Journal of Academia and Industrial Research (JAIR)
Volume 3, Issue 5 October 2014

ISSN: 2278-5213

RESEARCH ARTICLE

Optimum Dose of Metakaolin in Steel Fibre Reinforced Portland Pozzolona Cement Concrete

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Abstract

Metakoline, a highly reactive pozzolona, reacts with the excess calcium hydroxide resulting from hydration of cement and produces calcium-silicate-hydrate (C-S-H) and calcium alumina silicate hydrates. It is quite useful material for improving concrete quality by enhancing strength and reducing setting time and may prove to be a promising supplementary material. This study presents the effect of metakaolin (as a partial replacement of portland pozzolona cement (PPC)) on strength of steel fibre reinforced concrete. An experimental investigation was carried out to evaluate the compressive and split tensile strength of steel fibre reinforced concrete made using PPC and 1% of steel fibre. The PPC replacement (with metakaolin) level varied between 10-16% by weight of cement at an interval of 1%. M-25 referral mix at 0.46 water cement ratio was used. The cube specimen and cylinder specimen were cast and tested for determination of compressive and split tensile strength of concrete at different replacement levels. It was observed that at 12% replacement level, compressive and split tensile strength increased substantially as compared to the referral concrete.

Keywords: Metakoline, concrete quality, portland pozzolona cement, split tensile strength, M-25 referral mix.

Introduction

Concrete is most used versatile construction material all over the world but brittle in nature. Addition of fibre and pozzolanic material, various properties of concrete viz., workability, durability, strength, resistance to cracks and permeability can be improved and ductility to some extent be resorted. Conventional concrete mixes are modified with addition of admixtures and supplementary cementious materials (SCM). Addition of admixtures and SCM improve the microstructure strength of concrete. Fine pozzolana particles, dissipated in the matrix generate a large number of nucleation sites for the precipitation of the hydrated products. This happens due to the reaction between the amorphous silica of the pozzolanic material and calcium hydroxide, produced during the hydration of cement. Several researches have been so far worked out to find the use of various pozzolanic materials in Ordinary Portland Cement (OPC) however; their use in PPC concrete is still dearth area for research. Metakaolin is used as supplementary cementious material to enhance the mechanical properties of concrete and steel fibre is used to enhance the structural property of concrete, specially tensile and flexural strength. Steel fibre enhances properties of concrete such as fatigue resistance, abrasion resistance, permeability, impact resistance etc. Metakoline, a highly reactive pozzolana, reacts with the excess calcium hydroxide resulting from hydration of cement and produces calcium silicate hydrate and calcium alumina silicate hydrates (Courard *et al.,* 2003).

It is quite useful material for improving concrete quality by enhancing strength and reducing setting time and may prove to be a promising material for manufacturing high performance concrete (Li and Ding, 2003). Metakaoline may be used as supplementary cementitious material in concrete to reduce the cement consumption and permeability; increase strength and rate of strength gain and make more durable concrete (Khatib and Wild, 1998; Aquino *et al.,* 2001; Asbridge *et al*., 2001; Boddy *et al*., 2001; Justice *et al*., 2005). Dubey and Banthia (1998) reported that on inclusion of 10% high reactivity metakaolin (HRM), compressive strength increased by 9.10% at 28 d. Quian and Li (2001) reported that the compressive strength increases substantially with increase in metakaolin content. Vikas *et al*. (2011) reported that the gain in compressive strength depend upon the replacement level of Ordinary Portland Cement (OPC) by metakaolin. The metakaolin inclusion generally improves tensile strength, flexural strength, bond strength and modulus of elasticity. The quantum of increase in the individual properties depends upon replacement level. Splitting tensile strength of concrete made using metakaolin is similar to that observed in concretes without metakaolin. As the compressive strength increases, the tensile strength also increases with replacement level up to its optimum level. Quian and Li (2001) reported that the tensile strength of concrete increases systematically with increasing metakaolin replacement level.

Table 1. Properties of cement.

Properties	Experimental value	Codal requirement (IS 1489(Part 1):1991
Normal consistency (%)	31%	-
Initial setting time	160 min	Not less than 30 min
Final setting time	215 min	Not more than 600 min
Soundness of cement (Le-Chatelier expansion)	0.75 mm	Not more than 10 min
Fineness of cement (Percentage retain on 90 µ IS sieve)	4.15%	10%
Specific gravity of cement	2.67	3.15
7 d	33.0	22 N/mm
28 d	43	33 N/mm^2

The tensile strength increase reported as 7% (5% metakaolin), 16% (10% metakaolin) and 28% (15% metakaolin) at 28 d. Srivastava *et al.* (2011) reported that the optimum replacement level of OPC by metakaolin is 15%. The gain in compressive strength on metakaolin inclusion is quite considerable and makes the concrete almost equal to M_{40} grade. This study presents the effect of metakaolin (as a partial replacement of PPC) on strength of steel fibre reinforced concrete. An experimental investigation was carried out to evaluate the compressive and split tensile strength of steel fibre reinforced concrete made using PPC and 1% of steel fibre.

