Comparative Analysis between Use of Polypropylene Fibers and Steel Fibers in Fiber Reinforced Concrete – A Review

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Abstract - *This research work explores the effect of fibers i.e. steel and polypropylene with nominal concrete. For this purpose, several past research studies have been investigated to evaluate the physical properties of concrete like compressive strength, flexural strength and split tensile strength respectively. During olden days, only plain concrete were used and after that reinforced of steel concrete was introduced. In this work, the effects of steel and polypropylene fibers were observed after 28 days of casting.*

This present study highlights the main points of benefits of use of steel fiber reinforced concrete and polypropylene fibers reinforced concrete over reinforced cement concrete and plain concrete. It also highlights that there are certain critical observations that have not be included in any study so far such as there is no properly defined the use of polypropylene and steel on minimum grades. Moreover, there is not so much work proceeded to determine the use of fibers to the concrete to produce high strength and durability to the concrete and the determination of the quantity of the synthetic fibers that are used in concrete as admixtures to the nominal cement concrete to produce a good and valid outcome.

Key Words: *fibers, steel fiber, polypropylene fiber, compressive strength, impact resistance*

1. INTRODUCTION

The most consumed man-made materials in construction field are concrete. It is the combination of cemetitious materials, water, aggregates and different kinds of admixtures in a particular ratio. Fresh concrete has a property of plasticity, which means before casting it behaves like plastic but as time goes, it gets hard like rock. These hardening properties happens due to chemical reactions between water and cement, it gets stronger with long time period.

Since the last century, the durability of RCC structures was primarily based upon the OPC round steel bars of mild steel, which was easily available in market. As time spent, these materials also changed with their physical appearance, properties and strength. For example, Pozzolana cement is used at the place of Ordinary cement and TMT bars are used at the place of mild steel bars.

For FRC, steel, glass fiber, synthetic and natural fibers can be used. For research purpose, here only steel and polypropylene is considered. Since, they are most common used type of fibers. The properties of concrete gets improve by mixing of fibers. The properties of concrete are durability, flexural strength, toughness, impact resistance and compressive strength. The physical improvement depends on the fiber type, size, configuration and fibers amount.

1.1 STEEL FIBER REINFORCED CONCRETE

The applications of SFRC are in tunnel lining, rock stabilization, mines, thin shell dome construction, dam construction, repairing of surface and fiber protective coatings. SFRC is a combination of concrete and steel fibers. It may be placed by using same equipments of mixing and placing used as for conventional concrete. Use of steel fiber in the reinforced concrete is limited to two percent by volume mix, improves flexural strength, toughness and ductility. If we talk about the use of steel fibers at higher temperature, some applications up to 815^{o}C for elements from one side only are available. Stainless Steel fibers may also be used for production of refractory concrete.

Steel fibers can:

- Improve ductility.
- Control crack widths very tightly, hence improve durability.
- Blends of the polymeric fibers and steel are generally used for construction projects to cumulate the merits of products, structural improvements imparted by the use of steel fibers and resistance against the plastic shrinkage and explosive spalling improvements imparted by the use of polymeric fibers.

1.2 POLYPROPYLENE FIBER REINFORCED CONCRETE

This concrete is also a great use in thin shell domes; surface repairing and as a component in overlaying systems. Polypropylene fiber reinforced concrete is significantly in use over last two decades.

Polypropylene fibers are not able to provide the primary or 1° reinforcement to the concrete work because of its low strength and low value modulus of elasticity compared to that of steel fibers. These are also used to provide a support to make a desired material behavior such as decrease in plastic behavior, shrinkage and improved toughness.

Polypropylene fibers are used in structural applications up to the maximum level since 1950 and recently in the pavement formation of roads. The availability of polypropylene is in the two forms that are film fibers and monofilament fibers. Production of monofilament fibers possible by the process by using the orifices in the spinner jet and then cut them in desired length. This film may be stretchable into tapes axially. These tapes are stretched over carefully over design roller pin systems which generates longitudinal cutting and these may be cut or twisted to produce the different types of fibrillated fibers. The fibrillated fiber contains a net-like formation structure. The tensile strength of fibers may be formed by the use of some molecular which is orientation obtained during extrusion process.

