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Experimental analysis of tensile & compressive properties of recycled tyre rubber composite

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Abstract

One of the major environmental challenges facing municipalities around the world is the disposal of worn out automobile tires. To address this global problem, several studies have been conducted to examine various applications of recycled tire rubber (fine crumb rubber and coarse tire chips). Examples include the reuse of ground tire rubber in a variety of rubber and plastic products, thermal incineration of waste tires for the production of electricity or as fuel for cement kilns, and use of recycled rubber chips in asphalt concrete. Unfortunately, generation of waste tires far exceeds these uses. The use of recycled tire rubber in Portland cement concrete is the attractive option. This paper emphasizes another technically and economically attractive option, which is the use of recycled tire rubber in production of tire rubber particulate composites. Achievements in this area are examined in this paper, with special focus on engineering properties of tire rubber particulate composites. These include: compressive strength, tensile strength, flexural strength, elastic modulus, impact strength, damping characteristics. Various applications in which tire rubber particulate composites could be advantageous over conventional concrete are described.

Key words: compressive strength, tensile strength, recycling, solid waste, tyre rubber

1. Introduction

Solid waste management is one of the major environmental issues in the world. The waste tyre rubbers are becoming a major environmental problem. A huge volume of waste tyres are generated every year. These tyres are thermoset and are virtually resistant to biological degradation. The world generates about 13.5 million tonnes of waste tyres annually. Analysis indicates that about 1 million ton of tyres scrap is stockpiled in India. These stockpiles are dangerous from environmental threats, fire hazards and provide breeding grounds for mosquitoes. The drawbacks underlying the disposal of waste tyres by methods such as landfill, pyrolysis, and incineration encouraged further researches on the recycling technology of waste tyres. Recycling the waste tyre is thus a great challenge for both environmental and economic reasons.

Several approaches have been proposed to deal with the problem of used tyres such as converting it into tyre-derived fuel in solid-fuel burners, using pyrolysis to recover valuable chemical components, incorporation in various rubbers for non-tyre applications, and their use as fillers/tougheners in plastics. Large scale utilization of rubber waste could be made by adding waste rubber into plastics with a view to obtain impact-resistant plastics and thermoplastic elastomers. Generally, waste tyres are ground to small particles known as ground tyre rubber (GTR), which are still thermosets. Recycled rubber chips have been used in asphalt concrete.

Figure 1: Used tyres waste in an open area

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The use of recycled tyre rubber in Portland cement concrete is an attractive option. A technically and economically attractive option is the use of recycled tyre rubber in production of tyre rubber particulate composites.

1.1 Composition of Tyres

Tyres contain so many different compounds and ingredients because they are engineering miracles, expected to handle the tortures of heat and cold, high speed, abrasive conditions, and often not enough air pressure. They are expected to perform for tens of thousands of miles and retain their essential properties despite horrendous driving habits and sometimes poorly maintained or built roads.

Table 1: The Composition of a Tyre: Typical Components

Ingredients	% Composition
Rubber/Elastomers	45- 47
Carbon Black	21.5- 22
Metal	12- 25
Textile	0- 10
Zinc Oxide	1- 2
Sulphur	1
Additives	5- 7.5
Carbon-based materials, total	67- 76

Source: The Waste & Resources Action Programme, 2006

Tyres are made up of numerous different rubber compounds, many different types of carbon black, fillers like clay and silica, and chemicals & minerals added to allow or accelerate vulcanisation. The tyres also have several types of fabric for reinforcement and several kinds and sizes of steel. Tyre is a mixture of Natural Rubber (14%) and Butadiene Rubber (27%).

1.2 Composite

A composite material is made by combining two or more dissimilar materials. They are combined in such a way that the resulting composite material or composite possesses superior properties which are not obtainable with a single constituent material. So, in technical terms, we can define a composite as 'a multiphase material from a combination of materials, differing in composition or form, which remain bonded together, but retain their identities and properties, without going into any chemical reactions'. One of the constituent is called the Matrix which surrounds other constituent often called the Reinforcing or Dispersed phase.

