Performance of Ternary Blended Fiber Reinforced Concrete under Flexure with Metakaolin Mixed with Fly Ash

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Abstract **- Concrete is most used construction material because of ease of construction and its properties like compressive strength and durability. It is difficult to point out another material of construction which is versatile as concrete. Several admixtures have been developed to improve the strength and workability properties of concrete. Of all admixtures used in concrete metakaolin occupies a special position for quite a few reasons. The improvement increase in compressive strength, flexural strengths, reduces the permeability and bleeding. The present experiment is carried out to investigate the behavior of compressive and flexural strength of ternary blended steel fiber reinforced concrete with 0%, 6%, 8% of metakaolin and 30% of fly ash by weight of cement as partial replacement of cement and addition of 0%, 0.5%, 0.75%, and 1% of crimped steel fibers with aspect ratio of 80. Compressive strength of concrete is measured by testing standard cubes (150mmx150mmx150mm) at the age of 7 and 28 days, Shear strength of concrete is measured by testing beams (1400mmx100mmx150mm) at the age of 28 days.**

Key words**: Metakaolin,compressive strength, flexural strengths, Fibre Reinforced concrete and mixed flyash.**

I. Introduction

Concrete is one of the most extensively use construction materials in the world, with about two billion tons of utilization worldwide each year. It is attractive in many applications because it offers considerable strength at a relatively low cost. Concrete can generally be produced of locally available constituents, can be cast in to wide variety of structural configurations, and requires minimal maintenance during service. However, environmental concerns, stemming from high-energy expense and CO_2 emission associated with cement manufacture, have brought pressures to reduce consumption through the use of supplementary materials.

Metakaolin (MK) is a pozzolanic material. It is obtained by the calcination of kaolinitic clay at a temperature ranging between 500 °C and 800 °C. The raw material input in the manufacture of metakaolin (Al2Si2O7) is kaolin.

Metakaolin on reaction with Ca(OH)2, produces CSH gel at ambient temperature and reacts with CH to produce aluminacontaining phases, including C4AH13, C2ASH8, and C3AH6 [1,2].

1.1 Uses of metakaolin Metakaolin finds usage in many aspects of concrete: • High performance, high strength and lightweight concrete • Precast concrete for architectural, civil, industrial, and structural purposes • Fiber cement and ferrocement products • Glass fiber reinforced concrete • Mortars, stuccos, repair material, pool plasters

1.2. Advantages of using metakaolin • Increased compressive and flexural strengths • Reduced permeability • Increased resistance to chemical attack • Increased durability • Reduced effects of alkali-silica reactivity (ASR) • Reduced shrinkage due to particle packing, making concrete denser • Enhanced workability and finishing of concrete • Reduced potential for efflorescence • Improved finishability, color & appearance[3].

For the beam flexural behavior, steel fibres are generally found to have aggregate much greater effect on the Moment of Resistanceof SFRC than on either the compressive or tensile strength, with increases of more than 100%having been reported. The increases in Moment of resistence is particularly sensitive, not only tothe fibre volume, but also to the aspect ratio of the fibres, with higher aspect ratio leading tolarger strength increases [6]. Flexural or shear failure are the two main failures occurs in reinforced concrete beams. Shear strength of concrete beam is a complex phenomenon that is still not very well understood. When bending stresses is more than shear stresses than flexural failure occurs mostly in long span beam (slender beam) and deep beam fails in shear below the ultimate flexural capacity of beam [7].

The experiment programme carried out with standard cubes (150x150x150mm), standard beams (1000x80x100mm) and prism were casted and tested for finding the flexure strength property of plain cement concrete and ternary blended steel fiber reinforced concrete and compared.

II. MATERIALS AND METHODS

The materials used in this experimental study are cement, fine aggregate, coarse aggregate, water, steel fiber, metakaolin , fly ash and super plasticizer.

