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Latest Trends and Technologies for Railway Engineering Using Composite Sleepers

[1] Abhishek Budhavant, [2] Priyanka Danane, [3] Shreyas Joshi , [4]Dr.ShantiniBokil
[1][2][3] Research students, [4] Professor and Head
[1][2][3][4] Dept. of Civil Engineering, MITCOE, Pune

***Abstract*— Railway sleepers are one of the most important elements of the railway track system. Timber is the most widely used material for railway sleeper. Although timber sleepers are the most common, use of pre-stressed concrete, steel materials are also increasing. Composite sleeper is becoming suitable alternative for replacing the existing concrete, steel and particularly timber sleeper. Use of composite sleepers not only reduces the land pollution from disposed waste plastics but also ensure less destruction to the forests. Composite sleeper technologies are already available in the last 20 years but they have limited acceptance by the railway industry. In recent years, reinforced polymer sleepers have emerged as a potential alternative but their implementation has been very slow. This paper reviews the use of composite sleeper which is a new initiative on focusing of alternative sleepers, their advantages and disadvantages over traditional sleeper. For the upcoming years every construction activity needs to focus on sustainable engineering and this research attempts to give the alternative smart solution for future infrastructure engineering sector.**

Keywords— Infrastructure and Sustainable engineering, Railway sleepers, Composite sleeper, reinforced polymer sleepers.

I. INTRODUCTION

Railway sleeper are one of the most important element of railway track system. Their function is to transfer and distribute rail load to ballast and hence secure displacement of gauge, maintaining gauge-width. Sleepers also resist the lateral and the longitudinal movement of the rail system. Sleepers are exposed to large temperature variations, excessive amount of UV light, severe weather conditions, attack from microorganisms and insects. To prevent the occurrence of accidents, the materials used for manufacturing sleepers need to be stiff, strong and resistant to UV light, temperature fluctuations, and insect attack. Also, the material should be nonconductive to prohibit electrical flow between the rails.

Different kinds of materials are used in sleeper production. Hardwood timber is the most widely used sleeper material. Timber sleepers are declining 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 degraded sleepers are being replaced with new ones. Strength and durability of the sleepers is one of those ingredients that play an important role in track system. Failure to adequately serve these roles can lead to a derailment endangering both lives and property.

Beside timber wood, pre-stressed concrete and steel were widely applied in sleepers but the results were not satisfactory. This is because concrete and steel sleepers were not economical in comparison to timber sleepers. Steel's risk of corrosion, high electric conductivity, fatigue cracking, and difficulty of packing it with ballast has made it an inferior material to be used in sleepers. On the other hand, pre-stressed concrete sleeper, which offers a great durability than timber and steel sleepers, suffers due to heavy weight, high initial cost, low impact resistance, susceptibility to chemical attack consequently; have failed to satisfactorily meet the demands.

Several investigations have been carried out in an attempt to investigate the strongest, durable and cost

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effective material for replacing traditional sleepers. Hence, the use of composite sleepers has emerged as a potential alternative. Composite sleepers are environment friendly, highest in performance in comparison to other sleepers and provide an outstanding value to its rail customers. Composite sleepers use decreasesmaintenance cost of track and increases its lifespan up to 50 years. Indian railways use composite sleepers for construction of rail road bridges. Use of timber sleepers were banned in 1998-1999 and trials were made on Channel Sleepers, FRP sleepers and Composite Sleepers in which composite sleepers are under trial, but got very limited acceptance from railway industry and their implementation has been very slow.

II. MATERIALS FOR RAILWAY SLEEPER

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.

