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EVALUATION OF THE PHYSICAL AND MECHANICAL PROPERTIES OF A COMPOSITE RAILWAY TURNOUT SLEEPER

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ABSTRACT

The Centre of Excellence in Engineered Fibre Composites at the University of Southern Queensland and CarbonLOC Pty Ltd, Australia have developed and investigated the behaviour of a new fibre composite railway sleeper technology, which can be used to replace deteriorating timber turnout sleepers. The building block of this sleeper is the new generation composite sandwich structure made up of glass fibre composite skins and modified phenolic core material. This paper presents the results of the experimental testing and evaluation on the physical and mechanical properties of fibre composite railway sleeper and its component materials in order to evaluate the performance and quality of the technology. Based on the results, the bending strength, modulus, shear, and compressive strength of the sleeper are 79 MPa, 7.2 GPa, 16 MPa, and 77 MPa, respectively while the pulling strength of screw spike is 74 kN. These properties are suitable for a railway turnout sleeper application.

KEYWORDS

Railway sleepers, composites, turnout, sandwich construction, mechanical properties.

INTRODUCTION

Railway companies worldwide have used timber sleepers for nearly two centuries and there are more than 35 million of old timber sleepers in railway lines throughout the world that need to be replaced to maintain the track quality into a specified level of service (Manalo et al. 2010). In Australia alone, railway lines require in excess of 1.5 million timber sleepers per year for railway maintenance (Van Erp et al. 2005). However, good quality timber has become scarce and more expensive. Whilst concrete sleepers have gained increasing acceptance, their size and stiffness typically limits their use to locations where complete sleeper replacement is undertaken or where new track is constructed. For existing railway lines with timber sleepers, the replacement sleeper should have properties comparable to that of timber to minimise the uneven distribution of forces and maintain the overall performance characteristics of the railway system. Thus, railway companies worldwide continue to use timber sleepers to maintain their existing timber lines despite a range of environmental concerns. In fact, Queensland Rail is still purchasing more than 80,000 timber sleepers per year including 5,000 turnout sleepers for track maintenance as there is still no viable alternative for timber sleepers (Miller 2007). This trend is set to continue and will become critical within the foreseeable future. Hence, the use of reinforced polymer sleepers have emerged as a potential alternative as they can be designed to mimic timber behaviour, are almost maintenance free, and are more environmentally sustainable.

During the last few years, the Centre of Excellence in Engineered Fibre Composites (CEEFC) at the University of Southern Queensland (USQ) and CarbonLOC Pty Ltd in collaboration with different railway industries in Australia, have dedicated significant research effort towards understanding the behaviour of innovative composite railway sleepers to replace deteriorated hardwood sleepers. One of these technologies is the composite turnout sleeper. Because of the special nature of turnout sleepers, fibre composites is the most suitable alternative as it can be produced with varying lengths (up to 4-5m) and with different fastening locations. However, composites sleepers must be properly engineered as sleepers in the railway turnout are subjected to a complicated mixture of flexural and shear loads due to the wheel-rail impact force caused by the crossing train (Remennikov and Kaewunruen, 2008).

In this paper, the development and evaluation of the composite sleeper technology is presented. It covers the physical and mechanical testing conducted to demonstrate the performance of the sleepers and evaluation for the approval of railway industries to use in railway lines. These results are also anticipated to help increase the confidence of engineers and asset owners in the use of this new sleeper.

PRODUCTION OF SLEEPERS

The building block of the turnout composite railway sleeper is the new generation composite sandwich panel which comprises a proprietary core material sandwiched between two high strength glass fibre reinforced polymer (GFRP) skins as shown in Figure 1. The solid core has been purposely designed to have high compressive and shear strength to carry the concentrated loads typical for railway sleepers. The sleepers are produced using the proprietary casting technique developed by CarbonLOC Pty Ltd. The sleeper has a prismatic rectangular shape and contains long glass reinforcement fibres in both the longitudinal and transverse directions. This is done by combining the strength and stiffness of glue-laminated sandwich panels oriented in the edgewise positions, with high tensile strength and modulus top and bottom GFRP skin plates. In this concept, the glued sandwich beams in the edgewise position provide the required shear strength while the top and bottom GFRP plates provide the needed stiffness. This economical use of materials combined with the fast production cycle has resulted in a polymer sleeper which is significantly more cost effective than the alternatives.

