

Moisture influence on solid wood bonded with modified starch

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Abstract: *Moisture influence on solid wood bonded with modified starch.* A growing and developing population is contributing to the ever-increasing global warming, which is caused, among other things, by the heavy use of chemicals. Most of them are crude oil-based, which is a non-renewable source. That is why the population tries to find organic substitutes in every area, even in the wood industry. Here, the most common and popular binders - amine resins, are subjected in research to partial or full replacement by more natural binders, non-formaldehyde, made of renewable raw materials, preferably plant-based. In this project, the studies were carried out on the possibility of starch-based glue application in wood bonding and its effect on glued birch wood (*Betula pendula* Roth) under various environmental storage conditions of bonded samples (0%, 65%, and 100% of RH). The results show, that the samples at room temperature and normal humidity, as well as another – additionally dried, have a very similar shear strength. In-wood damages, on the other hand, are much more varied. The research also included moistened samples, which gave poorer results (about 12% lower than the remaining samples). Based on the results, it can be concluded, that modified starch is a very good organic glue, that can potentially replace some chemical products in certain applications.

Keywords: starch, glue, birch wood, *Betula pendula* Roth, bonding, shear strength

INTRODUCTION

Starch is a naturally occurring carbohydrate found in almost all plants (Soykeabkaew et al. 2015). Natural starch does not have many uses, but it is an important processing raw material (Leszczyński 2004). Starch is not soluble in cold water. Under the influence of hot water, the grains swell to form a gruel. New hydrogen bonds are formed between the water and the starch, so the molecules are hydrated (Gadhawe et al. 2017). Modified starch is a natural starch, that has been subjected to chemical, physical or enzymatic processes (Soykeabkaew et al. 2015). Due to its abundance, low cost, renewable nature, biodegradable quality (Norström et al. 2018), and adhesive properties, it attracts the attention of the plastics industry as a substitute for adhesives, especially for paper and wood surfaces. However, the hydrophilicity of native starch makes formulating waterproof adhesives from it challenging as the starch hydroxyl groups easily form hydrogen bonds with water. Until now, starch has been used as a binder in the production of fibreboards with different starch weight content (Wronka et al. 2020). Acetylated and natural starch has been used in the production of polyethylene composite materials with the addition of mixtures with various proportions of starch and acids (Zdybel and Leszczyński 2004). Mixtures of protein-dialdehyde-starch glue were used for the production of birch plywood (Weakley et al. 1971). The production of esterified starch was developed and its use

in gluing processes, including for paper, plywood, or wood composites (Watcharakitti et al. 2022). Thermoplastic starch in the form of grains of various sizes was used for the production of MDF boards (Kowaluk et al. 2013). Wirabuana and Alwi (2021) used starch in the production of Durian peel briquettes.

The aim of this research was to evaluate the possibility of using modified starch as a glue in bonding wood and its effect on glued birch wood under various environmental storage conditions of bonded samples.

MATERIALS AND METHODS

Bonding of the lamellas

As many as 30 of the same samples made of air-dried birch lamellae (*Betula pendula* Roth) with dimensions of 110 (along the grain) x22x8 mm³ were prepared for a mixture of granules (about 3 mm diameter, transparent) starch and hot, distilled water in a 1 : 1 w/w ratio. In the beginning, the trials were made to melt the dry starch granules under the influence of temperature. Unfortunately, the high temperature meant, that the starch was very dry, hard, and not melted. The resulting adhesive, produced by mixing starch with water, was thinly applied (with small excess) to each lamella on one wide surface at room temperature. Then, every two lamellas were joined with the surfaces covered by a binder and placed in the press for 10 min at the temperature of 100°C in order to remove excess polymer and stabilize the connection. Then, the samples were stored in a normal environment (20°C, 65% RH) for one week.

All 30 samples were divided into 3 equal parts. Each of them was stored at different humidity in the next stages to weight stabilization. The following temperature and RH of ambient air have been applied (variants) for sample conditioning: 70°C/0%, 20°C/65%, and 20°C/100%.

Shear strength testing and in-wood damage evaluation

All the conditioned samples have been tested for tensile strength according to EN 205 (2016) using a standard testing machine. The tensile strength was taken as the maximum load [N] in relation to the area of the bond line. In addition, after the samples were broken, each damaged zone was analyzed to estimate the area of in-wood damage (%).

The moisture content of tested samples

Testing of the samples' moisture content (MC) has been completed by using the dryer-weighing method. As many as 5 samples of every tested variant, with dimensions of 110x22x8 mm³, have been dried for 72 h at 105°C, then cooled down in a desiccator, and weighed.

Hardness testing

The testing of the relative hardness of bonding lines has been done with an AWS-9 pendulum apparatus. A 3 mm HDF plate was used for this test. A starch-based glue was applied to the plate, and then its hardness was tested and compared to the results of PVAc (polyvinyl acetate) and MUF (melamine-urea-formaldehyde) glue, 9% melamine content, prepared as for industrial plywood production.

