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Original Article

Experimental Investigation of the Mechanical and Vibrational Properties of a Fibreglass and Polyester Resin Composite for use in Railway Sleepers

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Abstract - *Fibreglass-reinforced composites have been used in varied applications due to their high mechanical strength. The purpose of this work was to improve railway sleeper structural strength that frequently fails due to heavily loaded trains in the railway industry. Using composite materials in these sleepers can improve their mechanical properties significantly, hence the sleeper's durability. The experiment design followed in the fabrication of the composite in this study consisted of varying the fibreglass volume fraction between 5 and 8%. The composite tensile strength, compression strength, flexural strength and hardness were then ascertained. The experimental results showed that the fabricated composite had a maximum tensile and flexural strength at 8 % fibre content of 12.13 MPa and 42.658 MPa, respectively. The highest compression strength achieved was 55.164 MPa at 8% fibre loading. The maximum flexural was realized at 8% fibre content giving a strength of value. The maximum hardness was 745 Leeb at 7% fibre content. The vibration damping increased from 0.050 to 0.089, with the increase of fibreglass from 5 to 8 %. There is still a need for further research into the use of alternative resins in order to come up with optimized composite sleepers that have enhanced durability and mechanical strength.*

Keywords - *Composites, Fibreglass, Mechanical properties, Railway sleeper*

1. Introduction

The components of a railway structure often suffer from high vibration due to heavily loaded trains[1]. The railway sleeper is a critical part of the railway track system. Several different types of sleepers are used in the railway industry, namely timber, steel, composite and concrete sleepers [2]. The function of railway sleepers is to distribute and sustain the rail gauge length and transmission of the rail load to the ballast [3]. Additionally, the railway sleeper guards against abrasive activities, cuts to the bearing plates, and ballast material protection. Railway sleepers are crucial for keeping the railway track system from moving laterally and longitudinally.[3].

Different brands of railway sleepers are in use in the railway structure. Timber sleepers have a long history of usage in the railway network [4]. However, termite attacks, split ends and fungus have made these timber sleepers fall out of favour [5]. Steel possesses greater strength when compared with timber and concrete [6]. However, steel sleepers have the disadvantage of being susceptible to corrosion and fatigue failure [7].

Concrete sleepers have a good life span but have the disadvantage of forming micro-cracks during use which ultimately coalesce and form macro cracks [8,16]. Composite sleepers have a good life span and mechanical properties. Polymer materials combined with fibre composites could enhance both the mechanical and physical properties of railway sleepers [9]. However, thermoplastic polymer composite sleepers have the disadvantage of the creep phenomenon, which can significantly affect their mechanical properties[10]. Composites' damping properties depend not only on the material but also on the load frequency since the viscoelasticity and the defect behaviour depend on the frequency [23]. Composite sleepers are more durable and have a longer service life of how long? (Ref). The damping of impact loads, sound absorption and lateral stability properties of the sleeper from waste plastics has been shown to be close to that of timber sleepers [12]. Due to advancements in train technology and demand of faster and heavier trains the railway track has to sustain greater mechanical forces hence the need for improved railway sleepers [13].

