

Performance Evaluation of Steel–Polypropylene Hybrid Fiber Reinforced Concrete

Sureddi sindhura^a, C. Venkata Siva Rama Prasad^b

^aM.Tech Student, Department of Civil Engineering, Malla Reddy Engineering College, Secunderabad-500100, Telangana, India.

^bAssociate Professor, Department of Civil Engineering, Malla Reddy Engineering College, Secunderabad-500100, Telangana, India.

^aCorresponding author: sureddi.chowdary90@gmail.com

Abstract: This paper is an experimental study on the effect of steel fibers as such, polypropylene fibers as such and when combined in hybrids on fresh and hardened properties of M40 grade concrete. The main aim is to test the workability, compressive strength, split tensile strength and flexural behaviour of concrete to the different types of fibres and volume fractions of the fibres. An equal mixture of crimped steel fibers and polypropylene fibers were used together and separately to prepare concrete mixtures at different proportions. The fresh concrete properties were also evaluated using slump and compaction factor tests, the results of which showed that workability decreased with fiber content especially the steel fiber-dominant mixes. The hardened concrete properties were tested at the following curing times namely, 7 days, 14 days and 28 days. The experimental evidence showed that there were significant differences in compressive and split tensile strengths of all fiber-reinforced mixes in comparison to conventional concrete with hybrid fiber-reinforced concrete showing the highest increase in strength. Flexural tests on beam specimens have shown improved resistance to cracks, increased ultimate load capacity and improved deflection control particularly in fiber hybrids. The interaction between steel and polypropylene fibers was found to enhance the distribution of stresses, the introduction of cracks, and ductility. On the whole, the results prove that a hybrid type of fiber reinforcement has a substantial positive effect on the mechanical performance and structural behavior of concrete and can be used in the context of better durability, strength, and crack resistance.

Keywords: Hybrid Fiber Reinforced Concrete, Steel Fibers, Polypropylene Fibers, Compressive Strength, Flexural Performance, Workability.

I INTRODUCTION

Concrete is a building construction material that happens to be highly valued in most cases due to its compressive strength, longevity in addition to its usage in structural construction. Nevertheless, traditional concrete is not tension resistant and it is of brittle nature when flexed and loaded in tension, which leads to formation of cracks and unforeseen

breakdown. These limitations demand a certain adaptation of the concrete composition in regards to the mechanical behaviour, the crack resistance and the post-cracking behaviour. Various approaches have been embraced over time to enhance the overall performance of concrete particularly in application of structural elements that are subjected to dynamic and flexural loads and they include: chemical admixtures, replacement of minerals, and fiber reinforcement.

FRC has emerged as an alternative that can be used to solve the failure of plain concrete. The discrete fibers that are incorporated in the concrete matrix help in controlling the crack propagation, tensile strength as well as the ability to generate energy. Fibers are crack arresters they interlock micro-cracks and retard their development to macro-cracks. Steel, polypropylene, glass, carbon and basalt fibers are the most commonly used with various mechanical and durability benefits. The importance of mix optimization is that the ability of FRC to perform is highly dependent on the type of fiber, geometry, aspect ratio and the volume fraction.

The application of steel fibres is not new in improving the strength and ductility of the concrete. Steel fibres possess high modulus elasticity that provides high compressive strength, split tensile strength and flexural behaviour as a result of good transfer of tear at cracks. They increase the strength after cracking and reduce sudden brittle fracture especially in flexural members such as beams and slabs. However, this leads to reduced proportions of workability in increased percentages of steel fibers, difficulties of mixing and compaction that, in any case, adversely affects the quality of concrete when not controlled.

Polypropylene fibers on the other hand, are artificial fibers which have a light weight, chemical resistance as well as high elongation capacity. The fibers are employed to control the cracks in the plastic shrinkage and toughness and impact resistance enhancement. Although polypropylene fibers do not contribute much in compressive strength, they contribute much in tensile and flexural performance in terms of optimizing distribution of cracks and dissipation of energy. They are both corrosive and chemical resistant; therefore, they can be deployed in places that are prone to unfavorable conditions. Mechanical performance of polypropylene fibers would however not suffice as a structural application which requires high load bearing capacity.

