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COMMUNICATION IV

The Glue Joint Strength of Laminated Timber Decking made from Three Malaysian Hardwood Species

RINGKASAN

Kekuatan perekatan geladak kayu lapis yang diperbuat daripada tiga jenis kayu keras Malaysia iaitu Kempas (Koompassia malaccensis), *Nemesus* (Shorea pauciflora) *dan Seraya* (Shorea curtisii) *telah diselidiki. Pelapisan campuran menggunakan perekat Fenol-resorsinol formaldehid telah dihasilkan pada suhu bilik. Ujian kericihan telah dilakukan menurut spesifikasi ANSI/ASTM, D 905-49(76). Spesimen-spesimen menunjukkan nilai kekuatan kericihan garis perekat yang tinggi dengan setiap gabungan, melainkan satu, mencapai takat minimum yang diperlukan oleh industri iaitu 5515 kilopaskal (kPa) bagi spesimen kering dan 4137 kPa bagi spesimen basah. Perbandingan di antara geladak yang dihasilkan di makmal dan di kilang serta faktor-faktor yang mempengaruhi kekuatan kericihan garis perekat juga dibincangkan.*

SUMMARY

Glue joint strengths of laminated timber decking made from three Malaysian hardwood species i.e. Kempas (Koompassia malaccensis), *Nemesu* (Shorea pauciflora) *and Seraya* (Shorea curtisii) *were evaluated. Single and mixed species laminations were produced using a phenolresorcinol formaldehyde adhesive at room temperature. Shear block tests were performed according to the ANSI/ASTM D 905-49(76) specification. All specimens except one exhibited high glueline shear strength values with each combination, exceeding the minimum industrial requirements of 5515 kilopascal (kPa) and 4137 kilopascal (kPa) for dry and wet specimens, respectively. A comparison between laboratory and factory-made assemblies and various factors affecting the glueline shear strength of these assemblies are discussed.*

INTRODUCTION

Wood-using industries usually aim towards making full use of all available timber. As the relative quantity and quality of wider lumber declines, possibilities of upgrading lumber by gluing narrow pieces into wider boards will be earnestly studiec Glued laminated timber was first successfully fabricated in Europe in early 1900 (Moody, 1970). In Malaysia, this product in the form of laminated decking was introduced about a decade ago but restricted to a few popular species such as Keruing *(Dipterocarpus* spp.), Kapor *(Dryobalanops aromatica)* and Sepetir *(Sindora* spp.).

Being a relatively new product, laminated decking manufacturers in Malaysia are at present lacking the necessary information and fundamental data on this product with respect to present species as well as other potential timber species. This information is particularly important for the promotion of such a product. The present study was conducted with three major objectives i.e. to evaluate the glueline shear strength of laminated assemblies consisting of single and mixed species combinations, to determine the various factors that affect the glue joint strength and to provide basic technical information on the manufacture of laminated decking using certain Malaysian hardwood species.

MATERIALS AND METHODS

Three Malaysian hardwood species, namely Kempas *(Koompassia malaccensis)*, Nemesu *(Shorea pauciflora)* and Seraya *(Shorea curtisii)* were used to produce sample boards. The boards were made by bonding laminae with a phenol-resorcinol formaldehyde adhesive into specimen sizes sufficient to conduct tests in the laboratory. The laminates were sawn from one log of each species. The average size of the log was 660 mm in diameter and 5.5 m in length. The boards were selected at random and sent for air drying for 16 days before being kiln dried. For the final moisture content to reach 10-12% in the kiln drying process, it took about 16 days for Kempas, 10 days for Nemesu and 9 days for Seraya.

[1]Part of thesis for Master of Science degree, S.U.N.Y., College of Environmental Science and Forestry, Syracuse, New York, USA.

The adhesive used in this research was phenol-resorcinol formaldehyde – the most commonly used adhesive in the production of laminated decking in Malaysia. It is a synthetic thermosetting adhesive and a copolymer of resorcinol formaldehyde and phenol formaldehyde.

Laboratory Sample Fabrication

Rough lumber was cut into strips 22 mm x 57 mm x 300 mm by dimensions. Each strip was then planed to a final dimension of 19 mm x 57 mm x 300 mm. The planing and gluing were done on the same day.

The adhesive was mixed according to the manufacturer's specifications, i.e.:

Resin adhesive	10 parts by weight.
Hardener	2 parts by weight.
Total mixture of	12 parts by weight.

