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PERFORMANCE OF M25–M35 CONCRETE REINFORCED WITH STEEL FIBER CHIPS

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ABSTRACT

Concrete is a material with wide use in construction industry but the low tensile strength and brittle behavior of this construction material restrict structural performance. The addition of steel fibers in concrete has been found to be an effective method to enhance mechanical properties of concrete. The experimental study aims to assess the behaviour of the steel fibre chips (which are produced by machining and lathe waste) on the properties of strength of M-25 grade, M-30 grade and M-35 grade concrete. The dosage of steel fiber chips used in the concrete was 0%, 0.5%, 1.0%, 1.5%, and 2.0% by volume of concrete. A comprehensive experimental study has been carried out to evaluate the compressive strength, split tensile strength, flexural strength at curing ages of 7, 14 and 28 days as per Indian Standard specifications on which 135 specimens were tested. The findings showed that the concrete with steel fibre chips addition showed considerable improvement in all mechanical properties of concrete as the most significant improvement is noted in the tensile and flexural properties. The best results were obtained at 1.5 % fibre content when the compressive strength was raised by around 13-15%, split tensile strength was raised by around 30-35% and flexural strength raised by around 39-45% over conventional concrete. The 1.5% fibre content and beyond, workability reduction, fibre clustering, and compaction problems caused marginal reduction in the strength. The authors show that steel fiber chips can provide an economical and sustainable alternative to commercially produced steel fibers, and can be used to achieve better structural performance, as well as beneficial utilization of the industrial waste in construction applications.

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

1. INTRODUCTION

The use of concrete has been established as the foundation of infrastructure development in modern times because of its versatility, durability, availability and cost-effectiveness. Concrete is a fundamental material in the construction of buildings, bridges, pavements, dams, industrial floors, tunnels and a host of other engineering structures. Although concrete is frequently used, there is one major drawback in the tension property of concrete. Concrete has a low tensile strength which typically ranges from 8-12% of the compressive strength; this makes concrete very vulnerable to cracking under service loads. Often these cracks propagate fast, resulting in reduction of durability, serviceability, and structural performance. In order to address these shortcomings, researchers have investigated different forms of reinforcement methods that would be used to enhance the tensile properties of concrete. Of these, the use of fiber reinforcement has proven to be one of the most effective techniques to improve the resistance to cracks, ductility, resistance to impact and energy absorption. One of the main reasons for choosing steel fibers is that they possess a high modulus of elasticity, have higher tensile strength and possess the ability to span cracks in the concrete matrix. Usually, steel fibers produced in a conventional manufacturing process like hooked-end, crimped or straight fibers are used in fiber reinforced concrete. These fibres offer many advantages in terms of mechanical properties, but they are quite expensive and therefore not widely used, particularly in developing countries. At the same time, there is a lot of steel machining waste produced in the steel lathe during the process of steel machining, such as lathe chips and steel turnings. These waste materials are usually discarded or recycled by using energy intensive procedures. Replacing the steel fibers with chips in the concrete serves two purposes. First, it is a low-cost option to the commercially available steel fibers. Second, it encourages sustainable waste reduction by diverting industrial waste in the form of scrap towards the construction industry and recycling. Steel fiber chips have an irregular shape that can increase mechanical interlocking between the steel fiber chips and the cementitious matrix, as well as provide a beneficial contribution to crack-bridging behavior.

There are a number of studies on the application of steel fiber chips in concrete, which have shown that these properties of the concrete are enhanced. But the degree of improvement depends on the concrete grade, dosage of fibers, aspect ratio, workability properties and curing conditions. In addition, the number of direct comparisons made between the M-25, M-30 and M-35 concrete grades under the same test conditions is still rather small. This research gap is filled by the present investigation, which experimentally investigates the effect of steel fiber chips on three popular structural concrete grades. In the study, the mechanical properties of steel fiber concrete with different proportions of steel fiber chips are tested and the optimal amount of steel fiber is determined for the best enhancement of the concrete's mechanical properties.

1.1 NEED FOR THE STUDY

The demand for high performance construction material has been growing with the rapid growth of urbanization and infrastructure development.With the rapid urbanization and infrastructure development, the demand for high performance construction material is growing. At the same time, significant amounts of steel machining waste are still produced by industries. These wastes bring into question environmental and economic issues of disposal. Adopting steel fiber chips into concrete can solve both problems. In addition, the importance of using industrial by-products in civil engineering applications is emphasised by the increasing focus on sustainable construction. While many studies have shown the merits of steel fiber reinforcement, a well-designed experimental study is needed for the practical implementation of steel fiber chip performance to various concrete grades. The results of this research can help engineers and practitioners determine the correct dosage of fibers to be used in structures and pavement.