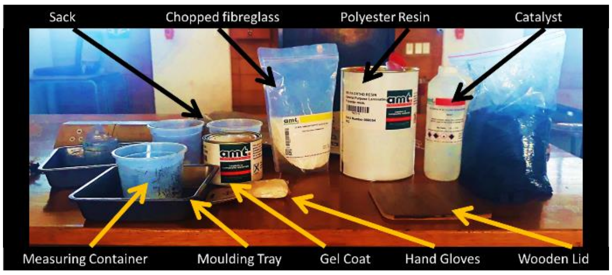

Fig. 1 Material used to fabricate composite

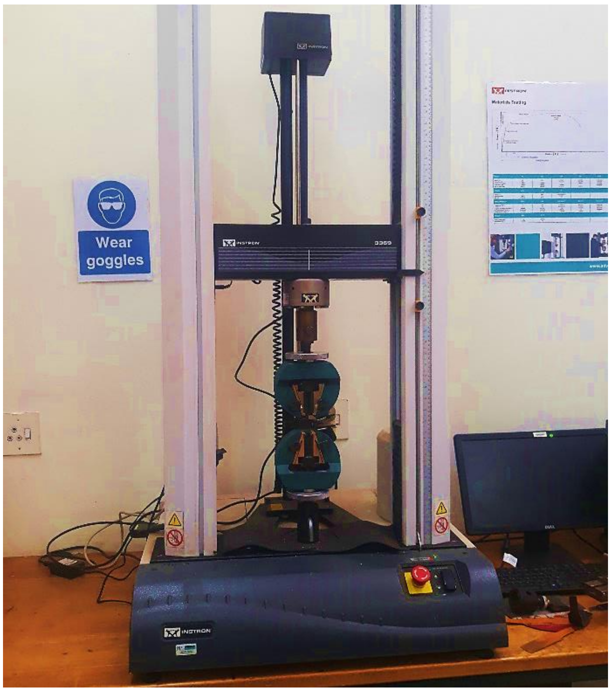

Fig. 2 UTM (universal testing machine)

2. Methodology

2.1. Details of Materials

In this study, 12 mm glass fibre and polyester resin were used to fabricate the composite. Methyl Ethyl Ketone Peroxide (MEKP) was utilized as an accelerator (quickening agent) and catalyst.

2.2. Fabrication of Composites

The fabrication process of the composites was done using the hand layup method. Fibreglass and polyester resin were used to fabricate the composite samples. A gel coat was applied to the surface of the mould to impact smoothness and aesthetically pleasing finish to the composite. Figure 1 shows the materials and equipment that were used in fabricating the composite. The fibreglass ratio ranged from 5 - 8%, and the polyester resin ratio ranged between 72 - 90%. Moulding trays made of stainless steel of size 22,5 cm x 22,5 cm were used for the fabrication of the composites

2.3. Mechanical Properties of Composite

2.3.1. Tensile Strength

The tensile strength test was conducted in accordance with ASTM D3518/D3518M-18 (D 3518 2007). The universal testing machine INSTRON model 3369, shown in Figure 2, was used to conduct the tensile test.

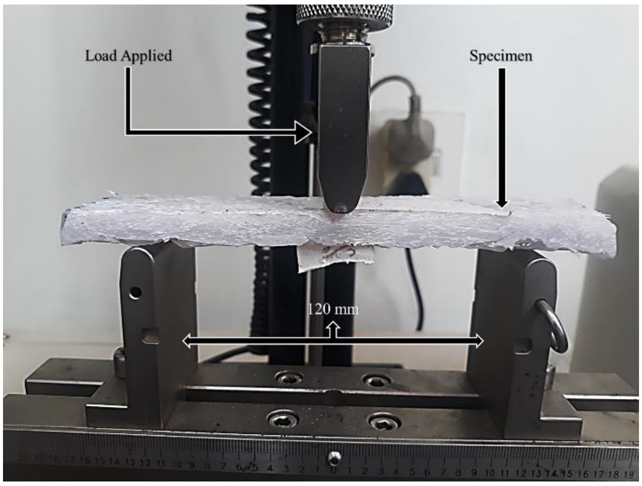

Fig. 3 Flexural strength specimen setup

A Static load cell of 5 kN was used to conduct the test. The machine was operated at a continuous speed of 5 mm/s, and a gauge length of 150 mm was used.

2.3.2. Compression Strength

The specimen test was conducted in accordance with ASTM D3410/D3410M (ASTM D3410 2014), which uses a specimen size of 140 mm long and 13 mm wide, having an unsupported gauge length of 13 mm when installed in the fixture.

The universal testing machine INSTRON model 3369, shown in Figure 2, was used to conduct the compression strength test.

The compressive strength of the composites material was calculated according to equation 1

$$C = \frac{F}{A} \tag{1}$$

Where C is compression strength (MPa), F is applied force (N), and A is the area (m^2)

2.3.3. Flexural Strength

The flexural strength test was conducted in accordance with ASTM D8058-19 (ASTM D8058-19 2019). A Universal Testing Machine, INSTRON model 3369, was used to conduct the flexural tests. The ASTM standard carried out three-point bending tests.

The flexural strength test was run until the specimen completely failed, and the machine stopped when the resistive force had fallen below 20 N. The flexural strength was calculated for each specimen using equation 2

$$R = \frac{3PL}{2bd^2} \tag{2}$$

Where R is the flexural strength of the specimen (MPa), P is the breaking load of the specimen (N), L is the length of span (mm), b is the width of the specimen (mm), and d is average thickness specimen (mm).

