A Combined use of Fly ash and Metakaolin as Supplementary Materials for Cement in Cement Concrete

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ABSTRACT - Rapid infrastructure development worldwide augments the demand for concrete. Nowadays concrete is a basic component of the construction industry. Like concrete, consumption of cement also plays a vital role to meet the requirement of the construction industry. Due to excessive demand of cement-concrete and at same time scarcity of these important components of the construction industry, it is essential to find out alternative supplements of cement and concrete. In this regard, we have focused on partial alternative material of cement-concrete. Fly ash and Metakaolin were tested for their performance in the cement-concrete as a supplementary material. Concrete having 35 MPa Compressive strength was targeted in the experimental investigation. Mechanical properties like compressive strength, flexural strength, and split tensile strength have been taken into consideration for comparison of conventional concrete with modified concrete. The modified concrete was evaluated by using NDT like Rebound hammer test and USPV Test. Furthermore, a relation was developed between compressive strength and NDT for the aforementioned supplementary materials. Experimental results revealed that the compressive strength of modified concrete is better than conventional concrete. Among the various combinations tested, an admixture of Fly ash at 10% and Metakaolin at 30% was found to provide higher compressive strength.

Key Words- Concrete, Metakaoline, Fly ash, NDT, Rebound hammer test, USPV test, Compressive strength, Flexural strength, Split tensile strength.

1. Introduction

In the past few decades, demand for concrete is rapidly increasing at a faster pace in construction works such as construction of buildings, dams, highways, railway bridges, airports etc. Concrete is stone-like material obtained artificially by hardening of the mixture of cement, inert-aggregate materials (fine & course) and water in predetermined proportions [1]. When these ingredients are mixed they form a plastic mass which can be poured in suitable molds (forms) and set-on standing into a hard solid mass, as a result of exothermic chemical reaction between cement and water. All these ingredients are naturally available but the constant use of these natural additives has led to exhausting of the natural sources and results into global warming [8]. Therefore, the use of alternative and partial materials for concrete is becoming essential. The recycling of waste materials can be the possible solution to this challenge. As we know concrete is weak in tension but very strong in compression, therefore, the concrete specialists are trying to improve the compressive strength of concrete by using recycled materials and other naturally available minerals as a material. In this regard, various materials like blast furnace slag, Metakaolin, silica fume, fly ash, plastic aggregate, crushed clay bricks etc. have been demonstrated to be used as partial replacement of cement and aggregates, [9, 12].

The consistency of concrete decreases an increase in Metakaolin content without a change in compaction of concrete. Tensile and flexural strength have had lower impact compared to compressive strength. Furthermore, it has been observed that the modulus of elasticity of modified concrete slightly increased. It was also noticed that drying shrinkage and creep of concrete are reduced significantly [6, 21].

Various studies have shown non-destructive evaluation of concrete using Metakaolin as supplementary material. The mechanical properties of modified concrete were compared using NDT and destructive test. Metakaolin was used at 5%, 10%, 15% and 20%, and it was found that for 5% and 10% the compressive strength increased by 7% and 16.75% respectively and for 15% and 20% the compressive strength of modified concrete was 11.42% and 6%, respectively. Therefore, 10% Metakaolin was found to be effective in increasing the compressive strength. It was also observed that the fresh properties of concrete like workability increases with an increase in percentage of Metakaolin [1, 10, 15, 18].
Fly ash has also been demonstrated as a potential alternative for cement concrete. Recent researches on Fly ash have concluded the following important points- (1) it requires slightly more water than conventional concrete. (2) The compressive strength of modified concrete slightly decrease at 7-28 days but after 3 months it will be equal to or greater than

the normal strength and increases as time passes. (3) The modulus of elasticity is lower at an early age but higher at later ages. (4) Fly ash plays important role in heat reduction; if the percentage of fly ash is 30% then it reduces 50-60% heat compared to normal concrete. (5) Fly ash can replace cement up to 60%, hence, it is a great alternative for cement concrete [16].