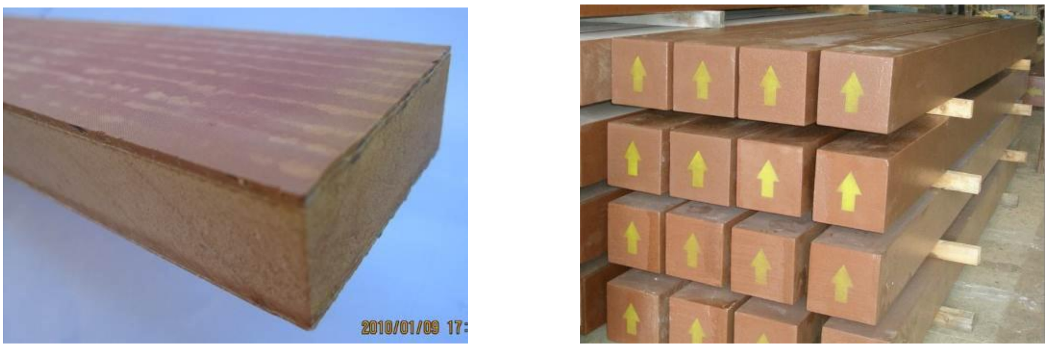

Figure 1. The composite sandwich panel (left) and composite sleepers (right)

TEST METHOD

Specific Weight and Dimensions

The actual weight and dimensions of a 230 mm x 230 mm x 3700 mm long fibre composite railway sleeper were measured to determine the unit volume mass and dimensional tolerances. Five railway sleepers were randomly selected from a batch of 120 manufactured sleepers and the actual depth, width and length were measured using a measuring tape.

Shear and Compressive Strength Tests

Small-scale beam specimens representing the sleepers were tested under asymmetrical beam shear (Figure 2) to evaluate the shear strength of the composite sleepers. The representative sleeper specimens are made up of 3 layers of glued sandwich panels and top and bottom GFRP laminates and with a nominal width and depth of 60 mm and 100 mm, respectively. The beam was loaded up to failure to determine the strength and observed the failure mechanism. On the other hand, the longitudinal and transverse compressive strength tests were performed to determine if the sleepers have sufficient compressibility to withstand rail seat loading. A rectangular specimen of 60 mm x 100 mm x 120 mm high was cut from the sandwich beam section and tested under compression (Figure 2). In both the tests, the load was applied at a rate of 2 mm/min using the SANS hydraulic testing machine.

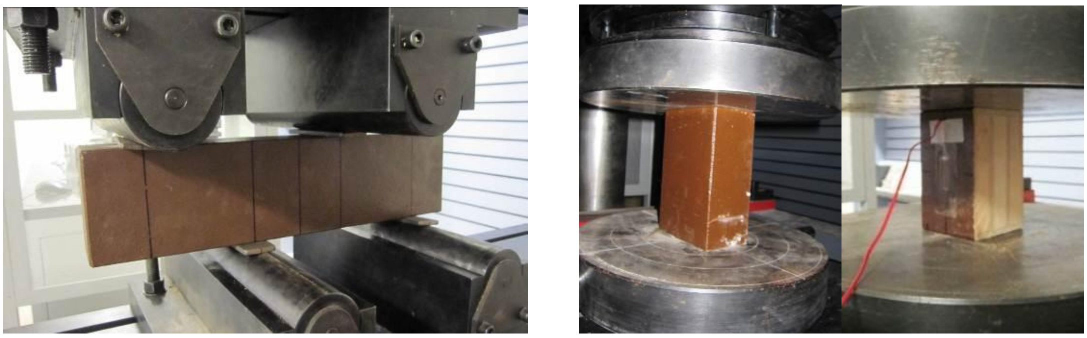

Figure 2. Shear strength (left) and compressive (right) tests

Screw Spike Pulling Strength

The low pull-out force of mechanical connection in composite sleepers is considered the most likely reason for sudden catastrophic failure of the track system due to derailments (Lampo et al., 2003). Thus, the screw spike pulling resistance of the fibre composite railway sleeper was evaluated through direct withdrawal test. Portion of the sleeper was used and clearance holes measuring 18 mm in diameter were drilled through the depth of 110 mm into the specimens. The 24 mm diameter and 165 mm long 'R' type screw-spike was then inserted into the holes until the clearance was approximately 30 mm under the neck. The spikes are pulled using a 500 kN hydraulic jack at a rate of 2 mm/min (Figure 3) and the maximum value of pulling strength was determined.

