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RECENT DEVELOPMENTS AND APPLICATIONS OF COMPOSITE RAILWAY SLEEPERS

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SUMMARY

Several composite sleeper technologies have been developed in different parts of the world. These technologies have emerged as a potential alternative to timber sleepers. Different from steel and concrete, composite sleepers can be designed to mimic timber behaviour (an essential requirement for timber track maintenance), are almost maintenance free, and are more sustainable from an environmental perspective. This paper presents and compares the performance of currently available composite railway sleeper technologies with different amounts, length and orientation of fibres and including their application. The common challenges encountered in using composite sleepers are also discussed. Finally, potential approaches are suggested to overcome the challenges in the utilisation and acceptance of composite sleeper technologies.

1. INTRODUCTION

Timber was the earliest material used and more than 2.5 billion timber components have been installed worldwide (1). They are adaptable and have excellent dynamic, electrical and sound-insulating properties. Around the 1880s, due to the scarcity of timber and the sensitivity to its use, steel railway sleepers were introduced as an alternative to timber. As their design has evolved, original steel sleepers are now being replaced by the modern ‘Y’ shaped design. During the last few decades, the railway industry has focused on a cement-based concrete rather than timber and steel sleepers. Mono-block prestressed concrete sleepers were first applied in 1943 and are now used in heavy haul and high speed rail track constructions throughout the world (2).

This leads to the question on why the railway industry uses a variety of sleeper materials rather than a particular one? Undoubtedly, the main reason is that none of the existing materials (timber, steel and concrete) are able to satisfactorily meet all the requirements of a sleeper. The global market for composites is rapidly increasing because of the many advantages including high strength-to-weight ratio, excellent resistance against corrosion, moisture and insects, and thermal and electrical non-conductivity (3). This material can be engineered according to the specific requirements of railway sleepers (4). A review by Manalo et al. (5) on alternative materials to timber indicated the high demand for new sleeper materials. Therefore, this study focused on the recent developments and application of alternative railway sleeper materials. The common challenges of using alternative materials are also discussed and potential approaches are suggested to overcome those challenges and increase the acceptance of these technologies.

2. ISSUES WITH TRADITIONAL SLEEPER MATERIALS

Traditional materials for railway sleepers are timber, concrete and steel, which are generally designed for 20, 50 and 50 years, respectively (6-8). The problems associated with timber rotting, splitting and insect attack, as well as the scarcity of suitable hardwood timber introduced a new challenge. The risk of corrosion, high electrical conductivity, fatigue cracking, and difficulty of packing with ballast made steel an inferior material for use in sleepers. Prestressed concrete sleepers, which offer greater durability than timber and steel, suffer from being heavy and having a high initial cost, low impact resistance and susceptibility to chemical attack. Due to the heavy weight, their transportation and installation costs are also significantly higher (9). Moreover, concrete and steel sleepers require special fasteners and cannot replace timber ones in an existing track because of their incompatible behaviour. The higher stiffness of concrete compared to timber can transfer higher loads that could lead to greater deterioration due to flexural cracks, and the shape and size of steel sleeper has proven a differential settlement (5). A
recent study on the potential causes of failures of railway sleepers (10) showed that traditional materials have not satisfactorily met demand requirements to resist mechanical, biological and chemical degradation. From an environmental perspective, the production of traditional sleeper materials creates several problems; for example, many trees need to be cut down to make timber sleepers while the cement and steel industries emit huge amount of carbon-dioxide. Table 1 summarised the advantage and disadvantages of traditional sleeper materials. The problems associated with the traditional materials of sleeper summarised in Table 1 have motivated researchers around the world to develop and investigate new and effective alternative sleeper technologies for railway industry.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Hardwood</th>
<th>Softwood</th>
<th>Concrete</th>
<th>Steel</th>
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<tr>
<td>Adaptability</td>
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<td>Difficult</td>
<td>Difficult</td>
<td>Difficult</td>
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<tr>
<td>Workability</td>
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<td>Easy</td>
<td>Difficult</td>
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<tr>
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<td>Difficult</td>
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<td>Low</td>
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<td>Low</td>
<td>High</td>
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<tr>
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<td>Very high</td>
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<td>Poor</td>
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<tr>
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<td>High</td>
<td>Very high</td>
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<td>Impact</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Weight (standard sleeper), kg</td>
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<td>60–70</td>
<td>285</td>
<td>70–80</td>
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<tr>
<td>Service life, years</td>
<td>20–30</td>
<td>20</td>
<td>60</td>
<td>50</td>
</tr>
</tbody>
</table>

Table 1: Comparison of the traditional materials for sleeper (5)

3. DEVELOPMENTS AND APPLICATIONS

Several composite sleeper technologies have been developed in different parts of the world, mostly in last two decades. These sleeper technologies can be classified into three categories based on the amount, length and orientation of fibres are discussed in the following sub-sections.

