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Research Article

EFFECT OF GEOMETRY OF RECYCLED PET FIBER ON THE PROPERTIES OF CONCRETE FOR RIGID PAVEMENT

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ABSTRACT

The aim of this paper is to fruition waste material like PET bottles in concrete pavement to saves natural resources, to saves energy and reduces solid waste. An experimental investigation was carried out to look over the effect of five geometrical shapes of PET fibers on M30 concrete characteristics after adding 0.5% fibers by volume of concrete. Multiple physical, mechanical and performance experiment were performed on concrete constituent materials along with fresh and hardened concrete. One side circular cut fiber indicates better improvement in results when added in the concrete mix. Therefore, this may be utilized in concrete pavement construction to bridge cracks, increase ductility.

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INTRODUCTION

Road transportation network undoubtedly play a very crucible role in overall economic and social growth of the country. Cement concrete pavement can provide a sustainable and more efficient transport infrastructure in the context of longer service lives, lesser maintenance and rehabilitation requirement and smoother riding surface in comparison of asphalt roads. Other advantages of concrete pavement is 15-20% less fuel consumption of vehicles than asphalt road, saving of 10% electrical energy in road lighting, saving of 40% stone aggregate in concrete pavement. Life cycle cost of concrete pavement is 10-15% less than bituminous pavement over a period of 20 years. However, still in developing countries like India, generally concrete pavement is less preferred due to its high initial cost, which is about 15 % more than bituminous pavement.

Since concrete is a brittle material, which is weak in tension and the tensile stresses, become the cause of unwanted micro Cracks. Due to drying shrinkage and early opening of pavement to traffic, various micro cracks also occurs on the bottom and top surface of pavement. With time, due to loading, temperature and weathering effect, micro cracks convert into macro crack and at last fracture or different distresses in pavement. These minor cracks can be controlled by fiber reinforced concrete.

Fiber reinforced concrete is a composite material resulting from the addition of reinforcing fibers to the brittle matrix of ordinary concrete. Fiber reinforced concrete (FRC) performs better than normal concrete. It shows ''sewing effect'' that the fibers have on the cracks, with consequent benefits in terms of toughness, ductility, impact strength (toughness), abrasion and fatigue. It has been noted experimentally that the fibers are more effective in the post-crack phase, preventing the spread of cracks. Different types of fibers are generally used in concrete like steel fibers, glass fibers, synthetic fibers like nylon fiber, aramid fibers, propylene fibers etc. But, PET (Polyethylene Terephthalate) fibers has been less investigated. PET is generally used in packaging of water, oils, beverages etc. Each year, around 500 billion plastic bottles are discarded globally. In India, 15,300 tons of plastic waste is generated every day, in which 10% is PET, as per strategy & FICCI report and its Demand will increased by two fold over the next five years. Recycling rate of PET bottles is low, due to which it is either sent in landfill or for incineration or dumping in sea. All processes of disposal causes pollution of our environment and harmful for animal and human beings. These bottles can be used for fiber production for concrete.

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Objective of the study

This study has been done for the objectives of investigation of properties of individual constituents material of concrete and strength parameter and properties of plain and PET fiber reinforced concrete as additive, which is useful in the context of pavement.

Literature Survey

PET fibers obtained by waste PET bottles was used in different shapes and sizes by various researchers.