Figure 3. Pulling strength test of screw spike (left) and direct-current insulation resistance (right)

Direct-current Insulation Resistance Test

An indication of the electrical resistance properties of the sleepers was determined by measuring the direct-current insulation resistance of the fibre composite skin of the sandwich panels as shown in Figure 3. The direct-current (DC) insulation resistance for dry and wet specimens was measured using the Megger MIT 320, an instrument which can measure up DC insulation resistance of up to $1x10^9$ ohms. The specimens used have dimensions of 5 mm x 20 mm x 40 mm. The specimens have two holes with a diameter of 5 mm and distanced 15 mm from centre where a 5 mm diameter brass tapered pin was used as electrode to measure the DC resistance of the fibre composite materials.

Proof Loading and Destructive Testing of Full-scale Sleepers

Five selected production (of 120) sleepers were proof loaded up to an applied load of 200 kN under 3-point static bending test as shown in Figure 4. In addition, one full-scale specimen was loaded up to failure to determine the ultimate bending strength of the fibre composite railway sleeper. Figure 1 shows the test set-up for the bending strength and modulus test. The concentrated load was applied at a rate of 3 mm/min and the vertical displacement was measured at midspan. Steel plates were provided on the supports and over the loading point to prevent premature indentation failure. The applied load and displacement were recorded and obtained using a System5000 data logger.

(a) Proof loading (b) Ultimate strength

Figure 4. Bending strength and modulus tests

RESULTS AND DISCUSSIONS

Specific Weight and Dimensions

The average width, depth and length of the sleepers are 229.8, 229.6 and 3698 mm, respectively. This showed that the railway sleepers are produced with very consistent dimensions as the maximum variation between the actual and the nominal dimensions is only 0.3%. Furthermore, the density of the railway sleeper is 1.074 kg/m^3 which is very similar to that of a hardwood sleeper.

Shear and Compressive Strength

The specimen tested under asymmetrical beam shear failed at a maximum applied load of 203.5 kN (16.96 MPa). This shear strength is more than twice the shear strength of 7 MPa required by the JIS E 1203 (2007) for synthetic turnout sleepers. At this level of load, shear failure in the vertical fibre composite skins was observed with indentation on the top and bottom GFRP laminates as shown in Figure 5. The specimen tested for longitudinal and transverse compression exhibited an average compressive strength of 77.03 MPa and 61.20 MPa, respectively, which is almost double than the specified minimum compressive strength of 40 MPa (JIS E 1203, 2007; AREMA 2013). The specimen tested under longitudinal compression failed by crushing at the top section and delamination and buckling of the GFRP skin while the specimens under transverse compression failed by formation of diagonal shear cracks in the phenolic core as shown in Figure 5.

Figure 5. Failure behaviour in shear (left), longitudinal and transverse compression (middle), and screw spike pulled from the sleeper (right)

Screw Spike Pulling Strength

The screw-spike remained in the sleepers throughout the test as shown in Figure 5 with the screw-spike withdrawal resistance at around 74 kN. This result showed that the modified phenolic core of the sandwich panel has sufficient strength to hold mechanical connections as the screw-spike withdrawal resistance of fibre composite sandwich sleeper is higher compared to that of the usual Red Oak hardwood sleeper which has only around 38 kN (AREMA, 2013). This is also much higher than the required pull-out force of 15.6 kN in most fibre composite sleepers (Lampo et al., 2003). Consequently, the high resistance to pull-out screw spikes from glued sandwich beams can address the inability of most composite sleepers to meet the performance requirement for mechanical connections and show that it can provide a comfort level to installing these types of spikes in field trials.

