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THE INFLUENCE OF FIBRES IN CONCRETE: A REVIEW

ERIN JAKE WILSON[1] & NIVIN PHILIP[2]

[1]P G Scholar, Computer Aided Structural Engineering, Mar Athanasius College of Engineering, Kothamangalam, Kerala, India

[2]Assistant Professor, Department of Civil Engineering, Mar Athanasius College of Engineering, Kothamangalam, Kerala, India

ABSTRACT

Fibers are generally used as resistance of cracking and strengthening of concrete. The interest in the use of fibers for the reinforcement of composites has increased during the last several years. A combination of high strength, stiffness and thermal resistance favorably characterizes the fiibers. Metal strands embedded in the concrete mass are commonly known as composite metal fibers. Their use has been necessary to reduce some defects in the concrete materials. In this paper, the influence of steel and polypropylene fibers in concrete are discussed based on various studies conducted.

KEYWORDS: The Influence of Fibres in Concrete: A Review

INTRODUCTION

Concrete is generally known for its resistance against compression and similarly steel is known for its resistance against tension. Since conventional concrete has limited ductility, low impact and abrasion resistance and little resistance to cracking, alternative composite materials are gaining popularity because of ductility and strain hardening. Addition of fibers improves the post peak ductility performance, pre-crack tensile strength, fracture strength, toughness, impact resistance, flexural Strength resistance, fatigue performance etc. The ductility of fiber reinforced concrete depends on the ability of the fibers to bridge cracks at high levels of strain. Since adding fibers in concrete is gaining popularity, study about its influence in concrete is important.

FIBER REINFORCED CONCRETE (FRC)

The term fiber reinforced concrete (FRC) is defined by ACI Committee 544 as a concrete made of hydraulic cements containing fine and coarse aggregates and discontinuous discrete fibers. FRC is concrete containing fibrous material which increases its structural integrity. So we can define fiber reinforced concrete as a composite material of cement concrete or mortar and discontinuous discrete and uniformly dispersed fiber. Fiber is discrete material having some characteristic properties. The fiber material can be anything. But not all will be effective and economical. According to the terminology adopted by American Concrete Institute (ACI) Committee 544, there are four categories of Fiber Reinforced Concrete namely

- SFRC (Steel Fiber Reinforced Concrete),
- GFRC (Glass Fiber Reinforced concrete),
- SNFRC (Synthetic Fiber Reinforced Concrete) and

- NFRC (Natural Fiber Reinforced Concrete).

Adding fibers to concrete increases its ductility, tensile strength, flexural strength and resistance against dynamic and impact loads furthermore, adding fibers reduces the possibility of spallingand scabbing failures, prevents crack propagation and extends the softening region in the concrete matrix.

By utilization of Polypropylene fibers in concrete not only optimum utilization of materials is achieved but also the cost reduction is achieved. Steel and polypropylenefibers are the most useful fibers. The aspect ratio (L/d) and volume fraction (V_f) are important fibers parameters in FRC. When cracks are initiated in FRC, the fibers bear the applied loads. When the load increases, the fibers tend to transmit the excess stresses to the matrix. If these stresses exceed the fiber-matrix bond strength, which in turn is influenced by fiber properties the fracture processmay lead to fibers pullout or rarely rupture of the fibers. Thus, fiber reinforced concretes are more ductile than other concretes.

Requirements of Fiber

A good fiber is the one which possess the following qualities

- Good adhesion within the matrix.
- Adaptable elasticity modulus (sometimes higher than that of the matrix)
- Compatibility with the binder, which should not be attacked or destroyed in the long term
- An accessible price, taking into account the proportion within the mix
- Being sufficiently short, fine and flexible to permit mixing, transporting and placing
- Being sufficiently strong, yet adequately robust to withstand the mixing process.

LITERATURE REVIEW

Steel Fiber Reinforced Concrete (SERC)

Steel fiber reinforced concrete (SFRC) is concrete made of hydraulic cements containing fine or fine and coarse aggregate and discontinuous discrete steel fibers. In tension, SFRC fails only after the steel fiber breaks or is pulled out of the cement matrix shows a typical fractured surface of SFRC.

