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Effect of Basalt Fibre on Mechanical Properties of Concrete Containing Fly Ash and Metakaolin

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ABSTRACT: Application of composites science and technology can impart a major influence on the production of high performance concrete for the enhanced service life of concrete structures. During the last three decades, research on Fibre Reinforced Concrete (FRC), one of the advanced composite materials, is carried out to enhance concrete toughness by using high-modulus fibres as substitute, partially or totally to the conventional reinforcement, for structural applications. In the present investigation, basalt fiber is chosen as reinforcement material. Basalt fibre is a single material fibre manufactured by melting of basalt and extruding the molten basalt through small nozzles to produce continuous filaments of basalt fibre. The basalt fibre used in the present study has a diameter of 13 µm and a length of 12 mm. As the addition of pozzolanic materials to concrete leads to pozzolanic reaction, 2.5 % of fly ash and metakaolin by weight of cement is added to concrete. The reaction involves the consumption of hydration product, $Ca(OH)_2$ and the production of CSH, which enhance the packing efficiency from micromechanics point of view. The grade of concrete chosen is M20 and the respective cubes, cylinders and beams are casted with and without basalt fibre reinforcement. The amount of basalt fibre added is 1% of the total mass of the concrete. Mechanical characterisation such as compression, split tensile and flexural tests are performed and the results show that, basalt reinforcement enhanced the split and tensile strength of the concrete.

KEYWORDS: Fibre reinforced concrete; basalt fibre; mechanical properties; micromechanics

I. INTRODUCTION

CONCRETE is widely used in the construction industry, as it can take up compressive stress significantly. However, the brittle nature and the inability of concrete to withstand tensile stress are the major limitations. In order to overcome these limitations of concrete, fibres are generally introduced to concrete. Addition of pozzolanic material with particle size smaller than that of cement improves the compressive strength of concrete. Different studies have been carried out by using varying amounts of different types of fibres. The fibres used for making fibre reinforced concrete are steel fibres, synthetic fibres, glass fibres and natural fibres.

The main hydration products of cement are calcium silicate hydrate (CSH) and calcium hydroxide ($Ca(OH)_2$). Out of these two, CSH contributes to enhancement of strength, whereas, $Ca(OH)_2$ adversely affects the durability of concrete. Pozzolanic materials like fly ash reacts with $Ca(OH)_2$ and produces CSH, which enhances strength. Also, addition of particles finer than cement helps to improve the particle packing in concrete.

II. LITERATURE REVIEW

Alavi et al (2012) studied the compressive strength, split tensile strength and impact resistance of FRC reinforced with steel and polypropylene fibres. Water-binder ratios of 0.46 and 0.36, steel fibers at 0.5% and 1% volume fractions and polypropylene fibers at 0.2%, 0.3% and 0.5% volume fractions were used. Results showed that as the volume fraction of fibers increased, the compressive strength and split tensile strength also increased. The results indicate that steel fibers, due to their high tensile strength, improved the tensile strength of the specimens more effectively than polypropylene fibers. Fibers in concrete also improved its impact strength. Steel fibers with hooked-ends exhibited a better performance than with using polypropylene fibers, because of their larger length, greater tensile strength and better cohesion due to their hooked-ends.

Krishna et al.(2011) studied the flexural and shear behaviour of polypropylene fibre reinforced fly ash concrete (PFRFAC) deep beams. The variables of study included the characteristic strength of concrete, f_{ck} (15 MPa, 20 MPa, and 25 MPa) and polypropylene fibre content (0%, 0.5% and 1%). The polypropylene fibre and 20% of fly ash as cement replacement are incorporated in all the concrete mix proportions considered in the study. The flexural strength of fly ash concrete deep beams increased significantly with the addition of fibres, the increase being 15% & 18%, 16% &18% and 16% & 20% for concretes of characteristic strengths 15 MPa, 20 MPa and 25 MPa respectively, with the increase of fibre content from 0% to 0.5% and 1%. The failure of the fibrous fly ash concrete deep beams was observed to be more ductile and gradual in comparison to plain concrete deep beams.