The reinforcement is of particle nature. It may be spherical, cubic, tetragonal, a platelet, or of other regular or irregular shape, but it is approximately equiaxed or stress free. In general, particles are not very effective in improving fracture resistance but they enhance the stiffness of the composite to a limited extent. Particle fillers are widely used to improve the properties of matrix materials such as to modify the thermal and electrical conductivities, improve performance at elevated temperatures, reduce friction, increase wear and abrasion resistance, improve machinability, increase surface hardness and reduce shrinkage. An example of particle reinforced composites is an automobile tyre, which has carbon black particles in a matrix of poly-isobutylene elastomeric polymer.

1.3 Damping

Damping is the conversion of mechanical energy associated with a vibrating structure into thermal energy. The heat is then transferred or lost to the surroundings. Many forms of damping can be utilized to convert the mechanical energy into heat. Some of these are viscoelastic damping, coulomb friction damping, fluid viscosity damping, particle damping, magnetic hysteresis damping, and piezoelectric damping. The most common type of damping, that can be applied to a material structure as an add-on treatment is the viscoelastic damping.

The understanding of vibration also requires knowledge of damping and how to quantify the damping associated with a particular structure or damping application. Several techniques are used to quantify the level of damping in structure. These are Half-Power Bandwidth Method, Log Decrement Method, Amplification or Q Factor Method, and Hysteresis Loop Method. The Half Power Bandwidth and the Q Factor Methods both take advantage of the shape of the shape of the Frequency Response Function (FRP) to quantify the damping. The Half Power method determines the level of damping by asserting the sharpness of the resonant peak. The Log Decrement method computes the damping based on the measured exponential rate of decay of the response. The Hysteresis method calculates the damping by estimating the energy loss per cycle of oscillation due to steady state harmonic loading. The stress versus strain plot for a given cycle of motion generates an elliptically shaped hysteresis curve. The area of hysteresis loop is equal to the energy dissipated per cycle. The area of loop is used to predict the loss factor.

2. Literature Review

Tyre recycling is the process of recycling vehicles tyres that are no longer suitable for use on vehicles due to wear or irreparable damage. Recently, amounts of waste tyres are being raised with development of the automotive industry. In case of Landfill or incineration of waste tyres, environmental pollution and economic problems are causing through waste of resources. As one of theways to prevent this problems, crushed waste tyre powder used to composite material manufacturing. After physically removed the bead wire from the waste tyres, the waste tyre powder gained mechanical fracturing through crushers and grinders. In addition, through a magnetic force mats and a dust collector, iron components and fibers were removed. The waste tyre powder was ground by a shear crushing method and a 2-stage disk mill method instead of cutting crushing one. Rubber chips of various sizes can be obtained crushing or grinding step. Shear crushing method and 2-stage disk mill method are composed of two drum-type blades with different rotation speed and direction [1]. Several publications have been published in concern with the use of rubber from scrap tyres in portland cement concrete (PCC) mixtures, particularly for highway applications. D. Raghavan and H. Huynh [2] prepared the recycled tyre rubber-filled cementitious composite. They studied its workability, mechanical properties and chemical stability. Two different shapes of rubber particles were used- one is granules of about 2 mm diameter and other is shreds having sizes 5.5mm×1.2mm and 10.8mm×1.8mm (length × diameter). They reported that the addition of rubber decreases the flexural strength and plastic shrinkage due to cracking in the mortar. The crack length and crack width due to plastic shrinkage were reduced for mortar containing 10.8mm×1.8mm rubber shreds compared with a mortar without shreds.

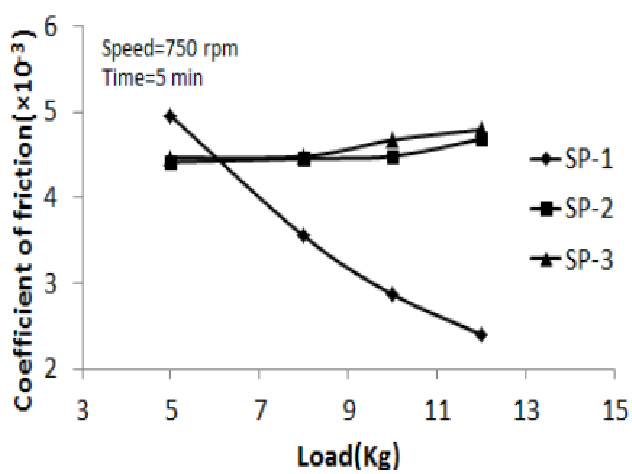
The addition of rubber particles in a cementitious matrix may lead to new composite materials with interesting properties. The particle size of the scrap tyres used has a significant effect on many properties [3]. The smaller rubber particles resulted in a lower density and apparent porosity, as well as the highest mechanical compressive strength of the composites [4].