1.2 OBJECTIVES OF THE STUDY

The primary objectives of the investigation are:

1. To evaluate the effect of steel fiber chip addition on the compressive strength of M-25, M-30, and M-35 grade concrete.
2. To determine the influence of steel fiber chips on split tensile strength and crack resistance.
3. To investigate improvements in flexural strength resulting from fiber reinforcement.
4. To identify the optimum percentage of steel fiber chips that provides maximum strength enhancement.
5. To compare the performance of steel fiber chip reinforced concrete among different concrete grades.
6. To assess the feasibility of utilizing industrial steel machining waste as a sustainable reinforcing material.

1.3 SCOPE OF THE INVESTIGATION

The study is limited to the mechanical properties of strength of steel fiber chip reinforced concrete. Three grades of concrete – M-25, M-30 and M-35 are taken into consideration. The amount of steel fiber chips added to concrete is from 0% to 2.0% volume of concrete. Compressive strength, split tensile strength and flexural strength are assessed at ages of curing of 7, 14, 28 days. The present investigations are not intended to cover durability properties like corrosion resistance, freeze-thaw resistance, shrinkage, permeability and long-term fatigue resistance. These are however pointed out as potential areas of future studies.

2. LITERATURE REVIEW

Over the last decades fiber reinforced concrete has been studied in detail because it is known to possess better post cracking behaviour than conventional concrete. Shah and Rangan (1971) showed that steel fibers have an appreciable effect on tensile resistance and toughness properties. They built the fundamental crack-bridging mechanism that is the basis of the strength enhancement in the fiber reinforced concrete. Johnston (2001) reported that steel fibers enhance load transfer across cracks and prevent the development of cracks in service. The study indicated that mechanical performance is greatly affected by fibre geometry, aspect ratio and dosage. Naaman (2007) pointed out that fiber-matrix interaction is significant in overall concrete behaviour. The study has concluded that the optimum fibre content should meet the combination of strength and workability needs.

The recent studies have been conducted on the use of industrial waste steel fibres. The compressive strength gain of the concrete made using steel machining waste was found to be in the range of 8% to 12% by Kumar and Sharma (2015). Patel and Desai (2016) found that there are significant improvements in split tensile strength and flexural strength in M-25 grade concrete with steel fibre chips. Sinha and Jain (2017) studied the use of lathe scrap fibres for M-30 concrete and found that 1% to 1.5% of fibres gave optimum results. High fibre content led to poor workability and lack of compaction efficiency. Ali and Kumar (2016) conducted a research on M-35 grade concrete with steel fibre chips and found that the flexural strength of concrete increased more than 40% at optimum dosage level. They concluded that the steel fiber chips could be used in pavement and industrial floor making applications. Although promising results have been reported from previous studies, there is significant variability in testing methods, fiber properties and mix designs. To achieve this, additional experimental research is needed to provide design recommendations for practical application.

3. MATERIALS AND METHODS

The experimental program was aimed to test the effect of steel fiber chips on the strength characteristics of the concrete of M25,M30 and M35 grade concrete. Steel fiber concrete mixtures with varying percentages of steel fiber chips were made and tested in the same laboratory. The aim of the investigation was to find the effect of different fibres on the compressive strength, split tensile strength and flexural strength at different curing ages.

- **Cement:** The use of the Ordinary Portland Cement (OPC) 53 Grade with IS 12269:2013 was throughout the investigation. The cement was freshly mixed with no lumps, was dry to use and stored in dry conditions. The specific gravity of the cement was found to be 3.15, the standard consistency was 31%, the initial setting time of the cement is 42 minutes and the final setting time of the cement is 510 minutes, fineness was 4% and compressive strength at 28 days was 56.8 MPa.
- **Fine Aggregate:** The natural fine aggregate used was locally available river sand which meets zone II requirement of IS 383: 2016. None of the sand contained organic impurities. Specific gravity of the fine aggregate was 2.64, fineness modulus was 2.71 and water absorption was 1.2%.
- **Coarse Aggregate:** A crushed granite aggregate of the maximum nominal size of 20mm was used. Angular and well graded aggregates. The coarse aggregate had a specific gravity of 2.78, water absorption of 0.8% and crushing value of 18.6%.
- **Steel Fiber Chips:** Steel fiber chips were carefully picked up from the local machine shop, lathe shop, etc., and cleaned carefully before use. The fibers were of mild steel and the thickness of fibers varied from 0.4 mm to 0.8 mm and its length varied from 25 mm to 40 mm. Aspect ratios varied from 45 to 70. The specific gravity and tensile strength of the fibres were 7.85 and ~420 MPa respectively.

