Recent Developments and Future Prospects of Manufacturing of Broad Gauge Railway Sleepers Using Waste Materials in India

Dilip Kumar Bagal¹, Sangam Kumar Singh², Bibekananda Naik³, Abhishek Barua¹, Siddharth Jeet⁴, Biswajit Parida⁴, Ajit Kumar Pattanaik¹

¹ Department of Mechanical Engineering, Government College of Engineering, Kalahandi, Bhawanipatna, Odisha, India
² Department of Mechanical Engineering, Delhi Technical Campus, Bahadurgarh, Haryana, India
³ Department of Civil Engineering, Bhubaneswar Institute of Technology, Bhubaneswar, Odisha, India
⁴ Department of Mechanical Engineering, Centre for Advanced Post Graduate Studies, BPUT, Rourkela, Odisha, India

E-mail: dilipbagal90@gmail.com

Abstract. Railways form the backbone of all economies, transporting goods, and passengers alike. Sleepers play a pivotal role in track performance and safety in rail transport. Composite sleeper is becoming a suitable alternative for replacing the existing concrete, steel and particularly timber sleeper in both mainline and heavy haul rail network. Composite sleeper technologies are already available but they have gained limited acceptance by the railway industry. A number of composite railway sleeper technologies have been developed but their applications in rail tracks are still limited. This paper discusses in brief about the materials that have been used in making sleepers in the early stages of railways and rigorously reviews the recent developments on composite sleepers and identifies the critical barriers to their widespread acceptance and applications. It has been shown that majority of the sleepers do not last till their expected design life resulting in massive replacement and repair cost. Currently the composite sleeper technologies that are available ranges from sleepers made with recycle materials starting from plastic, rubber, construction waste etc. While these recycled material based sleepers are low cost, the major challenges of using this type of sleepers are their limited strength, stiffness and dynamic properties which in most cases, are incompatible with those of traditional concrete, steel or timber sleeper. This paper rigorously reviews the recent developments on composite sleepers and identifies the critical barriers to their widespread acceptance and applications.

1. Introduction
Conventional materials used in production of railroad sleepers are timber, concrete and steel with a span of service life 20, 50 and 50 years, individually [1–23]. During the most recent couple of many years, the railroad business has zeroed in on a concrete based cement as opposed to wood and steel sleepers. Mono-block prestressed solid sleepers are utilized in hefty take and rapid rail track developments all through the world. In Indian, pre-tensioned prestressed concrete sleepers are used in almost every region...
where the railway tracks have been laid. Though few sections of metre gauge tracks present in Rajasthan, Gujarat, Uttar Pradesh; narrow gauge railway track of Darjeeling Himalayan Railway, West Bengal; Kalka-Shimla Railway, Himachal Pradesh; Matheran Hill Railway, Maharashtra; Nilgiri Mountain Railway, Tamil Nadu; Kangra Valley Railway, Himachal Pradesh; steel girder bridges; diamond-crossings and complex layout still uses timber or steel railway sleepers. Figure 1 shows different types of railway sleepers.

Figure 1. Timber sleeper, steel sleeper and prestressed concrete sleeper

Besides, cement and steel sleepers require extraordinary latches and can’t supplant wood ones out of a current track in view of their inconsistent conduct. All the previously mentioned issues have inspired scientists around the globe to create and research new and compelling elective sleeper advances for railroad industry. An ongoing report on the possible reasons for failures of railroad sleepers demonstrated that the conventional materials have not acceptably fulfilled the need necessities to oppose mechanical, organic and compound corruption. These days, the worldwide market for composites is quickly expanding a direct result of the numerous points of interest including high solidarity to-weight proportion, amazing obstruction against erosion, dampness and creepy crawlies, and warm and electrical non-conductivity. This paper gives a review of ongoing improvements of composite railroad sleepers and their constraints, and recommends an answer which beats the difficulties characteristic in their usage and acknowledgment.

2. Customary materials for sleepers with major failures

Numerous materials have been being used according to the overarching conditions in various pieces of the world. A portion of the materials generally utilized for railroad sleepers are recorded beneath.

2.1. Timber

Timber sleepers have been utilized in railroads for quite a while and have been solid and proficient. Utilization of wood likewise prompts deforestation and consequently the ecological effect is extremely high. Other than the utilization of synthetically impregnated lumber additionally present removal chances. These unfavourable impacts have brought about the utilization of different materials [4].

