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Recent Australian Developments in Fibre Composite Railway Sleepers

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ABSTRACT: Despite a range of environmental concerns, railway companies worldwide continue to use timber sleepers to maintain their existing timber lines. In recent years reinforced polymer sleepers have emerged as a potential alternative but because of their high price their uptake has been very slow. In Australia a number of exciting new developments in reinforced polymer sleepers have recently been introduced into the market place by Carbonloc Pty Ltd, a spin-off company of the University of Southern Queensland in Toowoomba. This paper will discuss the details of these new polymer sleepers and compare their performance to the polymer sleepers that have been available in the market for some time.

Keywords: Railway sleepers, cross ties, reinforced polymers, fibre composites, Australian developments

1 INTRODUCTION

Railway companies worldwide have used timber sleepers for nearly two centuries and there are millions of old timber sleepers in railway lines throughout the world that need to be replaced. However, good quality timber has become scarce and more expensive. Whilst concrete sleepers have gained increasing acceptance, their size and stiffness typically limits their use to locations where complete sleeper replacement is undertaken or where new track is constructed. Areas where railway owners continue to use large numbers of timber sleepers include:

- Maintenance of existing timber lines
- Turnout sleepers (switch ties)
- Transoms (bridge ties)

In recent years reinforced polymer sleepers have emerged as a potential alternative to timber sleepers. Different from steel and concrete, reinforced polymers 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. Despite this potential the uptake of these polymer sleepers in Australia has been extremely limited. The main reason for this is their price which has been approximately 5-10 times higher than that of a standard timber sleeper making them commercially unviable.

Two different types of polymer sleepers have been available in the Australian market for some time. Both types of sleepers are conveniently referred to as “composite sleepers” however the composition and structural behavior of these sleepers are quite different.

Type 1 – Polymer sleepers with short or no glass fibre reinforcement

These sleepers consist of recycled plastic or bitumen with fillers. The fillers often include sand, gravel, recycled glass or short glass fibres (shorter than 20mm) and they are generally included to increase the stiffness and/or crack resistance. Because of their short length these fillers do not have a major reinforcing effect and the failure behaviour of these sleepers is mainly polymer driven. Due to the lack of any long reinforcement fibres these sleepers are very flexible and expand and contract significantly with temperature, which can result in undesirable gauge widening. The most prominent sleeper in this category was marketed by an American company called Tietek and more recently Axion. Table 1 summarizes the advantages and disadvantages of this type of polymer sleeper.

Table 1 Advantages and disadvantages of Type 1 sleeper

Advantages	Disadvantages
Easy to drill and cut	Low Strength
Good durability	Low Stiffness
Recycled material	Limited design flexibility
Reasonably priced	Temperature sensitive
Tough	Creep sensitive
	Low fire resistance

Type 2 – Polymer Sleepers with long longitudinal glass fibres

This type of sleeper has long continuous glass fibre reinforcement in the longitudinal direction and no or very short random fibre reinforcement in the transverse directions. The longitudinal flexural behaviour is mainly determined by the long glass fibres. The structural behaviour in the transverse directions (shear) is largely polymer based. This type of sleeper performs well in applications which are dominated by flexural loading (sleepers on ballast) but it is less than ideal in situations where they have to carry high shear forces (sleepers on bridges). The major player in the Australian market for this type of product is the Japanese company Sekisui.

Table 2 Advantages and disadvantages of Type 2 sleeper

Advantages	Disadvantages
Easy to drill and cut	Average shear strength
Good durability	Average Shear Modulus
Good flexural strength	Expensive
Good Modulus of Elasticity	Limited design flexibility
	Marginal fire resistance

Despite the advantages of these polymer sleepers uptake of both types of sleepers in Australia has been very slow.

During the last few years Carbonloc Pty Ltd, a spin-off company of the University of Southern Queensland (USQ) in Toowoomba, Australia, has dedicated a significant research effort toward reducing the cost of reinforced polymer sleepers without reducing their overall benefits. This work has concentrated on three types of sleepers; timber replacement sleepers, turnout sleepers and transoms. The following sections will describe each of these sleepers in more detail.

2 TIMBER REPLACEMENT SLEEPERS

The research approach adopted by Carbonloc to address the high costs of standard polymer sleepers is based around the observation that a standard timber sleeper has a rectangular shape because that is the easiest way to cut a sleeper out of a tree. Any extra work to change this rectangular shape would only add to the cost of the sleeper and therefore does not make sense. However, as a sleeper is only loaded in two distinct locations (at the rails) it does not need the same strength along its total length. In between the rails there are different strength requirements from under the rails. By taking into account the real loading and support conditions and using the latest in computer analysis software, Carbonloc has managed to create a sleeper that requires significantly less volume of polymer material while still complying with all strength and stiffness requirements of a timber sleeper (Fig. 1).