Nehdi, M. and Khan, A. [5] represented the overview of engineering properties and potential applications of cementitious composites containing recycled tyre rubber. They reported about the effect of using rubber in concrete on density (unit weight) and on air content. Crumb rubber of different sizes is used in the concrete. Due to the low specific gravity of rubber, the unit weight of rubcrete mixtures decreases as the percentage of rubber increases.

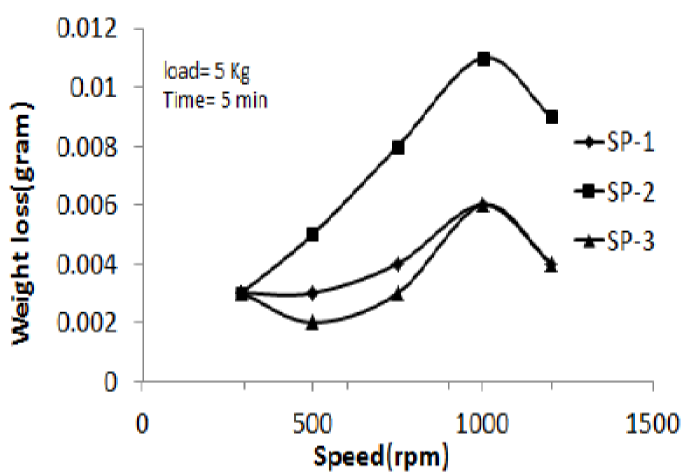
Gintautas Skripkiūnas, et al. [6] reported damping properties of concrete with rubber waste additives. The influence of rubber waste additive on hardened concrete damping characteristics and strength properties were evaluated. Compressive and flexural strength of concrete are decreased with increasing tyres rubber waste additive amount. The addition of rubber waste to concrete decreases the dynamic modulus of elasticity but increases damping decrement of the concrete. The amount of rubber waste has more noticeable effect on concrete damping properties than particles size distribution. He suggested that concrete with rubber waste can be used for isolation of structure-borne-noise in buildings, foundations and industrial floors.

Antaryami Mishra [7] reported about dry sliding wear behavior of epoxy-rubber dust composites. The rubber-epoxy composite was prepared by mixing rubber dust (at different wt. percentage of 10%, 15% and 20%- Weight fractions of 9, 13, and 17% respectively) with epoxy at room temperature. Wear test for the tyre rubber dust epoxy resin composites have been conducted using pin-on disc-testing machine. The pin is held stationary against the counter face of a 210mm diameter rotating mild steel disc having a hardness of HRC65 and average surface roughness of 0.391 micron.

Very low co-efficient of friction was obtained (Fig. 2 a) in case of 10% specimen and also for other specimens with higher percentage of rubber reinforcement. Probably this phenomenon has occurred due to high surface finish of the steel disc which was of the order of 0.391 micron after regrinding. For specimen with 10% weight percentage the friction coefficient decreases with load where as for others it has shown an increase in the same. The order of coefficient of friction was within 0.0025 to 0.005. For all the specimens the weight loss (Fig.2 b) shows an increasing trend with varying speeds up to a level of 1000 rpm and then decreases. A peculiar behaviour of decrease in weight loss has been observed with 20% rubber dust composites when slid against steel disc at varying speeds. This might have occurred due to adhesion or formation of transfer layer of composites after rubbed for certain period. Weight loss of each specimen has increased with variation of time (Fig.2 c). Weight loss of 20 % composite is being the maximum. The graphs plotted between wear rate and sliding velocity (Fig.2 d) shows that there is increase in wear for all the specimens for higher sliding distances and velocities. After covering a distance of around 5 Km the wear volume seems to stabilize. Similar trends for all the specimens have been observed when wear rate is plotted against sliding velocity. The volume of material removed in all cases was found to be very less because of the high surface finish of the disc and low percentage of rubber dust.



