EFFECTS OF MOISTURE CONTENT AND SAWING PATTERN ON THE GLUING OF MERANTI TEMBAGA (*SHOREA LEPROSULA*)

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TAN, Y. E., MOHD. ZAINI UJANG & KOMATSU, M., 1992. Effects of moisture content and sawing pattern on the gluing of meranti tembaga (*Shorea leprosula*). The effects of two moisture content levels, namely air dry and 12 to 15% range, on the gluing performance of meranti tembaga of different sawing patterns were examined using various types of adhesives. Three different tests were carried out: block shear, delamination and weather exposure tests. The block shear test showed that all treatment combinations produced satisfactory bonding strength meeting the requirement stipulated in the Malaysian Standards. The laboratory delamination test results, however, revealed that timbers glued at air dry condition were generally inferior to those glued at 12 to 15% moisture content level. The weather exposure test further strengthened the need to adhere to the lower moisture content level in order to obtain a more reliable performance.

Key words: Moisture content - sawing pattern - phenol resorcinol formaldehyde - urea formaldehyde - polyvinyl acetate - adhesive - block shear - delamination - exposure

TAN, Y. E., MOHD. ZAINI UJANG & KOMATSU, M., 1992. Kesan-kesan kandungan kelembapan dan pola gergaji ke atas perekatan meranti tembaga (*Shorea leprosula*). Kesan-kesan dua paras kandungan kelembapan, iaitu kering-udara dan julat 12 hingga 15% keatas prestasi perekatan meranti tembaga yang berlainan pola gergaji telah diselidik dengan menggunakan beberapa jenis perekat. Tiga ujian berlainan telah dijalankan: ujian ricih blok, ujian nyahlaminaan dan ujian pendedahan cuaca. Ujian ricih blok menunjukkan bahawa semua kombinasi rawatan menghasilkan kekuatan perekatan yang memenuhi keperluan yang disyaratkan dalam Piawaian Malaysia. Keputusan ujian nyahlaminaan yang dijalankan di makmal, bagaimanapun, menunjukkan bahawa kayu-kayu yang direkatkan pada keadaan kering-udara pada umumnya adalah lebih lemah daripada yang direkatkan pada julat 12 hingga 15%. Keputusan ujian pendedahan cuaca menguatkan lagi keperluan bagi merekatkan kayu pada paras kandungan kelembapan yang lebih rendah bagi memperolehi prestasi yang lebih meyakinkan.

Introduction

Moisture content of timber at the time of gluing and the grain pattern of laminations are known to affect the gluing performance of timbers (Chugg 1964, Miller 1987). The moisture content must be confined within certain limits for various types of adhesives in order to avoid unnecessary failures (Kollmann *et al.* 1975). Flat grain laminations are also known to give rise to higher residual stresses than edge grain laminations because of the considerably higher movement due to moisture changes in the tangential as compared with the radial directions (Chugg & James 1965).

Certain phenolic glues have produced good results compared to unsatisfactory results for polyvinyl acetate and epoxy glues in the bonding of softwoods at moisture content levels up to 26%. Promising results were obtained for the Malaysian hardwood mengkulang (*Heritiera* sp.) when bonded with moisture content of 9 to 20% using phenol resorcinol formaldehyde (PRF) adhesive (Ser & Lopez 1983) even though the assessments were made based only on the dry shear strength of the bonded timbers.

In this study, the effects of two moisture content levels on the gluing performance of meranti tembaga (*Shorea leprosula*) of different sawing patterns were examined. The timber investigated is the lighter variety of one of the five botanical species commercially known as light red meranti (LRM) (Choo & Lim 1983), which is currently used in the manufacture of laminated door and window components for the export market. The main objective of this study was to compare and establish whether it is necessary to condition timbers to the moisture content level as specified in the current Malaysian Standard for gluing timbers for structural use (Anonymous 1981). The scope was also extended to include adhesives for non-structural applications and boards of two different sawing patterns.