FIBER

Crimped steel fiber was used in the present investigation crimped steel fiber manufactured by Stewals India Private ltd, Nagpur the properties of crimped steel fiber are given in table 4.9 confirming to ASTM A820 STANDARD.

Pozzolonic materials are finely divided siliceous and aluminous materials and have little or no cementitious value and in the presence of moisture at ordinary temperature, The engineering benefits likely to be derived from the use of pozzolona in concrete include improved resistance to thermal cracking because of lower heat of hydration, enhancement of ultimate strength and impermeability due to pore refinement, a better durability to chemical attacks such as acid, sulphate water and alkali-aggregate expansion.

FLY ASH ash produced in small dark flecks by the burning of powdered coal, the classes depends on its calcium content, in recognition of the difference in behavior between low and high lime fly ashes. These classes are as follows:

Type F, low calcium, 8% CaO

Type CI, intermediate calcium, 8–20% CaO

Type CH, high calcium, .20% CaO

ADVANTAGE OF FLY ASH IN CONCRETE

The technical benefits of using fly ash in concrete are numerous. The various advantages found by different investigators in India are summarized below:

- Superior Pozzolonic action
- Reduced water demand (for fly ash low carbon content and high fineness)
- Improved workability
- More effective action of water reducing admixtures
- Reduced segregation and bleeding
- increases setting time but remains within limits
- Less heat of hydration
- Less drying shrinkage
- Higher ultimate compressive strength, tensile, flexural and bond strength
- Higher ultimate modulus of elasticity.
- Reduced alkali-aggregate reaction
- Improved freezing and thawing

METAKAOLIN

A dehydroxylated form of the clay mineral kaolinite. Rocks that are rich in kaolinite are known as china clay or kaolin, traditionally used in the manufacture of porcelain. The particle size of metakaolin is smaller than cement particles.

Pozzolanic reaction in concrete

C_3S / C_2S (clinker) + H_2O ----> Calcium Silicate Hydrates (C-S-H) + $Ca(OH)_2$

$Ca(OH)_2$ + MK ---> C-S-H pouzz. + crystalline products (C_2ASH_8 , C_4AH_{13}, C_3AH_6)

Highly-reactive pozzolona with high specific surface When used in concrete, Replacement level of PC will depend on the nature of the constituents and reaction time Produces significant pore refinement modifies water transport properties and diffusion rates of harmful ions.

Enhances several mechanical (early-age compressive strength, flexural strength) and durability properties (chemical attack, ASR expansion, sulphate resistance, F/T cycles) of concrete.

FIBER REINFORCED CONCRETE

Fiber reinforced concrete is the composite material essentially consisting of conventional concrete or mortar reinforced by the random dispersal of short, discontinuous, and discrete fine fibers of specific geometry. There are many kinds of fibers, no matter metallic or polymeric, widely used in concrete engineering for their advantages [12–16]. In fact, no single fiber-reinforced concrete has the perfect mechanical properties. Recently, many researches have an orientation to discuss the mechanical properties of the hybrid fiber-reinforced concrete, such as a proper proportion between carbon fibers and polypropylene fibers [17], glass fibers and polypropylene fibers [18], or carbon fibers and glass fibers to concrete [19].

Steel fibers can be defined as discrete, short lengths of steel having ratio of its length to diameter (i.e. aspect ratio) in the range of 20 to 100 with any of the several cross-section, and that are sufficiently small to be easily and randomly dispersed in fresh concrete mix using conventional mixing procedure (ACI 544.IR 1996).

FIBRE MECHANISM

Fibers work with concrete utilizing two mechanisms: the spacing mechanism and the crack bridging mechanism.

FIBRE - MATRIX INTERACTION

The tensile cracking strain of cement matrix (less than 1/50) is very much lower than the yield or ultimate strain of steel fibers. As a result, when a fibre reinforced composite is loaded, the matrix will crack long before the fibers can be fractured.