In a recent report, the compressive strength of concrete decreased up to 28 days with 30-40% of fly ash, however, after 28-180 days, the compressive strength of modified concrete was found to be increased in comparison to conventional concrete. The research has concluded that Class-F fly ash minimized the sorptivity of concrete in both initial 28 days stage of curing and later stages of curing at 180 days, hence, the sorptivity were decreased [17, 19].

Fly ash was found to show considerable effect on the strength and durability of concrete. The durability was tested by three methods namely water absorption, oxygen permeability, and concrete resistivity. Partial replacement of Portland cement by fly ash at 30% leads to a sudden decrease in early age compressive strength compared to reference mix made with 100% Portland cement [14].

According to the reported literature, several works have been performed on the partial replacement of cement and concrete, however, there are only a few research reports on the non-destructive evaluation of Metakaolin and fly ash concrete. Therefore, in the present study, an attempt has been made to examine and investigate the combined effects of Metakaolin and fly ash on the mechanical properties of modified concrete.

2. Material Properties and Methods

The materials used for investigation are mentioned in Table 1.1 along with their properties

Table 1.1 Properties of materials [20]

Sr. No.	Type of material	Properties of materials
1.	Cement	OPC Grade 53
2.	Sand	Spc. Gravity 2.67 (River Sand)
3.	Coarse Aggregate	10 and 20 mm spc. Gravity (2.70)

Note : The coarse aggregate was air-dried and sieve analysis was done.

2.1 Metakaolin

Metakaolin is derived from clay mineral kaolinite which is a fine white clay mineral. The traditional use of kaolinite was to manufacture the porcelain. The particle size of Metakaolin is finer than the cement particles but coarser than the silica fume. Metakaolin is a pozzolanic material for use in concrete. It is formed when China clay, the mineral kaolin is heated at a temperature between 600-800^{0}C, "As far as India is concerned metakaolin actually came into the market as a cheaper material than micro silica. It was only after reputed companies started using metakaolin that the product began to generate a buzz in the market and most importantly Metakaolin's reaction rate is rapid, significantly increasing compressive strength, even at early ages, which can allow for earlier release of formwork [2, 3, 4, and 22].

2.2 Fly Ash

Fly ash is known as "pulverized fuel ash" in the United Kingdom. It is a fine powder which is the byproduct of burning pulverized coal in an electric power plant. It is also a pozzolan which contains aluminous and siliceous material that form cement in presence of water. The density of fly ash was used at 2.47 gm/cm^3 and 2.36 gm/cm^3, (Michael Thomas, 2007). The detail of chemical compositions for Fly ash and Metakaolin are mentioned in table no. 1.2. Also, physical and chemical properties of Metakaolin are listed in table no. 1.2 [5, 6].

Table 1.2 Chemical compositions of fly ash and MK [12]

Particles	% Fly ash by mass	% Metakaolin by mass
SiO_2	35.91	31
Al_2O_3	16.02	53.5
Cao	14.43	1.1
Fe_2O_3	12.34	6.58
K_2O	1.28	5.79
MgO	9.09	0.12
Na_2O	5.87	0.04
TiO_2	0.66	0.919

Table 1.3 Physical and chemical properties of MK [7]

S. N	Physical properties	Range	Chemical properties	% Range
1.	Specific Gravity	2.40 to 2.60	SiO_2	51-53
2	Physical form	Powder	Al_2O_3	42-44
3.	color	Off-white, gray to buff	Cao	<2.20
4.	Specific surface	8-15 m^2/g	TiO_2	<3

2.3 Superplasticizer

The plasticizers used were lignosulfonate and hydrocarboxylic (HC) acids. It is water reducing admixture (WRA) type A in ASTM C 494. It can reduce 5-12% water while maintaining a certain level of consistency, measured by the slump as prescribed in ASTM C 143-90 [11,13].

