Composite Railway Sleepers in the Indian Sub-continent

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Abstract: Railway Sleepers, or railroad ties, are one of the major components of the entire railways network and are very critical to its existence in a way that it clamps together the rails and avoid slippage, while maintaining the entire alignment. In entire Indian subcontinent, timber, steel or concrete based sleepers have been employed. However since usage of timber exerts pressure on natural supplies of resources and results in forest depletion and other adverse environmental problems, and with advancements in technologies and minimal maintenance requirement, a shift was observed towards usage of steel or concrete sleepers. Owing to the low life span, heavy weight, high costs, increased vibrations and noise, even steel and concrete didn't prove to be an effective substitute. No significant advances have been observed in the region in terms of technology and sustainability, where India only contributes to more than 115,000 KMs of tracks and over 127,000 railway bridges. Given the current scenario there is an immediate requirement of a smart substitute that offers longer life-span, minimal maintenance, low cost, high strength to weight ratio and good vibration absorption properties.

The research gap highlighted herewith also could be construed as an industrial gap given its significance and volume of applicability, and both have together been addressed in this paper. Our research proposes a new design for the sleepers using composites to suit Indian context with twice the usual life-span, higher strength to weight ratio, low moisture absorption, minimal maintenance, recyclability, reusability and good vibration absorption properties at low cost. The research proposes design framework which accords with both Broad and Metric gauge, the two gauges being currently used in Indian-subcontinent.

The research adheres to the specifications of the current market and due analysis have been done using Finite Element Modelling for deformations due to force, temperature, pressure and ambient conditions on tracks in Indian Sub-continent. Further a modal analysis to establish the vibration and absorption properties of the material has been done. The later part of paper constitutes a detailed comparison of the proposed sleeper with the existing sleeper model highlighting the advantages. The analysis and the results presented in this paper conclude a promising solution for the problem at hand of Railway Networks in Indian-Subcontinent.

Keywords: Indian Railways, Composites, Reinforced Plastic, Composite Sleepers, Railroad Ties, Railway Sleepers.

I. INTRODUCTION

Sleeper is one major component of the entire railways network and is used to clamp the rails to avoid any slippage of rails and to maintain their alignment. In olden days wooden sleepers were primarily used and were associated with certain inherent problems including rots, spilling, insect infestation, spike pull and environmental decay.

With advancements in technologies concrete sleepers were seen replacing wooden, however at specific places, such as bridges, wooden sleepers were still preferred. On the other hand steel based sleepers were also employed for applications on bridges with higher traffic and low maintenance requirement.

With ever-growing dependence on railways in the subcontinent and continued pressure to improve green footprints, there is a requirement of eco-friendly and low maintenance sleepers. Which should not only be green in concept, but also employs 3R methodology and reduces wastes.

Only in Indian perspective there is an immediate demand for sleepers on over 1,27,000 bridges, however for indian perspective there are certain specific and different specifications required and our research and paper outlines the design and specifications requirements for the Indian Sub-continent..

II. LITERATURE REVIEW

Railways have been an indispensable element of contribution towards development and expansion of economies. Railway sleeper or railway tie is one of the most important element of a railway system. It is a beam/tie beneath the rails to support the track and maintain the required gauge width [1][2]. Along with this basic functionality railway sleeper is responsible for distribution and transfer of load to ballast, and prevent any lateral and longitudinal movement of rail system [5].

To maintain quality service level of rail system it is imperative to maintain strict standards of sleeper over entire lifetime. Thus a slight deterioration of sleeper material leads to replacement of the sleeper. This makes imperative for a sleeper to provide a required life-span. Replacement of sleepers is the most significant contributor towards maintenance of rail system, and thus various industries across the globe have adopted spot replacement strategy, which involves replacement of damaged sleepers only rather than re-instalment of the complete rail patch [8]. Thus sleeper must be compatible to current industry standards for allowing instant application.