2.3.4. LEEB Hardness

The composite hardness was measured using a model Time 5330 hardness tester shown in Figure 4. The test method used was based on the dynamic rebound principle, and the test was carried out in accordance with ASTM A-956 (ASTM A-956 1998).

Fig. 4 LEEB hardness testing

2.4. Vibration Test

The composite vibration test was carried out using a shaker table. This test was conducted according to the ASTM E756 standard (ASTM E756 2009). This test method measures the loss factor, young modulus or shears modulus, and vibration properties of materials. It is accurate over a frequency range of 50 to 5000 Hz over the useful temperature range of materials. The vibration specimens with dimensions of 140 mm x 14 mm x 5 mm, as shown in Figure 5, were used for the vibration tests.

Fig. 5 Specimen preparation for vibration and damping test

The base of the cantilever beam was clamped over a length of 20 mm, with 120 mm free to vibrate in the air. The metal bases were securely bolted to the shaker table, and the individual test specimens were clamped tightly to the metal base. The specimens were clamped onto the steel base on the vibrating table, so the test specimen acted as a simple cantilever. The principle of the test was to apply a vertical vibration spectrum to the fixed end and then measure the responsive vibration at the free end of the specimen. An accelerometer was used to determine the vibration spectra, with one at the fixed end to measure the input vibration spectrum and the other at the free end of the specimen.

3. Results and Discussion

The following subheading discusses tensile strength, compression strength, flexural strength, and hardness.

3.1. Tensile Strength

This section analyses the composite tensile strength results in accordance with the experimental design of the study.

Figure 6 presents the effects of fibreglass volume fraction on the composite tensile strength.

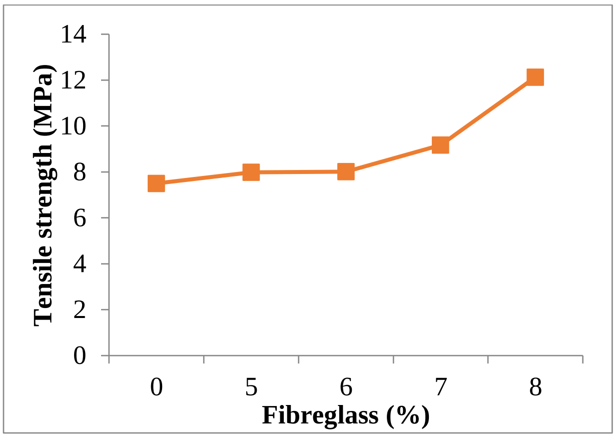

Fig. 6 Effect of fibreglass volume fraction on the tensile strength of the composite

Figure 6 presents a general increasing trend in the tensile strength of the composite with an increase in the fibreglass volume faction. The graph shows an increase in tensile strength from 6.71 MPa to 12.13 MPa with an increase in fibreglass volume fraction of 5 to 8%, respectively. An overall tensile strength gain of 38% was realized with an 8% fibreglass volume fraction compared to the control sample.

The results in Figure 6 suggest that a higher fibreglass volume fraction must be used in the composites as the tensile strength increases with the increase in reinforcing fibreglass volume fraction. Low fibreglass volume fractions of less than 5% do not give adequate reinforcement. The dominant tensile strength failure mode at a low fibreglass volume fraction of less than 5% is largely fibre breakage and matrix cracking. However, when the fibreglass volume fraction was increased to greater than 8%, the dominant failure mode was fibre pull out and fibre breakage. This failure mode could be attributed to fibres tending to take up the bulk of the tensile forces before failure resulted in matrix cracking and propagation of cracks.

3.2. Compression Strength

This section analyses the composite compression strength results in accordance with the experimental design of the study.

Figure 7 presents the effects of fibreglass volume fraction on the composite compressive strength.

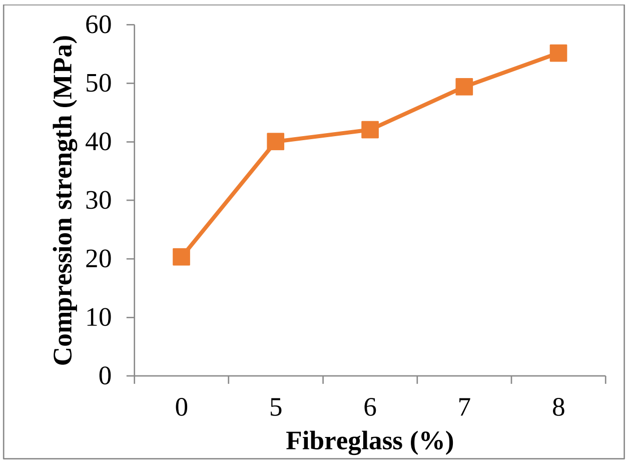

Fig. 7 Effects of fibreglass volume fraction on the compression strength of the composite