Material and methods

Meranti tembaga of flat and quarter-sawn types was used in this study. Two batches of material were prepared: one was air dried under cover for more than two months until an equilibrium condition of about 16 to 20% in wood moisture content was achieved; the other was kept in a conditioning room of about 20°*C* and 65% RH after air-drying to below 25% moisture content to produce an equilibrium moisture content of about $13 \pm 1\%$. The former was conveniently attained in the Malaysian ambient condition of about 25 to 35°*C*, 70 to 85% R.H., while the latter was within the range of 12 to 15% as specified in the existing Malaysian Standard (Anonymous 1981). The final dimension of the laminations used for the gluing process were $19 \times 105 \times 600$ *mm*.

The adhesives used for the study were polyvinyl acetate (PVAc), phenol resorcinol formaldehyde (PRF), urea formaldehyde/polyvinyl acetate (UF/PVAc) and powdered urea formaldehyde (UF). These adhesives were recommended by Matsumoto (unpublished) after an extensive physical and chemical analysis was conducted. PRF was recommended for exterior structural application, the cold setting UF and UF/PVAc were meant for interior non structural wood lamination whereas PVAC was used as a control to UF/PVAc mixture. The PVAc was added to the mixture to reduce the brittleness of UF.

Flat-sawn and quarter-sawn boards were used in this investigation. For each sawing type, four types of adhesive and two moisture content levels were assigned. Ten laminations were required, from which three 2-ply and one 4-ply laminates were prepared. Gluing was carried out shortly after planing of laminations to the final dimensions. The glue spread adopted was 300 $g\,m^{-2}$, being applied onto both gluing surfaces. The following formulations were then used: PVAc used as supplied, PRF: hardener = 5 : 1 by weight, UF (liquid): PVAc : filler : hardener = 80 : 20 : 5 : 0.2 and UF (powder): water: filler: hardener = 60 : 40 : 10 : 0.3. The laminations were clamped with a hydraulic cold press at a pressure of 1.5 *MPa* (15 $kgf\ cm^{-2}$). This was maintained for a period of not less than 24 *h*, followed by a conditioning period of not less than seven days. The above treatment was necessary particularly for PRF adhesive to facilitate bond curing.

Three different types of tests were carried out: the block shear test, delamination tests and weather exposure test. The block shear test was conducted in accordance with MS:758:1981 (Anonymous 1981) to evaluate the shear strength of the bonded specimens in dry or interior conditions. Different delamination tests were carried out according to the type of adhesives used to assess the gluing performance of the bonded timbers under simulated service environments. The weather exposure test was generally employed to verify the delamination results particularly in the case when weather-boil-proof or exterior grade adhesive was used. The dimensions and allocation of samples for all the tests are illustrated in Figure 1.

