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A Comparative Analysis of Timber and Composite Sleepers

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Abstract **–** Traditionally, timber sleepers have been widely used in railways around the world; however, timber sleepers are prone to various forms of damage and failure. Additionally, recent decrease in supply of suitable wood for timber sleepers has generated interests in various railways to explore alternative materials for sleeper manufacturing including composites. This paper briefly compares the main mechanical properties of timber sleepers and glass fibre reinforced polymer (GFRP) composites. Additionally, finite element analyses of the sleepers are undertaken and the von-misses stress and vertical deflection of the timber and GFRP sleepers under static load are evaluated and discussed.

Keywords**:** Railways, timber sleepers, composite sleepers, finite element analysis

1. Introduction

Sleepers, as a vital component of railway structure, play an important role in the track system (Figure 1). The sleepers have two primary functions. This includes transferring the loads acted on the rails to the track sub-structure and also to connect the rails keeping them in correct gauge. Track gauge is different in different railways; for example, the standard track gauge in New Zealand on straight sections is 1068 mm and in Australia is 1435mm which is the most common gauge used in railways around the world. Sleepers are also important to provide track stability in the longitudinal and lateral directions [1]. The sleepers experience high magnitudes of bending moment and stresses under repeated vertical loads from the passing trains which can result in various structural failures. Additionally, the vertical wheel loads may be significantly amplified due to irregularities on the wheel or on the track [2] [3].

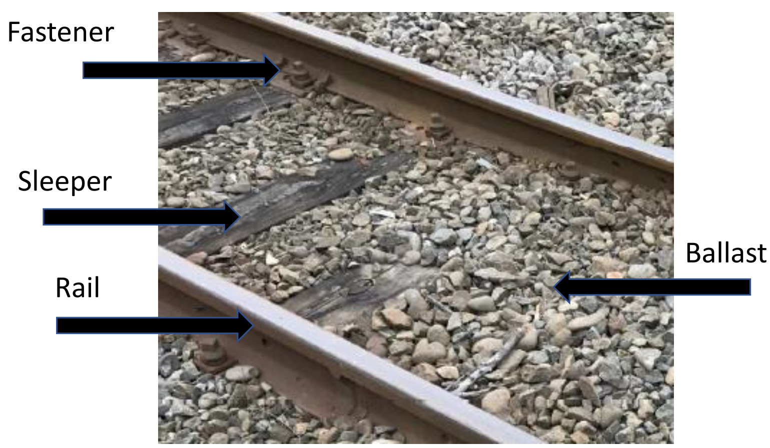


Fig. 1: Typical timber sleeper in a railway track

2. Material Properties and General Behaviour of Timber and Composite Sleepers

2.1 Mechanical Properties

Timber sleepers are produced worldwide using either hardwood or softwood timber; Beechwood, Oak and Pine are three common wood types. For example, in New Zealand, about 68% of the sleepers in track and rail bridges are timber sleepers where the majority are made of Treated Pinus Radiata [4]. However, radiata pine structural timber has on average lower strength and stiffness than timber produced from European and North American species such as Scots pine [5]. Beechwood is a medium to heavyweight hardwood and usually shows the highest modulus of elasticity and tensile strength amongst sawn timbers. A summary of typical mechanical properties of four example wood types obtained from literature are shown in Table 1.

Recently, composite sleepers are considered as alternative for timber sleepers and have been used in some railways around the world, however, the total number of composite sleepers relative to the conventional timber sleepers is still very low. Ferdous et al., 2015 [6] provides a comprehensive review of recent developments and prospects in use of composite sleepers. Glass Fibre-reinforced polymer (GFRP) is one type of composite which is recently used for sleeper manufacturing. Comparing with timber material, Glass Fibre-reinforced polymer (GFRP) has high strength-to-weight ratio, and much higher environment resistance. GFRP are produced with stringent and consistent quality control in order to provide stiffer and stronger laminates [7]. Typical mechanical properties of GFRP are shown in Table1.

