Recent Trends in Civil Engineering and Built Environment Vol. 2 No. 1 (2021) 656-664
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RTCEBE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rtcebe
e-ISSN :2773-5184

A Study on Moment Capacity of Timber Beam with Passive Prestressing

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DOI: https://doi.org/10.30880/rtcebe.2021.02.01.071
Received 30 January 2021; Accepted 28 April 2021; Available online 30 June 2021

Abstract: In Malaysia, Kempas timber is widely used as structural components for civil construction. The application of prestressed timber starts emerging in Malaysia to enhance the load carrying capacity and allow the use of longer span with reduced cross-sectional size simultaneously, since timber is weak in bending and susceptible to cracking under flexural load. This research was conducted to investigate the change in bending strength and moment capacity of timber beam with passive prestressing rods installed at different lever arm positions, and the enhancement of moment capacity of timber beam with and without passive prestressing. Five Kempas timber specimen configurations with a volume of 40mm×90mm×900mm were prepared for four-point bending test, and their flexural behaviors were evaluated subsequently. Strengthening tension side of timber beam had the greatest enhancement of flexural strength and moment capacity among the specimens. In the absence of the torsion influence, all prestressing schemes had a significant improvement in timber properties compared to non-prestressed beam. In terms of timber stiffness, it has been improved in all prestressed sample configurations, with the exception of TBN specimens. Future research should increase number of specimens to minimize variation in timber properties.

Keywords: Kempas Timber, Passive Prestressing, Flexural Strength, Moment Capacity

1. Introduction

Malaysia is a timber-rich country but the application of timber products in construction industry is quite insignificant [1]. There are several high-quality timbers produced in Malaysia, which are extremely demanded all over the world. The current state of affairs in Malaysia is the minor interest in application of prestressed timber as a structural member [2].

Timber is the most versatile building material in construction industry due to its decorative and structural purposes [3]. Kempas timber is a medium hardwood with air dry density of 770-1120 kg/m^3 [4]. It has better economic benefits for construction, as it is largely prepared in factory and transported to site for rapid assembly [5]. However, the collapse of timber beam may occur when brittle failure

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Corresponding author: david@uthm.edu.my appears on its tension side under flexural load [6]. Since timber is weak in bending due to its fibrous structure, it is important to strengthen timber adequately to improve its mechanical properties [7].

Therefore, the experimental investigation was conducted on different configurations of Kempas timber beams with passive prestressing to evaluate the contribution of prestressing to the improvement of timber strength, as well as the effect of changes in the behavior of timber beams to the failure. Through prestressing method, it was designed to improve serviceability feature of strengthened beams in contrast with non-strengthened beams [8]. Prestressed timber is commonly used in bridges, roofs and the gravity load resisting system of tall buildings [9].

The research was aimed to investigate the change in moment capacity and bending strength of timber beam with passive prestressed rods installed at different lever arm position, and the enhancement of moment capacity of timber beam with and without passive prestressing. It contributes significantly in encouraging the application of prestressed timber beam in Malaysia by improving the structural performance of timber.

2. Materials and Methods

In the research, the four-point bending test was conducted on 40mm×90mm×900mm Kempas timber beams to determine their bending strength and moment capacity. There were five types of timber specimens prepared for conducting the experiment and the notation of each specimen was displayed in Table 1.

Table 1: Notation of specimen types

Specimen Types	Notation
Timber beam only (Control Beam)	TB
Timber beam with passive prestressed rods at its neutral axis	TBN
Timber beam with passive prestressed rods at its compression side	TBC
Timber beam with passive prestressed rods at its tension side	TBT
Timber beam with passive prestressed rods at both tension and compression side	TBTC

2.1 Detailing of Specimens

In the research, passive prestressing technique was utilized to strengthen the timber beams. It was applied through external installation of threaded rods and connecting rods to timber beam by using particular steel elements. These steel elements ensure the anchorage of rods and increase prestressing actions through eccentricity [10]. The anchorages were used to avoid premature debonding mechanisms and to allow for further loading on timber beams. The presence of threaded rods assured a small reserve in load capacity and allowed for certain additional loading of timber beams [11]. The details of timber specimens are illustrated in Figure 1. The clear spacing between the holes is 20mm, which is larger than the minimum clear spacing requirement (8 mm diameter of the holes) for externally prestressing tendons in accordance with [12]. The threaded rods were installed at both sides of timber specimen by screwing them together with end plates. The 10mm thick steel plates were used to ensure the anchorage of the strips and to increase the prestressing actions through an eccentricity.

