CHARACTERIZATION OF SEALANTS AND ADHESIVES BEHAVIOUR AS FULFILLMENTS OF CRACKS IN WOOD

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Abstract
The primary aim of this research is to assess the durability of available adhesives and sealants, intended for rehabilitating oversized cracks in wood structures. Spruce wood was used as filling material to prepare surface-glued samples. The highest compressive shear strength values were observed for reference samples (without exposure stress) bonded with adhesives. The achieved shear strength values for the epoxy and polyurethane adhesives were 80% higher than for the sealants. The adhesion failure was visually assessed. The effect of the filler on the tensile properties was assessed for the epoxy adhesive.

Keywords
Cracks in wood elements, adhesives, sealants, filler

1 INTRODUCTION

Wood is one of the oldest natural materials. With the need for housing, primitive joints of wood were gradually created, which over time developed into sophisticated the carpentry joints seen today. However, wood is very sensitive to changes in humidity, it swells or dries up, and it is prone to biological degradation [1], [2]. These processes often result in the development of cracks. Cracks in wooden elements are either acknowledged or in the case of larger ones with an impact on the statics of the element, these cracks must be rehabilitated [3]. In load-bearing wooden structures, oversized cracks can reduce strength and stability. Cracks can be mechanically stabilised (e.g., by steel fasteners) or filled with adhesives and sealants. The most important thing for the rehabilitation process of wood cracks is the right choice of the filling material. The quality and strength of the fulfilment are determined by such factors as adhesion or adhesion failure, serving as a measure to determine the connection quality. If it is necessary to rehabilitate wood load-bearing structures with filling material, an adhesive capable of carrying the load and effectively interacting with the wooden element must be selected [4], [5], [6].

Flexible sealants are commonly used to fill small cracks in wood. For larger cracks, it is good to use wood adhesives (e.g., epoxy adhesive). Adhesives are often enhanced with fillers for better workability. Among the fillers used are particle fillers based on $CaCO_3$, SiO_2 and tree bark; fibrous fillers such as cotton flake type or various types of fabrics (e.g., basalt fabric) [7], [8], [9], [10].

The motivation behind this work is the fact that a large number of filling materials are available on the market for wood restoration. However, the applicability and durability of some types of adhesives or sealants in the rehabilitation of wooden load-bearing elements remains unclear.

The aim of this study was to verify the durability of selected commercial adhesives and sealants for crack rehabilitation. The research is focused on studying the changes in the properties of glued joints due to temperature and humidity stress. The evaluation of the behaviour of adhesives and sealants focuses on shear strength and adhesive failure. This work also includes an assessment of the impact of the fillers in the form of cotton flakes and spruce sawdust on the tensile properties of samples prepared from epoxy resin (necessary to fill due to low viscosity).

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2 METHODOLOGY

For experimental purposes, two types of filling materials were selected, based on established methods for rehabilitating drying cracks using various structural adhesives and sealants. Two types of adhesives and two types of sealants were selected:

- adhesives:
  - one-component polyurethane KESTOPUR 1030 (KiiLTO, Finland),
  - epoxy resin LH 160 with hardener 285 MGS (Havel composites, Czech Republic),
- sealants:
  - MS polymer Sikaflex-118 Extreme Grab (Sika CZ, Switzerland),
  - polyurethane Sikaflex 11 FC+ (Sika CZ, Switzerland).

Preparation of test samples

Adhesives and sealants were applied to the spruce wood surface (300 g/m^2 for each surface) and samples were made according to the diagram depicted in Fig. 1. Spruce (*Picea*) boards, with a density of 470 ± 30 kg/m^3 had a moisture content of (10 ± 2)% during the gluing process. The dimensions of the pasted board were 100 × 100 × 30 mm. The filling material was manually applied to the spruce board using a notched trowel. Then the board was inserted into a cut hole (cross-section 60 × 32 mm) in a spruce prism with dimensions of 160 × 160 × 1 000 mm. Polystyrene was used as a base for the spruce board. Additional boards were glued into the 1 m long prism at approximately 100 mm spacings. The samples were not pressed. Three test sets (for the exposure stress – A1, A3 and A5) were prepared from each filling material, with ten pieces of samples per set.