3.1 Sleepers with Short or No Fibres (Type 1)

Sleepers that consist of recycled plastic (plastic bags, scrapped vehicle tyres, plastic coffee cups, milk jugs, laundry detergent bottles etc.) or bitumen with fillers (sand, gravel, recycled glass or short glass fibres < 20 mm) falls under the category of Type-1 sleepers (Figure 1). The structural behaviour of these sleepers is mainly polymer driven. While some of these technologies introduced short glass fibre to increase the stiffness and/or resist crack, they do not have major reinforcing effect to improve the structural performance required for heavy duty railway sleeper application. The high demand for alternative sleeper materials has resulted in some railway maintenance companies to adopt and trial the usage of these materials. As a sleeper material, Type-1 sleepers offer a range of benefits including the ease of drill and cut, good durability, consumption of waste materials, reasonable price, and tough. The notable sleepers in this category are TieTek (11, 12), Axion (13, 14), IntegriCo (15, 16), I-Plas (17, 18), Tufflex (19, 20), Natural rubber (21, 22), Kunststof Lankhorst Product (KLP) (23, 24), Mixed Plastic Waste (MPW) (25) and Wood-core (26).

Figure 1: Axion ECOTRAX sleeper (Type 1)
3.2 Sleepers with Long Fibres in Longitudinal Direction (Type 2)

Type-2 sleepers are sleeper technologies reinforced with long continuous glass fibre reinforcement in the longitudinal direction and no or very short random fibre in the transverse direction. The strength and stiffness in the longitudinal direction is primarily governed by long glass fibre while it is dominated by polymer in the transverse direction. These sleepers are primarily suitable for ballasted rail track where the stresses in sleepers are governed by flexural loading, but less than ideal in bridge applications where the sleepers are subjected to high level of combined flexural and shear forces. Easy to drill and cut, good durability, superior flexural strength and modulus of elasticity are the advantages of the sleeper in this category. The FFU (Fibre-reinforced Foamed Urethane) synthetic sleeper (27-29) is classified in this sleeper category. The key features of this material include its light weight, good resistance to water absorption, heat and corrosion, its ease of drilling, and its more than 50 years of design life. FFU material has been used in railway industry as plain-track sleepers, bridge transoms, and turnout bearers with a wide range of sleeper height from 100 mm to 450 mm. To date, this material has been installed (Figure 2) in more than 1300 kms of track (approximately 2 million sleepers) with its main application in turnouts, open steel girder structures and tunnels (30). Apart from Japan, Sekisui FFU components have been installed in Germany, Austria, Taiwan, Netherland, USA and Australia. Their applicability is also now investigated for a long span rail bridge in Chongqing city, China (31).

3.3 Sleepers with Fibres in both Longitudinal and Transverse Direction (Type 3)

Type-3 sleepers have long reinforcement fibres in both longitudinal and transverse directions and consequently both the flexural and shear behaviour are dominated by fibres. The structural performance of this sleeper can be engineered through the adjustment of the fibre reinforcements in each direction according to the specified performance requirements. The sandwich polymer sleeper (Figure 3) (4, 32) and the hybrid composite (33, 34) sleeper wherein fibres are oriented in the two directions to resist flexural stresses as well as shear forces falls under this category.

For comparison, the performances of composite sleeper technologies are summarised in Table 2.
4. CHALLENGES AND OPPORTUNITIES

Composite sleeper technologies have emerged as an effective alternative for railway track maintenance and renewal. However, there are barriers that still need to be overcome for their increased acceptance and use. This section discusses the emerging issues on composite sleepers and presents opportunities for their widespread use and application.