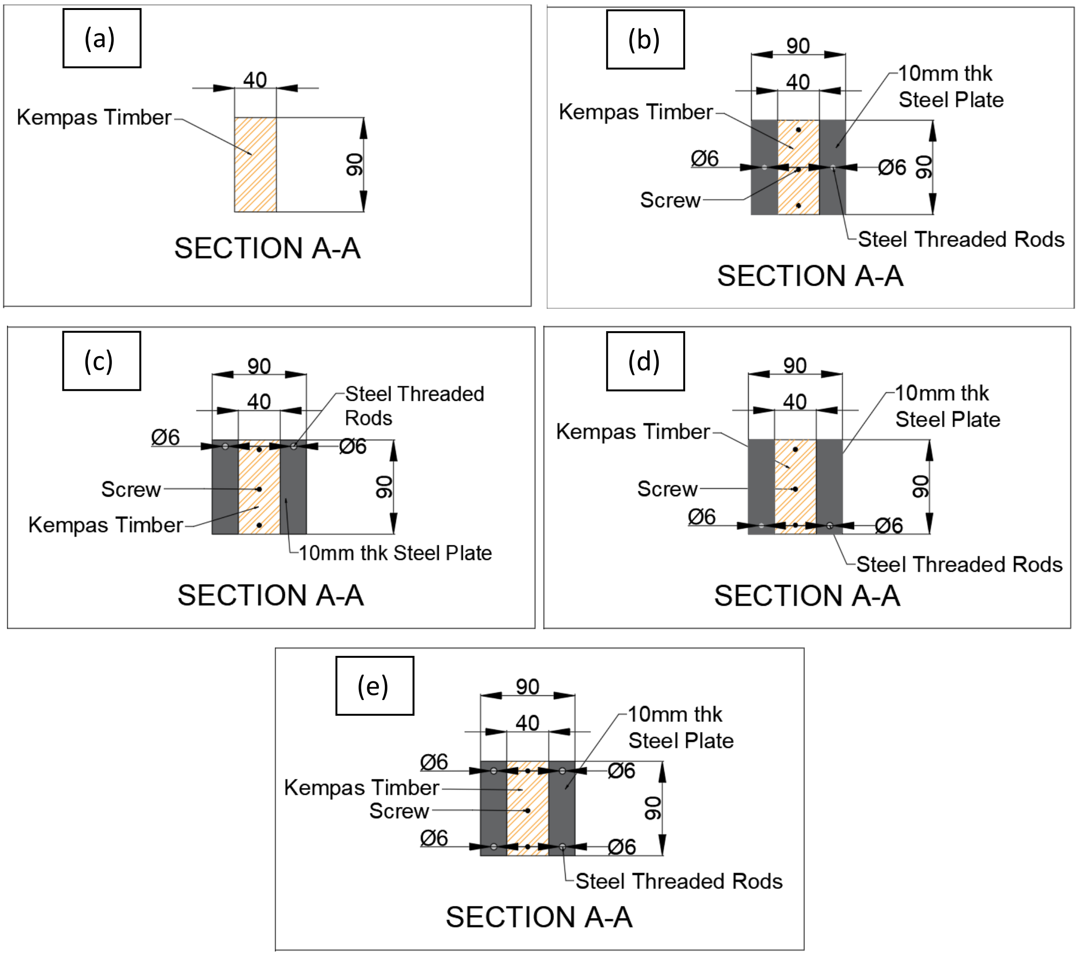

Figure 1: The details of timber specimens: (a) TB (b) TBN (c) TBC (d) TBT (e) TBTC (in mm)

2.2 Specimen Testing

Several tests were performed on the materials used. Each timber specimen was tested under oven-dry test and four-point bending test, whilst the tensile strength test was conducted on 6mm diameter steel threaded rods.

The threaded rods were tested by Universal Testing Machine (UTM) to ensure the efficiency of prestressing. The mechanical properties of threaded rods were determined by plotting stress-strain diagrams to provide detailed information on properties. The oven-dry test was performed on timber specimens (TB, TBN, TBT, TBC and TBTC) to determine their moisture content, while the timber beams were tested under four-point loading to identify the load-deflection curves in accordance to BS EN 408:2010.