Insulation Resistance

The direct insulation resistance of both the dry and wet specimens is higher than $1x10^9$ ohms. This is significantly higher than the minimum electrical impedance of 20,000 ohms required by AREMA (2007) for polymer composites and $1x10^6$ ohms for the electrical insulation resistance of concrete and steel sleepers (AS1085.19, 2003). This indicates that a fibre composite sleeper has high resistance to the flow of electrical current and eliminates the need for expensive insulation pads.

Bending Strength and Modulus

Figure 6 shows the load and midspan displacement relationship of the fibre composite railway sleepers tested up to failure (FL) and the load deflection behaviour of five sleepers proof loaded (PL) up to 200.3 kN. As observed, all sleepers behaved linear elastic up to the applied proof load (bending moment = 92.3 kN-m, bending stress = 45 MPa) without any observed failure. On the other hand, the sleepers tested up to failure failed at a bending strength of 79.60 MPa due to the debonding of the bottom GFRP plates. The average Young's modulus in flexure of the six sleepers is 7.2 GPa with a standard deviation of 0.19 GPa (coefficient of variation of 2.7%) indicating that the sleepers are consistently produced through the proprietary casting technique. Moreover, the strength and stiffness of the composite sleeper satisfy the minimum requirements specified by AS3818.2 (2004) of using only stress-grades F17 or higher for railway turnout sleepers. Furthermore, the strength and modulus of the composite sleepers are comparable to the properties of the existing timber turnout sleepers (Ticoalu et al., 2008). These values are also higher than the bending strength and stiffness of 70 MPa and 6 GPa, respectively required by the JIS E 1203 (2007) for synthetic turnout sleepers.

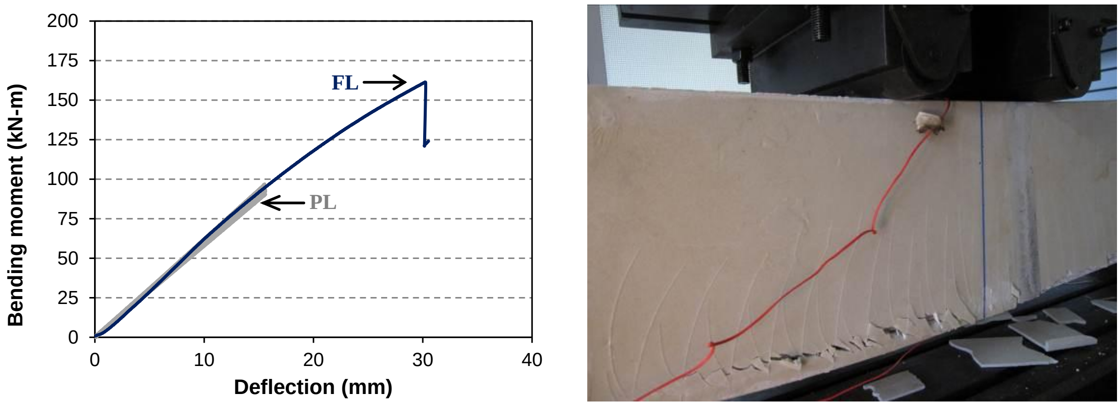

Figure 6. Bending moment and deflection relationship (left) and failure of full-scale sleeper (right)

CONCLUSIONS

This paper presented the development and performance evaluation of a fibre composite railway turnout sleepers. Based on the results, the following are the major findings of the investigation:

- The fibre composite sleepers are consistently produced through the proprietary casting technique with the coefficient of variation for dimensions and strength properties of only 0.3% and 2.7%, respectively.
- The fibre composite sleeper withstood a proof load of 200 kN under bending without any signs of failure. The effective Young's Modulus in flexure of the sleeper is 7.2 GPa.
- The bending, shear and compressive strength of the sleeper are 79 MPa, 16 and 61 MPa, respectively. These are higher than the required performance for turnout railway sleeper.
- The pulling strength of screw spike is 74 kN which is higher than the resistance of timber and available composite sleepers.
- The insulation resistance of the fibre composite materials used in manufacturing the railway sleepers are higher than the required with the dry insulation resistance higher than $1x10^9$ ohms.

The above findings indicate that the performance properties of the fibre composite sleeper technology are suitable for replacement of timber turnout sleeper and higher than the minimum requirements specified by the national and international standards.

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