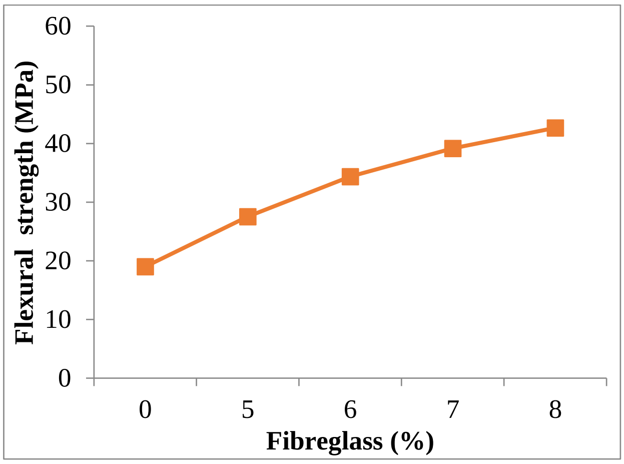

Fig. 8 Effects of fibreglass volume fraction on the flexural strength of the composite

Figure 7 presents a general trend in the compression strength with an increase in the fibreglass volume faction. The graph shows an increase in compression strength from 20.30 MPa to 55.16 MPa with fibreglass volume fractions of 0 to 8%, respectively. There is an increase in compressive strength between 0 and 8% fibreglass volume fraction. An overall compression strength gain of 63% was realized with an 8% fibreglass volume fraction compared to the control sample.

The increase in compressive strength with progressive increment in fibreglass volume fraction can be attributed to hybrid composite increasing strength due to the interfacial bond between fibres and polyester.

The results observed in this study are consistent with research by Prema [24] and Srivastava [17]. They both reported that an increase in fibreglass volume fraction also increases the composite compression strength. It was observed that a fibreglass volume fraction greater than 5% gave even fibre distribution resulting in a composite with acceptable compressive strength.

3.3. Flexural Strength

Figure 8 presents the effects of varying fibreglass volume fractions on the composite flexural strength.

Figure 8 presents a general increasing trend in the flexural strength with an increase in the fibreglass volume faction. The graph shows an increase in flexural strength from 27.51 MPa to 42.60 MPa with an increase in fibreglass volume fraction of 5 to 8%, respectively. The overall flexural strength gained from 5 to 8% fibreglass volume fraction is 35.50%.

The flexural strength of the composite increases as the glass fibre volume fraction is increased.

The results observed in this study align with the research by Rachchh [18] that showed an increase in flexural strength with an increase in fibreglass volume fraction. However, the study by Rach [18] noted that the composite flexural strength decreases when the glass fibre volume fraction is greater than 9% due to insufficient polyester resin to transmit the load from one fibre to another.

Figure 9 shows the dominant failure mode of the fabricated fibreglass composite. It was observed that at a high fibre volume fraction greater than 5%, the dominant composite failure modes mainly include fibre breakage, ultimately leading to matrix breakage.

3.4. LEEB Hardness

This section discusses the composite hardness results according to the full factorial experimental design followed in this study.

Figure 9 presents the effects of fibreglass volume fraction on the composite hardness.