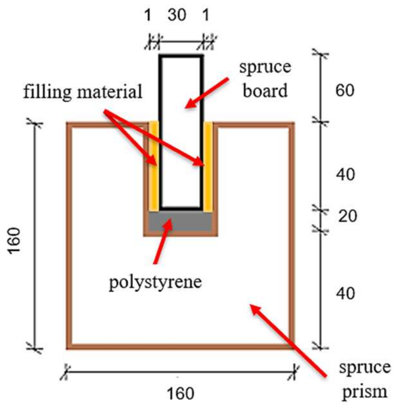

Fig. 1 Schematic representation of the dimensions of the test specimen in millimetres (left) and part of the prepared test specimens before formatting to the required dimensions (right).

After a week, the glued prisms were formatted to match the dimensions of the spruce board. Before determining the shear strength, the cut samples were subjected to selected exposure stresses according to standard EN 302-1:2013 [11]. The reference samples were acclimatised in laboratory conditions of 20 °C and 65% relative humidity (A1). The second set of samples was subjected to moisture stress – for 4 days in cold water at a temperature of 20 °C (A3). The third set was exposed to hydrothermal stress for 6 hours submerged in boiling water, then 2 hours in cold water at 20 °C (A5).

Part of the experiment was the verification of the effect of the fillers on the strength of the epoxy adhesive. Epoxy adhesive, known for its low viscosity, can be filled for better workability. Two types of fillers were selected:

- cotton flakes in the amount of 10 wt.% and 20 wt.% (Havel composites, Czech Republic),
- spruce sawdust in the amount of 10 wt.%, 20 wt.% and 30 wt.% (Czech Republic).

Cotton flakes exhibit a maximum fibre length of 0.5 mm and a width of 0.025 mm, while spruce sawdust has a maximum particle size of 0.5 mm. The fillers were manually dispersed in the epoxy matrix in the selected amount. After mixing, the mixture was poured into a mould. To determine the tensile strength, dogbone-shaped samples (type 1B), were prepared according to standard EN ISO 527-2:2012 [12].

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Determination of shear and tensile strength

The shear compressive strength was determined according to standard EN 302-1:2013 [11]. The specimens were tested after two weeks of exposure stress (after reconditioning in standard climate [20 °C/65%] to regain their original mass). The TIRA test 2850 S apparatus, with an addition for deriving compressive stress (Fig. 2), was used for the determination. The crosshead was constantly moved until the specimen broke at a speed of 1 mm/min. After the failure of the test specimen, the maximum applied force was recorded. The percentage of adhesion failure (rounded to the nearest 10%) was visually assessed for each sample. The average shear strength value was determined from ten values for each set of samples.

Fig. 2 Specimens in the test equipment TIRA test 2850 S.

The tensile strengths of dogbone specimens were determined according to standard EN ISO 527-1:2020 [13]. The specimens were tested one week after preparation (allowing for moisture stabilization of glued joints) at a temperature of 20 °C and a relative humidity of 65%. A Universal Testing Machine with full computer control was used for the determination. The sample was clamped, and the crosshead was set at a constant rate of 3 mm/min until the test specimen broke. The maximum applied force was recorded. The average tensile strength value was calculated from five values for each filling mixture and reference (pure epoxy adhesive).

Microscopic analysis

To observe the dispersion, porosity, and fracture location of the dogbone samples a Keyence VHX-950F digital optical microscope was used. Microscope images were taken at magnification of 200× and 30×.

3 RESULTS

The experimental part of the work focused on the evaluation of the shear strength under compressive stress of the glued joints along with the visual assessment of the degree of adhesion failure of these joints. The results of this initial part are shown in Fig. 3. The graph represents the average shear strength values, and the columns include the standard deviations values for each type of bonded joint.

