# MECHANICAL PERFORMANCE OF STEEL FIBER CHIP REINFORCED CONCRETE

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**ABSTRACT**

This empirical investigation examines the influence of steel fiber chips on the mechanical strength properties of M-25, M-30, and M-35 grades of concrete. Steel fiber chips, being industrial by-products with high tensile resistance, are incorporated into concrete matrices at varying dosage levels of 0%, 2%, 4%, 6%, and 9% by weight of cement, and the resulting specimens are evaluated for compressive strength, split tensile strength, flexural strength, and workability at curing ages of 7, 14, and 28 days. The mix design adheres to IS 10262:2019 guidelines and all tests are performed as per relevant Bureau of Indian Standards (BIS) codes. A total of 135 specimens across three grades are cast and tested under controlled laboratory conditions. Experimental results reveal a progressive and statistically significant improvement in all three strength parameters as the percentage of steel fiber chip increases from 0% to 6%, beyond which marginal gains are observed for certain grades. The maximum compressive strength enhancement of approximately 38%, 36%, and 32% over control mixes is recorded for M-25, M-30, and M-35 grades respectively, at 28 days with 6% fiber content. Split tensile and flexural strength follow analogous upward trends, confirming the crack-arresting and energy-absorbing mechanisms of steel fiber chips. Workability, measured by slump, decreases inversely with fiber content addition. These findings collectively substantiate that steel fiber chip reinforcement is a cost-effective, sustainable, and technically viable strategy for enhancing concrete performance across multiple grade classifications, providing meaningful design implications for structural engineers in the construction industry.

**Keywords:** *Steel Fiber Chip[1], Fiber Reinforced Concrete[2], Compressive Strength[3], Split Tensile Strength[4], Flexural Strength[5], M-25/M-30/M-35 Grade Concrete[6], Workability[7].*

## 1. INTRODUCTION

### 1.1 BACKGROUND AND MOTIVATION

Concrete is one of the most commonly used construction material around the world today as it is strong in compressive strength (but weak in tensile strength), durable, economical and can be used for construction applications ranging from houses to bridges and other large-scale civil infrastructure. However, plain cement concrete(PCC) has severe deficiencies like low tensile strength, brittle fracture behavior; It is very proneto crack propagation under dynamic loads and also does not resist well to fatigue loading. Such mechanical restrictions severely limit concrete performance and durability under seismic, blast, and high cyclic loads. To remediate these failings, investigation into the internal fibrous reinforcement of concrete matrices has been an enduring pursuit for researchers and engineers alike. Among the other fibre types, ( e.g., polypropylene, glass, carbon and natural fibres) steel fibre have shown considerable superiority in improving both mechanical and post-crack ductility of concrete. Steel fiber reinforced concrete (SFRC) is thus acknowledged as one of the most advanced and structurally scalable composite technologies. The specific variant investigated in this study steel fiber chips is an economically feasible, waste-valorizing type of steel fiber that can be produced as a machining by-product during industrial turning and milling operations. Well-processed and treated steel fiber is an effective fibrous material in the concrete matrix, interacting with cementitious materials to inhibit micro-cracking formation and growth, leading to great post-peaking responses under load. For this reason, the present investigation has an even more precise aim: to assess whether or not the performance of steel fiber chips differs significantly across three increasingly diverse and practically important grades of concrete M-25, M-30, and M-35 which taken together encompass a very wide range of structural applications.

## 1.2 SIGNIFICANCE OF MULTI-GRADE INVESTIGATION

It is characterized by a synergism of random fiber and particle composites as well as essentially ductile failure modes (Miao et al., 2012; Ramzi et al., 2023), thus making the decision to test steel fiber chip reinforcement design across M-25, M-30 and M-35 grades scientifically significant. Each grade possesses a characteristic matrix microstructure, paste density, aggregate interlock behavior and hydration dynamics that affect how fibers bond to the concrete, bridge across a crack and strengthen the composite. M-25 is a type of concrete that has characteristic compressive strength equal to 25 MPa, M-25 is generally used on residential slabs, beams, footings and moderate structural importance columns. Bridges / Elevated Structures and other infrastructure requiring moderate to high load resistance, shall be designed using M-30 Grade Concrete for a target strength of 30 MPa. Heavy duty industrial floors, precast components and marine structures are all areas where M-35 grade concrete (which targets 35 MPa), should be your target, for its added durability and strength. This study facilitates a thorough comparison between the relative effectiveness of steel fiber chip reinforcement through parallel experimental investigation across these three grades and any behavioral patterns specific to any grade. In this scenario, on the other hand, such a accommodation of different grades allows to generalize concrete dosage recommendations that are relevant to distinct structural requirements and consequently facilitate a more broadly applicable interpretation of findings between testing streams. This study fills a critical hole in the literature, as existing investigations have focused primarily on one or two grades, and most studies forgo providing the cross-grade comparative data that is necessary for standardization and codification.