Figure1. New Carbonloc Reinforced Polymer Sleeper

The new shape uses only 1/3 the material of a standard rectangular sleeper resulting in a polymer sleeper which is only marginally more expensive than a timber sleeper. An innovative casting process is used to produce the sleeper and this approach allows for the placement of reinforcing fibres in both the longitudinal and transverse directions. Consequently the flexural and shear behaviour of these sleepers are all fibre dominated and the required load carrying capacity can be easily tailored.

The sleepers can be drilled on site similar to timber sleepers and are available with resilient fasteners or standard rail screws. The innovative casting process creates a very strong layer in the rail seat area and allows for this area to be shaped similar to concrete sleepers which removes the need for steel rail plates (Figure 2).

Figure 2.Timber replacement sleeper with shaped rail seat area

In addition to reducing the amount of polymer material in the sleeper, the novel shape also offers significantly increased resistance against lateral movement (particularly important in curved track). Because of the protruding rail seat areas it is difficult for the sleeper to slide sideways. The middle section of the sleeper will generally be covered by ballast which will significantly reduce damage to the sleeper in the case of derailments.

This new sleeper is currently being trialed in Australia by Queensland Rail and in the USA by Union Pacific. A provisional patent application has been submitted.

3 TURNOUT SLEEPERS

A railway turnout enables a train to be guided from one track to another (Figure 3). The structure of a timber turnout is complicated and requires special sleepers with varying lengths (up to 4-5m) and fastening locations. Because of diminishing availability of long hardwood sleepers there is a need for an alternative solution that is compatible with existing timber turnout sleepers. The type 2 sleepers mentioned earlier have been successfully used for turnouts but they are very expensive.

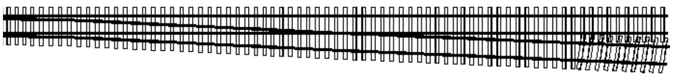

Figure 3 A right handed turnout

Following a request from a Taiwanese company for a more economical alternative to the Type 2 turnout sleeper, Carbonloc developed a new reinforced polymer sleeper using its proprietary casting technique. The sleeper has a prismatic rectangular shape and contains long glass reinforcement fibres in both the longitudinal and transverse directions. By strategically concentrating the fibres in locations where they are most effective in carrying the bending moment and shear forces, the total amount of fibres used is significantly less than in a typical Type 2 sleeper. This economical use of materials combined with the fast production cycle has resulted in a polymer sleeper which is significantly more cost effective than the alternatives. The sleepers were independently tested by USQ & SGS Australia Pty Ltd and met or exceeded the requirements of JIS E1203 2007. In December 2012 120 turnout sleepers were supplied to Taiwan (Figure 4).

Figure 4. Turnout Sleepers for Taiwan

4 TRANSOMS

Transoms are large sleepers used on railway bridges to transfer the loads from the rails to the bridge girders (Figure 5). In general there is no ballast present and the transoms have to transfer all the loads.

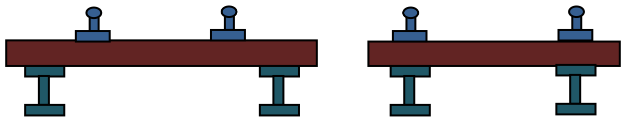

Figure 5. Transoms with different locations of the rails relative to the bridge beams

The loads on the transoms depend on the position of the rails relative to the bridge beams. In Australia the rails and the support beams are generally off-set by approximately 250mm which creates significant bending moments and shear forces in the transom. In other countries (for example India) the rails are often located directly above the support beams in which case the transom acts like a packer and is not subjected to major bending moments and shear forces.

In Australia due to the off-set of the rails the strength requirements for transoms are significantly higher than those for standard sleepers which are supported by a ballast bed. Table 3 shows the limit state design requirements for a typical transom.

One of the disadvantages of glass fibre reinforced polymer sleepers is that they do not exhibit ductile behaviour and may fail with little warning. For sleepers supported by a ballast bed this is generally not a major issue because even a cracked sleeper will still continue to provide some support to the rail. However for transoms this can be a serious problem because once failed they no longer support the rail. In this type of application sleepers that exhibit ductile behaviour when overloaded have a major advantage. Carbonloc has developed a hybrid polymer sleeper which exhibits this desired ductile behaviour. This is achieved by including some steel reinforcement bars at strategically chosen locations within the sleeper. This does not affect the electrical insulation properties of the sleeper and creates a very reliable structural element that gives ample warning of failure. Figure 6 shows a typical cross section of Carbonloc's transom concept together with the characteristic load-unload-reload deflection curves (Figure 7).

