

Advancing Timber for the Future Built Environment

AGEING RESISTANCE OF PRESERVATIVE-TREATED CROSS-LAMINATED TIMBER UNDER HIGH HUMIDITY ENVIRONMENTAL CONDITION

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ABSTRACT: Engineered wood products are globally recognized for their low carbon footprint and are increasingly utilized in environmentally conscious construction. Traditionally, formaldehyde-based adhesives have been the preferred choice in the formation of strong durable bonds in more extreme service classes. The structural performance of one-component polyurethane (1C-PUR) adhesives in the engineered wood industry has continuously developed since the 1990s, and their utilization has expanded due to their ease of use. While there is much evidence with reliable data for, the durability of adhesive bonding using 1C-PUR with different wood species, very limited work has been undertaken on the durability of 1C-PUR when bonding preservative-treated softwood. In this study, the bonding of cross-laminated timber was assessed. Two commercially available 1C-PURs were subjected to experimental ageing and a comparison with a resorcinol formaldehyde (RF) adhesive was conducted. A series of Mode I fracture energy tests using the single-end notched beam test configuration was carried out on crossbonded specimens, which examined the use of two different preservative treatments and also untreated Radiata pine grown which was grown in New Zealand. The tests were conducted using artificially accelerated ageing subject to high humidity and temperature at three-month intervals for up to a period of six months. Favourable wood failures were achieved in the unaged and aged investigations to date for all combinations. No noticeable chemical changes in the adhesive layer were recorded by examination using Fourier Transform Infrared Spectroscopy (FTIR) in the ageing regime to date.

KEYWORDS: Durability, Cross-laminated timber, Adhesives, Fracture energy, Preservative treatment

1 – INTRODUCTION

Engineered wood has been a preferred material of choice more recently because of its favourable mechanical properties and advantages in the field of green building development. In past decades, the construction industry has been focusing on the use of larger engineered wood systems in an endeavour to develop more sustainable and environmentally friendly buildings [1]. Cross-laminated timber (CLT) is an increasingly popular engineered wood product due to its structural performance, environmental benefits, and suitability for sustainable building practices. Different adhesives affect the mechanical properties and durability of CLT panels [2]. Continued research on adhesive formulations and preservative compatibility is essential for optimizing CLT for outdoor and structural applications. The benefits of 1C-PUR as the primary adhesive include not requiring pre-mixing and preparation, formaldehyde free, and it allows for high production efficiencies. However, there remains unknown behaviour in relation to fully exposed outdoor conditions in such bonded assemblies. The use of preservative treatments with softwood species, such as chromated copper arsenic (CCA), which is regularly used in the industry in New Zealand, and micronized copper azole (MCA), introduces new complexities to the bonding process[3], [4].

1.1 Environmental ageing of 1C-PUR bonds

The durability of 1C-PUR adhesives is of high importance 1 to the ability of engineered structures to meet service life standards, particularly when in exterior environments. It was reported that 1C-PUR adhesives

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showed good long-term durability on Beech and Spruce wood, even under moisture and temperature changes, with the wood being the weak layer in the bond line [5]. Limitations were specified in relation to 1C-PUR adhesives which matched the bond strength of resorcinol adhesives in dry and wet conditions, but one formulation of 1C-PUR adhesive showed a 71.1% delamination rate under severe cyclic heat and humidity, whereas resorcinol adhesives were fully resistant [6]. By using a primer, the durability of 1C-PUR is improved and the wet wood failure percentage and delamination resistance are enhanced [7].

1.2 Adhesion characteristics of treated wood

The use of preservative treatments and chemical impregnation can protect the wood and prolong the lifespan of wood products against decay, insects, and microbial deterioration. Cyclic ageing tests and scanning electron microscopy (SEM) investigations were undertaken on CCA preservative-treated Southern pine and it was reported that chromium, copper, and arsenic deposits in wood cells blocked the molecular bonding between the adhesive and the wood [8]. It was reported that preservative-treated Red Maple had different surface characteristics with lower wettability, which could negatively impact the adhesion performance of waterbased adhesives like phenol-formaldehyde [9]. It was shown that the fixation state of the preservative within the wood is a critical factor in determining its impact on adhesive curing by assessing the curing characteristics of a commercial phenol-formaldehyde (PF) adhesive on preservative-treated Southern Pine [10]. Without risks of arsenic or hexavalent chromium leaching, MCA treatment is considered a favourable solution by the industry [11]. Shukla and Kamdem showed that the copper-based preservative-treated Southern Pine LVL exhibited higher water absorption and swollen thickness than the untreated specimens [12].

