Influence of carbon steel fibers on the flexural crack width of RC beam

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Abstract. Reinforced concrete beams are the significant structural elements in the structure. They improve resistivity against flexural loads. The concrete portion in the reinforced concrete beam is good in compression but at the time of bending reinforcement will take about the structural element. When the flexural stresses exceed the flexural capacity of the reinforced concrete beam cracks will occur at the flexural portion. In this investigation for avoiding and delaying flexural cracks, carbon steel fibres are incorporated into the concrete mix. The carbon steel fibres are added in concrete concerning the total volume of concrete. Different percentages like 0.5%, 1%, 1.5% and 2% of carbon steel fibres are added to the conventional concrete. Another side large amount of CO₂ emission occurs while manufacturing the cement in the industry. Because of that the cement content is replaced 30% with GGBS (Ground Granulated Blast Furnace Slag). The mix design used in this investigation is M30 with a water-cement ratio of 0.4. Cubes, cylinders and RC beams of 1.5 m X 0.23 m X 0.23 m are cast and placed in curing for 7 days and 28 days respectively. In this investigation single crack and multiple crack behaviour is analysed. The compression and split tensile strength of concrete are enhanced by incorporating carbon steel fibres in the conventional concrete. The RC beams with 28 days effective curing were tested under the loading frame of 2000T capacity. The result shows the initial crack propagation time is increased by increasing fibres content because at the time of crack propagation fibers present in the concrete mix will resist the entry of crack in the concrete and crack width is reduced by increasing fibres content compared with conventional concrete.

1. Introduction
Concrete is one of the heterogeneous mixes with materials like cement, aggregates and water. The applications of concrete are increased in day to day developed society [1]. One of the major components in concrete is Portland cement. Because of the heavy usage of concrete, the production and usage of OPC were increased simultaneously. For manufacturing 1 tone of OPC 1.5 tones of clay and limestone is required. The large amount of CO₂ is released while manufacturing the ordinary Portland cement. Because of this, investigations have been started identifying the alternate product to cement and also eco-friendly [2]. GGBS is one of the by-products of industrial raw materials that
exhibits excellent binding mechanism to concrete and is considered to be the best cement substitute among all alternatives. This replacement is used frequently as supplementary cemented materials [3].

GGBS is an iron-making by-product of blast ovens. It is produced with a high temperature between 1500 and 1600 degrees C and has a regulated mix of calcareous, iron ore and coke [4]. Additional iron ore was reduced to iron and the resulting slag by-products floating on the rock. More iron ore was reduced to iron and the remaining by-products of slack floating on the surface. It must be constantly immersed in enormous amounts of water [5] in the processing of GGBS. The suppression optimizes the cemented properties and shapes of granules identical to the ground sand. This “granulated” slag is then dried into and ground into a fine powder. Recently the UK has been substituted with cement each year for stopping 2 M tons of CO2 2.5 M tons of GGBS.

Usually plain concrete is excellent at compression, but therefore stress week. During dynamic loading situations, it exhibits cracks and failure will occur [6]. To overcome this situation reinforced concrete it means steel bars are inserted into the concrete to enhance the tensile behaviour. This is called as reinforced cement concrete. From the past, recent decades discrete and discontinuous short fibres were introduced into the construction industry to improvise the concrete tensile behaviour. Longevity and durability have increased when the fibres were applied to the concrete mix. Fibre-reinforced concrete is very rapidly utilized in recent years [7]. Various types of fibres such as synthetic and metallic are available in the market. In this investigation, carbon steel fibres are utilized to improve the concrete properties. Carbon steel fibres are nothing but addition of carbon content while manufacturing of steel fibres [8]. Because Steel fibres had a disadvantage, that are corroded when it is in a concrete matrix because of alkali action and carbonation. To avoid this corrosion action carbon steel fibre are introduced in this investigation, the carbon steel fibres are having carbon flame coating on the surface of the fibre to avoid corrosion effect and those shows good resistive nature against cracking while loads are applied on the concrete member [9].