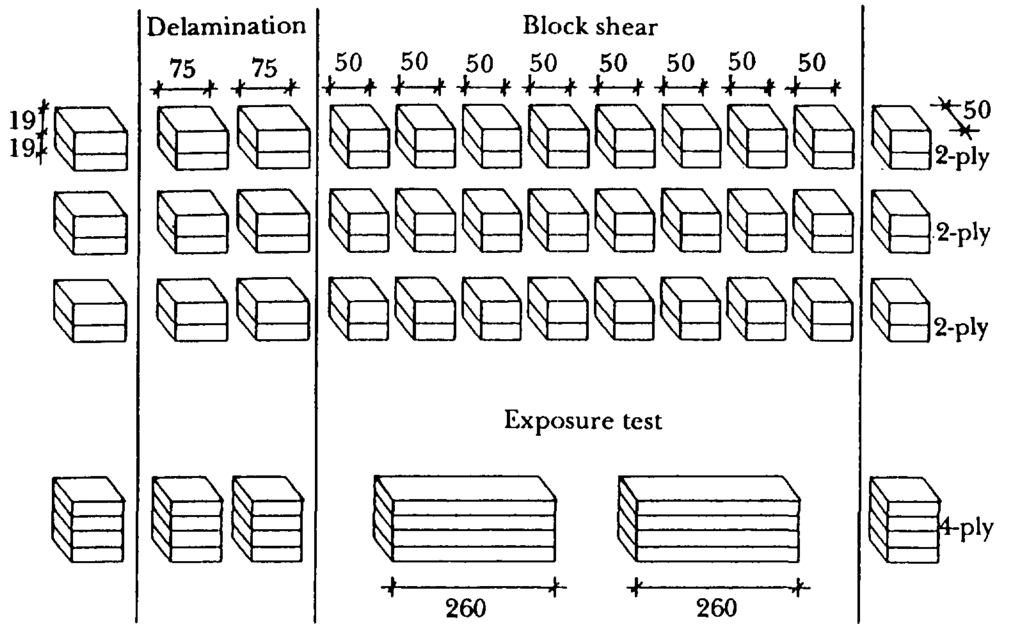

Figure 1. Allocation and dimensions (*mm*) of samples for various tests

In the case of PRF bonded specimens, the vacuum-pressure cyclic delamination test as stipulated in the Malaysian Standard, MS 758: 1981 (Anonymous 1981), was adopted. The test was catered for structural glued-laminated timbers in exterior applications. Basically, this test involves immersing of bonded specimens in water at room temperature in a pressure vessel or autoclave where a vacuum of at least 500 *mm* Hg followed by a pressure of 0.5 ± 0.3 $MN m^{-2}$ were introduced and maintained for a period of 1.5 *h*, respectively. The cycle was repeated after which the specimens were removed and dried for a period of 88 *h* in a conditioning chamber at 27 ± 3^0 *C* and 25 to 30% relative humidity. Assessment was made based on the percentage of the total length of open gluelines at the two end surfaces to the total length of gluelines at the same end surfaces. The standard requires a value not exceeding 10%.

For UF and UF/PVAc bonded samples where the adhesives used are moisture resistant and generally meant for interior non-structural applications, the cold soak dry delamination test as stipulated in the Japanese Agriculture Standard (Anonymous 1985) was applied. This requires the specimens to be subjected to 6 *h* soaking in water at room temperature and then 18 *h* drying at 40°*C*. For samples glued with PVAc which is non-moisture resistant, they were subjected to 6 *h* soaking at room temperature followed by seven days air drying at 20°*C* and 65% RH . This cold soak air dry test which is not specified in any standard is sometimes used for PVAc bonded specimens.

In the weather exposure test, specimens of 4-ply blocks bonded with various adhesives were exposed for two months (from mid-October to mid-December, 1988) on a rack placed at the top of an office block. The extent of glue-line delamination at the end grain surfaces at the conclusion of the test was recorded.

Results and discussion

Block shear test

The mean values for bonding shear stress parallel to the grain, average wood failure and moisture content of the wood at test are summarised in Table 1. Each stress value was corrected to 19% moisture content using the relationship of corrected shear stress at 19% (Tan *et al.* 1992):

$$\frac{0.88 \times (\text{shear at test})}{1 - (\text{M.C . at test} - 15) \times 0.03}$$

The Malaysian Standard (Anonymous 1981) stipulates that the ratio of the mean of the shear stress values obtained for the bonded samples must be at least 3.5 times, and the minimum must be at least twice the dry basic shear stress for shear parallel to the grain of the solid, defects-free timber. Table 1 also presents the ratios obtained. This stipulation is not applicable for non-structural adhesives such as PVAc, UF/PVAc and UF as strength is normally not a selection criterion. The dry basic shear stress of 1.95 *MPa* was derived for meranti tembaga using the raw data available (Lee *et al.* 1979) and procedures

Table 1. The shear stress parallel to the grain of meranti tembaga bonded with different adhesives