Some researchers used machine manufactured PET fibers. Ochi T. et al (2007) thoroughly investigated different aspect of these PET fibers (0.75 mm dia. and 30mm length). PET fiber showed better alkali resistance in comparison of other polymeric fibers and better mixing and dispersion ability of fiber in concrete. At 1% of fiber volume, maximum compressive strength and at 1.5% maximum flexural strength was found. Other properties like toughness and energy absorption capacity were also increased. Kim J. H. J (2008) et al used embossed, straight and crimped recycled PET fiber (length 50mm) in cement mortar and found better mechanical bond strength by embossed type fiber and control of plastic shrinkage cracking by of all fibers at Minimum 0.25%. Ghernouti Y. (2015) investigated about effect of length and quantity of fibers on concrete strength. 4 cm length fiber with 7kg/m3 amount showed best result of increment of 9.5 % of compressive strength, 13.3% increment in flexural strength. The machine-manufactured fibers (40-52mm length) of Fraternali F. (2011) had showed better results than propylene fiber at 1% by volume. PET (dia. 1.1mm and 40mm length) fibrous concrete showed 35% increment in compressive strength, 41% increment in first crack strength, 15% increment in first crack ductility, 656% increment in ultimate crack ductility and finally 18% decrement in thermal conductivity than unreinforced concrete. However, Research on embossed PET fiber (0.2mm x1.3mm x50mm) and polypropylene fiber (0.38mm x0.9mm x50mm) by Kim S. B. et al. (2010) showed, reduction in compressive strength upto 1-10% at different proportions and improvement in flexural strength, drying shrinkage and macro crack formation.

Some researchers also used such PET fibers, which were directly obtained by cutting of PET bottles. Foti D.(2010) examined the usability of lamellar (5mm width and 35mm length) PET fibers and ring shaped “O” fiber cut at cross section of bottle and found reduction in compressive strength but better performance in tensile strength, in ductile nature and post crack behavior. As per Foti D. (2013) investigation of “O” fiber and half bottle reinforcement also showed better results. Foti D et al. (2014) showed better impact resistance of PET strip reinforcement also. Oliveria L. (2011) mixed 0.5, 1.0, and 1.5% PET fiber (2mm width and 35 mm length) in mortar in 1:1:6 ratio of cement, lime and mortar. Flexural strength and energy absorption capacity were increased at optimum percentage 1.5% by volume, but Density & compressive strength were not altered significantly. Marthong C. (2015) study showed that smaller size of flattened end sheet fiber (length 40mm) gave better results than straight slit fiber at 0.5% volumetric content. Which was 12.45% increment in compressive strength, 8.45 % increment in flexural and 33.6% in splitting tensile strength. As per investigation of Marthong C & Marthong S (2015), it was found that 20 % of natural aggregate also can be replaced by recycled aggregate with 0.5 % of PET fiber in concrete without compromising with strength. Further, Marthong C. and Sharma D. K (2015) had done comparative analysis of fibrous concrete reinforced on four shape of hand cut PET bottle fiber (straight slit sheet, flattened end slit sheet, deformed slit sheet and crimped end sheet). Best result was found by deformed slit sheet shaped fiber, which were 24.1% increment in compressive strength test, 51.72% increment in splitting tensile strength, 33.77% increment in flexural strength. But as per study of Borg R. P. et al. (2016) on shredded pet bottle fiber by mechanical shredder of 30 and 50mm length and 2mm width and deformed pet fiber with 0.5, 1.0, and 1.5% by volume in concrete, there was found 8.5 % reduction in compressive strength, marginal increment in flexural strength, 68.7 % reduction in crack formation. However, deformed fiber showed better bond strength than normal fiber.

As per IRC SP:46:2013 guidelines about fibers reinforced concrete pavement, Coarse aggregate of 20 mm maximum size is suitable for low volume fraction. Length of fiber may be 2 to 3 times the normal maximum size of aggregate.

In summary it can be said that PET fiber is better than propylene fibers. Plain PET fiber may reduce compressive strength due to its slipping effect, but it always increases flexural strength, which is more beneficial for pavement. Deformed shape can also increase compressive strength. 0.5 % of PET fiber by volume and 50mm length is better for concrete. Therefore, in this study five different shapes of fiber were chosen, which are shown in fig. 1.