2. Literature Review
The OPC finds B. Kaviya GGBS to be the best option to reduce CO2 emissions. 30%,40%,50% and 0.46% water-cement ratios are replacements for GGBS. GGBS The best results for M35 grade concrete were recorded from the experimental study. 30% substitution for GGBS gives. In addition to the GGBS substitution, the power parameters are reduced accordingly by more than 40% concerning OPC [1-2].

GGBS is used as a void filler for self-composting GVBS, which minimizes the total void content in j.vengadesh marshall Raman The GGBS shall be substituted by cement material of M30 grade concrete of 0 per cent, 25 per cent, 30 per cent, 40 per cent. The water-cement ratio is approximately 0.4. GGBS produces the best performance compared to normal concrete with 25 per cent of the substitution [3-4].

The mechanical properties of the concrete have been noted for Ashfaque Ahmad Jhiali with the addition of stainless steel yarn, achieving a greater strength than the standard version. By enhancing the functionality of the fibre content [5-6].

P.lakshmaiah Chowdary to study the GGBS effect on conventional M-20 grade concrete strength parameters with a 43 grade PPC. The rest of the mixtures substituted the cement with GGBS. The final results indicate that GGBS replacement is about 10 and 30 per cent and causes significant mechanical improvement over traditional resources. Having GGBS makes it more cost-effective [7].

Oguz Akkn Duzgun study the effect of steel fibers on the mechanical properties of pumice aggregate concrete. the unit weight and mechanical properties are reduced by replacing pumice aggregate[8]. The strength parameters are increased by adding of fibers compared with conventional concrete and hallow beams shows better ductility than solid beams [9].

A.safi the failure load and ductility property also increased by adding fibres to the conventional concrete. Flexural rigidity and ductility index is also studied. The ultimate load carrying capacity is increased by 49% compared with conventional beam specimen [10-11].
Masoud ghahremannejad conducted experiments on single cracking and multiple cracking analysis. By using synthetic fibres improves serviceability and number of cracks will be reduced [12]. The crack width is also reduced. Beam middle span deflection is reduced by increase fibres content [13-14].

Ashraf abdalkader to study the utilization of steel fibre in bending crack width control [15]. The addition of 1.0% of fibres increases 81% of the reduction of crack width. However, the wet density increases slightly and workability decreases as well [16-17].

3. Material Properties

3.1. Cement
The OPC 53-grade cement used in this study was IS: 12269-2013 and IS 4031-1988 was taken into this work. The test carried out on cement is 3.15 for its specific gravity. It takes 35 minutes to set the initial time and 240 to set the final time. Cement was 33 per cent consistency [13]. Properties shown table 1.

| S.NO | Material | % of composition |
|------|----------|-----------------|
| 1    | SiO₂     | 19.71           |
| 2    | Al₂O₃    | 5.20            |
| 3    | Fe₂O₃    | 3.73            |
| 4    | CaO      | 62.91           |
| 5    | MgO      | 2.54            |
| 6    | SO₃      | 2.72            |
| 7    | SO₃      | 0.90            |
| 8    | Na₂O     | 0.25            |
| 9    | LOI      | 0.96            |

3.2. Ground Granulated Blast Furnace Slag (GGBS)
For chemical composition and properties, GGBS is dependent on raw materials used in the iron production process shown in figure 1 and Table 2 and 3. GGBS a white powder with fineness greater than cement. Because of usage of GGBS for replacing of cement the properties of concrete may changes. Below are the physical and chemical features of GGBS [14].

![Figure 1. GGBS.](image-url)
Table 2. Chemical Composition.

| S.No | Chemical   | % of composition |
|------|------------|------------------|
| 1    | Calcium oxide | 40%              |
| 2    | Silica      | 35%              |
| 3    | Alumina     | 13%              |
| 4    | Magnesia    | 8%               |

Table 3. Physical Properties.

| S.No | Physical property   |
|------|---------------------|
| 1    | Colour              |
| 2    | Specific gravity    |
| 3    | Bulk density        |
| 4    | Fineness            |

3.3. Coarse Aggregate

In this analysis, the ground aggregate is obtained from the nearby quarry. Used maximum size is 20 mm and considered minimum of 12.5 mm, conforming by IS 383-1970 and IS 2389-1963 is also used for physical properties shown in table 4 [15].

