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EFFECT OF STEEL FIBER ON PERFORMANCE OF HIGH PERFORMANCE FIBER REINFORCED CONCRETE

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ABSTRACT
Concrete is a brittle material. The present trend in concrete technology is toward increasing its strength and various properties like durability etc. to meet the demand of modern construction. The aim of this study is to see the effects of two different types of steel fibers in the concrete. In the present work, the Metakaolin were added in the percentage of 5, 10, 15 and 20 along with two different types of steel fibers in the percentage of 0.5, 1 and 1.5 to develop high performance fiber reinforced concrete. Result shows that there is minor increase in the compressive strength but major increase in flexural strength and split tensile strength after 28 days and 56 days of curing. It was also found that with increase in the fiber percentage, resistance towards acid attack and sulphate attack also increases.

1. INTRODUCTION

Concrete is a brittle material which is weak in tension and the tensile strength is found to be one tenth of its compressive strength. With such characteristics, concrete alone could not support such loads and stresses. The Concrete members are reinforced with continuous reinforcing bars in order to withstand these tensile stresses and to compensate for lack of ductility and thereby strength. Such steel reinforcement are effective in critical regions which are under high potential tensile and shear stresses. On the other hand, there are the micro-cracks present in plain concrete are main cause of its weakening in tension. On application of load, the micro cracks propagates within the matrix. The propagation of micro-cracks and thereby macro-cracks, cannot be arrested or slowed by the sole use of continuous reinforcement. The main role of fibers is to bridge the cracks that develop in concrete and increase the ductility of concrete elements. There is significant improvement in the post-cracking behavior of concrete containing fibers due to both plastic shrinkage and drying shrinkage due to the bridging action of the fiber and the concrete matrix. Presence of Metakaolin and fiber reduce the permeability of concrete and thus reduce bleeding of water. Some types of fibers produce greater abrasion resistance in concrete. Imparts more resistance to Impact load due to the increase in area under stress strain curve with infusion of fiber volume. Incorporation of Metakaolin and Randomly dispersed fibers in concrete help in reducing the crack width thus, reduces the permeability of concrete. Fibers also improve the mechanical properties of plain concrete such as split tensile strength, flexural strength, fracture resistance, resistance to impact, and resistance to dynamic loads. Concrete having Cement, Water, Aggregate, and uniformly dispersed or discrete fibers is called Fiber Reinforced Concrete (FRC). It is a composite obtained by adding a single type or a blend of fibers to the conventional concrete mix. Fibers can be in form of steel fibers, glass fibers, natural fibers, synthetic fibers, etc. In the present paper, we are focusing on the glass fiber and steel fiber effects on the mechanical properties of the concrete.

2. FIBER REINFORCED CONCRETE (FRC)

2.1 Mixing Of Fibers:

New manufacturing techniques and applications on fibers for concrete have been developed. These introduce various aspects of fiber reinforced concrete and introduced to market worldwide. Fibers can be used with the admixture to modify the hardening and setting of the cement by influencing the rate of hydration. Different type of admixtures are there to reduce the water content by reducing surface tension of water. They increase workability, accelerated and retarded rate of hydration of cements, and resistance to freeze and thaw conditions. They provided a significant improvement to the fiber-reinforced concrete used in the fields.

2.2 Role of Fiber in FRC:

Since concrete is a brittle material, main role of fibers is to bridge the cracks that develop in concrete and increase the ductility of concrete elements. There will be significant improvement in the post-cracking behavior of concrete containing fibers due to both plastic shrinkage and drying shrinkage. Concrete containing fibers also reduce the permeability of concrete and thus reduce bleeding of water. Some types of fibers produce greater abrasion resistance in concrete and imparts more resistance to Impact load due to the bridging action and efficient stress transfer.

2.3 Toughness Mechanism:

Toughness is ability of a material to absorb energy and plastically deform without rupture.

It can also be defined as resistance to fracture of a material when stressed. Stress strain curve for high fiber volume will have more toughness as the area under the stress strain curve is more which actually represent the toughness, the strain energy stored.

3. FACTORS AFFECTING THE FIBER REINFORCED CONCRETE

Following are the factors that affects the properties of the FRC:
- Volume of fibers
- Aspect ratio of fibers
- Orientation of the fibers
- Relative fiber matrix stiffness

VOLUME OF FIBERS:
Low volume fraction with less than 1% fiber volume is used in slab and pavement that have large exposed surface leading to high shrinkage cracking. Moderate volume fraction between 1 and 2 percent is used in Construction method such as Shortcrete & in Structures which requires improved capacity against delamination, spalling & fatigue. High volume fraction having fiber volume greater than 2% is used in making high performance fiber reinforced composites.

ASPECT RATIO OF FIBERS:
It is defined as ratio of length of fiber to diameter of fiber (L/d). Relative strength and toughness increases with increase in the aspect ratio but upto 75. But beyond 75, both Relative strength and toughness start decreasing.