Properties of SFRC in both the freshly mixed and hardened state, including durability, are a consequence of its composite nature. The mechanics of how the fiber reinforcement strengthens concrete or mortar, extending from the elastic precrack state to the partially plastic post-cracked state, is a continuing research topic. One approach to the mechanics of SFRC is to consider it a composite material whose properties can be related to the fiber properties (volume percentage, strength, elastic modulus, and a fiber bonding parameter of the fibers), the concrete properties (strength, volume percentage, and elastic modulus), and the properties of the interface between the fiber and the matrix. A more general and current approach to the mechanics of fiber reinforcing assumes a crack arrest mechanism based on fracture mechanics. In this model, the energy to extend a crack and debond the fibers in the matrix relates to the properties of the composite.

SFRC has advantages over conventional reinforced concrete for several end uses in construction. One example is the use of steel fiber reinforced shotcrete (SFRS) for tunnel lining, rock slope stabilization, and as lagging for the support of excavation. Labor normally used in placing mesh or reinforcing bars in these applications may be eliminated.

Definition of Fiber Types

Steel fibers intended for reinforcing concrete are defined as short, discrete lengths of steel having an aspect ratio (ratio of length to diameter) from about 20 to 100, with any of several cross-sections, and that are sufficiently small to be randomly dispersed in an unhardened concrete mixture using usual mixing procedures.\

ASTM A 820 provides a classification for four general types of steel fibers based upon the product used in their manufacture:

Type I —Cold-drawn wire.

Type II —Cut sheet.

Type III—Melt-extracted.

Type IV—other fibers

PHYSICAL PROPERTIES

Fiber Properties

The fiber strength, stiffness, and the ability of the fibers to bond with the concrete are important fiber reinforcement properties. Bond is dependent on the aspect ratio of the fiber. Typical aspect ratios range from about 20 to 100, while length dimensions range from 0.25 to 3 in. (6.4 to 76 mm).

Steel fibers have a relatively high strength and modulus of elasticity, they are protected from corrosion by the alkaline environment of the cementitious matrix, and their bond to the matrix can be enhanced by mechanical anchorage or surface roughness. ASTM A 820 establishes minimum tensile strength and bending requirements for steel fibers as well as tolerances for length, diameter (or equivalent diameter), and aspect ratio. The minimum tensile yield strength required by ASTM A 820 is 50,000 psi (345MPa).

Behavior under Static Loading—The mechanism of fiber reinforcement of the cementitious matrix in concrete has been extensively studied in terms of the resistance of the fibers to pullout from the matrix resulting from the breakdown of the fiber-matrix interfacial bond. Improvements in ductility depend on the type and volume percentage of fibers present. The amount of fibers required achieving a given level of improvement in strength and ductility is usually less than the amount of equivalent straight uniform fibers. Steel fibers improve the ductility of concrete under all modes of loading, but their effectiveness in improving strength varies among compression, tension, shear, torsion, and flexure.

Compression— In compression, the ultimate strength is only slightly affected by the presence of fibers, with observed increases ranging from 0 to 15 percent for up to 1.5 percent by volume of fibers.The addition of steel fibres up to 1.0% by volume has no significant effect on compressive strength. The compressive strength increased by about 3% only when 0.5% of fibre was used. The results shows that fibres usually have only minor effect on the compressive strength, slightly increasing or decreasing the test results [1].

The compressive strength of both plain and fibre reinforced concretes decreased after exposure to all the studied range of temperature. It is less affected at 150 ^{o} C (92%).At 350 ^{o}C, the fibre reinforced concrete suffered further minor decrease of about (8 to 10%). However, the use of 1.0% of steel fibres enhanced the compressive strength at 500 ^{o}C by about 16.5% compared to plain concrete at the same temperature [1].

Direct Tension— In direct tension, the improvement in strength is significant, with increases of the order of 30 to 40 percent reported for the addition of 1.5 percent by volume of fibers in mortar or concrete

The incorporation of steel fibres into concrete significantly increased the tensile strength of concrete The increase in tensile strength when compared to reference concrete for HS1 (0.25% flat fibres and 0.25 % wire fibres) is 28% and for HS2 (0.5% flat fibres and 0.5 % wire fibres) is found to be 42% [7].It can be seen that steel fiber had large effect on tensile strength, tensile strength increase with range up to 55% comparing with concrete without steel fiber. Failure mode of UHPC without steel fiber is a brittle failure, while failure mode of UHPFRC with steel fiber combined with large deflection and ductile failure. [2].