Currently timber is the most widely used sleeper material. Owing to its lower life-span and limited availability of quality timber for manufacturing of sleepers, industries have shifted towards alternative materials like steel and concrete. Both provide certain advantages, but owing to their respective short-comings, both have not been able to prove a smart alternative. Following is an extensive discussion on advantages and limitations of these materials which highlights the requirements and the need of a smart alternative solution.

Timber: The biggest advantage which timber gives is ease of adaptability. The sleeper can be replaced without any heavy structural instalments, thus making their use favourable for heavy traffic lines[5]. Timber offers vibration absorption properties thus making it suitable for fast speed lines. The main disadvantage of timber is its susceptibility to biodegradable and mechanical failures. Timber deteriorates due to moisture, pest attacks, and fungal attacks. It offers low strength because of which splitting at ends is a common failure mode of timber sleepers. This reduces their life-span considerably thus exerting pressure on environment for supply of more quality timber. Recently chemically impregnated timber has been used for sleeper manufacturing to address the issue of mechanical deterioration. These chemically impregnated sleepers have serious environment degrading issues while their manufacturing and disposal [3].

Steel: Owing to above limitations, industries shifted to steel timbers. It offers higher weight to strength ratio, is immune to biological decay, and has a life expectancy of over 50 years. Despite of these advantages, steel sleepers can only be used on low-speed tracks, due to its poor vibration absorption properties [4]. Moreover steel timber cannot be used in humid environments due to corrosion problems. Other than these disadvantages steel sleepers are prone to fatigue cracking in the fastening holes due to moving trains. High cost further adds on to its limitations for being used extensively.

Concrete: Concrete sleepers have been more successful than steel sleepers owing to their good absorption properties along with providing the required strength. Concrete sleeper are easily available, provide high durability and require low maintenance with a service life of over 60 years. Disadvantages of concrete sleeper are its heavy weight (4 times of steel/timber sleeper), difficult adaptability, handling and installation. Moreover the initial cost of concrete sleeper is extremely high in comparison to timber/steel sleeper.

All the above highlighted disadvantages combined with the significance and volume of applicability of railway sleepers in railway industries, clearly highlights the Industry gap. Thus the research objective of this paper is to provide a smart material alternative solution to the existing problem along with a new design which fulfils the requirements of a sleeper.

Following are the requirements for sleeper:

1. Sleeper shall permit use of standard rail, MS bearing plates and holding down fasteners.
2. Sleeper shall not be prone to failure due to weather-related high heat or freezing temperatures.
3. Sleeper shall not warp or sag to the level of permanent deformation that would require replacement of the sleeper.
4. Sleeper shall not require end caps, Sleeper shall not split or crack in any way requiring the sleeper to be replaced.
5. The sleeper shall be durable, so as to retain necessary strength and other structural properties during service in track.
6. The sleeper shall be resistant to rot, bacteria and insects such as termites, borers etc. which may reduce strength and/or integrity of sleeper.

Composites: It is, by definition, something made from 2 or more materials - in this case, a fibre and resin. Composites have been regarded as the material with high service life which is entirely recyclable with positives such as reduction in wastes and deforestation. Few advantages of using composites may include following,

- Excellent ‘specific’ strength and modulus, giving high performance per given weight, leading to fuel savings.
- Laminate patterns could be tailored to give a certain mechanical properties in different directions.
- Excellent resistance to corrosion, chemical attack and outdoor atmosphere.

Composites typically are anisotropic materials governed by second order tensor mathematics, with 21 materials property constants such as Young’s modulus, Shear modulus, Poisson’s ratio, etc. few strategic advantages for using composite materials include:

- Good rail holding ability
- Excellent vibration absorption characteristics
- long durability and Operational efficiency
- Improved maintainability

Given the immediate concerns in employing present sleeper forms, lack of any substantial and direct research in subcontinent and the intent on improving the entire rail infrastructure across sub-continent, a more prudent approach should be catered to and composite sleepers is a way to go with reduced maintenance costs and higher usability. With greater number of properties matching to wooden sleepers, composite is invariably the choice as these wouldn't require any changes to the present network of bridges in the subcontinent.