The load was applied to timber at 283mm intervals. The rate of loading was set to 5.0mm/min and maintained until failure. The schematic diagram of four-point flexural test set-up on timber specimens has been provided in Figure 2. The support length was 25 mm from each beam end and the concentrated loads were positioned at 283mm intervals on beams. The mid-span deflection of beam was measured from the bottom of timber specimen with LVDT, while the longitudinal slip of beam was measured by the dial gauge mounted at the beam ends. The four-point loading test arrangement was used to provide the flexural stress-strain response of the timber specimens.

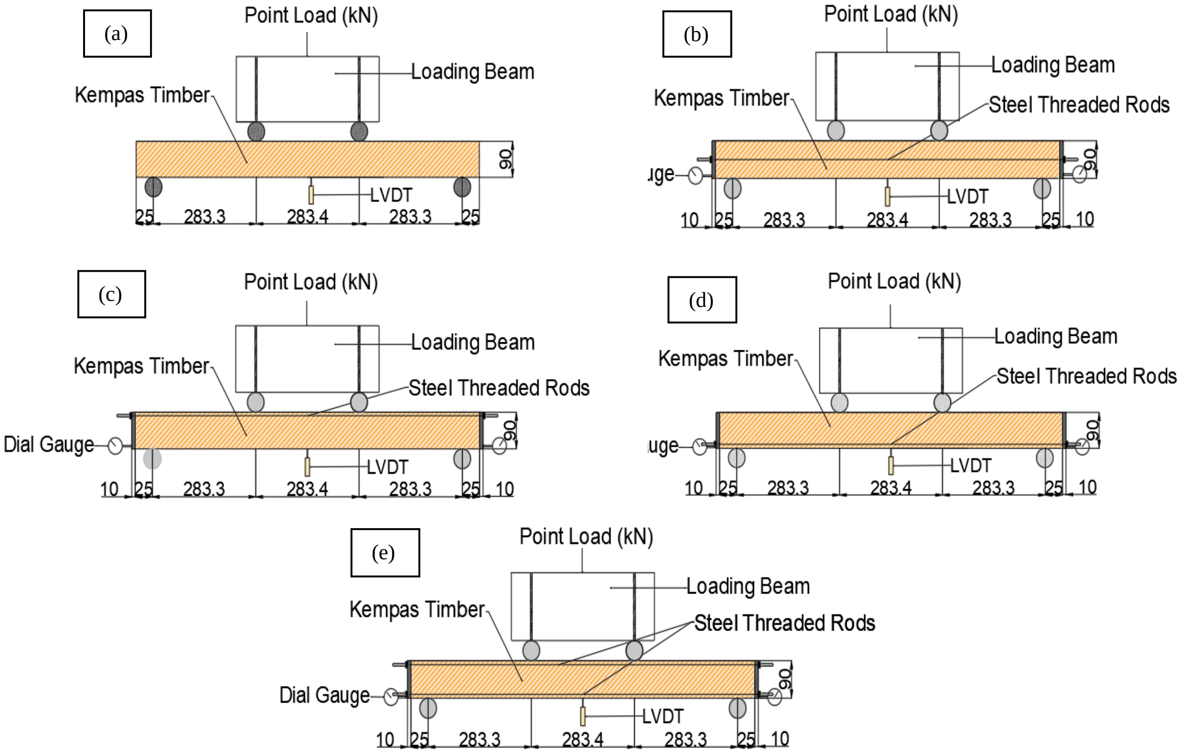

Figure 2: Schematic diagram of the four-point flexural test set-up on timber specimens: (a) TB (b) TBN (c) TBC (d) TBT (e) TBTC (in mm)

3. Result and Discussion

3.1 Preliminary result

The preliminary results explicated the values of material properties obtained from oven-dry method and tensile strength test. The distributional characteristics of timber strength and stiffness were influenced by the biological composition of timber population. Hence, the change in initial and final timber density values must be determined when considering different samples. The average density range of timber specimens was 769.4kg/m^3 to 788.9kg/m^3. The timber specimens were in dry condition, as their moisture content values were lower than 19%. Besides, the average tensile strength of 6mm diameter steel threaded rods was 751.5N/mm^2, which means that the tendons had sufficient strength to strengthen the timber.

3.2 Experimental result

The implication of different prestressed positions applied on timber specimens and their enhancement values of flexural strength and moment capacity were attained through four-point bending test.