Shear and Torsion—Steel fibers generally increase the shear and torsional strength of concrete, although there are little data dealing strictly with the shear and torsional strength of SFRC, as opposed to that of reinforced beams made with a SFRC matrix and conventional reinforcing bars. The increase in strength of SFRC in pure shear has been shown to depend on the shear testing technique and the consequent degree of alignment of the fibers in the shear failure zone. For one percent by volume of fibers, the increases range from negligible to 30 percent. From the curves obtained for Torque vs Twist, it was found that the twist for beams without steel fibers were more than the beams with steel fibers. The beams with 1 % by volume of steel fibers show that the twist under torque was lower when compared to all the other beams [3]. The torsional strength of SFRC beams has increased up to 47.27% which is very significant increase in the strength of concrete compared to conventional RC Beam when crimped steel of aspect ratio 38 was used when percentage variation of steel is from 0.25% to 1% [4].

Flexure—Increases in the flexural strength of SFRC are substantially greater than in tension or compression because ductile behavior of the SFRC on the tension side of a beam alters the normally elastic distribution of stress and strain over the member depth. A summary of corresponding strength data shows that the flexural strength of SFRC is about 50 to 70 percent more than that of the unreinforced concrete matrix in the normal third-point bending test. Use of higher fiber volume fractions, or center-point loading, or small specimens and long fibers with significant fiber alignment in the longitudinal direction will produce greater percentage increases up to 150 percent.

The increase in flexural strength for HS1 (0.25% flat fibres and 0.25 % wire fibres) and HS2 (0.5% flat fibres and 0.5 % wire fibres) with respect to reference concrete (M30) is found to be 6% and 13% respectively. [7]. The specimen without steel fibers seems to have a larger first-crack stress than the specimen cast with steel fibers. From results of flexure test, it can be seen that steel fiber had large effect on flexure strength, and it increased with range up to 40% comparing with concrete without steel fiber [5].

Behavior Under Impact Loading—To characterize the behavior of concrete under impact loading, the two most important parameters are the strength and the fracture energy. In terms of the differences between SFRC and plain concrete under flexural impact loading, it has been found that for normal strength concrete the peak loads for SFRC were about 40 percent higher than those obtained for the plain matrix. For high strength concrete, a similar improvement in the peak load was observed.

Concrete specimens were prepared with two water cement ratios 0.36 and 0.46. Hooked-end steel fibers with an aspect ratio equal of 80 at 0.5% and 1% volume fractions and polypropylene fibers at 0.2%, 0.3% and 0.5% volume fractions were used. Both the numerical and experimental analysis results indicated that increasing the fiber volume fraction increased the impact resistance of the concrete specimens. The results also demonstrated that steel fibers are more effective at increasing impact resistance than polypropylene fiber [6].In an experiment by adding 0.5%, 1.0% and 1.5% volume fraction of crimped steel fibre, the energy required to cause the visibility of first crack and failure increased up to 321% over plain concrete. When 0.5%, 1.0% and 1.5% volume fraction of hooked end steel fibre was added to concrete, the energy was increased up to 347% comparatively. The results shows that 1.5% volume fraction of steel fibre considerably increases the impact energy. Moreover the incorporation of steel fibre to concrete, changes the failure pattern from brittle mode to ductile [8].

Fatigue Behavior—Experimental studies show that, for a given type of fiber, there is a significant increase in flexural fatigue strength with increasing percentage of steel fibers. Depending on the fiber type and concentration, a properly designed SFRC mixture will have fatigue strength of about 65 to 90 percent of the static flexural strength.

The steel fibres in the concrete helps in bridging the cracks developed due to applied load thereby delaying the propagation of cracks and enhancing the fatigue resistance of concrete by using two parametric Weibull distribution. [7].

