Effect of Length of Fibers on Mechanical Properties of Normal Strength Concrete

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Abstract. Concrete as the most common building material possess very less tensile strength. To overcome this problem, different types of fibers are added with concrete matrix from from the ancient era. Investigation of fiber reinforced concrete reveals that short length fibers help in bridging micro cracks while long fibers are able to arrest macro cracks and also enhance toughness of the member. The combinations of different lengths of fibers are found to be more effective than mono length fibers for a fixed volume fraction of fiber. Combination of different lengths of fibers is termed as hybrid fiber and when different lengths of fibers are mixed in concrete it is termed as graded fiber. This investigation aims in finding out the enhancement of mechanical properties of a particular grade of concrete with addition of different lengths of fibers and with graded fiber with a fixed amount of fiber. M30 grade concrete with 1.5% weight of fiber is considered in this present investigation. The results shows that the mechanical strength of concrete increases with addition of fibers, decreases with long length of fibers with same volume fraction of fiber and increases with graded fiber. Workability decreases with addition of fiber, with higher length of fiber. There is enhancement of workability with graded fiber than same volume fraction of long fibers.

1. Introduction

During stacking of structure, the miniature airs out may up and proliferate after versatile zone. Short length strands or miniature filaments arbitrarily scattered in solid assistance to capture the launch of miniature breaks and upgrade the pre-splitting quality. Mechanical quality of solid ascents with increment in volume of filaments. The expansion of higher volume of strands prompts functional issues, for example, packaging, balling and decrease in usefulness, thus, explores have watched decrease in quality and sturdiness [1-3]. In a given volume if the shorter strands are utilized, closer will be their separating and simpler will be capturing opening of miniature breaks. These strands may at first add to postpone the augmenting the splits yet might be pulled out after the miniature breaks will be changed into full scale breaks. Long strands connect the breaks and improve the post-top misshapening of cement. Combination of short and long fibers provides better result than mono length fibers. The crux of the problem is borrowed from the idea of use of well graded aggregate rather than single graded coarse aggregate [1-13].

The aim of the present investigation is to study the effect of graded fiber on properties of normal strength concrete. M30 grade conventional concrete is considered for this investigation. Mono glass fibers with length of 6 mm, 12 mm and 20 mm are considered for this investigation. Graded glass fiber was
produced from these three lengths of fibers. The opportunity of the exertion is restricted to fiber dosage of 1.5% weight of cement. The experimental results were compared with theoretical results.

2. Experimental Program
In this phase materials and martial properties, casting procedure, testing and experimental results are presented.

2.1. Material and Material Properties
In this section, materials used for casting of cubes (150 x 150 x 150) mm$^3$, cylinders (150 mm dia. 300 mm height) and prisms (150 x 150 x 150) mm$^3$ are described. Properties of materials such as cement, gravel, sand, water and glass fiber are presented in the following sections.

2.1.1. Cement
53 grade Ordinary Portland cement (OPC) is used in the entire research program. Normal consistency was determined as 36% while specific gravity of the 53 grade cement was 3.12. Initial setting and final setting time from the test as per [8] was found 92 minutes and 350 minutes respectively. The 28 days compressive strength of cement was 56.2 N/mm$^2$.

2.1.2. Sand
River sand is used as fine aggregate. Sand properties confirms to [9]. The properties are mentioned in Table 1 along with coarse aggregate.

2.1.3. Gravel
Coarse aggregate such as gravel for the present investigation are taken from local area. Gravel is washed and dried before it is used for casting. Max. size of the coarse aggregate was 20 mm.

2.1.4. Water
Portable water freshly collected is used. It is colourless and odourless as [10].

Table 1. Properties of Fine and Coarse Aggregate

| Properties            | Fine Aggregate | Coarse aggregate |
|-----------------------|----------------|------------------|
| Specific gravity      | 2.61           | 2.7              |
| Bulk density          | 1600 kg/m$^3$  | 1450 kg/m$^3$    |
| Fineness modulus      | 2.70           | --               |
| Zone                  | Zone-III       | --               |
| Impact Value          | --             | 6.82%            |
| Crushing Value        | --             | 53.5%            |
| Water absorption      | --             | 0.5%             |

Table 2. Properties of Alkali resistant glass fiber

| Properties of Glass fiber | Values         |
|---------------------------|----------------|
| Tensile strength          | 1700 N/mm$^2$  |
| Young’s modulus           | 73 GPa         |
| specific gravity          | 2.6            |
| Specific surface Area     | 105 m$^2$/kg   |
| Diameter                  | 14 m           |
| Dosage of fiber           | 1.5% weight of cement |
2.1.5. Glass fiber
Single type of glass fiber was used in this study with different lengths. Glass fiber was used in this program are having properties as mentioned below. Figure 1 shows the glass fiber.