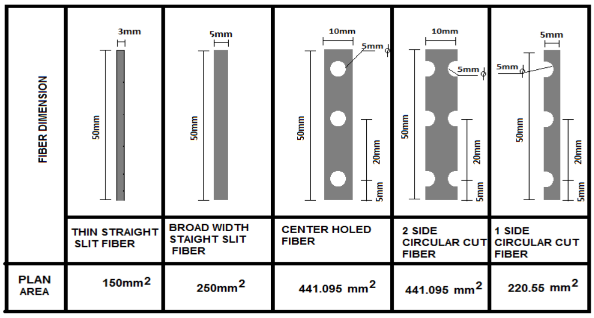

Fig 1 Geometry of PET fiber

Experimental Investigation

Materials

All constituent materials were tested for checking their appropriateness for rigid pavement. Ordinary Portland cement of 43 grade of JP Cement brand, river sand passing from 4.75mm as fine aggregate and crushed angular, passing through 20 mm sieve aggregate as coarse aggregate were used in this study. Properties of materials were determined by different tests as per various IS codes, given in table 1, table 2 and 3.

Table 1 Properties of cement

Tests	*Results*	*Standard Results*	*Reference Code*
Fineness test	3%	<10%	IS:4031 (part 1)-1996
Consistency Test	31%	Near 30%	IS:4031 (part 4)-1996
Initial Setting time	100min	>30 min	IS:4031 (part 5)-1996
Final Setting time	220min	<600 min	IS:4031 (part 5)-1996
Density	2.85	Near 3.15	(IS 4031 part 11(1988))
Compressive strength at 28 days	44.7 MPa	>43 MPa	IS:4031 (part 6)-1996

Fig 2 Cutting PET fiber

PET fiber

PET fibers were obtained by hand cutting of waste PET bottle of different brands like Bisleri, Aquafina, Rail Neer etc. Thin straight slit fiber and Broad width straight slit fiber were cut with scissors, while other fibers were holed by soldering iron and then cut by scissors. Since these fibers were for this study and required in lower amount, so that fibers were cut by hand, but for mass construction different machinery can be used for cutting like shredders.

Table 2 Properties of fine aggregate

Tests	*Results*	*Standard Results*	*Reference Code*
Specific gravity	2.44	2-3	IS:2386 (part 3)-1963
Water absorption	1%	<2%	IS:2386 (part 3)-1963
Sieve analysis	Grade iii	Grade iii for FRC	IS:383-1970

Table 3 Properties of coarse aggregate

Test	*Results*	*Standard Results*	*Reference Code*
Nominal Size(mm)	20	20 mm	IS:383-1970
Water absorption	0.4%	<2%	IS:2386 (part 3)-1963
Crushing strength	23.3%	<30%	IS:2386(part 4)-1963
Aggregate impact value	12.33%	20 to 30%	IS:2386(part 4)-1963
Los Angeles Abrasion test	28.4%	<35%	IS:2386(part 4)-1963
Specific gravity	2.73	2.5- 3	IS:2386(part 3)-1963
Flakiness vale	10.21%	25%	IS:2386(part 1)-1963
Elongation test	11.23%	Combined flakiness+ Elongation index<30%	IS:2386(part 1)-1963

Table 4 Properties of PET

Chemical formula	*$(C_{10}H_8O_4)_n$*
Density	1.38g/cm^3(at 20^{o}c)
Melting Point	>250^{o}c
Solubility in water	Practically insoluble
Related monomer	Terepthalic acid and ethylene glycol
Young modulus	2800-3100 MPa
Tensile strength	55-75 MPa
Water absorption	0.16

Concrete mixing and testing

Since this study was concerned with concrete pavement, therefore M30 grade of concrete was designed as per IRC 44:2008. Design mix proportion for 1m^3 was given in Table 4. Slump values were checked for each mixes. Six cube (150 mm X150 mm X150 mm) specimens, three beam (100 mm X100 mm X 500 mm) and six cylinder specimens (dia. 150mm and height 300mm) were casted for various tests. Which are Compressive strength test (IS 519. 1959), Flexural strength test (IS 519. 1959), Modulus of elasticity test (IS 519. 1959), Split Tensile strength test (IS 5816. 1999) and Ultrasonic Pulse velocity test (IS 13311-1:1992). Further, based on determined different results, pavement thickness was designed for a standard traffic load as per IRC 58:2015.