1.Timber sleeper

Timber sleepers have effective and reliable performance in the railway environment. Timbers most commonly used for sleepers in India are Sal (hardwood), Chir and Deodar (softwood). Softwood sleepers are treated in a creosoting plant before putting them in service, where as hardwood sleepers are generally used untreated. Like the others, it has advantages and disadvantages. The main advantage of the timber is their adaptability as it 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. Their susceptibility to mechanical and biological degradation leading to failure is their major disadvantage. Cleaving of timber at the ends is also common as railway sleepers support very large transverse shear loadings. However, the most typical problem that the railway is now facing is the diminishing availability of quality timber for railway sleepers. Use of chemical preservatives to timber sleepers is affecting environment as well as causing health hazards. The majority of timber railway sleepers are soaked in coal tar creosote in order to protect them from environmental wear and insect infestation. Creosote extends the life of wooden sleepers but is toxic hazard which creates an added cost for disposal and has damaged the environmental credibility of the industry's traditional railway sleeper material.

Reports worldwide suggest that the disposal to landfill of preservative-treated timber sleepers is at present an acceptable option.

Demerits

- Timber species available in India have relatively short life
- For modern LWR track, it is light sleeper
- Gets worn out faster under beater packing
- Need special treatment for fire protection
- Less scrap value

2. Concrete sleeper

Concrete, because of its natural weakness in tension is not used in sleeper's products. Pre-stressed concrete is a method for overcoming this matter. It can be used to produce beams, floors and bridges with longer span. Pre-stressed concrete sleepers have become widely and successfully accepted for railway sleeper usage especially in high speed lines. Mono-bloc pre-stressed concrete sleepers is the most commonly used. Twin-bloc, on the other hand, is gaining popularity because it weighs less compared to mono-bloc 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.

Their economic and technical advantages are the results of longer life cycles and lower maintenance costs. The appearance of modern track in the form of long welded rail, wherein the heavy weight of sleeper become a positive asset. With their great weight, concrete sleepers assure optimal position permanence and stability even for traffic at high speeds. The higher structural stiffness of the concrete means a higher load is transfer to concrete sleeper which could lead to greater deterioration due to flexural cracks.

The problem because of heavy weight of concrete sleeper is that it requires specialised machinery and skilled labour during laying and installation. The initial cost of concrete sleeper is almost double that of hardwood timber sleeper. The main disadvantage of concrete sleeper is, the manufacturing of concrete

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sleeper, their transport, laying and maintenance requires superior technology, which is not readily available in developing countries like India. The manufacturing plants generally have a heavy initial outlet. Also damage during derailment is excessive and no scrap value.

3.Steel sleeper

Steel sleepers are moderately used. Steel sleepers can be intermixed with the existing track but in a fixed intermixing pattern to reduce the variation in the track geometry and prevent the service failure of sleepers. A steel sleeper is lighter in weight than timber sleeper which makes it easy to handle as well as having a life span known to be in excess of 30-50 years. As steel sleepers stronger than wood and cheaper than concrete, they are usually considered as middle way between wooden sleeper and concrete sleeper. It is free from fire hazard and has good scrap value. 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.

A modern Y-shaped steel sleeper was developed to replace the traditional steel sleeper. 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. Another concern is that manufacturing concrete and steel sleepers requires considerably more energy and is one of the largest producers of atmospheric carbon. The carbon dioxide emissions during the production of concrete and steel are 10–200 times higher than that of hardwood timber, respectively. Key type fastening subjected to high frequency vibrations under the influence of traffic get loose and need frequent tightening. This results in enlarged holes, opening of the jaws and play between rail and the sleeper, affecting the track geometry quite adversely. Steel sleepers with their close spacing at the rail joints are difficult to pack.

III. NEED FOR ALTERNATIVE

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. Worldwide most of the 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. Concrete sleepers have the ability to provide better line and gauge-holding characteristics than timber sleepers, but they are relatively expensive, quite heavy and are often incapable of providing a projected 30-50year service life. 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.

These problems have resulted in more premature failures and higher replacement rates of timber sleepers. Table Isummarises 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 traditional sleepers is therefore both desirable and necessary.