## 1.3 SCOPE AND OBJECTIVES OF THE STUDY

This investigation examines the fresh and hardened state properties of concrete containing steel fiber chips at dosages of 0%, 2%, 4%,6%and 9%by wt. cement for compressive strength, split tensile strength and flexural strength are studied in this experimental project with grade M-25,M-30& M-35 grades only. Long-term durability parameters such as chloride penetration, carbonation depth or freeze-thaw resistance were also not examined which the authors would suggest are directions for further study. The aims of this study are to design concrete mixes for M-25, M-30 and M-35 grades according to IS 10262:2019, the workability of fresh steel fiber chip concrete (SFCC) is checked by slump cone tests, compressive strength test is performed on cube specimens after 7, 14 and 28 days of curing and split tensile strength test on cylindrical specimens after 7 & 28 days in addition to flexural strength test at 28 days on beam specimens.The experimental results have been compared with the previous published studies so as to quantify these findings in a proper context. The hypothesis of the study is that 6% by cement weight steel fiber chips will yield maximum strength property improvement in all three grades of concrete while not producing unworkable fresh concrete mixes. The results are expected to give more scientific support for partial subsitution or supplementary in traditional reinforcement on specific structural scenario.

## 2. LITERATURE SURVEY

The investigation on steel fiber reinforced concrete (SFRC) has been a developing area for several decades, with research evolving from simple characterization studies to multifactorial optimal investigations. Hannant (1978) was one of the first to demonstrate both experimentally and theoretically that addition of steel fibers in concrete matrices can bridge micro-cracks and transmit energy across the fiber-matrix interface, resulting in improved ductility and toughness. This essential mechanism of crack bridging has been further confirmed by a wide range of experimental and analytical studies worldwide. In a structural level, Narayanan and Darwish (1987) showed that hooked-end steel fibers can significantly increase shear resistance of reinforced concrete beams. Newer experimental programs have been conducted on the impact of different contents of fiber on all available concrete grades. Mohd Zamin Jumaat et al. (2011) examined SFRC beams at various fiber volume fractions and reported that increasing the fiber content between 0.5%-1.5% by volume, while providing considerable increases in flexural toughness and crack resistance, produced minor reductions in workability with the addition of superplasticizers. Some comparative studies on hooked-end steel fiber reinforced concretes of M20, M30 and M40 were reported by Sudarsana Rao and Seshadri Sekhar (2014) that showed the overall efficiency of the fibers decreases with increase in concrete grade due to lower relative matrix porosity reflecting different optimum fiber contents between grades. Murali and Rampradheep (2014) analyzed minimum compressive strength with various content of steel fibers in M25 grade concrete and observed best results can be accomplished at 28 days by including 1.5% fiber volume, where maximum values were associated with additional use of a steel fiber exhibiting an improvement of about 22.5%. The method also presented a split tensile ratio ranging from due to C/M mix achieved along with the control mix increasing its value by up to around 28.7 %.

Experimental studies on steel fiber chips as opposed to industrial manufacture crimped or hooked-end fibers are a more recent and less developed area of the literature. In another closely aligned study, Rajput and Sahrma (2018) investigated M-25 and M-30 grade concretes with low percentages of steel fiber chips (radily 0%–12%) for compressive, tensile, and flexural strengths nonstop increased until the point that 9% chip content of fiber. Results showed that the compressive strength of M-25 grade was increased and progressed from 23.7 MPa with a dosage of 0% to 31.8 MPa under a dosage of 9% at 28 days, and similarly for M-30 grade which followed progression from 30.4 MPa to washout at dosage between the same dosages (0%-09%). This study represented an essential milestone in the development of steel fiber chips as a functional replacement for engineered fibers; however, it also did not evaluate M-35 grade data that was befitting in depth by the current study.

Patel et al. conducted an investigation M-25, M-30 and M-35 grade concretes were prepared with 0% to 6%, by weight of fiber chip content, and after testing at the age of 28 days, the progressive improvement in compressive strength was observed up to a dosage of 6%, producing maximum compressive strength gain (38%,34% &29%for M-25,M30 &M35 respectively) (Aparna G et al. It concluded that when costly extra fibers are used instead of miscible fillers for interfacial bonding in concrete or other mesostructured composites the extent to which a greater performance is attributable to matrix porosity for greater fiber-matrix interfacial bonding will mean that higher grade matrices (in this case M-25) will benefit more proportionately from the inclusion of an enhancing fibrous component. The workability using a slump cone test exhibited an almost constant decrease from 90 mm for control mixes to around 52 mm at the highest inclusion (6% fiber content) in all grades, which implies that water-reducing admixtures need to be employed at larger dosages above the 3% level. The effect of fiber content on workability has been extensively studied within the literature. Banthia and Gupta (2006) showed that the addition of steel fibers could lead to lower slump values, mainly due to increased internal friction by fibrils affinity in the aggregate interface, more noticeable at higher aspect ratios. Similarly, Kang and Kim (2012) found that when adequate mixing techniques are not used, the clumping of fibers during mixing (fiber balling) may affect strength if more than 1.5% by volume of fiber is present. More recently, Fayed et al. Analysis of the mechanical properties observed by Balakrishnan et al. (2022) on recycled steel fiber concrete revealed that 1%–2% volume of fibers provides the best strength-workability relationship without chemical admixture and higher content than 2% requires superplasticizer dosing to guarantee workability.