Once the matrix is cracked the composite continues to carry increasing tensile stress; the peak stress and the peak strain of the composite are greater than those of the matrix alone and during the inelastic range between first cracking and the peak, multiple cracking of matrix occurs as indicated in the Figure 1.1.

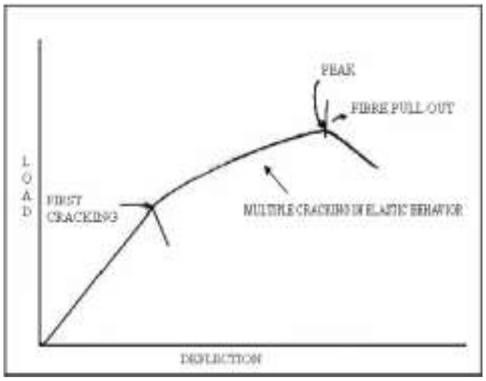

Figure 1.1 Fibre mechanism

BRIDGING ACTION

Pullout resistance of steel fibers (dowel action) is important for efficiency. Pullout strength of steel fibers significantly improves the post- cracking tensile strength of concrete. As an SFRC beam or other structural element is loaded, steel fibers bridge the cracks, as shown in Figure 1.2. Such bridging action provides the SFRC specimen with greater ultimate tensile strength and, more importantly, larger toughness and better energy absorption

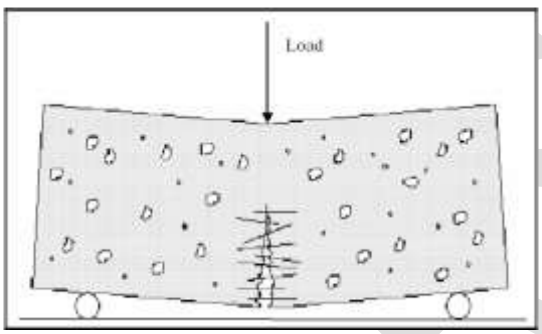

Figure 1.2 Fibre Pull-out

III. LITERATURE REVIEW

Yoon-keun kwak et-al, has conducted an experiment on reinforced concrete beams with three steel fiber-volume fractions (0, 0.5, and 0.75) and three span-depth ratios (2, 3, and 4) and two compressive strength. and he concluded that 1) the nominal stress at flexure cracking and ultimate flexure strength increases with increasing fiber. the nominal stress at flexure cracking and ultimate flexure strength increases with decreasing flexure span- depth ratio and with increase in compressive strength. as the fiber content increased, the failure mode changed from flexure to flexure [11].

Choi, kyoung-kyu et al, has made an attempt to find flexure strength of steel fiber-reinforced concrete beams without web reinforcement and concluded that the addition of steel fibers to concrete effectively improves the flexure strength of concrete. This is because the steel fibers can transfer tensile stress across crack surfaces, which is called the crack-bridging stress. Due to such material characteristics of the steel fibers, the flexure strength of a fiber reinforced concrete beam increases. Furthermore, the failure mode of the beam is changed to be more ductile. Also, the steel fibers can prevent excessive diagonal tensile cracking and localization of the tensile crack damage. Therefore, the steel fibers can increase the effective stiffness of the beam after diagonal tensile cracking occurs and can decrease the deflection of the beam [5].

Remigijus šalna, et al has submitted a paper on influence of flexure span ratio on load capacity of fibre reinforced concrete elements with various steel fibre volumes. This paper analyses the influence of steel fibre volume and flexure span ratio on the strength of fibre reinforced concrete elements in various states of stress. 36 beams with three different flexure spans (*a/h* = 1, 1.5, and 2) and three different fibre volumes (1, 1.5, and 2 %) were tested to examine how these factors influence the behavior of such elements. Test results suggest that steel fibre volume and flexurespan can increase load capacity, plasticity and cracking [4].

