Causes of the Water Resistance of Welded Joints of Paduk Wood (*Pterocarpus soyauxii* Taub.)

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Received July 11, 2012; Accepted September 18, 2012

ABSTRACT: Linear vibration welding of extractive rich Paduk wood from central Africa containing a high proportion of a native mixture of water-insoluble extractives, or of low water solubility, has been shown to yield joints of much upgraded water resistance. This has been shown to be due to the protecting influence the extractives from the wood itself has on the welded interphase, due to their inherent water repellence. Joints of unusually high percentage wood failure but modest strength were obtained; Paduk wood brittleness apparently yielding weld line strengths always higher than that of the surrounding wood itself. This indicated that Paduk wood welded joints present enhanced weather exposure durability in relation to welded joints using other species of wood.

KEYWORDS: Extractives, Paduk wood, wood welding, *Pterocarpus soyauxii*, water resistance, percentage wood failure, durability

1 INTRODUCTION

Mechanically induced friction welding techniques have recently been applied to joining wood, without the use of any adhesive [1–3]. Wood welding has been shown to be due to the melting and partial flowing of surface cell-interconnecting polymers in wood. This causes surface cell detachment and their immersion in a solidified matrix composed of lignin and hemicelluloses to form a high density composite interphase [1–3]. It is a phenomenon mostly based on natural polymers flowing. While rotational wood dowel welding [4–6] yields joints that possess a certain degree of long-term resistance to water [7–9] this is not the case for linear vibration welding of a flat wood surface to another flat wood surface [1]. Thus, linear vibration-welded wood joints are rather sensitive to water attack, the joints being suitable exclusively for interior grade applications such as furniture, in spite of their dry strength being at the structural level. There has been interest in overcoming this limitation without the use of synthetic waterproofing chemicals, which would spoil the totally environment-friendly characteristics of such welded joints. A first improvement in water resistance derived from the use of shorter welding times at a well-defined higher vibration frequency; This yielded both much improved dry strength and, particularly, much improved resistance to water of the joint [10] and the causes for this were identified [11]. Recently, however, use of rosin has considerably improved the water resistance of both linear welded joints as well as of rotationally welded wood dowels [12]. A lesser improvement in water resistance of welded dowels was also achieved by addition of acetylated lignin [13] a thermoplastic material, although a similar improvement did not appear to occur on its addition in the more exposed linear welded joints. One approach that has not been explored yet is in the use of wood which is known to be water repellent by cause of the type of natural extractives contained in it. This paper then deals with such an approach, both when the linear welded joint is composed exclusively of one water repellent species, and one is composed of one water repellent piece welded to a wood that is not naturally water resistant.

Paduk (*Pterocarpus soyauxii* Taub.) or coral wood is an intensely red-coloured wood from central and west Africa that has a relatively high density (700–900 kg/m^3) and that is known to have good natural durability. It is also known to be impervious to water mainly due to its high percentage content of extractives (around 13% of total mass). At 12% moisture content, the modulus de rupture of Paduk wood is of 101–218 N/mm^2, modulus of elasticity is 10 800–15 900 N/mm^2, axial

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DOI: 10.7569/JRM.2012.634101

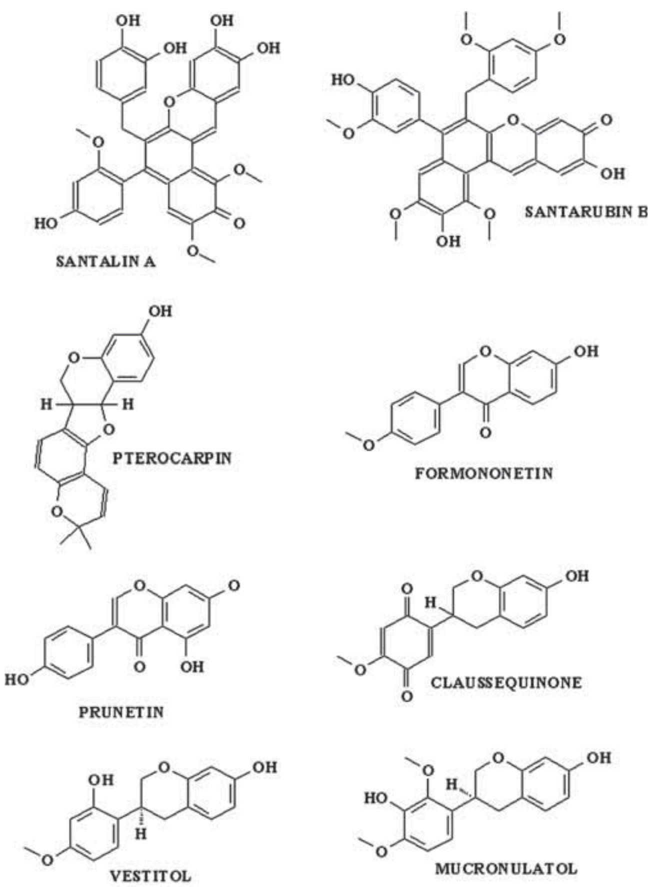

Figure 1 Main types of extractives in Paduk wood.