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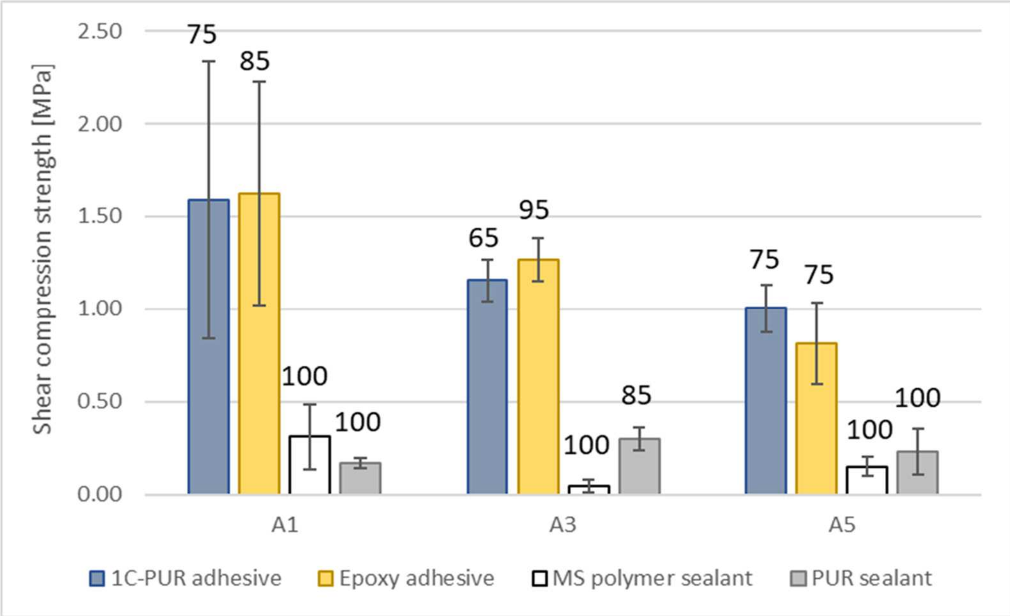

Fig. 3 The results of shear compressive strength for used adhesives and sealants (the number above the columns indicate the degree of adhesion failure).

The effect of the fillers on the ductility of the epoxy matrix is represented in Fig. 4. This box plot shows the average tensile strength values dividing data into quartiles (25% and 75%), The median is defined, and the maximum and minimum strength values are indicated.

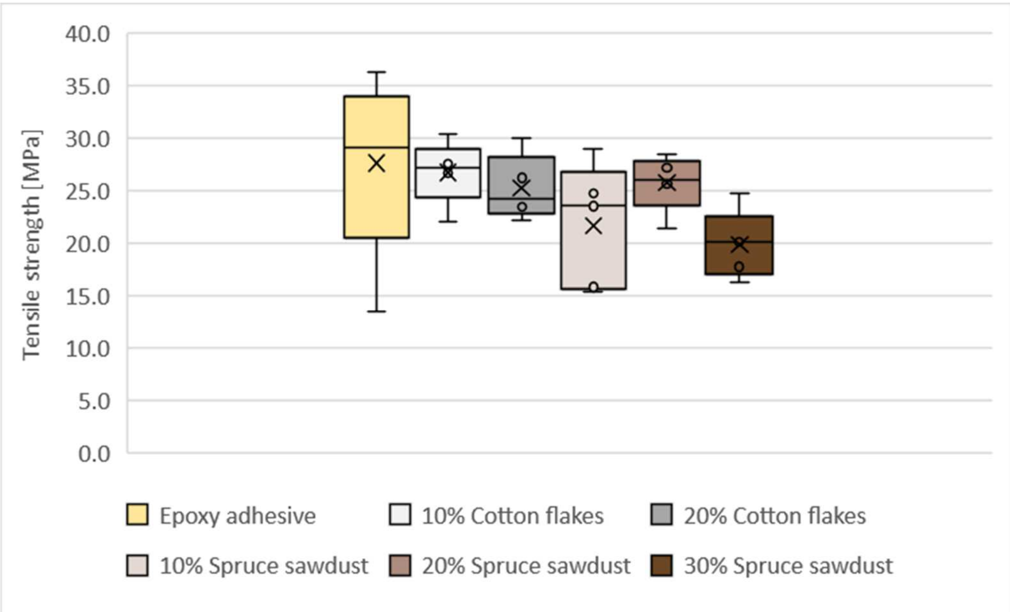

Fig. 4 The results of tensile strength for epoxy adhesive without filler and with filler in the form of cotton flakes and spruce sawdust.

