

Fibre composite sandwich beam:

An alternative to railway turnout sleeper?

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Abstract—The widespread deterioration of timber sleepers combined with an intensified pressure on limiting the use of hardwood timber because of various environmental concerns are the main drivers of research conducted throughout the world directed towards finding a suitable alternative for replacing timber sleepers. While many railway infrastructure companies have long been trialing pre-stressed concrete and steel for replacing timber sleepers, this has gained limited success as these materials have not proven reliable alternatives to timber turnout sleepers. Research and development has now been focused on fibre composites as this material can be made to have similar usability and design characteristics to hardwood timber with the added advantages. However, several challenges need to be overcome for fibre composite sleepers to become a suitable alternative to timber sleepers. This paper provides an overview of the various initiatives at the Centre of Excellence in Engineered Fibre Composites which aims to further the understanding of the design and performance issues associated with the eventual application of this new technology. Results of the on-going research and development on sleeper material made from a new generation fibre composite sandwich structure for replacement sleepers in a railway turnout are highlighted in this paper.

Keywords-railway sleepers; fibre composite; sandwich beam; timber sleepers; turnout.

I. INTRODUCTION

Railway sleepers are one of the most important elements of the railway track system. They are the beams laid underneath the rails to support the track [1]. Their function is to transfer and distribute the rail loads to the ballast, transversely secure the rails to maintain the correct gauge-width and to resist the cutting and abrading actions of the bearing plates and the ballast material. Sleepers also resist the lateral and the longitudinal movement of the rail system. The main components of a rail track system are illustrated in Fig. 1.

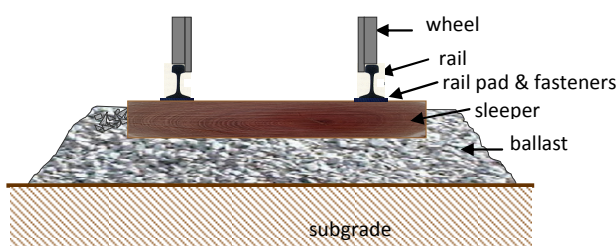


Figure 1. Components of a railway track system

Hardwood timber has been the preferred material for railway sleepers and maintenance work on existing timber sleepers continued to be provided by hardwoods. Currently, there are more than 2.5 billion timber sleepers installed in railway tracks throughout the world [2]. Within Australia, the state of Queensland alone has 8 million timber sleepers in service [3]. Most of these railway sleepers are deteriorating and becoming less capable of meeting performance requirements. In order to maintain the track quality to a specified service level and ensure a safe track operation, damaged and deteriorated sleepers are being replaced with new ones. The Australian railway lines require in excess of 1.5 million timber sleepers per year for railway maintenance while the railway industry in the US replaces two percent of its 700 million timber sleepers per year [4]. Over the last decade, it has been increasingly difficult to get good quality hardwood in quantities to keep up with the demand for railway maintenance. This trend is set to continue and will become critical within the foreseeable future, hence the need to develop a sleeper product made from renewable resources.

The problem of supply of quality hardwood for railway sleeper application is greater in specific locations of the railway track such as turnouts where stronger, bigger and longer timber is required. A railway turnout is the mechanical installation that enables trains to be guided from one track to another [5]. A turnout consists of individual sleepers with varying lengths and fastening locations which make their maintenance more costly. While many railway infrastructure companies have long been trialing pre-stressed concrete and steel for replacing timber sleepers in existing railway tracks, this maintenance practice has gained limited success as these materials have not proven reliable alternatives to timber turnout sleepers. Concrete and steel sleepers have mechanical properties incompatible with the existing timber sleepers. Research and development has now focused on fibre composites as this material can be made to have similar usability and design characteristics to hardwood timber with the added advantages. More recently, a research project is being carried out by the Centre of Excellence in Engineered Fibre Composites (CEEFC) at the University of Southern Queensland Toowoomba in collaboration with Austrak Pty Ltd to develop an optimised railway sleeper made up of a fibre composite sandwich structure for turnout sleeper application. This paper presents the results of the initial stages of this research project and the design and performance issues associated with the use of fibre composites in the development of an alternative sleeper material.

II. THE NEED FOR ALTERNATIVES

Hardwood timber sleepers have a long history of effective and reliable performance in the railway environment [6]. The major advantage of timber sleepers is their adaptability. They can be fitted with all types of railway track. Timber sleepers are workable, easy to handle, easy to replace and needs no complicated assembly equipment [2]. Thus, local problem sites can be repaired or replaced without the need for outside support in the form of either manpower or equipment. This is particularly attractive in high speed or high density lines where track time is both limited and constrained by the ability to bring in large scale production gangs.