1.3 Objective

The primary objective of this research was to advance knowledge in relation to the ageing resistance of 1C-PUR adhesives for the bonding of preservative-treated CLT. There has been extensive interest in the use of CLT in the construction industry but external application or applications where there are higher durability requirements remain limited. This study builds upon recent research by eliminating the reliance on an initial primer during fabrication [7], thereby effectively reducing production costs. It evaluates performance through a carefully designed matrix of tests . Two different commercial 1C-PUR adhesives were used in this study. The performance of RF adhesive specimens, which is the industry benchmark in New Zealand, was used as a control group. From the perspective of wood, solid wood specimens were used as further control groups which could be directly compared to untreated, CCA and MCA preservative-treated bonded specimens. The bonded specimens were aged for six-month accelerated ageing. Fracture energy, wood failure percentage and FTIR scanning were assessed at three monthly intervals.

2 – MATERIAL

2.1 Wood

The timber used in this research was New Zealand-grown Radiata pine, sourced from sawmills in the Auckland hinterland. All boards were flat-sawned and kiln-dried before delivery. The timber boards, including untreated, CCA and MCA preservative-treated, were 45mm thick, 145mm wide and 4.8m long. All the boards were located in a conditioning chamber with 65 ± 5 % relative humidity and 20 ± 2 °C when brought to the research laboratories. When the boards' weight was at the stable stage, the moisture content of 12 ± 1 % was recorded. Boards with excessively high density were excluded from specimen manufacturing. All the preservativetreated boards were suitable for exterior exposed aboveground conditions in accordance with the H3.2 classification in the New Zealand standards [13]. The chemical retention level of the preservative-treated boards was verified to ensure compliance with the minimum stated levels in the standard.

2.2 Adhesives

All three adhesives in this study are classified as Type I in AS/NZS 4364 adhesives for use in all service conditions including service class 3. Two different 1C-PUR adhesives, PUR 1 and PUR 2, were assessed as well as a resorcinol formaldehyde adhesive, RF, which was sourced from three different manufacturers. PUR 1 has a viscosity of 15500 ± 2500 mPas and PUR 2 has a viscosity of 24000 mPas.The resorcinol formaldehyde

Table 1. Characteristics of the PUR adhesives

Parameters	PUR 1	PUR 2	
Viscosity at 20°C (mPas)	15500 ± 2500	24000	
Density (kg/m3)	1150	1160	
Solid Content (%)	99 ± 1	100	

Table 2	Bonding	parameters	of	the	adhesives
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Parameters	PUR 1	PUR 2	RF
Assembly Time (minutes)	60	30	35
Pressing Time (minutes)	100	75	720
Spread (g/m2)	200	180	300
	(one-side)	(one-side)	(two-side)
Pressure (N/mm2)	1.0	1.0	1.0

(RF) adhesive was a two-part component formulation. The mixing ratio was three parts resin to one part hardener by weight. Table 1 summarizes the physical characteristics of the three adhesives. Adhesives were applied according to the manufacturer's recommended spread rates, and the specified clamping pressure, as detailed in Table 2, was applied using a compression machine.

3 – EXPERIMENTAL METHODS

3.1 Manufacturer of specimens

Assemblies were initially laminated using the untreated, CCA, and MCA preservative-treated boards with the RF and two 1C-PUR adhesives from which all test specimens were extracted (Fig. 1a). All fabrication was undertaken in the test laboratory to ensure optimum accuracy and uniformity during the process. Given the non-homogeneous nature of wood, best efforts were taken to record and reduce the effects of variables in the boards such as density, once the conditioning period was completed (Table 3). All material and assembly surfaces



Figure 1. Manufacturer of specimens. (a)Lamination assembly (b)First cut blocks; (c) Specimens.

