A review of alternative materials for replacing existing timber sleepers

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ARTICLE INFO

Article history:
Available online 1 September 2009

Keywords:
Railway sleepers
Replacement sleepers
Hardwood timber
Alternative materials
Fibre composites

ABSTRACT

Timber is the most widely used material for railway sleepers, however, as a sleeper material it deteriorates with time and needs appropriate replacement. In recent years, hardwood timber for railway sleepers is becoming more expensive, less available and is of inferior quality compared to the timber previously available. There are also now various environmental concerns regarding the use and disposal of chemically-impregnated timber sleepers. This has resulted in most railway industries searching for alternative materials to replace existing timber sleepers. This paper presents a review of recent developments and presents an initiative focusing on fibre composites as an alternative material for railway sleepers. Fibre composites are emerging as an alternative viable construction material. An overview of the on-going research and development on innovative fibre composite railway sleepers is also discussed.

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1. Introduction

Railway sleepers are one of the most important elements of the railway track system. They are the beams/ties laid underneath the rails to support the track [1]. Their function is to transfer and distribute the transported 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 [2]. 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.

Hardwood timber is the most widely used sleeper material. Currently, there are more than 2.5 billion timber sleepers installed in the railway track throughout the world [3]. Within Australia, the state of Queensland alone has 8 million timber sleepers in-service [4]. 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. Currently, the Australian railway lines require in excess of 2.5 million timber sleepers per year for railway maintenance [5]. In the US, the railway industry replaces 2% of the 700 million timber sleepers annually [6]. Furthermore, India imports 7 million timber sleepers per year to solve its railway maintenance problems [5]. Railway industries in Germany are in need of 11 million sleepers for replacement [7]. This figure still does not include other European countries and China where railway industries are almost exclusively using timber sleepers.

The Australian railway industry spends approximately 25–35% of its annual budget on rail track maintenance [8]. According to Hagaman and McAlpine [9], sleeper replacement represents the most significant maintenance cost for the railways, exclusive of rail cost. This has cost the US railway industries more than US$1 billion per year [10]. Thus, several railway industries have adopted the spot replacement strategy to lessen the cost of track maintenance [2,8,11]. The spot replacement strategy embraces the component replacement of failing timber sleepers with new sleepers to maintain the railway tracks. This is also the maintenance program being implemented by most Australian railway industries [12]. A prerequisite of this maintenance strategy is that replacement sleepers should have properties compatible with that of existing timber sleepers. Furthermore, the method of installation in situ should also be relatively easy. However, due to the vast number of deteriorating timber sleepers in the railway track and restriction on the supply of new timber sleepers of approved quality, the demand requirements cannot be matched to replace deteriorated timber sleepers. In addition, there have been intensified pressures for limiting the use of timber sleepers from durable hardwood species because of the various environmental concerns. These problems have resulted in many railway industries throughout the world investigating alternative materials for replacement timber sleepers. In the near future, railway companies would cease using native timber and instead switch to alternative materials like plantation timber, concrete, steel or composites.

Several investigations have been carried out in an attempt to investigate the most durable, the strongest and the most cost-effective material for replacing deteriorated and damaged timber sleepers. Some of these approaches attempted to optimise the use of the already existing materials for sleepers such as plantation timber, steel and pre-stressed concrete [13–16]. Another approach was to use fibre composites as reinforcement for existing railway sleepers [17–20]. Other approaches focused on the replacement of deteriorated timber sleepers using alternative materials such as polymer concrete, reinforced plastics, rubber and fibre composite material [6,21–24].

This paper provides an overview on the existing materials for railway sleepers and the consequent issues in using these materials for replacement railway sleepers. The paper aims to provide researchers and engineers with information on the different materials being used for the railway sleepers and the on-going research conducted throughout the world directed towards finding suitable alternatives for replacing existing timber sleepers. Research and developments on fibre composite railway sleepers are highlighted in this paper.