The adhesive was hand spread with a spatula. It was single spread at a rate of between 0.32 – 0.37 kg/m^2 followed by a closed assembly time of between 15 – 30 minutes.

The assemblies were pressed in a cold press with a pressure of 689.5 kPa for a 12-hour period. The temperature and relative humidity of the pressing area were 23°C and 50% respectively. The assemblies were stored for one week for room temperature conditioning.

Six different combinations of species were bonded for block shear tests. In the single species assemblies, Seraya was bonded to Seraya, Nemesu to Nemesu and Kempas to Kempas, and in the mixed species assemblies, Seraya was bonded to Nemesu, Seraya to Kempas and Nemesu to Kempas.

Block Shear Test

Five specimens were produced from each individual assembly (Figure 1). For each combination of species, eight assemblies were made yielding a total of 40 specimens. Half of these speciments were tested for dry shear strength and the remaining for wet shear strength. The finished dimensions of the test specimens were 38 mm x 0 mm x 50 mm with an effective gluline area of 36 mm^2. In the case of samples fabricated in factory, the dimensions obtained did not fulfill requirements specified by ANSI/ASTM* 9(76). The dimensions of these test specimens were 38 mm x 38 mm x 50 mm with an effective glueline area of 1452 mm^2.

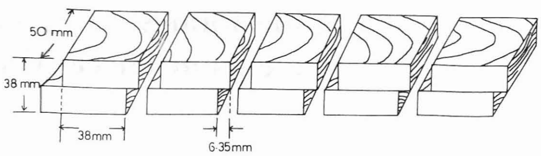

Fig. 1. Procedure of cutting sample specimens for shear block test.

(i) Dry shear test: The specimens were tested after being conditioned as specified by ASTM D 905-49(76).

(ii) Wet shear test: The following sequence was followed to condition wet shear specimens.

a. Specimens were submerged in the water at 18–27°C (65–80°F) for 48 hrs.

b. Specimens were then taken out and dried in the oven at 60°C (140°F) for 8 hours.

c. Specimens were again submerged in water at the same water temperature for 16 hours.

d. Steps (b) and (c) were repeated after which the specimens were tested wet.

The tests were performed using a Baldwin Emery SR – 4 testing machine, with a capacity of 22700 kg. The specimens to be tested were aligned and fixed in the testing machine. The load was applied with a continuous motion of the movable head at 0.038 mm (0.015 in) per minute, with a permissible variation of 25%. The maximum load required to fail the glueline was recorded and the percentage of wood failure was estimated.

RESULTS AND DISCUSSION

The average values of glueline shear strength for both single and mixed species with their respective average percentages of wood failure are tabulated in Table 1 and illustrated in Figure 2. The results clearly indicate that all the single species combinations meet the minimum industrial requirements of 5515 kPa and 4137 kPa shear value for dry and wet specimens respectively (Anon., 1979).

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TABLE 1
Average values of glueline shear strength and wood failure of single and mixed species board, assembled in the laboratory.

Combination	Shear Strength kPa		Reduction in shear based upon dry strength (%)	Wood failure (%)	
	Dry	Wet		Dry	Wet
Single species					
Seraya-Seraya	8412	7929	5.6	88	84
Nemesu-Nemesu	8964	6081	32	89	77
Kempas-Kempas	12756	1675	87	74	20
Mixed species					
Seraya-Nemesu	8688	7171	17.5	87	81
Seraya-Kempas	8826	4392	50.4	89	75
Nemesu-Kempas	10894	6847	37	79	65

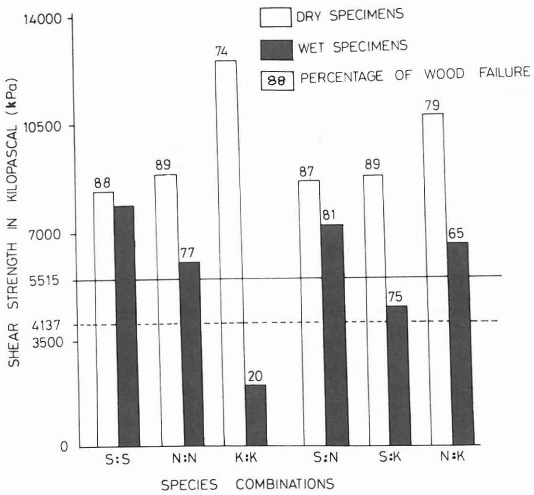

Fig. 2. Average glue line shear values of dry and wet specimens of the single and mixed species laminated decking boards.