Table 3 Design mix proportion for (M30 mix) for 1m3 of concrete

MIX	*Water*	*Cement*	*Coarse Aggregate*	*Fine Aggregate*	*Fiber*
NFC	186 kg	395.74 kg	1186.7 kg	587.22 kg	0.0
All FRCs	186 kg	395.74 kg	1186.7 kg	587.22 kg	6.9 kg

RESULT & ANALYSIS

Fiber Bond strength

Single fiber pull out test or bond strength test was conducted for evaluating the performance of individual PET fibers. In this test, each type of fiber was kept at center of briquette mould with a partition board as showing in the Fig. and further mould was tightly filled with mortar of 1:3 ratio cement and sand.

After 28 days of curing, Tensile strength was applied on each specimen to determine their bond strength with cement matrix. This test was conducted similar to JCI SF-8 standards.

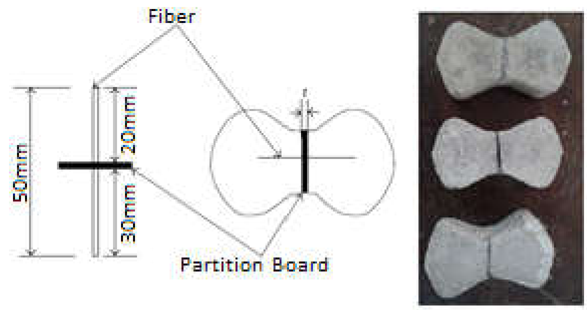

Fig 3 Fiber bond strength test

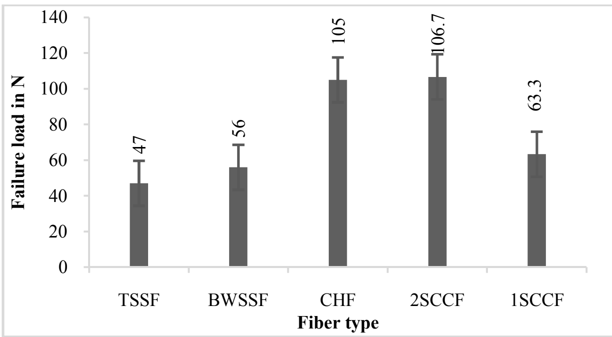

Fig 4 Fiber bond strength v/s Fiber type

In this experiment, two fibers TSSF and BWSSF failed by slipping, but rest three fiber failed by breaking. These results showed that increased surface area increased the bond, but when their sides are made rough, its anchorage value can reach at its tensile strength. CHF, 2SCCF and 1SCCF are the fibers, which can takes the load of concrete efficiently and also able to make concrete to resist comparatively more tensile stress.

Slump Test

Slump value, which shows workability of concrete, reduced slightly for straight fibers, but slump value reduced more for other three fibrous concrete(CHF, 2SCCF, 1SCCF) shown in Fig. 15. Therefore, it can be said that workability reduces due to anchoring behavior of fibers.

Compressive Strength

Results of compressive strength tests on cubes are shown in fig.9. The variation in result showed that two main factors, which affect the strength are unbound surface area and anchoring behavior. Since these fibers do not make any bond with concrete and these unbound surface area make concrete weaker, but its anchoring effect also try to strengthen concrete to failure. In first two fibers, TSSF and BWSSF, unbound area is more dominating, due to which, these fibers showed decrement in strength at 7 and 28 days. While in rest three CHF, 2SCCF and 1SCCF fibers, anchorage value dominants and showed increment in compressive strength. But, fibers with more surface area and more anchorage value (2SCCF) also reduced the 7 days compressive strength. 1SCCF showed maximum increment of 28 days compressive strength from 39.29 MPa to 44.5 MPa (which is 13.26%) among all, due to good bonding strength and less accumulation of unbound surface area and well dispersion in whole concrete.

