COMPARISON OF SUSTAINABLE MATERIALS FOR RAILWAY TRACK SUPPORT SYSTEMS: A LITERATURE REVIEW

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ABSTRACT

Timber transoms have been extensively used in the railway industry for decades and are considered the most efficient and effective in terms of reliability and performance for railway infrastructure transom components However, many studies have raised concerns surrounding the future of sustainable use and cyclic maintenance and replacement requirement of timber transom's in railway infrastructure Over the past decade, there has been significant research and development in alternative railway transom replacements using a variety of new materials. It is vital to develop a detailed understanding of existing and new alternative transom materials that are emerging into the railway industry and delineate whether these materials may be suitable as a sustainable alternative to traditional methods. Hence, the aim of this paper was to evaluate suitability of alternative transom materials as a substitute to existing transom materials in railway track support systems. The alternative materials considered were Precast Concrete and Composite Fibre Technology Panels against the conventional timber transforms. The paper offers a comparison between these materials through a literature review. It was concluded that the fibre composite alternative has the most beneficial alternative transom option and the railway industry could consider this material as an innovative, sustainable material for railway track support system.

Keywords: *Fibre Composite Technology; Precast Concrete; Railway Track Support Systems; Sustainability Timber Transforms.*

1. INTRODUCTION

The railway track support system is designed to interact with one-another to proficiently transfer imposed dynamic loading from the railway carriage wheels, through the support system and into the foundation (or other support system) (Esveld, 2001, Griffin *et al*., 2015, Kaewunruen and Remennikov, 2010, Remennikov and Kaewunruen, 2008). Railway infrastructure requires regular inspections to assess the service condition of each component of the tracks superstructure and the supporting substructure to ensure it is suitable operation. Transom inspection and replacement cycles must be efficient by balancing the opportunity to replace various components whilst the track is in possession of the maintenance crew, whilst also being cost effective (Krezo *et al*., 2014).

Railway sleepers are one of the most important elements of the railway system. Sleepers have the primary function of transferring and distributing lateral and longitudinal railway vehicle loads into the stratum below, and to provide a fixation point for maintaining a consistent gauge width of the railway tracks (Esveld, 2001, Manalo *et al.*, 2010, Remennikov and Kaewunruen, 2008). Commonly, in non-ballasted tracks, the sleeper components are referred to as 'transoms' or 'cross-ties', but still provide the same function as sleepers in ballasted track systems.

Timber sleepers and transoms have been used extensively for decades in the railway industry on an international scale (Esveld, 2001, Manalo *et al*., 2010, Sadeghi and Barati, 2012). Despite recent developments in alternative sleeper and transom materials, the mechanical properties in which timber inhibits make it the most effective railway track support component due to its ability to absorb and distribute the intense dynamic

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loading conditions (Manalo *et al*., 2010). However, in today's highly strenuous environment, timber materials experience issues with meeting its expected service life and concrete has now become the preferred sleeper and transom material.

In New South Wales, Australia, RailCorp (2013) produced an Engineering Standard - ESC Sleeper and Track Support - that provides specifications for timber and concrete sleepers, and polymer concrete half-sleepers. All transoms in non-ballasted tracks must meet the performance requirement set out in RailCorp's Engineering Standard - SPC 311 Timber Transoms - (RailCorp, 2009). This literature review provides further detail on the past, current and future developments in sleeper and transom support components. By identifying issues with existing transform materials, the literature intends to discuss new innovative alternative materials, their application and performance in railway infrastructure. The aim of this study was to evaluate suitability of these alternative transom materials as a substitute to existing transom materials in railway track support systems.

2. LITERATURE FINDINGS

2.1. TIMBER SLEEPERS AND TRANSOMS AND THEIR LIMITATIONS

Timber transoms have been extensively used in the railway industry for decades and are considered the most efficient and effective in terms of reliability and performance for railway infrastructure transom components (Rothlisberger, 2002, Zarembski, 1993). Timber transoms have been extensively used on an international scale as the primary rail support members for various types of railway service networks including regional freight systems, passenger rail services, light rail and even high speed rail services. Until recent developments in alternative materials, timber sleepers were the primary material used in typical ballasted track systems (see Figure 1 (a)). Timber is also used in non-ballasted track support and are commonly referred to as transoms or cross-tie components (see Figure 1 (b)) (Nunez, 2013).