Ilker et al (2007) studied the effect of different fibres on the mechanical properties of concrete containing fly ash. The study presented the effects of replacement of cement (by weight) with three percentages (10%, 15% and 20%) of fly ash and effects of addition of steel and polypropylene fibers. The compressive strength was found to decrease on increasing the fly ash replacement percentage. Significant increase in compressive strength was observed in concrete containing shorter polypropylene and steel fibres. In the case of split-tensile strength, decrements were observed for fly ash concrete, but fiber addition provides improvements. It was observed that the bending strength of concrete produced with fibers increased compared to concrete produced without fibers and the bending strength decreased as the amount of fly ash is increased.
Cengiz and Okan (2009) studied the effect of steel fibres on concrete containing fly ash. Fly ash content used was 0%, 15% and 30% as replacement on mass basis, and fiber volume fraction was 0%, 0.25%, 0.5%, 1.0% and 1.5% on volume basis. The addition of steel fibers into concrete mixture did not improve its ultimate compressive strength. In general only small increase in compressive strength with increase in fiber content was observed. It was observed that steel fibers did not recover the compressive strength lost due to addition of fly ash. It was found that flexural strength increased as the fibre concent increased, but was found to decrease as the fly ash content is increased. The same trend was observed for split tensile strength.

There is a significant amount of conflicting information in the literature regarding the mechanical behaviour of fibre reinforced composites. Therefore, it is hardly surprising that there does not seem to be a general consensus about the effects of fibre inclusion on the strength characteristics of concrete.

III. EXPERIMENTAL WORK

A. Materials Used

1.Cement : In the present work 53 grade Ultra Tech cement is used for casting all cubes, cylinders and beams. The cement has uniform colour i.e. grey with a light greenish shade and is free from hard lumps.
2.Sand : The sand used for the experimental work conform to grading zone III. The sand is sieved through 4.75mm sieve to remove any particle greater than 4.75mm size.

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3.Coarse aggregate : Broken stones having the maximum size of 20mm was used as coarse aggregate in the present work.
4. Fly ash :Fly ash is the residue obtained from combustion of pulverized coal collected by the mechanical or electrostatic separators from the fuel gases of thermal power plants. The fly ash can be used in concrete either as an admixture or in part replacement of cement. In this study, fly ash is used in concrete as admixture.
5.Metakaolin : Metakaolin is a dehydroxylated form of the clay mineral kaolinite.
6. Basalt fibre :Basalt fibre is a material made from extremely fine fibres of basalt, which is composed of the minerals plagioclase, pyroxene, and olivine. The fibres used in the study are of 13 µm in diameter and 12mm in length. Some of the properties of basalt fibre are give in Table 1.

Table 1 Properties of Basalt fibre

Property	Value
Tensile Strength	4.84 GPa
Elastic modulus	89 GPa
Elongation at break	3.15%
Density	2.7 g/cm³
Composition	45 – 55 % SiO_2, 2 – 6 % alkalis 5–14% FeO, 14% Al_2O_3, 0.5–2 % TiO_2

7. Superplasticizer :SikaViscocrete, the superplasticizer supplied by Sika India Pvt. Limited is used in the present study. It is a third generation highly effective superplasticizer for concrete. Technical data related to superplasticizer is provided in Table 2.

Table 2 Properties of Superplastcizer

Sl.No.	Characteristics	Value
1	Colour	Dark brown liquid
2	Specific gravity	1.17
3	Air Entrainment	Maximum 1%
4	pH	7 to 8

8. Water : Water is an important ingredient of concrete as it actively participates in the chemical reaction with cement. In the present investigation, tap water is used for both mixing and curing purposes.

B.Scanning Electron Microscope

Microstructural characterisation of Cement, Fly ash and Metakaolin are carried out by using scanning electron microscopy.