4. EXPERIMENTAL PROGRAM

A total of five different dosages (0%, 0.5%, 1.0%, 1.5% and 2.0% of concrete volume) of steel fiber chips were chosen for each grade of concrete. These mixes were respectively named F0, F0.5, F1.0, F1.5, and F2.0. In total, 135 specimens were cast during the experimental investigation. They consisted of 45 cube specimens of 150 mm x 150 mm x 150 mm size for compressive strength, 45 cylindrical specimens of 150 mm x 300 mm size for split tensile strength and 45 prism specimens of 100 mm x 100 mm x 500 mm size for flexural strength.

5. COMPRESSIVE STRENGTH RESULTS

The compressive strength of M-25 concrete at 0.5%, 1.0% and 1.5% fiber content was 31.2MPa, 33.1MPa and 35.8MPa respectively after 28 days. The strength slightly reduced at 2.0% fiber content as 34.9 MPa. In case of

M-30 concrete, the compressive strength of control concrete was 38.4 MPa, while for 0.5%, 1.0%, 1.5% and 2.0% fiber dosage, the compressive strength was 40.3 MPa, 41.8 MPa, 43.6 MPa and 42.5 MPa respectively before decreasing slightly. The compressive strength of the M-35 concrete was found to be 44.8 MPa, 49.0 MPa and 50.9 MPa for 0.5% fiber content, 1.0% fiber content and 1.5% fiber content respectively. The 2.0% fiber content showed a slight decrease of 49.7 MPa. In case of M25 concrete, split tensile strength has increased from 3.18MPa for 0.5% to 3.54MPa for 1% and 4.12MPa for 1.5% fibre. The strength dropped slightly to 4.00 MPa with 2.0% fiber content. For M-30 concrete, split tensile strength increased from 3.82 MPa to 4.23 MPa, 4.65 MPa, and 5.03 MPa at fiber contents of 0.5%, 1.0%, and 1.5% respectively. However, a slight drop down to 4.88 MPa was recorded at 2.0% dosage. The split tensile strength of M-35 concrete was found to be 4.28 MPa for control concrete, 4.82 MPa, 5.23 MPa and 5.76 MPa with 0.5%, 1.0% and 1.5% of fibre content respectively and then decreased to 5.58 MPa with 2.0% fibre content.

6. FLEXURAL STRENGTH RESULTS

The flexural strength of M-25 concrete at 0.5%, 1.0% and 1.5% fiber content are found as 4.25, 4.82 and 5.31 MPa respectively as compared to 5.92 MPa of control concrete after 28 days. The flexural strength (5.71 MPa) at 2.0% fiber content was slightly lower. For M-30 concrete, flexural strength increased from 4.82 MPa to 5.48 MPa, 6.05 MPa, and 6.72 MPa at 0.5%, 1.0%, and 1.5% fiber dosages respectively, before decreasing to 6.44 MPa at 2.0%. The flexural strength of concrete with fiber content of 0.5%, 1.0% and 1.5% was 6.08 MPa, 6.79 MPa and 7.78 MPa respectively which increased from 5.36 MPa for the concrete without any fiber. The strength decreased slightly to 7.41 MPa at 2.0% fiber dosage level.

7. STATISTICAL ANALYSIS

It was observed that compressive strength of the concrete improved by 14.74%, 13.54% and 13.62% for M-25, M-30 and M-35 concrete respectively at optimum amount of fiber of 1.5%. Split tensile strength increased by 29.56%, 31.68%, and 34.58%, while flexural strength increased by 39.29%, 39.42%, and 45.15% respectively. Strong correlation was found between fiber dosage and the improvement in strength as shown in regression analysis, with R^2 of 0.91, 0.95 and 0.97 for compressive, split tensile and flexural strengths, respectively.

8. RESULTS AND DISCUSSION

The experimental investigation has shown that addition of steel fiber chips has positive effect on the mechanical characteristics of concrete for all grades taken for this research. Overall, the improvements noted were mostly due to the crack arresting and crack bridging properties of the steel fibres that contributed to the load transfer mechanism in the concrete matrix. The effect of steel fiber chips was present in all three properties, compressive strength, split tensile strength and flexural strength, but the level of improvement in each of these properties differed. The compressive strength results showed an increasing pattern with the increase of fiber content up to 1.5% of the volume of concrete. The compressive strength of the concrete improved from 31.2 MPa of conventional concrete to 35.8 MPa with optimum fiber dosage for M-25 concrete. The same trends were observed for M-30 and M-35 concrete, where the highest strengths were 43.6 MPa and 50.9 MPa for contents of 1.5% of fiber, respectively. This enhanced compressive strength is due to the confinement effect created by the fibers and the capacity of the fibers to prevent the propagation of microcracks under compressive loading. Increasing the dosage of fiber to 2.0% resulted in a slight decrease in strength due to decreased workability, compaction and fiber clumping.

