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Original Article

Effects of Hybrid Rubber Particle and Glass Fibre Composite on Mechanical and Vibrational Damping Properties of Railway Sleeper

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Abstract *- A railway sleeper is a supporting and dampening beam placed underneath the railway track and can be made of different materials. Vibration and aggressive loading are frequent problems for the structural components of railroads., necessitating a material that can withstand significantly higher static and dynamic loads as trains become heavier and faster. Tyre disposal is a global environmental challenge, with approximately 1.5 billion tyre wastes generated annually. Tyres are non-biodegradable, making their disposal extremely difficult. This study seeks to find a way to recycle waste tyres in an environmentally friendly while reinforcing a composite railway sleeper. The study aimed to optimize a hybrid waste tyre rubber particles, fibreglass, and polyester resin composite railway sleeper to enhance the composites' structural strength while increasing the vibrational damping. The composite was fabricated using the hand layup method, where the rubber volume fraction varied between 5 and 20%, whereas the fibreglass volume fraction ranged from 5 to 8 %. A universal testing machine was used to carry out the mechanical tests, which included tensile strength, compression strength, and flexural strength. After that, hardness tests were carried out, and then the vibrational damping properties of the composites were determined using a shaker table.*

Keywords *- Composites, Fibreglass, Mechanical properties, Railway sleeper and Vibrational damping.*

1. Introduction

A Railway sleeper is an essential structural material of the railway track system (Meesit et al., 2017). This sleeper is a supporting and dampening beam placed underneath the railway track and can be made of different materials (Taherinezhad et al., 2013). Four main types of railroad sleeper materials are used: timber or wooden, steel, concrete, and composite materials. Concrete and steel sleepers were widely used in the late 1990s due to their durability over wooden sleepers (Lichtberger, 2005). However, the vibration of concrete and steel sleepers in the railway track system causes several problems, including concrete failure, rail fastener failure, flexural cracking, and rail seat abrasion. Kaewunruen and Remennikov (2011) implemented several approaches to solve the vibration problem in the railway sleeper industry by introducing ballast in the railway's structural material to improve the track system's damping (Kaewunruen and Remennikov, 2011). Ballasts used in railway sleepers improve the damping of the railway track system. However, the ballasts deteriorate with time as they are excited by the vibration from trains passing over them (Kaewunruen and Remennikov, 2011).

Furthermore, excessively severe abrasions can cause the rail to tilt, lose its clip-toe load, and broaden the gauge size. All these faults can ultimately result in train derailment (Richard R', 2012). The chipping loss of concrete material in the railway sleeper lands under the rail seat, which can lead to the concrete sleeper premature failure (Kernes et al., 2011).

Carrascal (2007) and Connolly (2015) introduced an innovative method of using railway sleeper pads which are mounted underneath the structural material of the railway to improve the damping of the railway track system. Yet, this composite sleeper pad material tends to loosen and slowly detach from the railway structure when heavily loaded trains are in motion. This is due to the vibration within the railway track system. Meesit (2017) introduced an innovative method of using waste tyre rubber particles with cement to make railway sleepers. This method was successful due to the ability of the rubber material to absorb the vibration of the railway line (Meesit et al., 2017). However, when the waste tyre rubber particles are mixed with concrete, the compression strength of the sleeper is reduced significantly (Sakdirat Kaewunruen and Remennikov, 2011; Meesit et al., 2017).

Abu-jdayil (2016) developed a composite material that consisted of polyester resin with rubber particles embedded within as the dampening medium. Abu-jdayil (2016) reported that, on the one hand, as the rubber volume fraction in the composite increased, the damping also increased, but on the other hand, the compressive strength of the composite decreased. However, Abu-jdayil et al. (2016) only used polyester resin and rubber particles in the composite material. This study will focus on using polyester resin, waste tyre rubber particles, and fibreglass to increase the sleeper's damping without adversely affecting its compressive strength. The choice of material was influenced by the ability of rubber particles to absorb vibration without any compromise on the structural integrity of the composite material.

2. Experimental Procedure, Materials, and Methods

2.1. Experimental Design

In this study, rubber particles of size 150 µm and 300 µm, polyester resin, fibreglass and catalyst were used in the composite fabrication. The fabrication process of the composites was done using the hand layup method. A gel coat was applied to the surface of the mould to impact smoothness and aesthetically pleasant finishing. The rubber particles used ranged from 5 - 20 %, and fibreglass from 5-8%. A full factorial experimental design was used, as shown in Table 1, to ascertain the effects of varying the volume fraction of the fibreglass and rubber particles on the mechanical and vibrational properties of the composite.

2.2. Experiments on Mechanical Properties of Composite

2.2.1. Tensile Strength

The specimen size for the tensile strength test was 250 mm long by 25 mm wide, with a 150 mm unsupported (gauge) length when put in the fixture, in accordance with ASTM D3518/D3518M-18. The tensile test was done using the universal testing equipment INSTRON type 3369, seen in Figure 1.

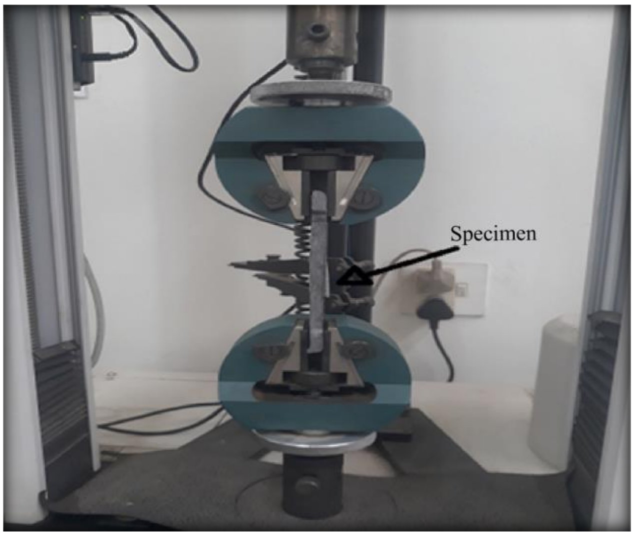

Fig. 1 UTM (universal testing machine)

Table 1. Shows the full factorial experimental design used in the composite fabrication

Run Order	Rubber particles (g)	Rubber particles Volume fraction (%)	Fibreglass (g)	Fibreglass Volume fraction (%)
1	0	0	0	0
2	0	0	20	5
3	0	0	24	6
4	0	0	28	7
5	0	0	32	8
6	20	5	0	0
7	20	5	20	5
8	20	5	24	6
9	20	5	28	7
10	20	5	32	8
11	40	10	0	0
12	40	10	20	5
13	40	10	24	6
14	40	10	28	7
15	40	10	32	8
16	60	15	0	0
17	60	15	20	5
18	60	15	24	6
19	60	15	28	7
20	60	15	32	8
21	80	20	0	0
22	80	20	20	5
23	80	20	24	6
24	80	20	28	7
25	80	20	32	8