The main disadvantage in using timber for sleepers is their susceptibility to mechanical and biological degradation leading to failure [7]. In Queensland, fungal decay is the most predominant form of timber sleeper failure [8]. Splitting of timber at the ends is also common as railway sleepers support very large transverse shear loadings. Most common failure modes in timber sleepers are shown in Fig. 2. However, the most difficult problem that the railway industry is now facing is the declining availability of quality timber for railway sleepers. Another growing concern is the environmental and health impact of the use of chemical preservatives to timber sleepers. The railway industry has historically almost exclusively used creosote impregnated timber sleepers.

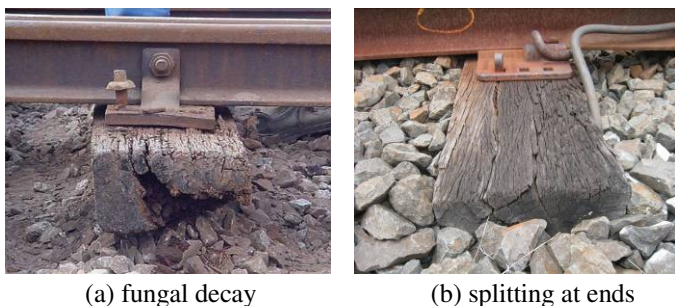


Figure 2. Common types of sleeper failure

Many railway infrastructure companies have long been trialing concrete and steel for replacing timber sleepers in existing railway tracks. However, this maintenance strategy has gained limited success. These materials did not prove to be a viable alternative to timber sleepers. Gruber [9] stated that over 90% of maintenance and construction of railway tracks still utilised timber sleepers despite the increasing reliability and effectiveness of alternatives such as steel and concrete. It is often more financially viable or convenient in the short term to replace sleepers with new timber sleeper [10]. As much as they want to eliminate the use of timber sleepers, Queensland Rail (QR) in Australia is still purchasing more than 80,000 timber sleepers including 5,000 sleepers for railway turnouts per year for track maintenance and development as there is still no viable alternative for timber sleepers [3].

Concrete sleepers have the ability to provide better line and gauge-holding characteristics than timber sleepers, but they are relatively expensive, quite heavy and are often incapable of providing a projected 50-year service life [11]. Sleepers made of steel, on the other hand, can offer superior strength over that of wood and concrete, but steel sleepers are being used in moderate quantities because of their high cost [7]. Frequent replacement and tightening of fastenings are also required. Similarly, replacement of timber sleepers with concrete or steel sleepers will be both difficult and costly. Concrete and steel

sleepers have mechanical properties incompatible with the existing timber sleepers. The higher structural stiffness of the concrete means a higher load is transferred to the concrete sleepers which could lead to greater deterioration due to flexural cracks. Similarly, steel sleepers should not be mixed with timber sleepers because of the differential settlement. The shape and size of steel sleepers result in a tendency to settle more quickly than timber sleepers. This problem can only be overcome by completely replacing timber sleepers in a rail track with concrete or steel sleepers but this practice is more expensive. Another concern is that manufacturing concrete and steel sleepers requires considerably more energy and is one of the largest producers of atmospheric carbon. The Australian Greenhouse Office [12] reported that the carbon dioxide emissions during the production of concrete and steel are 10 and 200 times higher than that of timber, respectively.

It is evident that timber has been the material of choice for railway sleepers, especially for the replacement of damaged and deteriorated timber sleepers. However, the main problem with timber sleepers is their tendency to rot, particularly near the points where they are fastened to the rails. Timber needs to be treated with preservatives; some of which are toxic chemicals [6] that are of concern for various environmental protection authorities. Similarly, replacement timber sleepers are now being cut from less desirable species due to the declining availability of quality hardwoods. Some of these species have poor resistance to decay and are more susceptible to mechanical degradation [7]. These problems have resulted in more premature failures and higher replacement rates of timber sleepers. Furthermore, the current supply of quality hardwood could not meet the significant demand of existing timber sleepers that require replacement. An alternative material for sleeper replacement to reduce maintenance cost and overcome problems encountered using timber sleepers is therefore both desirable and necessary.

