Mechanically-induced wood welding

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ARTICULOS

MECHANICALLY-INDUCED WOOD WELDING*

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ABSTRACT

Mechanically-induced vibration welding of flat wood surfaces and rotation welding of wood dowels, without any adhesives, gave strength values comparable to those obtained with adhesive bonded joints. The joints obtained have strength up to structural level but can only be used for interior joinery and furniture. The reasons of the welding effect are presented and explained both at the wood anatomical and molecular level.

Keywords: wood welding, wood fusion, bonding, adhesion, adhesives, lignin, joints, furniture, interface, composites

*Paper invited. Received April 2004. Accepted May 2004.
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INTRODUCTION

Friction welding induced by mechanical vibration for joining flat wood surfaces or rotation to weld timber dowels within a timber hole, as used for other, without any adhesive or resin, yields here welded wood joints of strength satisfying relevant requirements for structural applications materials (Tappe and Potente, 1989; Potente and Uebbing, 1997). This is due mostly to the melting and flowing of amorphous, cells-interconnecting wood material, mainly lignin. This causes partial detachment, the "ungluing" of long wood cells, wood fibres, and the formation of a fibres entanglement network immersed in a matrix of molten material which then solidifies. Thus, a wood cells/fibres entanglement network composite having a molten lignin polymer matrix is formed. Cross-linking chemical reactions of lignin with carbohydrate-derived furfural have been identified. These reactions are relatively minor contributors during the very short (3 seconds) welding period. Their contribution increases after welding has finished. Thus, 3-5 seconds holding times under pressure after the end of welding further contribute to obtain a good bond. X-ray microdensitometry of welded wood showed a considerable increase in density at the bonded interface (Bergsten et al., 2001; Pernestal and Jonsson, 1996). This is due to the loss of the intercellular structure of the wood at the interface.

METHODS

Specimens composed of two pieces of beech wood (*Fagus sylvatica*), each of dimensions 150x20x15 mm, were welded together to form a bonded joint of 150x20x30 mm dimensions by a vibrational movement of one wood surface against another at a frequency of 100 Hz. The parameters which yielded the best results were: welding time = 3s; the contact holding time (H.T.) mantained after the welding vibration had stopped = 5 seconds; the welding pressure = 2 MPa; the holding pressure after the welding had stopped = 2.7 MPa); the amplitude (A.) of vibration = 3 mm). Equally, beech dowels of 10 mm diameter were intoduced at 1200 rpm within a hole of 8 mm of the same beech wood. When fusion and bonding were achieved, the process was stopped. The clamping pressure was then briefly maintained for both processes until the solidification of the bond. Ten replicas of each specimen were tested in tension.

Scanning electron microscopy (SEM) micrographs of the surfaces of the joints opened by mechanical testing were obtained after metallizing with gold-palladium.

Three sections from each of these samples were tested by X-ray microdensitometry. The sections were 1.88 ± 1 mm thick. Their weight and density were 0.79 – 0.85 g and 760-783 kg/m^3. An X-ray negative photograph of the samples, conditioned at 12 % moisture content, was obtained at a distance of 2.5m from the X-ray tube. Exposure conditions were: 4 hours, 7.5 kW and 12 mA. Two calibration samples were placed on each negative photograph in order to calculate wood density values.

RESULTS AND DISCUSSION

The average wood welding tensile strengths obtained under the conditions outlined were between 10 and 11 MPa and were obtained at 3s welding time and 5s holding time. The average results satisfy the requirements of the EN 205-D1 specification (European Norm EN-205D1, 1992). Increasing welding time decreased joint tensile strength. Welding pressures higher than 2 MPa yielded worse results due to incipient bond degradation. The temperature of just the bondline reaches 170°C or higher during welding. This temperature is much higher than T_g of lignin and hemicelluloses, above which materials are known to flow (Kelley et al., 1987). Melting of some of the major structural, polymeric wood constituents occurs as observed by SEM (Fig. 1).

Fig 1: Scanning electron microscopy image of lignin fusion with cellulose fibers and wood cells (tracheids) immersed in it obtained during welding at 100 magnification showing the entangled and detached tracheids, a fused intercellular lignin mass and tracheids and fibers immersed in the fused lignin matrix.

