stress developed and the percentage of wood failure versus glue failure along the shear plane. Wood failure is normally desired, as it indicates that joints are made with strong adhesives. This meant that bondlines could resist more. Three different kinds of ruptures were distinguished, called by the origin of breaking point:

1. Wood failure: glue cohesion and glue adhesion to both surfaces are stronger than the axial breaking strength of wood. The result is that the wood breaks. It means that glue is strong, the gluing process was made in a proper way and there were no weakening environment conditions.
2. Glue adhesion to surface failure: glue cohesion and wood cohesion are good, but there is poor glue adhesion to one surface. The result is that a shear test specimen breaks at very low peak stress, and lets the glue just on one side of the specimen. It means that something was wrong during gluing.
3. Glue line failure: glue adhesion is good, glue cohesion is lower than the axial breaking strength of wood. The break occurred in the middle of the glue line plane, and as result there is glue on both surfaces of wood.

Usually fractures of specimens were one combination of these break types, presented in results as a percentage of each. This is a proposal of classification that resumes the seven classes of breaks presented by Bikerman (1967). The way to consider the breaking types suggested by the standards is to take note just of wood failure. In this work the wood failure values are reported as usual, adding a distinction among the rest of breaking type. A clarifying draw is presented below (Fig. 2).

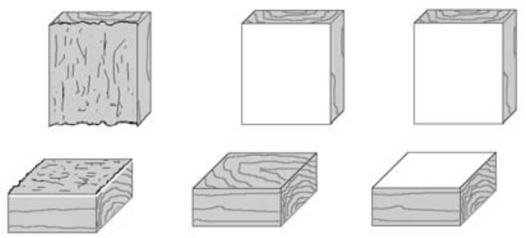

Fig. 2: wood failure (left), glue failure in adhesion to surface, glue line failure (right). Glue is white coloured

The evaluation of breaking type was done visually and sometimes with a Wood UV lamp, and reported as a percentage evaluated to the nearest 5%.

On this research it was evaluated shear strength results using these parameters to identify a good combination of wood, glue and machining variables, in order of importance:

1. Peak stress average and minimum values higher than 10 N/mm^2.
2. Wood failure percentage as closer to 100% as possible.
3. If wood failure was low, glue line failure as higher as possible.
4. Standard error of peak stress lower than 0,6 N/mm^2.

Shear strength or peak stress values were calculated following the equation:

$$\sigma_s = \frac{F_{\max}}{ab}\left[N/mm^2\right]$$

where F_{max} is the breaking load measured by the universal testing machine, a and b are the width and the length of glued face.

2.10 Microscopical analysis

It was supposed that a surface with broken, burned, compressed fibres, vessels or rays presents an unfavourable condition for gluing. In fact, superficial damages create a layer of crushed cells that hinders or makes difficult the penetration of liquids inside wood cells. An Olympus optical microscope with 40x, 100x and 400x magnification ratio was used. After evaluating peak stress values, a selection of the best and the worst specimens for each group was done. At least 5 slides for each specimen were prepared by radial razor blade cutting, in such a way to have on each slide the glue line and both wood pieces of laminated board. The radial (sometimes pseudo-tangential) cut permitted to evaluate damages of machining that was conducted over a tangential surface.

3. Results and discussion

3.1 Contact angles

Paper birch and American beech showed the best affinity with glue; their values of equilibrium contact angle are significantly lower than that of sugar maple (Table 1). Sugar maple had the lowest gradient (13%) between initial and equilibrium contact angles, which indicates that glue spreading was more difficult compared with the other two species.

The different machining methods used for sugar maple showed that this species had more affinity with glue when helical planed along and across the grain (Table 2). In fact, the equilibrium contact angles for these treatments were the lowest and the gradients between the initial and the equilibrium angles were the highest. Surfaces sanded with 120 and 150 grit size sandpapers had similar equilibrium angles but probably less spreading properties (lower differences between initial and equilibrium angles).

Wettability of different wood species sanded with paper 150 grit size. Analysis liquid: glue.	**Contact angle**		**Equilibrium angle**		**Difference (difference in %)**	**number of replicates**
	angle	St. Er.	angle	St. Er.		
	[°]	[°]	**[°]**	[°]	[°(%)]	n°
Sugar maple (*Acer*)	**133**	1,2	**116**	1,7	-17 (-12,8%)	24
Paper birch (*Betula*)	**136**	0,9	**111**	1,3	-25 (-18,4%)	17
American beech (*Fagus*)	**132**	1,0	**111**	1,1	-21 (-15,9%)	14

Tab. 1: Wetting results of the three wood species sanded with a 150 grit size sandpaper