The Polypropylene has melting point of 165°C and can resist the temperatures up to about 100 $\pm$ 5°C for short time period before softening. This is inert material in nature and any chemical which may damage to polypropylene fibers, will be highly harmful to concrete mix. The polypropylene fibers are capable to resist the degradation by ultraviolet radiations or oxygen. However, in concrete after mixing with fibers, these remedies can be eliminated.

These fibers are hydro-phobic in nature which do not absorb the water. So, when mixed with concrete, it requires distributing over a long area in concrete mixture. Monofilament fibers, provides control over cracking which happens due to shrinkage and thermal stresses at beginning stages. The economic factor to use polypropylene fiber reinforced concrete (RC) involves increase in durability and also low maintenance of concrete.

Polypropylene fibers can:

- Improve impact resistance.
- Improve mix quality over long time.
- Improve resistance towards explosive spalling if fire ceases.
- Reduce requirement of steel reinforcement.
- Improve impact resistance.
- Improve ductility.
- Improve resistance towards plastic shrinkage during curing.
- Control crack widths very tightly, hence improve durability.
- Improve structural strengths.
- Improve freezing point where exposed concrete contain many cracks.

This fiber reinforcement has a great capacity of development in construction field. In future, these can make with traditional reinforcements to reduce the quantity of various materials or remove fully the reinforcements of steel etc. the main reason for not using the FRC is only that today there is not any design guidelines and FRC structures are costly too specially in case of building design. But for road design and all ground construction work gets improvement in their strength by using fiber reinforced concrete. There is no special man power required when we use the FRC because the cost of any construction increases maximum due to man power.

The fiber reinforcement can be used in different forms just like randomly distribution over the length of the structural member. The benefit of this addition is the increase in the value of shear resistance, which further controls crack. In addition to this, the fiber reinforced concrete can also be used in the form of tensile member to balance the steel reinforcement if oriented dimensionally.

The mechanical properties of polypropylene fiber and steel reinforced concrete have an influence by several factors: the material, shape of fibers, and amount and composition of fibers to the concrete. FRC cannot be mixable with any standard grade concrete mix. There will be a composition of FRC mix with change in volume of aggregates or sand. The minimum amount of fibers depends upon their length and thickness. Length of the fibers should be about three times of aggregates sizes. This will make suitable to fill the cracks located on the border of grains and avoids pulling out of fibers during the formation of these cracks. The strength of FRC parameters depends mainly on the aspect ratio of the fibers and on the dose of fibers. A higher value of aspect ratio or higher fiber content generally gives the better performance of this reinforced concrete.

2.0 BACKGROUND STUDY

The major aim is the production of concrete which does not only based on the concrete strength, it also have many other aspects too like minimum absorption, maximum durability. So, to meet the above expectations, we need to add fabric materials along with super plasticizer with having low water cement ratio. The use of fibers such as polypropylene fiber and steel fiber is many, which having good activities and are best materials for the production of concrete having high performance. Now a day, one of the great applications in various structural fields of the fiber reinforced concrete, that has been getting popularity because of its positive effect on various properties of concrete.

A variety of fiber materials other than steel, glass or other natural fibers have developed and in use by the construction industries for fiber reinforced concrete. These fibers are classified as synthetic fibers, SNFRC for classification. Synthetic fibers are the complex man-made fibers that results from R & D in the textile industries and petrochemical industries. Fiber types which can be used in the concrete based matrices such as aramid, carbon, acrylic, nylon, polythene, polyester and polypropylene. The fiber reinforced concrete is a mix which contains water, cement, aggregates and discontinuous fibers of various shape and sizes.