Specimen group	Unaged	Three-month aged	Six-month aged
Untreated Solid	461 ± 38	463 ± 35	452 ± 34
Untreated PUR1	484 ± 39	509 ± 33	493 ± 44
Untreated PUR2	463 ± 8	500 ± 35	493 ± 45
Untreated RF	478 ± 36	478 ± 38	475 ± 32
CCA Solid	479 ± 8	474 ± 7	479 ± 11
CCA PUR1	490 ± 9	471 ± 18	476 ± 14
CCA PUR2	487 ± 8	512 ± 22	500 ± 47
CCA RF	439 ± 29	484 ± 41	482 ± 50
MCA Solid	448 ± 12	447 ± 12	455 ± 18
MCA PUR1	471 ± 40	455 ± 31	462 ± 25
MCA PUR2	475 ± 12	488 ± 54	494 ± 51
MCA RF	441 ± 13	446 ± 23	450 ± 13

Table 3. Specimen mean density and standard deviation

in the laboratory were thoroughly cleaned initially by air pressure. All bonding surfaces of the boards were checked to be free of knots and resin pockets to ensure bonding quality. The lamination boards were manufactured with two layers. To maximise the stress and effect of ageing on the adhesive bonds, the bottom layer was orientated outer face up and the top layer was orientated outer face down. The layer's dimensions were based on the requirement of ISO 16696 [14]. The bottom layer was 45mm thick, 140mm wide and a minimum length of 560mm. The top layer was four pieces of 45mm thick, 140 mm wide and 140mm long boards crossorientated with the bottom layer. The bond surfaces for the manufactured lamination boards were prepared by knife planning to provide a surface free from residue and any contamination. A time no greater than two hours was permitted to elapse between the planning process and adhesive application to the bond surface. The bonding parameters that were adhered to are detailed in Table 2 which followed the technical guidance of the adhesive manufacturers. Squeeze-out of the adhesives indicated that sufficient quantity was spread along the interface of the bond line. Upon completion of the pressure application period, the bonded elements were placed in a conditioned environment with a temperature of 20°C and 65% relative humidity for a minimum of two weeks to allow for full cure. Four blocks were cut from each lamination assembly (Fig. 1b). At a later stage, four specimens having dimensions of 45mm thick, 45mm width and 45mm in length with a centrally located adhesive bond line in the centre were cut from the core area (Fig. 1c). These dimensions complied with the testing process detailed in [15]. For the accelerated aged specimens, density was measured to ensure no bias to different ageing regimes was introduced. The specimen preparation process included bonding LVL wings to facilitate the fracture energy test. Two LVL wings, each measuring 45 mm by 45 mm, were bonded to the sides of the specimen. The wings were clamped for at least 24 hours to ensure a strong and secure bond.

3.2 Accelerated ageing methods

The test specimens were exposed to 40 ± 2 °C and 90 ± 4 % relative humidity for a range of constant periods in a Contherm CAT 5000VLEC environmental chamber based on ASTM D4502-92 [16] and ISO 6270 [17]. Both solid and bonded specimens were subject to the ageing regimes. Once the assigned ageing period of each specimen had been achieved, the specimens were returned to an environment of 20°C and 65% relative humidity until the specimens were fully conditioned.

3.3 Fracture energy test

The fracture energy test method involved a Mode 1 fracture test based on a three-point bending test set-up as shown in Fig. 2 and followed the guidance specified in [15] and The set-up essentially comprised a notched beam arrangement with a span of 270 mm. The width and thickness were 45 mm and 45mm. The single notch position was settled to ensure grain angles form a "V" shape pointing away from the crack initiation [18]. The notch depth was 27 mm cut with a band saw and a razor blade was used to create the final 2 mm which enabled the progression of a smoother crack growth during load application. All specimens were tested using a 100 kN Intron machine with a constant loading rate of 2.5 mm/min (Fig. 3). An approximate failure time of each specimen of within 3±1 minutes was anticipated. A steel prism on the cylinder supported the one end of the



Figure 2. Schematic of dimensions of SENB test



Figure 3. Fracture energy test arrangement

specimens, the other end is supported by a steel prism on a steel ball which allows the torque displays on the specimen. The load is applied on a steel ball on the steel prism, which is at the mid-point of the specimen. Two linear voltage displacement transducers (LVDTs) are placed on either side of the specimen to record the displacement of the specimen and take account of any possible twist in the wood. A further two LVDTs are positioned at both ends of the specimen in an inverted arrangement directly above the geometric centre of the support to account for any indentation when determining the overall displacement of the specimen. If a crack in the specimens did not follow the bond line during loading and affected the test results or data collection, the specimens were replaced and the test restarted.

3.4 Statistical analysis

The statistical analyses were conducted using SPSS software (version 29). The Shapiro–Wilk test and Levene's test were applied to assess the normality of data distribution and the homogeneity of variance, respectively, with a significance level set at 5%. If the assumptions were not met, logarithmic transformations were applied and repeated until the data passed the Shapiro–Wilk test. If Levene's test was satisfied, a one-way ANOVA followed by Tukey's Honestly Significant Difference (HSD) post hoc test was performed at the 5% significance level. If the homogeneity of variance assumption was still violated, Welch's test and the Games–Howell post hoc test were followed.