In Fig. 1 fibres, long wood cells (tracheids), immersed in a mass of molten polymer can be observed (Gfeller et al., 2004). The cells do not appear to be greatly damaged, hence melting has occurred mainly in the intercellular connecting tissue or *middle lamella.* Wood *middle lamella* is particularly rich in lignin, more than any other anatomical feature of wood. The welded bondline is then composed of a mass of entangled long wood cells immersed in a matrix of amorphous, fused intercellular material, mostly lignin but also including some hemicelluloses (Gfeller et al. 2004). CP-MAS C-13 NMR spectra indicated that chemical cross-linking reaction of lignin and of carbohydrates-derived furans also occurred (Gfeller et al., 2004). These contributed to the mechanical resistance but to a minor extent. Constant heating rate thermomechanical analysis of welded bondline joints yield a marked increase of the modulus of elasticity (MOE) of the joint at increasing temperatures. This further contribution to the joint strength comes to bear only after welding has finished. This might be why the longest holding time under pressure after the end of welding contributes markedly to the formation of a good bond.

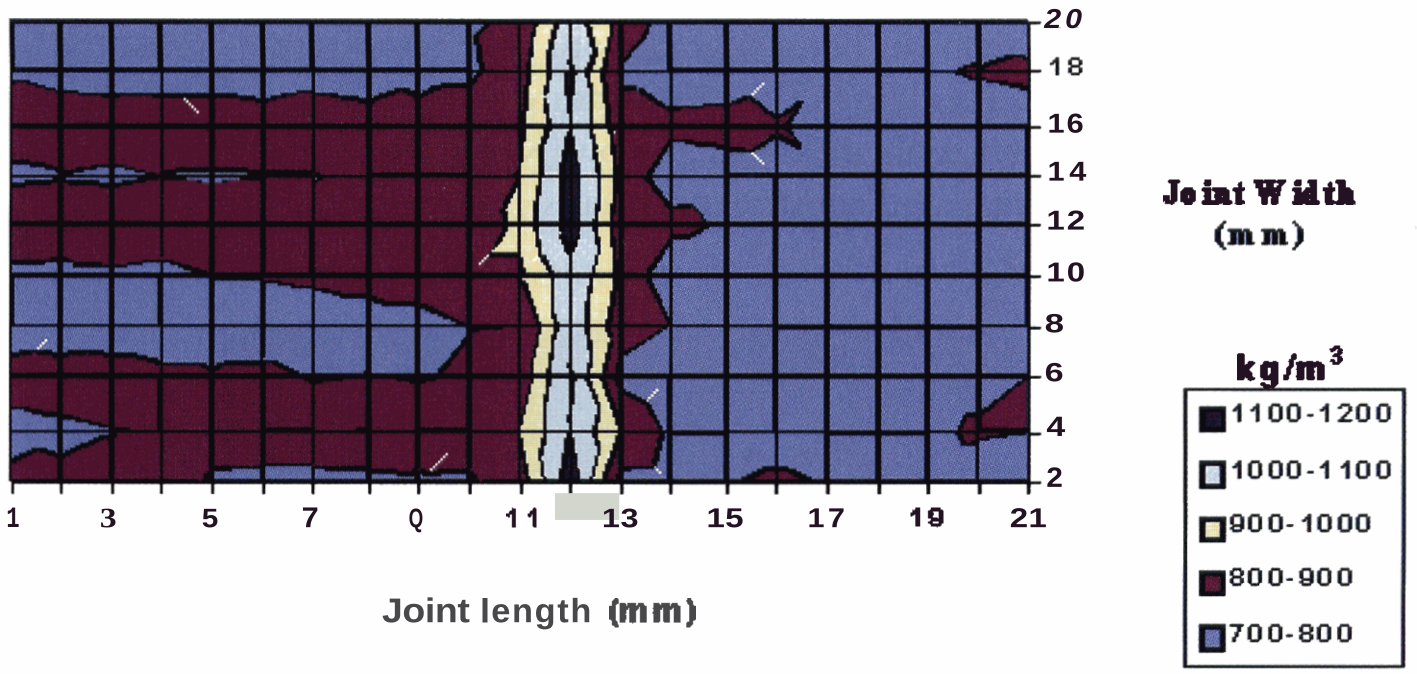

FIG. 2. X-ray microdensitometry map of actual density values in kg/m³ of well-bonded linear vibration-welded beech *wood.*