2.1 REVIEW ON PLAIN CONCRETE

According to **Bentur & Mindess (2006),** fibers are in use as reinforcement for quite some time now. Asbestos was first material widely used in the beginning of the 20th century. There are some man-made or synthetic fibers that may be produced from glass, steel, asbestos, synthetics and natural fibers like jute, sisal and cellulose. Before reinforcement of steel and materials which provides strength to resist the load, concrete always shows brittle nature having low tensile strength and very high compressive strength. Using the ordinary continuous reinforcing bars in concrete do not increases the load carrying capacity in the tensile and shear zones. But due to discontinuous or random distribution in mixing of concrete, they control the cracks. It leads to from the ductility of fiber reinforced concrete increases. Fiber reinforced concrete may also be used in thin and complex members where ordinary reinforced cannot fit.

Twentieth century interest in synthetic fibers as a component of construction materials was first reported in 1965. Synthetic monofilament fibers were used in blast resistant structures for the U.S. Army corps of Engineers Research Development Section. The fiber were of a size and shape similar to that which was then being tested using steel fibers (SFRC) and glass fibers (GFRC). That project also concluded that the addition of such types of fibers in mixing can be considered in small quantities. The quantity of synthetic fibers of about 0.5% by its volume leaded to production of such kind of composition with increase in both ductility and impact resistance.

During the late 1950s and and 1960s, the patent of steel fibers comprises of research on the random metallic fibers and closely-spaced wires. The investigation was done on the use of fiber as reinforcement by Association of Portland Cement (PCA) in 1950. The ethics on the use of composite materials was implemented towards the analysis of fiber reinforced concrete. The fibers addition was done to increase its toughness which imparts very higher value of the strength using first crack during testing. The other patent was defined for the bond strength and the use of the aspect ratios of fibers, granted in 1972. Many new steel fibers had been introduced so far. It was 1960s, in which the steel fibers were primarily introduced as reinforcement in the floor slabs, pavement roads, various refractory materials prestressed and pre-cast concrete products. The first commercial steel fiber reinforcement was used in 1971 at a truck weighing station near Ashland, Ohio, United States. The usefulness of steel fibers has been added by other new developments in the concrete field.

However, it was another fifteen years before large scale development activities began with synthetic fibers. Since the time early work, commercially available synthetic fibers in the 6 to 60 denier range have been shown to better distribute cracking, reduce crack size and improve other properties of concrete. The earlier applications of synthetic fibers first used in the late 1970s had denier 300 to 400 range and low aspect ratios. The finer denier fibers were used through 1980s. Applications with finer denier fibers, that is, relatively small diameter and high aspect ratio fiber began with fiber volume percentages of approximately one-fifth of that which had been previously used with coarser fibers. These low volume applications appeared at 0.1 to 0.3 percent by volume. However, even at these low volume additions, the fiber count and specific surface are comparable with values found with higher volume percentages of coarser size fibers.

According to **Naaman(2003),** fibers that are used in composite concrete, may be classified on the basis of the following parameters:-

1. Origin of fibers:
   Based on the origin of fibers, the fibers are classified as: natural organic fibers (bamboo, cellulose, sisal, jute etc.), natural inorganic fibers (rock, asbestos, wool etc.) and man-made/synthetic fibers (glass, steel, etc.)
2. Physical/ Chemical Properties:
   Fibers are classified based on their physical / chemical properties like density, flammability, reactivity or non-reactivity with matrix, surface roughness, etc.
3. Mechanical Properties:
   Fibers are characterized based on their mechanical properties e.g. tensile strength, specific gravity, elastic modulus, elongation to failure, stiffness, ductility, etc.
4. Shape and Size:
   Fibers are Classification on the basis of their geometric properties like their shape, diameter, surface deformation; length etc. fibers may be in the shape of square, circular, triangular, flat, rectangular, polygonal or any geometrical polygonal shape.

Today, straight fibers are very rarely used due to their week bonding with cement matrices. It is however, quite common to use brass-coated straight fibers containing concrete mix of high strength since the bond obtained is relatively strong.