3.5 Fourier Transform Infrared Spectroscopy

FTIR analysis is a critical process in understanding the chemical interactions and performance of the bonding interface. By analyzing functional group changes before and after ageing, FTIR provides valuable insights into perspective treatment effects, and the durability of adhesion under the examined environmental conditions.

Initially, fragments of clear 1C-PUR adhesive from the bond line and wood substrate were cut with a scalpel and picked with a tweezer to eliminate potential contamination. A Nicolet iS50 FTIR Spectrometer was set to 650 – 4000 cm-1 spectral range with a resolution of 4 cm-1 through mid-IR diamond ATR window. The build-in pressure press ensured the sample was fully attached to the diamond ATR window. Spectra were collected and analysed using the OMNIC software. A background spectrum consisting of 16 scans was recorded and ethanol was applied to clean the diamond ATR window before every new scan. Sample spectra were composed of 64 scans.

4 – RESULT AND DISCUSSION

4.1 Fracture energy test results

The fracture energy test results for the solid wood specimens, unaged bonded specimens and aged bonded specimens for all three adhesives are shown in Fig. 4 - 6. A reduction in performance is evident as the ageing progressed in the untreated specimens both for solid and bonded specimens. The reduction after six months ageing in relation to unaged specimens for solid control samples free of a bond line was 29.3%, for PUR 1 bonded specimens was 12.3%, PUR 2 bonded specimens was 16.4% and for RF bonded specimens was 21.7 % (Fig. 4). The statistical analysis revealed that the results for the PUR 2 bonded specimens and the RF bonded specimens were statistically significant. For the CCA preservativetreated wood specimens, the ageing on the solid control specimens after six months only had a reduction of 8.7% (Fig. 5). The result was not significant. After ageing for three months and six months, the fracture energy of the PUR 1 specimens decreased by 12.3% and 30.1%, respectively, compared with the unaged specimens, which was not statistically significant after three-month ageing but significant after six months ageing. Statistically significant reductions were analyzed in the fracture energy of the PUR 2 and RF specimens after three and six months of ageing. Compared to the unaged specimens, the PUR 2 specimens decreased by 23.4% and 39.6% after three and six months of ageing, respectively, while the RF specimens decreased by 41.8% and 50.9%, respectively. This reduction in performance is considerably higher than with the untreated wood which is believed to be because of the reported reduction in strength of the wood after impregnation with the chemical [19], [20]. It has also



Key: A = Unaged; B = 3 months; C = 6 months







Figure 6. Energy release rate of MCA preservative-treated specimens. Key: A = Unaged; B = 3 months; C = 6 months

been reported that CCA can physically and chemically block surfaces where the intermolecular forces of bonding develop [9]. Variability in the wood density can also directly influence the determined loading and energy release values. For PUR 2 and RF bonded CCA-treated specimens, a significant was observed after three months



Figure 7. Typical load-displacement behaviour - Untreated wood. (a) PUR 1 specimens; (b) PUR 2 specimens; (c) RF specimens.



Figure 8. Typical load-displacement behaviour – CCA treated wood. (a) PUR 1 specimens; (b) PUR 2 specimens; (c) = RF specimens.



Figure 9. Typical load-displacement behaviour - MCA treated wood. (a) PUR 1 specimens; (b) PUR 2 specimens; (c) = RF specimens.

of ageing. On assessment, this reduction in performance is of a more noteworthy effect when it is considered that the aged specimens in these groups were associated with higher densities than the unaged specimens (Table 3). The reduction in the fracture energy of the MCA preservative-treated specimens after ageing was similar to that of the CCA preservative-treated specimens, but the mean fracture energy value of the MCA preservativetreated specimens after ageing for three and six months was higher than that of the CCA group (Fig. 6). The solid specimens in the MCA preservative-treated wood had a reduction of 14.7% associated with it between the six months aged and unaged specimens which was not statistically significant. For the MCA preservativetreated specimens, the changes in the fracture energy compared with the associated unaged specimens for PUR 1, PUR 2, and RF were significant. Comparing the mean value of the fracture energy for the tested MCA bonded specimens after the six months of accelerated ageing to the associated unaged specimens, the reduction recorded for the PUR 1, PUR 2, and RF bonded specimens were 32.1%, 26.1% and 45.2%. In the case of MCA-treated specimens, more pronounced reductions were observed in the PUR 1-bonded six-month aged group which were associated with a lower mean density in comparison to the unaged and three months aged for the same configuration (Table 3). After six months of accelerated ageing, the untreated wood bonded specimens retained the highest fracture energy. The fracture energy of the untreated wood bonded specimens with PUR 1 was 42.8% and 30.4% higher than that of the CCA and MCA bonded specimens after six months of ageing, respectively. The fracture energy of the untreated wood bonded specimens with PUR 2 was 51.9% and 18.0% higher than that of the CCA and MCA bonded specimens after six months of ageing, respectively. The fracture energy of the untreated wood bonded specimens with RF was 55.4% and 42.6% higher than that of the CCA and MCA bonded specimens after six months of ageing, respectively. In contrast, the CCA bonded specimens had the lowest fracture energy