Single Species Combination

Under dry conditions, Kempas shows the highest average shear value of 12756 kPa followed by Nemesu with 8964 kPa and Seraya 8412 kPa. An analysis of variance was carried out to detect the differences among the four shear block assemblies for each moisture condition and within the five shear test specimens, from each assembly. Within each species, no significant difference in gluline shear strength was found at 99% confidence level, for dry specimens. Thus, the average value calculated on the basis of 20 specimens is representative of a single homogenous population.

However, the test results obtained from wet specimens showed a marked contrast to those of the dry specimens. Seraya offered the highest average value of glueline shear strength of 7979 kPa followed by Nemesu with 6081 kPa and Kempas with 1675 kPa. Kempas offered very low glueline shear strength under wet conditions and did not meet the minimum industrial requirement of 4137 kPa as specified by the industry, (Anon., 1979). The high percentage of glueline shear strength reduction in Kempas (87%) as compared to only 32% for Nemesu and 5.6% for Seraya, might be related to its poor gluability and its high specific gravity. Being the most dense species (881 kg/m^3) and having the highest wood strength caused much higher stresses to be placed on its gluelines under these severe wet conditions. Kempas also has a greater dimensional change coefficient (3.0%), as compared to Nemesu (2.5%) and Seraya (2.4%); thus the soaking and drying sequence created greater forces on the glueline and as a result, six out of 20 specimens for Kempas delaminated prior to testing.

Mixed Species Combination

Under dry conditions, the Kempas-Nemesu combination offered the highest average shea strength values followed by Kempas-Seraya and Nemesu-Seraya (Table 1). An analysis of variance was performed and the result showed that there was no significant difference at the 99% confidence level among replicates of S:N, S:K and N:K boards. All mixed species boards offered higher average glueline shear strength values as compared to single species assemblies of the weakest boards (S:S), but none was equal to the Kempas to Kempas combination.

Under wet conditions, all three combinations exceeded the minimum industrial requirements of 4137 kPa. The combination of Kempas with both Nemesu and Seraya showed a higher shear strength reduction than single species of Seraya-Seraya and Nemesu-Nemesu (Table 1). These large reductions were due to the difference in specific gravities of the species glued together. Chugg (1964) pointed out that assemblies from different species with different densities, moisture contents and other wood properties, adversely affect the gluing surface due to contrasting shringkage and swelling properties. In spite of the differences, the S:K and N:K were much better in wet shear strength than the same species K:K. This is due to less total stress being placed upon the glueline when lower specific gravity species are being bonded. Seraya and Nemesu are two different wood species and both have lower specific gravities (0.52) and 0.54 respectively) than Kempas. They experience little wet shear strength reduction (17.5%) compared to dry shear strength. The results confirmed that specific gravity plays an important role in determining wet shear strength of the gluelines. The other two combinations employed in this study were weaker as compared to the species combination studied by Wan Sardini (1979), which showed a reduction in shear strength of less than 35%

Under wet conditions, the reverse pattern is observed. All combinations involving Seraya experienced a relatively low shear strength reduction and this probably meant that Seraya showed better and more durable glue joints.

Comparison of Glueline Shear Strength Between Laboratory and Factory-made Assemblies

Similar samples that had been fabricated in a factory were tested for shear strength. The comparison of results between laboratory-made, factory-made and published data for solid wood shear strength is presented in Table 2 and illustrated in Figure 3. Laboratory-made assemblies offered higher average glueline shear strength values as compared to their factory counterparts, both for single and mixed species combinations, under dry conditions. Only the glueline shear strength of the laboratory-made assemblies compared favorably with the shear strength of the corresponding solid wood. However, the percentage difference between factory-made and solid wood shear strength is not all that great and this

TABLE 2
Average values of glueline shear strength and percentage of wood failure (dry condition)

Combination	Laboratory Made Assemblies		Factory Made Assemblies		Shear Strength of solid wood
	Shear (kPa)	W. Failure (%)	Shear (kPa)	W. Failure (%)	Shear (kPa)
Single species					
Seraya-Seraya	8412	88	7516	90	8529
Nemesu-Nemesu	8964	89	8136	87	9556
Kempas-Kempas	12756	74	12135	80	12340
Mixed species					
raya-Nemesu	8688	87	7998	80	—
va-Kempas	8826	89	—	—	—
ı-Kempas	10894	79	10756	75	—