2.2 REVIEWS ON STEEL FIBER CONCRETE

S. O. Santos, et al., (2009) considered the effect of high temperatures on fiber reinforced concrete. It might be concluded that the spalling of concrete can be prevented by the intrusion of the polypropylene fibers to the concrete compositions. The specimens containing polypropylene and steel fibers performed better as compared to those with glass fibers. A small detachment of surface concrete was observed in the glass fiber specimens. A more explosive rupture occurred in specimens without fibers and in those with glass fibers. The benefit of steel fibers in controlling cracking was confirmed. The incorporation of shorter steel fibers and a small amount of polypropylene fibers conferred greater strength on the concrete specimens.

Rashid Hameed et al. (2010) made conclusions that On the basis of three-point bending tests performed on notched prismatic specimens constructed with mono- and hybrid fiber-reinforced concretes containing two different fibers used in this study, the following conclusions can be drawn:

1. Adhering amorphous stainless metallic fiber, due to its high-bonding with the matrix, is very effective in controlling the micro-cracking mechanism, which results in an improved behavior in terms of smaller crack openings at peak resistance. On the other hand, high-modulus hook ended carbon steel fiber is effective in controlling macro-cracks over a wide range and at high stress level. As a result, the toughness of the material is significantly increased. It should also be noted that these fibers also have very different properties in terms of fiber geometry and tensile strength. These variables are also effective on flexural performance of beam samples at different loading levels.
2. The use of metallic fibers in hybrid form investigated in this study has resulted in improve behavior of the composite regarding cracking control, strength and toughness. For such structural application as in water retaining structures, hybrid combination of these fibers could be promising.
3. The response of the hybrid mixture containing both fibers at a total quantity of 80 kg/m3 (40 kg/m3 of each fiber) in terms of modulus of rupture, residual flexural tensile strength and flexural toughness has shown that there exists a positive synergetic effect between the metallic fibers used in this study.

According to J. Turmo, et al., (2013) studied that incorporation of fibers to the mixes increases the material toughness both tension or compression, as indicated by the toughness indexes of the JSCE and ASTM standards. The material toughness increase results in higher shear strength of concrete and better deformability, i.e. the significant higher deflection at maximum load is observed for FRC beams as compared to the plain concrete specimens.

In SFRC beams, the increment of the maximum load by about 20% with reference to the normal plain concrete beams was observed, but with twice the value of deflection at the value of maximum load. Though the implementation of polypropylene fibers could not affect the ultimate load value of the composite material, the shear load-carrying capacity of polypropylene FRC beams equaled that of the SFRC for high deflection values, i.e. beyond 5 mm. The beams having 1% reinforcement by volume of fibers has always lower/lesser response than the beams containing the same concentration of steel in the form of stirrups. The applied design formulations are found to be adequate for estimating the ultimate shear carrying capacity of rectangular cross-section beams, being sufficiently robust even when all the relevant material data may not be available.

Md Azree Othuman Mydin (2013) summarizes three prime properties of steel fiber induced FRC which are mechanical, workability and durability properties. The research study on the use of steel fibers might be promising in the form steel FRC is utilized for sustainability and the long-lasting concrete structures, and also the addition of steel fiber into concrete creates low workable or inadequate workability to the concrete.

Jaroslav Beno & Matouš Hilar (2013) said about the use of steel as fibers in tunnel linings. They said that SFRC is increasingly used as a material for precast segmental tunnel linings excavated by tunneling machines. In some cases SFRC is supplemented by steel bar reinforcement, while in other cases SFRC is used without steel cages. SFRC segments may leads to many benefits during tunnel construction and operation. The advantages of SFRC segments can be mentioned as possible price reduction (less steel is used, and there is faster production); easier production (less manual work, no problems with the shape and the position of cages); simpler placing of tunnel equipment (no risk of drilling to steel bars); reduced risk of segment damage during transportation and installation (the edges are reinforced by fibers); longer durability (no problems with corrosion).

G. Velayutham and C.B. Cheah (2014) concluded It has been found that steel fiber high strength concrete (SFHSC) is not suitable for hygro-thermal curing compared to normal strength concrete.

