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APPRAISAL OF USED WOODEN RAILWAY SLEEPER

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Abstract

Replacement of wooden sleepers to prestressed concrete sleepers has marked as advancement in the railway sleepers industry in Malaysia. Despite superiority of these man-made composite sleepers, wooden sleepers still lead in terms of track performance qualities in particular on its natural elasticity. An initiative to investigate the degree of degradation of used wooden sleepers and the possibility of reusing them on low capacity railway track in Malaysia as a means of reducing the overall track rehabilitation cost was undertaken. Used wooden sleepers were tested according to Australian Standard, Railway Track Material, Prestressed Concrete Sleepers (AS 1085:14:2003) on Rail Seat Vertical Load Test and Centre Positive Bending Moment Test. Six wooden sleeper samples were tested under the static load until failure. Benchmarking was carried on high strength prestressed concrete sleeper, tested according to AS 1085:14:2003: Rail Seat - Positive Moment Test. The results obtained showed the maximum load that the used wooden sleepers can carry surpassed the design load of KTMB specifications and it is about 58% of high strength prestressed concrete sleeper. The maximum deflection produced by all used wooden sleepers is 20 mm showing that the sleepers maintained their elastic behaviour. Modulus of Elasticity ranging from 21 to 27 kN/mm^2 of which within the standard value, indicating weathering process does not so much affect their stiffness. Most sleepers showed crack patterns propagated in the longitudinal direction. Toughness value is almost one half of the high strength prestressed concrete sleeper. This study indicates that there is a potential of reusing the wooden sleepers for light loading of the railway track. Hence, an extensive study is recommended to be carried out under fatigue loading condition.

Keywords: Used wooden sleeper, Bending Test, Rail Seat Vertical Load Test

Nomenclatures

a	Distance between point of reaction to the nearest loading point (=*L/2*), mm
b	Width of the wooden sleeper section respectively, mm
h	Depth of the wooden sleeper section respectively, mm
I	Moment of inertia, mm^4
L	Effective span, mm
M	Moment acting on the section being considered, N.mm
P_{el}	Load at elastic limit, N
P_{ult}	Ultimate load, N
y	distance from neutral axis to the layer being considered, mm
Greek Symbols	
Δ_{el}	Central deflection at elastic limit, mm

1. Introduction

Heavy hardwood timber is considered the most suitable natural material that can be used as railway sleeper due to its constructability, durability and less costly since 1800's. More importantly, it has strong ability to absorb any vibration and impact energy produced on it before transmitting the rest of the loading to the ballast, then to the ground. As technology advances, other materials have been used as sleepers such as prestressed concrete and steel, and researches had been carried out in the Universiti Teknologi MARA, Shah Alam (UiTM) [1-7]. However, almost 70% of existing railway network in Malaysia is still using wooden sleeper. The process of changing to prestressed concrete sleepers requires high cost and presently they had been installed only on the double tracking network. This rehabilitation plan generated an abundance of used wooden sleepers. In order to minimize the wastage of natural resources and to reduce the cost of refurbishment, reusing the used wooden sleeper on lesser critical and strategic area of the railway track may provide a better solution.

In Malaysia, the majority of the wooden sleepers are from timber strength group A which comprised of species such as Balau, Selangan Batu, Merbau or Cengal. In this study, used wooden sleepers from Balau of Select and better grade, and (127x254x2000) mm in size were selected. The rectangular geometric shape is easy to prepare compared to other shapes. At present, wooden sleeper has been changed to prestressed concrete sleeper due to the scarcity of good timber, escalating maintenance cost and reduced service life, which now has come to less than 15 years due to higher wheel load, speed and increased trip frequencies. Nevertheless, wooden sleepers are still being used on Malaysian railway track in which the train travels at speed less than 100 km/hr. Table 1 shows the typical characteristics of wooden sleeper [8].

Wooden railway sleeper requires high compressive strength perpendicular to the timber grain. This enables wooden railway sleeper to effectively resist rail crushing during service and stresses caused by the ballast [9]. Anon [10] specifies that wooden railway sleeper must have modulus of elasticity (MOE) in static bending (green) $\geq$ 8132 N/mm^2, and compressive strength perpendicular to grain (green)$\geq$2.44 N/mm^2. Anon [11] stated stresses and moduli for timber strength of Group A with grade Select as shown in Table 2.