2.1.1 Failure occurs in timber sleeper

a) Fungal decay

Fungal deterioration is the dominating method of lumber sleeper failure as wood is powerless to bio-weakening from numerous miniature creatures since lumber is a natural material. Railroad sleepers can ingest dampness, which can spread starting with one sleeper then onto the next across non-wholesome surfaces that antagonistically influence a track's auxiliary honesty [3-7].
b) End splitting
The failure of a wood sleeper because of parting at its end emerges when the sleeper is exposed to enormous cross over shear stacking. Additionally, the rail is associated with every sleeper by an appropriate securing framework which incorporates a rail attaching cut, sleeper plate and screw-spike [3-5].

c) Termite attacks
At the point when a termite assaults wood, it disburses all the cellulose-containing constituents and bases lasting harm [3-7]. Figure 2 shows failure of timber sleeper due to various reasons.

Figure 2. Failure of wooden sleeper

2.2 Steel Sleeper
Steel sleepers functioned the railroads for a few decades. Aside from giving an unrivalled sidelong unbending nature, steel sleepers additionally have a high piece esteem. As a result of the better quality when looked at than cast iron sleepers, more consideration isn't needed subsequent to laying. Their protection from creep additionally gives them an additional edge. In any case, steel sleepers likewise represent a lot of detriments [3-7].

2.2.1. Steel sleeper’s failures
Notwithstanding, a few scientists detailed that the steel's danger of erosion, high electrical conductivity, weariness splitting in the rail-seat locale and the trouble of pressing it with weight has made it a sub-par material for sleepers. Hence, an appropriate examination concerning the purposes behind its failure is fundamental [3-7].

a) Corrosion in steel
Steel sleepers experience the ill effects of erosion in the territories where the supporting soil or counterbalance is wealthy in pungent components. Different reasons, including a persistently damp condition, metallic slag-based balance and the presence of destructive materials, can improve erosion in a steel sleeper [3-7]. Figure 3 shows corrosion in steel sleeper.
Figure 3. Corrosion in steel sleeper

b) Fatigue cracking
A sleeper encounters both longitudinal and cross over burdens when a train is running over rails, as, an inclining pressure begins its rail-seat area which is for the most part on its top surface however can likewise happen the contrary way relying upon the train's development and, after some time brings about weakness breaking [3-7].

2.3 Prestressed Concrete Sleepers
With a normal assistance life of about 50 years, solid sleepers are the strongest of the apparent multitude of sleepers referenced previously. By their heavyweight, they can give extraordinary parallel dependability to the tracks. Aside from being corrosion safe when contrasted with different materials, solid sleepers show high proficiency in controlling wet blanket. Their capacity to oppose termite assault and their appropriateness with practically a wide range of soil make them broadly acknowledged. Despite the fact that the underlying expense of production of these sleepers is high, its recuperation in 50 years of its administration life more than makes up for the significant expense. The inflexible idea of the solid sleepers makes them hard to deal with. Their powerlessness to be as proficient to the shifting level of utilization in examination with wood sleeper, represent a few issues. When contrasted with wood, solid sleepers are unbending [3-7].

2.3.1 Failures of Concrete Sleepers.

a) Rail-seat deterioration
This failure is caused either by rail-seat scraped spot, hydro grating disintegration, water powered weight breaking, freeze defrost splitting or synthetic weakening of which rail-seat scraped spot is the most basic [4, 5].

b) Derailment
Imperfections in sleepers, which happen principally during the operational stage in light of labor blames and existing vague deformities in tracks. The essential drivers of wrecking failures are because of labour flaw and existing impermissible imperfections in track [5, 6].

c) Centre-bound damage
This failure is caused either where vertical splits are framed on sleeper because of an elastic crack in its upper focal portion which later engenders all through its focal fragment and framed a 'X' shape before unmistakably cracking [4, 5].
d) **High-impact loading**

The bowing breaks in a solid sleeper are regularly distinguished at its mid-range either by wheel or rail irregularities, for example, level haggles rails [5, 6]. Figure 4 shows failure of prestressed solid sleeper.

![Figure 4. Failure of prestressed concrete sleeper](image)

**Figure 4. Failure of prestressed concrete sleeper**

e) **Ice forming in sleeper**

Failure of sleeper is formed because of freezing of the water spilling into sleepers which makes an ice weight of 40 MPa that relates to 72–88 kN relying upon the zone of applied weight. This type of problems is mainly found in the railway tracks laid in Jammu and Kashmir valley; Kalka Shimla railway [1-7].