(a)



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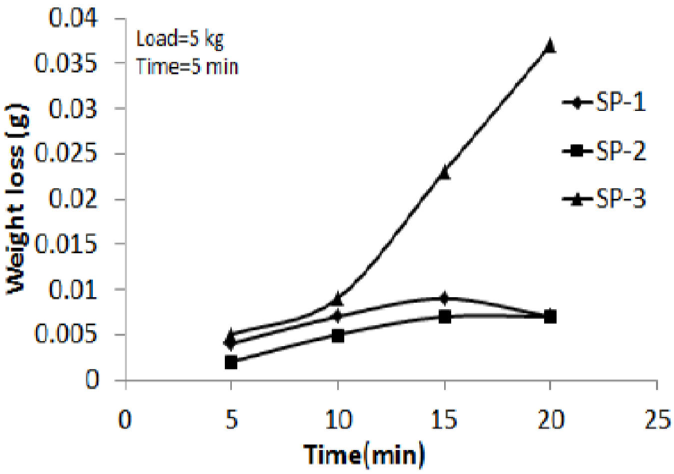

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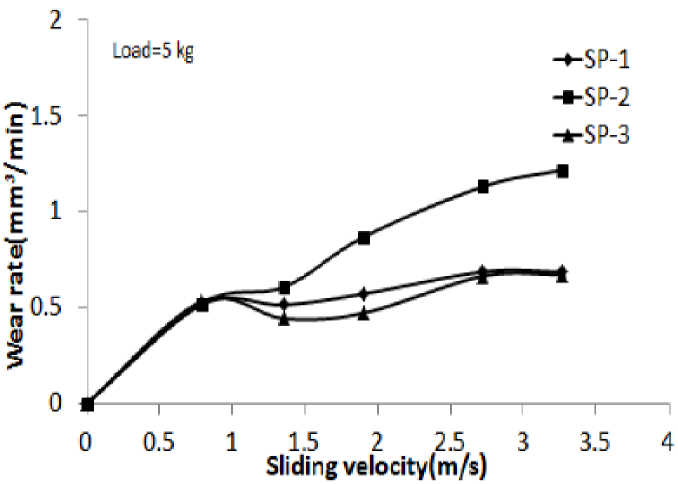
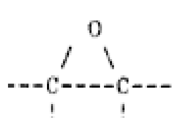


(d)

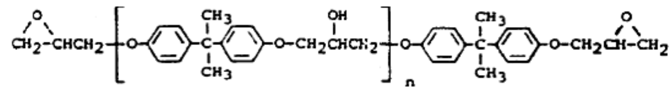
Figure 2: Different behavior of rubber dust composite, (a) Variation of coefficient of friction with load, (b) Variation of weight loss with speed, (c) Variation of weight loss with time, (d) Variation of wear rate with sliding velocity [7]
Specimen-1- 10%, Specimen-2- 15%
Specimen-3- 20% rubber dust by weight%

3. Materials and Method

Epoxy resins are polyether resins containing more than one epoxy group capable of being con- verted into the thermoset form. These resins, on curing, do not create volatile products in spite of the presence of a volatile solvent. The epoxies may be named as oxides, such as ethylene oxides (epoxy ethane), or 1,2-epoxide. The epoxy group also known as oxirane contains an oxygen atom bonded with two carbon atoms, which in their turn are bound by separate bonds as:



The simplest epoxy resin is prepared by the reaction of bisphenol A (BPA) (80-05-7) with epich-lorohydrine (ECH) (106-89-8). The value of *n* varies from 0 to 25.



Applications for epoxy resins are extensive: adhesives, bonding, construction materials (flooring, paving, and aggregates), composites, laminates, coatings, molding, and textile finishing. They have recently found uses in the air- and spacecraft industries.

Epoxy resins are prepared by the reaction of active hydrogen-containing compounds with epichlorohydrin followed by dehydro-halogenation. Bisphenol A (BPA) (80-05-7), on reaction with epichlorohydrin (ECH) (106-89-8) in the presence of caustic soda, produces diglycidyl ether of bisphenol A (DGEBPA) (1675-54-3). Here n is nearly zero (0.2). The resin is liquid when $n < 1$ and solid when $n > 2$. Polyesters, phenolic polyamide and Epoxies are important classes of thermoset resins.