Materials and methods

Materials: Materials used in present investigation were tested as per provision laid down in Indian Standards. However, more or less similar test results of cement and aggregates were reported by Harison *et al*. (2014) and Rahul *et al.* (2014).

Cement: In the present study, PPC of Birla Gold brand, obtained from a single batch was used throughout the investigation. The cement was satisfying the requirement of IS 1489 (part 1):1991. Properties of cement are given in Table 1.

Fine aggregate: Fine aggregate used in the investigation, was passed through 4.75 mm sieve. The specific gravity was found to be 2.2 and fineness modulus was 2.84.

Coarse aggregate: The coarse aggregate used was having two different sizes; one fraction was passed through 20 mm sieve and another fraction through 10 mm sieve. The specific gravity of coarse aggregate was found to be 2.66 for both the fractions and fineness modulus for 10 mm and 20 mm coarse aggregate fraction was calculated as 6.43 and 6.0 respectively.

Metakaolin: Physical and chemical properties of metakaolin (Fig. 1) used in this study is shown in Table 2.

Steel fibre: The fibres used were of straight rectangular shape and of size 0.8 mm x 35 mm having aspect ratio of 43.75 (Fig. 2).

Table 2. Properties of metakaolin.

Physical properties	
Appearance	Ivory to Buff
Density (g/cc)	0.38-0.42
Specific gravity	2.54
Moisture on board	Max 0.5-1%
Loss on ignition	<1.4
BET surface area	15-18 sq.m/g
Sieve residue on 45 µ	nil
d50: Average particle size	3-4 µ
d90	12-14 µ
Chemical properties	
SiO_2	60-65%
Al_2O_3	30-34%
Fe_2O_3	1.00%
TiO_2	<2.00%
CaO	0.2-0.8%
MgO	0.2-0.8%
Na_2O+K_2O	0.5-1.20%
ASTM Code	ASTM C-618
IS Code	IS 1344

Fig. 1. Metakaolin.

Fig. 2. Crimped steel fibre.

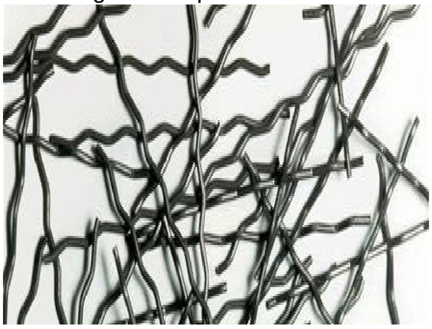


Table 3. Nomenclature of specimens.

Cube designation	Cylinder designation	Metakaolin (%, by weight of cement)	Steel fibre (%, by volume)
C1	Cy1	0	1
C2	Cy2	10	1
C3	Cy3	11	1
C4	Cy4	12	1
C5	Cy5	13	1
C6	Cy6	14	1
C7	Cy7	15	1
C8	Cy8	16	1

Water: The water cement (w/c) ratio of 0.46 was used throughout the investigation.

Nomenclature of specimen: Nomenclature of specimen is given in Table 3.

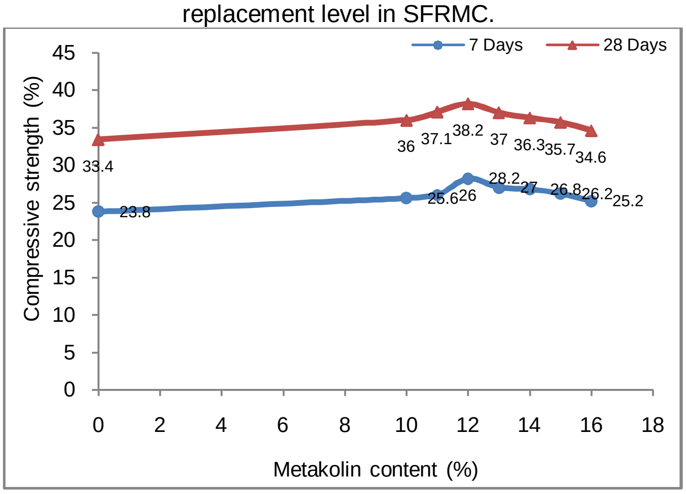
Results and discussion

It is observed that addition of metakaolin as partial replacement of PPC increases the compressive and split tensile strength of concrete at all replacement level, both at 7 and 28 d.