Table 1: Typical material properties of example timber and GFRP materials reported in the literature [7] [8] [9]

Material properties	Radiata pine	Scots pine	Beech	White oak	GFRP
Density (kg/m³)	500	520	640	450	2000
Modulus of elasticity (GPa)	11.5	11.25	13.81	12.25	18
Shear strength (MPa)	3.8	6.21	10.31	11.6	23.19
Tensile/ Bending strength (MPa)	41	104.2	120.8	109	500

2.2. Fatigue Behaviour and Failure Type

Limited studies on the fatigue behaviour of timber materials used in railway sleepers are available in the literature. However, a number of studies on fatigue behaviour of wood/timber material (used in other applications) are reported. For example, [8] studied the fatigue behaviour and static strength of Scots pine and beechwood using three-point bending tests. The fatigue test was carried out at 80 to 40 % stress level that corresponded to specific percentage of material ultimate strength modulus of rupture (MOR).

In regard to composites, Ferdous, et al 2020 [7] has reported some tests on GFRP laminates at stress level of 80% to 25% of the ultimate tensile strength. It was observed that the specimens were failed in pure tension due to the rupture of fibres at 80% and 70% load. The behaviour of GFRP is linear and generally shows brittle failure. Figure 2 summarises and compares the S-N curves obtained from the above studies. As shown in this figure, the GFRP composite has significantly higher fatigue strength compared to the wood samples. The fatigue life of Scots pine and beechwood is reported to about 1.5 million cycle, when the stress level was 45MPa (in average). At stress level of about 100MPa, the fatigue life of the wood samples are 100,000 cycles while this value for the GFRP sample is around 10 million.

It should be mentioned that in many scenarios the failure of timber sleepers will not be necessarily controlled by the fatigue but there are many other factors that can affect the service life of the timber sleepers. For example, Fungal decay and Termite attacks. Fungal decay is the predominant mode of timber sleeper failure as timber is susceptible to bio-deterioration from many micro-organisms because timber is an organic material. Additionally, the splitting of timber at the end or at location of rail fasteners (where the screw-spike is inserted), is another common timber sleeper failure mode [10].

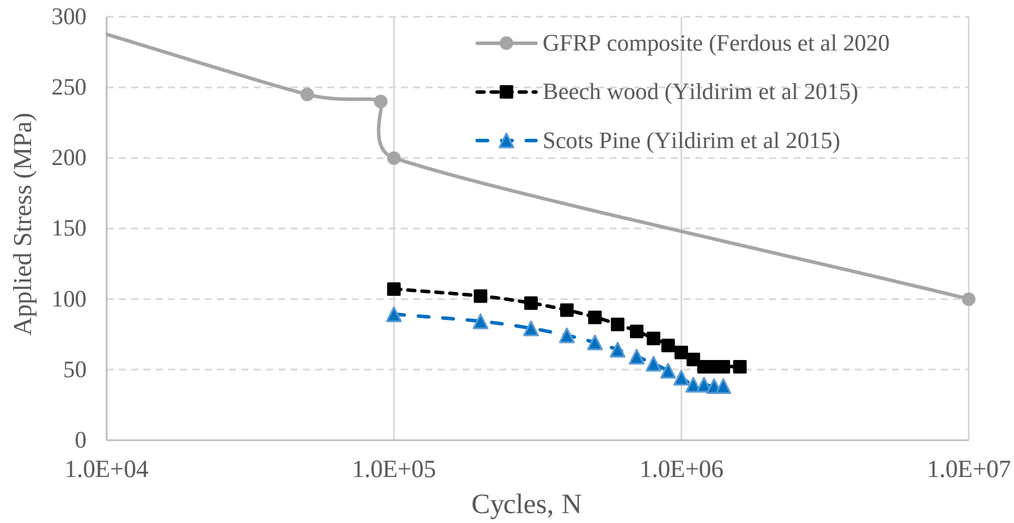
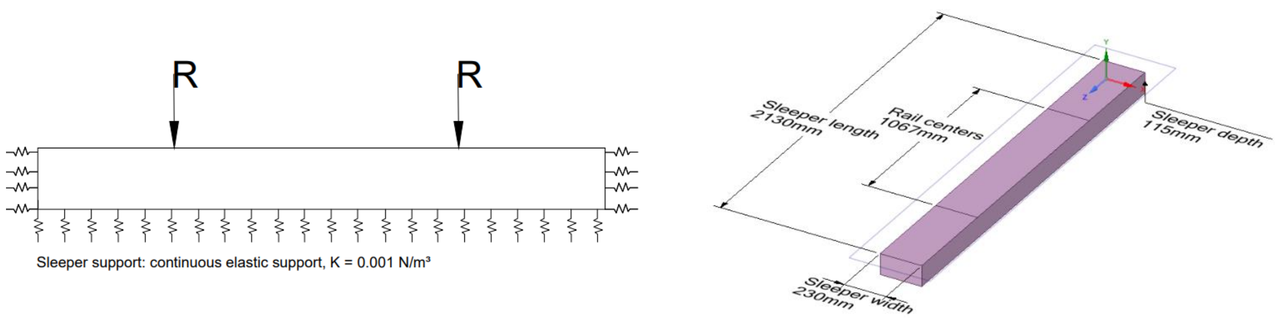