K. Abdelrahman and R. El-Hacha (2014) told about the ductility and cost effectiveness of the columns in which concrete is strengthened with the use of SFRP and CFRP Sheets. The ductility and cost effectiveness study was performed on the use of concrete columns which are wrapped with SFRP and CFRP sheets tested in laboratory under the application of uni-axial compression loading. The analytical procedure was also introduced to estimate the cost effective parameters of the various concrete columns which are wrapped with the SFRP sheets only. There are some of the parameters such as the strength of concrete, the various numbers of layers; size and slenderness of the SFRP that are wrapped around concrete columns were investigated analytically. Based upon this study, the ductility and cost effective investigations concluded that the columns that were wrapped with SFRP sheets were superior to the columns that were wrapped with CFRP. The conclusions drawn from the study pointed out the importance and considerations of cost effectiveness during calculation of the efficiency of FRP sheets to confine the use of concrete columns. The ductility and strength improvement by the fiber orientation of the FRP sheets may be tremendous. But, when the cost criteria are taken into account, the complete advantageous value of this strengthening enhancing system can be ignored. Hence, the optimum design for FRP strengthening imparting configurations may be attained by the use of the analytical approach to the cost and ductility effectiveness. Comparison between the cost effectiveness parameters determined experimentally with those analytically predicted showed good agreement. The proposed method provides a new tool for designers to predict the parameters of cost effectiveness of SFRP wrapped columns, resulting into the designs related to the efficient strengthening. However, the further investigation is necessary to develop the analytical process to estimate the ductile effectiveness of SFRP wrapped columns. Despite having the very wide database related to the FRP wrapped columns; there is always deficiency of accurate and reliable models to ascertain the axial strain produced to the SFRP confined columns. The proposal of the critical model is considered to be the first step to understand the effectiveness of ductility and its behavior of SFRP wrapped columns.

Y. Zheng et al. (2018) indicated that the production C-50 steel FRC and C60 steel was done by the use of some traditional mixing methods and the vibratory mixing methods, respectively. The various destructive tests such as cube test, cylinder test, splitting tensile test, flexural strength test, direct tensile test and bending test on the specimens were conducted. The effects of use of reinforcement on mechanical properties were examined experimentally by the comparison of the conclusions drawn by traditional mixing methods and methods of vibratory mixing. The conclusion indicates that the vibratory mixing may improve steel fibers distribution to the concrete and may enhance the density of steel FRC, and therefore, the improvement to mechanical and physical properties of steel FRC compared to the traditional mixing methods was also noted.

2.3 REVIEWS ON POLYPROPYLENE FIBER CONCRETE

V.M. Sounthararajan et al. (2013) showed that unconditional failure of specimens of plain cement concrete was limited to the volumetric bulging. The reasons that were primarily identified were found to be the gradual release & relief of the energy during the fracture of the specimen by the presence of Polypropylene fibers.

K.Srinivasa Rao, et al., (2013) gave their verdict about the effects of temperature on the highly performed FRC. The increment to the compressive strength of concrete along with its tensile strength had also been observed for the standard concrete and FRC when exposed to a 500°C temperature. However, the splitting tensile strength of standard PCC and fiber FRC was observed to be same in the temperature range between 500°-800°C. For the same temperature range i.e., 500°C-800°C, the flexural strength of standard PCC and FRC were also observed to be same. Moreover, both the types of concrete, a gradual fall to the compressive strength were also noted down beyod 500°C. The FRC was observed to contain higher value of the compressive strength, splitting tensile strength, direct tensile strength and flexural tensile strength when compared to the standard concrete specimens at all range of temperatures. About 6 – 10 % of difference between the compressive strength of FRC and PCC was also noted down. About 0 – 12 % of difference between the split tensile strength of FRC and PCC was also noted down. About 0 – 20 % of difference between the flexural tensile strength of FRC and PCC was also noted down.

Vikram J. Jayakumar and Sivakumar Anandan (2014) mentioned that the addition of fibers that consists of some amount of polypropylene and steel indicated some considerable improvements in the mechanical strength along with the rise of properties of strain hardening of slag based concrete. For hybrid short steel-Polypropylene fiber combinations in the concrete composite, the residual strength and residual toughness of the composite were found to be maximum.