Table 1. Characteristics of Wooden Sleeper [8].

Characteristics	Wooden Sleeper
Service life	12-15 years
Weight of sleeper for broad gauge	83 kg
Handling	Manual, no damage to sleepers during handling
Gauge adjustment	Difficult compare to other type of sleeper
Track circuiting	Best
Type of maintenance	Manual or mechanical maintenance
Cost of maintenance	High
Damage by corrosion and vermin	Can be damaged by white ants, needs to be treated.
Suitability for fastening	Suitable for elastic fastening and conventional fastening
Suitability to track	Suitable for all types of routes
Track elasticity	Good compare to other type of sleeper
Creep	Excessive creep
Scrap value	Low scrap value

Table 2. General Strength Properties of Balau Species.

Group: A Grade: Select	Tension parallel to grain	Compression parallel to grain	Compression perpendicular to grain	Shear parallel to grain	Modulus of elasticity	Modulus of rupture
	MPa	MPa	MPa	MPa	MPa	MPa
Green	16.55	68.8	9.53	12.9	18,400	121
Dry	20.00	76.0	9.79	15	20,100	142

From the static bending test, maximum bending moments and bending stresses at mid span of the wooden sleeper due to central point load can be calculated using basic structural mechanics Eqs. (1) and (2), modulus of rupture (MOR) and MOE using Eqs. (3) and (4) respectively.

$$M_{max} = \frac{PL}{4} \tag{1}$$

$$\sigma_{max} = \frac{My}{I} \tag{2}$$

$$\text{MOR} = \frac{3P_{ult}a}{bh^2} \tag{3}$$

$$\text{MOE} = \frac{P_{el}a(3L^2 - 4a^2)}{24\Delta_{el}I} \tag{4}$$

The values of MOR and MOE can be calculated by inserting the values of ultimate load and elastic limit load respectively, and the central deflection both obtained from experimental data into Eqs. (3) and (4). This study determines the basic mechanical properties, deflection of used wooden sleeper, stress strain relationship, toughness and suggestion for its recycleability.

2. Experimental Programme

Evaluation on used wooden sleepers from Balau with grade of Select was conducted at the Faculty of Civil Engineering, UiTM. The behaviour of these used wooden sleepers was investigated throughout a series of laboratory tests with reference to AS 1085.14-2003 [12]. Since there is no specific standard for testing of wooden sleeper, the Australian standard was chosen as a guide for this study, as the AS 1085.14-2003 had precisely detailed out test procedures for prestressed concrete sleepers, and this can help to benchmark results obtained from laboratory tests carried on the wooden sleepers.

A total of six used wooden sleepers from Balau species were supplied by Keretapi Tanah Melayu Berhad (KTMB). Samples of size (127x254x2000) mm were tested for structural bending strength including deflection and crack patterns. These wooden sleepers had been in service for more than 10 years. To investigate the possibility of reusing the wooden sleepers, a compliance test is conducted. The compliance test consists of three types of experimental procedures, namely the Rail Seat Vertical Load Test under Negative Moment (TRSN) and Positive Moment (TRSP) (Appendix I of AS1085-14 [12]) and Centre Positive Bending Moment Test (CPM) (Appendix M of AS1085-14 [12]). In each test, two wooden sleeper samples were used. In order to benchmark the results, another two used high strength prestressed concrete sleeper (HSC) were tested under TRSP. The concrete grade is 60 N/mm^2. During and after the tests, structural cracks were inspected on all sleepers, and values for deflections and loads were recorded. The set-up for the three tests was carried out as stipulated in Fig. I1, I2 and M1 of the AS1085-14 [12].