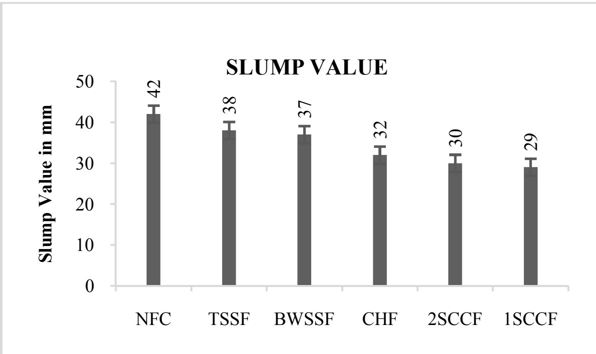

Fig 5 Slump value v/s Fiber type

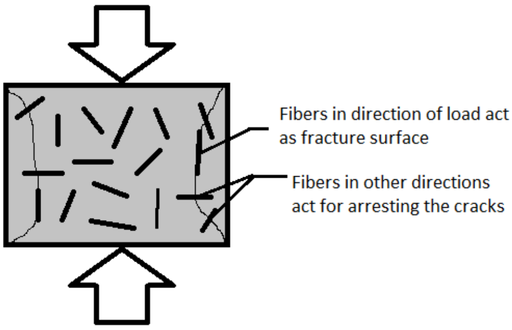

Fig 6 Compressive strength test

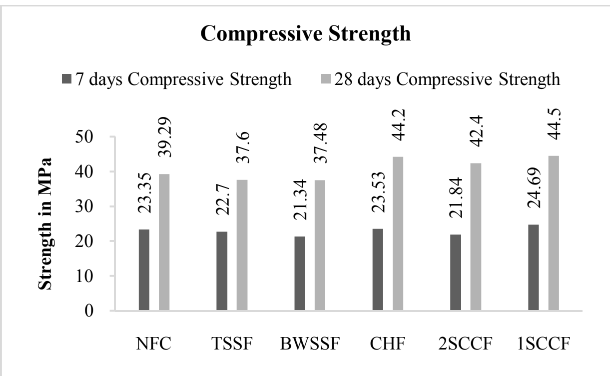

Fig 7 Compressive strength v/s Fiber type

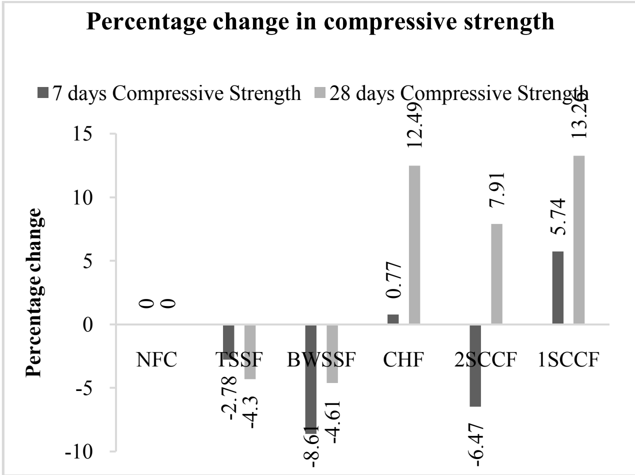

Fig 8 %age change in Compressive Strength

Flexural Strength

In flexural strength test, most of fibers act for arresting the cracks, due to which, all fiber reinforced concrete showed increment in flexural strength. BWSSF also showed increment but due to more area and less numbers, its flexural strength was found lower than TSSF. CHF and 2SCCF have more unbound surface area, which showed also cracking at near loading arrangement in the direction of loading. However, still CHF and 2SCCF showed better results. Due to well distribution and good anchorage value, 1SCCF showed maximum increment of 39.24%, which is up to 5.48 MPa flexural strength, shown in fig. 11 & 12.

Splitting Tensile Strength

Splitting tensile strength is indirect tensile strength. All shown results in fig. 13 gives idea about the enhancement of Split tensile strength of concrete. Fibers without anchorage surface showed less increment, while others like CHF, 2SCCF and 1SCCF showed better results of 3.55, 3.63 and 3.83 MPa. Except values, after failure of specimen of No fiber concrete was broken into two parts, while all fibrous concrete were joined with their fibers after failure. It shows better crack arrest property and energy absorbing property of PET fibrous concrete.