III. FIBRE COMPOSITE RAILWAY SLEEPERS

Recent developments in fibre composites now suggest their use as an alternative material for railway sleepers. In Japan, synthetic sleepers made of hard polyethylene foam and glass fibre are a unique development [13]. These sleepers are designed for long service life (more than 60 years) while maintaining the physical properties of timber sleepers. Also these sleepers are used in railway sections where maintenance or replacement is difficult. Railway sleepers manufactured from recycled plastic bottles with glass fibre reinforcements have been introduced in the US over the past ten years [4]. These sleepers possess physical and mechanical properties that are comparable to those of timber sleepers. The performance of these sleepers in the field is now being investigated. The Indian railways adopted these materials for use in bridge sleepers while composite polymer sleepers are being used in the mining industry in South Africa to support underground railway lines [14]. Another is the recycled plastic sleeper developed by the Transport Research Laboratory in the United Kingdom [15]. This sleeper exhibited similar stiffness to softwood sleepers but has greater strength. It also showed better resistance to the removal of the screw spikes. In Germany, an on-going study is being conducted by Woidasky [16] to develop railway sleepers from mixed plastics wastes (MPW) along with glass fibre wastes. The MPW sleeper is expected to meet the mechanical requirements for sleepers and expected to show superior weather resistance than timber sleepers. However, these composite products have gained limited acceptance by railway

industry due to their prohibitive cost. Another reason is the lack of long term performance testing such as fatigue, impact and durability.

The CEEFC in collaboration with different railway industries in Australia has been involved in a number of research and development projects involving innovative fibre composite railway sleepers to replace deteriorated hardwood sleepers in existing rail lines. One of the earliest technologies developed by CEEFC is a composite railway sleeper made of polymer concrete and glass fibre reinforcement (Fig. 3) that can be used as replacement for timber, steel and concrete sleepers in existing or new railway tracks [17]. A trial section of track was manufactured, trial tested and found to perform under actual service conditions. However, this composite sleeper has not entered the market to date as its cost is not competitive with that of the existing sleeper materials. Another development is the fibre composite (FC) railway transom (Fig. 4) which is now being trialed on an actual railway bridge in Australia [18]. The FC railway transom is made up of a new type of fibre composite sandwich panel with additional fibre reinforcements. An extensive research and testing program has shown that this special sleeper for railway bridges behaved similarly, or even better than the hardwood transoms. The first FC transoms were installed by the Australian Rail Track Corporation on a steel railway bridge located on a heavy and busy haulage line in November 2007 with monitoring done by Austrak Pty Ltd. The trial installation verified that the FC transoms are performing to expectations and estimated that its serviceable life should be well in excess of 50 years.

In its continuous effort on providing innovative solutions to the problems of the railway industry, a research project is being implemented by the CEEFC to develop an optimized fibre composite railway sleeper for turnout application. Ticoalu [19] began the investigation on the development of fibre composite turnout sleepers. In her work, laminated veneer lumber (LVL) with carbon fibre laminates on top and bottom, wrapped with triaxial glass fibres (Fig. 5) were prepared and tested. Although the results suggested that the concept is feasible for replacement railway turnout sleepers, the use of LVL has some maintenance issues as timber is not eliminated. Timber is a biodegradable material and requires continued maintenance. While wrapping the LVL with fibre composites provided structural enhancement and environmental protection, the drilling of holes for spike-screws enables moisture and surface water to penetrate and can cause degradation of the LVL. Development of a replacement sleeper made only from fibre composite materials which require low maintenance cost is promising.



Figure 3. Sleeper made of polymer concrete and fibre composites



Figure 4. Sleeper made of polymer concrete and fibre composites



Figure 5. Sleepers made of LVL wrapped with triaxial glass fibres

IV. R&D ON COMPOSITE SANDWICH SLEEPERS

Recent developments in the railway industry have focused on the use of fibre composite materials for railway sleepers. An on-going study to determine the suitability of an innovative sleeper concept using glue-laminated fibre composite sandwich panel for turnout application is discussed in this section.

A. Mechanical properties of timber turnout sleeper

It is desirable that the fibre composite turnout sleepers be produced to have similar modulus of elasticity to that of the existing timber turnout sleepers. Ticoalu [19] conducted an experimental study to evaluate the strength and stiffness properties of the existing timber turnout sleepers used in Australian railways to establish the design criteria for the development of fibre composite railway turnout sleepers. This is important since bending stiffness is one of the major issues in the design of fibre composite structures. Fig. 6 shows the bending test set-up for timber turnout beams.

The results of the test show that the bending strength of timber turnout sleepers vary between 64 and 160 MPa with the modulus of elasticity ranges from 7 to 26 GPa. The large variation in bending strength and stiffness of the existing timber turnout sleepers suggests that it is very difficult to maintain a similarity in the mechanical properties of timber sleepers in a railway turnout. From the test results, it is also difficult to conclude a desirable strength and modulus of elasticity for an alternative fibre composite turnout sleeper. However, the results indicate that the existing timber turnout sleepers in the Australian railways have an elastic modulus of

as low as 7 GPa. This information is beneficial as producing fibre composite turnout sleepers with high modulus of elasticity might be expensive. In the next section, the behaviour of sleepers with a lower range of elastic modulus in a turnout system was examined to ascertain an optimal elastic modulus for fibre composite sleeper alternatives.