In the micrographs with different magnifications (Fig. 5), the dispersion of the filler and the pore distribution of the specimens were visually observed at the point of failure of the tested specimens.

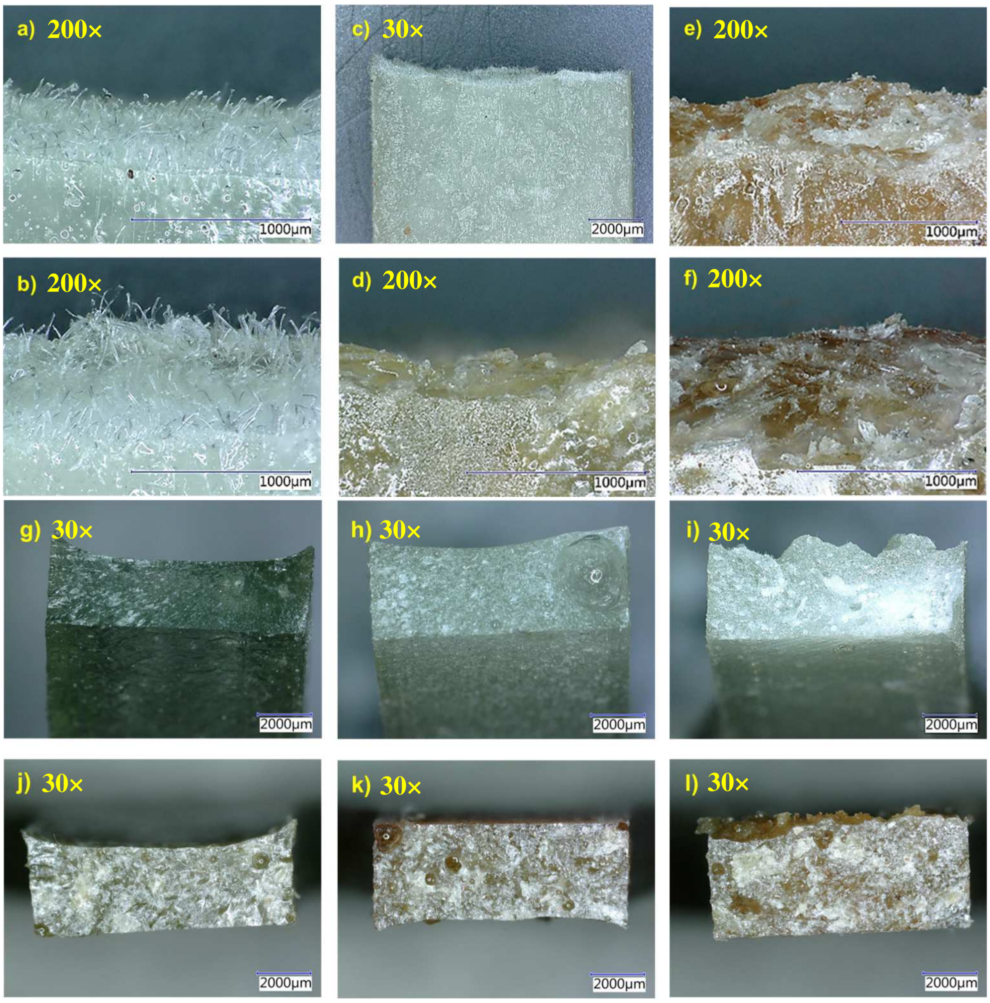

Fig. 5 Microscopic images of the fracture surface after the tensile test, magnification 200× and 30×: a), h) 10% cotton flakes; b), c), i) 20% cotton flakes; d), j) 10% spruce sawdust; e), k) 20% spruce sawdust; f), l) 30% spruce sawdust and g) reference sample of epoxy adhesive without filler.