Wettability of maple differently surfaced. Analysis liquid: glue. Number of replicates: 24.	**Contact angle**		**Equilibrium angle**		**Difference (difference in %)**
	angle	St. Er.	angle	St. Er.	
Surfacing method	**[°]**	[°]	**[°]**	[°]	[°(%)]
Planed Along the grain	**139**	2,6	**115**	2,7	-24 (-17,3%)
Planed Across the grain	**136**	1,6	**114**	2,6	-22 (-16,2%)
Sanded 60 grit size	**130**	2,1	**121**	1,7	-9 (-6,9%)
Sanded 100 grit size	**141**	1,4	**126**	2,0	-15 (-10,6%)
Sanded 120 grit size	**129**	1,8	**113**	2,2	-16 (-12,4%)
Sanded 150 grit size	**133**	1,2	**116**	1,7	-17 (-12,8%)

Tab. 2: Wettability of sugar maple surfaces obtained with different processes (means of 24 replicates)

3.2 *Roughness*

Roughness obtained for the three wood species showed clear differences among them. Sugar maple has the lowest one, paper birch the highest and American beech an intermediate (Tab. 3). A good correlation between roughness and density was found. High values of density correspond to low roughness. This indicates a more compact anatomical structure of the wood that is more difficult to be surfaced, and in this way wood during machining is subjected to less damages than a low density species.

Roughness of sugar maple, surfaced by the different machining methods are given in Table 4. The two planing methods had the same low roughness, and the four sanding methods had a tendency to cause a decrease in roughness with an increase of the grit size sandpaper.

Roughness of different wood species sanded with paper 150 grit size.	**Sa**	St. Error	replicates
	µm	µm	n
Sugar maple (*Acer*)	**6,6**	0,1	24
Paper birch (*Betula*)	**9,0**	0,3	17
American beech (*Fagus*)	**7,5**	0,3	14

Tab. 3: Measure of roughness of different wood species

Roughness of Sugar Maple surfaced with different machines	**Sa**	St. Error	Mean of n replicates
	µm	µm	n
Planed Along the grain	**6,4**	0,3	24
Planed Across the grain	**6,7**	0,3	24
Sanded 60 grit size	**9,3**	0,2	24
Sanded 100 grit size	**9,1**	0,1	24
Sanded 120 grit size	**6,1**	0,1	24
Sanded 150 grit size	**6,6**	0,1	24

Tab. 4: Roughness of different surfaced specimens

3.3 *Gluing shear strength*

The results of shear tests presented in Fig. 3 and Tab. 5 underline the differences among wood species. Gluelines of sugar maple had the best glue strength followed by American beech and paper birch. All wood species exceeded the considered acceptable shear strength of 10 N/mm^2, even for the lowest of the replicate values. Paper birch has the higher percentage of wood failure and the lower differences between replicates (Tab. 5).Therefore, even though this species did not show the stronger glueline, it should be considered as a good wood-glue combination, for giving reliable and predictable results. American beech also had a very high percentage of wood failure. Sugar maple and American beech has stronger gluing strength than paper birch, but lower wood failure; in particular sugar maple showed the lowest wood failure (but with a more than acceptable value of 82%).

The results of shear tests presented in Fig. 4 and Tab. 6 showed differences among the surfacing methods applied to sugar maple wood. Boards planed along and across the grain, and those sanded with 150 grit size sandpaper gave the highest peak stress of 22,5 N/mm^2. The lowest peak stress was obtained when sanding with 60 grit size sandpaper. Gluing strength increased with the increase of grit size paper. Planing gave the maximum strength among the machining treatment studied. Wood failure occurred mostly in sanded and planed across the grain boards; planing along the grain caused an high percentage (61%) of glueline breaks. Highest wood failure (89%) was found in specimens sanded with 60 g.s.p.

As expected, the gluing shear strength decreased after the aging process. (Fig. 5 and Tab. 7). Surfaces planed along the grain kept more their strength while those sanded with 150 g.s.p. lose more (Tab. 8). The aging treatment was therefore useful for detecting the best machining conditions to prepare wood for gluing.The loss of adhesion after aging could be associated with weak boundary layers formed at the surface during machining. As shown in previous works (River and Miniutti 1975; Stewart and Crist 1982; de Moura and Hernández 2005; 2006b), different processes produces surfaces with different distortions of the superficial wood tissues. In sanded surfaces, the layers of crushed cells at the surface and subsurface produced by the normal cutting forces were affected more by the aging cycle. In cross-grain and along to the grain helical planing, normal forces might have been lower but even distorting tissues near the cutting plan, weakening their structure and decreasing their aging resistance (Fig. 5). As a result, the highest gluing shear strength of aged specimens were obtained by boards planed along and across the grain; all sanded boards had lower values with not significant differences. Failures of aged specimens mostly occurred into gluelines.