C. Casting

Two series of cubes, cylinders and beams have been casted, one without basalt fibre and the other with basalt fibre. Both series have been casted by adding 2.5% of fly ash and metakaolin by weight of cement to enhance the pozzalonic activity and particle packing. The cubes are of size 150mm×150mm×150mm, cylinders are of diameter 150mm and height 300mm and beams are of size 500mm×100mm×100mm. The mix design for M20 grade of concrete is carried out based on IS 10262-1982. The amount of basalt fibre to be added is 1% of the total weight of cement, fly ash, metakaolin and sand. For the series of specimens with basalt fibre, in order to obtain workability, 0.5% of superplasctisizer by total weight of cement, fly ash, metakaolin and basalt fibre is added. A tilting type concrete mixer of 300 litres capacity is used for mixing. Fly ash and metakaolin are mixed separately before feeding to the mixer to ensure uniform mixing. Table 3 presents the details of mix proportion.

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Table 3 Mix Proportion

	Without fibre	With fibre
Cement	25.68 kg	25.68 kg
Fine Aggregate	36.61 kg	36.61 kg
Coarse Aggregate	79.6 kg	79.6 kg
Flyash	642 g	642 g
Metakaolin	642 g	642 g
Water cement ratio	0.5	0.5
Superplasticizer	-	137.9 ml
Basalt fibre	-	635.74

D. Curing

The specimens are demoulded after 24 hours of casting. Demoulded specimens are then transferred to curing tanks. Curing is carried out in separate plastic tubs filled with water.

E. Testing

1.Compressive test : Cubes of size 150mm×150mm×150mm have been tested after 28 days of curing. The test is conducted by using compression testing machine (CTM). The rate of loading given is 1000 N/s.

2.Spilt tensile test : Split tensile test has been conducted on cylinders of diameter 150mm and height 300mm. In order to avoid high compressive stress at the points of application of load, plywood strips of 25mm width and 3mm thickness are placed between the specimen and loading plates of CTM. The rate of loading applied is 500 N/s.

3. Flexural test : Flexural test has been conducted on beams of size 500mm×100mm×100mm. Four point bending method is employed to obtain the flexural strength of beams. The rate of loading applied is 30 N/s.

IV. RESULTS AND DISCUSSIONS

A.Particle size distribution

Particle size distribution raw materials such as cement, fly ash and metakaolinare shown in Fig 4.1.It can be observed from the fig. 4.1 that the cement and fly ash have similar particle size distribution, whereas, metakaolin contains a particle size distribution finer than that of both cement and fly ash. It is to be emphasized that in order to have tight matrix for uniform load transfer, the cementitious materials with different particle size distributions are chosen based on micromechanics point of view.

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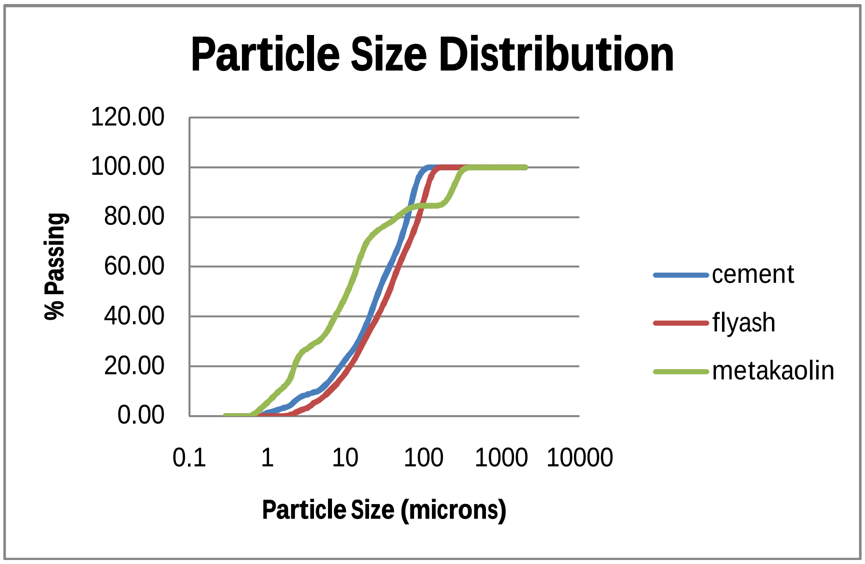

Fig 4.1 Particle size distribution of cement, flyash and metakaolin

B.Workability

Workability of the mix is reduced due to the addition of basalt fibres. A slump of 155 mm is retained for the mix containing basalt fibre by adding 0.5 %ofsuperplasticizer. For the control mix, the slump obtained is 130 mm with the same water-cement ratio without any plasticizers.