III. Method and Methodology

A. Requirements of Subcontinent

Characteristic requirements for the composite sleepers in the subcontinent could be further segregated into following subsets.

I. Material Requirements

It should be a base of polymeric resin imbibing not any toxic agents but binding agents i.e. Glass Fibres.

II. Dimensional Requirements

- LxWxH should be minimum 2500x200x150 mm^3
- Provision for notching, to compensate for high bending stresses on bridges

III. Performance Requirements

Mechanical Properties	Ideal Value
Modulus of Elasticity	1170 MPa (min)
Rail seat compression	6.2 MPa (min)
Modulus of Rupture	13.8 MPa (min)
Screw Spike Withdrawal	22.2 KN (min)
Coefficient of Thermal Expansion	$1.35\times10^{-4}/^{o}C$ (max)
Resistivity	500+ MegaOhms at 500V

IV. Structural Requirements

The specimen should pass the following tests to be ascertained of the material characteristics.

- *Static load test*: Assessing the design adequacy
- A gradual load is applied with specific intervals
- *Impact load test*: Assessing shock absorbing capacity
- Wheel dropped twice over a point to test for recesses
- *Dynamic fatigue test*: Assessing structural dynamics
- Test @ 5 Hz with 2 million cycles at a load of 4-20t

V. General Requirements

- Resistance against weather related failure
- Deformation should not generally occur
- Resistant to tears, avoiding end caps
- Fire resistant, suitable for use in track circuited area
- Free of voids; and resistants to insects

B. Material Selection

Commonly used matrix in the composites for heavy commercial products are High Density Poly Ethylene, High Density Poly Styrene and High Density Poly Urethane. Sample were taken as each of the matrix as base with Glass reinforcement and crumbed rubber for higher strength and shock absorbing ability.

Sample 1	Sample 2	Sample 3
High Density Poly Styrene	High Density Poly Ethylene	High Density Poly Urethane
Glass Reinforcement	Crumbed Rubber	Crumbed Rubber
Fillers	Glass Reinforcement	Glass Reinforcement
— —	Fillers	Fillers

All the 3 samples passed the material and dimensional requirements for the sleepers, however a significant deviation is identified for the performance requirements. Only sample 1 and 2 were observed to have a modulus of elasticity of over 1170 MPa, the minimum required value. However on further analysis it was observed that only sample 2 met with all of the required criteria, where modulus of rupture for sample 1 fell below of the minimum required value of 13.8 MPa.

Further for general requirements, sample 2 was most resistance to tears and cracks, as it is the most anisotropic composition; and it also observed to have only minutely localised voids relatively very negligible to other samples.

With all requirements and specifications in consideration, the samples were ranked in order as sample 2, followed by sample 1 and sample 3 respectively.

The composition for sample 2 are as enlisted:

Sample 2	
High Density Poly Ethylene	55%
Crumbed Rubber	10%
Glass Reinforcement	15%
Fillers	20% ($CaCO_3$, Mica, etc.)

C. *Design Parameters*

I. Design considering static loading

For a wagon with 4 bogies i.e. 8 wheels and Mass M_c could be regarded as with Mass $M_a = M_c/8$ at point of contact between wheel and rails. Here the applied force at a single point would be $F_a = M_a g$, and total force on sleeper as $F=2F_a$. Analysing the shear force diagram, we observe that on the rail seat bending stresses are maximum.