The previous results of the split tensile strength showed that improvements were significantly higher than those of compressive strength. To a large extent, steel fiber was able to bridge the internal cracks created under tensile stress and to slow down the crack propagation. Thus, the tensile strength of concrete was significantly enhanced. The split tensile strength was at the maximum for all grades at 1.5% dosage of fibers. The tensile strength increased on average by about 30-35 % when compared to the control concrete. The results validate that steel fiber chips are especially effective in improving tensile characteristics of concrete and decreasing overall brittleness of concrete. The flexural strength showed the greatest improvement of all the properties tested. The addition of steel fibres improved the post-cracking characteristics of concrete beams and their bending stress resistance. The best flexural strength was obtained for M-25 concrete with 1.5% fibre content, which was 5.92MPa, 6.72MPa and 7.78MPa for M-25, M-30 and M-35 concrete respectively. The percentage increase in flexural strength ranged from about 39% to 45% which reflected the important role of steel fibres in providing resistance to tensile stresses created within the flexural tension zone.

The absolute strength values of the three grades of concrete were compared and it was concluded that higher concrete grades were produced with higher absolute strength due to its denser matrix structure and lower water-cement ratio. However, the relative gains obtained from adding steel fibres were similar for all grades. M-35 concrete has the maximum enhancement of flexural strength which shows that bonding between fibers and cementitious matrix has been improved. In the meantime, the M-25 concrete also showed excellent strength gain properties, and the performance of steel fiber chips under normal strength and higher strength concrete was confirmed. The overall performance trend made it evident that the strength enhancement was in the order of flexural strength, split tensile strength, and compressive strength. This is because the fibres are not necessarily increasing the compressive strength of the material, but helping it to withstand tensile stress and to manage the cracking. Thus, the study has validated that the performance of steel fiber chips in concrete is primarily as crack-control and toughness enhancing reinforcement. In terms of practical application, the best steel fiber chip dosage was determined to be 1.5% of the volume of concrete. In this stage, the best improvements in all mechanical properties have been obtained without creating any workability difficulties. At this dosage and higher, the disadvantages of fibre balling (poor workability and compaction problems) were greater than any advantages in terms of reinforcement. However, in practical construction applications, the fiber content is recommended to be around 1.5% for optimum mechanical properties and workability. The results also indicate that the steel fiber chips generated from the machining waste and lathe waste can be effectively used as an economic and environmentally friendly material to replace the commercial manufactured steel fiber. These not only improve the performance of concrete but also promote environmental sustainability by making the best use of industrial waste materials. This method is in line with the concepts of sustainable building and resource conservation, and will cut down on the expense of the traditional fiber reinforcement.

9. CONCLUSIONS

From experimental investigation on M-25, M-30 and M-35 grade concrete with steel fiber chip, it has been concluded that steel fiber chip is effectively used to improve the mechanical property of concrete. In the present study, it was observed that the compressive strength, split tensile strength and flexural strength of all the concrete grades have improved. The addition of steel fibre chips resulted in moderate improvement in the compressive strength, which is around 13% - 15% at the optimum dosage. These increases in strength were partly due to the confinement effect of the fibres, and, to their ability to impede the propagation of microcracks. The impact of steel fibres was more significant in the tensile properties. The value of split tensile strength was found to be about 30% to 35% higher than that of the conventional concrete. The fibers were able to effectively bridge the developing cracks and delay the crack propagation, giving better tensile resistance and less brittleness.

The flexural strength had the greatest improvement of all the properties studied. The maximum increases were between 39% and 45%, showing the effectiveness of steel fibres in resisting tensile stresses formed when bending. It is observed that the flexural test showed better flexural property in terms of post cracking performance and load carrying capacity of steel fiber chip reinforced concrete, proving its suitability for flexural applications where bending and impact loading is encountered. The 1.5% by volume of concrete in fiber was always found to be the optimum fiber dosage. At this strength, relatively high strengths were achieved with no apparent workability issues.When the fiber content was more than 1.5%, it was found that the workability decreased and fiber balling occurred, in addition to some loss of strength due to problems with compaction and uniform distribution of fibers. M-35 concrete had the highest absolute strength values and the maximum increase in flexural strength of all the three grades of concrete tested. Despite this, there was significant improvement in all grades with the addition of fiber reinforcement, proving the versatility of the use of steel fiber chips in all strength grades of concrete. The study also proves that steel fiber chips from the machining waste can be employed as a feasible and environmentally friendly substitute for commercially produced steel fibers. Their use leads to reduction of waste, conservation of resources and sustainable construction and enhances the performance of concrete. So, for structural applications and pavement applications where higher tensile strength, flexural strength, toughness and higher crack resistance are required, steel fiber chip reinforced concrete is recommended. This material can offer engineering and environmental benefits and could be a good solution to future infrastructure projects.

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