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# Influence of surface preparation methods on moisture-related performance of structural hardwood–adhesive bonds

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ABSTRACT

The aim of this study was to investigate the influence of three surfacing methods (peripheral planing, sanding and face milling) on the moisture-related performance of bonded ash assemblies (*Fraxinus excelsior* L.). The different surfaces were tested in combination with four adhesives: phenol-resorcinol-formaldehyde (PRF), melamine-urea-formaldehyde (MUF), polyurethane (PUR) and emulsion polymer isocyanate (EPI). For evaluation, the surface roughness was measured and surfaces and bonds were examined by means of scanning electron microscopy (SEM) and transmitted light microscopy, respectively. To analyze bond performance, tensile shear tests were carried out as per EN 302-1 and the resistance to delamination was determined according to EN 302-2. Microscopy and roughness measurements showed significant differences between the bonding surfaces, notably with regard to cell damage and the level of fibrillation. The surface texture had significant impact on shear and delamination results. While shear tests showed good bond performance when tested in dry condition, moisture treatment revealed differences between surfaces, in particular with regard to wood failure. Based on shear results, the most appropriate surfacing method to produce moisture-resistant bonds appeared to be face milling together with PRF. Delamination results varied strongly with the surfacing method and adhesive types. PRF and MUF showed highest resistance to delamination with sanded surfaces, possibly because damaged cells helped to dissipate strain. PUR and EPI provided lower moisture-related durability. For these adhesives, best results were obtained with face milled surfaces, probably because of a more homogenous strain dissipation in the glueline caused by fibrillation.


## 1. Introduction

In recent years new fields of hardwood utilization have been subject to intensive discussions in Europe. In this context, ash (*Fraxinus excelsior* L.) is considered an important hardwood species that proves beneficial in load-bearing structures [1] because of valuable mechanical properties [2]. To facilitate application in engineered wood products such as glued laminated timber, it is important that bond strength and durability in ash wood assemblies can be guaranteed. It is generally considered more difficult to obtain durable bonds with hardwoods than with softwoods [3]. However, little information about moisture-related durability of bonded hardwood assemblies can be found in literature. A recent study on bonded ash assemblies revealed low moisture-related durability and extensive failure at the wood–adhesive interface with peripherally planed surfaces in delamination tests [4]. Because of these unsatisfactory results a possible positive effect of different surfacing methods (peripheral planing, sanding, face milling) on bond performance after exposure to moisture changes was investigated in this new study.

The preparation of wood surfaces is of high importance for bonding quality. The texture of a bonding surface is determined by two factors: (i) the kind and the quality of the machining process and (ii) the wood species, i.e., the exposed anatomical structure and the response to the machining process. To evaluate the machining quality or to characterize the bonding surface, the surface roughness has been used in several studies [e.g., 5–8]. However, based on literature, roughness and bonding quality do not clearly correlate. For example, a certain roughness caused by damaged or fibrillated fibers can help to improve the bonding quality when compared to smooth surfaces [9]. On the contrary, high roughness also may cause decreasing bond strength [10] when, for example, crushed and damaged cells become prevalent and create a mechanically weak boundary layer (MWBL) [9].

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Peripheral planing is the most common surfacing method in the woodworking industry and almost exclusively used in the production of glued laminated timber. In the literature, varying observations on the quality of planed surfaces can be found. Singh et al. [11] and Kläusler et al. [8] showed that surface quality significantly depends on the condition of planing knives. When using sharp knives, peripheral planing produced surfaces with open cells that facilitated penetration [7,12]. Bond quality of planed surfaces was heterogeneous compared to other surfacing methods. Therefore, both enhanced [13] and impaired [8] bond performance were found with planed surfaces.

Sanding is a widely-used method to create smooth, homogeneous surfaces previous to wood coating [14]. However, it has been given little attention as a preparation method for bonding of load-bearing products. The sanding process is characterized by a negative rake angle and high normal forces [15] which generally leads to increased surface damage. Sanded surfaces showed crushed and damaged cells [6,16,17] as well as torn-out fibrils [12,18]. The degree of damage highly depended on the grit size [13,16,18]. Damaged cells can have both the effect of inhibiting adhesive penetration into the sound wood tissue [10] and of preventing excessive penetration into earlywood [12]. As mentioned above, fibrillation, i.e., partially detached or slightly crushed cell walls components, is considered to contribute to a good bonding quality. This could be confirmed in studies from de Moura and Hernández [12] and Cool and Hernández [7] with sugar maple and black spruce wood, respectively. While bonds of surfaces sanded with coarse grit (36) performed poorly [13], utilization of finer grit (80–180) resulted in good performance [8,12].