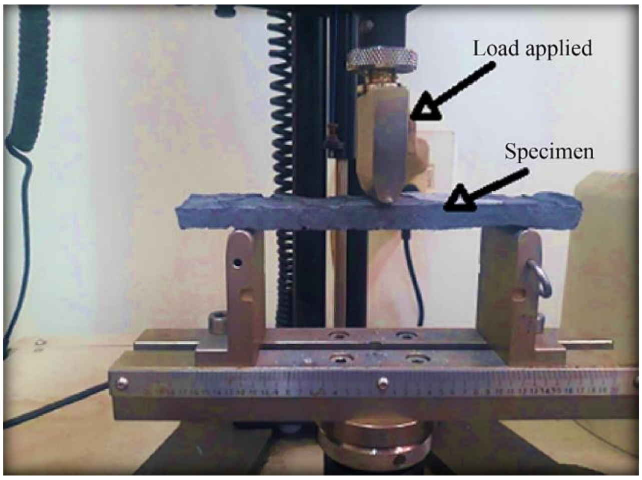

Fig. 2 - End plate used to prevent the splitting end

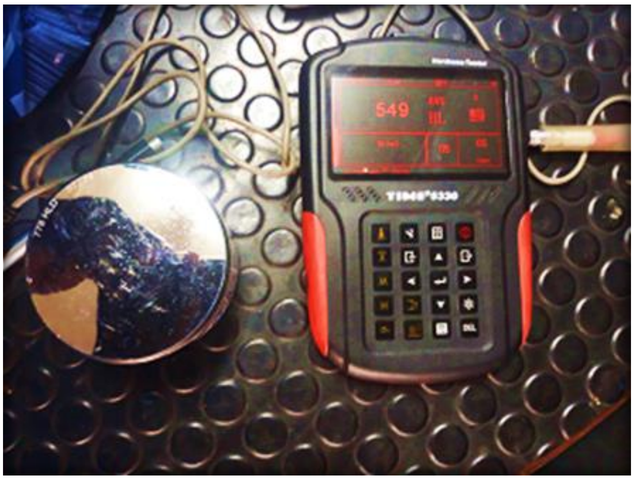

Fig. 3 LEEB hardness testing

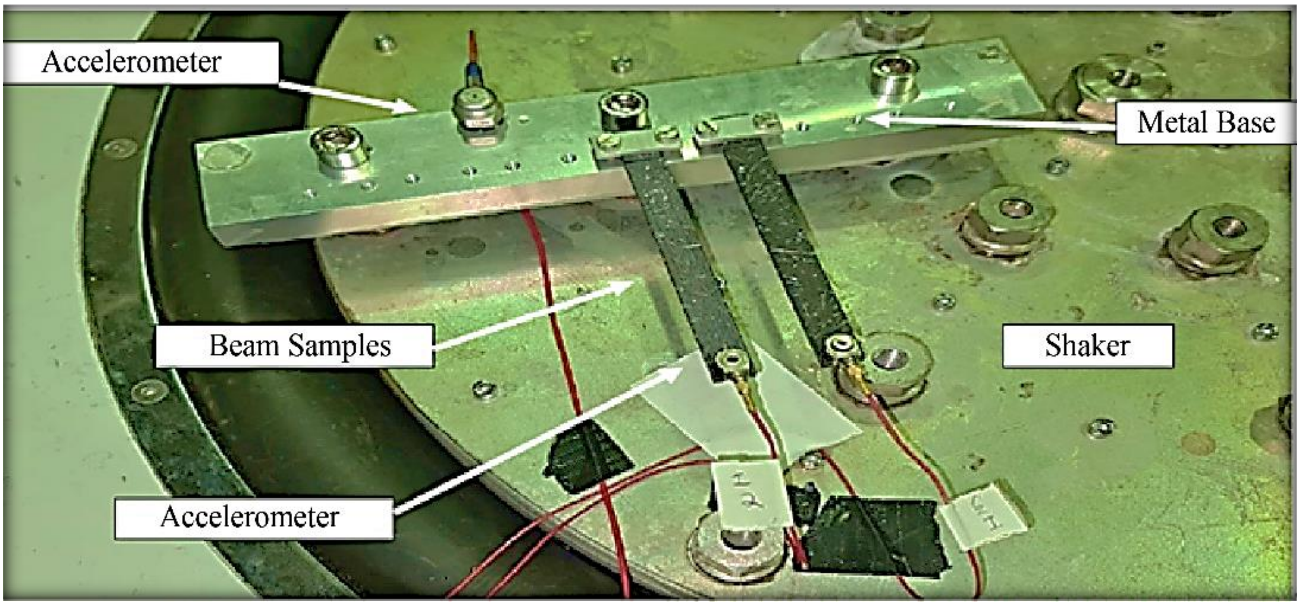

Fig. 4 Specimen preparation for vibration and damping test

The test was carried out using a 5 kN Static load cell. A gauge length of 150 mm was employed, and the machine was run continuously at a speed of 5 mm/s.

2.2.2. Compression Strength

According to ASTM D3410/D3410M, a specimen with dimensions of 140 mm long by 13 mm wide and an unsupported gauge length of 13 mm when inserted in the fixture is used for the specimen test. The compression strength test was carried out using the all-purpose testing device INSTRON type 3369.

Equation 1 was used to compute the material's compressive strength in the composite.

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

Where, C is the compression strength (MPa),
F is the applied force (N), and
A is the area (m2)

2.2.3. Flexural Strength

According to ASTM D8058-19, a flexural strength test was conducted. The flexural tests were performed using a Universal Testing Machine, INSTRON type 3369.

Three-point bending tests were carried out under the ASTM standard, as shown in Figure 2.

The flexural strength was calculated for each specimen using Equation 2

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

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

2.2.4. Hardness Test

Using a hardness tester with the Time 5330 model, as illustrated in Figure 3, the composite hardness was determined. According to ASTM A-956 (ASTM A-956 1998), the test was conducted using a methodology based on the dynamic rebound principle.

2.3. Vibrational Damping Test

On a shaker table, the composite vibration test was conducted. According to the ASTM E756 standard (ASTM E756 2009), this test was performed. This test method is accurate over a frequency range of 50 to 5000 Hz over the actual temperatures of the materials, and it evaluates the loss factor, Young modulus or shear modulus, and vibrational properties of the materials. The vibration tests were conducted using vibration specimens with the dimensions 140 mm x 14 mm x 5 mm, as illustrated in Figure 4.

The base of the cantilever beam was clamped over a length of 20 mm, with 120 mm free to vibrate in the air.

2.4. Fabrication of Composites

Hand layup was used to create the composites during the fabrication process. The composite samples were made using polyester resin and Fiberglass. In order to give the composite a smooth finish and visually pleasing finish, a gel coat was applied to the surface of the mould. The proportions of polyester resin and fibreglass varied from 72 to 90% and 5 to 8%, respectively.

The composites were manufactured using stainless steel moulding trays that were 22.5 cm by 22.5 cm in size.

3. Results and Discussion

3.1. Effect of Rubber Particles and Glass Fibre on Composite Tensile Strength

The graph in Figure 5 shows the effect on the tensile strength of a hybrid composite consisting of rubber particles and glass fibres.

Figure 5 shows that an increase in fibreglass volume fraction positively affects the tensile strength regardless of the rubber particle volume fraction.

The tensile strength of 5% rubber particle volume fraction increased from 8 MPa to 14 MPa with an increase in fibreglass volume fraction from 5 to 8 %.

The tensile strength of rubber particles with a 10 % volume fraction increased from 8 MPa to 14.5 MPa when the fibreglass volume fraction was increased from 5 to 8 %.

The tensile strength of the composite containing 15 % rubber particle volume fraction increased from 7 MPa to 13.5 MPa when the fibreglass volume fraction was increased from 5 to 8 %.

The graph in Figure 6 shows the effects that a hybrid composite consisting of 300 µm rubber particles and glass fibres has on the tensile strength.

Figure 6 shows that the tensile strength of the composite containing 5% rubber particles increases when a fibreglass volume fraction of 5 to 6% is used, then drops from 6 to 8% of the fibreglass volume fraction.

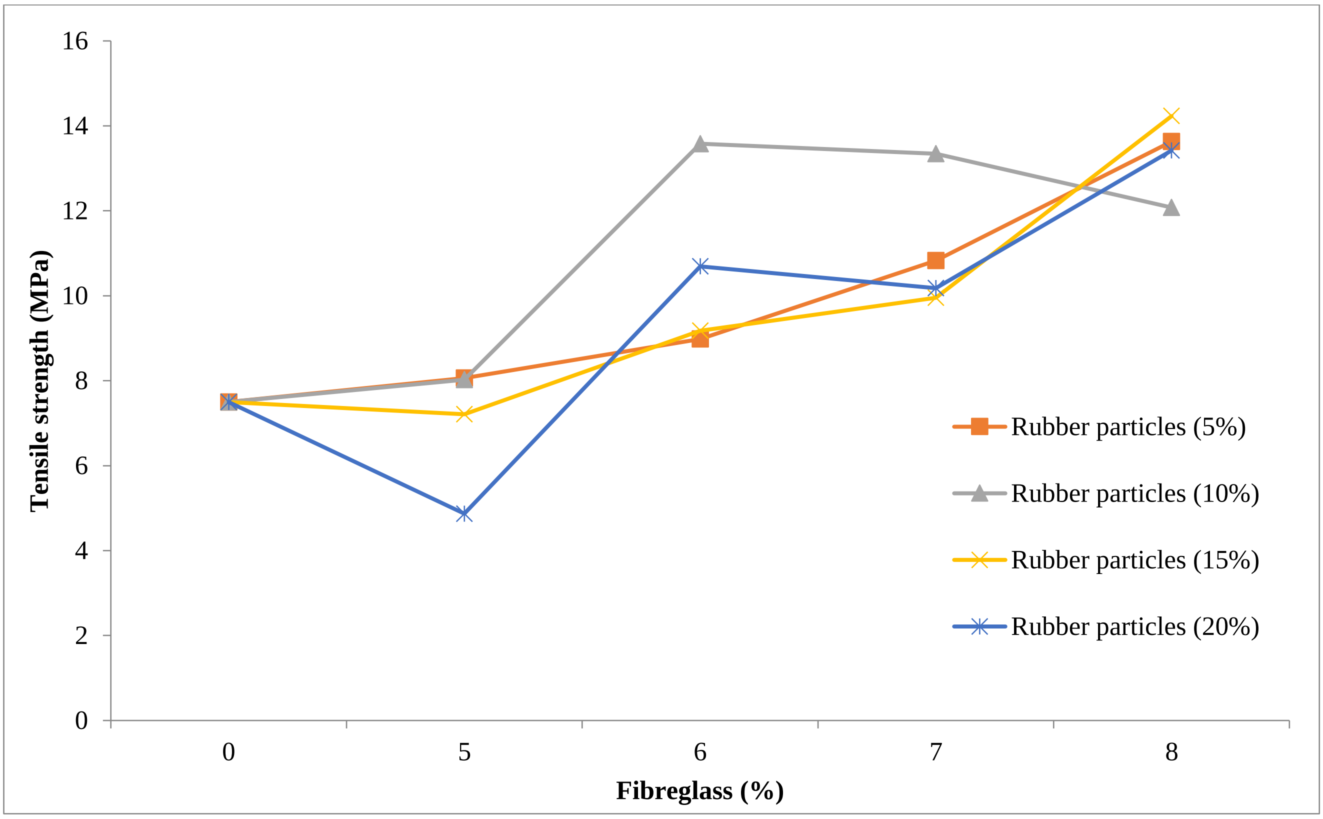

Fig. 5 Effect of 150 µm rubber particles and glass fibre on tensile strength of composite