Figures 2 and 3 show the density maps by X-ray microdensitometry of the linear and rotational friction-welded joints. In Fig. 2 the welding line is in the middle of the figure. The increase in density is limited to one small area close to the bond, about 0.6 mm of the joint's width (Fig. 2). The average wood density of the beech sections is about 760 kg/m³ while the maximum wood density in the bond is much higher at about 1100-1200 kg/m³ (Fig. 2).

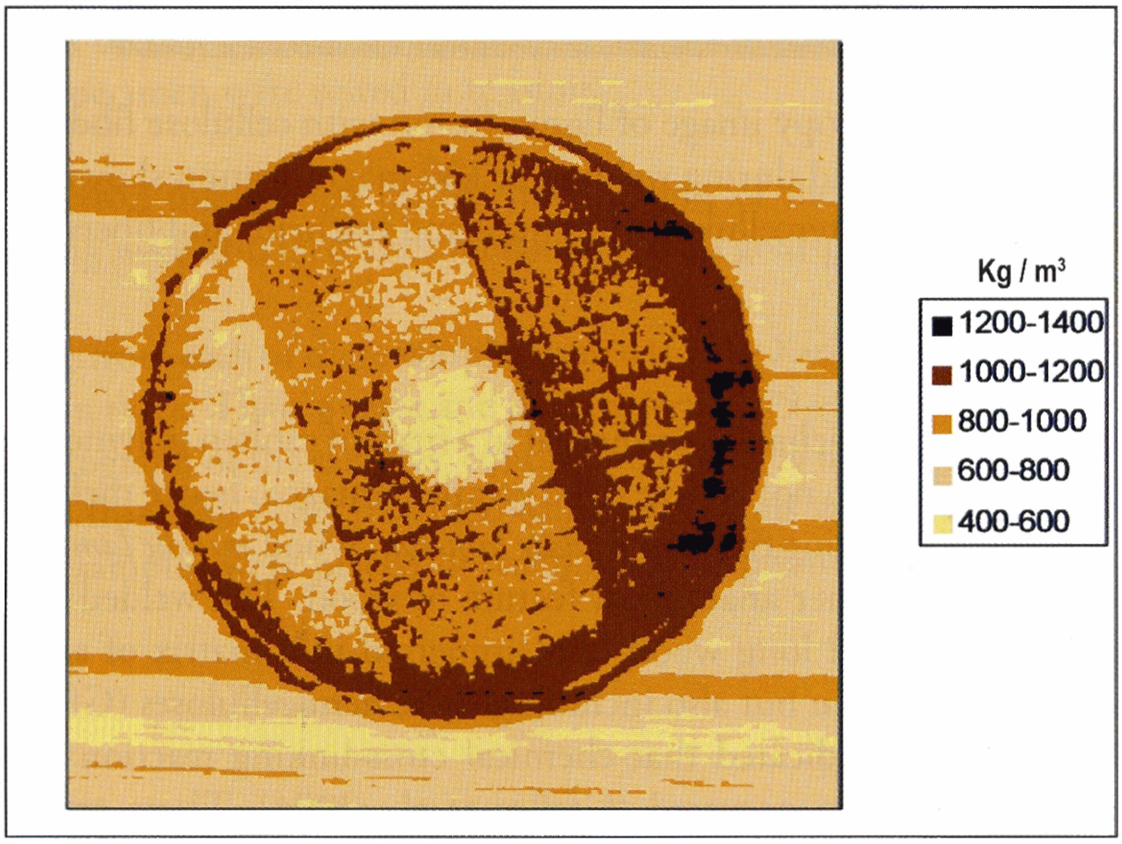

FIG. 3. X-ray microdensitometrymap of actual density values in kg/m³ ofwell-bonded rotationally-welded beech wood dowel. Normal section.