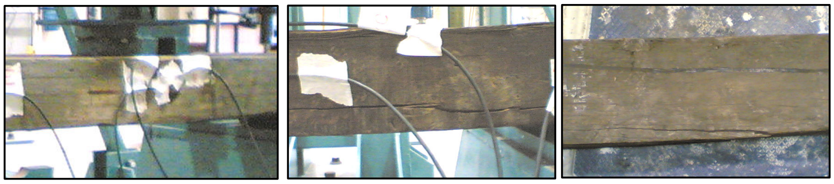
In all experimental tests, loading rate using displacement control was used, whereby rates of 0.004 mm/s and 0.008 mm/s were chosen, of which the latter is meant for prestressed concrete sleepers. As for wooden sleepers, the rate was decided to be halved. The decision was based on series of loading rate tests conducted for wooden sleepers in the preliminary works. Three transducers and three strain gauges were placed in all samples at supports and mid-span, and connected to the data logger for necessary recording. The transducer at mid-span measured central deflection, while the other two monitor the unwanted misalignments. The strain measured is used for the stress-strain relationship. The test was stopped once the sleeper has totally failed.

3. Results and Discussion

The discussion begins by analysing the crack pattern occurred during and after the tests. Subsequently, the discussion pursues on response of deflection to loading and stress strain relationship and flexural toughness.

3.1. Crack patterns

Figures 1 to 6 show crack patterns and behaviour for all six wooden sleeper samples before and after the experimental works. In all samples, it can be seen that most of the cracks occurred along the longitudinal grain of the timber, prevailed under the location of the applied load. These indicate that used wooden sleeper failed by shearing off between fibres. However, there are additional cracks seen in Fig. 2 for CPM2 sample where crack prevailed in the perpendicular direction to the grain of the wooden sleeper. This denotes a mixed mode of failure between bending and shearing. For the sleeper TRSP2 in Fig. 4, the crack occurred in the form of tangential crack at an inner ring of the timber fibre. The initial defects escalate crack propagations until failure. Noting that wood being an anisotropic material, it possess three modes of failure; namely circumferential or tangential, radial and longitudinal. Figure 6 shows sleeper TRSN2 contained defects which initiated the crack. In general, all samples failed in a combination of bending and shearing [13].



(Before test) (After test)

Fig. 1. Crack Patterns for CPM1 – Longitudinal Crack.

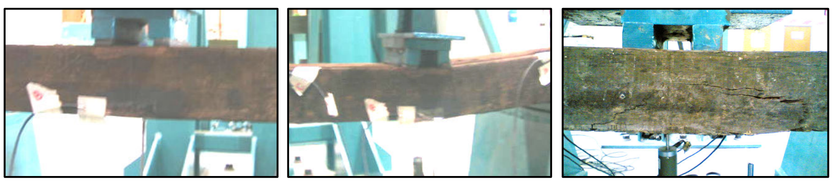


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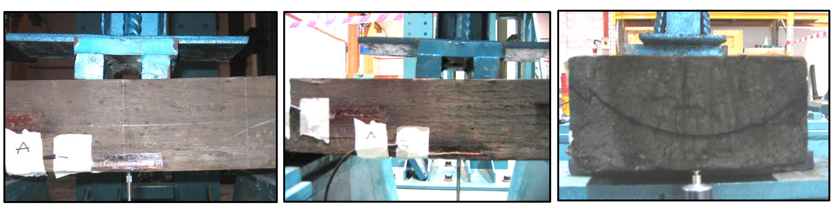
Fig. 2. Crack Patterns for CPM2 – Longitudinal and Radial Crack.

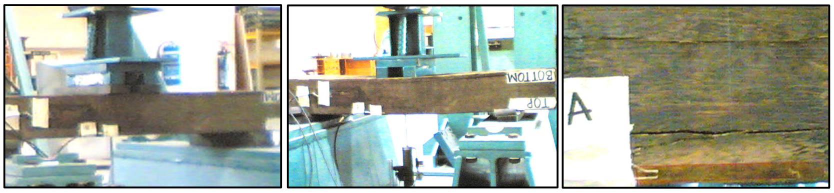


(Before test) (After test)

Fig. 3. Crack Patterns for TRSP1- Tangential Crack.

(Before test) (After test)

Fig. 4. Crack Patterns for TRSP2 – Tangential and Longitudinal Crack.



(Before test) **(After test)**

Fig. 5. Crack Patterns for TRSN1- Longitudinal Crack.

(Before test) **(After test)**

Fig. 6. Crack Patterns for TRSN2–Longitudinal Crack.