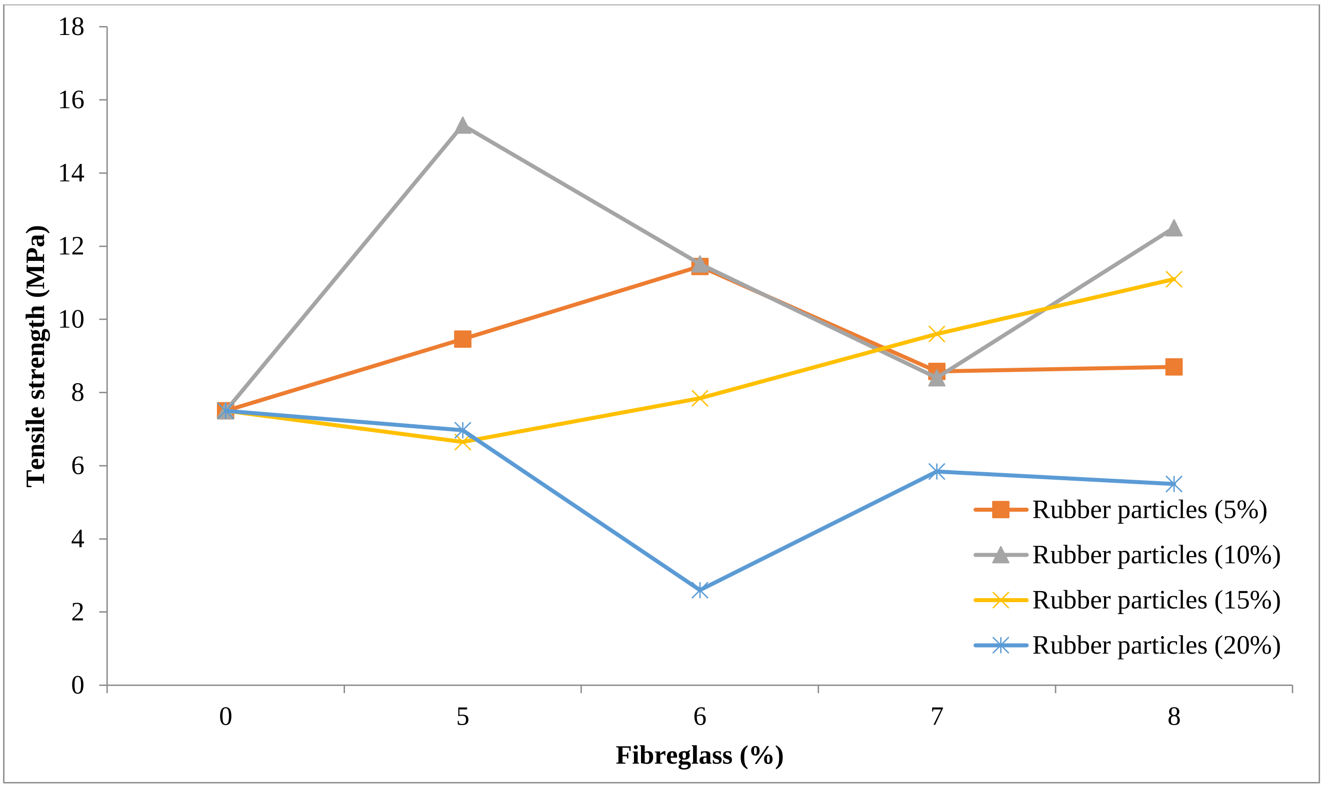

Fig. 6 Tensile strength of 300 µm particles at various fibre volume fractions

The results indicate that the tensile strength of composites with a rubber volume fraction of 10 % reduces when adding a fibreglass volume fraction of 5 to 7% and rises from 7 to 8%. The results indicate that the tensile strength of composites with a rubber volume fraction of 15% increases after adding a fibreglass volume fraction of 5 to 8%.

The tensile strength decreases from 10 MPa to 6 MPa because of an increase in the volume fraction of fibreglass. The tensile strength of fibreglass decreases by 40 %, with an increase in fibreglass from 5% to 8%. The tensile strength of the 150 µm rubber particle composite with 5% loading improved from 8.2 MPa to 14 MPa when 6% fibreglass loading was incorporated, ranging from 5 - 8%.

The tensile strength of the 150 µm rubber particles with 10% loading improved from 9 MPa to 13.9 MPa when fibreglass was incorporated, ranging from 5 - 8%. The tensile strength of 150 µm rubber particles at 15% composite loading improved from 8 MPa to 14.2 MPa when fibreglass was incorporated, ranging from 5 - 8%. Tensile strength of 150 µm rubber particle size with a volume fraction of 20% improved from 5.8 MPa to 13.5 MPa when fibreglass was incorporated, ranging from 5 - 8%.

The tensile strength of the composite consisting of 300 µm rubber particles at 5% loading improved from 7.5 MPa to 11.5 MPa when fibreglass was incorporated, ranging from 5 - 8%. Tensile strength of 300 µm rubber particle size with a volume fraction of 10% improved from 8 MPa to 13.9 MPa when fibreglass was incorporated. The tensile strength of 300 µm rubber particle size at 15% loading improved from 6.2 MPa to 14.2 MPa when fibreglass was incorporated, ranging from 5 - 8%. Tensile strength of 300 µm rubber particle size with a volume fraction of 20% improved from 5 MPa to 6.9 MPa when fibreglass was incorporated, ranging from 5 - 8%.

Figure 5 and Figure 6 shows that the increase in rubber particle volume fraction, regardless of particle size, has an adverse effect on the composite tensile strength. This phenomenon can be attributed to the low inherent tensile strength of the rubber particles.

Figure 7 shows the failure mode of the hybrid composite containing rubber particles and fibreglass reinforcement. The dominant failure modes for composites contain 5 - 15% rubber particles and 5 – 8% fibreglass volume fraction of fibre breakage. However, matrix cracking is observed in the dominant composite failure mode when the rubber particles' volume fraction is increased to 20%. When the fibreglass volume fraction is increased to 8%, the interfacial bond of the fibre to the polyester resin is weak due to the poor dispersal of fibreglass. This results in fibre pull-out, fibre breakage, and matric breakage.

Fig. 7 Failure mode of composites

A study by Lim et al. (2021) stated that the tensile strength of a plastic sleeper is 4.94 MPa and the highest recorded tensile strength in this study is 15.3 MPa. The tensile strength of the current study is three times that of the plastic recorded by Lim et al. (2021). Furthermore, heating can re-hardened composite sleepers made of thermoplastic materials when cooled and softened by heating, and a reversible process can influence the change of mechanical properties.

The fabricated composites showed better tensile strength when compared with concrete sleepers, which have a tensile strength of 6.5 MPa. However, the tensile strength of the concrete is negatively impacted, as noted with this fabricated composite.

3.2. Effects of Rubber Particles and Glass Fibre on Composite Compression Strength

The graph in Figure 8 shows the effects that a hybrid composite consisting of rubber particle size 150 µm and glass fibres has on the composite compression strength.

Figure 8 shows that the hybrid composites containing 5 % rubber particles and 5% fibreglass have a compressive strength 41.26MPa. As the fibreglass volume fraction increases to 6%, there is a marginal increase in compression strength to 44.35 MPa. Furthermore, any addition of fibreglass above 6% resulted in a decrease in hybrid composite compression strength, as observed with a composite containing 7% fibreglass, giving 33.29 MPa of energy. Further increase in fibreglass volume fraction to 8% decreases the compression strength to 31.31 MPa.

The compression strength of rubber particles with 10 % and 5% fibreglass has a compressive strength of 33.86 MPa. As the fibreglass volume fraction increases to 6%, the compression strength increases to 39.18 MPa. Furthermore, any addition of fibreglass decreased the compression strength, which is seen with 7% fibreglass, giving a strength of 33.29 MPa. Further increase in fibreglass volume fraction to 8% resulted in a reduction in compression strength to 30.75 MPa.

The compression strength of 15% volume fraction rubber particles and 5% volume fraction fibreglass has an initial compressive strength of 26.50 MPa. As the fibreglass volume fraction increased to 6%, the compression strength increased to 29.80 MPa. Further addition of fibreglass decreased composite compression strength, as observed with 7% fibreglass giving a strength of 22.61 MPa. Further increase in fibreglass volume fraction to 8% resulted in a reduction in compression strength to 21.15 MPa.

The compression strength of rubber particles with 20% and 5% fibreglass has an initial strength of 7.99 MPa. As the fibreglass volume fraction increased to 6%, the composite compression strength increased to 13.84 MPa. Further addition of fibreglass decreased the compression strength, as observed with the composite containing 7% fibreglass, giving a compressive strength of 12.53 MPa. Further increase in fibreglass volume fraction to 8% resulted in a reduction of compression strength to 10.42 MPa. The graph in Figure 9 shows the effects that a hybrid composite consisting of 300 µm rubber particles and glass fibres has on the compression strength.