		Sawing pattern											
		Tangential						Radial					
Moisture content (m.c.) level at gluing	Adhesive type	Average shear stress (*MPa*)	Average m.c. at test	Average corrected dry shear stress (*MPa*)	Wood failure (%)	Ratios to corrected dry shear stress: mean	Ratios to corrected dry shear stress: minimum	Average shear stress (*MPa*)	Average m.c. at test	Average corrected dry shear stress (*MPa*)	Wood failure (%)	Ratios to corrected dry shear stress: mean	Ratios to corrected dry shear stress: minimum
	PVAc	8.99	18.9	8.98	85.3	4.61	2.92	5.87	19.4	5.96	78.0	3.06	2.36
Air-dry	PRF	9.89	19.1	9.94	97.7	5.10	3.78	10.29	19.7	10.44	95.5	5.35	4.27
(16-20%)	UF/PVAc	8.36	18.3	8.18	81.7	4.19	3.43	7.43	18.0	7.18	99.7	3.68	3.23
	UF	10.53	18.6	10.41	99.7	5.34	3.93	6.27	19.5	6.37	100	(3.27)*	2.75
	PVAc	11.14	13.3	9.35	99.7	4.79	3.95	8.45	15.4	7.51	94.7	3.85	2.98
	PRF	10.82	16.4	9.94	97.8	5.10	3.85	8.29	17.0	7.78	100	3.99	3.21
(12-15%)	UF/PVAc	9.67	14.3	8.33	96.3	4.27	3.70	10.32	14.6	8.99	99.2	4.61	3.72
	UF	9.35	15.5	8.36	99.7	5.29	2.05	7.36	16.3	6.76	100	3.47	3.04

* Ratio with brackets denotes failure to meet the requirement in the standard (Anonymous 1981)

as described in Engku (1980). Comparison was also made between the corrected shear stress for meranti tembaga bonded with different adhesives and the lower bound values for both minimum and mean as required by the standard (Anonymous 1981) (Figure 2).