Figure 10. Wood failure percentage of untreated fracture energy specimens. Key: A = Unaged; B = 3 months; C = 6 months

Figure 11. Wood failure percentage of CCA preservative-treated fracture energy specimens. Key: A = Unaged; B = 3 months; C = 6 months

Figure 12. Wood failure percentage of MCA preservative-treated fracture energy specimens. Key: A = Unaged; B = 3 months; C = 6 months

after six months of ageing. Typical load-displacement behaviour is shown in Figures 7 - 9. The untreated bonded specimens are associated with the largest and widest peaks which are directly associated with a higher

Figure 13. Specimens during and after fracture test. (a) Crack propagation in PUR 2 bonded CCA specimen; (b) Fracture interface of PUR 1 CCA specimen; (c) Fracture interface of PUR 2 MCA specimen; (d) Fracture interface of RF CCA specimen.

fracture energy (Fig. 7). A noticeable reduction in fracture energy for bonded CCA and MCA-treated specimens is evident in Figures 8 and 9, as shown by the plots with lower peaks and more narrow trends. This trend is particularly evident for the CCA bonded specimens. When comparing RF bonded and 1C-PUR bonded specimens, the former appears to exhibit a marginally steeper and stiffer loading behaviour. This is likely due to the more ductile behaviour and lower elastic modulus of the 1C-PUR adhesives, in contrast to the stiffer and more brittle nature of the RF adhesive.

4.2 Wood failure percentage

The wood failure percentage readings for the bonding interface of untreated, CCA preservative-treated and MCA preservative-treated specimens after fracture energy test are shown in Fig. 10 - 12. Very good performance was achieved for the 1C-PUR adhesive bonded specimens with only slightly lower values compared to unaged wood after three months of ageing on all three types of wood substrates with all readings above 91%. For untreated wood (Fig. 10), after six months of accelerated ageing, the average wood failure percentages of the PUR 1 and PUR 2 bonded specimens exceeded 99%, while the average wood failure percentages of the RF bonded specimens reached 100%. For the CCA preservative-treated specimens (Fig. 11), PUR 1 and RF did not quite reach 100% in the threemonth ageing group, showing a minor reduction

Figure 14. Representative FTIR spectra of 1C-PUR adhesive (a) PUR 1 bonded CCA treated wood; (b) PUR 2 bonded MCA treated wood

compared to untreated wood, which suggests that CCA treatment introduces slightly more complexity for these adhesives' bonding. However, performance remained high, with only marginal deviations. For the PUR 2 bonded specimens, the average wood failure percentages exceeded 98%, confirming its consistent reliability. In the MCA-treated specimens (Fig. 12), a subtle reduction in wood failure was observed in the unaged and three months aged states when compared to untreated wood, particularly for PUR 1 and PUR 2. This may indicate additional bonding challenges posed by MCA treatment. The performance however remained more than satisfactory. Notably, the six months aged PUR 1 specimens recorded excellent wood failure percentages close to 100%, suggesting strong long-term bonding durability even under the MCA treatment. A typical failed specimen from the SENB test configuration illustrating the fracture path is shown in Figure 13(a). The excellent wood failures that were observed are demonstrated for PUR 1 with CCA preservative-treated wood (Fig. 13 (b)), PUR 2 with MCA preservativetreated wood (Fig. 13 (c)) and RF bonded MCA preservative-treated wood (Fig. 13 (d)). The failures indicated the durability of the adhesive bonded joints.