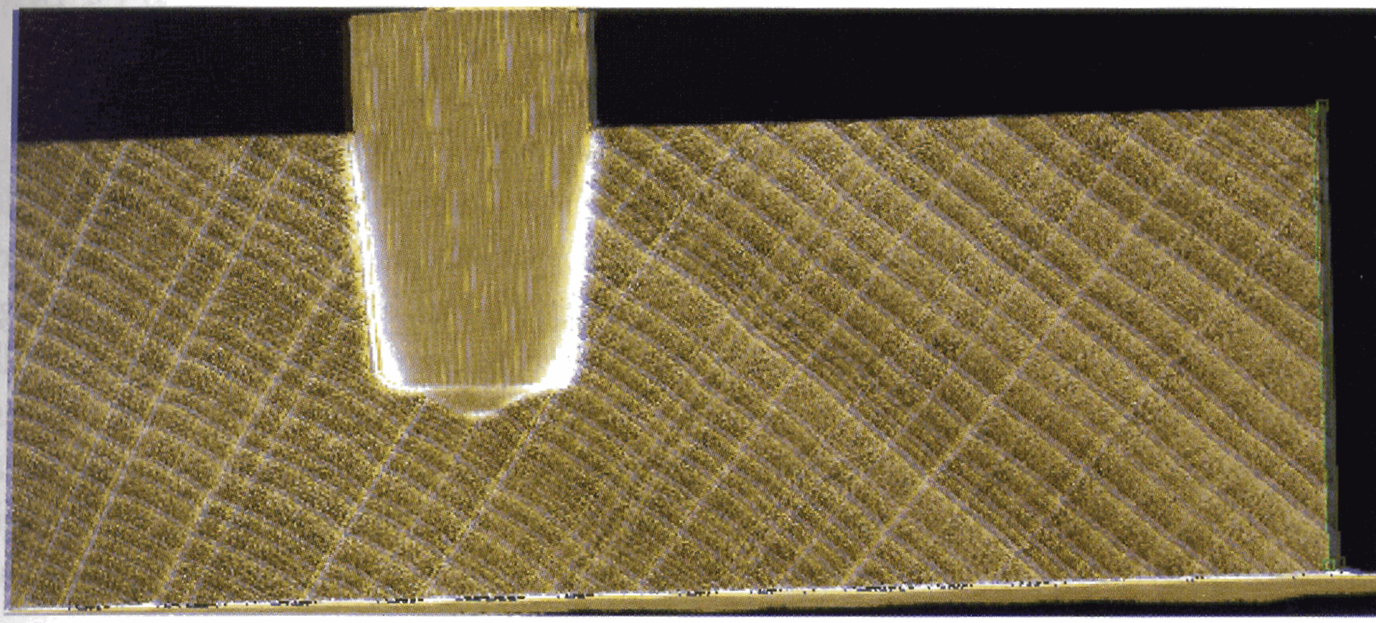

Fig. 4. X-ray microdensitometry map of actual density values in kg/m^3 ofwell-bonded rotationally-welded beech wood dowel. Parallel section.

Fig.3 and 4 shows the X-ray densitometry derived density maps of the rotational friction-welded dowel joint (Leban et al., 2004., Pizzi et al., 2004). It shows that approximately 60% of the joint surfaces have been welded, although densification has occurred even where welding has not. Allignement is then an important aspect of rotational welding of ribbed dowels within a timber surface. Dowels welding without adhesives and using simple equipment has given dowel withdrawal strengths comparable to those of dowels bonded with PVAc glues. Fig. 5 shows the scanning electron microscopy of a welded dowel surface to the substrate.