3.2. Load deflection relationship

Figure 7 shows relationship between load and deflection under CPM test. In this test, the average ultimate load achieved is P_{ult}=240 kN with an average maximum displacement recorded δ_{max}=24.8 mm.

Both samples show quite similar performance particularly within elastic limit and during plastic limit where sample CPM2 shows a longer ability to absorb energy. The ultimate load in CPM1 shows 14.7% higher in magnitude when compared to CPM2, while their maximum deflections are in close range.

Figure 8 shows load-deflection relationship for TRSN and TRSP tests. All the four samples behave in similar mode and trend except for TRSP2 where failure occurred much earlier. Under TRSN tests, the average ultimate load achieved is 258.9 kN with an average maximum displacement of 24.8 mm.

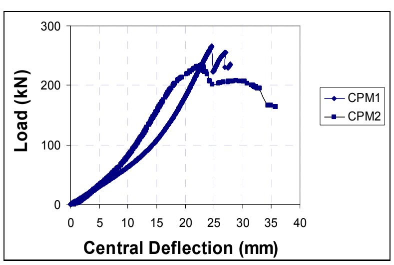


Fig. 7. Load-deflection of CPM Test.

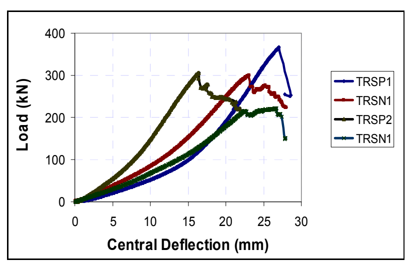


Fig. 8. Load-deflection of TRSN and TRSP Test.

From the TRSP tests, the average ultimate load achieved is 292.1 kN with an average maximum displacement of 20.9 mm. Table 3 shows details of the load-deflection results recorded from the experiments. Comparing TRSN and TRSP tests, samples from TRSN test failed at a lower load about 11.4 % in comparison to TRSP test. This may be due to residual flexural stress built in the wooden sleeper, since when the reverse side was loaded (in TRSN), the tensile side is now compressed and caused timber grain to experience reversal stress which then failed at a lower load. Nevertheless, in due consideration of the past service life, the lowest ultimate load recorded (from TRSN test) is still higher by 29.4% and the lowest yield load recorded (from CPM test) is higher than the KTMB specified design load of 200 kN, by 3.5%.

Table 3. Comparative Strength of Used Wooden and High Strength Concrete Sleeper.

Average value	CPM Mid Span	Rail Seat Negative (TRSN)	Rail Seat Positive (TRSP)	Rail Seat Positive High Strength Concrete (HSC)
P_{ult} (kN)	240	258.9	292.1	378
P_y (kN)	207	233.5	258.5	294
δ_{max} (mm)	24.8	24.8	20.9	15.5
Toughness (kNm)	4.25	3.83	3.50	5.00

Note: TRSN is Rail Seat Negative Bending, TRSP is Rail Seat Positive Bending and CPM is Centre Positive Bending Moment

Figure 9 shows deflection between wooden (TRSP1 and TRSP2) and prestressed concrete (HSC1 and HSC2) sleepers under rail seat test. Both the TRSP and HSC had undergone the same Rail Seat Positive Moment Test. The maximum ultimate load for HSC is 378 kN of which 29.4% higher than that of TRSP. The average maximum deflection for HSC is 15.5mm, 34.8% stronger than TRSP. High strength prestressed concrete sleeper gains it strength at early age indicating a stiffer material as compared to wooden sleeper which is more elastic.

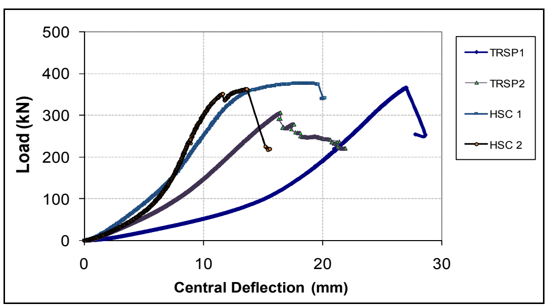


Fig. 9. Comparative Response of Deflection at Rail Seat Positive Moment Test.