2. Existing materials for railway sleepers

There has already been a vast research and development effort into materials for sleepers since railways were introduced. Timber sleepers are still the most common, however, use of pre-stressed concrete and steel sleepers is also increasing. The advantages and disadvantages of these railway materials will be discussed in the following sections.

2.1. Timber

Timber sleepers have a long history of effective and reliable performance in the railway environment [25]. 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 [3]. 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 [17]. In Queensland, fungal decay is the most predominant form of timber sleeper failure [9]. Splitting of timber at the ends is also common as railway sleepers support very large transverse shear loadings [26]. 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 [27]. This industry is still relying on these sleepers in the absence of satisfactory substitutes to timber [28]. In the near future, it is more likely that the chemical impregnated timber sleepers will require specific disposal procedures as timber sleepers are gradually being removed and replaced with new ones. Moreover, newer research has suggested that many of
the timber sleepers exceed the creosote critical limit set by the European Union environmental regulations and should be treated as hazardous waste when they are disposed [29]. Thus, efforts have been made in various countries to restrict the use of creosote impregnated timber sleepers and to tighten regulations on the production process due to environmental concerns [27]. Morris [30] reported that there is a need for a set of rules on how the old creosote-impregnated sleepers are to be stored and disposed of to prevent potential health hazards. Reports worldwide suggest that the disposal to landfill of preservative-treated timber sleepers is at present an acceptable option [27]. It is unlikely that existing landfills will be able to accept increasing loads of preservative-treated timber sleepers without impacting the environment. In Australia, the New South Wales Environmental Protection Agency [31] requires that treated timber be disposed of to engineered landfills with currently operating leachate management systems. Although options for the re-use of sleepers exist such as in home garden applications, these are only for untreated timber sleepers. Industries are also reluctant to recycle chemically-impregnated timber products due to concerns over workers safety and environmental problems [32]. Combustion or incineration is also not an acceptable option due to the toxicity of the ash [33]. Also the process is expensive and impractical on an economic basis. Clearly, an environment-friendly material should be developed as an alternative to chemical impregnated timber railway sleepers.

2.2. Softwood timber

Softwood timber does not offer the resistance of hardwood sleeper to gauge spreading and spike hole enlargement [34]. In addition, softwood sleepers are not as effective in transmitting the loads to the ballast as the hardwood sleepers do, thus they should not be mixed with hardwood sleepers on the railway track. However, since softwood timber is sourced mostly from plantations and is a renewable resource, a research project is being implemented by the Queensland University of Technology to transform softwood into timber suitable for railway sleepers [14]. A series of tests have already been completed which have proven the technical suitability of softwood timber for rail sleepers. However, it should be noted that this test was conducted only for more lightly used secondary rail networks.

2.3. Concrete

Pre-stressed concrete sleepers have become widely and successfully accepted for railway sleeper usage especially in high speed lines. Their economic and technical advantages are the results of longer life cycles and lower maintenance costs. With their great weight, concrete sleepers assure optimal position permanence and stability even for traffic at high speeds. In fact, many pre-stressed concrete sleeper technologies have now been developed and successfully tested. Monobloc pre-stressed concrete sleepers is the most commonly used [34]. Twin-bloc, on the other hand, is gaining popularity because it weighs less compared to monobloc sleepers. Twin-bloc sleeper is made up of two concrete parts supported by steel reinforcements. However, handling and placing of twin-bloc sleepers can be difficult due to the tendency to twist when lifted. ‘Ladder sleepers’ are another development [21]. These sleepers consist of a 12 m long pre-stressed longitudinal concrete member bound by lateral steel tubes like a ladder. The rails are supported continuously on the concrete members, which distribute the load lengthwise thereby reducing the need for ballast maintenance.