Epoxy resin of general purpose used was purchased from M/s Parikh Resins Limited, Kanpur, U.P., India. It is a colourless, odourless and non-toxic. Its trade name is PG 100. This epoxy is fluorine based epoxy resin and has a hard fluorine structure. Resin can be stored for at least a year if they are stored under cool, dry conditions in the original containers. It is also good solvent and has good chemical resistance over a wide range of temperature. It has versatile applications in technical and industrial applications. Curing takes place at room temperature and atmospheric pressure after addition of hardener. In the present investigation, it has been used as matrix material.

Hardener SY31 (B) is a white liquid. Hardener SY31 (B) is also purchased from M/s Parikh Resins Limited, Kanpur, U.P., India. It has been used as curing agent. In the present investigation 10% wt/wt has been used in all material developed.

3.1 Recycled Tyre Rubber Particles

Recycled tyre rubber particles are collected from nearby tyre retreading centre in Aligarh. Tyres of trucks, buses, cars and tractors are retreaded at the tyre retreading centre. Grinding of tyres is done by grinding wheel which is made of steel wires in radial directions. These wires causes abrasion on the tyre surface and small particles are generated and a rough surface on the tyres is resulted. This surface is now ready for retreding. The particles size between 100-200μm is obtained using two sieves of 100 μm and 200 μm successively. Recycled tyre rubber particles are used as reinforcing agent. Particles are black in colour.

The specimens are fabricated using the open mould casting technique. Moulds of size 300mm× 100mm×6mm for casting the tensile and flexural test specimens, size 100mm×100mm×25.4mm for casting the compressive test specimen, and size 300mm×100mm×4mm for casting the damping test specimen are made. The inner surface of the moulds is coated with petroleum jelly for easy removal of the cast plate of the composite. Epoxy PG100 and Hardener SY31 (B) are mixed in the ratio of 10:1. A homogenous mixture is prepared to cast the specimen plates. Different composite plates or beam are prepared by mixing different weight percentage (10%, 20%, and 30%) of recycled tyre rubber particles of size 100 to 200μm in the epoxy and hardener mixture and by casting the same into the prepared moulds. Curing of plates is done for 24 hours at room temperature (about 30^{0}C). After proper curing, the plates are taken out carefully from the moulds. Different sizes of specimens are then cut from the composite plates according to the test standards.

4. Results and Discussion

4.1 Tensile Test

Type-I tensile bar specimens with dimensions of 165mm × 19mm × 6mm are cut and machined from the composite plate. The tensile tests are performed on Universal Testing Machine, in accordance with ASTM D3039 using a standard material testing system at a crosshead speed of 5 mm/min. Load and corresponding displacement (elongation) resulted in the specimens are recorded. Three specimens for each configuration of composite are tested. The tensile strength was calculated by dividing the maximum load in Newton by the original minimum cross sectional area of the specimen in square meters.

Table 2: Experimental Values of Displacement/Load in tensile test with variation of tyre rubber particles percentage

Sr. No.	Displacement (mm) (10% Reinforcement)	Displacement (mm) (20% Reinforcement)	Displacement (mm) (30% Reinforcement)	Load (N) (10% Reinforcement)	Load (N) (20% Reinforcement)	Load (N) (30% Reinforcement)
1	0	0	0	0	0	0
2	0.1	0.1	0.1	9.81	19.62	39.24
3	0.2	0.2	0.2	19.62	39.24	68.67
4	0.3	0.4	0.3	29.43	88.29	98.10
5	0.5	0.7	0.5	49.05	117.72	137.34
6	0.7	1.0	0.7	68.67	137.34	196.20
7	0.9	1.2	0.8	117.72	156.96	215.82
8	1	1.4	1.0	137.34	186.39	274.68
9	1.2	1.6	1.2	176.58	235.44	284.49
10	1.4	1.8	1.5	206.01	294.30	353.16
11	1.6	2	1.8	255.06	362.97	382.59
12	1.8	2.2	2.0	313.92	441.45	441.45
13	2	2.4	2.2	412.02	529.74	480.69
14	2.3	2.6	2.4	549.36	568.98	559.17
15	2.5	2.8	2.6	618.03	667.08	598.41
16	2.8	3.0	2.8	765.18	784.80	657.27
17	3	3.3	3.0	873.09	917.19	765.18
18	3.3	3.5	3.2	1079.1	1108.53	833.85
19	3.6	3.7	3.4	1294.92	1275.30	882.90
20	3.7	3.9	3.7	1343.97	1363.59	961.38
21	4			1393.02		