Figure 6. Testing of timber turnout sleepers

B. Behaviour of sleepers in a railway turnout

A numerical model was developed to investigate the behaviour of sleepers in a turnout system. In this model, the maximum forces and the bending moments carried by the most critical sleeper in a railway turnout is determined. Similarly, an optimum elastic modulus of sleeper that satisfies the allowable vertical deflection and ballast/sleeper pressure is established.

a) *Turnout geometry:* Standard 1 in 16 right-hand turnout geometry using 60 kg/m rail and a narrow gauge (1067 mm) rail line commonly used in Queensland, Australia is considered. Sleeper dimensions were set at 230 mm x 150 mm in consideration for replacing deteriorating timber sleepers. Other design parameters for the turnout structure were determined from Jeffs and Tew [20] and AS1085.14 [21], and suggested by the industry partner. Table I details the components of the track structure used in the FE model.

TABLE I. COMPONENTS OF THE TURNOUT TRACK STRUCTURE

Component	Description
Rail section	60 kg/m
Rail gage	1067 mm
Distance between rail centres	1137 mm
Sleeper spacing	610 mm
Axle load	25 tons
Combined vertical load factor (j)	2.5
Sleeper support modulus, U_s	10 – 40 MPa
Allowable sleeper-ballast pressure	750 kPa
Modulus of elasticity of rails	200 GPa

b) *FEM model of a turnout system:* A simplified three dimensional grillage model consisting of longitudinal and transverse beam elements was developed using Strand7 finite element program to analyse the behaviour of sleepers in a 1:16 railway turnout structure (Fig. 7). A total of 1339 Beam2

elements representing the rails, sleeper plates and sleepers were used in the FEM model of the railway turnout. Only the equivalent quasi-static wheel load, R acting on the vertical direction is considered. This wheel load was moved along the turnout to simulate the passing of a train and to identify the location of the most critical sleeper in the turnout. This is also to determine the magnitude of the maximum bending moments, shear forces, vertical deflection and the ballast/sleeper pressure. The support provided by the ballast and subgrade is modelled as an elastic foundation with a combined effective sleeper support modulus which supports the sleepers continuously along its length. Typical values of support modulus for timber sleepers of 10 to 40 MPa with increments of 10 MPa are considered in the analysis. The behaviour of turnout sleepers with an elastic modulus of 1 to 10 GPa on the different support modulus was also determined.

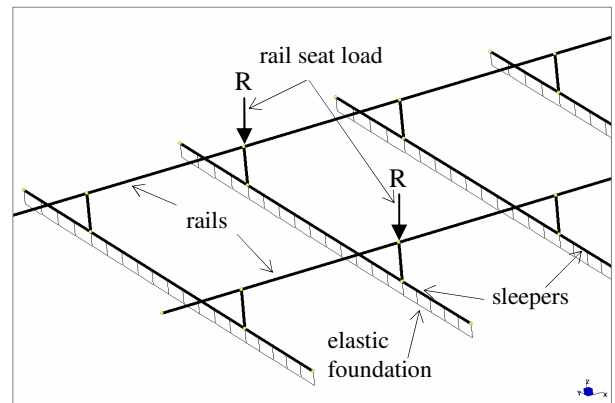


Figure 7. Grillage beam model for railway turnout

c) *FEM results:* The results of the FEM analyses provided a basis for an optimum design of fibre composite turnout sleepers. The result suggest that there is no significant difference in the bending moments and shear forces for turnout sleepers with elastic modulus of 4 to 10 GPa. On the basis of the simulations performed, the fibre composite turnout sleeper should be designed to carry minimum positive and negative bending moments of 19 kN-m and 11 kN-m, respectively and a shear force of 158 kN.