Further developments in the technology of concrete sleepers have since seen the introduction of low profile concrete sleepers. Researchers at the University of Queensland have designed the world’s first pre-stressed concrete railway sleeper specifically aimed at replacing timber sleepers [15]. Unlike existing concrete sleeper designs, the new sleeper has similar dimensions to a timber sleeper. This is of great benefit to the railway infrastructure owners who want the long term benefits of concrete but cannot (because of size restrictions) use the traditionally designed concrete sleepers. These sleepers are similar to the partial replacement sleepers shown in Fig. 3 [20]. This sleeper is specifically designed to be interspersed with timber sleepers in existing timber tracks or to replace timber sleepers that have reached the end of their useful life. However, this sleeper is limited to only mainline sleeper replacement as it has specific pattern to hold track gauge.

The problem with concrete sleepers is their heavy weight which requires specialised machinery during laying and installation. The initial cost of concrete sleepers is almost double that of hardwood timber sleepers. Studies conducted by Kohoutek...
confirmed that the sleepers manufactured from concrete performed differently to those made from timber. Concrete sleepers have high stiffness characteristics and the design requires higher depth than the existing timber sleepers. Concrete sleepers are also vulnerable to rail seat corrosion resulting from the absence of a resilient rail pad and the concrete [36]. In addition, the low profile concrete sleepers have been trialled with poor results because being relatively inflexible and with little damping it requires good standard rails and ballast to avoid damage [12].

2.4. Steel

Australia has developed a world reputation in technology related to the design and performance of steel railway sleepers. The Institute of Railway Technology at Monash University is working to minimise cost and ensure superior performance of steel sleepers [16]. Currently, steel sleepers account for over 13% of the railway sleepers used within Australia. Steel sleepers can be interspersed with the existing track but in a fixed interspersing pattern to reduce the variation in the track geometry and prevent the early in-service failure of sleepers. A steel sleeper weighs less than timber sleeper which makes it easy to handle as well as having a life expectancy known to be in excess of 50 years. However, steel sleepers are being used only on more lightly travelled tracks and are regarded as suitable only where speeds are 160 km/h or less [37].

A modern Y-shaped steel sleeper (Fig. 4) was developed to replace the traditional steel sleeper [38]. From the name itself implies, the Y-steel-sleeper is shaped like a “Y” in its horizontal layout. Compared to the usual steel sleeper, the Y-steel-sleeper possesses much greater resistance against cross movements due to the greater amount of ballast contained between the two parts of the Y-fork. However, due to its form, laying of the Y-steel-sleepers should follow strict guidelines that require high output renewal trains. Practical experiences have proven that it is not possible to adjust or pull the sleepers in the ballast subsequently by means of a simple laying device.

Steel sleepers require extra care during installation and tamping due to their inverted through profile which makes them difficult to satisfactorily pack with ballast. Observations of rail deflections under imposed vehicle track loading have shown that the steel sleepers settle a greater amount than the timber sleepers, indicating that the steel and adjacent timber sleepers are not carrying an even proportion of the imposed wheel loading [39]. Furthermore, steel sleepers are expensive and are used only in minimal number because of the fear of corrosion. Another problem with steel sleepers is fatigue cracking in the fastening holes caused by moving trains [36].

3. The need for alternatives

Many railway infrastructure companies have long been trialling 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 [40] 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 [18]. In 2006 alone, Queensland Rail (QR) in Australia purchased 80,000 timber sleepers for track maintenance and development [4]. In North America, the approximate market share for traditional timber sleepers was 91.5% compared to about 8.5% for concrete, steel and plastic composite sleepers combined as of January 2008 [37].

Concrete sleepers have the ability to provide better fine 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 [41]. 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 [17]. 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 [42]. Similarly, steel sleepers should not be mixed with timber sleepers because of the differential settlement [43]. The shape and size of steel sleepers results 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 even 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 Government Office [44] reported that the carbon dioxide emissions during the production of concrete and steel are 10–200 times higher than that of hardwood 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