In the past few years, a significant focus has been given to the hybrid fiber reinforced concrete (HFRC) in order to bring the best out of different types of fiber. During hybridization, two or more fibers with different mechanical properties are employed with the aim of complementing the behavior of concrete. Polypropylene and steel fiber combination enhances

strength and ductile properties that results in high crack-resistance, resistance to loading and deformation properties. The goal of the present study is to compare both fresh and hardened properties of the concrete strengthened by the steel fiber and the polypropylene fiber along with the combination of them with the view of establishing the best fiber mixtures that might result in a higher order of mechanical and structural performance.

II SURVEY OF RESEARCH

The study by Shende et al. (2016) investigated the mechanical behavior of the hybrid fiber reinforced concrete by using steel and polypropylene fibers in various ratios. Their research was aiming at compressive strength, split tensile strength and flexural behavior of concrete beams. Results of the experiment showed that hybrid fiber blends were much superior in tensile and flexural response than mono-fiber blends. The steel fibers were added to the load carrying capacity and bridging of cracks whereas the polypropylene fibers were added to the ductility and managing of micro-cracks. Another implication of the research was that workability decreased with the high percentage of fiber content in the mix, which underscores the need to optimize mix design. The authors established that, hybrid fiber reinforcement gives a synergistic effect which enhances the absorption of energy and the resistance of crack and hence its use in structural elements having dynamic and flexural forces.

Vikrant et al. (2012) performed an experimental research on the steel and polypropylene reinforced concrete made of M25 and M30 grade. Their study revealed that steel fibers contributed largely to compressive and flexural strength whereas polypropylene fibers contributed to tensile conduct and crack resistance. Hybrid fiber mixes performed better because their stress transfer mechanisms were better in the concrete mix. These authors emphasized that fiber reinforcement slowed down the initiation of cracks and minimized crack width during loading. The mechanical benefits were greater than the setback despite increased fiber content resulting in reduced workability. The research made a conclusion that hybrid fiber reinforced concrete is a good alternative that can be used to enhance structural performance of beams, slabs and pavements.

Eduardo Campello et al. (2014) discussed how randomly distributed polypropylene and steel fibers affect the cement mortar properties. They found that steel fibers enhanced the modulus of elasticity and the capacity of energy absorption capacity as it is very stiff. Polypropylene fibers increased post-cracking behavior and ductility by a uniform distribution of stresses. The research stated that hybrid fiber reinforcement had great effect in enhancing fracture toughness and crack propagation resistance. Bending tests gave positive results through experimental evidence that supported higher load-bearing capacity in hybrids. The

researchers came to the conclusion that the combination of fibers with varied elastic features leads to enhanced performance and durability of the structure especially in structures that need to offer resistance to cracking and impact loads.

The article by Han Ayliea et al. (2015) explores flexural performance of confined concrete beams of steel fiber. Their experimental findings indicated that the steel fibers had a minimal influence on ultimate moment capacity but had a tremendous effect on cracking load and energy absorption. Fiber was found to enhance post-cracking ductility and postpone failure. The paper focused on the fact that steel fibers did not increase strength, but strengthened control of cracks. As it was noted, fiber-reinforced beams had a gradual failure behavior as opposed to the conventional brittle failure. The authors have concluded that, steel fibers are specifically useful in enhancing serviceability performance and crack resistance in flexural members.

Rajarajeshwari et al. (2012) experimented on mono and hybrid fiber reinforced concrete with steel fibers and polypropylene fibers. They found that hybrid fiber concrete was able to gain 17 percent compressive strength, and both split tensile and flexural strength increased more than 50 percent over conventional concrete. The composite fiber system also improved the resistance of crack and toughness because of synergistic presence of high strength steel fibers and ductile polypropylene fibers. The paper has noted that hybridization is an effective method of leveraging the strengths of both types of fibers resulting in an enhanced overall performance. The authors suggested the use of hybrid fiber concrete in structural works with a higher level of durability and crack containment.

Surinder Pal Singh et al. (2011) concentrated on the fatigue behavior of the hybrid fiber reinforced concrete when subjected to repeated flexural loading. Various proportions of steel and poly propylene fibers were selected to compare the fatigue life and crack propagation properties. It was revealed that the hybrid fiber concrete had a high fatigue resistance, as compared to mono-fiber mixes. Fibers of steel and polypropylene enhanced the load resistance and the crack distribution and ductility respectively. The authors were able to come up with fatigue life prediction models basing on experimental findings. Their research established that hybrid fiber reinforced concrete can be used in pavements and bridges that have cyclic and dynamic loads.