![Figure 1. Alkali Resistant Glass fiber](image)

2.2. Mix Design
Normal Conventional Concrete (NCC) of M30 grade was designed by using IS code - 10262:2019 [11] method and adding different sorts of fibre such as 6 mm, 12 mm, 20 mm with a fixed percentage i.e. 1.5 % weight of cement, the optimum percentage of glass fiber at which previous researchers have been found more strength as compared to normal concrete. The slump test and compaction factor test is carried out on the fresh concrete properties. The strength properties such as compressive strengths of normal conventional concrete and addition of 1.5 % of glass fiber with different lengths such as 6mm, 12mm and 20mm of the total weight of material of concrete were studied. The mix was prepared with ratio of 1: 1.1: 2.5. For this water cement ratio was taken 0.40. The control mix was 100 % concrete and 1.5 % glass fiber and variation of glass fiber length 6 mm, 12 mm and 20 mm. Here 0G represents glass fiber is nil, 12G represents only 12 mm glass fiber while GG represents graded glass fiber which is combination of 6 mm, 12 mm and 20 mm glass fiber.

| Mix Designation | 0G | 6G | 12G | 20G | GG |
|-----------------|----|----|-----|-----|----|
| Cement (%)      | 100| 100| 100 | 100 | 100|
| Glass fiber (%) (with weight of cement) | 0 | 1.5 | 1.5 | 1.5 | 1.5|
| Glass fiber length (mm) | 0 | 6  | 12  | 20  | 6 mm-0.5% |
| Aspect Ratio (L/d ratio) | 428.57 | 857.14 | 1428.57 | 428.57-(weight-0.5% of cement) |

2.3. Experimental Program
For finding out the compressive, flexural and split tensile strength of glass fiber concrete, six cubes, six cylinders and six number of prisms respectively of size mentioned earlier were prepared. Here concrete was first prepared and taken in a tray where the fibers were added uniformly. Workability test was
conducted and then specimens were cast. All specimens were cured in water at room temperature till taken for testing.

Table 4. Experimental Values

| Test Values                          | Designation | 0G  | 6G  | 12G | 20G | GG |
|--------------------------------------|-------------|-----|-----|-----|-----|----|
| Slump (mm)                           |             | 85  | 55  | 50  | 40  | 50 |
| 7 Days Comp. Strength (N/mm²)        |             | 28.17 | 35.18 | 34.62 | 31.6 | 34.2 |
| 28 Days Comp. Strength (N/mm²)       |             | 40.10 | 50.12 | 49.32 | 45.00 | 48.75 |
| 7 Days Split Tensile. Strength (N/mm²)|     | 3.56 | 4.03 | 3.91 | 3.56 | 3.9 |
| 28 Days Split Tensile. Strength (N/mm²)|         | 4.39 | 5.16 | 4.98 | 4.71 | 5.00 |
| 7 Days Flexural Strength (N/mm²)     |             | 3.76 | 4.94 | 4.78 | 4.33 | 4.78 |
| 28 Days Flexural Strength (N/mm²)    |             | 5.17 | 6.50 | 6.36 | 5.76 | 6.27 |

3. Interpretation of Test Results
This section deals with interpretation of results obtained on fresh and hardened concrete. On fresh properties workability test was conducted. In hardened state compressive, split tensile and flexural test was conducted. The test results presented in Table 4 was compared with the values of different codes.

3.1. Workability
In terms of slump, all mixtures exhibited satisfactory slump flows in the range of 85-40 mm, which is an indication of a good deformability. There was decrease in slump value with addition of fibers and there was reduction in slump value with long fibers than short fibers with same fiber content. The reason may be that the long fibers might be distributed uniformly in concrete matrix and arresting concrete matrix against flowing. Figure 2 shows the slump value of different mixes and percentage of reduction of slump with respect to control specimen G0. The graded fiber (combination of 6 mm, 12 mm and 20 mm fiber) showed better slump value. 0G, 6G, 12G, 20G and GG showed 35.29 %, 41.18 %, 52.94 % and 41.18 % decrease in slump value than the control specimen G0.

Figure 2. Slump Value of different mixes and percentage decrease in slump value w.r.t. 0G

3.2. Compressive strength
Compressive strength of concrete specimen prepared with 0G, 6G, 12G, 20G and GG was found to be 28.17 MPa, 35.18 MPa, 34.62 MPa, 31.6 MPa and 34.2 MPa in 7 days and 40.10 MPa, 50.12 MPa,
49.32 MPa, 45.00 and 48.75 MPa in 28 days respectively. The same is plotted in Figure 3. Figure 4 also represents the compressive value captured in computerized UTM during testing.