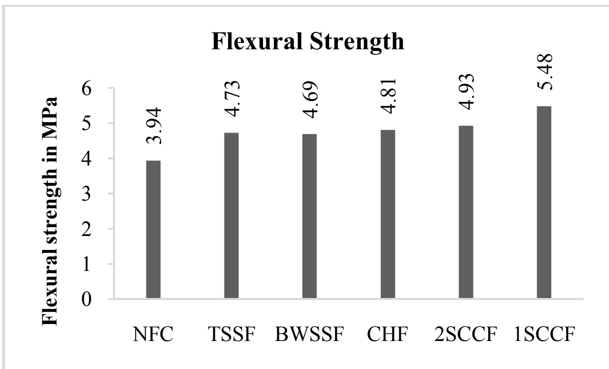

Fig 9 Flexural strength v/s Fiber type

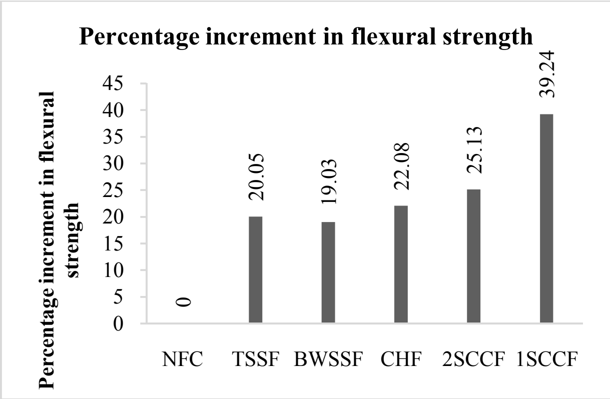

Fig 10 Percentage increment in Flexural strength

Modulus of Elasticity

As per results, for fibrous concrete containing more surface area and low bonding strength like TSSF, BWSSF & CHF, Modulus of elasticity was reduced, while for 2SCCH and 1SCCF, Modulus of elasticity increased. Reason behind increment or decrement of elasticity of concrete is stress-bearing characteristics of fibers. Plain straight fibers just slipped and could not resist more stress, therefore elongation became more and elasticity was reduced. While fibers with anchorage sides did not slip and bear the stresses of concrete with their full strength, which increased the elasticity of concrete, shown in fig. 15 & 16.

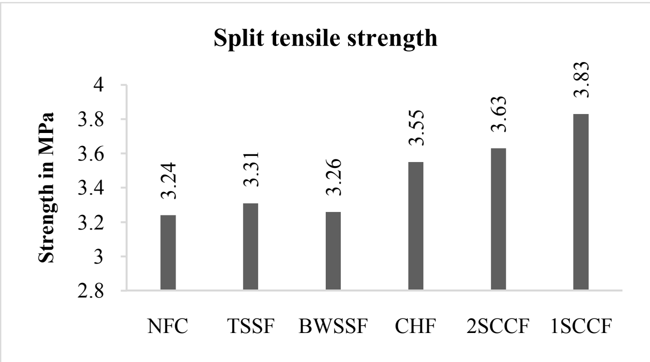

Fig 11 Split tensile strength v/s fiber type

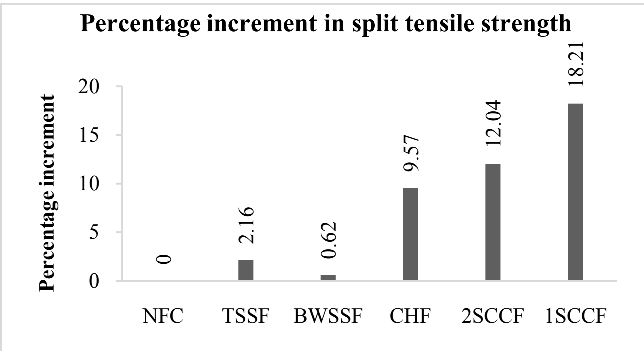

Fig 12 Percentage Increment in split tensile strength

Stress v/s Strain Curve

Stress v/s strain graph is shown in fig.17. In graph, it can be seen that in the beginning of graph, slope of 2SCCF and 1SCCF are more than others, which showed that modulus of elasticity of both fiber reinforced concrete was more than others. Further, in graph for higher strain, slopes of all mixes were reduced, but slope of No Fiber concrete mix was not reduced so much.