Table 4. 20 mm & 12.5 mm coarse physical properties.

| Property                  | 20mm | 12.5mm | code          |
|---------------------------|------|--------|---------------|
| Specific Gravity          | 2.72 | 2.8    | IS 2389-1963 |
| Water Absorption          | 0.36%| 0.49%  | IS 2389-1963 |
| Impact Test               | 27.3%| 12%    | IS 2389-1963 |
| Bulk Density              | 1662(kg/m³) | 1666 (kg/m³) | IS 2389-1963 |
| Flakiness                 | 8.89%| 15.3%  | IS 2389-1963 |
| Elongation                | 10.1%| 16.2%  | IS 2389-1963 |

3.4. Fine Aggregate

The finely designed aggregate used in this study is considered to be the IS 383-70 natural river sand that goes by 4.75 mm sieve shown in table 5 [16].

Table 5. Fine aggregate physical properties.

| Property          | Normal Sand |
|-------------------|-------------|
| Fineness Modulus  | 2.7         |
| Specific Gravity  | 2.64        |
| Bulk Density      | 1623(Kg/m³) |
| Bulking of Sand   | 22.5%       |
| Silt Content      | 0.24%       |
| Zone              | II          |

3.5. Carbon Steel Fibers

The carbon steel fibres which is used in this investigation are collected from the fibre zone India shown in figure 2. The fibres have been manufactured to a nominal standard length of 50mm whilst some minor variations in fibre zone does exist due to the manufacturing process shown in table 6 [17].
Figure 2. Hook Ended Carbon Steel Fibers.

Table 6. Carbon Steel Fibers Physical Properties.

| Property         | Value              |
|------------------|--------------------|
| Type             | Hooked end         |
| diameter         | 0.75mm             |
| Length           | 50mm               |
| Tensile strength | 128.21Kg/mm²       |

3.6. Super Plasticizer
Based on recent research work of the R&D laboratories of the Master Builders solutions of BASF, MasterGlenium is a high-quality water plasticiser reducer. The Master Glenium is designed to express fresh concrete extraordinary rheological characteristics. This significantly improves the positioning and finishing of concrete and enables the pouring of concrete for all building activities shown in table 7.

Table 7. Properties of Super Plasticizer.

| Property          | Value                                      |
|-------------------|--------------------------------------------|
| Specific Gravity  | 1.09                                       |
| Chloride ion content | Less than 0.2%                           |
| Recommended Dosage| 0.5 to 1.5 litre per 100kg of cementations material |
| pH                | 7+/−1                                      |
| Aspect            | Light Brown Liquid                        |

4. Mix Proportion
The mixing template used in this study is M30 grade and GGBS weights are replaced by 30 per cent. The water Celcius ratio adopted is 0.4. To maximize the flexural strength of the component in the overall concrete volume, the concrete is applied to carbon steel fibres. The variations to this experiment M1, M2, M3, M4, M5 are planned. M5 is a regular blend, and the rest are all carbon steel fibres that add up to 0.5%, 1%, 1.5%, 2%, each shown in table 8 and 9.

Table 8. Mix Proportion for 1M³ of Concrete.

| Component          | Quantity          |
|--------------------|-------------------|
| Cement             | 270kg/m³          |
| Fine Aggregate     | 684kg/m³          |
| GGBS               | 115kg/m³          |
| Water              | 153 kg/m³         |
| Coarse Aggregate   | 1279kg/m³         |
| Super Plasticiser  | 3.8kg /m³         |
4.1. Design of Reinforced Cement Concrete Beam:
Generally concrete is a week in flexural strength to overcome this situation reinforced bars are introduced into concrete to enhance the flexural strength. In the design of reinforcement 3 cases are considered they are under the reinforced, balanced section, over reinforced. the section which is designed under over reinforced the concrete reaches to maximum stress than steel because of that sudden failure will occur. In a balanced section, both are will fail simultaneously. In under reinforced section, the steel will reach to maximum stress first because of this failure will occur very slowly for that all reinforcement designs are designed for under reinforced condition. In this investigation, the beam of 230mm*230mm*1500mm was designed to analyze the flexural strength of reinforced beams in figure 3.