A. Shah et al, have made an attempt to investigate the flexure capacity of high strength concrete beams. The flexure capacity of the concrete beams having stirrups is assumed as the sum of individual contributions of both the concrete and flexure reinforcement. The variables considered were longitudinal reinforcement and flexure span to depth ratios. The beams are casted without and with flexure reinforcement to study the contribution of the stirrups in resisting the flexure. The beams were tested under the concentrated load at the mid span. The test results were analyzed for the contribution of stirrups, the effect of longitudinal steel and flexure span to depth a/d ratios. And they concluded that the assumption of summing the individual contribution of steel and concrete for theflexurestrength of reinforced beams is not proved[8].

P. Murthi et al, has presented a detailed experimental investigation on the acid resistance of ternary blended concrete immersed up to 32 weeks in sulfuric acid (H_2SO4) and hydrochloric acid (HCl) solutions. The results are compared with those of the control and binary blended concrete. Astm class f fly ash was considered to develop the binary blended concrete at the replacement level of cement as 20% by weight. Then metakaolin was considered to develop the ternary blended concrete and the replacement of cement in the ternary system by metakaolin was suggested as 8% of total powder content by weight. The variable factors considered in this study were concrete grades (m20, m30 and m40) and curing periods (28 days and 90 days) of the concrete specimens. The parameter investigated was the time in days taken to cause 10% mass loss and strength deterioration factor of fully immersed concrete specimen in a 5% H_2SO4 and 5% HCl solutions. The investigation indicated that the ternary blended concrete prepared by 20% fly ash and 8% metakaolin performed better acid resistance than the ordinary plain concrete and binary blended concrete[9].

G. Fathifazl et al has made an attempt to study the flexure performance of reinforced concrete (RC) beams made with coarse recycled concrete aggregate (RCA). In this RCA is treated as a two-phase material comprising of mortar and natural aggregate therefore to proportion the concrete mixture with RCA, the relative amount and properties of each phase are considered separately. Using the new mix proportioning method, several beams were designed and tested to study the effect of a number of parameters including the flexure span-to depth ratio and beam size on the serviceability and strength of RCA concrete beams without flexure reinforcement. For each beam its load–deflection curve, flexure formations, diagonal cracking load, crack pattern, ultimate flexure strength and failure modes were determined and they concluded that the flexure performance of RC beams made with RCA can be comparable, or even superior, to that of beams made entirely with natural aggregates at both serviceability and ultimate limit states, provided the proposed mixture proportioning method is used. Furthermore, the simplified methods of ACI and CSA standards as well as Euro code 2 were found applicable to all reinforced RCA-concrete beams[10].

IV. EXPERIMENTAL ANALYSIS

Here the behavior of reinforced concrete beams in flexure can be explained cracking stage

CRACKING STAGE

Before cracking, the reinforced concrete beam acts more or less like a homogeneous beam. The flexural stress (f) across any section are given by the classical formula

$$f = \frac{M}{I}y = \frac{6M}{bd^2}$$

Where M= bending moment, b=width of beam, d= depth of beam

When flexure displacement occurs along an bottom crack, dowel action in reinforcements gets mobilized. When the two faces of a flexural crack of moderate width are given a flexure displacement relative to each other, a number of coarse aggregate particles projecting across the crack interlock with each other generate significant flexure resistance.

As the applied flexure force is increased the dowel action is the first to reach to capacity after which a proportionally large flexure is transferred to aggregate interlock. The aggregate interlock mechanism is probably the next to fail, necessitating a rapid transfer of a large flexure force to the concrete compression zone, which as a result of this sudden flexure transfer, the beam often fails abruptly and explosively.

4.1 FAILURE IN FLEXURE

Principal failure mode of reinforced concrete components, after flexure, is shear.

Flexure cracks form where the flexural tension stresses are greatest, for example at the bottom of the mid span segment of a simply supported beam. Cracks due to shear forces form where the tension stresses due to shear are greatest, for example near the supports of a simply supported beam. he figure 1.3 below indicated the cracking patterns of beam andprism.