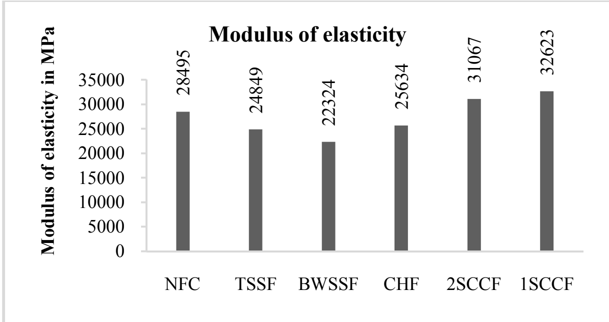

Fig 13 Modulus of Elasticity v/s fiber type

It can be said that No Fiber concrete mix was showing brittle nature and others were showing ductile in nature. Since this test was conducted on cylinder, therefore maximum strength was less than actual compressive strength of cubes. Maximum stress was also at higher strain in fibrous concrete in comparison of no fiber concrete and its maximum strain capacity was more than no fiber concrete, which showed that concrete can resist load after cracking.

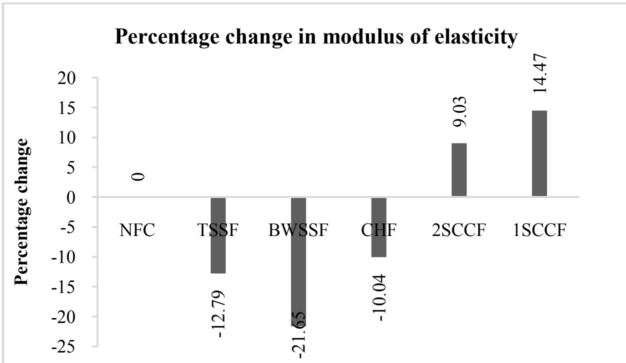

Fig14 %age change in Modulus of elasticity

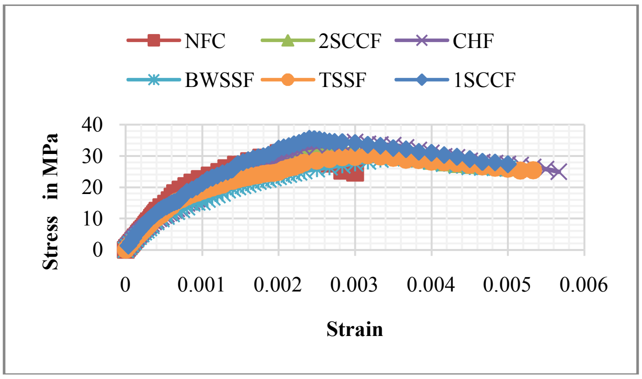

Fig 15 Stress v/s Strain

Hardened Density & Water absorption Test

Fibers were mixed in 0.5% volume, which is very less. Therefore change in density of hardened concrete is negligible and water absorption value increased in very less amount about 0.65%. Therefore it can be said that there is not much effect on density and water absorption.

Ultrasonic Pulse Velocity Test

UPV test results showed that traveling speed of ultrasonic pulse in different fibrous concrete was all-more than 3500 m/s and

NFC, TSSF & 1SCCF had more than 4500m/s. As per IS 13311-1:1992 standards we can say that concrete grading quality was good of BWSSF, CHF, 2SCCF and excellent of NFC, TSSF, 1SCCF. These results showed that due to addition of fiber, there is not much variation in its quality. Fibers did not make any type of voids, which is due to its sufficient flexibility.