C.Scanning Electron Microscope

SEM images of metakaolin, cement and fly ash are shown in Figs.4.2 to 4.4. It can be inferred that the phase distributions in cement are well separated. In the case of metakaolin, the needle or rod like phases formed indicates the almino silicates presence. The spherical shape formed in the fly ash microstructure confirms the presence of reactive silica. As the concrete is a heterogeneous material, which is inherently full of flaws (such as pores, air voids, lenses of bleed water under coarse aggregates and shrinkage cracks), it is believed that addition of pozzalonic materials such as metakaolin and fly ash helps in improving the load transfer at interface either through formation of additional portlandite ($Ca(OH)_2$)or by filler affect.

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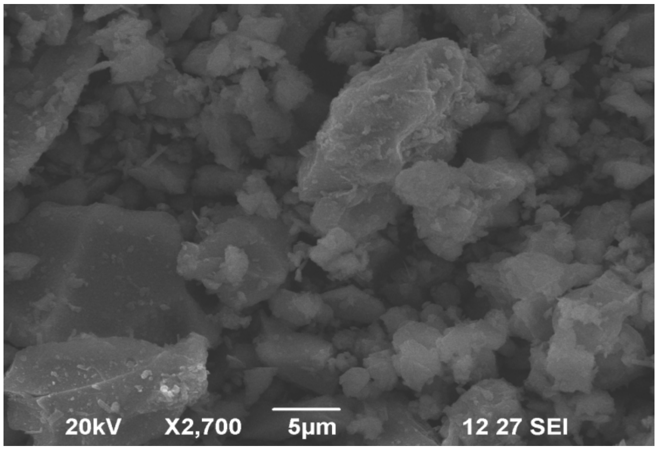

Fig 4.2 SEM Image of Cement

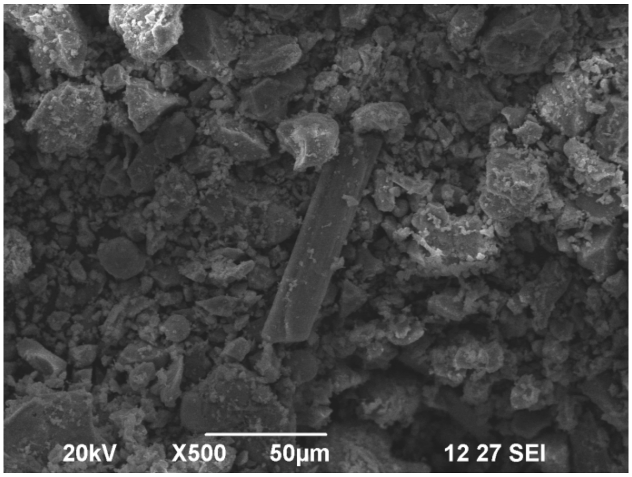

Fig 4.3 SEM Image of Metakaolin

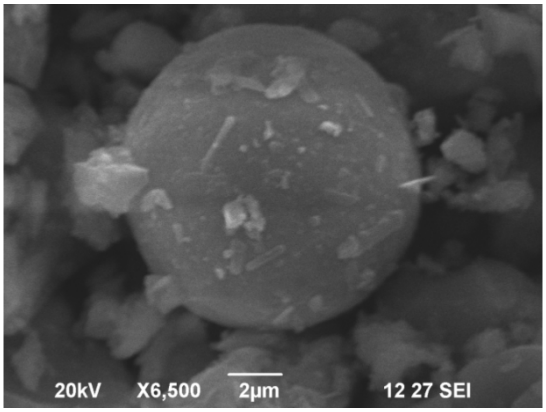

Fig 4.4 SEM Image of Flyash

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D Mechanical Characterization

Results of mechanical strength of the concrete in the presence and absence of the basalt reinforcement are shown in Fig 4.5. It is understood from the results obtained for the compressive strength of concrete without fibres is found to be 53.61 MPa. Whereas, the compressive strength of concrete with 1% basalt fibresis found to be 52.65 MPa.Thesplit tensile and flexural strength has enhanced for the basalt fiber reinforced concrete as the values are 4.53 MPa and 6.06 MPa with respect to 3.21 MPa, 4.05 MPa for control mix respectively. Hence, the basalt fiber inclusion enhanced the split tensile and flexural strength of concrete.