3.2.1 Failure observations

The timber specimens were mostly cracked in tension zone. The flexural cracks appeared at the bottom of beams and subsequently propagated toward their top surfaces with increased loads. The failure mode of timber specimens was depicted in Figure 3.

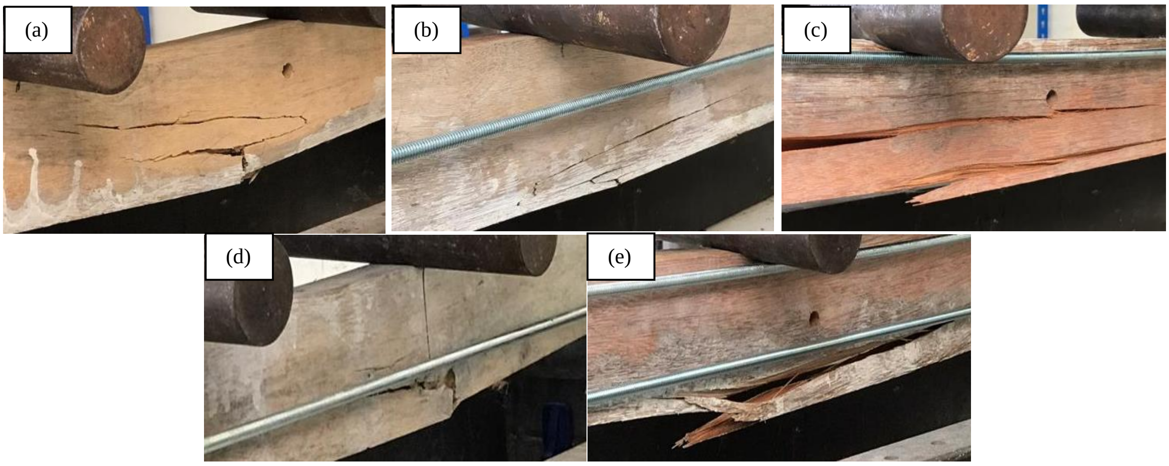

Figure 3: Failure mode of timber specimens: (a) TB (b) TBN (c) TBC (d)TBT (e)TBTC

3.2.2 Load-deflection curves

The load-deflection curves of timber specimens were manifested in Figure 4. There were several points marked on the load-deflection curves to explain the experimental behavior of specimens under the four-point bending test. Those explanations can be obtained from Table 2.