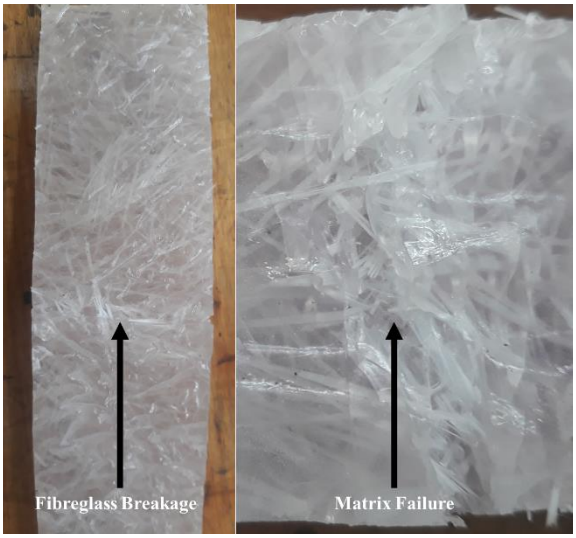

Fig. 9 Failure mode of composite

Table 1. Mechanical strength parameters of the sleepers

	Fabricated composite	Polycarbonate and polyethene plastic composite (Jain et al., 2016; Manalo et al., 2010).	Concrete sleeper (Meesit et al., 2017)	Timber sleeper (Hamzah et al. 2008)
Tensile	12.13 MPa	3.34 MPa	6.50 MPa	16.55 MPa
Flexural	42.60 MPa	3.20 MPa	61.2 MPa	18.4 MPa
Compression	55.16 MPa	29.68 MPa	61.20 MPa	68.80 MPa
Vibrational damping	0.089		0.022	

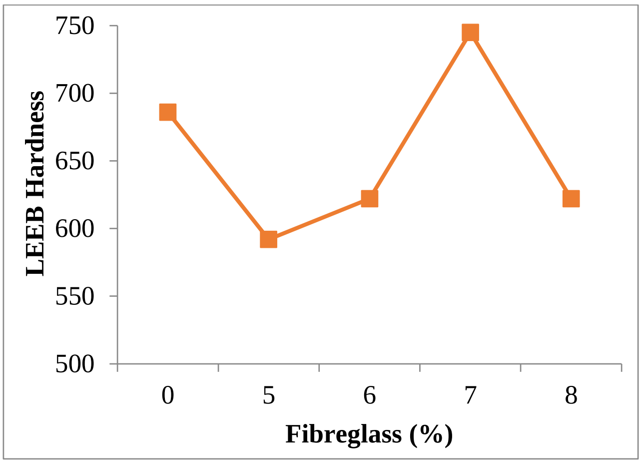

Fig. 10 Effects of fibreglass volume fraction on the hardness of the composite

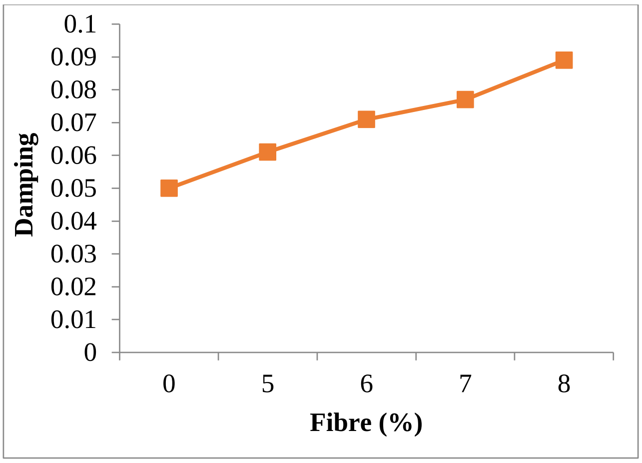

Fig. 11 Effect of fibreglass volume fraction on the vibration and damping properties of the composite

As observed in Figure 10, a sharp drop in from the control specimen with the addition of 5% fibreglass, giving a hardness of 592 from 690. As the fibre volume fraction increased to 6%, there was a marginal increase in hardness to 622. Further addition of fibreglass to 7% resulted in an increase in hardness to 745. However, an increase in fibreglass volume to 8% decreased the hardness to 622.

The results indicate that fibreglass of volume fraction 5 to 7% increases the hardness of the composite. However, a fibre volume fraction greater than 8% decreases the hardness of the composite. This phenomenon can be attributed to the fibreglass having low efficiency of polyester resin absorption when fibreglass is greater than 8%. Furthermore, the fibreglass volume fraction of greater than 8% results in a stress transfer that becomes poor in a matrix.

The results observed in this study align with the research by Rachchh [18], Zoalfakar [11,19,20] and [25], who stated the hardness increases with fibre volume fraction as observed up to 7% in Figure 9. However, the decrease in hardness observed in the current study beyond 8% can be attributed to insufficient polyester resin cover to transmit the load from one fibre to another. Furthermore, the matrix's poor fibre dispersion and distribution could result in low composite hardness at high fibre loading.