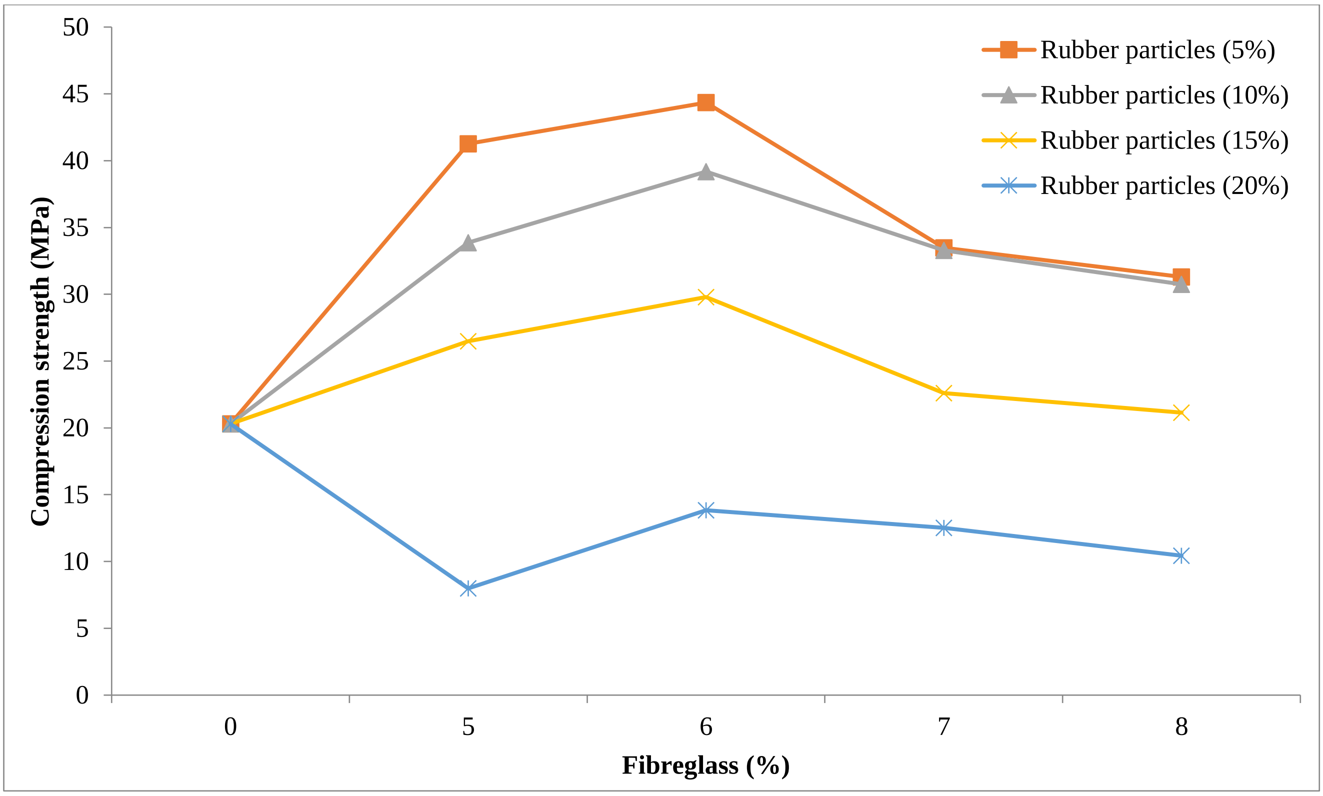

Fig. 8 Effects of 150 µm rubber particles and glass fibre on the compression strength of composite

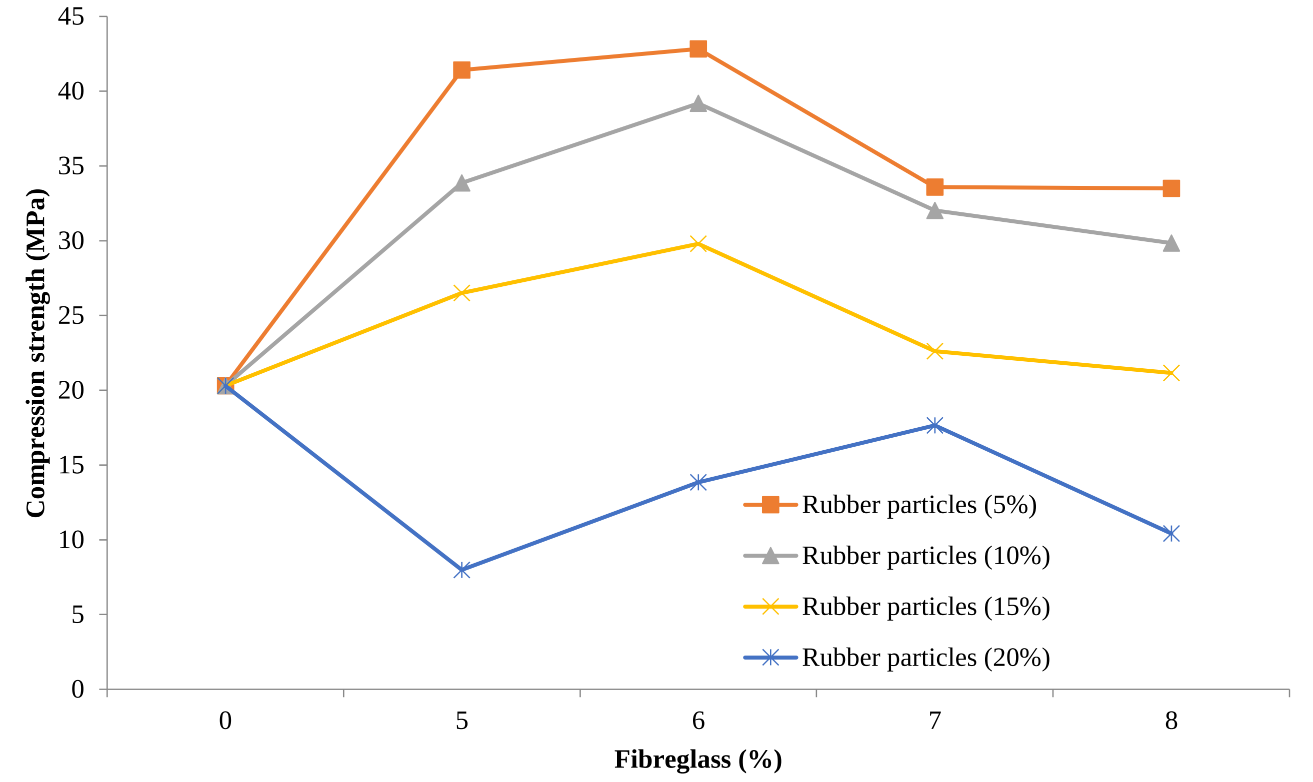

Fig. 9 Compression strength of 300 µm particles at various fibre volume fractions

Figure 9 shows that a hybrid composite with 5% rubber particle volume fraction and 5% fibreglass volume fraction had an initial strength of 41.42 MPa. As the fibreglass volume fraction increased to 6%, there was a marginal increase in compression strength to 42.83 MPa. Any further addition of fibreglass decreased the compression strength, as shown in Figure 9, with a 7% fibreglass volume fraction giving a strength of 33.59 MPa. Further increase in fibreglass volume fraction to 8% resulted in a decrease in compression strength to 33.31 MPa.

The compression strength of a 10% volume fraction of rubber particles with a 5% volume fraction fibreglass gave an initial strength of 33.86 MPa. As the fibreglass volume fraction increased to 6%, the compression strength increased to 39.18 MPa. Further addition of fibreglass decreased the composite compression strength, as observed in Figure 9, with 7% fibreglass giving a compressive strength of 32.03 MPa. Further increase in fibreglass volume fraction to 8% resulted in a reduction in the composite compression strength to 29.84 MPa.

The composite compression strength of 15% volume fraction of rubber particles and 5% fibreglass volume fraction had an initial strength of 26.50 MPa. As the fibreglass volume fraction increased to 6%, the composite compression strength increased to 29.80 MPa. Further addition of fibreglass volume fraction resulted in a decrease in composite compression strength as observed with 7% volume fraction fibreglass giving a strength of 22.61 MPa. Further increase in fibreglass volume fraction to 8% resulted in the reduction in the composite compression strength to 21.15 MPa.

The composite compression strength of 20% volume fraction rubber particles and 5% fibreglass volume fraction had an initial strength of 7.99 MPa. As the fibreglass volume fraction increased to 6%, the composite compression strength increased to 13.84 MPa. Further addition of fibreglass increased the compression strength. However, further fibreglass volume fraction increases beyond 8%, reducing the composite compression strength to 10.42 MPa.