According to **Amit Rai & Dr. Y.P Joshi (2014),** Plain concrete undergoes brittle failure if the corresponding deflection with respect to the ultimate flexural strength gets exceeded beyond its limit. However, the FRC continues to sustain the loads even at the various values of deflections which are in excess to the deflection caused by the fracture of the plain cement concrete.

Saadun et al. (2016) said that the increase in the values of the parameters due to the proper mixing of Polypropylene fibers with concrete could be implemented to other structures such as slabs, beams, columns, and walls bearing load and also Polypropylene fiber could increase the ultimate value of the dynamic compressive strength of the fibre reinforced concrete.

Accoring to the **Bosnjak et al. (2019),** Micro polypropylene fibres (PP) are mixed with the concrete to increase its corresponding performance under the action of thermal loads like in case of fire which prevents the explosive spalling of concrete. The specimens were tested in laboratory corresponding to the ambient environmental conditions along with the exposure to the pre-defined temperature and cooling down to the room temperature. For all the considered types of concrete mixtures, the thermal degradation of different properties of concrete like splitting tensile strength, direct tensile strength, compressive strength, flexural tensile strength, fractured energy and the static modulus of elasticity were thoroughly investigated.

3.0 CONCLUSIONS

In this present study with the stipulated time and laboratory set up afford has been taken to enlighten the use of so called fiber reinforced concrete in accordance to their proficiency. It was concluded that:

- With the use of super-plasticizer, it is possible to get a mix with low water to cement ratio to get the desired strength.
- In case of Ordinary Portland Cement with the use of steel fiber, the compressive strengths of concrete at various fiber content are observed to be maximum.

- When polypropylene fiber mixed with nominal concrete, the compressive strength is observed to be lesser than the concrete having steel fibre.
- Higher is the length of fibers, more will be the compressive strengths of such concrete.
- When there is no mixing of fibers, no changes will come in any strength.
- Maximum flexural strength is coming in polypropylene, it means for casting of beams is helpful by using the polypropylene fibers.
- The orientations of fibers also giving a good result for polypropylene fibers. Because as compared to steel, it is more flexible and able to resist the uniformly distributed loads.
- Polypropylene fibers will be more effective in tensile zone because they have property of plasticity.

3.1 CRITICAL OBSERVATIONS FROM THE LITERATURE REVIEW

- Not properly defined the use of polypropylene and steel on minimum grades.
- There is not so much work proceeded to determine the use of fibers to the concrete to produce high strength and durability to the concrete.
- Determination of the quantity of the synthetic fibers that are used in concrete as admixtures to the nominal cement concrete to produce a good and valid outcome.