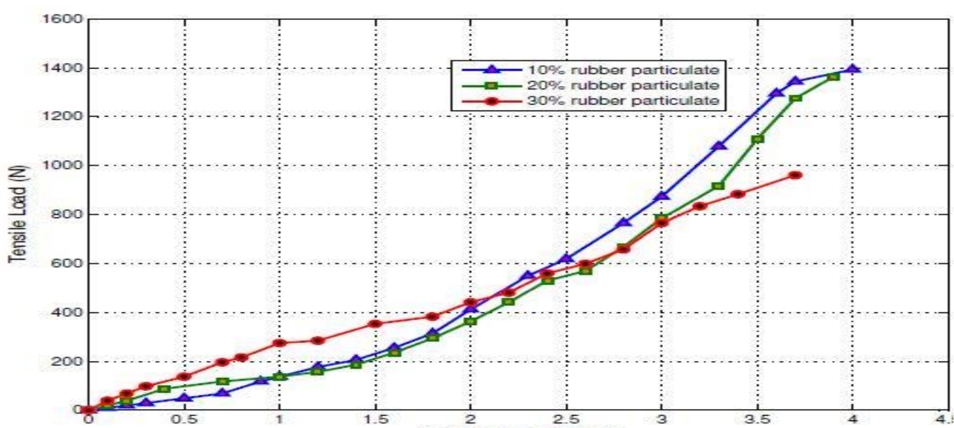


Figure 3: Load/Displacement curves for tensile test with variation of tyre rubber particles wt. percentage

The load/displacement graph shows that initially load is more for the 30 wt% rubber particulate composite but 30% rubber particulate composite breaks at lowest of the three loads i.e. at 961.38 N. 10% rubber particulate composite breaks at maximum load. Hence increasing the particulate decreases the load at fracture.

Table 3: Experimental values of Stress and Strain in tensile test with variation of tyre rubber particles percentage

Sr. No.	Strain (10% Reinforcement)	Strain (20% Reinforcement)	Strain (30% Reinforcement)	Stress(MPa) (10% Reinforcement)	Stress(MPa) (20% Reinforcement)	Stress(MPa) (30% Reinforcement)
1	0	0	0	0	0	0
2	0.061	0.061	0.061	0.0861	0.1721	0.3442
3	0.121	0.121	0.121	0.1721	0.3442	0.6024
4	0.182	0.242	0.182	0.2582	0.7745	0.8605
5	0.303	0.424	0.303	0.4303	1.0326	1.2047
6	0.424	0.606	0.424	0.6024	1.2047	1.7211
7	0.545	0.727	0.485	1.0326	1.3768	1.8932
8	0.606	0.848	0.606	1.2047	1.6350	2.4095
9	0.727	0.970	0.727	1.5489	2.0653	2.4955
10	0.848	1.091	0.909	1.8071	2.5816	3.0979
11	0.97	1.212	1.091	2.2374	3.1839	3.3561
12	1.091	1.333	1.212	2.7537	3.8724	3.8724
13	1.212	1.455	1.333	3.6142	4.6468	4.2166
14	1.394	1.576	1.455	4.8189	4.9911	4.9050
15	1.515	1.697	1.576	5.4213	5.8516	5.2492
16	1.697	1.818	1.697	6.7121	6.8842	5.7655
17	1.818	2.000	1.818	7.6587	8.0455	6.7121
18	2	2.121	1.939	9.4658	9.7239	7.3145
19	2.182	2.242	2.061	11.359	11.187	7.7447
20	2.242	2.364	2.242	11.789	11.961	8.4332
21	2.424			12.219		