![Figure 3. Compressive strength Value of different mixes and percentage increase in compressive strength value w.r.t. 0G](image)

It is found that there was enhancement of compressive strength with smaller aspect ratio and strength decreased with higher aspect ratio with same weight of fiber content. The reason may be large amount of fibers in low aspect ratio available in arresting micro cracks than less number fibers in higher aspect ratio in same volume fraction of fiber content. 6G, 12G, 20G and GG with a volume fraction of 1.5% weight of cement exhibited an enhancement of 24.88 %, 22.90 %, 12.18 % and 21.41 % compressive strength over the control specimen 0G in 7 days respectively. The same was found to be increased 24.99 %, 22.99 %, 12.22 % and 21.57 % over the control specimen in 28 days respectively for 6mm, 12 mm, 20 mm and graded fiber of combination of above three fibers with a volume fraction of 1.5 %. Graded fibers exhibit better compressive strength than long length fibers of same fiber content.

![Figure 4. Cube test of specimen 0G](image)

3.3. Split Tensile Strength
The split tensile strength of concrete specimen without addition of fiber and with fiber of 1.5% of 6 mm, 12 mm, 20 mm and a combination of all fibers 0G, 6G, 12G, 20G and GG was found to be 3.56 MPa and 4.03 MPa, 3.91 MPa, 3.82 MPa and 3.90 MPa in 7 days respectively. The same for all these specimens were found to be 4.39 MPa, 5.16 MPa, 4.98 MPa, 4.71 MPa and 5.00 MPa in 28 days respectively.
The split tensile strength of specimen 0G, 6G, 12G, 20G and GG in 7 days and 28 days was presented in Table 5. The 7 days and 28 days test value along with different theoretical values calculated by codes is plotted against the percentage of slag in the Figure 5. Here it is found that Huste et al. predicts closely to the test values while the others overestimate. The increase in the split tensile strength of 6G, 12G, 20G and GG was found to be 13.24%, 10.05%, 7.40% and 9.73% over control specimen 0G respectively for 7 days split tensile strength. The increase in the split tensile strength of 6G, 12G, 20G and GG was found to be 17.48%, 13.39%, 7.31% and 13.76% over control specimen 0G respectively for 28 days split tensile strength and Plotted in Figure 6.

3.4. Flexural Strength
7 days Flexural strength of concrete specimens of 0G, 6G, 12G, 20G and GG was found to be 3.76 MPa, 4.94 MPa, 4.78 MPa, 4.33 MPa and 4.78 MPa respectively. The same for 28 days was found to be 5.17 MPa, 6.50 MPa, 6.36 MPa, 5.76 MPa and 6.27 MPa respectively for specimens of 0G, 6G, 12G, 20G and GG as shown in Figure 7.
Figure 7. 7 days and 28 days Flexural strength of different length of Fibers

The figures show that ACI-1985 approximately predicts the flexural strength. The increase in flexural strength of 6 mm fiber 6G with respect to control specimen 0G was found to be 31.55% in 7 days strength and the same was found to be 25.64% for 28 days strength. For 12 mm fiber and 20 mm fiber the value was found to be reduced. The reason has already been described in previous split tensile strength. The percentage of increase in 7 days and 28 days flexural strength of 6G, 12G, 20G and GG over 0G were presented in Figure 8.

Figure 8. Percentage increase in flexural strength in 7 days and 28 days over different length of Fibers

4. Conclusions
The tests were performed to determine the fresh and mechanical properties of fiber added concrete. From the test results and theoretical values following conclusions were drawn.

- There is decrease in workability of concrete with mixing of glass fiber. Higher aspect ratio glass fiber added concrete has lower workability value than lower aspect ratio glass fiber for same amount of fiber.
- There is enhancement of workability for graded fiber.
- Slump value of glass fiber concrete with fiber aspect ratio 1428.57 decreases 52.94% than that of concrete without fiber. The same was found to be 41.18% for graded fiber.
- Mechanical properties of concrete increases with addition of glass fiber.
Lower aspect ratio fibers are able to increase strength more than higher aspect ratio fibers for same amount of fiber in concrete. Increase in strength for graded fiber is more than fibers with more length.

Graded fiber has an enhancement of compressive strength 21.5\% over zero fiber content.

Maximum increase in split tensile strength is noticed as 17.48\% with aspect ratio 428.57 over concrete without fiber.

ACI-1985 closely predicts flexural strength.

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