Table 1

<table>
<thead>
<tr>
<th>Properties</th>
<th>Hardwood</th>
<th>Softwood</th>
<th>Concrete</th>
<th>Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptability</td>
<td>Easy</td>
<td>Difficult</td>
<td>Difficult</td>
<td>Difficult</td>
</tr>
<tr>
<td>Workability</td>
<td>Easy</td>
<td>Easy</td>
<td>Difficult</td>
<td>Difficult</td>
</tr>
<tr>
<td>Handling and installation</td>
<td>Easy</td>
<td>Easy</td>
<td>Difficult</td>
<td>Difficult</td>
</tr>
<tr>
<td>Durability</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Maintenance</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Replacement</td>
<td>Easy</td>
<td>Easy</td>
<td>Difficult</td>
<td>Difficult</td>
</tr>
<tr>
<td>Availability</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Cost</td>
<td>High</td>
<td>Low</td>
<td>Very high</td>
<td>Very high</td>
</tr>
<tr>
<td>Fasteners</td>
<td>Good</td>
<td>Poor</td>
<td>Very good</td>
<td>Poor</td>
</tr>
<tr>
<td>Tie ballast interaction</td>
<td>Very good</td>
<td>Good</td>
<td>Very good</td>
<td>Poor</td>
</tr>
<tr>
<td>Electric conductivity</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>Very high</td>
</tr>
<tr>
<td>Impact</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>60–70</td>
<td>60–70</td>
<td>285</td>
<td>70–80</td>
</tr>
<tr>
<td>Service life, years</td>
<td>20–30</td>
<td>20</td>
<td>60</td>
<td>50</td>
</tr>
</tbody>
</table>

* Based on the weight of a standard mainline sleepers.
preservatives; some of which are toxic chemicals [25] 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 [17]. 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. Table 1 summarises the advantages and disadvantages of the currently used materials for railway sleepers. An alternative material for sleeper replacement to reduce maintenance cost and overcome problems encountered using timber sleepers is therefore both desirable and necessary.

4. Fibre composite alternatives

Recent developments in fibre composites now suggest their use as alternative material for railway sleepers. These developments can be subdivided into new railway sleepers produced by combining other materials with fibre composites and the strengthening of existing sleeper materials with fibre composite wraps.

4.1. Combinations with other materials

Early developments have shown that railway sleepers made of polymer materials combined with fibre composites could enhance both physical and mechanical properties. Pattamapron et al. [45] have investigated the possibility of using natural rubber for railway sleepers. The mechanical properties of natural rubber were engineered and resulted in a better compressive modulus and hardness. However, the engineered rubber is excessively stiff and inelastic. In Japan, synthetic sleepers made of hard polyethylene foam and glass fibre are a unique development [21]. 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. Furthermore, Hoger [22] investigated the use of bulk recycled plastic as material for railway sleepers. This material showed increased strength but is not competitive in terms of cost.

A number of companies are selling railway sleepers manufactured using recycled plastic materials and fibre composites. These sleepers are said to have high strength, be more durable and to weigh similar to timber sleepers while otherwise exhibiting properties similar to their wooden counterparts in terms of damping impact loads, lateral stability and sound absorption. Railway sleepers manufactured from recycled plastic bottles with glass fibre reinforcements have been introduced in the US over the past 10 years [6]. 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 [46]. In South Africa, composite polymer sleepers are being used in the mining industry to support underground railway lines [47]. Railway sleepers made of foamed urethane reinforced with long glass fibres shown in Fig. 5, has been used in the renovation project of the Zollant Bridge in Austria [23]. This sleeper is lightweight, can be screwed together and sawed using conventional woodworking tools. Another is the recycled plastic sleeper (Fig. 6) developed by the Transport Research Laboratory in the United Kingdom [24]. 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 [7] to develop railway sleepers from mixed plastics wastes (MPW) along with glass fibre wastes and other auxiliary agents. 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. Table 2 summarises the recent developments on fibre composite railway sleepers in different countries around the world.