ORIENTATION OF THE FIBERS:
It is observed that fibers aligned parallel to applied load offered more tensile strength and toughness than randomly distributed or perpendicular fibers.

RELATIVE FIBERS MATRIX STIFFNESS:
Modulus of elasticity of fiber must be more than of matrix for efficient stress transfer. Low modulus of fibers imparts more energy absorption while high modulus fibers imparts strength and stiffness. Low modulus fibers - Nylons and Polypropylene fibers. High modulus fibers - Steel, Glass, and Carbon fibers.

4. FIBER CEMENT INTERACTION

The effectiveness of fibers in enhancing the mechanical performance of the brittle matrix is dependent to a large extent on the fiber–matrix interactions. Three types of interactions are particularly important:
- Physical and chemical adhesion;
- Friction;
- Mechanical anchorage induced by deformations on the fiber surface or by overall complex geometry (e.g. crimps, hooks, deformed fibers).

The adhesional and frictional bonding between a fiber and cementitious matrix are relatively weak. They have however significant contribution and practical significance in the case of composites having high surface area fibers (e.g. thin man-made synthetic filaments such as carbon, referred to sometimes as microfibers, with diameters in the range of 10 µm

5. MATERIALS

The material used are cement, coarse aggregate, sand as fine aggregate water and steel fibers.
- Cement: ordinary Portland cement 43 grade.
- Fine aggregate: sand, locally available zone II with specific gravity 2.65 confirming with IS 383-1970
- Coarse aggregate: crushed stone of 20mm size of specific gravity 2.71 and 10mm size of specific gravity 2.68 confirming to 383-1970.
- Water: potable water for experiment.
- Steel fiber: Straight steel fiber and Crimped steel fiber are used with length 50mm and diameter 1mm, having aspect ratio 50.
- Mineral admixture: Metakaolin (MKP)
- Chemical admixture: MasterGlenium Sky 8866

6. RESULTS AND DISCUSSION

In the present work M60 grade of concrete is selected for the proportion 1:1.31:1.98 and water cement ratio 0.28 with 1% chemical admixture. In general to general ingredients, metakaolin are added in the percentage of 5, 10, 15 and 20. In addition to metakaolin, two different types of steel fibers that are added are 0.5, 1 and 1.5%.

6.1 Effect of Compressive Strength in HPFRC:
The compressive strength results are tabulated in tables below and variation for M60 grade is seen.

Results of the Compressive strength at 28 days and 56 days with different percentage of Metakaolin

Sr. No.	Metakaolin (%)	Compressive strength	
		28 days	56 days
1	0	59.16	61.5
2	5	61.20	64.6
3	10	62.50	66.2
4	15	66.20	68.4
5	20	64.40	67.8

Results of the Compressive strength for crimped Steel fiber

Sr. No.	Fiber (%)	Metakaolin (%)	Compressive strength	
			28 days	56 days
1	0.5	15	66.6	68.30
2	1.0	15	67.7	68.41
3	1.5	15	68.0	68.73

Results of the Compressive strength for straight Steel fiber

Sr. No.	Fiber (%)	Metakaolin (%)	Compressive strength	
			28 days	56 days
1	0.5	15	65.7	68.03
2	1.0	15	66.1	68.17
3	1.5	15	66.5	68.80

6.2 Effect of Split Tenile Strength in FRC:

The split tenile strength results are tabulated in the tables below and variation for M60 grade is seen.

Results of Split Tensile Strength Test at 28 days and 56 days with different percentage of Metakaolin

Sr. No.	Metakaolin (%)	Split tensile strength	
		28 days	56 days
1	0	2.98	3.09
2	5	3.13	3.41
3	10	3.80	4.16
4	15	4.13	4.37
5	20	4.02	4.23

Results of Split Tensile Strength for crimped steel fiber

Sr. No.	Fiber (%)	Metakaolin (%)	Split tensile strength	
			28 days	56 days
1	0.5	15	4.44	4.86
2	1.0	15	5.00	5.43
3	1.5	15	5.18	5.57

Results of the Split Tensile Strength for straight steel fiber

Sr. No.	Fiber (%)	Metakaolin (%)	Split tensile strength	
			28 days	56 days
1	0.5	15	4.23	4.40
2	1.0	15	4.31	4.62
3	1.5	15	5.06	5.25

6.3 Effect of Flexural Strength in HPFRC:

The flexural strength results are tabulated in the tables below and variation for M60 grade is seen.

Result of Flexural strength with different percentage of Metakaolin

Sr. No.	Metakaolin (%)	Flexural strength	
		28 days	56 days
1	0	5.83	5.98
2	5	6.13	6.26
3	10	6.94	7.10
4	15	8.95	9.22
5	20	8.09	8.26

Result of Flexural Strength for crimped steel fiber

Sr. No.	Fiber (%)	Metakaolin (%)	Flexural strength	
			28 days	56 days
1	0.5	15	9.81	9.92
2	1.0	15	10.5	10.48
3	1.5	15	11.31	12.51

Result of Flexural Strength for straight steel fiber

Sr. No.	Fiber (%)	Metakaolin (%)	Flexural strength	
			28 days	56 days
1	0.5	15	9.08	9.26
2	1.0	15	9.83	10.07
3	1.5	15	10.49	10.17

6.4 Sulphate Test

The results of change in mass and loss in compressive strength due to addition of 5% magnesium sulphate are tabulated in the tables below and variation with different types and percentage of fiber along with 15% metakaolin was seen.