4 DISCUSSION

Bonded joints glued with adhesives (1C-PUR and epoxy adhesive) achieved higher average shear strength values than joints glued with sealants (MS polymer and polyurethane sealant). For joints bonded with 1C-PUR adhesive, the average shear strength was determined to be 1.5 MPa, while for epoxy adhesive the value was 1.6 MPa. The standard deviations of the shear compressive strengths of joints glued with adhesives without exposure stress (A1) showed high values. Spruce wood, like any natural material, has variable properties and natural defects. The bonding process was the same for all samples. There may have been unevenness in the application of the adhesive and these samples may be the reason for the larger standard deviations. Due to exposure stress, the shear strengths decreased. The highest decrease in strength occurred after exposure to stress in boiling water (A5). For the 1C-PUR adhesive, there was an almost 40% decrease of shear strength compared to the reference (A1). A 50% decrease of shear strength was noted for the epoxy adhesive.

The sealants showed very low shear strengths compared to adhesives. The average value of the shear strength was 0.1 MPa for the MS polymer and 0.2 MPa for the polyurethane sealant. The strengths of the bonded samples with sealants did not change much after exposure stress. For most of the tested specimens bonded with sealants, 100% adhesion failure (at the interface of the sealant and wood surface) was observed.

The results of shear strengths were compared. The tested sealants are not able to transfer loads in the wooden elements of the load-bearing structures. According to the result of the shear strengths of the used adhesives, the assumption that the adhesives are a more suitable type of filling for oversized cracks was confirmed.

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The second part of the experiment showed that the filler reduces the tensile strength of the epoxy adhesive but improves workability. However, when applying epoxy adhesive to cracks, the filler is essential. The microscopic images (Fig. 5) show good dispersion of both fillers, but many clusters are observed. The porosity of the epoxy matrix was visible when both fillers were used. Pores are the weakest point for bonded joints. The reference sample without filler achieved the highest average tensile strength (27.7 MPa). From the achieved results (Fig. 4), it is possible to consider reducing the amount of filler below 10%. In a conducted research, Al-Turaif [14] verified the effect of NFC (nanofibrillated cellulose) on the tensile properties of epoxy resin at different amounts (0.05, 0.1, 0.2, 0.25, 0.5 and 1%). The best tensile property results were obtained by adding NFC cellulose at 0.1 wt.%. However, increasing the amount of NFC admixture did not yield a positive effect. Samples with 0.5% and 1% NFC loading achieved lower parameters than unfilled epoxy. In the experiment [15], MFC cellulose (microfibrillated cellulose) with a size of 10–100 nm at 0.5, 1.0 and 2.0 wt.% was used as filler for the epoxy resin. The tensile strength was almost constant at different MFC ratios. The optimal amount of filler should improve processability and reduce tensile strength as little as possible. However, the shape index/dimensions and the nature of the filler (fibrous/particulate) have a great influence on the resulting tensile properties.

5 CONCLUSION

The achieved results in this study correspond to the expectations. The key points representing the conclusion of this contribution are summarized as follows:

- The highest shear strengths were determined for the adhesives, the epoxy adhesive showed higher adhesion to the wood.
- Both tested sealants proved unsuitable as filling material for load-bearing structures.
- Fillers were effectively used to adjust the viscosity of the epoxy adhesive, showing good dispersion in the adhesive matrix.
- Both types of fillers reduced the tensile strength of the epoxy adhesive, but the cotton flakes and spruce sawdust improved the ductility and workability of the adhesive.

Further research will focus on improving the porosity of the epoxy matrix. This wood adhesive is strong but brittle. The goal is to minimize porosity in the matrix of the adhesive during the filling process. Identifying the right type of filler and determining its optimal amount can potentially improve the toughness and flexibility of the adhesive.

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