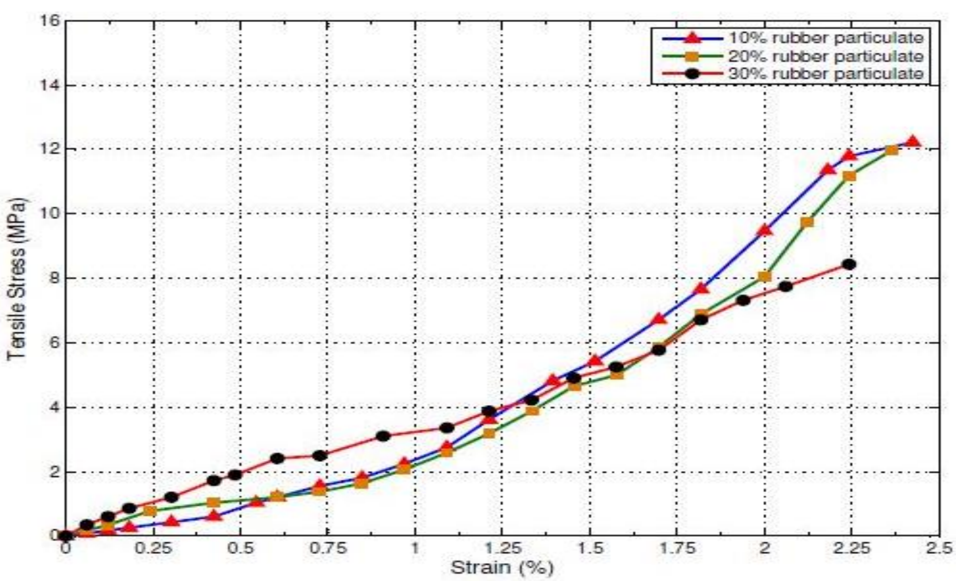


Figure 4: Stress/Strain curves for tensile test with variation of tyre rubber particles wt. percentage

Here the tensile stress is decreasing on increasing the particulate wt. percentages. Tensile stress for 10 wt % rubber particulate composite is decreases by about 85% of the pure epoxy. The decrease in 20% and 30% rubber particulate composite is recorded as 86% and 90%.

4.2 Compressive Test

The compressive property is measured in accordance with ASTM D695. Two 50 mm diameter hardened-steel compression plates mounted on a universal testing machine. The specimen is placed between the compression plates parallel to the surface. The specimen size for compressive test is 25.4mm×25.4mm×63.5mm. The specimen is then compressed at the rate of 1.3 mm/min. until fracture. Three replicates of each composite formulation are tested. The maximum load at fracture is recorded. This load is divided by original cross sectional area to find compressive strength of the composite.

Table 4: Experimental values of Load and Strength in compressive test with variation of tyre rubber particles percentage

Sr. No.	Tyre Rubber Particles Rein-forcement(wt%)	Compressive Load at Break	Compressive Strength (MPa)
1	10	30685.7	47.6
2	20	29069.7	45.0
3	30	19629.4	30.7

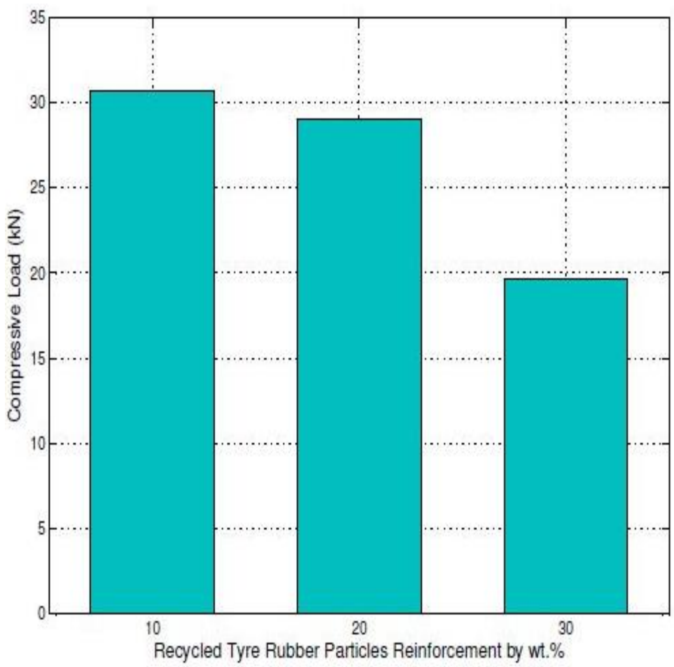


Figure 5: Compressive Load at break with variation of tyre rubber particles reinforcement by wt. percentage

Compressive strength is also decreasing on increasing the reinforcement of rubber particulates. It has been seen that 75%, 76% and 83% decrease in compressive strength are occurred for 10%, 20% and 30% rubber particulate composites respectively as compared to that of pure epoxy (compressive strength 190 MPa). 10 wt% rubber particulate composite have high value of compressive strength (47.6 MPa) of these three configurations.