Modulus of Elasticity and Poisson's Ratio—In practice, when the volume percentage of fibers is less than 2 percent, the modulus of elasticity and Poisson's ratio of SFRC are generally taken as equal to those of a similar non-fibrous concrete or mortar.

The inclusion of fibres into concrete considerably enhanced the elasticity modulus. The increase inelasticity modulus when compared to reference concrete for HS1(0.25% flat fibres and 0.25 % wire fibres) and HS2(0.5% flat fibres and 0.5 % wire fibres) is found to be 36% and 50% respectively[7].The modulus of elasticity is increased up to 13% comparing with concrete without steel fiber. Steel fiber had a little effect on Poisson's ratio results. The results showed that the stress strain curve appear to be linear up to (70% -80%) of compressive strength. [5].

Toughness— Toughness is a measure of the ability of the material to absorb energy during deformation estimated using the area under the stress-strain curves Early in the development of SFRC, toughness was recognized as the characteristic that most clearly distinguishes SFRC from concrete without steel fibers.

The fiber dosage is varied from 0 to 2 percent. Steel and Polyolefin fibers were combined in different proportions and their impact on strength and toughness studied. Addition of 2 percent by volume of hooked-end steel fibers increases the toughness by about 19.27%, when compared to the plain concrete. When the fibers were used in a hybrid form, the increase in above study parameters was about 31.42%, comparatively [9].

Applications

The applications of SFRC will depend on the ingenuity of the designer and builder in taking advantage of the static and dynamic tensile strength, energy absorbing characteristics, toughness, and fatigue endurance of this composite material. The uniform dispersion of fiber throughout the concrete provides isotropic strength properties not common to conventionally reinforced concrete.

SYNTHETIC FIBER REINFORCED CONCRETE (SNFRC)

A variety of fiber materials other than steel, glass, or natural fibers have been developed for use by the construction industry for fiber reinforced concrete. These fibers are categorized as synthetic fibers for use in synthetic fiber reinforced concrete, SNFRC for identification. Synthetic fibers are man-made fibers resulting from research and development in the petrochemical and textile industries. Examples of the synthetic fibers which have been studied are polyethylene (PE), polypropylene (PP), acrylics (PAN), poly(vinyl alcohol) (PVA), polyamides (PA) and polyester (PES). Among those fibers PP fibers were the most efficient. Polypropylene (PP) fibers have numerous properties that make them suitable for incorporation to concrete: low cost, ductility, ease of dispersal and good anchoring capacity Polypropylene fibers do not corrode, are thermally stable (high melting point), chemically inert and very stable in the alkaline environment of concrete. Moreover, the polymer has a hydrophobic surface (does not absorb water) and they do not interfere in the concrete hydration reaction. Also, the crack/ fiber interaction increases the crack propagation resistance.

The main disadvantage of PP fibers is their non-polar nature, which inhibits adhesion to concrete. Several methodologies use shrinkage reducing admixtures to increase compatibility of PP fibers and to limit crack width. The key factor to obtain good mechanical properties for concrete is the interfacial adhesion between the concrete matrix and the fiber. To this regard, mechanical modifications as fibrillations and indentation increase the bonding with cement matrix. Surface treatments are able to modify the fiber/concrete interface by roughening the fiber surface, altering surface polarity. The modification of the surface chemistry and morphology of polymers increase the interfacial strength compared to untreated PP fibers.

Physical and Chemical Properties of Polypropylene Fiber

Polypropylene fibers are chemically inert and hence, any chemical that will not attack the concrete constituents will not have any effect on the fiber also. When more aggressive chemicals come in contact, the concrete will always deteriorate first before fibers.

Polypropylene is hydrophobic, meaning it does not absorb water. Polypropylene fibers are not expected to bond chemically in a concrete matrix, but bonding has been shown to occur by mechanical interaction. Polypropylene fibers are produced from homo polymer polypropylene resin. The melting point and elastic modulus, which are low relative to many other fiber types, may be limitations in certain processes such as autoclaving. Test data have been compiled for composites containing polypropylene fibers at volume percentages ranging from 0.1 to 10.0 percent. The material properties of these composites vary greatly and are affected by the fiber volume, fiber geometry, method of production and composition of the matrix. This is true for all synthetic fiber types.