Statistical assessment

The results of all the tested features were evaluated statistically using Fisher's exact test, with a probability level of $p=0.05$, to establish whether the achieved average values were statistically equal. Where applicable, the mean values of the investigated features and the standard deviation indicated as error bars on the plots were presented.

RESULTS AND DISCUSSION

Shear strength testing and in-wood damage evaluation

The results of the shear strength measurements of birch lamellas stored in various conditions are shown in Fig.. The highest average value of shear strength is 5.16 N/mm^2 for birch lamellas conditioned in the air of 65% MC, while the lowest strength of 4.54 N/mm^2 was obtained for samples conditioned in the air of 100% MC. The only statistically significant differences between mean values of shear strength have been found for variants conditioned in 100% RH referred to as remaining variants. When referring the achieved results to other attempts of wood bonding with the use of other binders of natural origin, it can be concluded, that the tested here modified starch gave a quite high strength. According to Kowaluk and Wronka (2020), the shear strength of the same lamellas bonded with casein glue is 2.82 N/mm^2 , and 5.08 N/mm^2 for the gelatine/acetic acid blend. In the same test, the PVAc bonding line shear strength was 7.34 N/mm^2 , so it means, that the achieved here results for the natural origin binder are significantly lower when referred to the industrially applied binder. The results of the assessment of damage in wood for the tested samples are also shown in Fig.. The only statistically significant differences between mean values of in-wood damage have been found for variants conditioned in 100% RH referred to as remaining variants. Additionally, with the highest humidity, the share of wood was the lowest and amounted to an average of 17%. The water resistance of the starch-based adhesive can be improved by using, inter alia, sodium dodecyl sulfate (Gadhve et al. 2017). The examples of different forms of bond destruction have been presented in Fig.. The hydrophilic character of starch has been revealed (Bergel et al. 2018).



Fig.1. Examples of break zone of the tested samples a) 100 in-wood damage, b) 0% in wood, c) 70% in wood

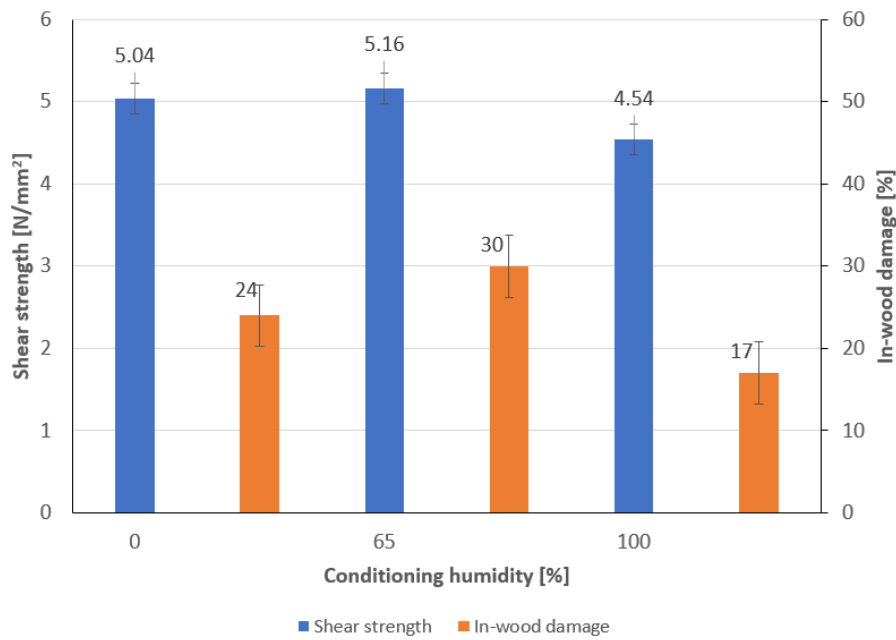


Fig.2. Shear strength and in-wood damage of tested samples

The moisture content of tested samples

The results of moisture content measurement of tested samples have been presented in Fig. 1. The highest average humidity of 10.1% had the samples with the highest conditioning air humidity, i.e. 100%. Similarly, the lowest average humidity of 0.6% was indicated by samples with 0% humidity. The equilibrium moisture content of the samples conditioned in an ambient air humidity of 65% was 6.6%. All the achieved mean values of sample moisture content have been statistically significantly different from others. For wood composites of corn starch modified with citric acid, the moisture content was tested for four different air humidity (35%, 55%, 75%, and 95%) (Hazim et al. 2020).