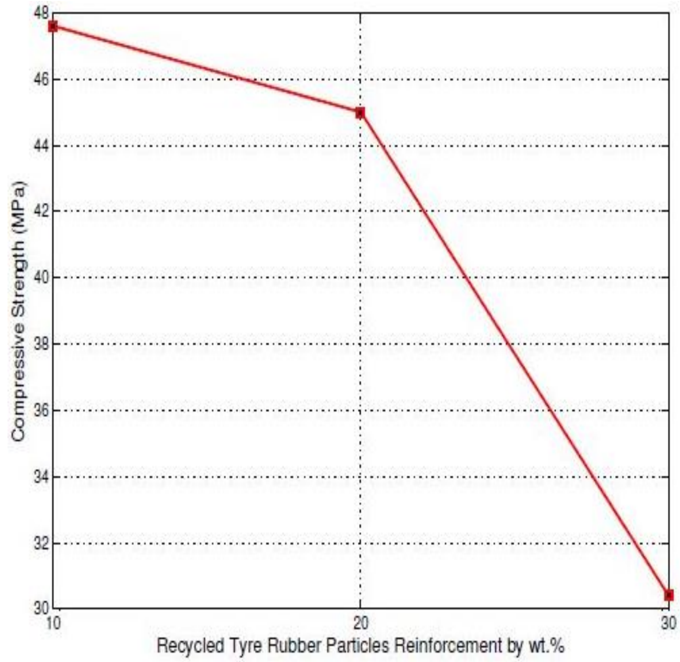


Figure 6: Compressive Strength with variation of tyre rubber particles reinforcement by wt. percentage

5. Conclusions

The focus of this thesis is to use the waste material (tyre rubber) in preparing composite material, which can be used in many applications. This thesis focuses on the effective utilization of environmentally hazardous waste tyres. The composites are successfully prepared by reinforcing different weight percentages of tyre rubber particulates with epoxy matrix.

The mechanical behavior of prepared composites is experimentally determined. Structural properties such as tensile, compressive, flexural, and dynamic property such as damping characteristics are determined. It has been seen that the variation of weight percentages of particulate reinforcement in the composite plays a vital role in influencing these properties. In the present case, tensile, compressive, and flexural strength are decreasing in nature with increase in the reinforcement of tyre rubber particulate in the composite. Tensile, compressive and flexural strength are maximum for 10% (by weight) tyre rubber particulate reinforcement composite.

Viscoelastic materials have good damping characteristics, which can be used for vibration suppression. Tyre rubber particles in particulate composite with epoxy matrix increase the loss tan- gent (loss factor). In the present case, logarithmic decrement, damping ratio, and loss factor are determined for various weight percentages of tyre rubber particulate reinforcement in the composite for impact damping test. Loss factor is maximum for 30% (by weight) tyre rubber reinforcement composite. The prepared composite material can be used in many applications such as flooring, playground surfacing, isolation etc. Fabrication of brake pad in automotive field is an ongoing process [7]. The prepared composite material has lower density as compared to metal particulate reinforced composites.

6. Future Scope

1. The particle size of tyre rubber is taken as constant in this case. A variation in particle size can be taken to observe the influence of size on the mechanical properties.
2. Pre-treatment of rubber particles can improve the results. For this, the rubber was treated with sulphuric (96%), nitric (60%) and perchloric acid (60%). It is immersed in concentrated acids for 1 minute, removed from the acid bath and left for the reaction in air for 2 minutes, and then neutralization of the acid is done using hot distilled water and ammonium hydroxide (15 wt% ammonia). After that washing is done with distilled water at room temperature until pH 7.
3. Further investigation could be carried out for tyre rubber particles reinforced with other polymer matrix.
4. There are very few works on damping characteristics of tyre rubber particulate composites. Therefore, this type of work is recommended.

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