The compression strength of the composite containing 150 µm rubber particles with a 5% fibre volume fraction improved from the control 36.52 MPa to 44.346 MPa when the fibreglass was varied from 5 to 8%. The compression strength of the composite containing 150 µm rubber particles with a fibreglass volume fraction of 10% improved from the control 24.547 MPa to 39.183 MPa when the fibreglass was varied from 5 to 8%. The compression strength of the composite containing 150 µm rubber particles with a fibreglass volume fraction of 15% improved from the control compressive strength of 17.657 MPa to 29.792 MPa when the fibreglass was varied from 5 to 8%. However, the compression strength of 150 µm rubber particle size with a volume fraction of 20% reduced from 23.346 MPa to 13.835 MPa when fibreglass was incorporated when fibreglass was varied from 5 to 8%. This results from poor dispersal of rubber particles and fibreglass, giving a weak interfacial bond of resin, glass fibres and rubber particles.

The compression strength of 300 µm rubber particle size with a volume fraction of 5% improved from 21.208 MPa to 42.827 MPa when fibreglass was incorporated when fibreglass was varied from 5 to 8%. The compression strength of 300 µm rubber particles with a volume fraction of 10% improved from 19.09 MPa to 39.183 MPa when fibreglass was incorporated, and fibreglass varied from 5 to 8%. The compression strength of 300 µm rubber particle size with a volume fraction of 15% improved from 16.363 MPa to 29.792 MPa when fibreglass was incorporated when fibreglass varied from 5 to 8%. The compression strength of 300 µm rubber particle size with a volume fraction of 20% reduced from 5 MPa to 6.9 MPa when fibreglass was incorporated when fibreglass was varied from 5 to 8%. Hybrid composites' workability becomes difficult and results in a poor dispersal of rubber particles and fibreglass since when the interfacial volume bond of resin increases, the glass and rubber particles become weak.

Figure 8 and Figure 9 shows that increasing rubber particle volume fraction, regardless of particle size, has an adverse effect on the composite compression strength. This phenomenon can be attributed to the low hydrophilicity of rubber particles on the resin resulting in weak interfacial bond strength. Both the rubber particle size 150 and 300 µm results suggest that hybrid composites with rubber particle volume fraction of less than 10% and fibreglass volume fraction of less than 7% give the optimal compressive strength.

The dominant failure modes of the composites containing rubber particle volume fraction of 5%, 10%, and 15 % and fibreglass volume of 5 to 8% were fibre breakage, split failure, and matrix failure, as shown in Figure 10. However, fibre breakage was observed in the dominant composite failure mode when the rubber particles' volume fraction was increased to 20%. When the fibreglass volume fraction is increased to 8%, the interfacial bond of polyester resin becomes weak, and the dispersal of fibreglass within the composite is poor. This resulted in the dominant failure mode being fibre pull-out and matrix breakage.

The fabricated composite showed an optimum compressive strength of 42.83 MPa, which was acceptable; however, concrete sleepers have a much higher compression strength of 61.2 MPa. However, despite the high compression strength of concrete sleepers, they have poor vibrational damping properties, elasticity, and flexibility compared to the fabricated hybrid composite. A study by Meesit et al. (2017) reported that adding rubber particles to concrete improves the vibrational damping properties. However, the concrete's compression strength reduces due to a weak interfacial bond between concrete and rubber particles.

The current study suggests composite sleepers possess great compression strength, elasticity, and durability. In addition, the fabricated composite has improved damping properties compared to traditional wooden and concrete sleepers.

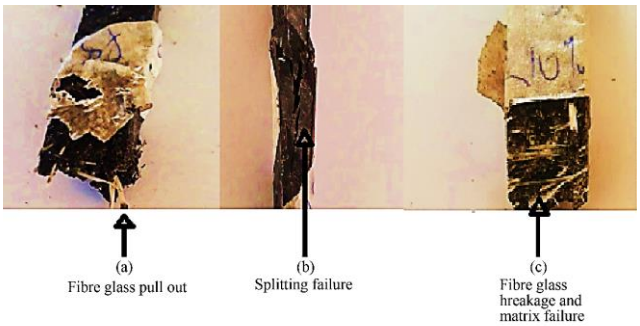

Fig. 10 Failure mode of fibreglass/rubber particle composite under compressive force

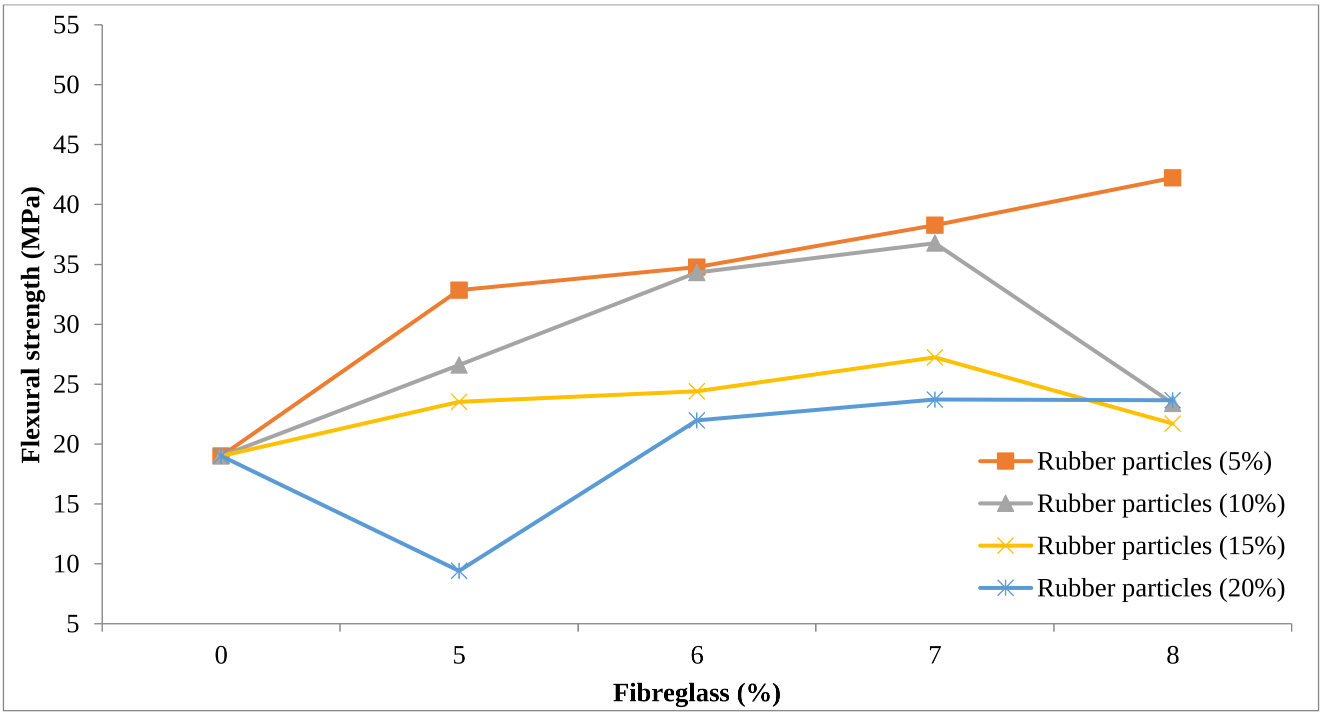

Fig. 11 Effects of 150 µm rubber particles and glass fibre on the flexural strength of composite

3.3. Effects of Rubber Particles and Glass Fibre on Composite Flexural Strength

The graph in Figure 11 shows the effects that a hybrid composite consisting of rubber particles and glass fibres has on flexural strength.

The hybrid composite containing 5% rubber particles and 5% fibreglass had a flexural strength 32.86MPa. As the fibreglass volume fraction increased to 6%, there was a marginal increase in flexural strength to 34.33 MPa. Any addition of fibreglass above 6% increased the composite flexural strength, as observed with 7 % fibreglass giving a flexural strength of 38.28 MPa. Further increase in fibreglass volume fraction to 8% increased the flexural strength to 42.22 MPa.

The flexural strength of 10% rubber particle volume fraction and 5% fibreglass had a flexural strength of 26.61 MPa. As the fibreglass volume fraction increased to 6%, the flexural strength increased to 34.33 MPa. Further addition of fibreglass to 7% increased the flexural strength to 36.77 MPa. Further increase in fibreglass volume fraction to 8% resulted in a reduction in flexural strength to 23.38 MPa.

The flexural strength of the composite with 15% rubber particles and 5% fibreglass volume fraction was 23.52 MPa. As the fibreglass volume fraction increased to 6%, there was an increase in flexural strength to 24.41 MPa. Further fibreglass addition to 7% resulted in a flexural strength of 27.24 MPa. Further increase in fibreglass volume fraction to 8% resulted in a reduction in composite flexural strength to 21.72 MPa.

The flexural strength of the hybrid composite with 20% rubber particles and 5% fibreglass was 9.41 MPa. As the fibreglass volume fraction increased to 6%, the flexural strength increased to 21.98 MPa. The addition of 7% fibreglass increased the flexural strength to 23.72 MPa. Further increase in fibreglass volume fraction to 8% resulted in a reduction of flexural strength to 21.72 MPa. The results for the flexural strength of 300 µm are presented in Figure 12.