![Figure 3. Reinforcement Detailing Of RCC Beam and Casting.](image)

Table 9. Different Types of Mix Proportions.

| S.No | Mix | Cement (Kg/m³) | GGBS (kg/m³) | Fine Gravels (kg/m³) | Gravels 20mm (Kg/m³) | Water (Kg/m³) | Super plasticizer (kg/m³) | Carbon steel fibers % | Carbon steel fibers (kg/m³) |
|------|-----|----------------|--------------|---------------------|---------------------|--------------|--------------------------|---------------------|--------------------------|
| 1    | M₁  | 270            | 115          | 684                 | 1279                | 153          | 3.8                      | 0                   | 0                        |
| 2    | M₂  | 270            | 115          | 684                 | 1279                | 153          | 3.8                      | 0.5                 | 12.52                    |
| 3    | M₃  | 270            | 115          | 684                 | 1279                | 153          | 3.8                      | 1.0                 | 25.04                    |
| 4    | M₄  | 270            | 115          | 684                 | 1279                | 153          | 3.8                      | 1.5                 | 37.56                    |
| 5    | M₅  | 270            | 115          | 684                 | 1279                | 153          | 3.8                      | 2                   | 50.08                    |
Main reinforcement is considered as 20mm having a length of 1500mm and stirrups are made with 12mm diameter bars. centre to centre spacing is 150mm for stirrups, the clear cover of 25mm is provided.

4.2. Phenomena and Methodology
The main phenomena involved in the carbon steel fiber reinforced concrete is the fibers which are used in this investigation are hooked end carbon steel fibers as shown in figure 2. External loads are applied on the concrete specimen when the loads exceeds the capacity of the specimen at that time concrete will undergoes cracking shown in figure 4. The incorporated fibers are distributed throughout the concrete in the mixing process. At the time of cracking the carbon steel fibers in side the concrete acts like a secondary reinforcement and the hooked ends are gripped the concrete portion and resist the crack propagation.

This research paper aims to control the cracks propagation in the reinforced concrete beam by using carbon steel fibres with different volume fractions according to its concrete volume. Collect and select materials that are based upon physical and chemical properties from various sources [10]. For the environmental and economic reasons, cement is replaced with 30 per cent GGBS. It's done casting cubes, cylinders and beams and it's curing for better results over 7 and 28 days. Conducting the tests for those specimens and compare the test result which is obtained. Finally, conclude our observations based on experimental results [11].

5. Testing and Results
5.1. Workability Test
Slump cone test is performed to assess the concrete workability. Normally the OPC performance depends on the water-cement ratio and the super plasticiser. In this investigation GGBS also replaced 30% to the cement, GGBS is fine material the workability is normally increased by the addition of GGBS. Carbon steel fibres are also incorporated into the mix because of that the workability is dropdown. The workability of the conventional mix is 80mm the workability was decreased by adding fibre to the concrete mix. In slump value for 0.5% adding of fibers is 72.5mm and 63mm, 52.5mm, 44mm for 1%,1.5%,2% of steel fibers respectively in figure 5.
5.2. Compressive Strength Test

The cubes of size 150mm×150mm×150mm are used in this investigation to identify the compression strength value. For each type of mix three cubes are cast for 7 days and 28 days testing. Thirty cubes are cast for 5 different types of mixes, placed in curing tank up to the testing date. Test results show that the compression strength of the material is increased by the addition of carbon steel fibres. Compression strength 7 days conventional specimen is 25N/mm² and 28 days conventional specimen is 40N/mm². Reinforced concrete with addition compared to the normal concrete fibre of 2% fibres compression values are increased to 41 N/mm² for 7 days test and 55N/mm² for 28 days test shown in figure 6 and 7.