4.3 Fourier Transform Infrared Spectroscopy

Comparing the spectra before and after three and six months of ageing, it was found that there were no major differences in the characteristic absorption peaks between the samples for the three different wood substrates and the two 1C-PUR adhesives studied in the test programme. There was therefore no spectroscopic evidence to indicate any significant structural changes during the accelerated ageing process. This indicates that the 1C-PUR adhesives demonstrated good resistance to degradation under the high temperature and humidity ageing environment. Additionally, there was no noteworthy evidence that the bond lines were affected by the presence of CCA or MCA preservative treatments when compared to the untreated samples. However, some subtle variations in peak intensity and shape were observed in some investigations. For example, in Fig. 14 (a), which illustrates spectra from the CCA preservativetreated wood bonded with PUR 1, the peak absorbance can be seen to be around 1100 cm-1, typically associated with C-O stretching, which slightly increased after three months, followed by a modest reduction at six months. A similar trend was noted in the broad O-H stretching region around 3300-3400 cm⁻¹, which may reflect minor changes in hydrogen bonding or moisture absorption. Also, in Fig. 14 (b), for the MCA-treated specimens bonded with PUR 2, slight increases in peak intensity around 1030 cm⁻¹ and 1240 cm⁻¹ (C-O stretching and C-N vibrations) were recorded with ageing, potentially suggesting some interactions with the MCA treatment. Despite these measured differences, the variations are subtle and do not provide evidence of meaningful chemical degradation within the adhesive matrix.

Figure 15. Spectra of PUR 2 from bonded MCA treated specimens. (a) 850-1250 cm-1 (C-O) region; (b) 2750-3050 cm-1 (C-H) region

Furthermore, the absorption peaks that may represent hydrolytic degradation were amplified and further examined. It was found that after three months and six months of accelerated ageing, the spectra of the PUR 2 bonded MCA preservative-treated samples had slight shifts in the C-H and C-O absorption peaks (Fig. 15). However, the changes again are not significant in nature and may also occur from wood fibre substrate contamination in the adhesive sample assessment as it was an extremely challenging and tedious operation to remove adhesive from the interface of the bonded specimens after the ageing was complete.

5 – CONCLUSION

This study aims to address the research gap in the ageing resistance of preservative-treated wood in crosslaminated timber when manufactured with 1C-PUR adhesives. The adhesion of wood treated with CCA and MCA preservatives was subjected to accelerated ageing for up to six months and evaluated by comparing the fracture energy in Mode 1 in comparison with solid wood and an RF adhesive. The accelerated ageing was carried out in a constant high temperature and humidity environment. The two 1C-PUR adhesives showed different patterns of fracture energy reduction on preservative-treated wood during the ageing process. PUR 1 exhibited a gradual and statistically nonsignificant decrease in fracture energy after three months of ageing on both CCA and MCA-treated wood. But from three to six months, the rate of decrease in fracture energy was accelerated and statistically significant. PUR 2 showed a statistically significant decrease in fracture energy from three to six months of ageing on both two preservative-treated wood. A main difference of PUR 1 compared to PUR 2 is the lower viscosity, which can result in better penetration and enhanced durability in the adhesive bonding of wood [21]. It was also found that the fracture energy of CCA preservative-treated wood bonded specimens with all three adhesive specimens was lower than those of the bonded specimens with untreated wood after six months of accelerated ageing. The fracture energy of both unaged and three months aged CCA preservative-treated solid wood specimens was lower than that of untreated solid wood specimens under the same ageing conditions. This is consistent with other studies indicating that the acid contained in CCA preservative-treated wood induces hydrolysis at the bonding interface and that impregnation of CCA preservative chemicals leads to a decrease in the mechanical properties of the wood [19], [20]. The overall performance of the 1C-PUR adhesives is good. After six months of ageing, the fracture energy of the two 1C-PUR adhesives on CCA and MCA preservative-treated wood exceeded those of the RF adhesive which was used as the control group. The decrease in the fracture energy of the 1C-PUR adhesively bonded specimens for both formulations when the wood had the CCA and MCA preservatives and was subjected to six months ageing was statistically significant. At the same time, the bonded specimens all had satisfactory wood failure percentage readings, so it is believed that the decrease in fracture energy is caused by the weakening of the wood in the ageing process. The FTIR analysis results showed no evidence of any chemical changes in the 1C-PUR bonding interface during ageing, nor was there any evidence of any chemical effects of the preservative components on the 1C-PUR. This study was carried out in accordance with the technical guidance provided by the adhesive suppliers, which was originally developed for bonding untreated wood. It is recommended that further research be conducted to investigate the performance of 1C-PUR cross-laminated specimens after a longer accelerated ageing process and to assess the influence of possible chemical alterations in the wood.

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