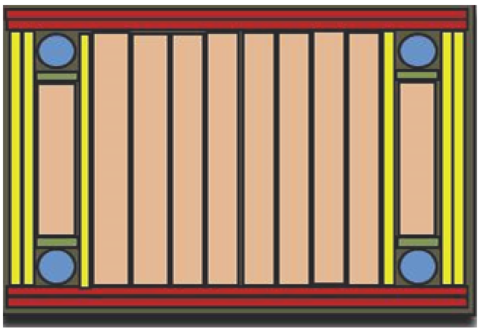

Figure 6 Transom cross section

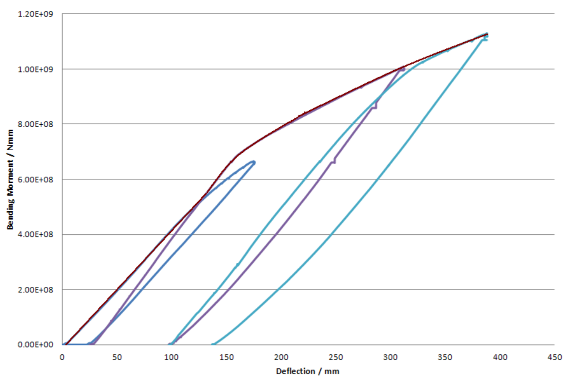

Figure 7 Load displacement curve of transom

In November 2007 the Australian Rail Track Corporation (ARTC) installed twenty two of these transoms on a railway bridge in the Hunter Valley, Australia (Figure 8)

Figure 8 Transoms installed in Hunter Valley

Limit State Action Effect	**Axle load (tonne)**	**Distance rail to girder web**	**Limit State Design requirement**
Strength Limit State Bending Moment	30	250 mm	60 kNm
Strength Limit State Shear Force	30	n/a	200 kN
Fatigue Limit State Bending Moment	30	250 mm	18.75 kNm
Fatigue Limit State Shear Force	30	n/a	75 kN

Table 3 Limit state design requirements for a typical transom

These sleepers are subjected to approximately 10 million load cycles per annum and have been in use for close to 6 years. To date they have been performing extremely well and they were recently approved for general use in the ARTC rail network.

5 ENVIRONMENTAL BENEFITS

Environmental consideration in the choice of construction materials is an issue of growing importance. Internationally, the construction of buildings, roads, railway lines and bridges is a major cause of resource depletion and environmental pollution. According to a report by Forintec Canada Corp (Forintec 2003), the construction industry consumes more of the earth's natural resources than any human activity. It consumes 40% of raw materials and energy produced on the planet and creates tens of millions of tonnes of greenhouse gasses, air and water pollution and other waste. Given this situation it is essential to improve on current processes involved in the production of building products and to shift the focus of the construction industry to materials and structures that are more environmentally sustainable.

Carbonloc has responded to this need for change with the development of a highly sustainable polymer material. The formulation uses a substantial amount of plant (non-food) based polymers rather than fossil fuel based polymers. Up to 50% replacement of fossil fuel based polymers by plant-based polymers has been achieved to date, with higher levels of replacement already demonstrated in lab work. This exciting development has resulted in an environmentally sustainable composite material with excellent structural and durability properties.

Because a major percentage of the polymers used are plant-based, the atmospheric carbon absorbed by these plants during their growth becomes permanently locked into the polymers during the manufacturing process, hence the name CarbonLoc^{TM}. By recycling the product at the end of its useful life, this carbon will not be returned to the atmosphere which greatly assists in reducing the carbon footprint of the construction industry.

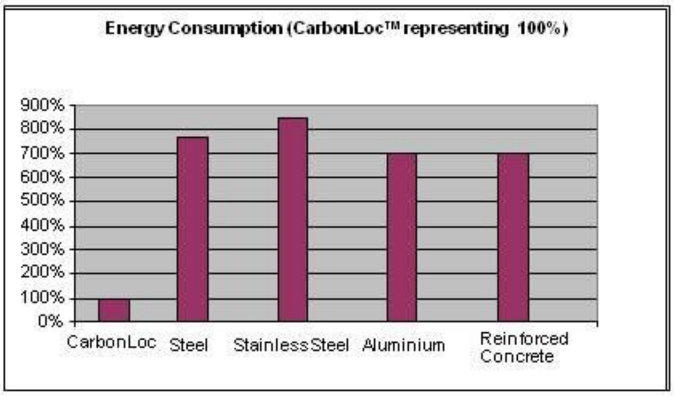

Figure 9 Comparison of Energy Consumption for CarbonLoc^{TM} and four common building materials

Compared to the production of concrete and steel, CarbonLoc^{TM} uses less than 1/7th the energy to produce and maintain (Figure 9), creates 1/10th the volume of polluted water and about 1/5th the air pollution. It is predicted to last 50 to 100 years with little maintenance and it can be fully recycled at the end of its useful life. To date the material has been successfully used for floors, bridge decking, structural beams and railway sleepers.

7 SUMMARY AND CONCLUSIONS

This paper presents a comparison between two more traditional fibre composite sleepers in the Australian market and a new type of composite sleeper recently introduced by Carbonloc Pty Ltd, a spin-off company of the University of Southern Queensland in Toowoomba. Due to the use of a new innovative resin technology and a highly optimized shape, the new sleeper offers improved performance at a much more economical price. In addition to the structural benefits, the new sleeper also has a range of environmental benefits due to the use of natural polymers. A number of Australian and American railway companies are currently trialing this sleeper in their networks.

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