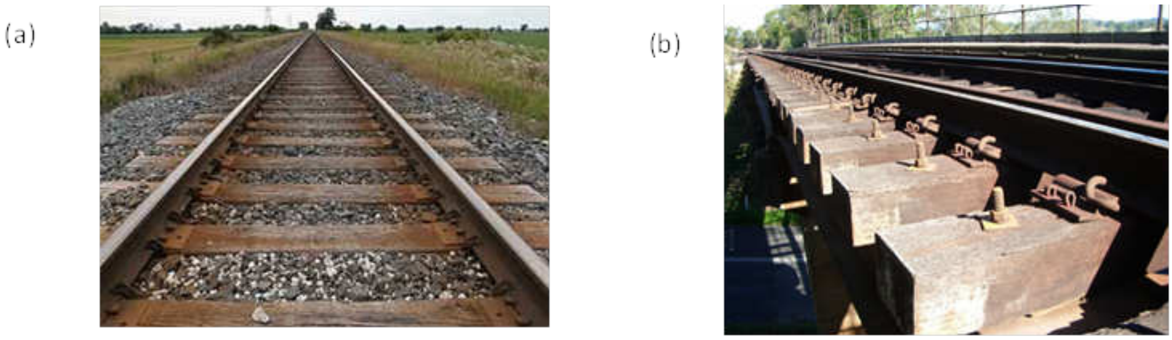

Figure 1: (a) Timber Sleepers in Ballasted Railway System (B) Timber Transoms in a Non-Ballasted Railway System (Nunez, 2013).

Timber is primarily used as a railway transom support material due to its adaptability in terms of on-site workability, ease in handling and easy replacement (Manalo *et al*., 2010, Miura *et al*., 1998). In Australia, the average service life for timber transoms equates to approximately 20 to 30 years and this estimate is substantially effected by; the frequency and distribution of the loads imposed, the environment in which the transoms are exposed to, and the condition of the adjacent sleepers (Manalo *et al*., 2010, Yun and Ferreira, 2003).

Australian railway lines require more than 2.5 million timber sleepers per year for replacement alone (Manalo *et al*., 2010). Depending on how defective the transoms that have been replaced are, determines whether they are re-used, recycled or disposed of. Manalo *et al*. (2010) identified that the two most common defects resulting in sleeper replacement are (a) splitting and cracking, and, (b) fungal decay. In addition to these, Hagaman and McAlpine (1991) examined 2200 sleepers in Queensland, Australia and identified the following additional modes of failure for timber transoms which included, knot failure, localized rail cut at the fasteners, sapwood failure, general weathering, and in some cases termite damage.

Studies have raised concerns surrounding the future of sustainable use and cyclic maintenance and replacement requirement of timber transom's in railway infrastructure (Manalo *et al*., 2010, Miura *et al*., 1998, Qiao *et al*., 1998, Rothlisberger, 2002, Yella *et al*., 2009, Hagaman and McAlpine, 1991). Manalo *et al*. (2010) articulated that the most prevalent problem that the railway industry is now facing is the declining availability of quality timber for railway sleepers. Hardwood timber is becoming scarce and its quality is declining, which is making it less desirable for what was once considered a quality and renewable resource (Manalo *et al*., 2010, Robinson and Plywood, 2009).

Griffin *et al*. (2015) and Krezo *et al*. (2014)) identified that the replacement of timber transom components is responsible for producing six times greater greenhouse gas emissions than equivalent reinforced concrete counterparts. Esveld (2003) discussed that with the increasing need for timber transom replacement on ballasted railway tracks, the design of innovative support materials offers a good opportunity to minimise overbearing maintenance schedules and the demand for timber transoms which are becoming a highly sort-after product. This ideology reinforces the need for integrating alternative sleeper and transom materials such as Composite Fibre Technology.