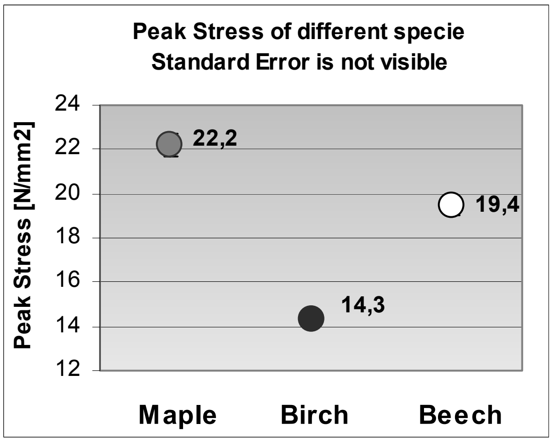

Fig. 3: Peak stress of different wood species

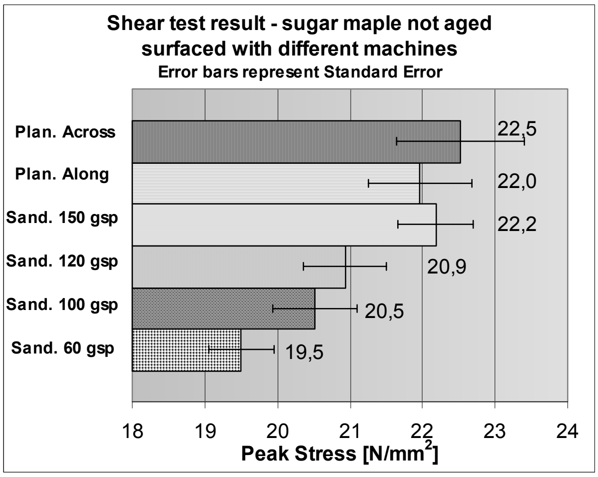

Fig. 4: Shear strength of differently surfaced maple specimens

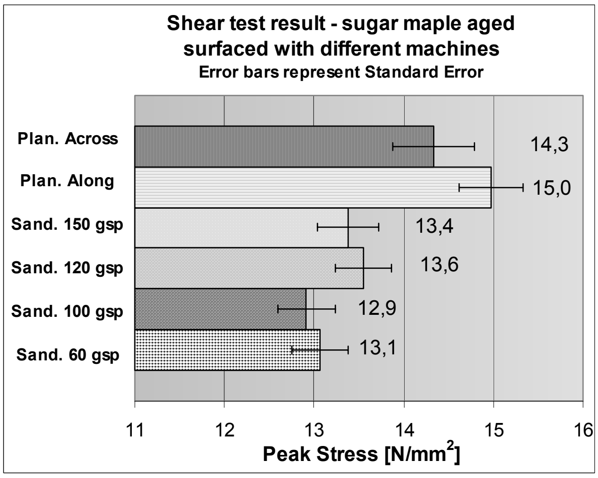

Fig. 5: Shear strength of differently surfaced maple specimens after aging

3.4 Microscopical analysis

All the following statements, except for indicated ones, must be intended for microscopical slides obtained by specimens that reached as high as low shear strength values.

Paper birch suffered the sanding process with high surface damages: torn fibres were present in glueline. There were no compressed cells. American beech showed a surface with less damage than paper birch: there are some torn fibres and some parenchyma rays slightly compressed. Sugar maple showed no damages in sample which had the highest peak stress. In the sample which gave the worst peak stress there were no torn fibres and parenchyma rays were folded.

Sugar maple surface planed across the grain presented some torn fibres. There were no damages in parenchyma rays and no cell compression and so an high number of anchorage points for mechanical adhesion of glue were available. These observations are slightly different with those presented by Hernández and Cool (2008), even though they used a different species (paper birch). Their SEM analysis showed a surface free of crushed cells produced with cross grain helical planing. For sugar maple, de Moura and Hernández (2005) observed that helical planing across the grain caused a slight torn grain in some specimens. Specimens planed along the grain presented a surface with no damage, without any compressed or torn cell. Microscopical analysis indicated a good penetration of glue also in a sub-surface area. Specimens sanded with 60 grit size paper showed compressed parenchyma rays and torn fibres. de Moura and Hernández (2006b) already reported that sanding produces a superficial layer of crushed cells that hinders the penetration of liquids as glues, and it may act as a weak boundary layer of cells. Specimens sanded with 100 grit size paper showed a smooth surface with a little of torn fibres. There were no parenchyma rays compressed or torn. Specimens sanded with 120 grit size paper showed a surface with torn fibres in sample which gave high peak stress values. There were also compression of parenchyma rays. Sample which gave low peak stress values showed a very smooth surface. Specimens sanded with 150 grit size paper showed no damages in sample which had the highest peak stress. In the other sample, which gave the worst peak stress, there are no torn fibres and parenchyma rays are slightly compressed. In conclusion a not uniform behaviour of wood cells subjected to sanding was found. Damages in fact were discovered in specimens sanded with all grit sizes, even though the magnitude of damages seemed to decrease with the increase of grit size paper. Very little damage was observed in surfaces planed across the grain, and no damages were found in surfaces planed along the grain.