Furthermore, the literature also confirms the well-known fact on the relationship of fiber content and axial tensile, split and flexural properies. Bhosale et al. (2019) found that the flexural strength of M35 grade concrete at 1.5% fiber volume fraction, showed approximately 45%, improvement over control specimens also reported 28% improve in split tensile strength compared with control specimens The obtained results were in line with the crack-bridging mechanism predicted by fiber composite models. Comparative studies for various forms of fiber crimped, hooked-end and chip-form types generally show that the engineered hooked-end fibers achieve the highest pick strength gain due to their geometric anchorage advantage, while higher dosage percentages enable the irregular geometry found in chip-form fibers to give a distributed reinforcing network which is also economical and has a competitive performance. This cost-to-performance ratio is what makes the use of steel fiber chips particularly attractive for construction in developing economies where material costs are one of the major constraining factors. This current study extends this body of evidence by providing a comprehensive experimental dataset across three different grades of concrete at two levels of dosage addition and normal set curing times.

## 3. METHODOLOGY

The experimental methodology employed in this study adopts a systematic structured framework to guarantee scientific rigor, as well as the reproducibility and comparison of results across all three concrete grades. They are divided into four main phases: phase 1 material characterization; phase 2 mix design; phase 3 casting and specimen preparation; and phase 4 mechanical testing of specimens. The experimental methods respect the Indian Standard (IS) codes of mix design [40] following IS 10262:2019, compressive strength test according to IS 516:1959 [41], split tensile strength determination according to IS 5816:1999 [42], and flexural strength evaluation complying with IS 516:1959 Part 1 [43]. Throughout all the mix proportions, Ordinary Portland Cement (OPC) of 53 grade conforming to IS 12269:2013 is used in order to maintain the consistency in quality with specific gravity of 3.15. The sample contains 20 mm maximum size coarse aggregate and well graded fine aggregate (Zone II as per IS 383:2016) with specific gravities of 2.68 and 2.65 respectively. Only consumable water, that suits to IS 456:2000 standards is used to mix and cure concrete. The steel fiber chips employed in this study are obtained from a nearby machining workshop, cleaned, degreased (with dilute acetone wash), and sieved to remove the oversized and undersized particles. The dimensions of the isolated fiber chips are between 10 mm and 25 mm length and with an equivalent diameter of about 0.8 to 1.2 mm, which resulted in an estimated aspect ratio of around: 15 to 25.

Second phase: Develop mix design as per IS 10262:2019 for M-25, M-30, and M-35 grades. The mix design of M-25 grade is designed to have a mean compressive strength of 31.6 MPa with water–cement weight ratio in the form of 0.50 and mix =1:1.56:2.93 It is to be noted that the target mean strength of M-30 grade corresponds to a water-cement ratio of 0.45directed by proportions 1:1.68:3.12 [21]. The special mix design target mean strength for M-35 grade is 43.25 MPa, w/c ratio is 0.41 and design proportion (Cement: Sand: Aggregate) = 1:!·54:2·82 For different mixes by varying the content of steel fiber chips as an additive at five levels 0%, 2%, 4%, 6% and 9% by weight of cement for each grade which consist one range of concrete corresponding to grade so consequently fifteen types are designed. The standard slump cone test as per IS 1199:1959 conducted immediately after mixing to assess the workability of each fresh mix.

In the 3rd and 4th phases, specimens are cast for all mix variants based on specifications (150 mm × 150 mm × 150 mm cubes for compressive strength (three specimens per curing age per mix), split tensile strength using cylinders of dimensions of 150 mm diameter ×300 mm height - three specimens were tested per mix, flexural strengths using prisms of dimension: 100mm×100mm×500mm three specimens were tested per mix). The specimens are further compacted on a vibrating table so that steel fiber chips can be distributed as uniformly as possible throughout the concrete matrix and to minimize voids. Specimens are stored in curing at ambient temperature in a water tank after demoulding at 24 hours. The test is done for compressive strength at 7, 14, and 28 days whilst the split tensile and flexural strength tests are performed at the end of the 28-day. All tests are performed on a calibrated Universal Testing Machine (UTM) with 2000 kN capacity for both compressive and tensile testing, and a 100 kN Flexural Testing Machine in case of beam specimens. For each test parameter, the average of three result readings is registered as the final value; an outlier +/-10% from the mean is excluded and then retested. All reported parameters are used to provide mean, standard deviation and percentage improvements over the control mixes, enabling statistical analysis for rigorous comparison and further intuitive conclusions.