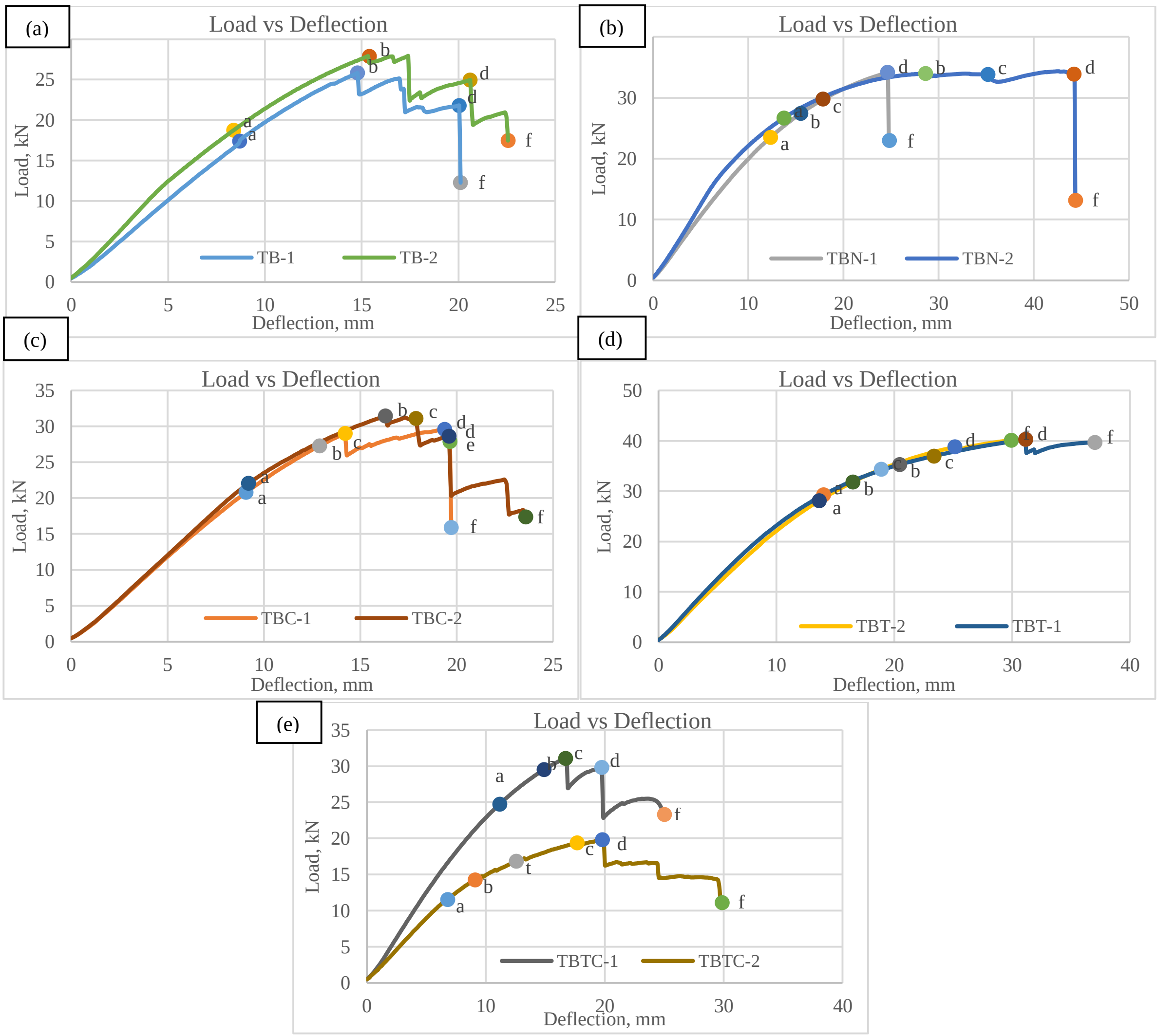

Figure 4: Load-deflection curves of timber specimens: (a) TB (b) TBN (c) TBC (d)TBT (e)TBTC

Table 2: Experimental behavior of specimens under the four-point bending test

Point	Experimental behavior of specimens under four-point bending test
a	Slight hair cracks appeared at bottom of specimens.
b	Cracks enlarged and propagated to load points.
c	Longitudinal slip reached 10mm.
d	Loud 'bang' sound was heard and 'peeling' of timber occurred.
e	Shear longitudinal failure of anchorage and timber ends
f	Final failure of timber
t	Twisting effect (torsion) existed on timber beam.

3.3 Comparison of flexural strength and moment capacity among timber specimens

Table 3 displayed a comparison of average results among timber specimens. Since TBTC-2 was controlled by torsional failure, the findings of TBTC-1 specimen were selected for comparison. The incremental ratio was calculated to validate the enhancement of flexural strength, F_{ult} and moment capacity, M_{exp} of each specimen.

The TBT specimen had the highest incremental ratio (1.5) and the enhanced effect on the mechanical properties of timber was evidently reflected by reducing the flexural stress acting on tensile side of beam. It was followed by TBN specimen (1.3) with a higher incremental ratio than TBC (1.1) and TBTC specimens (1.2).

Through passive prestressing, it had a significant improvement in timber properties compared to the control beam in all prestressing schemes due to the participation of threaded rods in transferring loads. In terms of properties enhancement, the specimens arranged in descending order were TBT, TBN, TBTC, TBC and TB.

Table 3: Comparison of average results among timber specimens

Timber Specimen	F_{ult} (kN)	M_{exp} (kNm)	$\sigma_{m,ult}$ (Mpa)	Δ_{max} (mm)	Incremental Ratio
TB	26.9	3.8	70.4	16.0	1
TBN	34.3	4.9	89.8	34.0	1.3
TBC	30.6	4.3	80.1	17.5	1.1
TBT	40.2	5.7	105.5	30.5	1.5
TBTC	31.1	4.4	81.6	17.0	1.2

3.4 Comparison of timber stiffness among timber specimens

The timber stiffness at serviceability limit state, $K_{0.4Fu}$ was determined from 40% of the observed maximum load, whereas timber stiffness at ultimate limit state, $K_{0.6Fu}$ and at near collapse limit state, $K_{0.8Fu}$ were obtained from 60% and 80% of the observed maximum load [13].