4. Conclusions

Different wood species had different roughness: more dense wood was more resistant to machining and suffered less damages then a low density species. A correlation between roughness and peak stress was noticed: high values of shear strength were obtained on smoother surfaces.

Maple boards planed along and across the grain, and sanded with 150 grit size paper showed the highest peak stress of 22,5 N/mm^2. The lowest was obtained when sanding with 60 g.s.p.. Gluing shear strength increased as grit size sandpaper increases, even though differences were not so significant.

Anatomical microscopy analysis permitted to look at damages caused by different machining methods, finding no damages in wood cells helical planed along the grain, few damages on wood cells planed across the grain, few and sometimes strong damages in sanded surfaces.

A possible relation between wettability and gluing shear strength was also found: highest values of strength were correlated with a highest variation between initial and equilibrium contact angle.

This research shows how many and how much different variables have an influence on the gluing process, causing strong or weak bonds. In this work it is shown that is possible to reach strong bonds choosing among different wood species or surfacing methods.

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Tab. 5: Glue lines shear strength in different wood species. Satisfactory glue lines are indicated with "+". "A, B…" identify the best and other satisfactory glue lines in order of goodness

Evaluation	Wood sanded 150 grit size / Wood species	Shear strength test: Peak stress N/mm²	St. Error N/mm²	n° of replicates n°	Min. N/mm²	Max. N/mm²	Wood %	Type of failure: Glue line %	Glue adhesion to surface %
+A	Sugar maple (*Acer*)	**22,2**	0,5	24	15,7	26,3	82	9	9
+B	Paper birch (*Betula*)	**14,3**	0,3	34	10,0	16,7	99	0	1
+A	American beech (*Fagus*)	**19,4**	0,4	28	15,7	23,6	93	3	4

Tab. 6: Peak stress results of sugar maple surfaced with different machines

Evaluation	Sugar maple / Surfacing method	Shear strength test: Peak stress N/mm²	St. Error N/mm²	n° of replicates n°	Min. N/mm²	Max. N/mm²	Wood %	Type of failure: Glue line %	Glue adhesion to surface %
+	Planed Along the grain	**22,0**	0,7	24	13,1	27,4	29	61	10
+	Planed Across the grain	**22,5**	0,9	24	12,2	27,3	58	29	14
+	Sanded 60 grit size	**19,5**	0,4	24	14,5	23,0	89	1	9
+	Sanded 100 grit size	**20,5**	0,6	24	13,2	24,9	78	6	16
+	Sanded 120 grit size	**20,9**	0,6	24	15,3	25,5	83	8	9
+	Sanded 150 grit size	**22,2**	0,5	24	15,7	26,3	82	9	9

Tab.7: Peak stress results after aging of sugar maple surfaced with different machines

Evaluation	Sugar maple after AGING / Surfacing method	Shear strength test: Peak stress N/mm²	St. Error N/mm²	n° of replicates n°	Min. N/mm²	Max. N/mm²	Wood %	Type of failure: Glue line %	Glue adhesion to surface %
+	Planed Along the grain	**15,0**	0,4	24	10,9	17,5	3	91	6
+	Planed Across the grain	**14,3**	0,5	24	9,4	18,1	4	87	9
+	Sanded 60 grit size	**13,1**	0,3	24	10,5	16,4	22	73	6
+	Sanded 100 grit size	**12,9**	0,3	24	9,9	15,3	13	74	13
+	Sanded 120 grit size	**13,6**	0,3	24	10,8	17,1	11	81	8
+	Sanded 150 grit size	**13,4**	0,3	24	10,9	16,9	11	82	7

Tab. 8: Reduction in glueline shear strength caused by aging treatment

Glue-line strenght comparison between not aged and aged specimens	**Peak stress of not aged spec.** NN/mm²	**Peak stress of aged spec.** NN/mm²	**Glue-line strenght reduction** NN/mm²	%
Maple Planed Along the grain	22,0	15,0	-7,0	**-31,8**
Maple Planed Across the grain	22,5	14,3	-8,2	**-36,4**
Maple Sanded 60 grit size	19,5	13,1	-6,4	**-33,0**
Maple Sanded 100 grit size	20,5	12,9	-7,6	**-37,1**
Maple Sanded 120 grit size	20,9	13,6	-7,4	**-35,3**
Maple Sanded 150 grit size	22,2	13,4	-8,8	**-39,7**