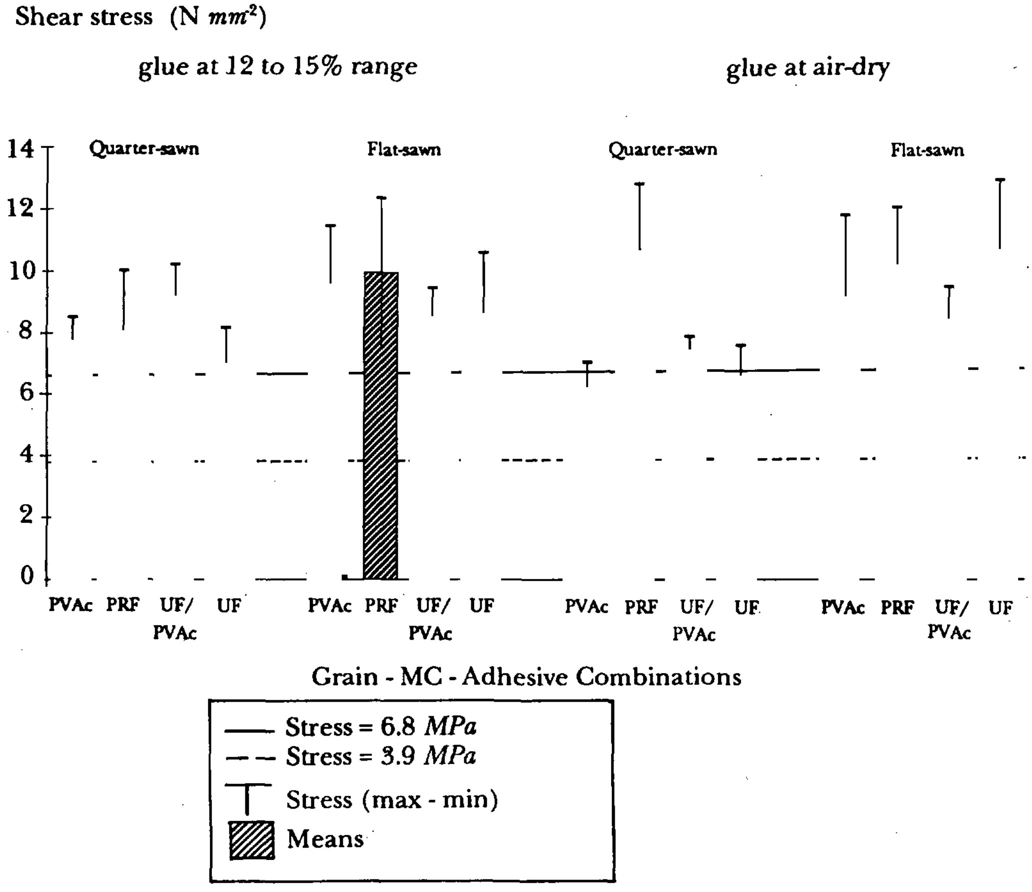

Figure 2. Shear stress results as compared to lower bound values for minimum and mean of 3.9 and 6.8 *MPa*

Table 1 and Figure 2 reveal that all the adhesives tested fulfilled the stipulated shear stress requirement of structural glue lamination. Only PRF is accepted for structural use owing to its creep resisting and weather resistant properties. Other adhesives, for instance PVAc, are known to exhibit plastic flow characteristics under sustained loading. Encouraging results were obtained on wood failure from PRF and UF adhesives, with average values exceeding 90% (Figure 3).

Due to unforeseen circumstances, the number of data points to be used in the analysis was unequal. As a result, the General Linear Model Procedure as available in SAS (Anonymous, 1990) statistical package was employed in the analysis. No attempt was made to check the data for normality, homogeneity of variance, *et cetera,* as F-test is considered rather robust (Kirk 1982).