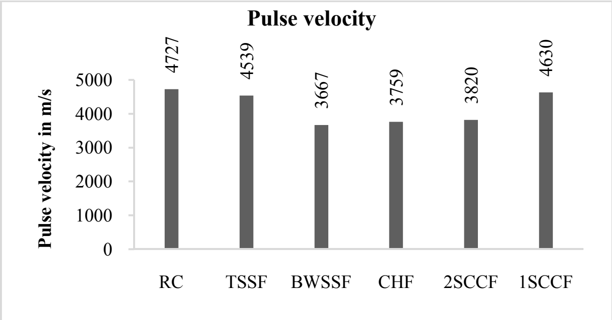

Fig 17 Ultrasonic pulse velocity v/s fiber type

Pavement Slab thickness

As per finding results for standard traffic condition given in IRC 58:2015, concrete pavement thickness was designed for all fibrous and no fiber concrete, which designing procedure are given in Appendix B. Design showed decrement in pavement thickness for all fibrous concrete due to increment in flexural strength, which is shown fig. 21 & 22.

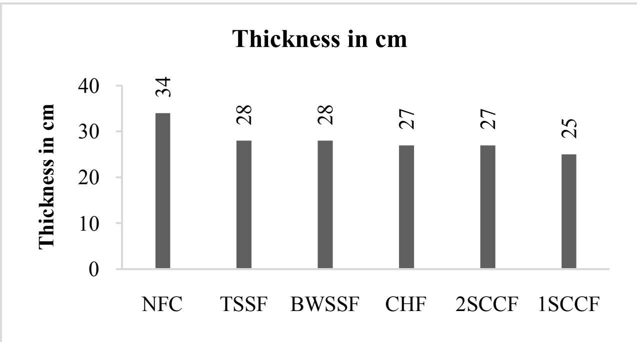

Fig18 Slab thickness v/s fiber type

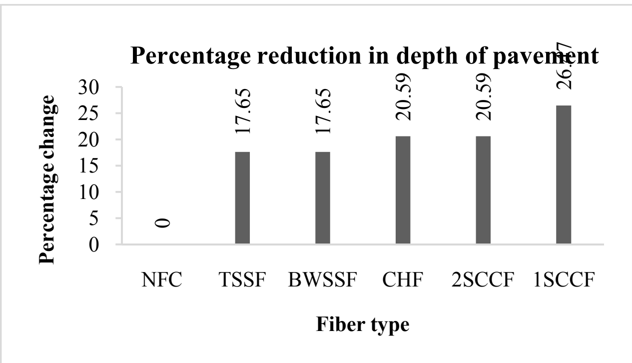

Fig19 Percentage Reduction in depth v/s fiber type

CONCLUSION

Based on this experimental investigation, following conclusion have been drawn.

1. Addition of PET fiber in concrete reduces the slump value. When its anchorage value increases, slump value reduces more and become harsh. Therefore PET fiber reinforced concrete needs addition of admixture for increasing workability.
2. Compressive strength decreases with increment in surface area of single fiber and increases with better anchorage sides of fiber. Therefore, 1SCCF fiber with smallest area and good anchorage surface gave best result of increment of 13.26%.
3. Addition of all types of PET fibers increases the flexural strength at 0.5% volumetric content. Because, tensile stress on concrete was taken by fibers. Maximum strength gained by this study was 5.48MPa for M30 concrete by addition of one side circular cut fiber.
4. Due to these PET fibers, splitting tensile Strength was also increased for all types of fiber. Best results was again given by one side circular cut fiber of 18.21% increment.
5. Modulus of elasticity in compression was reduced by these PET fibers except two side circular cut fiber and one side circular cut fiber, due to better anchoring with concrete.
6. Hardened density was reduced very less and water absorption was also increased very less due to use in very less amount.
7. Ultrasonic Pulse velocity test showed that PET fibers did not add any crack or voids, due to which, quality of all concrete mixes was not reduced with addition of PET fibers.
8. Concrete pavement designed with PET fibrous concrete of M30 grade with 0.5 % volumetric content of 1SCCF can help to reduce the pavement thickness from 34cm to 25 cm, which is up to 26.47 %.

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