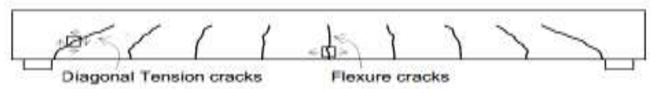

Figure1.3Crack pattern in beams and prism

INFERENCE ON TEST RESULTS

Compressive strength of various concrete mixtures with different percentage of metakaolin and different percentage of fly ash at 28day's are mentioned in table number 1.

S.No.	Mix ID %	Compressive strength (MPa)			
		Fi(0%)	Fi(0.5%)	Fi(0.75%)	Fi(1%)
1	(C70+FA30)MK0	37.8	38.2	42	39
2	(C70+FA30)MK6	36.6	39.1	38.3	37.8
3	(C70+FA30)MK8	36	40.7	39.4	40.4

C- % of Cement(OPC), FA- %Fly ash, MK% of metakolin and Fi- Fiber percentage.

Table number 1: compressive strength of Metakaolin and Flyash.

Flexure strength of various concrete mixtures with various percentages of steel fibers

The flexural strength of various concrete mixtures with different percentage of metakaolin and different percentage of fly ash at 28day's are mentioned in table number 2.

S.No.	Mix ID %	Prism Flexural strength (N/mm²)			
		Fi(0%)	Fi(0.5%)	Fi(0.75%)	Fi(1%)
1	(C70+FA30)MK0	7.91	11.54	14.25	13.25
2	(C70+FA30)MK6	6.38	13.6	13.9	14.82
3	(C70+FA30)MK8	7.66	12	15.75	16.87

Table number 2: Flexural strength of Metakaolin and

Flyash.

Beam flexural strength of various concrete mixtures with various percentages of steel fibers are mentioned in the below table 3.

S.No.	Mix ID %	Beam Flexural strength (N/mm²)			
		Fi(0%)	Fi(0.5%)	Fi(0.75%)	Fi(1%)
1	(C70+FA30)MK0	4.23	6.67	9.01	10.36
2	(C70+FA30)MK6	3.98	8.23	10.33	10.12
3	(C70+FA30)MK8	5.11	7.11	11.01	11.98

Table 3.Beam flexural strength of various concrete mixtures

V. RESULTS AND DISCUSSIONS

1. Addition of fibers along with fly ash and metakaolin increases the flexure strength of concrete.
2. In addition of fiber in concrete the flexure strength increases thus giving the good results for flexure strength
3. The addition of 1% crimped fiber in concrete along with 8% metakaolin and 30% Fly ash of remaining cement can give optimum but at the same time compressive strength of concrete decreases
4. The addition of 0.75% crimped fiber in concrete along with 8% metakaolin and 30% Fly ash of remaining cement can give optimum compressive strength and flexure strength.

VI. CONCLUSIONS

GENERAL From the experimental investigations on flexure strength of concrete containing steel fibers, metakaolin and fly ash the following conclusions are drawn.

Conclusions

- Steel fibers are crack arrestors.
- Concrete beams without fibers failed in flexure which corresponds to sudden failure along a single flexure crack.
- Optimum percentage of concrete mix containing metakaolin and fly ash as partial replacement of cement was found to be 8% and 30% respectively.
- Addition of steel fiber consistently decreased crack spacing's and sizes, increased deformation. capacity and changed a brittle mode to a ductile one.
- Fiber addition improves ductility of concrete and its post-cracking load-carrying capacity.
- The addition of metakaolin as second mineral admixture to form the ternary blended concrete improves the initial age strength development.
- Addition of steel fibers ranging from 0% to 1.0% by volume of concrete enhances the flexure stress better compared to compressive stresses. The maximum increase in strength is achieved for concrete mix having 1.0% fiber content.flexure strength were increased
- Concrete mixture with 8% metakaolin and 30% fly ash as replacement of cement along with 0.75% fiber content had shown significant improvement in various

Ternary blends of OPC with metakaolin and fly ash are particularly useful to render greater durability to concrete.

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