2.4Method

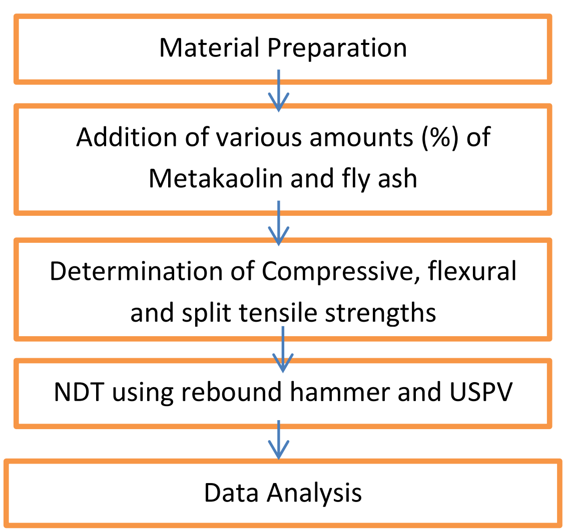

Fig.1 Experimental Flowchart diagram

3. Design of Mix detail

The mix proportion was designed to know the mechanical properties of M35 grade concrete. The mix proportions are determined based on the IS 10262 and SP 23. The mix proportions for M35 concrete were 1:1.715:2.485 with a w/c ratio of 0.3. Superplasticizer was 2.80 kg/m3 used in all the concrete mixes. The percentage of Metakaolin was varied from 6-14% of the used cement at 2% increment while fly ash was varied from 10-50% of the used cement at 10% increment (Table 1.4).
Mixing: All the ingredients were mixed in a pan mixer. First, coarse and fine aggregates were mixed at 1:1.715:2.485 ratios, water was added gradually as per mix requirement at 4 stages. Super Plasticizers, lignosulfonate and hydrocarboxylic acids, were added in equal amounts at 2.80 Kg/m^3. It was ensured that the mix was homogeneous and slump test was carried out to know the workability of concrete. Specimens casting detail are shown in table no. 1.4.

Table 1.4 Casting detail

Sr. No.	Size of specimen	No. of specimen	% Metakaolin	% fly ash
1	150x150x150 mm Cube	20 Nos.	6-14% of OPC with 2% increment	10% to 50% of OPC with 10% increment
2	300x150mm cylinder	10 Nos.	6-14% with 2% increment	10% to 50% of OPC with 10% increment
3	100x100x100mm beam	10 Nos.	6-14% with 2% increment	10% to 50% of OPC with 10% increment

4. Destructive Test of concrete

To know the workability of concrete, slump test was carried out. It is found that workability was slightly better than the normal concrete.

To calculate the compressive strength and split tensile strength of the modified concrete 2000KN CTM was used and 200 KN testing machine was used to find the flexural strength of modified concrete.

The compressive strength (fck) of modified concrete was determined after 7, 28 and 180 days respectively. After 7, 28 and 180 days the compressive strength (fck) of modified concrete was 29MPa, 38MPa, and 52MPa, respectively with 10% of Metakaolin and 30% of fly ash (Fig. 1.1). Therefore, the compressive strength of modified concrete was increased 2% at 7 days, 7.60% after 28 days and 12.95% after 180 days at combined use of 10% Metakaolin and 30% of fly ash as compared to normal concrete.

The admixture of 10% Metakaolin and 30% fly ash is found to give a better result for compressive strength.

In the case of split tensile strength and flexural strength, there was increment by 4.95% and 5.50%, respectively at the age of 28 days. After 180 days, the split tensile strength and flexural strength were increased by 6.85% and 7.05% respectively, compared to the normal concrete. Split tensile strength and flexural strength has been shown in Fig. 1.2 and 1.3, respectively.

Split tensile strength ($Y=0.6158\ fck^{0.4409}$ and $R^2=0.9948$) (1)
Flexural strength ($Y=0.7218\ ffx^{0.4880}$ and $R^2=0.9989$) (2)

1. Rebound Hammer Test:

The test is performed as per the guidelines given by IS: 1331 (Part 2): 1992 & BS 1881: Part 202: 1986 to estimate the *in situ* strength of concrete based on the correlation established between *in situ* strength at the particular casted cube and rebound numbers. The standard values for average rebound and quality of concrete are shown in table 1.5.

Table 1.5 Rebound hammer test

Average Rebound	Quality of Concrete
>40	Very Good
30-40	Good
20-30	Fair
<20	Poor
0	Very Poor

2. Ultra Sonic Pulse Velocity test

Following velocity criterion for concrete quality, grading is given by IS 13311 (Part- I): 1992. The standard values for Pulse velocity, concrete quality and concrete grades for USPV test are mentioned in table 1.6.