3.5. Vibration Results

Figure 11 presents the effects of fibreglass volume fraction on the composite damping properties. Figure 11 shows an overall trend in the damping with an increase in the fibreglass volume faction. The graph shows an increase in damping from 0.050 to 0.089 with an increase in fibreglass volume fraction of 5 to 8%, respectively. The overall damping gained from 5 to 8% fibreglass volume fraction is 44 %.

A study by Tang [21] stated that the volume fraction of fibre reinforcement directly influences the energy dissipation within the composite matrices. The observation made by Tang [21] supports the present study's results that the incremental volume fraction of fibreglass enhances composite vibrational damping properties due to the presence of interpenetrating polymer networks [22]. These networks dissipate the vibrational forces depending on the orientation and stacking sequence of fibres within the composites. This has been observed in the present study, as shown in Figure 10, with an increase in fibre loading resulting in an increase in damping.

4. Application of the Composite in Railway Sleeper

The railway sleeper reinforced with fibre glass is suitable for use. The railway sleeper has greater strength when compared with plastic sleepers.

5. Conclusion

The work investigates the mechanical properties of 12 mm fibreglass and polyester resin. The results reveal that the composite consisting of fibreglass had a maximum tensile of 8 % fibre content giving tensile strength of 12.13 MPa. The highest compression strength of the composite was 55.164 MPa at 8% fibre loading. The maximum flexural strength was realized at 8% fibre content giving a strength value of 42.658 MPa. The maximum hardness measured on a composite containing fibreglass was 745 LEEB. It was observed that the glass fibre increased the vibrational damping of the composite to a maximum of 0.089 at an 8% glass fibre volume fraction.

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Reference

[1] Sensitivity Kaewunruen and Ratthaphong Meesit, "Sensitivity of Crumb Rubber Particle Sizes on Electrical Resistance Of Rubberised Concrete," *Cogent Engineering*, vol. 30, no. 1, pp. 1–8, 2016. *Crossref*, https://doi.org/10.1080/23311916.2015.1126937

[2] Bernhard Lichtberger, *Track Compendium*, Eurailpress, pp. 1–192, 2005.

[3] J. Zhao, A. H. C. Chan, and M. P. N. Burrow, "Reliability Analysis and Maintenance Decision for Railway Sleepers using Track Condition Information," *Journal of the Operational Research Society volume*, vol. 58, pp. 1047-1055, 2007. *Crossref*, https://doi.org/10.1057/palgrave.jors.2602251

[4] M. Allan Zarembski, "Concrete vs . Wood ties: Making the Economic Choice," *Conference on Maintaining Railway Track; Determining Cost and Allocating Resources*, 1993. [Online]. Available: https://udspace.udel.edu/handle/19716/30839

[5] Wahid Ferdous, "Composite Railway Sleepers – Recent Developments, Challenges And Future Prospects," *Composite Structures*, vol. 134, pp. 158–168, 2015. *Crossref*, https://doi.org/10.1016/j.compstruct.2015.08.058

[6] Pizhong Qiao, Julio F. Davalos, and Michael G. Zipfel, "Modeling and Optimal Design of Composite-Reinforced Wood Railroad Crosstie," *Composite Structures*, vol. 41, no. 1, pp. 87–96, Jan. 1998. *Crossref*, https://doi.org/10.1016/S0263-8223(98)00051-8

[7] B. G. Herbandez FCR, K. Kock, Transit Cooperative Research program, Transportation Research Board. Final Report for TCRP project D-7.Task 14 Rail base corrosion detection and prevection, 2007.

[8] Wahid Ferdous, and Allan Manalo, "Failures of Mainline Railway Sleepers and Suggest Remedies-R Eview of Current Practice," *Engineering Failure Analysis*, vol. 44, pp. 17-35, 2014. *Crossref*, https://doi.org/10.1016/j.engfailanal.2014.04.020

[9] Duangkamol Dechojarassri, "*Natural Rubber Composites for Railway Sleepers, a feasibility study,"* Faculty of Engineering, Thammasat University, *2005*

[10] Amir Ghorban, and Seckin Erden, "Polymeric Composite Railway Sleepers," *ISERSE*, pp. 9–11, 2013.