![Figure 5. Workability Test on Different Percentage of Steel Fibres.](image)

**Figure 5. Workability Test on Different Percentage of Steel Fibres.**

![Figure 6. Testing of Specimen.](image)

**Figure 6. Testing of Specimen.**

![Figure 7. Different Steel Fiber compressive testing.](image)

**Figure 7. Different Steel Fiber compressive testing.**
5.3. Single Crack Analysis

In this investigation single crack analysis is nothing but flexural strength of unreinforced beam of 150mm*150mm*700mm. because of concrete brittleness, the failure will occur suddenly and single crack will be obtained at the time of failure. Single crack analysis test is conducted under UTM machine. The average load-carrying capacity of the unreinforced beam with conventional concrete is a little bit less in comparison with fibre reinforced concrete. The carbon steel fibers are added to concrete 0.5%, 1%, 1.5%, 2% respectively. The average failure load is 25.94 KN and average flexural strength is 4.62N/mm² for M₁ mix. The flexural strength of the fibre added is improved up to 1.5 per cent. Further 2% fibres are added to concrete but flexural strength is going down shown in figure 8 to 10.

![Figure 8. Testing of beam specimen for single crack analysis.](image)

![Figure 9. Different mix Vs Average Failure Load.](image)

![Figure 10. Different mix Vs Average Failure Strength.](image)

5.4. Multiple Crack Analysis:

Elcometer 900 one of the operating instrument The Elcometer 900 is an extremely simple measurement instrument designed to measure the width of cracks in concrete. Use for measuring crack
width in concrete. The graduated lighted dimension within a 50x lightening microscope permits the user to quickly determine the width of the crack by measuring the number of graduations. A metric scale is given to the microscope. To measure crack width first mark the cracks on the concrete portion and place the elcometer over the crack. Rotate lamp barrel to anticlockwise to switching the lamp. View crack through the eyepiece and for Concentration keep the body of the microscope and rotate the ring of focus. Use the visible size of the column to measure the width of the crack. Switch the lamp barrel in the direction of the clock to turn off the light after the measurement shown in figure 11 to 15.

In this investigation, multiple crack analysis is nothing but flexural cracks analysis of a reinforced concrete beam of 230mm*230mm*1500mm. to avoid the sudden failure reinforced bars are introduced into the concrete portion. Because of this major crack width is reduced and the number of cracks is increased with minor crack width. Carbon steel fibres also used to improve the failure load capacity. The average crack width for M1 mix is 1.84mm by adding os fibres no of cracks will increase but the crack width will be reduced for M5 mix of 2% fibres the average crack width is 1.01mm shown in table 10.

| Mix no. | Ultimate load (kN) | No. of Cracks | Total Crack Width (mm) |
|---------|---------------------|---------------|------------------------|
| M1      | 80                  | 5             | 9.2                    |
| M2      | 92.5                | 6             | 10.3                   |
| M3      | 99.3                | 8             | 10.4                   |
| M4      | 110                 | 8             | 11.23                  |
| M5      | 122.7               | 11            | 11.12                  |

Figure 11. Loading Frame.  
Figure 12. Tested Specimen.
6. Conclusion
The findings are listed below based on experimental results.
1. By adding GGBS, the cement gel enters the narrow vacuums because of its fineness. The concrete finally becomes more powerful than plain concrete.
2. The workability of concrete is decreased around 45% by incorporating carbon steels fibres by increasing the fibre content.
3. With the addition of fibre content, the compressive force is increased, 25N/mm² and 40N/mm² strength are obtained to normal concrete for 7 days and 28 days. The concrete with the addition of 2% of fibres the compression strength is increased 64% and 40% for 7 and 28 days respectively.
4. The average failure load and flexural strength of the unreinforced concrete beam is increased continuously with fibres added up to 1.5% it will increased 66% compared with conventional. the flexural strength is reduced by adding 2% fibres content.
5. With the addition of fibres, the reinforced concrete beam's overall load-carrying capacity increases 52.2% than the standard specimen.
6. The number of cracks are increases with the addition of fibres but the width of each crack is reduced because of that ultimate load carrying capacity is increased.
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In this project, Indian Codes are used
a. IS 12269 - 2013, Indian code of practice for ordinary Portland cement, 53 grade — specification.
b. IS 4031-1988, Indian code of practice for physical tests for hydraulic cement.
c. IS 2389-1963, Indian code of practice for a method of tests for aggregates for concrete.
d. IS 383-1970, specifications for coarse and fine aggregate from natural sources for concrete.
e. IS 456-2000, Indian code of practice for plain and reinforced concrete

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