4.2. Strengthening of existing sleepers

Another successful application of fibre composites in railway maintenance is the strengthening of existing sleepers. Quiao et al. [17] evaluated the performance of timber sleepers wrapped in glass fibre reinforced polymer or GFRP (Fig. 7). The results of their study demonstrated that the GFRP-wood beams exhibited significant improvement in performance. The composite reinforcement increases the stiffness and the ultimate load capacity of a timber sleeper while decreasing stresses and providing a tough surface to resist plate cutting and ballast abrasion. The GFRP wrapping also improved the resistance of the sleepers to moisture. The

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**Fig. 5.** Composite sleepers installed in Zollant Bridge, Austria [23].

**Fig. 6.** Testing of plastic railway sleeper [24].
Transportation Technology Centre in Colorado, USA [48] evaluated the performance of fiberglass fabric wrapped solid-sawn timber sleepers and discovered that the fiberglass wraps improved the durability of the timber sleepers. However, metal cover plates were provided to prevent damage to the fiberglass wrap under high loads. Furthermore, Humphreys and Francey in Australia [18] made a preliminary study on the rehabilitation of timber railway sleepers with fibre-reinforced materials. The results of their study indicated that the load carrying capacity of timber sleepers externally reinforced with carbon can significantly increase if delamination of the carbon reinforcement did not occur prematurely. In another study, Shokrieh and Rahmat [19] investigated the effect of reinforcing concrete sleepers with carbon and glass composites (Fig. 8). According to the results, reinforcing concrete sleepers with two layers of glass fibres is more economical than one layer of carbon fibres as the increase in the load capacity of the concrete sleepers reinforced with carbon and glass fibres is almost equal. Ticoalu [20] 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. 9) were prepared and tested. Although the results suggested that the concept is feasible for replacement railway 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 spikes enables moisture and surface water to penetrate and can cause degradation of the LVL. Development of a replacement sleeper made from fibre composite materials which required low maintenance cost is promising.

Table 2
Recent developments on fibre composite railway sleepers.

<table>
<thead>
<tr>
<th>Country</th>
<th>References</th>
<th>Description</th>
<th>Type of application</th>
<th>Level of development</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>sleepers</td>
<td></td>
</tr>
<tr>
<td>Austria</td>
<td>[23]</td>
<td>Hard polyurethane foam and glass fibres</td>
<td>Standard sleepers</td>
<td>Trial application</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Standards sleepers</td>
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<td></td>
<td></td>
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<td>Standards sleepers and</td>
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<td></td>
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<td>bridge transoms</td>
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<tr>
<td>Japan</td>
<td>[21]</td>
<td>Hard polyurethane foam and glass fibres</td>
<td>Polymer concrete with glass</td>
<td>R&amp;D</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>fibres composite sandwiches</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>with glass fibre wraps</td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>[5, 20, 42]</td>
<td>FRP sleepers and Composite plastic sleepers</td>
<td>Standard sleepers</td>
<td>Trial application</td>
</tr>
<tr>
<td></td>
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<td>LVL with glass fibre wraps</td>
<td></td>
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<tr>
<td></td>
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<td></td>
<td>Standard sleepers and bridge</td>
<td>Trial application</td>
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<td>transoms</td>
<td></td>
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<tr>
<td>India</td>
<td>[39]</td>
<td>Composite polymer</td>
<td>Underground railway</td>
<td>Trial application</td>
</tr>
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<td>South Africa</td>
<td>[40]</td>
<td>Engineered natural rubber</td>
<td>Standard sleepers</td>
<td>R&amp;D</td>
</tr>
<tr>
<td>Thailand</td>
<td>[38]</td>
<td>Engineered natural rubber</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 7. Timber sleepers wrapped in GFRP [17].

Fig. 8. Strengthening of concrete sleepers with fibre composites [19].

Fig. 9. Fibre composite sleepers made of LVL wrapped with triaxial glass fibres [20].