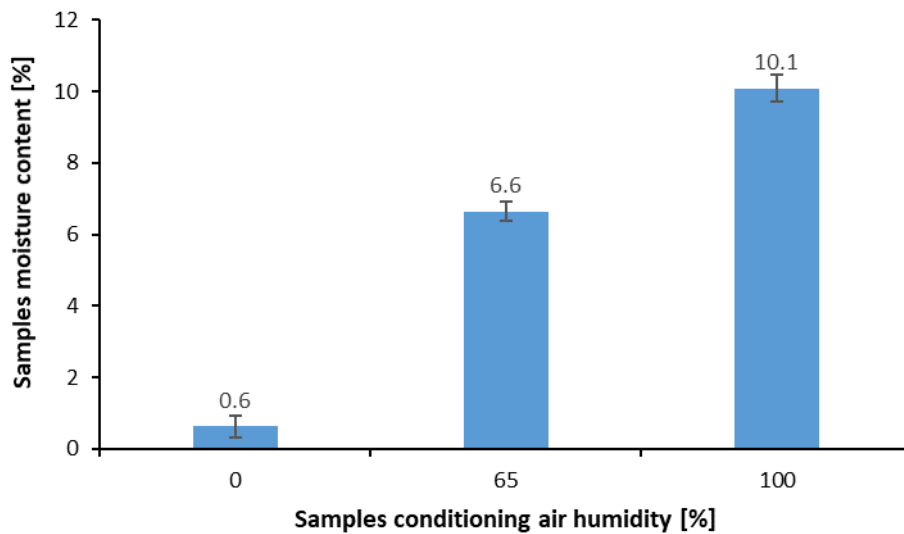


Fig. 1. Moisture content (equilibrium) of tested samples in regard to ambient air humidity

Hardness testing

Fig. 2 shows a comparison of the hardness of the bonding line depending on the type of binder. All the achieved mean values of bonding line relative hardness have been statistically significantly different from others. The softer the surface, the lower the hardness. If the bonding line is of high hardness, it can damage the cutting tools when machining this type of material, which contains the selected binder. In this research, the 0.308 starch bonding line came out less hard than MUF and harder than PVAc. It is possible to plasticize the joint with the addition of glycol or glycerin (Mamiński and Sedliacik 2016).

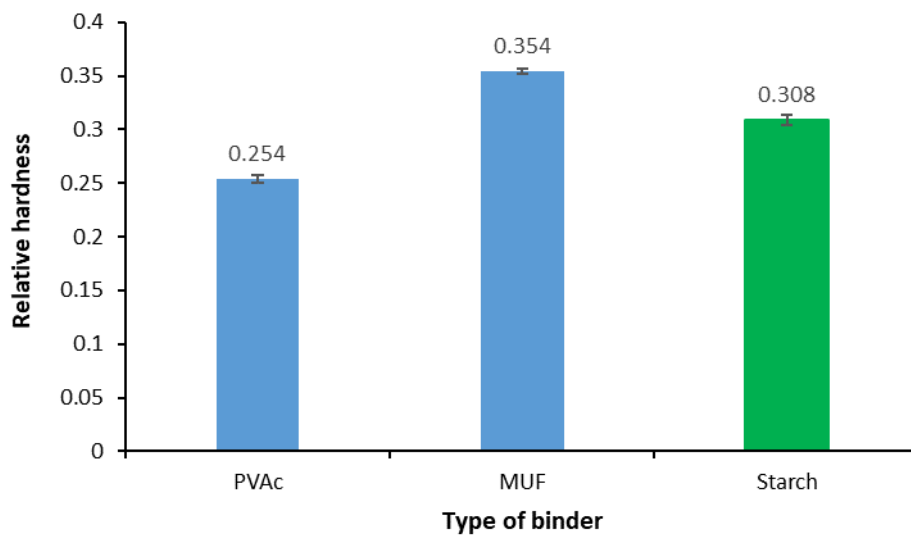


Fig. 2. The relative hardness of the bonding line of different wood binders

CONCLUSIONS

Based on the conducted research and analysis of the obtained results, the following conclusions and comments can be drawn:

1. The highest values of shear strength of the wood samples bonded with modified starch have been reached for wood conditioned in ambient air of 65% RH. The increase in humidity conditioning of the birch wood samples bonded with modified starch over 65% RH cause a significant decrease in the shear strength.
2. The higher sample's moisture content over 6.6%, the smaller the in-wood damage area.
3. The relative hardness of the modified starch bonding line is significantly lower than that of the melamine-urea-formaldehyde bonding line.
4. The modified starch is a very good, potential organic glue, which in some cases can replace some chemical products.

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Streszczenie: *Wpływ wilgoci na drewno lite sklezione skrobią modyfikowaną.* Przeprowadzono badania nad możliwością zastosowania kleju skrobiowego w spajaniu drewna i jego wpływem na klejone drewno brzożowe (*Betula pendula* Roth) w różnych warunkach środowiskowych przechowywania sklejonnych próbek. Wyniki pokazują, że próbki w temperaturze pokojowej i normalnej wilgotności, a także inne – dodatkowo wysuszone, mają bardzo zbliżoną wytrzymałość na ścinanie. Z drugiej strony uszkodzenia drewna są znacznie bardziej zróżnicowane. Badaniami objęto również próbki nawilżane, co dało gorsze wyniki. Na podstawie uzyskanych wyników można stwierdzić, że skrobia modyfikowana jest bardzo dobrym klejem organicznym, który potencjalnie może zastąpić niektóre produkty chemiczne w szczególnych zastosowaniach.

Słowa kluczowe: skrobia, klej, brzoza, *Betula pendula* Roth, klejenie, wytrzymałość na ścinanie

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