Parveen (2013) examined polypropylene fibers coupled with steel fibers on mechanical properties of concrete. The experiment discovered that polypropylene fibers caused minimum effect to compressive strength, whereas tensile and flexural performance were significantly enhanced. In hybrid form with steel fibers, massive enhancement of the crack resistance,

toughness, and energy absorption was achieved. The hybrid mixes exhibited improved post-cracking, as well as, reduced crack width in comparison to the steel fiber concrete. The author came to a conclusion that hybrid fiber reinforcement offers a moderate increase in strength and ductile, so it is used in structural and durability-oriented applications.

III METHODOLOGY OF RESEARCH

It was an experimental work, which sought to establish the impact of the steel fibers, the polypropylene fibers on fresh and hardened properties of concrete and their composite. The material that was utilized to become M40 grade concrete according to the requirements of the IS 4031 standard was ordinary Portland cement (OPC) 53 grade. Since the fine aggregate was natural river sand of specific gravity 2.62 and fineness modulus 2.58, it was utilized. The granite coarse aggregate that was crushed and had maximum size of 20 mm with specific gravity of 2.75 was used. Clean potable water was used as the mixing and curing agent. Workability was increased by adding Superplasticizer.

The concrete mix consisted of crimped steel fibers, polypropylene fibers in varying volume ratios separately and in combination ratios. Fresh concrete properties were measured by use of slump test and compaction factor test. Specimens were used in the forms of concrete (like cubes 150 x 150 x 150 mm), cyclone (150 x 300 mm), and beams (150 x 150 x 1200 mm). All the specimens were cured in 7, 14 and 28 days.

Tests done as required by IS 516:1959 in order to determine hardened concrete were compressive strength test on cubes, split tensile strength test on cylinders, flexural strength test on beam specimen. Findings were compared to establish the effectiveness of fiber reinforcement.

IV RESULTS EXPLANATION

Compaction factor and slump tests were used to control the workability of concrete which they assessed through steel fiber, polypropylene fiber, and hybrid fiber mixes. The control mix had a compaction factor of 0.70 with a slump of 1.8 cm which was moderate. The knowledge of steel fiber mixes was observed to have diminished workability with increase in fiber content with compaction factors decreasing to as low as 0.62 at higher percentages of steel fibers. Conversely, polypropylene fiber blends showed a higher workability with the highest compaction factor of 0.90. The behavior of hybrid fiber mixes was also found to be different with the balanced steel-polypropylene mixes having better workability compared to pure steel mixes. These findings have shown that the presence of polypropylene fibers enhances fresh concrete performance, whereas too much steel fiber negatively impacts on the workability.

The outcomes of compressive strength showed that there was a great improvement when adding fibers at all ages of curing. The control concrete of 28 days had a compressive strength of 32.44 N/mm². There was a moderate increase in steel fiber concrete to at least 35.42 N/mm². Concrete made using polypropylene fibers had a maximum strength of 34.66 N / mm². Nonetheless, hybrid fiber concrete showed the best performance, and compressive strengths were between 39.32 and 45.64 N/mm². The HYC5 hybrid mix reported the highest strength of 45.64 N/mm² which is impressive as it has been greatly improved through the synergistic effect of steel and polypropylene fibers.

The results of the split tensile strength were also following a similar pattern. The tensile strength of the control mix was 4.60 N/mm² at 28 days. The highest tensile strength was achieved to 5.10 N/mm² with steel fiber mix and 4.93 N/mm² with polypropylene fiber mix. The tensile performance was best in Hybrid fiber mixes with a value of up to 6.31 N/mm². This is a very high increase over conventional concrete. It is explained by the fact that effective bridging of cracks by steel fibers and high ductility by polypropylene fibers contribute to the better tensile strength and delay the crack propagation.