Weight gain with crimped steel fiber due to sulphate attack

Sr. No.	Fiber (%)	Metakaolin (%)	Initial weight	Final weight	Percentage gain in weight
1	0	15	8.04	8.07	0.497
2	0.5	15	8.06	8.08	0.248
3	1.0	15	8.11	8.13	0.246
4	1.5	15	8.20	8.22	0.243

Weight gain with straight steel fiber due to sulphate attack

Sr. No.	Fiber (%)	Metakaolin (%)	Initial weight	Final weight	Percentage gain in weight
1	0	15	8.04	8.07	0.497
2	0.5	15	8.15	8.17	0.319
3	1.0	15	8.11	8.13	0.283
4	1.5	15	8.13	8.15	0.246

Loss in compressive strength with crimped steel fiber due to sulphate attack

Sr. No.	Fiber (%)	Metakaolin (%)	Initial compressive strength	Final compressive strength	Loss in compressive strength (%)
1	0	15	66.2	61.43	7.2
2	0.5	15	66.6	63.03	5.36
3	1.0	15	67.7	65.03	3.94
4	1.5	15	68	65.52	3.64

Loss in compressive strength with straight steel fiber due to sulphate attack

Sr. No.	Fiber (%)	Metakaolin (%)	Initial compressive strength	Final compressive strength	Loss in compressive strength (%)
1	0	15	66.2	61.43	7.2
2	0.5	15	65.7	62.06	5.54
3	1.0	15	66.1	62.56	5.35
4	1.5	15	66.5	63.66	4.27

6.5 ACID ATTACK TEST

The results of change in mass and loss in compressive strength due to addition of 2.5% sulphuric acid are tabulated in the tables below and variation with different types and percentage of fiber along with 15% metakaolin was seen.

Weight loss with crimped steel fiber due to acid attack

Sr. No.	Fiber (%)	Metakaolin (%)	Initial weight	Final weight	Percentage loss in weight
1	0	15	7.98	7.42	7.00
2	0.5	15	8.07	7.68	4.75
3	1.0	15	8.07	7.74	4.17
4	1.5	15	8.09	7.72	4.57

Weight loss with straight steel fiber due to acid attack

Sr. No.	Fiber (%)	Metakaolin (%)	Initial weight	Final weight	Percentage loss in weight
1	0	15	7.98	7.42	7.00
2	0.5	15	8.18	7.64	6.51
3	1.0	15	8.21	7.83	4.62
4	1.5	15	8.23	7.78	5.46

Loss in compressive strength with crimped steel fiber due to acid attack

Sr. No.	Fiber (%)	Metakaolin (%)	Initial compressive strength	Final compressive strength	Loss in compressive strength (%)
1	0	15	66.2	59.35	10.34
2	0.5	15	66.6	61.39	7.81
3	1.0	15	67.7	62.63	7.48
4	1.5	15	68.0	63.39	6.77

Loss in compressive strength with straight steel fiber due to acid attack

Sr. No.	Fiber (%)	Metakaolin (%)	Initial compressive strength	Final compressive strength	Loss in compressive strength (%)
1	0	15	66.2	59.35	10.34
2	0.5	15	65.7	60.28	8.24
3	1.0	15	66.1	60.96	7.77
4	1.5	15	66.5	61.98	6.80

7. CONCLUSION

- This study illustrates that it is possible to design HPFRC by incorporating Metakaolin with different proportions of steel fibers such as 0.5, 1.0 and 1.5%.
- Workability of concrete decreases with increase in percentage of Metakaolin replacement level.
- The compressive strength, split tensile strength and flexure strength were higher at 15% metakaolin replacement level.
- Minor increase in compressive but major increase in split tensile strength and flexure strength was observed on using crimped steel fiber and straight steel fiber.
- The split tensile strength and flexural strength were maximum when the optimum dosage of crimped steel fiber and straight steel fiber was 1.5%. However strength by crimped steel fiber was more as compared to straight steel fiber.
- The compressive strength, split tensile strength and flexural strength was found to be more when crimped steel fiber were used as compared to straight steel fiber.
- The compressive strength of concrete show better results at 15% replacement of Metakaolin and addition of 1.5% crimped steel fiber when immersed in sulphate and acid solution for 56 days. This is because the metakaolin makes the concrete dense due to formation of new compounds, and addition of fibers results in the bridging action. Thus the porosity of the concrete is reduced and there will be less effect of acid and sulphate, thereby making high performance concrete.

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