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Properties	Timber	Concrete	Steel
Adaptability	Easy	Difficult	Difficult
Workability	Easy	Difficult	Difficult
Handling and installation	Easy	Difficult	Difficult
Durability	Low	High	Low
Maintenance	High	Low	High
Replacement	Easy	Difficult	Difficult
Availability	Low	High	High
Cost	High	Very high	Very high
Fasteners	Good	Very good	Poor
Tie ballast interaction	Very good	Very good	Poor
Electric conductivity	Low	High	Very high
Impact	High	Low	Medium
Weight (kg)	60-70	285	70-80
Service life (years)	20-30	60	50

IV. COMPOSITE SLEEPER

Plastic railway sleeper, also called composite sleeper, mainly refers to the railway sleeper made of the plastic composite. Plastic composite is a total modern material for making rail sleepers. It is the mixtures of plastic or waste rubber. Plastic sleeper combines the pliability of wood and durability of concrete.Composite material is made from two or more materials to obtain properties which are superior to the individual components. Each material combination will have different properties from one another. Plastic sleepers are a good alternative that can give solutions for specific problems in the track which are mentioned above. In recent years reinforced polymer sleepers have emerged as a potential alternative to traditional sleepers. Reinforced polymers can be designed to mimic traditional sleeper behaviour (an essential requirement for track maintenance) are almost maintenance free and are more sustainable from an environmental perspective. Despite this potential the implementation of these polymer sleepers in India 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 sleeper making them commercially unviable.

Three different types of polymer sleepers have been available in the market for some time. Both types of sleepers are conveniently referred to as "composite sleepers" however the composition and structural behaviour 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 rein-forcing 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.

Table II summaries the advantages and disadvantages of this type of polymer 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).

Table III summaries the advantages and disadvantages of this type of polymer sleeper.

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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. In some cases, the disadvantage of a non-ductile behaviour of glass fibre reinforced polymer sleeper can be overcome by including some steel reinforcement bars. The ductile property is particularly important when the sleepers are installed in bridge, where sufficient warning before failure is expected. The excellent design flexibility, good flexural and shear strength, easy drilling and good fire performance are the key benefits of this sleeper. However, the production process of composite sleeper technologies under this category is quite slow which may increase the manufacturing cost. The sandwich polymer sleeperand the hybrid compositesleeper wherein fibres are oriented in the two directions to resist flexural stresses as well as shear forces falls under this category. A brief description of these sleeper technologies are provided in Table IV.

Table IV. Performance comparison of different types of composite sleeper.

Performance Measurement	Type:1	Type:2	Type:3
Density	850-1150	740	1040-2000
Modulus of Elasticity	1.5-1.8	8.1	1040-2000
Modulus of Rupture	17.2-20.6	142	1040-2000
Shear Strength	4	142	1040-2000
Rail seat compression	15.2-20.6	142	1040-2000
Screw withdrawal	31.6-35.6	142	1040-2000

Wahid Ferdous (2015) has worked on sleepers with short or no fibre reinforcements (Type:1) Sleepers that consist of recycled plastic (plastic bags, scrapped vehicle tires, plastic coffee cups, milk jugs, laundry detergent bottles etc.) or bitumen with fillers sand, gravel, recycled glass or short glass fibres (less than 20mm). 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

Table V. Comparison of some bridge sleepers

Advantages Disadvantages

Item	Type of Bridge Sleepers		
	Wooden	Steel	Composite
Durability (years)	8-10	15-20	40-50
Weight (kg)	100-171	110	54
Replacement sleepers	Easy	Difficult	Easy
Handling	Not so easy	Difficult	Easy
Suitability for track circuited areas	Suitable	Problematic	Suitable
Cost per eeper with ttings	Rs. 3500/-	Rs. 9500/-	Rs.19240/-
Life cycle ost (Rs./year)	402/-	575/-	385/-

materialshave resulted in.
(Chattree R and Manoharan S, 2014) has highlighted on the aspect that Indian Railways have already adopted recycled High-density polyethylene(HDPE), crumbled rubber, glass reinforcement, mineral fillers, and some other patented items materials for use in bridge sleepers, and they also made a comparison of fibre reinforced plastic sleepers with wooden and steel ones (Table V). Their composites consisted of E-glass woven

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fabric as the reinforcement and polyester as the resin. Polyester resin was also mixed with accelerator, hardener, fire retardant, and UV Stabiliser.