Compressive strength—Compressive strengths have been reported for polypropylene FRC with fiber contents ranging from 0.1 to 2.0 percent by volume. There is no consensus in the reported results. In general, it can be stated that the addition of polypropylene fibers at different quantities has no effect on the compressive strength. The minor differences noticed are expected variation in experimental work. They can also be due to variations in the actual air contents of the hardened concrete and the differences in their unit weights. However, the addition of polypropylene fibers has a significant effect on the mode and mechanism of failure of concrete cylinders in a compression test. The fiber concrete fails in a more ductile mode. This is particularly true for higher strength fiber concretes.

The improvement in cube strength observed in commonly used mixes due to fibre addition is small.

The addition of polypropylene fibres increased the 28 day's compressive strength of the mix with the dosage of 1.5% by 16% due the confinement provided by fibres. The compressive strength at 1.5% dosage is slightly higher than strength at 2% dosage. Strength enhancement ranges from 8% to 16% for PFRC. [11]. Another study shows a reduction of compressive strength of concrete (with low, medium and high strength) can be explain by the presence of high number of fibres (almost 20500 polypropylene fibres in $1m^3$ fibre) create breakage of bond between cement and aggregates and this inclusion represents a large surface area of material breaking the cement and aggregates bonding to cause loss of compressive strength [10].

Flexural Strength (Modulus of Rupture)—By using fibrillated polypropylene fiber content of 0.1 percent by volume, there was a slight increase in flexural strength (0.7 to 2.6 percent), and at 0.2 to 0.3 percent by volume there was a slight decrease. Moreover the modulus of rupture determined at 7 and 28 days was slightly greater for fibrillated polypropylene FRC at fiber contents of 0.1 to 0.3 percent by volume in comparison to plain concrete. Another study reveals that the flexural strength of the mix with the dosage of 0.5% and 2% increased by 16% and 36% respectively [11].

Split Tensile Strength- In a study the split tensile strength varies from 7.48 MPa to 9.2 MPa for 28 days. Failure patterns of splitting tensile test indicate that specimens after first cracking do not separate unlike the concrete failure. Fibre bridging mechanism is responsible for enhanced ductile failure pattern. Strength enhancement in splitting tensile strength due to polypropylene fibre addition varies from 5% to 23% at 28 days [11]. Another study indicates that the addition of PP fiber has profitable influence on the residual splitting strength of concrete after elevated temperature (about 400^oC) at $0.9kg/m^3$ [12].

Impact Strength— A large number of test setups has been used to investigate the performance of polypropylene FRC under impact loading. Due to the variable nature of such testing and the need to apply specialized analytical techniques to each test setup, cross test comparisons cannot be made. There are reports of increased impact strength when using polypropylene fibers.

Fatigue Strength — One of the important attributes of FRC is the enhancement of fatigue strength compared to plain concrete. Failure strength is defined as the maximum flexural fatigue stress at which the beam can withstand two million cycles of non-reversed fatigue loading. In many applications, particularly in pavements and bridge deck overlays, full depth pavements and industrial floors, and offshore structures, flexural fatigue strength and endurance limit are important design parameters mainly because these structures are subjected to fatigue load cycles.

In a study at four different loading frequencies, 4 Hz, 1 Hz, 1/4 Hz and 1/16 Hz, the fatigue life (the number of cycles to failure) at lower frequencies is less than that at higher frequencies. However, the fibers do improve the fatigue behavior significantly under low loading frequencies. Such trend can be attributed to the effectiveness of the fibers in bridging cracks, and thus inhibiting the crack extension under cyclic loads [13].

Flexural Toughness and Post-Crack Behavior— Flexural toughness and post-crack behavior have been reportedfor fiber contents ranging from 0.1 to 2.0 percent byvolume. Factors such as fiber length, fiber material, fiber geometry, and bonding characteristics also influence the toughness and post-crack behavior.

The flexural strength of the mix with the dosage of 0.5% and 2% are increased by 16% and 36% respectively and the enhancement in flexural strength is achieved due to the improvement in mechanical bond between the cement paste and fibre. As amount of fibre increases in mix, widening of crack is reduced more effectively, and increased the flexural strength [11].