The composite containing 5 % rubber particles and 5% fibreglass had a flexural strength of 26.15 MPa. As the fibreglass volume fraction increased to 6%, there was a marginal increase in flexural strength to 36.82 MPa. The addition of fibreglass above 6% increased flexural strength. However, adding 8% fibreglass decreased the flexural strength to 26.33 MPa.

The flexural strength of the composite with 10% rubber particles and 5% fibreglass was 20.53 MPa. As the fibreglass volume fraction increases to 6%, there is an increase in flexural strength to 24.724 MPa. Adding fibreglass to 7% and 8% fibreglass resulted in flexural strength of 32.03 MPa and 19.09 MPa, respectively.

The flexural strength of the composite with 15% rubber particles and 5% fibreglass gave a flexural strength of 20.53 MPa. As the fibreglass volume fraction increased to 6%, there was an increase in flexural strength to 24.72 MPa. Further addition of fibreglass up to 7% steadily increased flexural strength. However, the addition of 8% fibreglass resulted in a decrease.

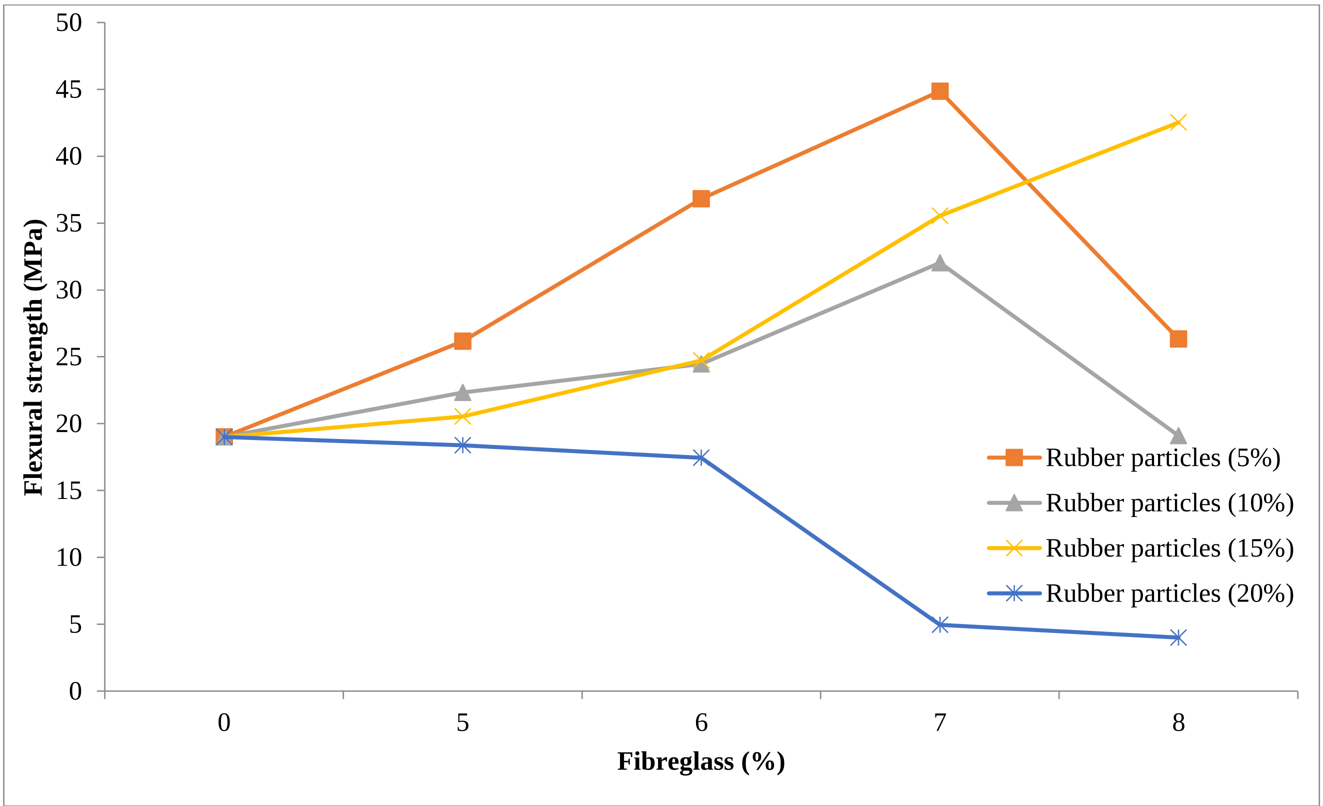

Fig. 12 Flexural strength of 300 µm particles at various mass

The flexural strength of the composite with 20% rubber particles and 5% fibreglass gave a flexural strength of 18.39 MPa. As the fibreglass volume fraction increased to 6%, the flexural strength decreased to 17.46 MPa. Further addition of fibreglass to 7% resulted in a decrease in flexural strength to 4.96 MPa. Further increase in fibreglass volume fraction to 8% gave a flexural strength of 4.00 MPa.

The results indicate that rubber particle volume fraction less than 15% must be used in composites for optimal flexural strength.

Figure 11 and Figure 12 indicate that an increasing rubber particle volume fraction, regardless of particle size, has an adverse effect on the composite flexural strength. This phenomenon can be attributed to the low hydrophilicity of rubber particles on the resin resulting in weak interfacial bond strength.

The failure mode of hybrid composites containing fibreglass and rubber particles. Fibreglass was used to enhance the flexural strength of the hybrid composite and the contour effect of rubber particles that reduce the composite flexural strength. The dominant failure mode of composites with rubber particle volume fraction of 5% less than 15 % was fibre breakage. However, when the rubber particles' volume fraction was increased to 20%, the dominant composite failure mode was matrix breaking and fibre pulling out.

3.4. Effects of Rubber Particles and Glass Fibre on the Composite Hardness

The graph in Figure 13 presents the effect that a hybrid composite consisting of rubber particle size 150 µm and glass fibres in varying proportions on the composite leeb hardness.

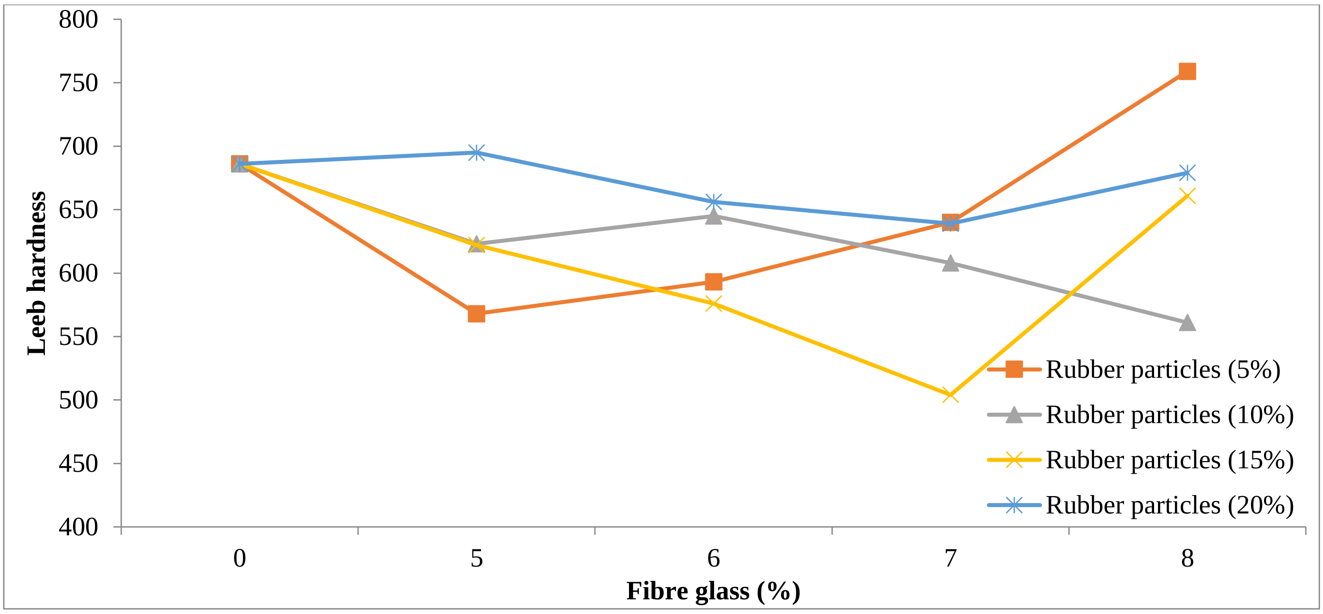

Fig. 13 Effects of 150 µm rubber particles and glass fibre on the hardness of composite