Table 4 demonstrated the results of timber stiffness. It can be noted that all specimens indicated a decrease in stiffness before reaching the failure point. The values of $K_{0.4Fu}$ was higher than that of $K_{0.6Fu}$. When reaching the near collapse limit state, $K_{0.8Fu}$ indicated the lowest stiffness value. The stiffness ratio was calculated to validate the stiffness enhancement of each specimen, and the specimens arranged in ascending order were TBC, TBT, TBTC, TB and TBN. The TBC specimen had the lowest stiffness ratio with a value of 1.07, followed by TBT specimen (1.13). The lower stiffness ratio implied that there was a subtle difference between the stiffness $K_{0.6Fu}$ or $K_{0.8Fu}$, and the stiffness $K_{0.4Fu}$. Thus, the specimens with lower stiffness ratio can withstand a higher load at lower deflection value.

It can be summarized that the timber stiffness of all prestressed sample configurations had been improved, with the exception of TBN specimen. The increase in bending stiffness promoted the redistribution of the load and subsequently reduced the deflection of timber.

Table 4: Results of timber stiffness at serviceability, ultimate and near collapse limit state

Timber Specimen	**Beam Stiffness (kN/mm)**			**Stiffness ratio**	
	Avg. $K_{0.4Fu}$	**Avg. $K_{0.6Fu}$**	**Avg. $K_{0.8Fu}$**	$\frac{K_{0.4Fu}}{K_{0.6Fu}}$	$\frac{K_{0.4Fu}}{K_{0.8Fu}}$
TB	2.19	1.82	1.46	1.20	1.50
TBN	2.21	1.69	1.17	1.31	1.89
TBC	2.44	2.27	1.70	1.07	1.44
TBT	2.24	1.98	1.51	1.13	1.48
TBTC	2.43	2.06	1.63	1.18	1.49

3.5 Comparison between theoretical and experimental results

There were several factors that caused the difference between theoretical and experimental results, which must be considered in reliable assessment. Firstly, it was affected by high variations in timber properties due to small number of specimens used in experiment (two samples for each configuration). The distributional characteristics of flexural strength and stiffness can be influenced by the biological composition of Kempas timber [14]. Thelandersson explained that the coefficient of variation for flexural strength of timber beam was in the range of 20-40%, depending on the species [15]. The smaller sample sizes tend to have larger variations, reduce accuracy when evaluating parameters and subsequently affect the experimental results.

In addition, the experimental results were also dependent upon the condition of recycled timber, and the level of workmanship. For instance, the shear failure of anchorage of TBC-1 specimen can be partially attributed to poor condition of recycled timber used. The torsional failure of TBTC-2 specimen due to uneven load distribution and specimen skewness, was partly triggered by poor workmanship and timber condition.

Lastly, in accordance with Kliger's previous research, strengthening both tension and compression side of timber exhibited the greatest enhancement of strength and stiffness [16]. It was different from the current study, in which the strength and stiffness of TBTC specimens were lower than those of TBT and TBC specimens. The different results were caused to several reasons, such as sample size and prestressing method. For instance, the dimension of specimen used by Kliger was 115mm×200mm×4000mm, whilst the timber used in this study was much smaller, with a value of 40mm×90mm×900 mm. For prestressing method, Klifger used glulam beams strengthened with bonded steel plates or CFRP-laminates, whereas the externally passive prestressed rods were used for strengthening Kempas timber in current research.

4. Conclusion

In spite of limited number of specimens used, it can be concluded that passive prestressing method effectively improved the structural performance of Kempas timber beams. Compared with non-prestressed beams, it enhanced the serviceability features of the prestressed timber beams.

In accordance with experimental investigation, all prestressing schemes caused an increase of flexural load-carrying capacity of specimens. The flexural strength and moment capacity of TBT specimens were the highest among the specimens, with average values of 105.5Mpa and 5.7kNm. The passive prestressed rods at tensile side of specimen significantly improved the mechanical properties of specimen, as timber was weak in tension when it was subjected to flexural loads. Thus, TBT specimen could be the best choice for construction due to the greatest enhancement of structural performance of

Kempas timber. In terms of timber stiffness, it has been improved in all prestressed sample configurations, with the exception of TBN specimens.