Fig. 2: Fatigue behaviour of wood samples vs GFRP composite

3. Finite Element Analysis of Sleepers under Static Load

Finite element analyses of the sleepers are undertaken to evaluate the stress and deflection values of the timber and GFRP sleepers under static load. The simulations were undertaken using ANSYS workbench. Figure 3, shows the dimension and the geometry of the sleeper modelled in this study. The sleepers are supported on a continuous elastic support (to replicate the elastic ballast/subgrade layers). The boundary conditions are shown in figure 3.



(a) Sleeper modelled on an elastic foundation

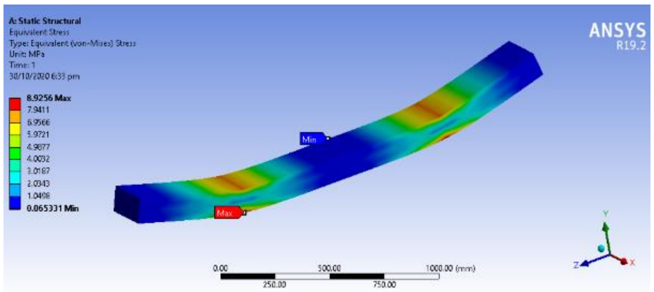
(b) Geometry of the sleeper model

Fig. 3: Geometry and boundary conditions of sleeper model

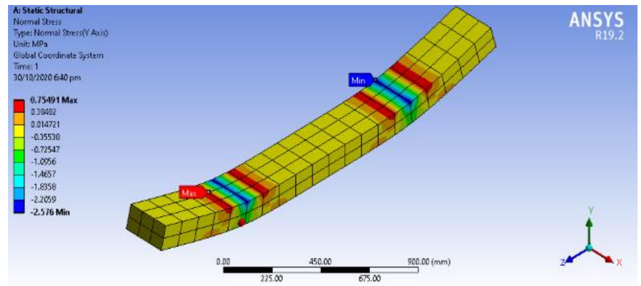
The value and position of the vertical load applied on one sleeper (rail seat load) depends on a number of factors such as the train axle load, sleeper spacing, track gauge, train speed and track irregularities. The speed and irregularities generate dynamic impacts on the track. Eq. (1) is a simplified equation suggested by American Railroad Engineering and Maintenance-of-way Association (AREMA) [11] to estimate the load value on applied on the sleeper based on the wheel load and track condition.

$$R = \theta * Q * DF \tag{1}$$

Where R is the load applied on the sleeper (rail seat load), Q is the train wheel load, ɵ is the impact factor and DF is the wheel load distribution factor. For this study, the wheel load of 100kN with impact factor of 1.5 was considered. Assuming the 685 mm sleeper's spacing, the axle load distribution factor DF of 0.48 is used. Using the equation, the rail seat load applied on the sleeper (R) is calculated as 72kN. Figures 4 and 5 shows the stress and deflection outputs obtained from the simulations. The deflection vales are shown for the sleeper model with three wood types and the composite sleeper.