3.3. Flexural toughness

Flexural toughness is another important mechanical property to measure energy absorbing capacity of the material that can be evaluated via area under load-deflection (L-Δ) diagram using the basis of elastic theory. Higher toughness means greater ductility against dynamic loading, in this case sleeper experiences fatigue and impact impulsive loading. Table 3 shows that HSC possess higher toughness over used wooden sleeper. Experimental results for sleepers tested under TRSP and TRSN show similar behaviour. Among the tests conducted, wooden sleeper under CPM test has higher ability to absorb energy and the value is just 15% lower than tests results obtained from prestressed concrete sleepers. It can be said within this scope of study, the used wooden sleeper shows a potential ability to sustain railway loading.

3.4. Stress-strain relationship

Figures 10, 11 and 12 show the stress-strain relationship for CPM, TRSP and TRSN, and HSC tests respectively. Load-deflection and stress-strain relationship prevailed linearity between them until yield limit was achieved and failed about 10 % beyond the yield strength. The used wooden sleepers continued to show good elasticity characteristics based on the deflection magnitudes recorded during the experiment.

However, from Fig. 10, the stress-strain relationship for CPM1 and CPM2 are distinctly different, yielding a modulus of elasticity equivalent to 59.0 kN/mm^2, which is significantly higher than the average result calculated from other samples to be 24 kN/ mm^2, as shown in Table 4. CPM1 showed flexural failure, confirmed by the transverse cracks that happened at the mid span section. Results for Rail Seat Test on all four samples shown in Fig. 11, gives close agreement between one to another. The MOEs are within the value given by MS 544 [14] and [11] for wood in dry condition.

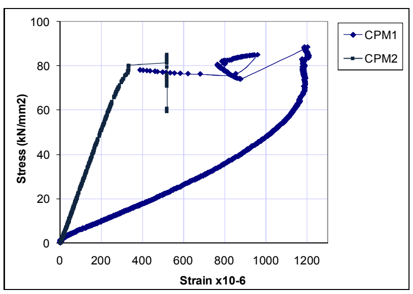


Fig. 10. Relationship of Stress and Strain for CPM Sleeper at Mid-span.

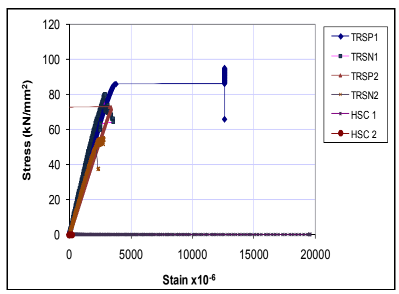


Fig. 11. Stress-Strain for TRSN and TRSP Sleeper at Rail Seat.

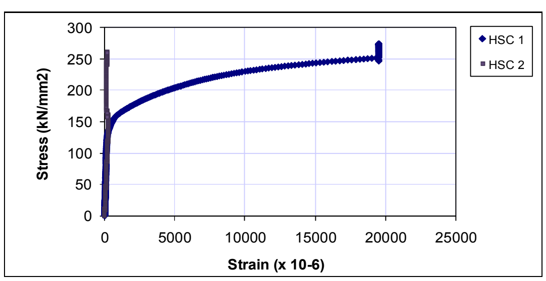


Fig. 12. Stress and Strain Relationship of High Strength Prestressed Concrete Sleeper at Rail Seat.

In comparison with HSC sleepers, both samples attained almost the same value of ultimate stress and yield load. Sleeper HSC1 seems to be more brittle whereas HSC2 shows prolonged ability in sustaining the static railway load.

With regard to MOR, the result shown in Table 4 is calculated by using Eq. (3). The strengths are relatively lower, in the range of 50% of the MOR as compared with standard data shown in Table 2. The MOR for CPM test is the highest and appropriate to be compared with standard value that is obtained by third point bending test and the data is collected at the centre of sample. The sample under CPM test produced 38% lower MOR than standard value of 142 kN/mm^2 at dry condition.

Table 4. Modulus of Elasticity and Modulus of Rupture for Wooden and Prestressed Concrete Sleepers.