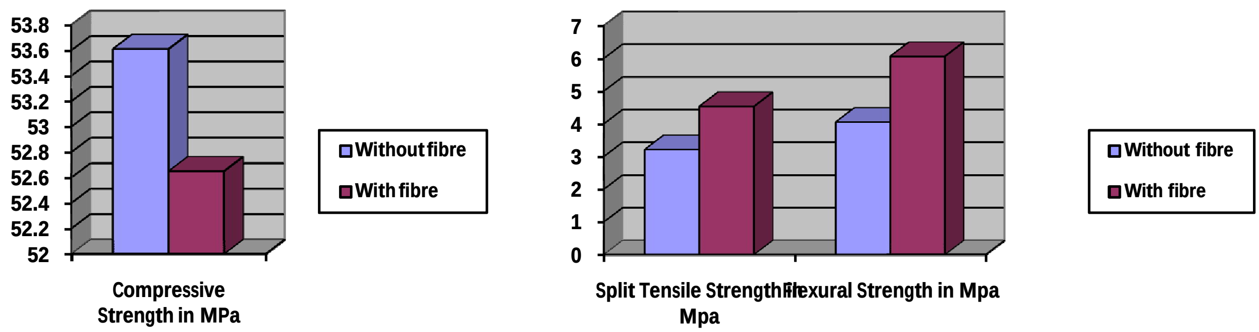

Fig 4.5 Comparison of Compressive, Split tensile and Flexural strength with and without fibres

In order to prove the interface mechanism behind the fiber reinforced concrete, representative samples has been cut from the failed specimens after flexural test and probed by SEM. In the SEM image as shown in Fig 4.6, it can be observed that the Calcium hydroxide ($Ca(OH)_2$) lining can be seen at the interface of cement matrix and fibre. Also, a highly densed CSH microstructure is formed, which indicates the normal rate of hydration of calcium and silicates in the presence of basalt fibre. The rod like structure of basalt fibre observed at the interface of cementitious and aggregate matrix could probably be the reason for the increased split tensile and flexural strength of concrete, as it bridges or connects the weak and strong matrix upon loading.

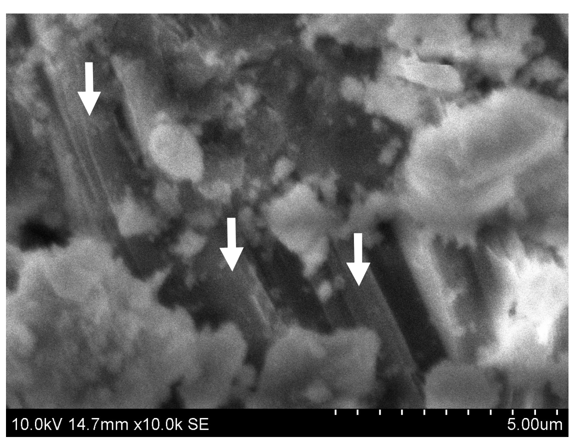

Fig 4.6 SEM – Hardened concrete with basalt fibres

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V. CONCLUSIONS

Based on the studies conducted, it is observed that the basalt fiber inclusion enhanced the split tensile and flexural strength of concrete. Through the SEM analysis, it is confirmed that the rod like structure of basalt fibre observed at the interface of cementitious and aggregate matrix could probably be the reason for the increased split tensile and flexural strength of concrete, as it bridges or connects the weak and strong matrix upon loading. However, the quantitative nature of this benefit is difficult to determine, as it is required to conduct further studies to prove, which is also authors future scope of work, as well.

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