Abrasion Resistance-An accelerated test of abrasive erosion of concrete was performed allowing the high-velocity jet of water/sand mixture to act on the surface of the test specimens. The research results demonstrate that the abrasive resistance of concrete is in an inverse function of the water/cement factor; the concretes with higher compressive strength and higher bending strength have also the higher abrasive resistance; the micro-reinforced concretes demonstrate higher abrasive resistance in comparison to the benchmark concrete. The addition of polypropylene fibers has a positive effect and contributes to increase of concrete resistance to abrasive erosion by increasing the value up to 15.43% by conducting experiments at different water/cement ratios [14].

Shrinkage and Cracking—Rectangular and square slab specimens have been used to demonstrate the ability of SNFRC at low volume fiber additions to control cracking resulting from volume changes due to plastic and drying shrinkage. Several reports have shown that low denier fiber, and therefore high fiber count (number of fibers per unit volume), reduces the effects of restrained shrinkage cracking. There is presently no standardized procedure for quantifying the effects of polypropylene, or any other synthetic fiber, on plastic or drying shrinkage or on cracking that result from volume changes under restrained conditions. However, many procedures have been suggested and their results are being studied by the ASTM Subcommittee C09.42

Four commercially available polypropylene fibers were investigated at dosage rates varying from 0.1% to 0.3%. Results indicate that while polypropylene fibers in general are effective in controlling plastic shrinkage cracking in concrete, a finer fiber is more effective than a coarser one, and a longer fiber is more effective than a shorter one. Further, fiber fibrillations appear to be highly effective in controlling plastic shrinkage cracking [15].

Permeability Tests at Elevated Temperatures—It has been shown that polypropylene fiber reinforced concrete may not be compatible with certain autoclave curing techniques. Results of certain tests indicate that composites cured in an autoclave at 58 psi (0.4MPa), 284 F (140^{o}C) for 24 hours and then oven-dried at 241 F (116 C) for 24 hours suffer a considerable loss in ductility due to thermal oxidative degradation of the polypropylene fibers. It was later proven that the thermal degradation was caused by the high oven-drying temperature employed and that autoclave curing in conjunction with oven-drying could be used only if drying temperatures are greatly reduced.

Shear Strength-In a test, the polypropylene fibres added to the mix increased the shear strength of the mix with the dosage of 0.5% and 2% by 23% and 47% respectively. A fibre reduces the crack spacing, thus indicating a more redistribution of stresses. As the first crack forms, the fibres bridge it, transmitting stresses across the crack surface. In order to enforce further crack opening the applied load has to be increased, which leads to the formation of another crack [11].

Applications of SNFRC

Commercial use of SNFRC currently exists worldwide, primarily in applications of cast-in-place concrete (such as slabs-on-grade, pavements, and tunnel linings) and factory manufactured products (such as cladding panels, siding, shingles, and vaults). Currently, there are two different synthetic fiber volume contents used in applications today. They are 0.1 to 0.3 percent, which is referred to as low volume percentage, and 0.4 to 0.8 percent, which is referred to as high-volume percentage. There are also two different physical fiber forms. They are monofilament and fibers produced from fibrillated tape. Most synthetic fiber applications are at the 0.1 percent by volume level to control plastic shrinkage cracking.

CONCLUSIONS

- There is a wide range of fibers to use as the fiber reinforcement in concrete such as steel, polymeric, glass, carbon, aramid, natural, etc.
- Increment in modulus of elasticity and in compressive strength provided by steel fibers can be considered negligible for design purposes.
- With respect to fiber geometry, the fiber length vs. fiber diameter ratio (aspect ratio) is particularly important for mixing and for the performance.
- High fiber volume fraction and high yield strength of fiber is needed for high strength concrete to produce ductile failure.
- Pre cracking behavior in tension can be defined by neglecting the effect of steel fibers. Postcracking behavior can be different depending on the fiber length, content, shape and diameter.
- Application of steel fiber reinforcement in concrete may produce residual tension forces in the cracked cross section after cracking resulting tougher behavior.
- According to the results of compressive strength tests, the concrete compressive strength increased proportionately with the increase in volume ratios of propylene fibers.