[11] Srinath T. Rafik, Mohamed, and Prince Cheladurai, "Experimental Study on Sections Made Using Glass Fibers," *SSRG International Journal of Civil Engineering*, vol. 2, no. 3, pp. 18-21, 2015. *Crossref*, https://doi.org/10.14445/23488352/IJCE-V2I3P106

[12] Amanda Jacob, "Indian Composites Industry Set to Take Off," *Reinforced Plastics*, vol. 48, no. 3, pp. 34–39, 2004. *Crossref*, https://doi.org/10.1016/S00343617(04)00231-0

[13] Sakdirat Kaewunruen, Ratthaphong Meesit, and Paramita Mondal, "Early-age Dynamic Moduli of Crumbed Rubber Concrete for Compliant Railway Structures," *Journal of Sustainable Cement-Based Materials*, vol. 6, no. 5, pp. 1–12, 2017. *Crossref*, https://doi.org/10.1080/21650373.2017.1280425

[14] "Standard Test Method for Compressive Properties of Polymer Matrix Composite Materials Using a Combined Loading Compression (CLC) Test Fixture," *ASTM D6641*, pp. 1–13, 2014.

[15] "Standard Test Method for Determining the Flexural Strength of a Geosynthetic Cementitious Composite Mat (GCCM) Using the Three-Point Bending Test 1," *ASTM D8058*, pp. 1–6, 2019.

[16] U. Venkat Tilak, and A. Narender Reddy, "Effect of Different Percentage Replacement of Weathered Aggregate in Place of Normal Aggregate on Young's Modulus of Concrete to Produce High strength and Flexible/Ductile Concrete for use in Railway Concrete Sleepers," *SSRG International Journal of Civil Engineering*, vol. 2, no. 11, pp. 21-26, 2015. *Crossref*, https://doi.org/10.14445/23488352/IJCE-V2I11P105

[17] V. K. Srivastava, and S. Lal, "Mechanical Properties of E-glass Fibre Reinforced Nylon 6/6 Resin Composites," *Journal of Materials Science*, vol. 26, no. 24, pp. 6693–6698, 1991. *Crossref*, https://doi.org/10.1007/BF02402662

[18] N. V Rachchh, and D. N. Trivedi, "Mechanical Characterization and Vibration Analysis of Hybrid E-glass / Bagasse Fiber Polyester Composites," *Materials Today Proceeding*, vol. 5, no. 2, pp. 7692–7700, 2018. *Crossref*, https://doi.org/10.1016/j.matpr.2017.11.445

[19] M. S. El-wazery, M. I. El-elamy, and S. H. Zoalfakar, "Mechanical Properties of Glass Fiber Reinforced Polyester Composites," *International Journal of Applied Science and Engineering*, vol. 14, no. 3, pp. 121–131, 2017. *Crossref*, https://doi.org/10.6703/IJASE.2017.14(3).121

[20] M. Nelson Prem Kumar, V.S. Anantha Sivaraman, and N. Prakash, "Design and Development of Secondary Glass Fiber Roving Waste Prototype for Preventing Environmental Hazard," *SSRG International Journal of Mechanical Engineering*, vol. 4, no. 4, pp. 27-32, 2017. *Crossref*, https://doi.org/10.14445/23488360/IJME-V4I4P108

[21] Xiaoning Tang and Xiong Yan, "A Review on The Damping Properties of Fiber Reinforced Polymer Composites," *Journal of Industrial Textiles*, vol. 49, no. 6, pp. 693–721, 2020. *Crossref*, https://doi.org/10.1177/1528083718795914

[22] P. S. Senthil Kumar, K. Karthik, and T. Raja, "Vibration Damping Characteristics of Hybrid Polymer Matrix Composite," *International Journal of Mechanical & Mechatronics Engineering,* vol. 15, no. 1, pp. 42–47, 2015.

[23] Ankit Gupta, Rajeev Sharma, and Rajnish Katarne, "Experimental Investigation on Influence of Damping Response of Composite Material by Natural Fibers-A Review," *Materials Today Proceeding,* vol. 47, no. 11, pp. 3035–3042, 2021. *Crossref,* https://doi.org/10.1016/j.matpr.2021.05.513

[24] G. Dhanasekar, and P. Prema, "Mechanical Behaviour of Aramid and Glass Fibre Reinforced Polyester Resin Composite," *International Journal of Innovative Science and Research Technology,* vol. 5, no. 4, pp. 1469–1472, 2020.

[25] H. Ku et al., "A Review on the Tensile Properties of Natural Fiber Reinforced Polymer Composites," *Composites Part B Engineering,* vol. 42, no. 4, pp. 856-873, 2011. *Crossref,* https://doi.org/10.1016/j.compositesb.2011.01.010