Fig. 8 shows the maximum vertical deflection and ballast/sleeper pressure of turnout sleepers with different elastic moduli and subgrade moduli. The results indicated that except for a support modulus of 10 MPa and sleepers with modulus of elasticity of lower than 4 GPa for a support modulus of 20 MPa, the calculated vertical deflection in all the combinations used is within the recommended value. For railway track in Australia, the maximum static deflection in a railway structure on ballasted track should be around 6.35 mm to give requisite combination for flexibility and stiffness [20]. This result further suggests that a fibre composite turnout sleeper at 610 mm spacing and 60 kg/m rail should be supported by a foundation with a support modulus of at least 20 MPa. Furthermore, the recommended maximum allowable contact pressure between the timber sleeper and the ballast of 750 kPa can only be satisfied using a turnout sleeper with an elastic modulus of at least 4 GPa (Fig. 9). This elastic modulus value can easily be achieved using fibre composite materials. The following section describes the extensive experimental investigation to evaluate the suitability of a glue-laminated sandwich structure in the development of fibre composite turnout sleepers.

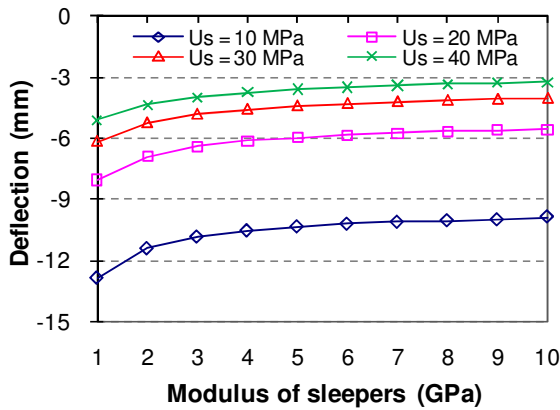


Figure 8. Vertical deflection of turnout sleepers

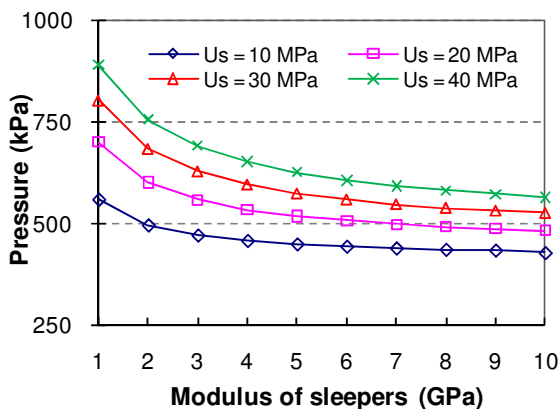


Figure 9. Sleeper/ballast pressure

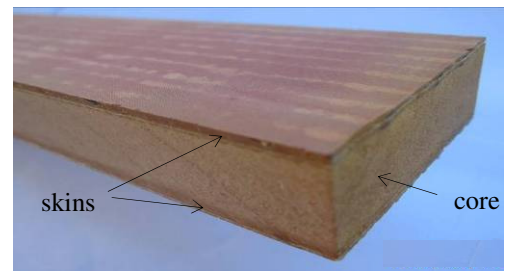


Figure 10. The structural fibre composite sandwich panel

Strength and stiffness of sandwich beams: Figs. 11 to 13 show the apparent bending modulus, bending strength, and shear strength of the glue-laminated sandwich beams for the different number of laminations, respectively. As can be seen in Fig. 11, the bending modulus of the sandwich beams in the flatwise and edgewise positions converges with increasing laminations. The elastic modulus of the glue-laminated sandwich beams in both flatwise and edgewise positions is at least 4 GPa. The results of the experimental investigation also show that gluing the composite sandwich beams together in the edgewise position resulted in an increase of at least 25% in bending strength. Fig. 12 shows that the glulam sandwich beams tested in the edgewise position failed at an average bending strength of 74.2 MPa while in the flatwise position at around 60.4 MPa. Fig. 13 indicates that the orientation of testing has a significant effect on the shear strength of the sandwich beams. In the edgewise position, increasing the number of laminations resulted in an increasing shear strength, whereas in the flatwise position, the shear strength is almost constant for all sandwich laminations. On the average, the shear strength of glulam beams in the edgewise position is around 11.7 MPa and 6.1 MPa in the flatwise position.

C. Mechanical properties of composite sandwich beam

A comprehensive testing program to determine the feasibility of using a structural fibre composite sandwich panel in the development of fibre composite turnout sleeper was conducted. In most sandwich construction, the brittle nature of the core causes a sudden collapse and could be a limiting factor in designing such structure. This study aims to improve the structural performance of a composite sandwich structure without any material modification but only by orienting the fibre composite skins to carry the shear that is usually carried by the core material. Thus, the behavior of glue-laminated sandwich beams in the flatwise and the edgewise positions were evaluated to determine the most effective use of this material for railway turnout sleeper. The results of the characterization of the strength and stiffness this sandwich structure is discussed here.

a) Materials and testing: The structural composite sandwich panel is made up of glass fibre composite skins and phenolic foam core material produced by LOC Composites Pty Ltd., Australia [22]. Fig. 10 shows the structural panels used in the development of the composite sandwich beams. A number of these composite sandwich panels were assembled and glued together to produce the glue-laminated sandwich beams. The mechanical behaviour of these sandwich beams in the flatwise and in the edgewise positions were evaluated under 4-point static bending and asymmetrical beam shear tests.