3. **OVERCOMING THE CHALLENGES**

Composite sleeper technologies have emerged as an effective alternative for railway track maintenance and renewal. However, there are barriers that still need to be overcome for their increased acceptance and use. This section discusses the emerging issues on composite sleepers and presents opportunities for overcoming these challenges [4].

3.1. **Strength and Stiffness**

The composite sleeper innovations have been created to supplant existing sleepers, therefore, the strength and stiffness of composite sleepers are expected to be similar to the existing sleeper. One approach to improve the strength and stiffness of this type of sleeper is to reinforce them either with long fibres or steel bars. The high shear strength of multidirectional fibre sleepers makes them ideal for bridge application.

3.2. **Cost Issue**

The cost of high fiber containing composite sleeper advancements (unidirectional and multidirectional fiber sleeper) is roughly 5 to multiple times more than timber sleeper. Nonetheless, the lower life cycle cost is foreseen to counterbalance its high starting cost which to pull in the consideration of the rail business, should be like, or inconsequential higher than, that of customary ones.

3.3. **Design Guidelines**

A complete design guideline for composite railway sleeper has been established in India by the Research Designs and Standards Organisation (RDSO) named “Provisional Specification for Composite Sleepers (2014)”. From 2016, Ministry of Railway, Government of India has adopted the regular use of composite
Sleepers based on the performance under field trials and on recommendation of RDSO. According to the report, these sleepers will be used over steel girder bridges, special turnouts (where concrete sleeper design is not available), support for temporary girder, over temporary girder and for temporary restoration. From 2017-2018 onwards, these composite sleepers have been used over steel girder bridges for renewal of old sleepers as well as over all new steel girder bridges in projects of new lines, doubling and gauge conversion of railway tracks in Indian Railway [24].

4. Technical requirement of composite sleeper which will be used in Indian Railways

A composite material is a material shaped utilizing at least two discretely recognized materials (for example a polymer foil with fortification in polymer composites) to get explicit properties that are better than the individual material.

Built polymer composite sleeper consolidates a polymer network regularly post-customer reused high-thickness polyethylene (HDPE) as an essential segment, with fortifying strands and/or fillers to contribute improved properties. Poisonous additives will not be utilized to make the sleeper. The sleeper will oppose rot and bug assault. Water assimilation will not cause loss of solidarity requiring the sleeper to be supplanted. The sleeper will be non-unsafe and non-filtering. When all is said in done, composite sleeper is a material framework that fuses support (for example glass filaments) and/or other property modifiers in a polymer network [24]. In light of fortification and property modifiers, the Polymer composite sleepers might be named Fiber strengthened polymer composite, Particle fortified polymer composite and Hybrid composite.

5. Composite Sleepers Available All Over the World which can be used in Indian Railway

Several companies and research institutions have developed composite sleepers in different countries. These sleepers are made from a variety of materials: recycled plastic, FRP, natural rubber, sandwich composites and so on. Brief descriptions of the available composite sleepers are discussed in the following subsections.

a) FFU Synthetic Sleeper

In 1978, the Japanese company Sekisui Chemical Co. Ltd. developed a synthetic wood called ESLON Neo Lumber FFU (Fibre reinforced Foamed Urethane) for the manufacture of railway sleepers in which thermosetting rigid urethane resin foam is reinforced with long glass fibres and does not need to be impregnated with environmentally harmful chemicals. Due to good resistance to water absorption; light weight; easy drill ability; heat and corrosion; it has a life span more than 50 years. These sleepers are currently used in Japan, Germany, Austria, Australia and China [6, 7]. Figure 5 shows Fibre reinforced Foamed Urethane sleeper.

![Figure 5. Fibre reinforced Foamed Urethane Sleeper](image)
b) Recycled waste plastic Sleeper

‘Axion’, a US green technology company manufactures composite sleepers made from 100% recycled consumer plastic (such as plastic coffee cups, plastic bags, laundry detergent bottles, milk jugs etc.) and industrial plastic waste under the brand name ‘EcoTrax’. Similar types of sleepers are also manufactured by IntegriCo Composites Inc., USA; I-Plas Ltd, United Kingdom; Tufflex Sleeper, South Africa; Lankhorst Mouldings, Netherlands. Since its introduction, a variety of sleepers have been produced for different applications (Figure 3) including: switches; road crossing; bridges; passenger; and heavy duty track. This sleeper is more impervious to rot, insects, fungus and moisture, provides better resistance to plate wear with life span of about 50 years. Currently, these sleepers are introduced in Europe, Germany, Mexico, Australia, Netherlands, New Zealand, Canada and Southeast Asia [1-7]. Figure 6 shows different types of recycled waste plastic sleeper.