compression is 54–79 N/mm², and shear strength is 7–8 N/mm². The main extractives are [14-16]: (i) some red biflavonoïdes such as santalin A (Fig. 1), santarubin A and santarubin B (Fig. 1); (ii) some isoflavonoids such as pterocarpine, formononetine and prunetine (Fig. 1); (iii) an isoflavanquinone, namely the claussequinone (Fig. 1), and (iv) some isoflavanes: the vestitol and mucronulatol (Fig. 1) plus (vi) some oligomeric tannins.

2 EXPERIMENTAL

2.1 Preparation of joints by linear vibration welding, density profile and test results

Specimens composed of two pieces of imported West Africa Paduk wood (*Pterocarpus soyauxii* Taub), each of dimensions 200mm × 20mm × 20mm, were welded together. They formed bonded joints of 200mm × 20mm × 40mm dimensions by a vibration movement of one wood surface against another at a frequency of 150 Hz. When welding was achieved the vibration process was stopped. The clamping pressure was then maintained for 60s until solidification of the weld. The welded samples were conditioned for one week in an environmental chamber (20 °C and 65% RH) before testing. The welding parameters used were according to a four phases welding process, a welding time divided into three successive phases of 1s, 2s and 2s each under a pressure of 2,3 and 4 kN at a displacement amplitude of 1mm, 2mm and 2mm respectively. These welding phases were followed by a holding time of 60 s at 15 kN pressure. The frequency of welding was maintained at the high frequency of 150 Hz to ensure a much steeper rise of the weldline temperature [10,11]. The equilibrium moisture content of the samples was 12% and remained the same before and after welding due to the sharp temperature gradient within the sample [10,11]. The samples were welded in the longitudinal wood grain direction.

The linear welding machine used was a KLN linear welding machine with CPC (Complete Process Control) - vibration technique, type 2261, 150 Hz (Mecasonic, Crest group, Annemasse, France). The welded samples were cut according to the method described in European standard EN302-1 [17] for bonded wood joints, i.e. with a welded overlap of 1 cm along the length of the joint and 2 cm width. The strengths of the joints were measured using an Instron universal testing machine at a rate of 2 mm/minute as described in standard EN 302-1.

The specimens were cut according to the method described in European Norm EN 302[17] for bonded wood joints, i.e. with a welded overlap of 1 cm along the length of the joint and 2 cm width. Series of 10 samples so prepared were tested dry and a series of other samples immersed in cold water (15 °C) and the strength of the joints at two days interval immersion in water was measured. The strength of the joints was measured in traction with an Instron universal testing machine at a rate of 2 mm/minute.

The panels density profiles were done on all the specimens tested for internal bond, before destructive testing, by using a Grecon Da-X (Greten, Germany) density profiler.

3 RESULTS AND DISCUSSION

Paduk is a wood species that is reputed to be brittle but to contain as much as 13% extractives rendering it impervious to water. These extractives, giving to the wood an intense red colour, mainly santalin A (Fig. 1), santarubin A and B (Fig. 1), pterocarpine, formononetine, prunetine, claussequinone and vestitol and mucronulatol (Fig. 1) coupled with some oligomeric tannins cause the imperviousness to water of Paduk