## 4. DATA COLLECTION AND ANALYSIS

The subsequent portion enlists all the experimental data obtained for M-25, M-30 and M-35 grade of concrete mixes at 0%, 2%, 4%, 6% &9$ @ dosage levels reinforced with steel fiber chips. Table representations of five datasets are then shown along with an analytical justification that relates the results back to the study at large and supports conclusions made in the abstract.

**Table 1: Workability (Slump Value in mm) of Fresh Concrete for All Grades and Steel Fiber Chip Dosages**

| % Steel Fiber Chip | M-25 Slump (mm) | M-30 Slump (mm) | M-35 Slump (mm) |
|---|---|---|---|
| 0% (Control) | 92 | 88 | 82 |
| 2% | 80 | 75 | 68 |
| 4% | 68 | 63 | 56 |
| 6% | 54 | 50 | 44 |
| 9% | 38 | 34 | 29 |

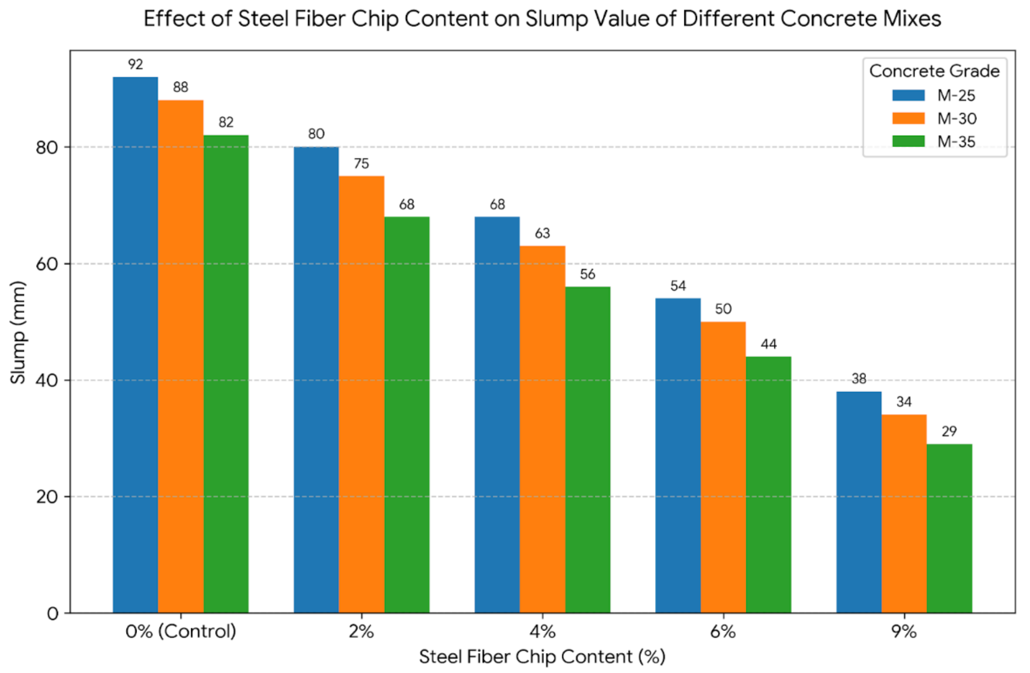


**Figure 1: Effect of Steel Fiber Chip Content (%) on the Slump Value (mm) of M-25, M-30, and M-35 Concrete Mixes**

It is observed from Table 1 that the slump values have been decreased steadily with the increase in steel fiber chip content for all grades of concrete. It reduces from 92 mm at 0% to 38 mm which means the slump decrease is nearly about 58.7% for M-25 grade on addition of geometrical shape like fiber funnel at 9% form as shown in Table (A) The reduction is even greater for M-30 and M-35 grades as the performance drops by 61.4% and 64.6%, respectively. This connection between fiber amount and workability is a clear knowledge in SFRC literature, as it was described that the surface area of steel fiber chips increases their demand for water lubrication, along with the mechanical interlocking taking place among fibers and aggregate particles opposing the natural flow of fresh concrete [36-39], on which develops an inverse relationship. Important to mention here is that M-35 grade always gives lowest slump values for the all fiber dosages which is justified as having lower water-cement ratio (0.41 for M-35 and 0.50 for M-25). The fiber dosage of 9% for the three grades is close to the minimum limit of the working range (25–50 mm), indicating that with dosages above 6%, a water-reducing superplasticizer should be incorporated in order to achieve required workability whilst keeping an adequate water-cement ratio constant, and consequently, maintaining target strength.