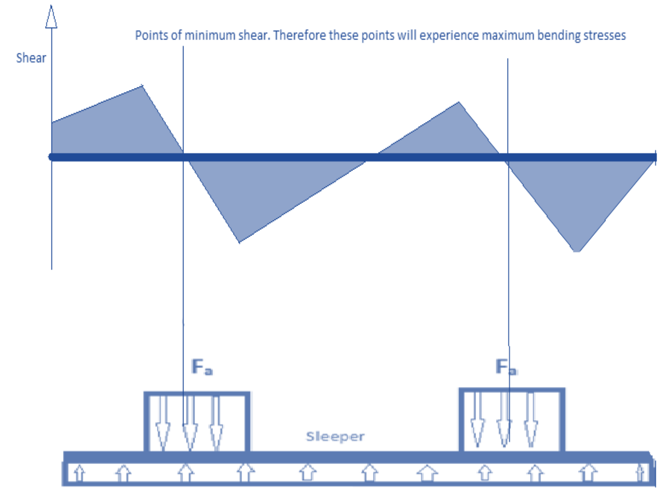

Fig.1

Furthermore on employing, in-order, the following formulae width and height of the sleeper is calculated.

$$\sigma_a = F_a/A$$
$$A = L_p.w$$
$$\sigma_a = S_{ys}/FOS$$
$$w = (F_a.FOS)/L_p.S_{yc}$$

For height,

$$M = F_a.(L_p^2/L - L_p/2) : \text{Moment}$$
$$\sigma_b = Mc/I$$
$$c = h/2$$
$$I = L_p.h^3/12$$
$$\sigma_b = [F_a.(L_p^2/L - L_p/2)]. [h/2]/ [L_p.h^3/12]$$
$$[F_a.(L_p^2/L - L_p/2)]. [h/2]/ [L_p.h^3/12] \leq S_{ys} / FOS$$

On calculating height and weight for both passenger and freight wagons on broad gauges, the minimum values of height are as:

Height	Width
150mm	200mm

D. *Product Design*

The strength requirements have already been translated into structural requirements of the sleeper, giving the dimensions required for the sleeper using the new proposed composite material.

Designing and analyses of the true structure is been carried out in this section to come-forth with the optimum design for the composite sleeper. The dimensions as calculated are as follows:

Length: 2500mm (Industry requirement, for Broad gauge)
Height: 150mm
Width: 200mm

With the above dimensions and a load of 50t [6] a dynamic analyses of the structure would result in the following results:

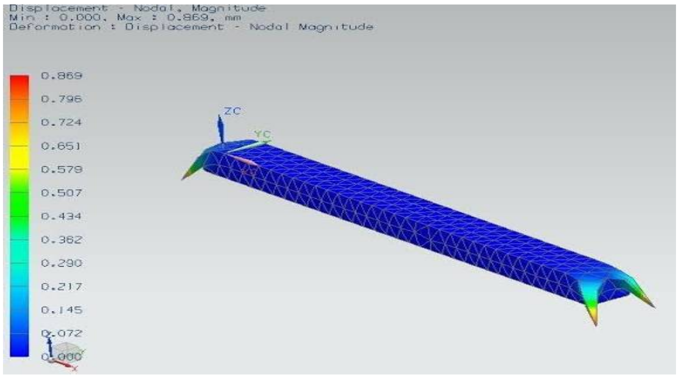

Fig.2

(Software: NX NASTRAN; Mesh size: 53.6mm; Mesh Type: CTETRA 10;)

As is clear from the analysis, no displacement is observed in the middle portion whereas the point of load application has deformed heavily.

Thus the next design iteration has been done with material removal in the centre, and application of a steel rod in the centre of the sleeper structure (Fig.3 & Fig.4). The hollow steel rod in centre provide increased torsional strength to the structure, and further reduces the weight of the structure. Moreover material has been removed from unwanted areas which brings down the cost of the sleeper significantly.

This design allows for load transfer in a controlled flow manner owing to its continues trapezoid geometry. This geometry allows load dissipation to a greater extent thus leaving the sleeper structure unharmed.

Analyses of the new structure with the rod insert keeping same load conditions clearly highlights the advantages of this design. Displacement is very less and only in the area directly below the rail seat.