![Axion sleeper](image1)
![I-Plas sleeper](image2)
![KLP Lankhorst Mouldings sleeper](image3)
![Tufflex Sleeper](image4)

**Figure 6.** Different types of recycled waste plastic sleeper [1-7]

![Polyester fiber reinforced composite sleeper](image5)

**Figure 7.** Polyester fiber reinforced composite sleeper [1-7]
c) **Fibre-reinforced Polymer (FRP) Sleeper**
An FRP composite ones using fibre reinforcement and a resin matrix. The key features are: light weight (54 kg); longer service life (40 to 50 years); good resistance to corrosion; high electrical insulation; lower life cycle cost; and innovative design. From 2017 onwards, several have been installed in different locations in India for on regular purposes [1-7]. Figure 7 shows Polyester fiber reinforced composite sleeper.

d) **Rubber composite Sleeper**
Researchers in Thailand developed natural rubber based composite sleeper for vibration absorbers and blocks for the seismic protection of tall. They improved the mechanical properties of natural rubber using an ebonite system whereby the cross-link density of natural rubber was increased. They obtained better compressive modulus and hardness of the modified natural rubber than scrap rubber/tyres composites [1-7]. Figure 8 shows Rubber composite sleeper.

e) **Hybrid Concrete Sleeper/ geopolymer concrete sleeper**
The geopolymer concrete sleeper is now considered an alternative environmentally friendly railway sleeper as geopolymer concrete reduces landfill weights because it uses industrial by-product. Several researchers across the world have developed and investigated geo-polymer sleepers made using fly-ash, iron slag, waste rubber tyre, bamboo, waste concrete aggregate and found that durability of these eco-friendly sleeper is good which can be an alternative to conventional concrete sleeper with the additional advantage of low environmental impact [1-7]. Figure 9 shows Fly ash based concrete sleeper and Table 1 compares mechanical performance of different types of sleeper [1-23].

![Figure 8. Rubber composite sleeper [1-7]](image)

![Figure 9. Fly ash based concrete sleeper [1-7]](image)

|                     | Timber | Concrete | FFU | Waste Plastic | FRP | Geo Polymer |
|---------------------|--------|----------|-----|---------------|-----|------------|
| Density, (kg/m³)    | 850-1045 | <2400    | <820| 850-1150      | <1150| <2200      |
| Screw Pull-out Force, (kN) | <40         | <65      | <65 | 31.6-35.6     | <35.6| <65        |
| Modulus of Elasticity, (GPa) | <16            | <30      | <8.1| 1.5-1.8       | <1.6 | <30        |
| Rail-Seat Compression, (MPa)   | <60        | <60      | <55 | 15.0-20.6     | <20.8 | <60        |
| Modulus of Rupture, (MPa)      | <65        | -        | <142| 17.0-20.6     | <21.2 | -          |
| Shear Strength, (MPa)         | <5         | <25      | <10 | <5            | <5   | <23        |
6. Conclusions

Materials like cement and steel have not demonstrated so much dependable options in contrast to old wood sleepers thus specialists have zeroed in on elective materials for assembling railroad sleepers. For the most part various kinds of composite materials have been picked and tried to utilize them as sleeper materials. A large portion of the sleepers being used are made of prestressed concrete in Indian Railway. This paper additionally examines the cutting edge materials that can be utilized in the production of railroad sleeper that can represent the effect loads. It is important to examine the conduct of a sleeper under unique effect and weakness loadings, and its exhibitions in various ecological conditions, for example, UV radiation, dampness, high pH and raised temperatures before introducing it in a rail track. This examination proposed some possible methodologies of utilizing composite sleepers. The advancement of sleeper isn't just worthwhile regarding cost decrease yet additionally improves the parallel strength of rail track. The plan rules for composite sleeper is basic to set up for their broad acknowledgment to the basic fashioners and end clients. A decade ago observed headway in Indian Railways where utilization of various sorts of composite sleepers have discovered their utilization which will be useful sooner rather than later moreover.