	Mid Span		Rail Seat					
	CPM1	**CPM2**	**TRSP1**	**TRSP2**	**TRSN1**	**TRSN2**	**HSC1**	**HSC2**
σ_{max} (kN/mm²)	88.5	85.2	94.9	75.9	80	55.3	264	261
σ_y (kN/mm^2)	70.0	74.0	80.7	70.0	73.9	54.2	155	141
ε_{max} x10^{-6}	1205.5	520.8	3835.5	3433.1	3590.8	2770.8	19524	18084
E (kN/mm²)	59.0	25.2	24.5	21.3	27.8	21.6	59.8	58.3
MOR (kN/mm^2)	-	88	78.5		56.7		NA	

Apparently according to the design criteria of prestressed concrete sleeper [12], the used wooden sleepers are still within the frame of reference, whereby they portray sufficient strength to be reused on railway track. However, remaining service life need to be quantified through further study on these used wooden sleepers by applying repeated load of more than 2 million cycles, so that the ability to reuse these sleepers can be recommended to appropriate railway network in Malaysia.

4. Conclusions

The experimental work showed that the used wooden sleeper can carry at least another 20 % additional load than the required design load. Considering the used wooden sleepers had been in service for more than 10 years, the maximum deflection under ultimate load showed timber still maintained its elasticity. The crack patterns initiated from the defected sections, propagated in the longitudinal direction to an extent the grain were seen to separate. With the results obtained from the compliance test, it is safe to conclude that the used wooden sleepers are still safe to be used for static loading cases, such as at depot or residing area that do not experience normal train speed.

Further analysis in quantifying the wooden sleeper endurance limit and its continual service life through repeated load test is recommended before extended use of wooden sleepers of age more than 10 years in service on main line railway tracks.

Acknowledgment

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References

1. Hamzah, S.H. and Din, K. (1997). Analysis of prestressed concrete under dynamic load. *Proceedings of Fifth International Conference on Concrete Engineering and Technology*, Kuala Lumpur, Malaysia, 5-7 May, 291 – 298.
2. Hamzah, S.H. and Baharom, B. (1998). Investigation of concrete sleepers under dynamic load. *BRC Journal*, UiTM, Vol. 5(1), June.
3. Din, K., Ahmad, J. and Ahmad, Z. (2002). Crack propagation in prestressed concrete railway sleepers. *Proceedings of 2nd World Engineering Congress*, Malaysia, 22-25 July.
4. Abu Bakar, A. and Din, K. (2004). Design and development of concrete sleepers on Malaysian rail networks. *Proceedings of 22nd Conference of Asean Federation of Engineering Organization*, Myanmar, 18-19 December.
5. Abu Bakar, A., Din, K. and Marwi, M.S. (2007). Design and performance of prestressed concrete railway sleepers containing fibers. *Proceedings of Conference on Scientific and Social Research (CSSR)*, Malaysia, 13-14 June
6. Rosli, M.I.F, Hamzah, S.H. and Abu Bakar, A. (2007). Prestressed concrete sleepers in Malaysian permanent way. *18th International Invention, Innovation & Technology Exhibition* (ITEX 2007), Kuala Lumpur, 18–20 May.
7. Rosli, M.I.F, Hamzah, S.H. and Abu Bakar, A. (2007). Prestressed concrete sleepers in Malaysian permanent way. *UiTM Inventions, Innovations and Designs Exhibition (IID 2007)*, Shah Alam, 24-25.
8. Gupta, B.L. and Gupta, A. (2004). *Railway engineering*. Standard Publishers Distributors, New Delhi, India, Third Edition.
9. Bhattacharjee, P.K. and Basu, A.K. (1963). *A Textbook of railway engineering*. Orient Longman Limited, New Delhi, India, Revised Edition.
10. Anon (2000). *100 Malaysian timbers.* Malaysia Timber Industry Board, Third Reprint, April 2000.
11. Anon (1979, 1993). The strength properties of some Malaysian timbers. *Timber Trade Leaflet No. 34*, Malaysia Timber Industry Board.
12. Australian Standard, AS 1085-14. (2003). *Railway track material: prestressed concrete sleeper*, Third Edition.
13. American Specification and Testing Method. (1997). ASTM D198-97: Standard Test Methods of Static tests of Lumber in Structural Sizes, *ASTM Standard,* Vol. 03.01, USA.
14. Malaysian Standard, MS 544: Part 2. (2001). *Permissible stress design of solid timber*, SIRIM, First Revision.