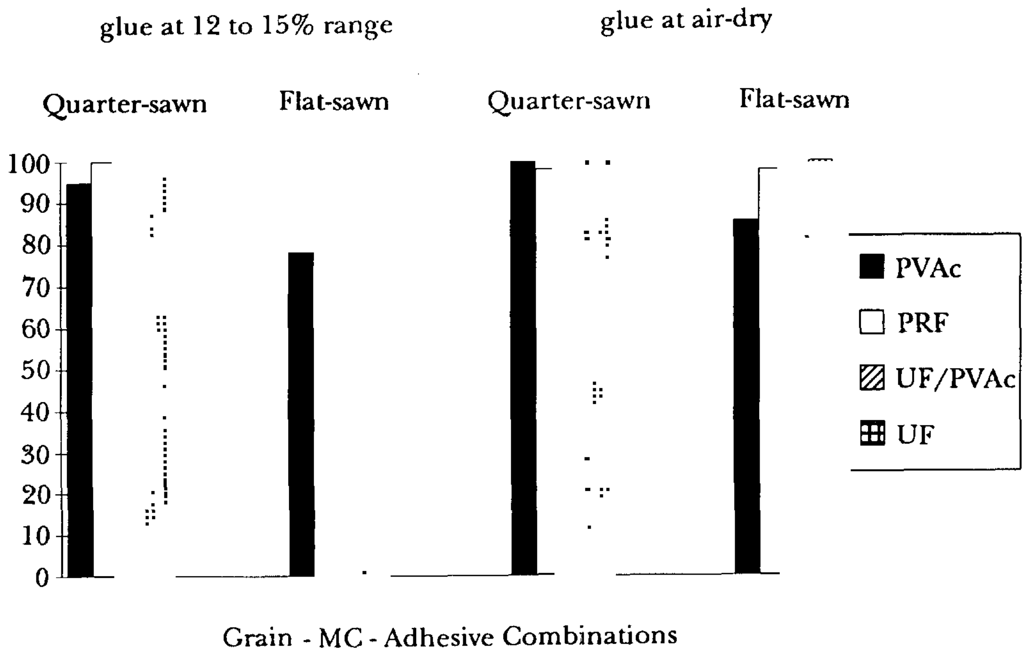

Figure 3. Wood failure (%) for block shear test

The shear strength and wood failure results obtained indicated that strong interactions prevailed between moisture content level at the time of gluing, grain or sawing type and types of adhesive at 1% confidence limit. Hence they were partitioned and analysed. Based on the Scheffe's test conducted, it may be inferred that :

i) PRF bonded timbers are statistically stronger ($P<0.05$) than other adhesives when the factor of sawing pattern was set aside. When included, the strength produced by PRF was then found to be superior to UF except when air dried flat sawn boards were used. The PRF and UF bonded samples also produced high wood failure of more than 90%;

ii) The UF/PVAc combination produced satisfactory bonding strength compared to UF except when air dried flat sawn boards were used. When compared to PVAc, better UF/PVAc bonding was achieved when quarter-sawn boards were used irrespective of the m.c. range at the time of gluing, and *vice versa* when flat sawn boards were employed;

iii) In terms of wood failure, using the same partition and based on the similar Scheffe's test carried out, comparable results between UF and PRF were obtained when quarter sawn boards were employed ($P < 0.01$). Inferior results were, however, produced by UF/PVAc and PVAc compared to UF and PRF when air-dried flat-sawn boards were used. The UF/PVAc also produced wood failure poorer than that of PVAc in the case when flat sawn timbers were employed. No significant difference was observed between different adhesives used when flat sawn boards were bonded at 12 to 15% m.c.

Delamination test

Interesting results were obtained from these tests (Figure 4). Both PRF and UF bonded samples exhibited excellent results in the vacuum-pressure test and soak-dry test. The cold soak air dry test results for PVAc bonded samples were also excellent. In the cold soak dry delamination test conducted on UF and UF/PVAc combinations, satisfactory results were obtained except for flat sawn UF/PVAc bonded at air-dry condition. The poor results by the latter could be attributed to the addition of PVAc which is non-moisture resistant in nature. This is aggravated by the use of flat-sawn boards which was known to develop higher stresses for a change of moisture content compared to quarter-sawn timbers (Chugg & James 1965). In addition, the high moisture content of the timber at the time of gluing might have further hampered the results.