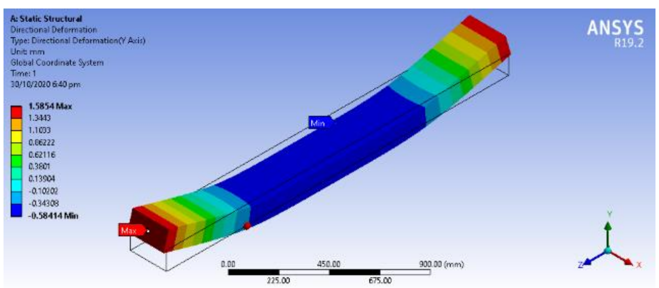


(a) Von-Mises stress

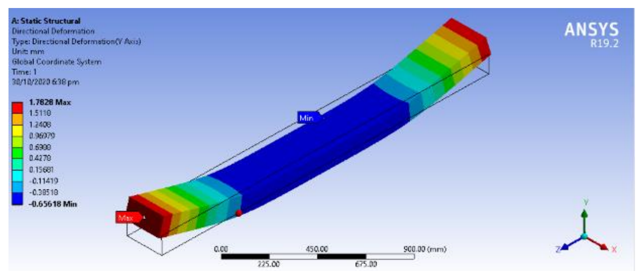


(b) Normal stress

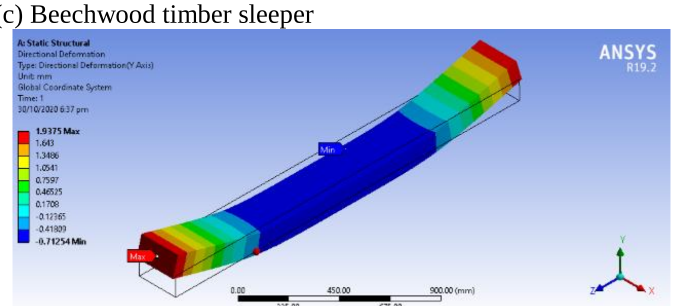
Fig. 4: Stress generated in the sleeper under wheel loads



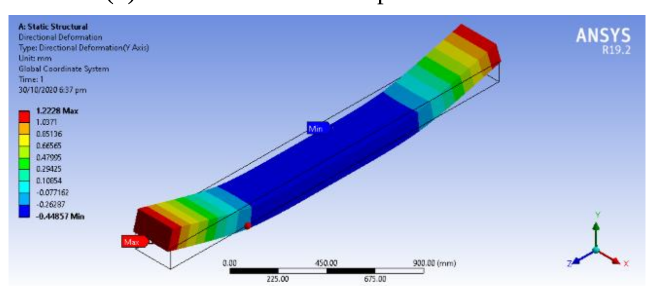
(c) Beechwood timber sleeper



(d) White oak timber sleeper



(e) Scot pine timber sleeper



(f) GFRP composite sleeper

Fig. 5: Vertical deflection of sleepers under wheel loads

As shown in Figure 4, for the load and boundary conditions (elastic support stiffness) considered in this study, the maximum Von-Mises stress in the sleeper is calculated as 8.9MPa. It should be noted that, this value can increase significantly depending on the dynamic impacts on the sleepers generated due to the wheel or track irregularities. According to Figure 5, comparing the deflection values, it can be observed that the GFRP sleeper shows about 0.4mm downward deflection (in the middle) which is considerably lower compared to the Scots pine sleeper model with 0.7 mm vertical deflection (about 75% lower). This is expected considering the higher modulus of elasticity of GFRP compared to timber. It should be noted that the sleeper deflection values could be highly variable in different railways depending on the rail types and support condition (track support stiffness), plus the loading condition (train axle load and dynamic impacts). Additionally, it should be considered that the simulations in this study were focused on GFRP composite. There are other types of composites which can be potentially used in the railway sleeper application.

4. Conclusion

In recent years, a number of railways around the world are considering the use of composite sleeper as a possible alternative to traditional timber railway sleepers. This paper provides a preliminary comparative study of timber and GFRP GFRP composite railway sleeper in terms of their mechanical properties and stress/deflection values under static vertical loads. The main mechanical properties and fatigue behaviour of some typical example wood samples were compared with the GFRP composite material based on the studies reported in the literature. Additionally, a series of numerical simulations were undertaken in ANSYS to evaluate the stress and deflection values in the sleeper model under a typical wheel load. The sleepers were modelled as a uniform beam on elastic foundation. For the loading condition and track properties considered in this study, the results show that the GFRP composite sleeper can potentially deflect up to 75% less compared to a Scots Pine timber sleeper under a vertical load. This would mean the cross-section size of the GFRP sleeper can be potentially smaller than typical timber sleepers. Further research on the composite sleepers is in progress to look into the dynamic behaviour as well as long-term performance and failure behaviour using more detailed and comprehensive numerical modelling and experiments.

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