REFERENCES

1. Amit Rana, "some studies on steel fiber reinforced concrete" International Journal of Emerging Technology & Advanced Engineering, Vol. 3, Issue 1, Jan-2013
2. A.L. Ardeshana, Dr. Atul K. Desai, "durability of fiber reinforced concrete of marine structures" International Journal of Engineering, Research and Applied Sciences, Vol. 2, Issue 4, pp 215-219, July-August 2015
3. Amir M. Alami, Morteza Aboutalebi, "Mechanical properties of fiber reinforced concrete- A comparative experimental study" International Jounral of Civil, Environmental, Structural, Construction & Architectural Engineering, Vol. 7, No. 9, pp 310-216, 2013
4. A.M. Vasumathi, K. Rajkumar & G.Ganesh Prabhu, "Compressive behavior of RC column with fiber reinforced concrete confined by CFRP sheets." Volume 2014, Article ID- 601915
5. Amit Rai & Dr. Y.P. Joshi, "Applications & Properties of fiber reinforced concrete" International Journal of Engineering Research & Applications, Vol. 4, Issue 5 (version 1), pp 123-131, 2014
6. A. Ravichandran, K. Suguma & P.N. Raghunath, "Strength modeling of high strength concrete with hybrid fiber reinforcement" American Journal of applied sciences, 6(2), 219-223, 2009
7. A. Saadun, Azrul A. Mutalib, R. Hamid & Mohd. H. Mussa, "behavior of polypropylene fiber reinforced concrete under dynamic impact load" Journal of Engineering, Science & Technology, Vol. 11, No. 5 (2016), 684-693
8. Dr. Abhijit P. Wadekar, Prof. Rahul D. Pandit, "comparative evaluation for experimental and analytical mode for tensile behavior of high strength fiber reinforced concrete. American Journal of Engineering & Research, Vol. 03, Issue 11, pp 198-203, 2014
9. Deepa A Sinha, "Strength characteristics of hybrid fiber reinforced concrete" Volume 1, Issue 5, oct-2012, pp 71-73
10. Jaroslov Beno & Matuous Hilar, "Steel fiber reinforced concrete for tunnel lining- verification by extensive laboratory testing & numerical modeling, Acta Polytechnica, Vol. 53 No. 4, 329-337, 2013
11. J. Turmo, N. Banthia, R. Gettu Y, B. Barrayan "Study of the shear behavior of fiber reinforced concrete beams" Materials of construction, Vol. 58, 292, 5-13, 2013
12. K. Anbuvelan, "experimental studies on impact characterstics of steel fiber reinforced concrete." Research Journal of Applied Sciences, Engineering & Technology, 8(14):1625-1629, 2014
13. Khaled Abdelrahman & Raafat El-Hacha, "Cost and ductility effectiveness of concrete columns strengthened with CRFP and SRFP sheets" by www.mdpi.com/journal/polymers, 2014, 6, 1381-1402
14. K. Srinivasa Rao, S. Rakesh Kumar & A. Laxmi Narayana, "comparision of performance of standard concrete & fiber reinforced standard concrete exposed to elevated temperatures" American Journal of Engineering Research, Vol. 02,Issue-03, pp 20-26
15. J. Bosnjak, A. Sharma & K. Grauf, "Mechanical Properties of Concrete with Steel and Polypropylene Fibres at Elevated Temperatures" Fibres-2019 MDPI, Vol, 01, pp 01-13
16. Maniram Kumar & Er. Anush Khadewal, "strength of evaluation of steel-nylon hybrid fiber reinforced concrete" International journal of engineering Research & applications, Issue 7(version 6) pp 32-36, July 2014
17. Md. Azree Othuman Mydin, " Engineering performance of high strength concrete containing steel fiber reinforcement" ANALELE UNIVERSITATII, 'EFTIMIE MURGU' RESITA, ANULL XX, NR-31, 2013
18. Milind V. Mohod, "Performance of steel fiber reinforced concrete" International Journal of Engineering & Science, Vol. 1, Issue 12, pp 01-04, Dec-2012
19. N. Pannirselvam, P.N. Raghunath & K. Suguna, "strength of reinforced concrete beam with externally bonded fiber reinforced polymer reinforcement." American Journal of applied sciences, 1(3), 192-199, 2008
20. Piero Colajanni, Marinella Fosseti, Maurizia Papia, " An analytical step by step procedure to derive the flexural response of RC sections in compression" Hindawi Publishing Corporation, Advances in civil engineering, Volume 2013, Article ID-275657
21. Rashid Hameed, Anaclet Turatsinze, Fraderic Duprat & Alain Sellier "Study of the flexural properties of metallic

hybrid fiber reinforced concrete, International Journel of Science and Technology, Vol. 4(02), 169-184, 2010

22. S.O. Santos, J.P.C. Rodrigues, R. Totedo, R.V. Velasco, “Compressive behavior of high temperatures of fiber reinforced concretes. Acta Polytechnica, Vol. 49 No. 1, 2009
23. S. Eswari, P.N. Raghunath, K. Suguna, “Ductility performance of hybrid fiber reinforced concrete” American Journal of applied sciences, 5(9), 1257-1262, 2008
24. Vikram Jothi, Jayakumar & Sivakumar Anandam, “composite strain hardening properties of high performance hybrid fiber reinforced concrete.” Volume 2014, Article ID-363649.
25. Y. Zheng, X.Wu, et al., “Mechanical Properties of Steel Fiber-Reinforced Concrete by Vibratory Mixing Technology”, Volume 2018, Article ID 9025715.