Table 2: Recent developments on fibre composite railway sleepers.
program has shown that the FC transom behaved similarly, or even additional fibre reinforcements. An extensive research and testing made up of a new type of fibre composite sandwich panel with actual railway bridge in Australia [49]. The FC railway transom is sleeper materials. Another development is the fibre composite ket to date as its cost is not competitive with that of the existing conditions. However, this composite sleeper has not entered the mar-

One of the earliest technologies developed by CEEFC is a composite railway sleeper (Fig. 10) that can be used as replacement for timber, steel and concrete sleepers in existing or new railway tracks [5]. The sleeper is made of polymer concrete and glass fibre reinforcement and weighs only 61 kg. This sleeper has excellent electrical insulation properties and can be fitted with standard fasteners. The revolutionary shape of the sleeper provides it with excellent resistance against lateral movement. A trial section of track was manufactured to determine if the rail clips could be installed with sufficient accuracy in a production trial. The trial test has shown that the sleeper performs well 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. 11) which is now being trialled on an actual railway bridge in Australia [49]. 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 the FC transom behaved similarly, or even better than the hardwood transoms. The trial test also confirmed the very good ability to hold rail fasteners. The first FC transoms were installed on top of a steel railway bridge located on a heavy and busy haulage line in November 2007. The trial investigation verified that the FC transoms are performing to expectations and permitted on estimate 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 in collaboration with an Australian railway industry to develop an optimised fibre composite railway sleeper. The initial stage of the study was conducted by Ticoalu [20] to evaluate the strength and stiffness properties of existing timber sleepers used in Australian railways. The results of her experiment confirmed that the modulus of elasticity of timber sleepers varies from 9000 MPa to 26,000 MPa. However, a sleeper with modulus of 10,000 MPa showed no significant difference in bending moment, shear and deflection. This information is important in establishing the design criteria for the development of fibre composite railway sleepers. Further development is underway, with the objective of developing and testing the performance of fibre composite sleepers.

6. Challenges and possible solutions

The major challenge in civil engineering is to develop an economically competitive structure of suitable strength which will satisfy the needs of the industry and all the requirements for serviceability, durability, maintenance and ease of construction. These challenges need to be overcome for fibre composite sleepers to become a suitable alternative to timber sleepers.

The material and geometric properties have a significant effect on the design and performance of railway sleepers. In the Australian railway systems, timber sleepers need to satisfy specific requirements such as strength, durability and stiffness properties based on AS 1720.1-1997 [50]. In addition, it should be within the specified dimensions listed to meet the standard for railway track timber [51]. Fibre composites could be an ideal material for the development of railway sleepers. This composite material typically consists of strong fibres embedded within light polymer matrix offering high strength, lightweight, durability and low lifecycle maintenance costs and may provide a suitable material for the replacement of deteriorated timber sleepers.

One of the ways to reduce the cost of railway maintenance is replacing only the damaged and deteriorated timber sleepers (spot replacement). Thus, alternative material with strength and performance characteristics similar to that of timber sleepers is more suitable. Fibre composite is very appropriate as this material can be engineered based on the required structural applications. Sleepers produced from fibre composites could be manufactured with almost the same size/depth and weight to that of hardwood timber. It has excellent durability requiring less maintenance. Like timber sleepers, fibre composite railway sleepers can be inserted under the track and provide flexibility to be drilled in situ for the attachment of rail plates. Being lightweight, it offers easy installation and great flexibility in construction. Fibre composite sleepers combine properties of being high strength and low weight thereby making it competitive over other materials.

Most fibre composite sleeper developments still have a higher costs compared to traditional sleeper materials. However, in specific applications such as transoms and turnouts, larger and longer timber with higher grade is required. The cost of these special timber sleepers is higher than the mainline sleepers. The use of pre-stressed concrete and steel sleepers for these special sleepers is more expensive and difficult. A footprint of every single sleeper

Fig. 10. Sleeper made of polymer concrete and fibre composites [22].

Fig. 11. Fibre composite railway transoms [49].
to be replaced had to be made. The replacement sleepers need to be pre-measured on the site and then fabricated at the factory with accurate bolt holes. Fibre composites railway sleepers could be produced to specified lengths but basically with the same production cost. The high proportion of replacement sleepers required for bridge transoms and turnouts could further benefit from the development of fibre composite railway sleepers. Furthermore, the premium benefit of fibre composite sleepers will make this material a viable alternative to existing timber sleepers.