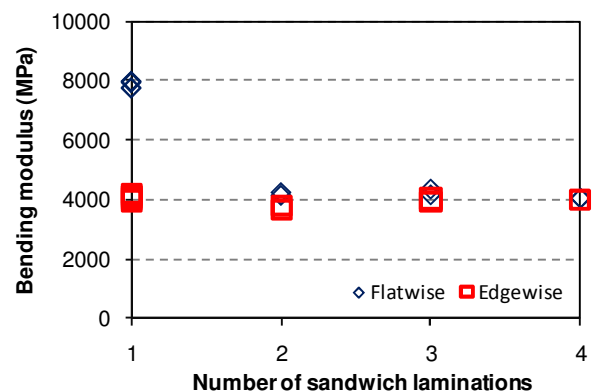


Figure 11. Apparent bending modulus of glulam sandwich beams

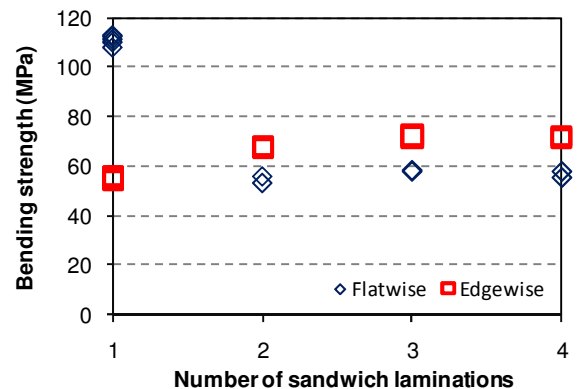


Figure 12. Bending strength of glulam sandwich beams

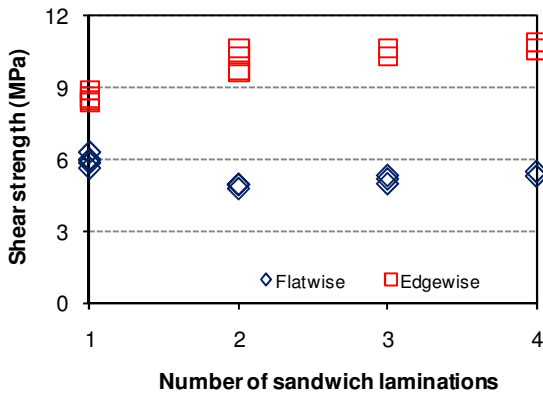


Figure 13. Shear strength of glulam sandwich beams

b) *Comparison with structural timber:* The strength and stiffness properties of the glue-laminated beam were compared to the design properties of the structural timber listed in Australian Standards AS 1720.1 [23]. Comparison showed that the strength properties of glue-laminated sandwich beams in the flatwise position is similar or higher than that of the stress-grade F17 structural timber while the strength properties of the sandwich beam in the edgewise position is comparable to that of the stress-grade F22 structural timber. The elastic modulus of both the sandwich beam concepts is only 70% of the lowest stress grade or F4 structural timber. However, this elastic modulus value satisfies the minimum requirement for railway turnout sleeper application. In addition, the composite sandwich beam has an overall density of around 1000 kg/m³. Overall, the density of the structural composite sandwich panel is comparable to that of hardwood red gum timber which weighs 900 kg/m³ air dried but still very much less compared to concrete and steel which weigh 2400 kg/m³ and 7850 kg/m³, respectively. The higher density of this composite sandwich construction compared to other fibre composite sandwich structures improved its compressive strength and rigidity. These results suggest that the innovative concept of glue-laminated fibre composite sandwich beams has shown to meet strength and stiffness requirements for railway turnout sleeper application. The next step in the development process is to produce the full size turnout sleepers made from these sandwich structures for performance testing and install in the test track and monitor their performance. The progress on the detailed evaluation of the suitability of sandwich beam for a typical timber railway turnout sleeper is discussed next.

V. DESIGN CONCEPT AND EVALUATION

The innovative concept of glue-laminated fibre composite sandwich beams for turnout sleeper application was verified through practical experimentation and should be evaluated against technical, performance and economic benchmarks. This section discusses the design and development of the full-size fibre composite railway turnout sleepers.