REFERENCES

1. Dr. Muhaned A. Shallal,(September 2007)“*Strength And Elasticity Of Steel Fiber Reinforced Concrete At High Temperatures*” Journal Of Engineering And Development, Vol. 11, No. 2,
2. D. Tensing, L. S. Jayagopal,(August 2003) “*Steel Fiber Reinforced Concrete Beams Subjected To Combined Bending And Torsion - Skew Bending Approach*”, 28th Conference On Our World In Concrete & Structures, Singapore Pp.553-560
3. Likhil L. Raut, D. B. Kulkarni(Jun-2014)“*Torsional Strengthening Of Under Reinforced Concrete Beams Using Crimped Steelijret: International Journal Of Research In Engineering And Technology*” Volume: 03 Issue: 06, Pp.466-471
4. Hamdy K.Shehab Eldin, Heba A. Mohamed, Mahmoud Khater, Sayed Ahmed, (October 2014)“*Mechanical Properties Of Ultra-High Performance Fiber Reinforced Concrete*”,International Journal Of Engineering And Innovative Technology (IJEIT) Volume 4, Issue 4
5. A. Alavi Nia , M. Hedayatian , M. Nili , V. Afrough Sabet,(2012) “*An Experimental And Numerical Study On How Steel And Polypropylene Fibers Affect The Impact Resistance In Fiber-Reinforced Concrete*”, International Journal Of Impact Engineering 46 Pp.62-73
6. Girish M, A. Chandrashekar, A. U. Ravi Shankar,(October 2012), “*Flexural Fatigue Analysis Of Steel Fibre Reinforced Concrete*” International Journal Of Earth Sciences And EngineeringVol. 05, (01), Pp. 1352-1357
7. G. Murali, A. S. Santhi And G. Mohan Ganesh,(April 2014) “*Impact Resistance And Strength Reliability Of Fiber Reinforced Concrete Using Two Parameter Weibull Distribution*” ARPN Journal Of Engineering And

Applied Sciences Vol. 9, No. 4,

8. Vikrant S. Vairagade, Kavita S. Kene, May 2012"*Introduction To Steel Fiber Reinforced Concrete On Engineering Performance Of Concrete*", International Journal Of Scientific & Technology Research Volume 1, Issue 4, ,Pp.139 -141
9. Khatere Moftakhari Nazaripour, Ramin Khajav, Mohammad Esmaeel Yazdan Shenas, Abbas Akbarpour (2012)"*Effect Of Punching On Polypropylene Fiber TapesFor Reinforcing Concrete*",World Applied Sciences Journal 19 (1), Pp.26-30
10. Priti A. Patel, Dr. Atul K. Desai And Dr. Jatin Desai, January-March, 2012 "*Evaluation Of Engineering Properties For Polypropylene Fibre Reinforced Concrete International Journal Of Advanced Engineering Technology*" Vol.3 Issue IPp.42-45
11. Danying Gao, DongmingYan, XiangyuLi,(2012)"*Splitting strength of GGBFS concrete incorporating with steel fiber and polypropylene fiber after exposure to elevated temperatures*", Fire Safety Journal 54 Pp.67–73
12. Arthur Medeiros, Xiaoxin Zhang , Gonzalo Ruiz , Rena C. Yu , Marta de Souza Lima Velasco,(2015)"*Effect of the loading frequency on the compressive fatigue behavior of plain and fiber reinforced concrete*", International Journal of Fatigue 70 Pp.342–350
13. Zoran J. Grdic, Gordana A. Toplicic Curcic, Nenad S. Ristic, Iva M. Despotovic, (2012) "*Abrasion resistance of concrete micro-reinforced with polypropylene fibers*", Construction and Building Materials 27 Pp. 305–312
14. Nemkumar Banthia , Rishi Gupta,(2006) "*Influence of polypropylene fiber geometry on plastic shrinkage cracking in concrete*", Cement and Concrete Research 36 Pp.1263–1267
15. Josipa Bosnjak , Josko Ozbolt, Rolf Hahn, (2013) "*Permeability measurement on high strength concrete without and with polypropylene fibers at elevated temperatures using a new test setup*" Cement and Concrete Research 53 Pp.104–111