In most of the demonstration projects constructed to date, the design of structures using fibre composite materials has been driven by the stiffness requirement rather than strength [52]. This drawback of fibre composite materials has been overcome with the development of innovative materials and structures utilising the inherent advantages of this material. An example of this efficient structure is the composite sandwich. The main benefit of using the sandwich concept in structural components is its high bending stiffness and high strength to weight ratios [53]. The significant improvement in strength of the core structure of an innovative fibre composite sandwich being developed in Australia [54] presents an ideal opportunity to increase the use of this material for civil engineering applications. The potential of this fibre composite sandwich for sleeper applications is now being explored. It is anticipated that with optimum arrangement of fibre materials, the overall structure would achieve high flexural and shear rigidity with minimal deflection under service loads.

There is currently no widely recognised standard on composite sleepers and the standard for existing sleeper materials is being used to determine the required loads in the design of railway sleepers. It is important therefore to determine the magnitude of forces transferred to the sleepers and to understand more clearly how the sleepers respond to these forces to efficiently design the fibre composite sleepers. A more rigorous design process may be necessary in order to design the fibre composite sleepers efficiently. As a railway sleeper can be analysed as a longitudinal beam resting on an elastic foundation, the influence of changes in the modulus of the supporting ballast and subgrade in the performance of fibre composite sleepers should be analysed in detail. These might have an effect on the bending moment, shear forces and deflection of the composite sleeper. Evaluation of these contributions to the overall performance of fibre composite sleepers could lead to an optimised and cost effective cross section.

Fibre composite sleepers are a relatively new technology compared to the more conventional hardwood, concrete or steel sleepers. Most of the fibre composite sleepers developed and trialled are very much in their formative stage (Table 2). Thus, developments of specifications for this new material are intended to provide the necessary guidance in the design, manufacture and use of fibre composite railway sleepers. The specification should contain a minimum performance requirement for this innovative material. Performance testing should be continuously carried out on these new materials to ensure that they will carry the required loads and solve the maintenance issues in timber sleepers.

The many advantages of fibre composites support the development of lightweight, high strength and more durable sleepers for replacing timber sleepers. Fibre composite sleepers have a longer service life and require minimal maintenance. They have similar installation requirements to those of timber sleepers which reduces labour costs. Most importantly, fibre composite materials use less amounts of energy and release small amounts of greenhouse gases.

Fibre composite sleepers will find their place in the railway industry. There is a huge level of research interest in this material, however, the potential end-users are still reluctant to use this material because of issues such as security of supply, lack of material and design standards and approved performance requirements. Continued efforts are needed to improve their performance and further innovations should be trialled to construct sleepers from these materials that provide a suitable solution and cost effective alternative to existing timber sleepers.

Fibre composite alternatives for railway sleeper have the ability to compete effectively with conventional sleeper materials. Several researches and developments on fibre composite sleepers have shown that this alternative material has physical and mechanical properties comparable or even better than that of timber sleepers. However, the performance history of these new materials is relatively short compared to timber sleepers. Continuous research and development are essential to develop the market and increase confidence in using this alternative material. Field trials and in-service performance evaluation will be very valuable in achieving this goal. Finally, development of national and international standards will encourage the adoption of fibre composites as an alternative railway sleeper material.

7. Concluding remarks

The widespread deterioration of most timber sleepers country-wide and the declining supply of quality timber for replacement sleepers resulted in many railway industries relying on alternative materials for sleeper replacement to maintain the functionality of railway structure during its service life. However, materials like concrete and steel have not proven reliable alternatives to existing timber sleepers. Research and development has focused on fibre composites as the many issues related to the currently used sleeper materials could be simulated using this material.

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References


[51] Australian Rail Track Corporation Ltd. Engineering (Track and Civil) Standard, ETA-02-01 Timber sleeper, turnout and bridge transom specification.