The Australian Forest and Wood Product Statistics indicated that hardwood forestry in New South Wales, Australia has seen a decline in the total volume of timber harvested by 44% over the past decade (Timber NSW, 2015). The rate of renewal of hardwood timber species as transoms must be less than the rate of renewal for the product to be sustainable. Timber NSW (2015) described that a typical hardwood plantation takes 35 to 40 years to reach a level of maturity before it can be commercially logged. With the expected service life of timber transoms being only 20 years or less, it can be seen that the rate of renewal of hardwood timber species for timber transom replacement is not meeting the demands at a sustainable rate. With declining numbers of Australian hardwood species being harvested, this is threatening the sustainable ongoing use of the material.

Hazardous chemical products, such as ‘creosote’, have been used to extend the service life of the transom component. Thierfelder and Sandström (2008) indicated that creosote impregnated transoms can have an increase service life by up to nearly 50 years which is more than double that of a typical un-treated timber transom. However, there is a growing concern with the disposal techniques of creosote soaked timber sleepers when replacement is required (Manalo *et al*., 2010). Sinclair Knight Merz Pty Ltd and South Australian Environmental Protection Agency (1999) conducted a report for the Environmental Protection Authority (EPA) which identified that the disposal and re-use for treated timber has not yet been fully developed. Incineration is the most effective method of disposal, however, is cost prohibitive due to the chemical control requirements. Manalo *et al*. (2010) stated that “the New South Wales Environmental Protection Agency requires treated timber to be disposed of at engineered landfills with leachate management systems”. Alternatively, re-use applications of non-treated timber sleepers typically only include landscaping.

2.2. CONCRETE SLEEPERS AND TRANSOMS AND THEIR LIMITATIONS

The development of concrete transoms as an alternative to timber transoms has been widely implemented and accepted by the railway industry internationally, particularly for the use in high speed railway networks (Manalo *et al*., 2010, Sadeghi and Barati, 2012, Zarembski, 1993). Concrete sleepers were introduced in the 1980’s, and since then, various developments in conventionally reinforced and pre-stressed concrete transoms have been developed. Over the years, sleeper design has been focused specifically to maximise strength, durability and performance, whilst remaining low in cost and low in labour requirements. The average design life of concrete sleepers is 50 years and this far outweighs that of timber transoms 20 years (Ferdous *et al.*, 2015).

There has been a substantial development in the design of precast concrete sleepers and transoms resulting in an increased application in railway networks as track support components. In design, there has been an emphasis on efficiency during manufacturing, as well as encouraging methods for better onsite handling practices. All concrete sleepers are generally precast and transported to site for placement. Concrete sleepers are beneficial for use in railway track support as they provide economic and technical advantages with increased service life and an overall reduced maintenance costs (Manalo *et al*., 2010). Despite concrete sleepers being more durable and reliable in service than timber counterparts, Manalo *et al*. (2010) indicated that concrete sleepers are far too expensive, quite heavy and are often incapable of meeting the 50 year service life. However, contrary to this, Crawford (2009) articulated that with proper maintenance of rails, pads, fastenings, ballast and sub-grade, concrete transoms can quite easily meet their anticipated 50 year design service life. (Bureau of Transport Economics (1972), Manalo *et al*. (2010)) showed concern that the substantial weight difference between timber transoms and reinforced concrete was a significant disadvantage for the materials adopted use.

Concrete transoms are substantially higher in cost to produce than timber transoms (Bureau of Transport Economics (1972), Ferdous *et al.* (2015), Manalo *et al.* (2010), Sadeghi and Barati (2012)). They are more than three times the weight of a traditional timber transom, and susceptible to 'bending cracks' from highly intense dynamic loading of passing locomotives, as well as 'sleeper breakage due to derailment' (Zakeri and Rezvani, 2012). However, Raju (2006) identified that the percentage of failures due to cracking of sleepers is in order of 1% in German railway lines for the design life of the sleepers.

The substantially larger outlay costs for purchasing concrete transoms is more than double the cost for equivalent timber transoms. This puts a negative stigma around the use of this material due to scarcity of funds (Sadeghi and Barati, 2012). However, various comparative studies between concrete and timber transoms recognise that the maintenance cost is substantially reduced as a result of the improved serviceable performance (du béton, 2006, Manalo *et al*., 2010, Zarembski, 1993).