Table 1.6 USPV Test (Part-I) 1992

Pulse Velocity	Concrete Quality	Concrete Grade
>4.0km/s	Very good to excellent	I
3.5-4.0km/s	Good to very good	II
3.0-3.5km/s	Satisfactory but loss of integrity is suspected	III
<3.0km/s	Poor and loss of integrity exist	IV

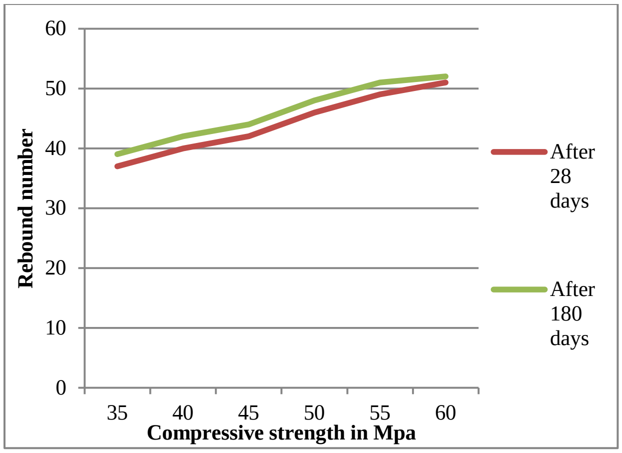

Fig 1.1 Relation between rebound number and compressive strength

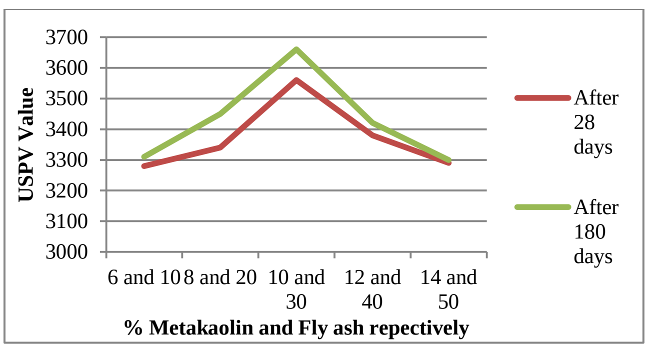

Fig 1.2 USPV test of concrete at the age of 28 days and 180 days

Fig 1.3 Compressive, Tensile and Flexural test setup at 7 days, 28 day and 180 days.

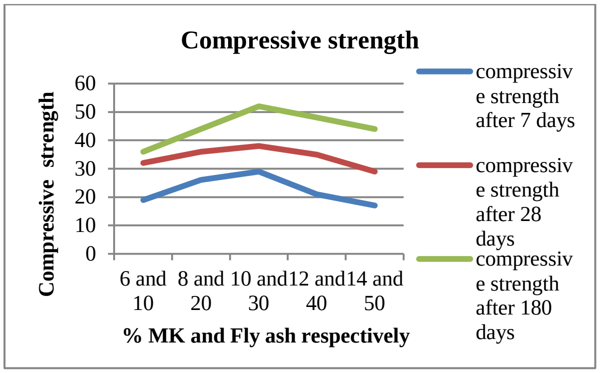

Fig. 1.4 Compressive strength of modified concrete after 7, 28 and 180 days, respectively

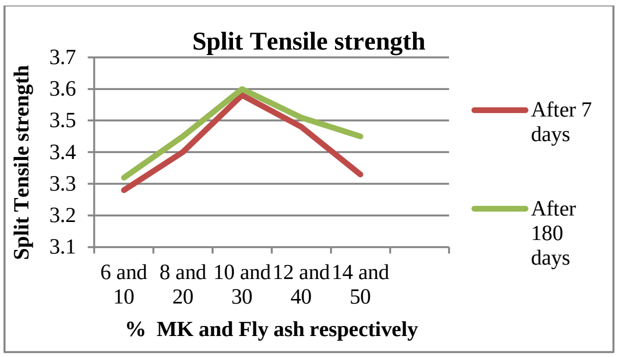

Fig. 1.5 Split tensile strength of modified concrete after 28 and 180 days, respectively.