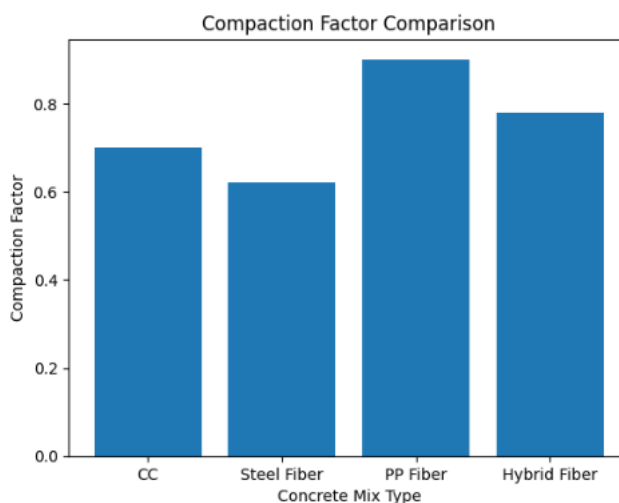


Fig.1. Compaction factor results

The results of flexural tests showed significant changes in the capacity of the beam to carry the loads and crack resistance of the fiber-reinforced concrete beams. The ultimate load on control beams was 30 kN, and had a very small ability to deflect. The ultimate loads of steel fiber beams were between 45 and 49 kN whereas polypropylene fiber beams reached 51 kN. The performance of hybrid fiber beams was more superior with the final loads varying between 43-52 kN. One of the best performances was demonstrated by the hybrid beam HYB5, which bore 50 kN with the deflection measure at the minimum of 2.19 mm, which is indicative of increased stiffness and control of the crack.

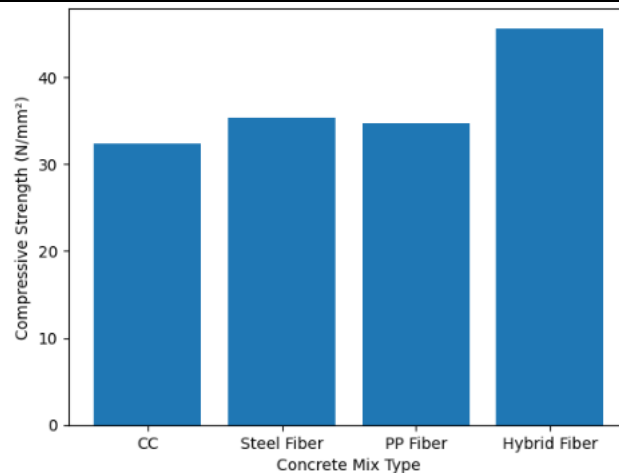


Fig.2. 28-Day Compressive Strength Comparison

All in all, the findings of the experiment prove that hybrid fiber reinforced concrete is superior to mono-fiber and conventional concrete regarding strength, ductility, and structural performance. Although the steel fibers greatly increase the load resistance and the polypropylene fibers increase the control of cracks and workability, the combination of these two types of fibers yields optimal performance. These findings prove that hybrid fiber concrete has a great application in structural building requiring enhanced durability, resistance to crack, and carry-out ability as long as the workability is well managed during mix designing.