Concrete constructed transoms are now considered as a traditional method of railway construction. However, their design efficiency in production and on-site handling is yet to be refined for optimum performance ergonomically and practically. The Australian railway networks have seen concrete systems being widely implemented as an alternative to timber sleepers in both ballasted track systems (Lo, 2014) and the use of slab tracks in non-ballasted systems, specifically in bridges and tunnels (Bilow and Randich, 2000). A number of comparative studies have been conducted comparing timber and concrete as sleeper materials, however these studies have not examined the LCC benefit of using Composite Fibre as sleeper material (Bureau of Transport Economics, 1972, Ferdous *et al*., 2015, Manalo *et al*., 2010, Sadeghi and Barati, 2012). This reinforces the purpose of this study to undertake a LCC analysis of utilising CF technology.

2.3. FIBRE COMPOSITES AND THEIR POTENTIAL FOR SLEEPERS AND TRANSOMS

A number of new alternative technologies have been developed as transom replacement solutions, and yet their introduction into the railway industry has been very limited. This section aims to highlight innovative sustainable sleeper and transom technologies, in particular fibre composites, and discuss their benefits and applications as new or replacement transom and sleeper components.

The key benefit of using reinforced fibre composites sleepers is that they can be designed to imitate the structural action of a timber transom components. They have the ability to be integrated as a replacement component in an existing system and are far more effective than concrete or steel (Van Erp and Mckay, 2013). However, Van Erp and Mckay (2013) indicated that the introduction of Fibre Composites to Australian railways has been limited despite the many benefits. The price of FC materials are approximately 5-10 times higher than a standard timber sleeper making them commercially unviable (Van Erp and Mckay, 2013). However, due to significant reduction in maintenance requirements, cost savings are expected in the longer run.

Fu and Lauke (1996) concluded that the effects of fibre length distribution and fibre orientation distribution has identified a vital role in the strength characteristics of fibre composite components. Ferdous *et al.* (2015) identified that there are various types of fibre composite sleepers available in the railway industry, each of which have varying fibre compositions in terms of length, orientation as well as the addition of filler materials. These fibre composite railway sleepers are categorised into three different types due to their material composition.

- Type 1 fibre composite sleepers have short or no glass fibre reinforcement with the addition of filler materials including bitumen or recycled plastics (Ferdous *et al*., 2015, Van Erp and Mckay, 2013).
- Type 2 fibre composite sleepers have long continuous longitudinal glass fibres creating great flexural strength (Ferdous *et al*., 2015, Van Erp and Mckay, 2013). Ferdous *et al*. (2015) stated that these (Type 2) sleepers are suitable for ballasted rail track where the stresses in sleepers are governed by flexural loading. However, they are less than ideal in bridge applications as transom components where they are subjected to high level of combined flexural and shear forces.
- Type 3 sleepers have fibre reinforcement in longitudinal and transverse directions and consequently both the flexural and shear strength of these polymer sleepers is significantly increased (Ferdous *et al.*, 2015). This makes Type 3 fibre composite products more desirable as a bridge transom component.

2.4. APPLICATIONS OF FIBRE COMPOSITES IN AUSTRALIA AND INTERNATIONALLY

Van Erp and Mckay (2013) stated that both Type 1 and Type 2 fibre composite polymer sleepers had been introduced into the Australian market. Van Erp *et al*. (2005) indicated that Queensland Rail had implemented trial fibre composite polymer sleepers in April 2004. More recently, Van Erp and Mckay (2013) stated that an Australian Fibre Composite product called 'CarbonLoc', a type 2 sleeper, had been installed in a Railway bridge as transom components in the Hunter Valley. CarbonLoc is referred to as a Fibre-reinforced Foamed Urethane (FFU) product due to its material composition. FFU characteristically acts similarly to timber enabling the material to be integrated into the existing system with ease (Koller, 2015). FFU is easily workable for handling and processing (Koller, 2015). Koller (2015) indicated that in Japan, an investigation was carried out into FFU sleepers that had been installed and in operation for 30 years. The results concluded that the FFU sleepers would still be serviceable for a further 20 years.