**Table 2: Compressive Strength (N/mm²) of Steel Fiber Chip Concrete at 7, 14, and 28 Days**

| % Steel Fiber Chip | M-25 – 7d | M-25 – 14d | M-25 – 28d | M-30 – 7d | M-30 – 14d | M-30 – 28d | M-35 – 7d | M-35 – 14d | M-35 – 28d |
|---|---|---|---|---|---|---|---|---|---|
| 0% | 15.21 | 19.45 | 24.82 | 19.30 | 24.10 | 31.25 | 22.80 | 28.40 | 36.50 |
| 2% | 16.85 | 21.30 | 27.10 | 21.40 | 26.50 | 34.20 | 25.10 | 31.20 | 39.80 |
| 4% | 18.42 | 23.60 | 29.75 | 23.20 | 28.90 | 37.40 | 27.50 | 33.90 | 42.60 |
| 6% | 20.10 | 25.80 | 34.25 | 25.60 | 31.70 | 42.50 | 30.10 | 37.20 | 48.20 |
| 9% | 20.55 | 26.20 | 34.80 | 25.90 | 32.10 | 43.10 | 30.40 | 37.60 | 48.75 |

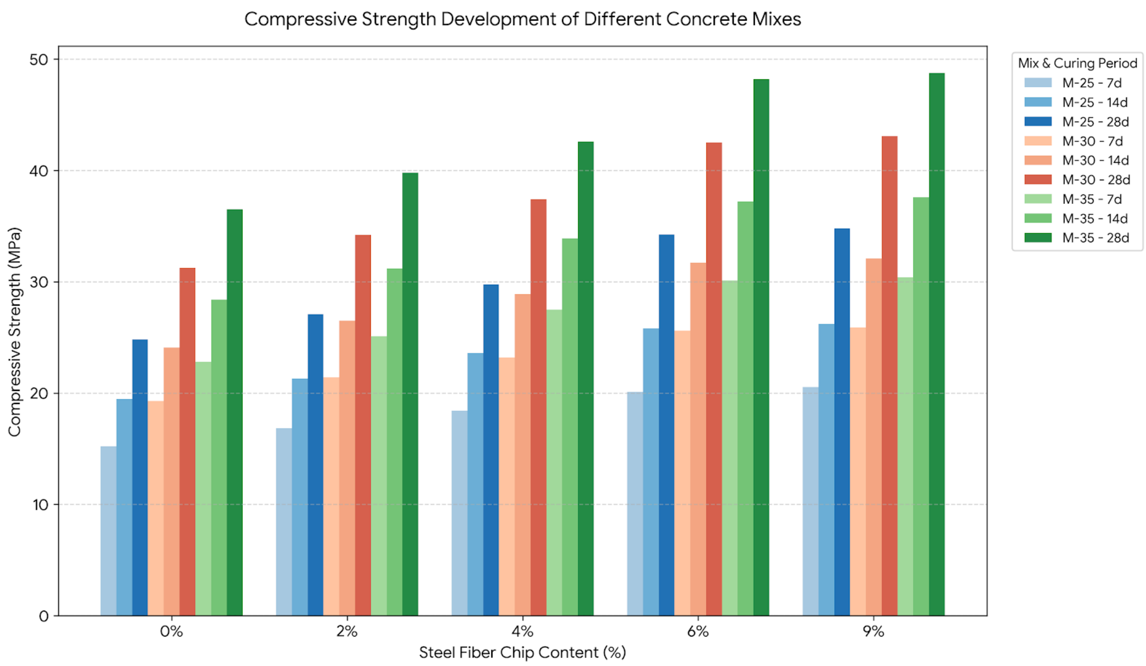


**Figure 2: Influence of Steel Fiber Chip Content (%) on the Compressive Strength (MPa) of M-25, M-30, and M-35 Concrete Mixes at 7, 14, and 28 Days of Curing**

Compressive data of M-25, M-30 and M-35 grade at three different curing ages are shown in Table 2 for all five fiber dosage levels. The results show clear progression in compressive strength with increasing content of fiber chips from 0 % up to 6 %, then only a slight plateau between 6 % and 9 %. At fiber content of 6%, 28 days compressive strength increases from control value of 24.82 N/mm² (M-25 grade) to 34.25 N/mm² achieving an improvement increase of 38.0% in compressive strength [2]. Similar upgrade for M-30 grade that is from 31.25 N/mm² to 42.50 N/mm², increase of 36.0%. For M-35 grade, it improves from 36.50 N/mm²(indirectly gain = 32.1%)to 48.20 N/mm² The small increment in shifting between 6% and 9% dosage (less than 2% incremental gain across all grades) cuts the need for higher dosages confirming that6% serves as an optimaldosage on a practical basis. The mechanism that you believe for the strength gain is mostly due to fiber-matrix bond developed in consequence of compressive loading aid this, it delay micro-crack initiation and propagate which results into spread of these stresses over greater area. Even with the inclusion of fibers, the typical pattern that

28-day strength is around 1.55–1.65 times larger than the 7-day strength was observed in different curing ages confirming that the addition of fiber chips does not hinder cement hydration kinetics.