To summarize, passive prestressing technique improved the overall behavior of timber beams, thereby increasing the bending strength and moment capacity, as well as reducing the deflection of Kempas timber. Nonetheless, the increased amount of reinforcement did not necessarily enhance the timber strength due to the counteraction between top and bottom reinforcements. The different arrangements of prestressed rods can be used to control the strength, stiffness and moment capacity of timber specimens. Future research should increase number of specimens to minimize variation in timber specimen properties. The dimension of specimens should also be increased to emphasize the differences between each specimen due to the larger eccentricity.

Acknowledgement

Author would like to express sincere gratitude and appreciation to all parties who have contributed to this research.

References

[1] Wong.T.M., “Ensuring Quality Assurance in Timber Applications,” *Master Build. J.*, vol. 1, pp. 84–87, 2008.

[2] M. Z. Jumaat, A. H. A. Rahim, J. Othman, and F. M. Razali, “Timber Engineering Research and Education in Malaysia,” *9th World Conf. Timber Eng. 2006, WCTE 2006*, vol. 3, no. May 2014, pp. 2494–2497, 2006.

[3] M. Ali, M. Al-Bared, T. Anita, and M. Al Bared, “Structural Performances of Kempas Subjected to Bending,” in *International Conference of Engineering, Information Technology, and Science, 2014 (ICEITS 2014)*, 2014, no. August, pp. 4–5.

[4] MS 544:Part 2:2001, *Code of Practice for the Structural Use of Timber: Permissible Stress Design of Solid Timber*. Selangor, Malaysia, 2001.

[5] M. H. Ramage *et al.*, “The Wood from The Trees: The Use of Timber in Construction,” *Renew. Sustain. Energy Rev.*, vol. 68, no. September 2016, pp. 333–359, 2017, doi: 10.1016/j.rser.2016.09.107.

[6] J. H. Negrao, “Prestressing Systems For Timber Beams,” *World Conf. Timber Eng.*, vol. 2, no. July, pp. 1–10, 2012.

[7] A. R. Balseiro and J. M. Faria, “Use of Active and Passive GFRP Reinforcement for The Strengthening and Rehabilitation of Timber Beams,” in *Enhancing Bonline Performance - Final Conference on Bonding of Timber. Sopron, Hungary*, 2008, no. May 2014.

[8] B. Shi, W. Zhu, H. Yang, W. Liu, H. Tao, and Z. Ling, “Experimental and Theoretical Investigation of Prefabricated Timber-Concrete Composite Beams with and without Prestress,” *Eng. Struct.*, vol. 204, p. 109901, 2020, doi: 10.1016/j.engstruct.2019.109901.

[9] Jegatheswaran Ratnasingam, “Wood Use in Building Construction: The Malaysian Dimension,” *Asian Woodwork.*, vol. 14, no. 3, pp. 18–23, 2016.

[10] L. C. C. De Lima, A. A. Costa, C. F. Rodrigues, L. C. C. De Lima, A. A. Costa, and C. F. R. On, “On the Use of Prestress for Structural Strengthening of Timber Beams: Assessment with Numerical Support and Experimental Validation,” *Int. J. Archit. Herit.*, vol. 00, no. 00, pp. 1–16, 2018, doi: 10.1080/15583058.2018.1442526.

[11] A. Ajdukiewicz and M. Kałuża, “Comparison of Behaviour of Concrete Beams with Passive and Active Strengthening by Means of CFRP Strips,” *Archit. Civ. Eng. Environ.*, vol. 1, no. 2, pp. 51–64, 2008.

[12] *Eurocode 2: Design of Concrete Structures - Part 1-1 : General Rules and Rules for Buildings*, vol. 1, no. 2005. 2011.

[13] F. Moshiri, "Structural Behaviour of Timber Concrete Composite Connections and Floors Utilising Screw Connectors," no. December, 2014.

[14] P. Castera and P. Morlier, "Variability of the Mechanical Properties of Wood: Randomness and Determinism," pp. 109–118, 1994.

[15] S. Thelandersson and D. Honfi, "Behaviour and Modelling of Timber Structures with Reference to Robustness," *Jt. Work. COST Actions TU0601 E55*, pp. 125–138, 2009.

[16] R. Kliger, M. Al-Emrani, M. Johansson, and R. Crocetti, "Strengthening Timber with CFRP or Steel Plates - Short and Long-Term Performance," in *10th World Conference on Timber Engineering 2008*, 2008, vol. 1, pp. 414–421.