The key characteristic that separates Fibre Composites from other transom materials (i.e. concrete, steel and timber) in railway networks is that fibre composites offer 40% better strength characteristics in comparison to their weight (Van Erp and Mckay, 2013). This offers many benefits in relation to onsite handling processes, transportation to site, and reduced dead-load on the existing structural support system. Other benefits include exceptional installation times in comparison to concrete counterparts, longer service life, reduced maintenance, excellent corrosion resistance and with the use of plant-based-based polymers, the effect on the environment is minimal (Van Erp and Rogers, 2008).

A new, Type 3 fibre composite polymer (CFT) product was developed in response to the need for sustainable building solutions for existing and new structural components in various industry sectors. Van Erp and Rogers (2008) showed that the new material has major environmental benefits over traditional construction materials. It uses only a fraction of the energy in the manufacturing process compared with traditional construction materials and is carbon neutral. The material has extensive uses in the building market as well as uses in bridge construction and maintenance. Bakis *et al*. (2002) stated that the forms of fibre composite polymer (CFT) construction materials has more advantage with the perceived near-term economic and sustainable benefits of the materials. CFT has been integrated as replacements for existing heavy structural components, and as new structural elements for various new designs (Queensland Government, 2013) and has been used for conveyor-belt systems in the mining industry, new road bridges and rehabilitation of existing timber bridges, and in pedestrian walkway structures (Wagners CFT, 2016). It has also been utilised in marine environments as support structures, electrical cross-arms of high-voltage towers, and as reinforcement in concrete slabs (Wagners CFT, 2016). Table 1 provides a comparison of the different railway materials discussed above.

Overall, it is evident through this literature review on the need for the application of alternative materials for railway support structures. Timber sleepers and transoms are functional in service due to their ability to absorb locomotive loads, however they are incapable of meeting their design life. Monobloc concrete sleepers provide superior strength and increased service life in comparison to timber, however they are expensive, heavy to manoeuvre onsite, and experience brittle failure. Fibre Composites offer the strength characteristics of concrete and steel, the design life is far more superior, and the maintenance requirements are far less. With the limited introduction of Fibre composite transoms (in particular, Type 3) into Australian Railway systems, ongoing costly maintenance requirements that are experienced with timber and concrete materials could be overcome and thereby address the environmental issues.

Table 1: Comparison of Transom and Sleeper materials

Criteria	Timber Sleepers and Transoms		Concrete Sleepers and Transoms		Composite Fibre Sleepers and Transoms	
	Advantages	Disadvantages	Advantages	Disadvantages	Advantages	Disadvantages
Properties	Good mechanical behavior Light-weight	Prone to cracking/ splitting Experience fungal decay Termite attack	Monolithic structural action.	Experience cracking. Experience breakage due to high dynamic loading	Good mechanical behavior for trains (similar to timber) Lightweight and corrosion resistant	Degrades strength when exposed to direct sunlight Protective paint required to limit solar exposure
Durability	Durable in optimum locations	Often incapable of meeting design life (20 years)	Durable (capable of meeting 50yr design life).		Durable (expected 100 year design life)	
Cost	Cheap in capital cost	High maintenance costs	Pre-cast manufacturing for efficient transportation.	High capital cost to purchase	Pre-cast manufacturing for efficient transportation.	High capital cost to purchase
Sustainability	Re-usable for other applications (landscaping, building etc.)	Declining volume of hardwood available to meet rate of renewal.	Constructed from recyclable materials.	High carbon emissions during manufacturing.	Readily available resources	Limited use due to emerging nature

3. CONCLUSIONS

The aim of this paper was to evaluate alternative transom materials as a substitute to existing transom materials in railway track support systems. The alternative materials considered were Precast Concrete and Composite Fibre Technology Panels against the conventional timber transforms. Based on the literature findings, it can be concluded that the fibre composite alternative has the most beneficial alternative transom option. The results dictate that transom materials with higher design life, higher capital costs, less installation time, and less maintenance requirements is more beneficial than less expensive alternative materials that require more maintenance and high labour costs required to perform maintenance operations. The composite fibre alternative offers increased service life, faster installation process and less overall long term maintenance expenditure, as well as offering a significantly less dead-load on the structure (than concrete alternatives).

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