V. ENVIRONMENTAL BENEFITS

Recycled raw materials are used in manufacturing composite sleepers, diverting tonnes of would-be wastes from landfills to a productive, "clean" use. Composite sleepers are manufactured from recyclable materialsand are 100% recyclable after production. Since composite sleepers incorporate readily available waste material in the manufacturing process, they have no harmful impact on environment. Because composite sleepers are recyclable themselves, there are no disposal issue. At about 118 kg each and about 1.2 million whole post-consumer tyres worth of recycled rubber granulate, using about 4 tyres-worth for each sleeper. Additionally, it has used about 22,000 tonnes of recycled HDPE, using about 70 kg per sleeper.

VI. CHALLENGES AND POSSIBLE SOLUTION

Despite many advantages of the newly developed composite sleepers, they have gained a very limited acceptance by railway industry. This section presents some of the common challenges encountered in using composite sleepers.

• Price of composite sleeper- The prohibitive costs of most composite sleeper technologies is one of the main reasons identified for their slow uptake in the market. The price of high fibre containing composite sleeper technologies (Type:2 and Type:3) is approximately 5–10 times higher than that of a standard timber sleeper. However, its lower life cycle cost is anticipated to offset its high initial cost, which to attract the attention of the railway industry, needs to be similar to, or insignificantly higher than, that of traditional ones. Similarly, optimising the manufacturing process and material usage would result in a more cost competitive sleeper product.

• Low anchorage capability- The low anchorage capacity of holding screw is another problem for Type:1 composite sleeper. It has been reported that the modified compound of a natural rubber composite sleeper (Type:1) showed a very stiff and inelastic performance when holding the spike for a fastening system

• Formation of material voids- During the manufacturing process for a plastic composite sleeper there is a high possibility of voids being formed inside the materials. When in-service, voids can break and transfer stresses from one part to others which creates a stress concentration and later leads to local failure of a sleeper before the end of its design life.

• Creep deformation- The long-term performances of plastic sleepers (Type:1) are becoming a critical issue as their continuous service over time has a significant effect on their mechanical properties. It has been reported that, under sustained loads, a composite sleeper may be subjected to permanent deformation due to creep , the rate of which depends on the magnitude and duration of the stress and the temperature at which the load is applied. Because of the effect of creep and the subsequent stress relaxation, the fastening system tends to become loose, particularly in a curved track, which has an adverse effect on gauge holding. These effects may reduce the service life of a plastic sleeper.

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. 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.

VII. CONCLUSION

This paper presents the comparison between the traditional sleepers and new plastic composite sleepers. Due to the use of a new innovative technology and a highly optimised shape, the new sleeper offers improved performance at a much more economical price. A number of composite sleeper technologies have been developed in different parts of the world but their implementation in the market is extremely slow. The primary obstacles of their widespread application are their low anchorage capability, high price, low capacity of holding screw, formation of voids into the body of sleeper, and permanent deformation due to creep and temperature variations. Test results and performance of composite sleeper reveals that it can be an alternative of traditional sleepers. They require minimal labour for their installation, repair and maintenance. They release less amount of energy and produce minimum greenhouse gases. In composite sleepers recycled raw materials are used, hence waste in a large amount from landfill can be turned into a productive use. Adoption of composite sleeper proves to be less destructive to forests. Composite sleepers have comparable physical and chemical properties to traditional sleepers. The introduction of long fibre reinforcements will improve the strength and stiffness of recycled plastic sleepers. Continuous research and development are essential to develop the market and increase confidence in using this alternative material. Finally, development of national and international standards will encourage the adoption of fibre composites as an alternative railway sleeper material.

In the infrastructure sector, a new integrated approach is needed to sustain and satisfy the worldwide demand of natural resources. This research paper highlights the recycle and reuse of waste material can address the disposal problem and also create a resource for manufacturing economical units in transportation engineering.

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