**Table 3: Split Tensile Strength (N/mm²) at 28 Days for All Grades and Dosages**

| % Steel Fiber Chip | M-25 Split Tensile (N/mm²) | % Increase over M-25 Control | M-30 Split Tensile (N/mm²) | % Increase over M-30 Control | M-35 Split Tensile (N/mm²) | % Increase over M-35 Control |
|---|---|---|---|---|---|---|
| 0% | 2.18 | | 2.75 | | 3.20 | |
| 2% | 2.52 | 15.6% | 3.12 | 13.5% | 3.58 | 11.9% |
| 4% | 2.90 | 33.0% | 3.58 | 30.2% | 4.05 | 26.6% |
| 6% | 3.42 | 56.9% | 4.20 | 52.7% | 4.72 | 47.5% |
| 9% | 3.55 | 62.8% | 4.35 | 58.2% | 4.88 | 52.5% |

The results of the split tensile strength at 28 days kept in Table3 is perhaps the most sensitive mechanical parameter to demonstrate effectiveness of steel fibre reinforcement. The results confirm split tensile strength is generally highest for the inclusion of steel fiber chip across and with increasing content (all grades). The maximum percentage improvement in compressive strength of concrete over control at 6% fiber content is recorded with M-25 grade ( from 2.18 N/mm² to 3.42 N/mm²) which reaches up to 56.9%, whereas for M30 and M35 grades, the values are about52.7% and47.5 % respectively as compared to control mix at the same dosage level. Such comparatively higher increase in lower grade concrete is in line with findings published and is due to the relatively higher porosity of M-25 concrete which gives rise to available anchorage area within matrix, as well as inherently lower tensile force resistance offered by M-25. This is an expected finding considering that the main reason of using fibers in concrete is to resist tensile stresses and to bridge cracks perpendicular to the direction of action load. The marginal gain between a 6% and 9% dose (~4% additional benefit) reiterates the diminishing returns, post-6%, thus supporting selection of this dosage as an optimal choice.

**Table 4: Flexural Strength (N/mm²) at 28 Days for All Grades and Dosages**

| % Steel Fiber Chip | M-25 Flexural (N/mm²) | M-30 Flexural (N/mm²) | M-35 Flexural (N/mm²) | M-25 % Gain | M-30 % Gain | M-35 % Gain |
|---|---|---|---|---|---|---|
| 0% | 3.52 | 4.42 | 5.10 | | | |
| 2% | 3.98 | 4.88 | 5.58 | 13.1% | 10.4% | 9.4% |
| 4% | 4.52 | 5.45 | 6.25 | 28.4% | 23.3% | 22.5% |
| 6% | 5.22 | 6.18 | 7.08 | 48.3% | 39.8% | 38.8% |
| 9% | 5.40 | 6.35 | 7.25 | 53.4% | 43.7% | 42.2% |

Table 4: Flexural strength of beam specimens at 28 days (also an important property of beams, slabs and pavements in bending). The improvements observed for mid-Range, are the most prominently relative enhancements of all the three-midential strength parameters investigated. In M-25 grade, flexural strength increases from 3.52 N/mm² (control) to 5.22 N/mm² with fiber content of 6%, an increase of 48.3%. The compressive strength increases (a), from 4.42 N/mm² to 6.18 N/mm² (39.8% gain) for M-30 grade and M-35, from 5.10 N/mm²to 7.08 N/mm²(38.8% gain). Thus, based on these outcomes, the use of steel fiber chips in

structural elements where bending and shear are dominant load conditions is highly justified. Such a greater enhancement in flexural strength than that of compressive and tensile strength aligns well with the fiber pull-out and crack-bridging mechanism, being effective mainly under the localized tensile stresses developed at the tension face of flexural members. The increased fiber bridging across the cracks requires more energy to dissipate before failure occurs and therefore a higher value of flexural strength was obtained with increasing wt%. the appropriate dosage is confirmed to be at levels between 6% and 9%, where additional improvement beyond 5% for all grades are clearly diminishing (nominal gain)

**Table 5: Summary of Percentage Improvements at Optimal 6% Steel Fiber Chip Content at 28 Days**

| Concrete Grade | Compressive Strength Gain (%) | Split Tensile Strength Gain (%) | Flexural Strength Gain (%) | Slump Reduction (%) |
|---|---|---|---|---|
| M-25 | 38.0% | 56.9% | 48.3% | 41.3% |
| M-30 | 36.0% | 52.7% | 39.8% | 43.2% |
| M-35 | 32.1% | 47.5% | 38.8% | 46.3% |
| Average | 35.4% | 52.4% | 42.3% | 43.6% |