Table 4. Compressive strength of specimens at different replacement level.

Cube	Compressive strength (N/mm^2)	
	Strength (7 d)	Strength (28 d)
Co	23.4	31.6
C1	23.8	33.4
C2	25.6	36.0
C3	26.0	37.1
C4	28.2	38.2
C5	27.0	37.0
C6	26.8	36.3
C7	26.2	35.7
C8	25.2	34.6

Fig. 3. Variation of compressive strength at different replacement level in SFRMC.



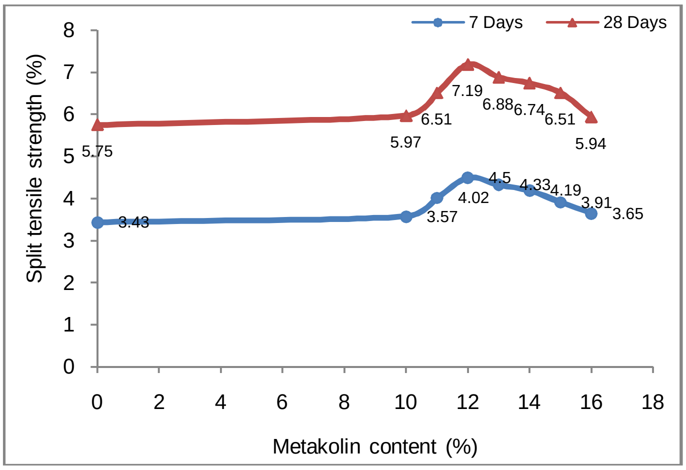
Compressive strength of steel fibre reinforced metakaolin concrete (SFRMC): As compared to the referral SFRC and PPC concrete, the compressive strength is maximum at 1% steel fibre and 12% metakaolin and it is nearly 18% and 20% more than that of referral SFRC at 7 and 28 d respectively. Compressive strength of referral concrete as well as SFRMC at 7 and 28 d are given in Table 4 and the variation of compressive strength of specimens at different replacement level of metakaolin is shown in Fig. 3. It can be seen from table and figure that compressive strength is increased with addition of metakaolin at all the replacement levels. This is similar to the findings of Vikas *et al.* (2012a, b). They concluded that the gain in compressive strength is improved depending upon the replacement level of cement by metakaolin. The 28 d compressive strength of concrete generally increases with the metakaolin content up to its optimum content. Vikas *et al.* (2011) reported similar trend and concluded that the optimum replacement level of cement by metakaolin is 15%. The gain in compressive strength on metakaolin inclusion is quite considerable and makes the concrete almost equal to M_{40} grade at a design mix of M_{25}. However, all the studies referred were carried out with OPC.

Split tensile strength of SFRMC: As compared to the referral SFRC, the split tensile strength is maximum at 1% steel fibre and 12% metakaolin and it is nearly 30% and 25% more than that of referral SFRC at 7 and 28 d respectively. Split tensile strength of referral concrete as well as SFRMC at 7 and 28 d are given in Table 5 and the variation of split tensile strength of specimens at different replacement level of metakaolin is shown in Fig. 4. Rahane and Pasnur (2014) reported similar finding that metakaolin inclusion improves compressive strength and flexural strength. The quantum of increase in the individual properties depends upon replacement level. However, they carried out the study with OPC.

Table 5. Split tensile strength of specimens at different replacement level.

Cylinder	Split tensile strength (N/mm^2)	
	Strength (7 d)	Strength (28 d)
Cyo	2.97	5.23
Cy1	3.43	5.75
Cy2	3.57	5.97
Cy3	4.02	6.51
Cy4	4.50	7.19
Cy5	4.33	6.88
Cy6	4.19	6.74
Cy7	3.91	6.51
Cy8	3.65	5.94
Cyo	2.97	5.23

Fig. 4. Variation of split tensile strength at different replacement level in SFRMC.



Conclusion

From the above study following conclusions may be drawn:

1. Compressive strength of SFRC made using metakaolin is increased both at 7 and 28 d at all the replacement levels.
2. Tensile strength of SFRC made using metakaolin is substantially increased at all replacement levels.
3. Optimum replacement level of PPC by metakaolin is 12%.

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