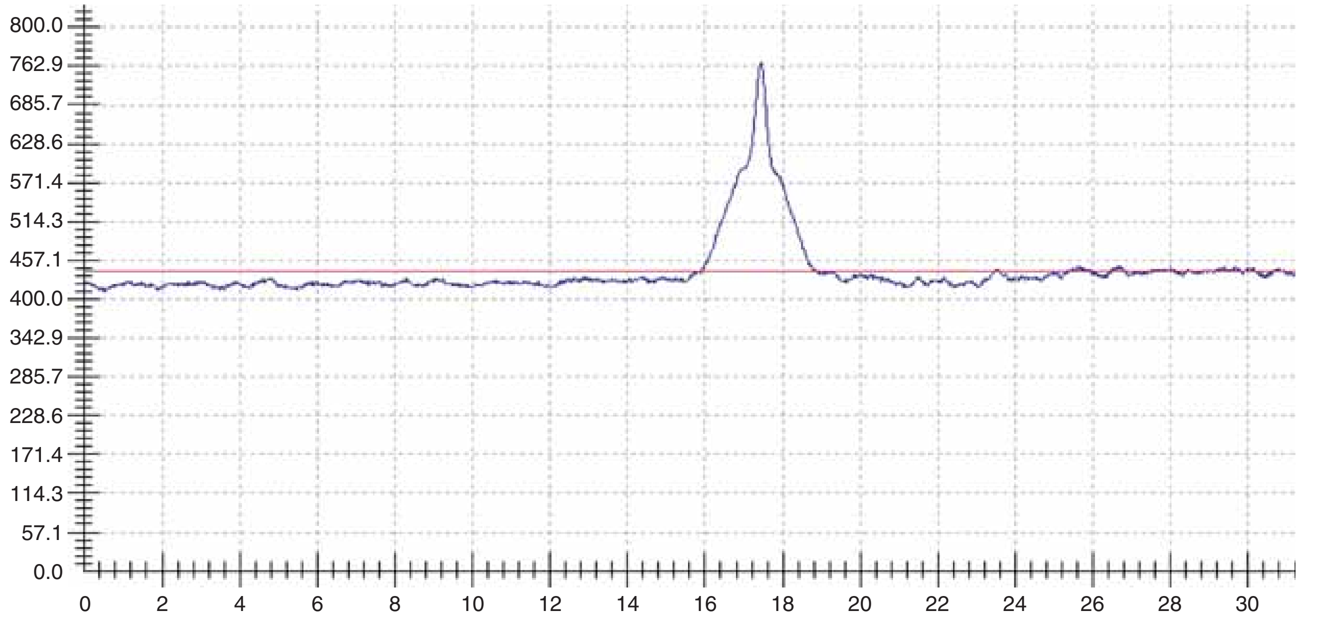

Figure 2 Example of an X-ray microdensitometry density map of a Paduk welded wood joint. Density of joints (in kg/m^3) and surrounding wood as a function of joint thickness (in mm).

wood. In Fig. 2 it is shown the X-ray microdensitometry map of welded Paduk wood. The weldline trace is wider than what observed in normal welding indicating that an additional substance has melted and somewhat flowed outwards away from the weldline but closely surrounding it. This can be noticed by the acute central spike characteristic of the narrowness of a normal weld line being surrounded by the two shoulders giving to the welded line peak a much wider appearance (3.5 mm against a traditional weld line thickness of 1 to 1.5 mm) (Fig. 2).

Tests were done first to determine if the effect of such materials inherent to Paduk wood were beneficial or not to the welded joint water resistance. As the material seemed to be impervious to water, water immersion tests of the welded joints were done. The results in Table 1 indicate that while the tensile strength of the joint is not too high for a weldline, this due to the inherent and recorded brittleness of Paduk wood, the percentage wood failure however, is really high. This is unusual in linear wood welding were generally joint strength is very high but percentage wood failure is relatively low. To have lower strength and exceptionally high wood failure (Table 1) indicate simply that the strength measured is that of the timber and that this is then much weaker than the welded interphase. More notable, however, is the time that these joints are capable to withstand immersion in water without falling apart. Thus, in Table 1 are reported the shear strength and percentage wood failure of Paduk welded joints both dry and after a number of days immersion in cold water. Furthermore, the same type of joints withstood more than 30 days in cold water without falling apart and conserving a reasonable joint strength of more than 3 MPa.

All these results (Table 1) compare very favourably with linear welded beech wood joints. These latter at first were not able to stand in water for more than 30 minutes[1], and when the welding conditions were improved [7,10,11] were able at maximum to reach 25 hours cold water immersion. Fig. 3 shows Paduk wood joint specimens that were immersed in water for 18 days: the light colour indicating dryness of the wood surrounding the weld line can be clearly perceived, when compared with the darker colour due to wetness of the rest of the wood.

4 CONCLUSIONS

Linear vibration welding of extractive rich Paduk wood from central Africa containing a high proportion of a native mixture of insoluble extractives has been shown to yield joints of much upgraded water resistance. This has been shown to be due to the protecting influence the extractives from the wood itself has on the welded interphase, due to their inherent water repellence. Joints of unusually high percentage wood failure but modest strength were obtained, Paduk wood brittleness apparently yielding weld line strengths always higher than that of the surrounding wood itself.

Table 1 Shear strength of Paduk joints welded without adhesives as a function of their immersion in cold water and their durability in cold water.

Days in cold water	Average strength (MPa)	Wood failure (%)	Resistance to cold water soak (days)
0	4.49	100	
2	4.38	100	
4	4.24	100	>30 (>3 MPa at 30 days)
6	5.06	100	
8	4.98	100	
10	3.51	100	

Figure 3 Photograph of sections of Paduk welded wood joints after immersion in water for 20 days showing the lighter wood colour zone surrounding the weld line indicating that no water has reached it.

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