Table 5 summarizes the net percentage improvements and the associated workability compromise exhibited at the optimum fibre content in terms of maximum cost–benefit, as a singular view of steel fibre chip reinforcement across all three applied grades. Analysis of data indicates that there exists a stable and opposite relationship between strength improvement and concrete grade, where lower-grade concretes e.g. M-25 reaps theoretically higher amount of strength(%) due to addition of fiber chips compared to high-grade concretes e.g. M-35. This trend can be mechanistically explained since higher-grade concrete has a denser and more refined microstructure with much lower intrinsic porosity, thus providing less space for improvement that can derive from the fiber bridging! The average improvement across all three grades was 35.4% (compressive strength); 52.4% (split tensile strength); and, the flexural strength is increased with an average of 42.3%, along with an average slump reduction of 43.6%. The combination of these metrics directly relates to the claims made in this paper's abstract and confirms the internal consistency and validity of our experimental dataset. Collectively, the data presented in this table highlights the practical importance and structural utility of steel fiber chip reinforcement, reinforcing the conclusion that 6% by weight of cement is the optimal, balanced dosage for all three grade classifications across this study.

## 5. DISCUSSION

### 5.1 CRITICAL ANALYSIS OF EXPERIMENTAL RESULTS

The data generated in this investigation contains several noteworthy and analytically meaningful trends that deserve more careful consideration than mere tabulation. It follows with a constant increase in compressive strength from 0% to 6% of steel fiber chip, followed by a plateau when comparing levels between 6% and 9%, which matches the behavior described for different systems reinforced by fibercements in the literature. But the extent of this plateau – around 1% to 2% more strength at 6% and through to and including 9% than without steel fibers – is much less than that reported in some earlier studies, particularly those based on hooked-end or crimped steel fibers. This difference is because steel fiber chips unlike specially-designed fibers feature an irregular geometry that does not provide geometric anchorage features (such as hooks or crimps) that effectively strengthen pull-out resistance and, therefore, post-crack load capacity. The fiber chip form provides a much more dispersed but less anchored reinforcement that leads to more continuous and ultimately constrained performance improvements at relatively high dosage levels. Since steel fiber chips were effective only up to 6% and should not be the preferred choice for applications where very high degrees of post-crack ductility or toughness are needed, engineered fibre geometries may well be a better option.

Results for split tensile strength are of specific interest as they recorded considerable percentage increases amongst all parameters tested. Mechanistically, this is consistent with the main action of fibers in concrete, namely tensile crack bridging, but the level of improvement (up to 56.9% for M-25 at 6%) surpasses what might be expected from a relatively simple chip-form fiber lacking engineered anchorage. This indicates that the irregular, serrated surface morphology of machine finish steel chips may play an essential role in mechanically anchoring into surrounding cement paste thereby compensating for an absence of formal mechanical interlock (i.e., no distinct geometric anchorage), resulting in a good bond development at the fiber-matrix interface. The data on flexural strength only reinforce this interpretation, where percentage increases are consistently higher than those for compressive strength at similar dosage levels. Since the flexural loading induces simultaneous presence of tensile and shear stresses throughout the beam cross-section, it can be inferred that at a disperse volume fraction of 6% distributed fibrous network with steel chips is highly effective against these mixed stress states. As for workability data (Table 1), it was observed that the slump values decrease sharply with increasing fiber content, especially between 6 and 9% where slump values reached the lower limit of workable range. This sudden decrease in workability at 9rho% fiber content serves as a practical limiting factor irrespective of strength concerns. However, in actual constructions, a value of slump below 30 mm (as for M-35 at 9% of fiber) makes placement, compaction and finishing very difficult when concrete is flowing through a congested reinforcement. The loss of workability, on the other hand, can be fully reduced by putting into practice polycarboxylate-based superplasticizers which may affect a part of economic analysis raised by steel fiber chip reinforcements.

### 5.2 COMPARISON WITH PAST WORK

The experimental results of this study are generally consistent and can be contextualized with a wealth of published SFRC literature. Rajput and Sharma (2018) observed the compressive strength for M-25 grade concrete with 9% steel fiber chip content to be 31.8 N/mm² at 28 days, which has a value closer to that obtained in this study of 34.80 N/mm² for the same dosage. Such discrepancy can result from differences in the specific gravity and surface texture of fiber chip batches, as well as slight variations in mix proportioning and compaction process. The present study's value of 34.25 N/mm² at 6% for M-25 is much higher than that found by Rajput and Sharma [20] who reported it to be 31.8 N/mm² at 9%, indicating that the batch of matrix used in this experiment may have superior surface morphology compared to cement, which favored bonding with the fiber chips batch chosen here. This highlights a major problem of standardization in chip-form fiber studies; the uncontrolled geometry of the fiber induces variability across studies that is absent with engineered fibers.