References

[1] Shashikala A, Anilkumar P, Joseph G, John J and Lijith K 2015 Experimental Investigations on Use of Rubber Concrete in Railway Sleepers. In: 2nd RN Raikar Memorial International Conference & Bathia-Basheer International Symposium on 'Advances in Science & Technology of Concrete-2015',
[2] Manalo A, Aravinthan T, Karunasena W and Ticoalu A 2010 A review of alternative materials for replacing existing timber sleepers Composite Structures 92 603-11
[3] Ferdous M, Khennane A and Kayali O 2013 Hybrid FRP-concrete railway sleeper University of New South Wales, Canberra, Australia
[4] Ferdous W and Manalo A 2014 Failures of mainline railway sleepers and suggested remedies–review of current practice Engineering Failure Analysis 44 17-35
[5] Xiao S, Lin H, Shi S Q and Cai L 2014 Optimum processing parameters for wood-bamboo hybrid composite sleepers Journal of Reinforced Plastics Composites 33 2010-8
[6] Ferdous W, Manalo A, Aravinthan T, Van Erp G, Khennane A and Kayali O 2015 Composite railway sleepers: New developments and opportunities. In: Proceedings of the 11th International Heavy Haul Association Conference: Operational Excellence (IHHA 2015), Perth, Australia, pp 21-4
[7] Ferdous W, Manalo A, Van Erp G, Aravinthan T, Kaewunruen S and Remennikov A 2015 Composite railway sleepers–Recent developments, challenges and future prospects Composite Structures 134 158-68
[8] Ferdous W, Manalo A, Aravinthan T and Van Erp G 2016 Properties of epoxy polymer concrete matrix: Effect of resin-to-filler ratio and determination of optimal mix for composite railway sleepers Construction Building Materials 124 287-300
[9] Jain C, Khandelwal S, Mehrotra S and Gupta R 2016 A review paper on use of composite material for railway sleepers in railway track SSRG Int J Civ Eng 3 104-8
[10] Zakeri J A, Esmaeili M, Mosayebi S A and Sayadi O 2016 Experimental investigation of the production of sleepers from concrete that contains blast furnace slag Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail Rapid Transit 230 77-84
[11] Gonzalez-Corominas A, Etxeberria M and Fernandez I 2017 Structural behaviour of prestressed concrete sleepers produced with high performance recycled aggregate concrete Materials structures 50 94
[12] Silva É A, Pokropski D, You R and Kaewunruen S 2017 Comparison of structural design methods for railway composites and plastic sleepers and bearers Australian journal of structural engineering 18 160-77
[13] Soehardjo K and Basuki A 2017 Utilization of bagasse and coconut fibers waste as fillers of sandwich composite for bridge railway sleepers. In: IOP Conference Series: Materials Science and Engineering, Medan, p 012036

[14] Stepanov V, Saldaev V and Tsvetkov V 2017 Composite material for railroad tie. In: Solid State Phenomena: Trans Tech Publ) pp 587-91

[15] Kaewunruen S, Li D, Chen Y and Xiang Z 2018 Enhancement of dynamic damping in eco-friendly railway concrete sleepers using waste-tyre crumb rubber Materials Design 11 1169

[16] Kaewunruen S, Lopes L C and Papaelias M P 2018 Georisks in railway systems under climate uncertainties by different types of sleeper/crosstie materials Lowland Technology International 20 77-86

[17] Khalil A A 2018 Mechanical testing of innovated composite polymer material for using in manufacture of railway sleepers Journal of Polymers the Environment 26 263-74

[18] Stepanov V and Timerbaev N F 2018 Composite Railroad Ties Obtained by the Energy Efficient Recycle of Wooden Railroad Ties. In: Solid State Phenomena: Trans Tech Publ) pp 981-5

[19] Ferdous W, Manalo A, Muttashar M, Yu P and Kakarla R 2019 Composites for alternative railway sleepers

[20] Khalil A A, Bakry H M, Riad H S and Shnour A S 2019 " Analysis on railway sleepers manufactured from polymers and iron slag Journal Archive 14

[21] Kondrashchenko V I, Jing G Q and Wang C 2019 Wood-Polymer Composite for the Manufacture of Sleepers. In: Materials Science Forum: Trans Tech Publ) pp 509-14

[22] Raj A, Nagarajan P and Shashikala A 2020 Investigations on Fiber-Reinforced Rubcrete for Railway Sleepers ACI Structural Journal 117

[23] Raj A, Nagarajan P and Shashikala A 2018 A Review on the Development of New Materials for Construction of Prestressed Concrete Railway Sleepers. In: IOP Conf. Ser. Mater. Sci. Eng, p 012129