In the analysis carried out above it is assumed that the complete load is not acting at a point but is spread through the rail seat area.

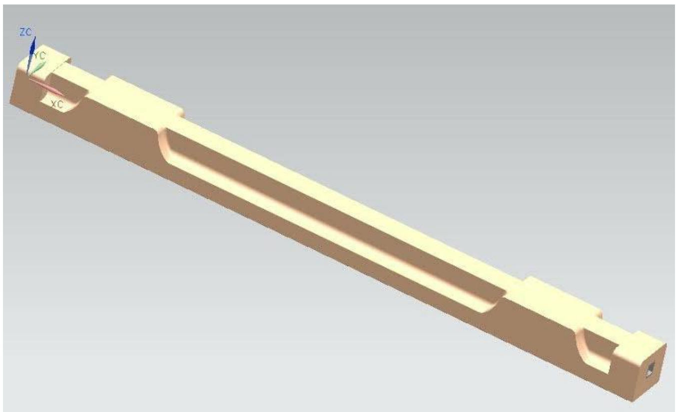

Fig. 3

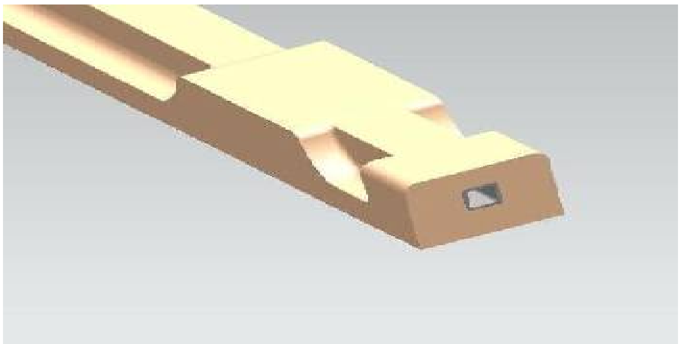

Fig. 4

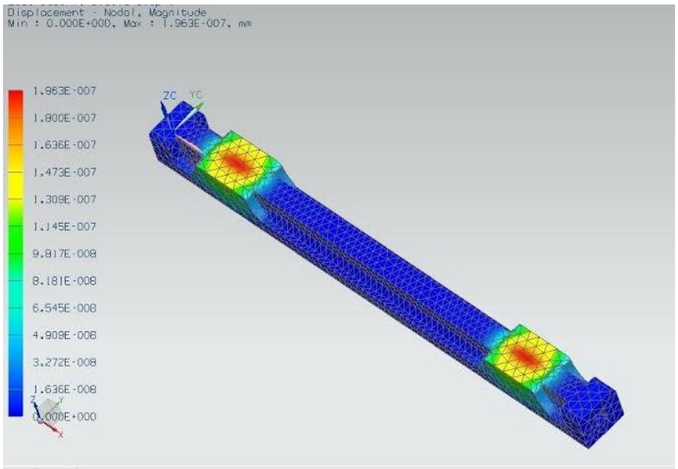

Fig. 5
(Software: NX NASTRAN; Mesh size: 51.9mm; Mesh Type: CTETRA 10;)

The above design is thus a promising alternative to the existing sleeper. The material fulfils all the biological and environmental requirements, whereas this design satisfies all the mechanical requirements.

IV. Result

Our paper highlighted the gaps in the current research and the employed model in the railway networks across subcontinent, upon which on due consideration of possible composite materials presented a composite based railway sleeper which is not only light weighted but has better strength values and complies with the required specification of the subcontinent’s railways.

On comparative analysis, it is also observed that the sleeper is resistant to any hazardous chemical and wear & tear which are primary concerns for weeded sleepers; therefore further avoid the irrelevant maintenance costs. On the other hand it also outperforms steel based sleepers on the maintainability, and the requirement of ballast. Thus the overall implementation cost of composite based sleepers comes down, as it is not only has high life expectancy but also requires lower amount of ballast materials.

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