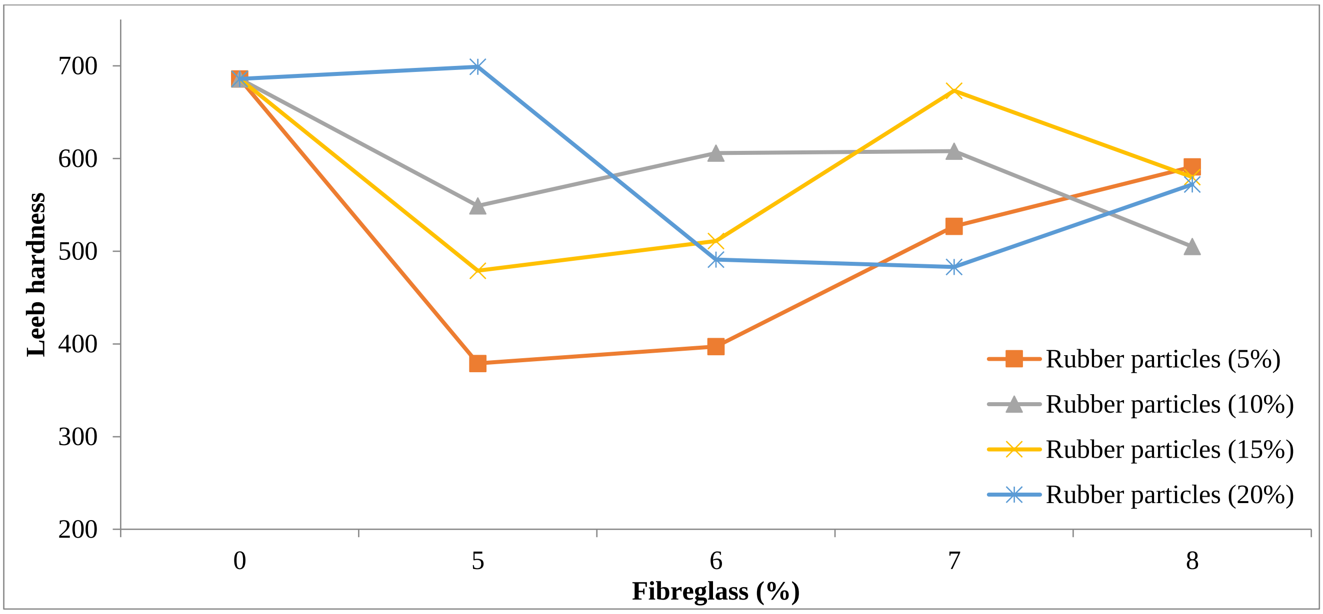

Fig. 14 Effects of 300 µm rubber particles and glass fibre on the hardness of composite

Figure 13 shows that the hybrid composite containing 5% rubber particles and 5% fibreglass had a hardness of 568. As the fibreglass volume fraction increased to 6%, there was a marginal increase in hardness to 593. Further addition of fibreglass above 6% increased the composite hardness, as shown with the composite containing 7 % fibreglass giving a hardness of 640. Further increase in fibreglass volume fraction to 8% increased the hardness to 759.

The composite containing 10% rubber particles and 5% fibreglass had a hardness of 623. As the fibreglass volume fraction increased to 6%, there was an increase in the hardness to 645. However, any further addition of fibreglass decreased the composite hardness, as observed with 7% fibreglass giving a hardness of 608. A further increase in fibreglass volume fraction to 8% reduced the hardness to 561.

The composite, made up of 15% rubber particles and 5% fibreglass had a hardness of 622. There was a decrease in composite hardness to 576, with an increase in fibreglass volume to 6%. The total amount of fibreglass volume fraction decreased the composite hardness, as observed with a 7% fibre volume fraction, which had a hardness of 504. In contrast, there was a gain in composite hardness with an 8% fibre volume fraction to 661.

The composite has a hardness of 695 because it contains 20% rubber particles and 5% fibreglass. The hardness of the material decreases to 656 as the volume fraction of fibreglass increases to 6%. Furthermore, adding more fibreglass reduced the hardness of the material. This may be shown with 7% fibreglass, which has a strength of 639. However, increasing the fibreglass volume percentage to 8% resulted in a hardness increase 679.

The graph in Figure 14 presents the effects that a hybrid composite consisting of 300 µm rubber particles and glass fibres has on the composite hardness. The hardness of the composite shown in Figure 14, containing 5% rubber particles and 5% fibreglass, had a hardness of 379. As the fibreglass volume fraction increased to 6%, there was a marginal increase in hardness to 397. Adding fibreglass above 6% gave a general incremental trend in composite hardness. The composite containing an 8% fibreglass volume fraction had the highest hardness for that composite of 591.

The hardness of the composite containing 10% rubber particles and 5% fibreglass was recorded as 549. As the fibreglass volume fraction increased to 6%, there was an increase in hardness to 606. The incremental increase in fibreglass to 7% fibre gives a composite hardness of 608. However, a further increase in fibreglass volume fraction to 8% reduced the hardness to 505.

The hardness of the composite with 15% rubber particles and 5% fibreglass was 479. As the fibreglass volume fraction increased to 6%, the hardness increased to 511. Further addition of fibreglass to 7% resulted in an increase in hardness to 673. Yet, a further increase in fibreglass volume fraction to 8% resulted in a reduction in composite hardness to 580.

The hardness of the composite consisting of 20% rubber particles and 5% fibreglass was 699. As the fibreglass volume fraction increased to 6%, the hardness decreased to 491. Adding fibreglass to 7%, fibreglass decreased the composite hardness marginally to 483. However, a further increase in fibreglass volume fraction to 8% resulted in an increase in composite hardness to 572.

The hardness of 150 µm rubber particles with a volume fraction of 5% was 648. Increasing the fibreglass content increased the composite hardness. Composite had an initially incremental trend in composite hardness with adding fibreglass up to 8%, hardness of 150 µm, and rubber particle size with a volume fraction of 15% was 538. However, the composite hardness increased at 8% fibreglass loading to 661. The hardness of 150 µm rubber particle size with a volume fraction of 20% was 659, but after varying the fibreglass from 5 to 8%, the hardness was increased to 695.

The fabricated composites with fibreglass, polyester resin and rubber particles showed outstanding hardness compared to composites with only rubber particles and polyester resin. The thickness of 300 µm rubber particle size with a volume fraction of 5% was 549. However, after varying the fibreglass from 5 to 8 %, the hardness was increased to 591. The hardness of 300 µm rubber particle size with a volume fraction of 10% was 501, but after varying the fibreglass from 5 to 8 %, the hardness increased to 608. The hardness of 300 µm rubber particle size with a volume fraction of 15% was 587. However, after varying the fibreglass from 5 to 8%, the hardness increased to 673. The hardness of 300 µm rubber particle size with a volume fraction of 20% was 536, but after varying the fibreglass from 5 to 8%, it was increased to 699.

Figure 13 and Figure 14 indicate how increasing rubber particle volume fraction, regardless of particle size, has an adverse effect on the composite hardness. This phenomenon can be attributed to the roughness and hardness of the rubber particles on the resin, resulting in the composite being hard. The polyester is brittle; adding fibreglass and rubber particles aids the hybrid composite to be hard.

The results observed in this study align with the research by Rachchh et al. (2018) that showed volume fraction of fibreglass increases hardness. Composites with greater than 15% rubber particles were observed to have higher hardness. However, those composites had low mechanical strength due to the presence of voids and pockets due to insufficient resin and poor dispersal of rubber particles and fibreglass. The current study fabricated composite sleepers with excellent hardness and durability compared with composite sleepers made of thermoplastic materials. The plastic sleeper can be rehardened when cooled and softened.

3.5. Effect of Rubber Particles and Glass Fibre on Composite Vibration and Damping Properties

The graph in Figure 15 shows how a hybrid composite consisting of rubber particle size 150 µm and glass fibres in varying proportions affects the composite vibrational damping.

Figure 15 presents the hybrid composite containing 5% rubber particles and 5% fibreglass damping of 0.103. As the fibreglass volume fraction increased to 6%, there was a minimal increase in damping to 0.104.

Further addition of fibreglass above 6% increased the composite damping, as observed with the composite containing 7 % fibreglass giving a damping of 0.105. A further increase in fibreglass volume fraction to 8% resulted in an increase in damping to 0.118.

The composite containing 10% rubber particles and 5% fibreglass had a damping of 0.146. As the fibreglass volume fraction increased to 6%, there was an increase in the damping to 0.155. Further addition, fibreglass increased the composite damping as observed with 7% fibreglass giving a vibrational damping of 0.158. A further increase in fibreglass volume fraction to 8% resulted in a further increase in damping to 0.192.

The composite made up of 15% rubber particles, and 5% fibreglass had a damping of 0.121. There was an increase in composite damping to 0.141, with an increase in fibreglass volume to 6%. The incremental amount of fibreglass volume fraction increased the composite damping, as observed with a 7% fibre volume fraction, which had a damping of 0.162. Further addition of fibreglass to 8% resulted in a constant damping of 0.162.