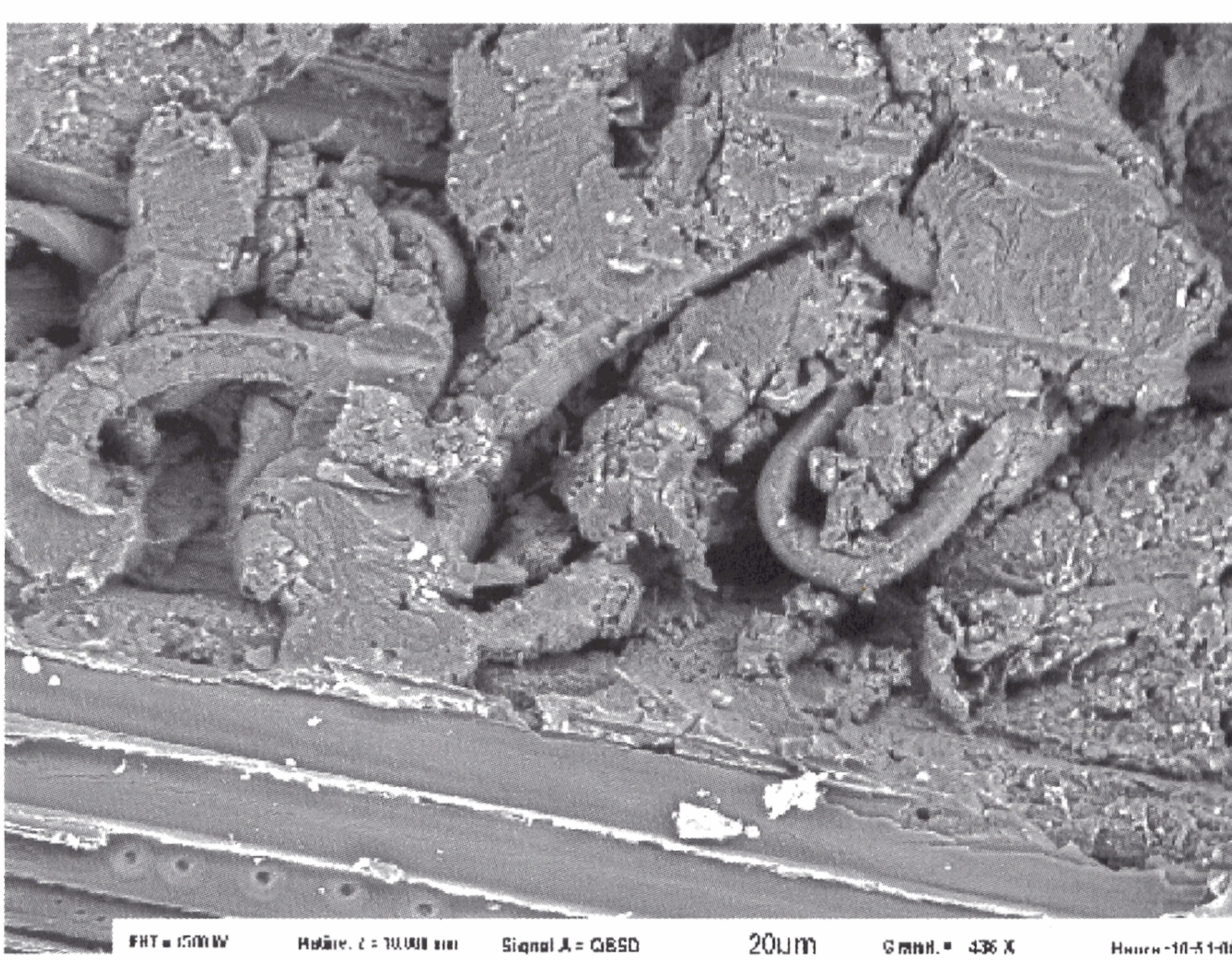

Fig. 5. Scanning electron microscopy image of lignin fusion with cellulose fibers and wood cells immersed in it, in direct contact with little alterd wood surface in rotational wood dowels bonding.

CONCLUSIONS

Interior grade solid wood joints have been obtained by vibrational welding without the use of any adhesive opening the possibility to wood bonding without adhesive for furniture and for interior joinery. The same effect is observed for dowel welding into a substrate by high speed rotational welding. Mainly middle lamella lignin melting is one of the main causes of the bonding observed. The entanglement network encased in a matrix of molten intercellular material, mainly lignin, that has subsequently solidified on cooling constitutes a composite that is the joint's bondline. Some of the excess wood cells that are no longer held by the interconnecting material are pushed out of the joint as excess fibre during welding. Some cross-linking chemical reactions appear to occur mainly after the welding action is finished, explaining why relatively longer holding times under pressure improve the joint strength. Polymerisation and cross-linking of lignin and of carbohydrates-derived furfural appear to be the reactions involved.

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