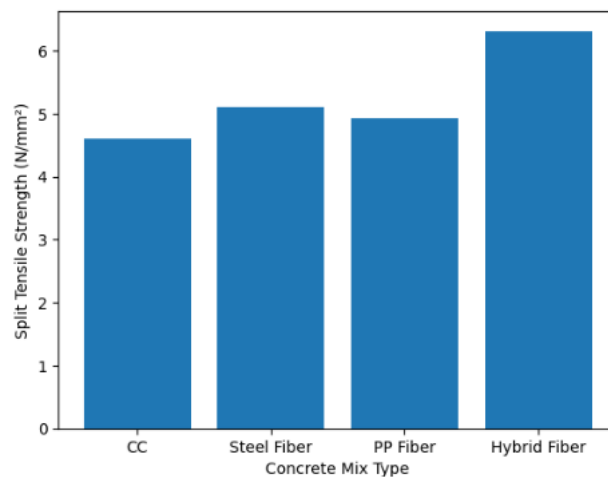


Fig.3. 28-Day Split Tensile Strength Comparison

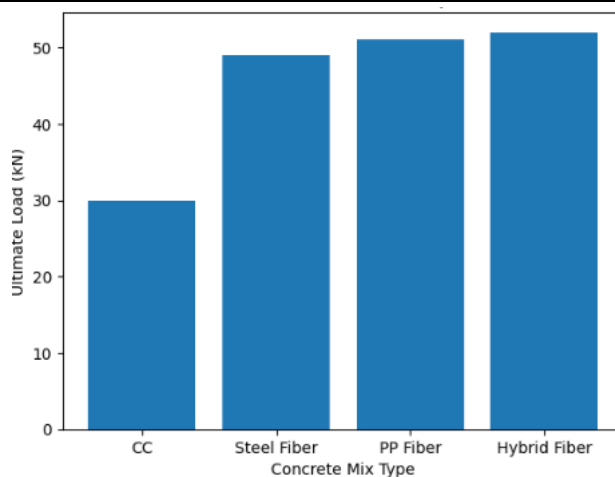


Fig.4. Flexural Ultimate Load Comparison

CONCLUSION

This experimental study is a clear indication that the mechanical behavior and structural behavior of concrete are increased tremendously by the addition of fibers. These findings show that the inclusion of both, steel and polypropylene fibers in individual capacities enhances the properties of strength and crack resistance but their combination gives higher overall performance. The hybrid fiber reinforced concrete showed significant increments in compressive strength, split tensile strength and flexural capacity in comparison to the conventional and mono fiber concrete mixes. This synergistic interplay of steel fibers that help in load transfer and crack bridging with polypropylene fibers that help in improving ductility and crack distribution led to delayed crack initiation and improved post-cracking behavior. Even though the workability was decreased due to the incorporation of fibers especially at the higher level of steel fiber content, the incorporation of superplasticizers was used to effectively counter the shortcoming. Beam specimen flexural tests revealed an enhanced capacity to carry loads, deflection, and control of cracks in fiber-reinforced beam, and a combination with hybrid mixes exhibited the most positive response. In general, the results confirm that hybrid fiber reinforced concrete is a safe and effective material that can be used structurally in the case of greater durability, strength, and serviceability. This requires adequate optimization of fiber proportions and mixes to maximize the advantages of fiber reinforcement in the construction of concrete.

REFERENCES

- [1] Abdul Ghaffar (2014), "Steel fibre reinforced concrete," International Journal of Engineering Trends and Technology (IJETT), Vol. 9, No. 15, pp. 791–795.
- [2] Adebar, P., Mindess, S., Pierre, D. S., and Olund, B. (1997), "Shear tests of fiber concrete beams without stirrups," ACI Structural Journal, Vol. 94, No. 1, pp. 68–76.

- [3] Anbuvelan, K., Khadar, M. H., Lakshmiathy, M., and Sathyannarayanan, K. S. (2007), “Studies on properties of concretes containing polypropylene, steel and reengineered plastic shred fibre,” *Indian Concrete Journal*, Vol. 81, No. 4, pp. 17–24.
- [4] Banthia, N., and Gupta, R. (2006), “Influence of polypropylene fiber geometry on plastic shrinkage cracking in concrete,” *Cement and Concrete Research*, Vol. 36, pp. 1263–1267.
- [5] Corinaldesi, V., and Moriconi, G. (2004), “Durable fiber reinforced self-compacting concrete,” *Cement and Concrete Research*, Vol. 34, pp. 249–254.
- [6] Foster, S. J. (2010), “Design of FRC beams for shear using the variable engagement model,” *fib Bulletin*, Vol. 57, pp. 195–210.
- [7] Han Aylie, A., Aldyan, A., and Okiyarta, W. (2015), “Experimental study on steel fibre reinforced concrete beam with confinement,” *Procedia Engineering*, Vol. 125, pp. 1030–1035.
- [8] IS 456:2000, “Plain and reinforced concrete – Code of practice,” Bureau of Indian Standards, New Delhi, India.
- [9] Kani, G. N. J. (1997), “How safe are our large reinforced concrete beams?” *ACI Journal*, Vol. 64, pp. 128–141.
- [10] Kutalmış Recep Akca, Özgür Çakır, and Metin İpek (2015), “Properties of polypropylene fiber reinforced concrete using recycled aggregates,” *Construction and Building Materials*, Vol. 98, pp. 620–630.
- [11] Mahendra Prasad, Chandak Rajeev, and Grover Rakesh (2013), “Comparative study of polypropylene fibre reinforced silica fume concrete,” *International Journal of Engineering Research and Science & Technology*, Vol. 2, No. 4, pp. 127–136.
- [12] Muntadher Ali Challob (2013), “Effect of fly ash and steel fibre on Portland pozzolana cement concrete,” *International Journal of Engineering Trends and Technology (IJETT)*, Vol. 5, No. 3, pp. 141–145.
- [13] Parveen (2013), “Mechanical properties of hybrid fibre reinforced concrete,” *International Journal of Engineering Research and Applications*, Vol. 3, No. 4, pp. 172–177.
- [14] Rajarajeshwari, B., Dhinakaran, G., and Suganya, P. (2012), “Mechanical properties of hybrid fiber reinforced concrete,” *International Journal of Engineering Research and Technology*, Vol. 1, No. 6, pp. 1–6.
- [15] Surinder Pal Singh, Kaushik, S. K., and Shukla, A. K. (2011), “Flexural fatigue behavior of hybrid fiber reinforced concrete,” *Construction and Building Materials*, Vol. 25, pp. 3628–3635.