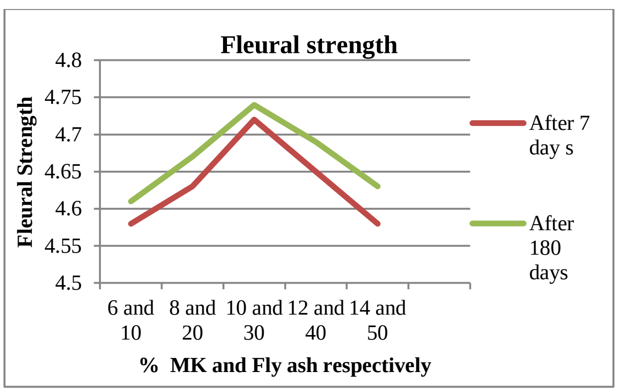

Fig. 1.6 Flexural strength of modified concrete after 28 and 180 days, respectively.

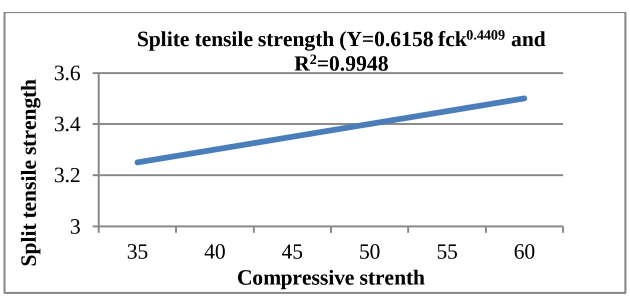

Fig 1.7 Relation between compressive strength and split tensile strength

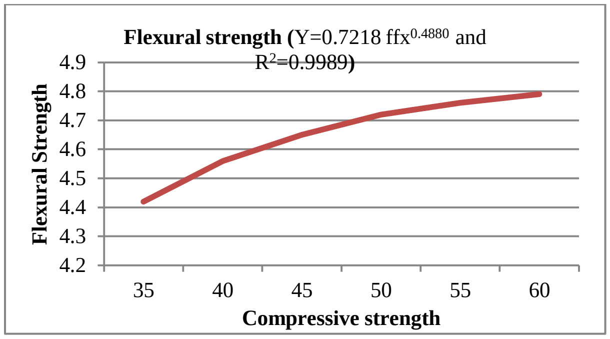

Fig 1.8 Relation between compressive strength and Flexural strength

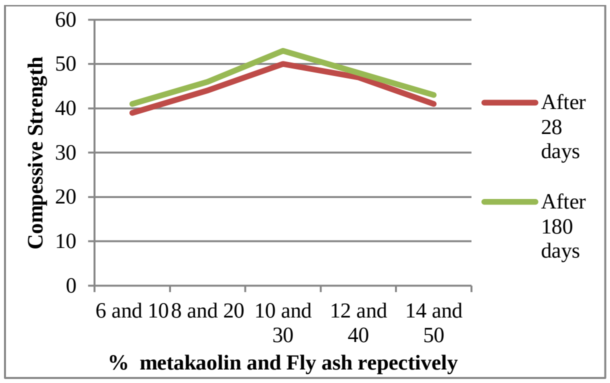

Fig 1.9 Rebound hammers strength at the age of 28 and 180 days respectively.

Conclusion

From the above experimental work we conclude the following points:

- Partial material for cement, fly ash and Metakaolin can be used to increase the compressive strength of concrete.
- The combination of 10% Metakaolin and 30% fly ash gave better compressive strength of concrete as compared to normal concrete.
- Workability of concrete increases by the addition of fly ash and Metakaolin.
- Less impact has been recorded for split tensile and flexural strength of concrete by the addition of Metakaolin and fly ash as compared to compressive strength.
- Metakaolin act as filler in concrete and thus increases the integrity of the concrete as recorded by using the USPV test.
- Water absorption was recorded less in comparison to normal concrete due to the presence of fly ash.

Note: On behalf of all the authors, the corresponding author states that there is no conflict of interest.

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Biographies

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