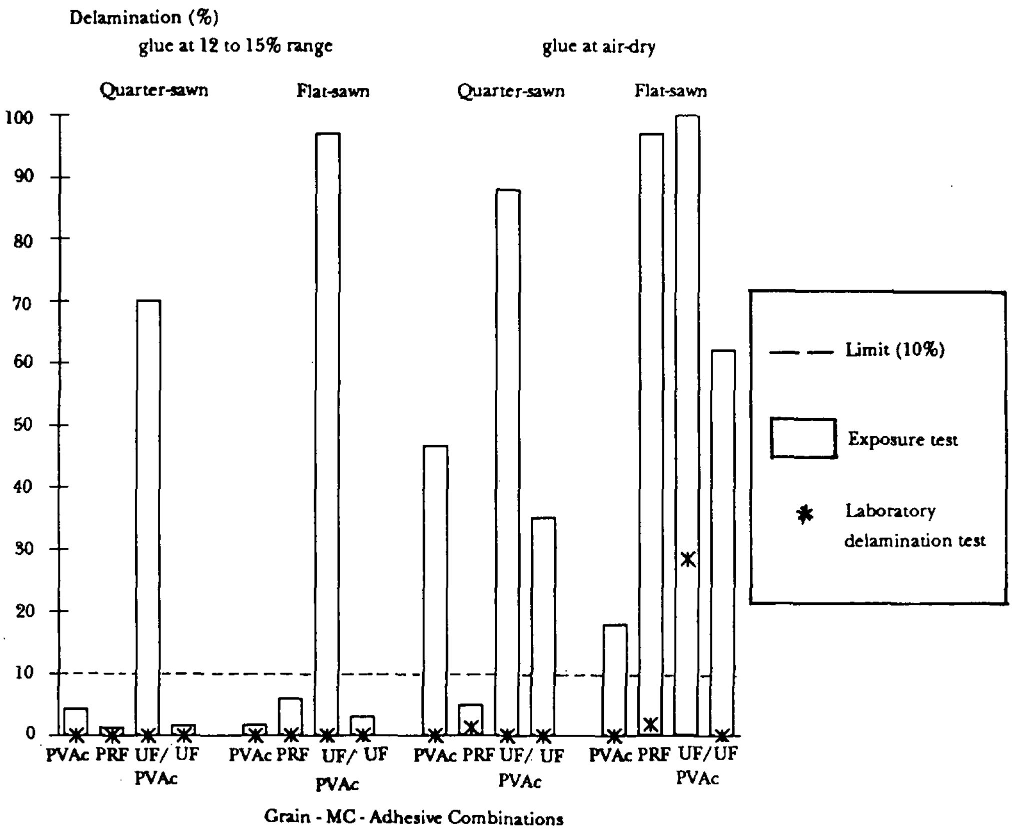

Figure 4. Laboratory delamination test and exposure test result

Weather exposure test

As all the samples irrespective of the type of adhesives used were subjected to the same exposure condition for the same duration, the outstanding results exhibited by some non-weather resistant adhesives were indeed surprising if not unexpected (Figure 4). The flat sawn and quarter sawn timbers bonded with PVAc at 12 to 15% moisture content produced excellent results, with delamination not exceeding 10%. All the UF/PVAc bonded boards, however, failed to meet the same requirement, and were almost totally delaminated. One possible explanation would be the incompatibility of the UF and PVAc mixture, which was not revealed under normal dry testing and delamination test. This incompatability was exposed when the bonded timbers were subjected to severe shrinking and swelling stresses as prevalent in the weather exposure test.

The PRF samples maintained their integrity in the exposure test and the UF samples glued at 12 to 15% m.c. also produced excellent results. The UF samples bonded at air-dry condition, however, failed.

Conclusions

All the treatment combinations produced satisfactory bonding strength surpassing the lower bound values specified in the standard for structural glue lamination (Anonymous 1981). The weather-boil-proof PRF adhesive which possesses the desired creep resisting characteristics justified its use for structural applications. The excellent vacuum pressure cyclic delamination test results also confirm its suitability to be used in the exterior environment, while the weather exposure test reaffirms it although a longer exposure period and the application of mechanical loading may be required to arrive at a more convincing conclusion.

The non-structural adhesives, both PVAc and UF/PVAc, were found to produce shear strengths comparable to the structural adhesive, PRF. This, however, does not indicate their suitability for use in structural application owing to their known lack of creep resisting characteristics. The non-compliance of UF/PVAc samples bonded at air dry conditions as indicated by the delamination results suggested that the addition of PVAc has affected the resistance of UF in service. Hence its inclusion should be restricted to timbers bonded at lower moisture content ranges. Such restriction, however, should not apply when only UF or PVAc is used. The relatively poor weather exposure test results obtained should not hinder the use of these adhesives as they are generally not used in the exterior environment.

In general, based on the laboratory delamination tests, timbers glued at air dry condition were found to be inferior to those bonded at 12 to 15% m.c. such as in the cases of PRF and UF/PVAc glues (Figure 4). Although the weather exposure test might be too severe to be used as a means to distinguish the service performance especially of non-weather resistant adhesives, it provides an important indication on the relative performance between the two moisture content levels investigated. For more reliable performance, the lower level as specified in the standard should be adhered to.

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