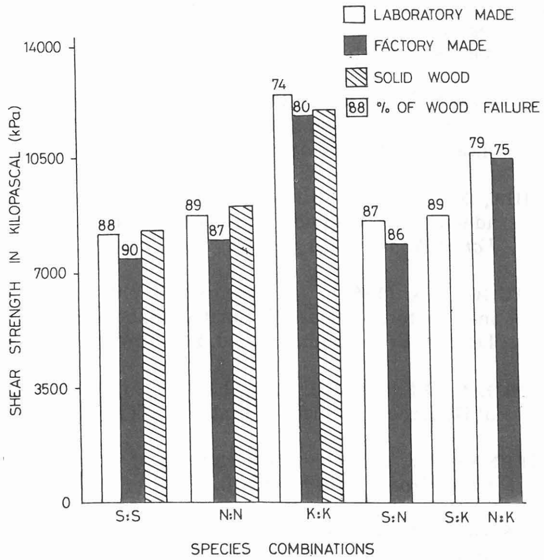

Fig. 3. Average dry glue line shear values of laminated decking. Comparison between laboratory and Factory made assemblies and the corresponding solid woods.

difference is not critical in terms of commercial application of factory-made material.

The lower values of glueline shear strength of factory made assemblies might be attributed to specimen size. All the specimens had an effective glueline area of only 1452mm^2, instead of 1936mm as specified by ASTM. The difference in specimen size will adversely affect the shear strength, (Longworth, 1977). Kennan (1974) showed that smaller specimens are stronger per unit area than larger specimens. Bendtsen and Porter (1978) however, came to the opposite conclusion, i.e. no significant difference was detected at 5% probability level between results of standard and undersized specimens.

Under wet conditions the factory-made assemblies exhibited a pattern similar to that of their laboratory counterparts. The Nemesu to Nemesu combination offered the highest average glueline shear strength followed by Nemesu-Kempas assemblies under wet conditions Both cases strengthened the earlier assumption that the glueline experiences a high level of stress because of a high specific gravity.

Kempas has a low pH value (4.7) as compared to Nemesu (5.0) (Wong, 1980). This low wood pH value may contribute in some ways to the low wet shear strength and low percentage of wood failure observed in Kempas gluelines. The adhesive is an alkaline curing thermosetting type and wood substances having acidic pH level may interfere with the chemical reaction of the adhesive. Jordan and Wellons (1977) and Chia (1970) reported that extractive removal pretreatment will improve wettability and increase the pH of the wood.

Wood Failure

The average values of wood failure for dry and wet specimens are given in Table 1. Percentage of wood failure is commonly used to detect the strength of glue joints. From Table 1, it is clear that all combinations involving Seraya will produce high percentages of wood failure for both dry and wet conditions. Kempas to Kempas assemblies have the lowest percentage of wood failure in the wet condition. Nemesu and its combinations offered a moderate wood failure percentage.

Currently, there is no standard wood failure requirement for this product. According to Product Standard (PS-56-73), for laminated beams, 80% wood failure must be met and according to the Product Standard (PS-1–74), for C – D grade exterior plywood, 85% wood failure is required for exterior bonds. Based on these two standards, the combinations of Seraya and Nemesu employed in this study meets the minimum requirement for exterior bonds. Under wet conditions, only two combinations, namely Seraya to Seraya and Seraya to Nemesu, met the minimum requirement as specified by Product Standard (PS-56 – 73).

CONCLUSIONS

With the exception of the Kempas to Kempas combination in the wet condition, the glueline shear strength of Seraya to Seraya, Nemesu to Nemesu and Kempas to Kempas, S:N, S:K and N:K, met the standard industrial requirements of 5513 kPa and 4137 kPa for dry and wet conditions respectively. All combinations employed in this study offered higher glueline shear strengths than the most commonly used species for this product, namely Sepetir, Keruing and Kapor.

The glueline shear strengths of mixed species boards were superior to the lowest single species board tested but none were equal to Kempas-Kempas glueline in dry conditions.

Glueline shear strength of laboratory made assemblies compared favorably to solid wood of the corresponding species. This means the glue joints produced by these species were as strong as the wood itself.

Factory-made assemblies demonstrated slightly lower shear strength values as compared to their laboratory counterparts and corresponding solid woods. This indicates that factory production of a suitable decking with sufficient glueline shear strength under wet and dry conditions is possible.

The results are considered as preliminary evidence due to the limited supply of materials for the specimens and are insufficient to establish absolute glueline shear strength levels. However, it provides information for evaluating the feasibility of using these species for production of laminated decking boards.

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