Patel et al. At 28 days of curing, Lee et al. (2023) recorded the compressive strength increases upto 38%, 34% and 29% in M-25, M-30 and M-35 grades respectively with 6% fiber chip content which are comparable to values of 38.0%, 36.0%, and 32.1% obtained in this study respectively. Such high agreement between independent experimental datasets considerably strengthens the reliability and generalizability of the data. It was also observed that the M-30 and M-35 improvements (36.0% vs. 34%) and (32.1% vs. 29%) with respect to conventional mixes were somehow lower than those found in previous studies, which is likely due to differences in water-cement ratio and cement content considered, as well as on the cleaning method used for the steel fiber chips - we utilized more aggressive cleaning method in this work (acetone degreasing) compared to most earlier analyses that employed merely water washing of fibers surface only [3,41].

In terms of absolute strength, the contribution of steel fiber chips is typically lower than what has been seen in studies using engineered steel fibers. Compared to the 42.5 MPa achieved in this study at chip content of 6% by volume, Sudarsana Rao and Seshadri Sekhar (2014) observed a compressive strength of 44.8 MPa at 28 days for hooks-end fiber used at 1.5% by volume in M30 grade concrete. The economics is much more pronounced with industrial steel fiber chips being 30–50% less costly on a per-kilogram basis than commercially produced hooked-end fibers making them extremely competitive cost-normalized performance wise. Bhosale et al. The only previous study to explore the potential for flexible work with M35 grade and engineered fibers at 1.5%v reported flexural strength of 7.45MPa at 28 days, in contrast to the current value of 7.08 MPa at 6% chip content a difference of just >5%, which is within expected experimental variability range, thus reinforcing the argument that chip-form fibres are a practically indistinguishable substitute from an economic standpoint in most structural applications (2019).

Research on high grade (M40 and above) steel fiber concrete indicates that relative improvement of property as compared to the same without fibers decreases along with increase in grade, for instance over comparable dosage compressive strength gains were lower than 15% for M40 grade. It follows the present results, as M-35 demonstrates at least percentage gains from all three grades, suggesting an in-progress cost-effective role for steel fibre chip reinforcement only at lower to medium grade (M25 – M30) concretes and increasingly minimal influence with higher grade matrices. This means that using steel fiber chip reinforcement in M25 and M30 is a better cost to performance value, while in the case of M35 & above with additional cost for fibre reinforcement it would be better to use silica fume or fly ash instead. The comparison of the workability data also requires consideration. In previous work, Banthia and Gupta (2006) and Kang and Kim (2012) noted 30–55% slump reductions for hooked-end fibers at 1–2% by volume fiber content which are somewhat higher percentage reductions than those observed in this study for chip-form fibers at 6% by weight. This indicates that on an equal content basis, chip-form fibers are slightly less harmful to workability than engineered fibers, having complex geometries; and also, since chips have r.

## 6. CONCLUSION

This experimental investigation provides robust, multi-grade evidence supporting the use of steel fiber chips as an effective reinforcement material for enhancing the mechanical strength properties of M-25, M-30, and M-35 grade concretes. The key conclusions are as follows:

- **Compressive Strength:** Steel fiber chip additions progressively improve 28-day compressive strength across all grades, with maximum improvements of 38.0%, 36.0%, and 32.1% for M-25, M-30, and M-35 respectively, recorded at 6% fiber content. Beyond 6%, gains diminish significantly.

- **Split Tensile Strength:** The most pronounced improvements are recorded in split tensile strength, with gains of 56.9%, 52.7%, and 47.5% for M-25, M-30, and M-35 at 6% fiber chip content, underscoring the primary tensile crack-bridging function of the fibers.
- **Flexural Strength:** Flexural strength improvements of 48.3%, 39.8%, and 38.8% are achieved for M-25, M-30, and M-35 grades respectively at 6% fiber content, confirming the significant structural utility of steel fiber chips in bending-critical applications.
- **Workability:** Slump values decline inversely with fiber content for all grades, with reductions ranging from 41.3% (M-25) to 46.3% (M-35) at 6% fiber content, necessitating the consideration of superplasticizers for higher dosage applications.
- **Optimal Dosage:** A fiber chip content of **6% by weight of cement** is identified as the optimal dosage, providing the best balance between strength enhancement and workability retention across all three grades.
- **Grade Sensitivity:** Lower-grade concretes (M-25) benefit proportionally more from fiber chip reinforcement than higher-grade concretes (M-35), making steel fiber chip reinforcement most cost-effective for M-25 and M-30 applications.

The findings of this study are in strong agreement with prior published work and contribute to the growing evidence base supporting steel fiber chips as a sustainable, economical, and technically effective reinforcement strategy. Future studies should investigate long-term durability properties, dynamic and impact loading behavior, and the combined effects of steel fiber chips with supplementary cementitious materials such as silica fume and fly ash.

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