4.1 Improve Structural Performance

Most of the composite sleeper technologies have been developed to replace existing timber sleepers. In Australia, approximately 1.5 million timber sleepers are required per year for maintaining rail track (35). Even with this high demand for sleeper alternatives, there still limited usage and application of composite sleeper technologies. This may be expected since most of the available composite sleepers fall under the Type-1 category that has strength and stiffness characteristics significantly lower than traditional timber sleeper (Figure 4). The incorporation of longitudinal fibre makes the Type-2 sleeper stronger than Type-1 to resist flexural loading but its capacity to resist shear force is still moderate as no reinforcements are provided in transverse direction. The capacity of sleeper to resist shear force is particularly important for bridge application (transoms) where the sleepers are subjected to high shear force due to the position of rails and support beams which are generally offset by approximately 250 mm in Australia (4). The high shear capacity of Type-3 sleepers is achieved by placing fibres in both longitudinal and transverse direction.

4.2 Optimal use of Sleeper Materials

The prohibitive cost of most composite sleeper technologies is one of the main reasons identified for their slow uptake in the market. Van Erp and Mckay (4) indicated that the price of high fibre content composite sleeper technologies (Type-2 and Type-3) is approximately 5 to 10 times higher than that of a standard timber sleeper. However, its lower life cycle cost is anticipated to offset its high initial cost (14, 16, 37) which to attract the attention of the railway industry, needs to be similar to, or insignificantly higher than, that of traditional ones.

Nosker et al. (38) and Bank (39) recommended optimising structural dimensions to avoid material wastage, which can lead to minimising the cost. The materials of a composite sleeper have been optimised in developments of KLP plastic sleepers (Type-1), with the optimised design reducing plastic volume by 35% compared with that of a traditionally shaped solid sleeper. The optimisation of sleeper is not only advantageous from an economic point of view but also improves the lateral stability of rail track because of their non-uniform shape (40). The optimised sleeper can be designed based on the wheel load distribution pattern provided in Figure 5.

4.3 Long Term Performance

Although most composite sleeper manufacturers have evaluated the static performances of their products, the long-term performances in terms of aspects such as dynamic properties, impact resistance, fatigue and durability of all sleeper types are still unknown.

In addition to operational load requirements, the performance of the composite material is determined by durability and ability to withstand environmental loads from UV radiation, high pH, high and low temperatures, moisture, and so on. As composite railway sleepers are a relatively new technology, the performance histories of these new materials are relatively short in railway industry compared with those of more conventional sleeper materials such as hardwood, concrete and steel. Thus, short- and long-term investigation of the behaviour of composite sleepers is essential to develop the market and increase confidence in using these alternative materials.

Figure 5: Typical load distribution pattern

Figure 4: Local settlement (Type 1) (36)
4.4 Development of Design Guidelines

Guidelines for sleeper design and quality are well established for traditional timber, steel and concrete sleepers. Although relevant standard provisions containing specifications for composite sleepers are provided by the American Railway Engineering and Maintenance-of-way Association (AREMA), Chicago Transit Authority (CTA) and Union Pacific Railroad (UPRR), there are no widely recognised standard for composite sleepers (particularly Type-3). While the AREMA (2013) provides the minimum physical and mechanical performance requirements for an engineered composite sleeper (Type-1) and, FFU (Type-2) using JIS Z2101 (27) and DIN EN standard (41), these are limited to a standard gauge railway track. Design recommendations for composite railway sleepers should be developed so that their true capabilities can be exploited to achieve a satisfactory level of structural reliability.

5. CONCLUSION

Composite sleeper technologies have emerged as an effective alternative for railway track maintenance and renewal. Research and development are now focussed on these materials because of their superior performance such as (a) high strength-to-weight ratio, (b) excellent resistance against corrosion, (c) moisture and insects and (d) thermal and electrical non-conductivity which may solve the common problems of traditional timber, concrete and steel sleeper.

Composite sleeper technologies are now available ranging from sleepers made with recycle plastic materials containing short or no fibre to high volume of fibres. They have been installed in many countries with the primary application in both mainlines and bridges.

The cost of high fibre content sleepers can be minimised by optimising the material usage and improving manufacturing process. Long-term performance evaluation and establishment of the design guidelines for composite sleeper are essential for their widespread acceptance to the railway engineers and end users.

6. ACKNOWLEDGEMENT

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