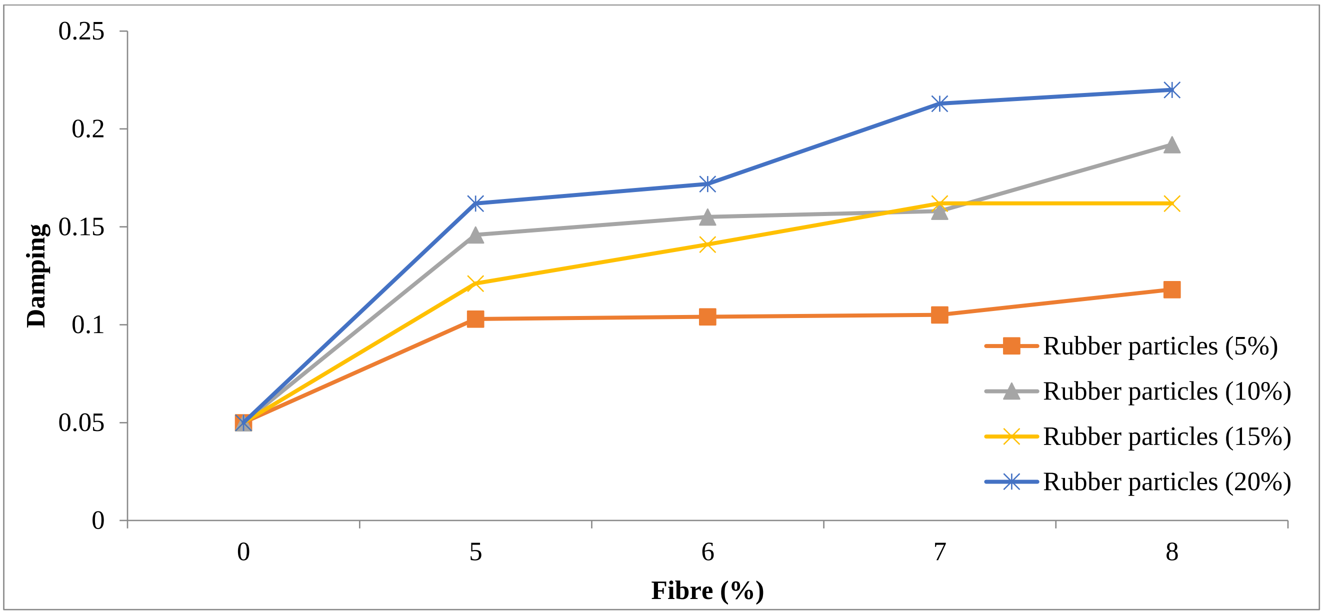

Fig. 15 Effect of 150 µm rubber particles and glass fibre on the vibration-damping properties of composite

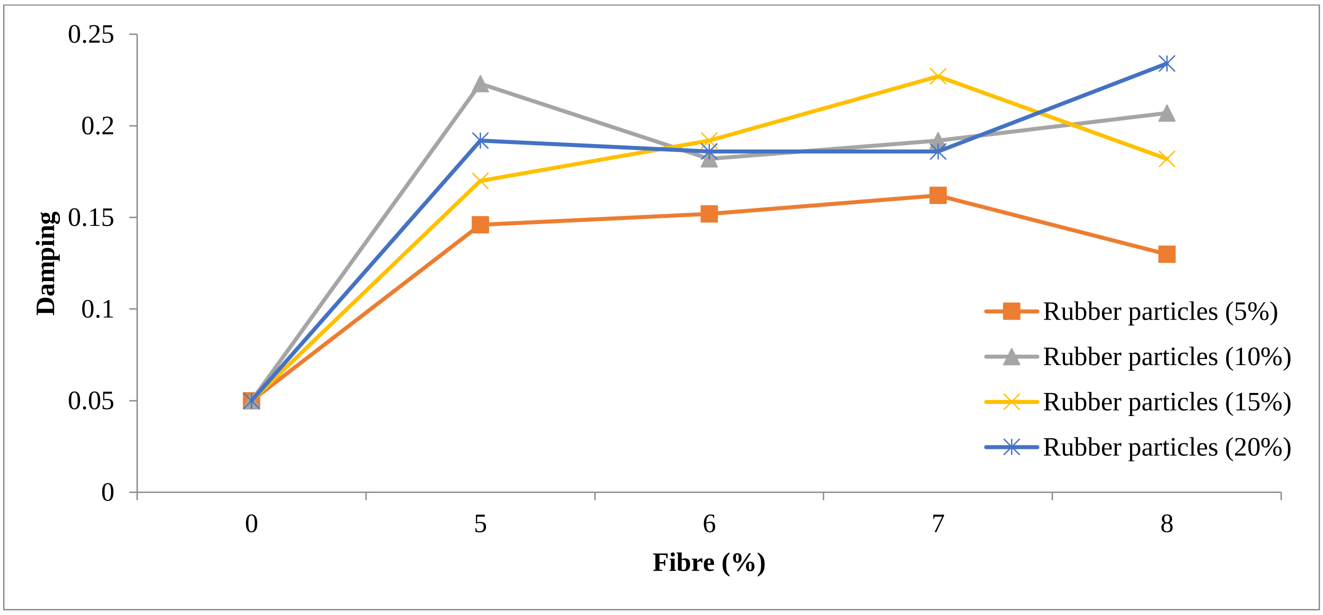

Fig. 16 Effects of 300 µm rubber particles and glass fibre on vibration-damping properties of composite

The composite constituted of 20% rubber particles and 5% fibreglass, gave a damping of 0.162. The material's damping increased to 0.172 as the volume fraction of fibreglass increased to 6%. Further addition of fibreglass beyond 5% gave an increase in damping. This is observed with 7% and 8% fibreglass volume fractions giving damping 0.213 and 0.220, respectively.

The graph in Figure 16 shows the effect that a hybrid composite consisting of rubber particle size 300 µm and glass fibres of varying proportions has on the composite damping.

Figure 16 shows that the hybrid composite containing 5% rubber particles and 5% fibreglass had a damping of 0.146. As the fibreglass volume fraction increased to 6%, there was a minimal increase in damping to 0.152. Further addition of fibreglass above 6% increased composite damping, as observed with the composite containing 7 % fibreglass giving a vibrational damping of 0.162. However, a further increase in fibreglass volume fraction to 8% decreased the damping to 0.130.

The composite containing 10% rubber particles and 5% fibreglass had a vibrational damping 0.223. As the fibreglass volume fraction increased to 6%, there was a decrease in the damping to 0.182. However, any further addition of fibreglass increased the composite damping, as observed with 7% fibreglass, giving a vibration damping of 0.192. Furthermore, an increase in fibreglass volume fraction to 8% resulted in a further increase in damping to 0.207.

The composite is made up of 15% rubber particles and 5% fibreglass, damping 0.170. There was an increase in composite damping to 0.192, with an increase in fibreglass volume to 6%. The incremental amount of fibreglass volume fraction increased with composite damping, as observed with a 7% fibre volume fraction, which had a damping of 0.227. However, there was a reduction in composite damping with the use of an 8% fibre volume fraction to 0.182.

The composite containing 20% rubber particles and 5% fibreglass had a vibrational damping 0.192. The damping of the composite material decreased to 0.186 as the fibreglass volume increased to 6%. Adding more fibreglass to 7% did not significantly change the vibrational damping of the composite. However, increasing the fibreglass volume percentage to 8% resulted in a vibrational damping increase 0.234.

4. Conclusion

The study investigated the effect of varying the volume fraction of rubber particles and fibreglass on a composite railway sleeper's mechanical and vibrational properties. The following conclusions were drawn from the study.

- The composite consisting of fibreglass only had a maximum tensile of 8% fibre content giving a tensile strength of 12.13 MPa. The composite consisting of rubber particles only had a maximum tensile strength of 8.86 MPa at 10% of 150 μm rubber particle loading.
- The composite consisting of a combination of rubber particles and fibreglass gave a full tensile strength of 15.31 MPa at 8% fibre content and 300 µm and 10% rubber particle content. The hybrid composite fabricated increased the structural tensile strength while growing damping for the composite to eliminate aggressive forces applied to composite railway sleepers by heavily loaded trains.
- The highest compression strength with Fibreglass only was 55.164 MPa at 8% fibre loading. The maximum tensile strength recorded with rubber particles was 36.515 MPa at a 5% rubber particle volume fraction. The combination of rubber particles of size 150 µm and fibreglass gave a maximum compression strength of 44.35 MPa at 5 % rubber content and 6 % fibreglass.
- The composite consisting of fibreglass only had a maximum flexural at 8% fibre content giving a strength value of 42.658 MPa. The composite consisting of rubber particles only had a maximum flexural strength of 20.369 MPa at 5% of 150 µm rubber particles. The composite consisting of a combination of rubber particles and fibreglass gave a maximum flexural strength of 44.45 MPa at 7% fibre content and 5% rubber particles. The composite sleeper's flexural strength was increased while the composite's structural damping increased due to rebound forces exerted on the railway composite.
- The composite's only fiberglass composition had a maximum hardness measurement of 745 leeb. on rubber particles, only the composite was 659 leeb. The hybrid composite consisting of fibreglass and rubber particles gave a maximum hardness value of 759 Leeb at 8% fibre and 20% 150 µm rubber particle content.
- The highest vibrational dampening of the composite was found to be achieved by adding 150 m rubber particles. of 0.162 at a 20% rubber particle volume fraction. Furthermore, using bigger rubber particles, such as 300 µm, further positively affected the vibrational damping. Maximum vibrational damping of 0.202 was realized at 10% 300 µm rubber particle volume fraction. However, the increase in vibrational damping negatively affected the composite's mechanical strength properties. This decrease necessitated a compromise on the optimum properties of the composite.

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