Face milling is a surfacing method characterized by a cutting direction primarily perpendicular to the grain. The blades are mounted on a cutter disk and are characterized by two cutting edges – a peripheral cutting edge for material removal and a face cutting edge to create the surface [19]. As concluded by de Moura et al. [20], the machining principle results in lower cutting forces than a machining process parallel to the grain because of lower strength of the wood in transverse direction. As a consequence, damages at wood surfaces prepared by face milling are comparatively low [6,7]. In addition, face milling produces cell-wall fibrillation which is considered to be beneficial for adhesion [20,21]. When compared to other surfacing methods, face milled surfaces showed equivalent or better bond performance [7,8].

For the present study, the above presented surfacing methods peripheral planing, sanding and face milling were applied to prepare bonded assemblies with four different adhesive types phenol-resorcinol-formaldehyde (PRF), melamine-urea-formaldehyde (MUF), polyurethane (PUR) and emulsion polymer isocyanate (EPI). Surface topology was examined by means of surface roughness measurements and microscopy (SEM, transmitted light microscopy). Bond performance of surfaces and adhesives was evaluated in tensile shear tests according to EN 302-1 [22] and delamination tests following EN 302-2 [23]. Emphasis was placed on performance after exposure to moisture change.

## 2. Materials and methods

### 2.1. Wood and surface preparation

The study was performed with ash wood (*Fraxinus excelsior* L.) from southern Bavaria, Germany. Kiln dried timber of approximately 40 mm thickness was cut to 170 mm wide and 1050 mm long boards. The boards were stored at 20 °C and 65% relative humidity (RH) until equilibrium moisture content was reached. The moisture content $\omega$ and the density $\rho_{12}$ were $(10.8 \pm 1.2)$% (mean $(\bar{x}) \pm$ standard deviation (sd)) and $(633 \pm 75)$ kg/m³, respectively. Boards for tensile shear tests and surface analyses showed angles between 30° and 90° between surface and annual rings. For those examinations, the boards were cut lengthwise into three layers with each layer being divided into three panels of 320 mm length. The nine panels were machined to a cross-section of 5 mm by 140 mm. With eight of these panels, tensile shear specimens were prepared. The remaining panel was used for surface roughness measurements and SEM microscopy. Boards with tangentially aligned annual rings were used for the delamination tests. The boards were cut into two sections to obtain lamellas of 500 mm length, 160 mm width and 30 mm thickness.

The surfaces were prepared by means of the three surfacing methods peripheral planing (hereinafter referred to as planing), sanding and face milling. The surfacing machines and parameters used in this study are displayed in Table 1.

### 2.2. Adhesives and bonding parameters

The adhesive selection represents the range of chemical systems available on the market for structural face gluing: PRF, MUF, PUR and EPI. As far as known, the four adhesives used in this study have all been successfully applied with spruce and comply with the requirements of European standards [24-26] for adhesives for load-bearing timber products. For the two component adhesives (PRF, MUF, EPI), mixed application was used. All adhesives were spread one-sided with a spatula. Bonding was performed in a climate room at 20 °C and 65% RH within 6 h after surface preparation. Further bonding parameters are displayed in Table 2. The bonding operations were all performed within the specifications of the adhesive manufacturers. A random selection of specimens including all adhesives and surfacing methods showed a mean glueline thicknesses of 81 μm (±34 μm (sd)).

### 2.3. Analysis and test methods

#### 2.3.1. Microscopy

SEM was used to examine the surface textures. For this purpose, small specimens with 20 mm length, 10 mm width and 5 mm thickness were prepared and coated with a thin layer of gold to provide conductivity. Micrographs were taken at 20 kV acceleration voltage using a Zeiss "EVO 40 XVP" microscope with "Smart SEM V05.04.03.00" software.

**Table 1**
Surfacing machines and parameters.

| | Planing | Sanding | Face milling |
|---|---|---|---|
| Surfacing machine | Otto Martin "T43" | Kuendig "MAGIQ" | Ledinek "Rotoles 400 D" |
| Characterization of knives/sanding belt | HSS, freshly sharpened | 80 grit, new sanding belt | HSS, freshly sharpened |
| Number of cutting edges $z$ | 4 | n/a | 48 |
| Cutting speed $v_c$ (m/s) | 32.7 | 17 | 80 |
| Feed speed $v_f$ (m/min) | 6 | 7 | 10 |
| Feed $f_z$ (mm) | 0.3 | n/a | 0.07 |
| Cutting depth (mm) | 2 | 0.5 | 2.5 |
| Rake angle | 34° | n/a | Axial: 10°, radial: 15° |