A. Production of full-size fibre composite turnout sleeper

Two section configurations for full-size fibre composite turnout sleepers were considered: a sleeper section with composite sandwich panels glued together in the flatwise position and a section with sandwich panels glued together in the edgewise position. The fibre composite turnout sleeper specimens were fabricated by gluing a number of 18 mm thick

sandwich panels using a structural epoxy resin to form a 150 mm deep and 230 mm wide section. The specimens in the flatwise position was produced by laminating 8 sandwich panels while in the edgewise position with 13 sandwich panels. Fig. 11 shows the full-size composite turnout sleeper specimen.



Figure 14. Full-size fibre composite turnout sleeper

An initial analysis on the two fibre composite sleeper sections was conducted to determine if these proposed sections have strength and stiffness required for railway turnout sleeper application. The initial calculation shows that both sections could carry the design bending moment and shear forces in the most critical sleepers determined from the FE analyses. The sleeper section with sandwich laminations in the flatwise position has a maximum bending moment capacity of 41.2 kN-m and shear capacity of 507 kN while the section made by laminating the sandwich panels in the edgewise position has capacities of 47.2 kN-m and 727 kN in bending moment and shear, respectively. These strength values are more than double the design bending moments and shear forces in the most critical railway turnout sleeper. Both concepts also satisfy the minimum elastic modulus of 4 GPa for allowable deflection and ballast/sleeper pressure.

B. Screw-spike withdrawal resistance

Preliminary investigation on the screw-spike holding resistance of the fibre composite turnout sleeper specimen was conducted. Clearance holes measuring 17 mm in diameter were drilled through the depth of 100 mm into the specimens. The screw-spikes were then screwed into these holes until the clearance under the screw-spike head was approximately 45 mm. Fig. 12 shows the test set-up and the specimen for the screw-spike withdrawal resistance of the fibre composite turnout sleepers made-up of glue-laminated sandwich beam.



Figure 15. Test set-up and specimen for screw-spike withdrawal resistance

The results of the test showed that the resistance to hold screw-spike for both fibre composite turnout sleeper configurations is almost the same. In the edgewise position, the withdrawal resistance varies between 62 to 98 kN while in the flatwise position between 60 to 64 kN. This shows that the presence of horizontal skins did not contribute significantly to the mechanical holding resistance of the sandwich beams. This could be due to the fibre composite skin is relatively thin compared to the phenolic core. In general, the results showed that the modified phenolic core material has sufficient strength to hold mechanical connections. The screw-spike withdrawal resistance of both fibre composite sleeper configurations is higher compared to that of the Red Oak hardwood sleeper which has only around 38 kN [24].

C. Comparison with available fibre composite sleepers

Table II compares the mechanical properties of the proposed fibre composite turnout sleeper concepts to some of the commercially available composite sleepers and the minimum performance requirements recommended by the American Railway Engineering and Maintenance-of-way Association (AREMA). In the table, sleeper A represents turnout sleeper made of sandwich beam in the flatwise position, B for sandwich beam in the edgewise position, C for AREMA [24], D for Dynamic Composites LLC [25], E for IntegriCo [26], F for TietekTM [27] and G for Eslon Neo Lumber (Sekisui sleeper) [28]. On the other hand, the MOE, σ_b , SSW, σ_c and τ correspond to the modulus of elasticity, bending strength, screw-spike withdrawal resistance, compressive strength, and shear strength of the fibre composite railway sleepers, respectively.

TABLE II. PROPERTIES OF FIBRE COMPOSITE RAILWAY SLEEPERS

Sleeper	MOE, GPa	σ_b , MPa	SSW, kN	σ_c , MPa	τ , MPa
A	4.27	60.4	62.1	23.5	5.9
B	4.13	74.2	63.7	49.8	11.7
C	1.17	13.8	22.2	6.2	--
D	1.73	17.9	17.8	310.1	--
E	2.00	24.2	16.6	15.2	--
F	1.24	13.8	17.8	206.7	--
G	8.10	142.0	65.0	58.0	10.0

The comparison shows that the mechanical properties of the turnout sleeper section made up of glue-laminated composite sandwich structures are higher than the AREMA recommended values and the commercially available fibre composite sleepers, except for one with higher strength and stiffness. The low mechanical properties of most of the currently available fibre composite sleepers indicate that these sleepers are not suitable for turnout application. This further justifies the need to develop a cost effective fibre composite turnout sleeper alternative with an approved structural performance.

D. Cost comparison with other sleeper materials

The literature provides limited information on the estimated cost for the different sleeper materials. Similarly, sleeper’s manufacturers and suppliers are very reluctant in giving information on the prices of their product especially for very small amount of orders. The best indication for cost comparison of the different sleeper materials is provided in a

report by GHD for WestNet rail on 2008 Review of Unit Prices prepared [29]. In the cost comparison, only the cost of special sleepers is considered as it is anticipated that fibre composite alternatives are cost effective in this specific application. For steel and concrete, special sleepers require a significant amount of manufacturing techniques to complete the fabrication as the fastening components are already incorporated in the sleeper manufacturing process. For timber sleepers, the costs for fastening system have been obtained separately and applied to the timber sleeper to produce an all inclusive costs. As fibre composite alternatives is produced and installed similar to timber sleepers then this information is very useful in its cost estimation. Table III shows a preliminary cost comparison for each sleeper material commonly used in the Australian railway tracks and the cost of fibre composite sleepers made from glue-laminated sandwich beams. The length of the sleepers is 2.4 m.

TABLE III. COST COMPARISON OF DIFFERENT SLEEPER MATERIALS

Sleeper	Cost (AUD)	Remarks
Concrete	210.00	Includes rail fasteners
Steel M8.5 insulated system	313.45	Includes rail fasteners
Timber ^a	183.00	assumes x4 base plates, x8 lockspikes and x8 rail clips ^b
Fibre composites ^c	559.60	assumes x4 base plates, x8 lockspikes and x8 rail clips ^b

a. Timber is AUD 65 per sleeper [29]

b. Base plate – AUD 22 each; Lock spikes – AUD 1.25 each; Rail clip – AUD 2.50 each [29]

c. Fibre composite sandwich panel is AUD100 per square meter of panel

While the comparison showed that fibre composite sleeper has the highest cost, it is important to note that the cost of concrete, steel and timber sleepers is based on the order quantities of 160,000 to 170,000 railway sleepers and including estimated volume discounts. Where a project of the scale of replacement of the railway sleepers was involved, the price of the fibre composite turnout sleepers would presumably decrease considerably and would become competitive with steel, concrete and timber sleepers. Similar to timber, fibre composite sleeper offers easy installation and great flexibility in construction which can further reduced the overall cost of the fibre composite alternatives.

In the particular report for WestNet rail, it was highlighted that the supply of timber sleepers could meet the “network replacement” criteria of large lengths such as railway turnouts. Thus, the development of fibre composite alternatives with a production cost similar to that of special timber sleepers currently used in the railway turnouts, will result in a saving of approximately more than 50% of maintenance cost as the service life of fibre composites is expected to be more than double to that of timber sleepers. After its service life, there is also a high potential for fibre composite sleepers to be recycled and used in the production of new fibre composite products.

E. Full-scale test

A comprehensive testing program should be carried out to determine the structural behavior of the structural behavior of the full-size fibre composite turnout sleepers when subjected to load. The full-size turnout fibre composite sleepers are already produced and a comprehensive testing on the structural

behaviour of these turnout sleepers is now on schedule. The results of the experimental investigation will verify the predicted strength and stiffness of the developed fibre composite railway turnout sleeper in bending and shear. The results of these tests will be used to further optimise the fibre composite sleeper section for the final design and in the production of prototypes to put this technology in practice.

Field trials and in-service performance evaluation is important to demonstrate to railway engineers and authorities the high performance characteristics of fibre composite materials and encourage its adoption as an alternative railway turnout sleepers. Several prototypes of fibre composite turnout sleepers will be produced and installed in the actual turnout sections as part of the railway industry's sleeper maintenance program. Once installed, the systems behaviour of the new sleeper material under real conditions and its compatibility with the existing timber sleepers will be determined. Its capability of being installed in track without errors and being fitted with fastening component will be observed. All assumptions during the design and analysis process will be confirmed to come up with the most efficient section.

VI. CONCLUSIONS

This paper presented the investigation onto the effective use of glue-laminated composite sandwich beams for an innovative fibre composite turnout sleeper. A comprehensive review of literature suggested that the advantages of hardwood timber can be simulated using fibre composite materials with the added advantages. The results of the experimental and numerical investigations suggest that the innovative concept of glue-laminated composite sandwich beam has strength and stiffness suitable for railway turnout application. Comparison also showed that this fibre composite turnout sleeper has better mechanical properties than most of the commercially available composite sleepers and showed compatible performance with timber sleepers. Most importantly, this material can be cost competitive with other sleeper materials in specific applications such as railway turnout. However, testing of the full-size specimens and field trials should be conducted providing a proof-of-performance necessary to facilitate the adoption of this technology. Once completed, it is anticipated that this technology is ready for the approval of railway industries to use this product as an alternative timber turnout sleeper.

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