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RESEARCH ARTICLE

AN INVESTIGATION ON THE PROPERTIES OF HIGH VOLUME FLY ASH AND METAKAOLIN BLENDS IN CONCRETE

Akshatha K., Dr. K. B. Prakash

1. M Tech Structural engineering, Department of Civil Engineering, Government Engineering College Haveri.

2. Principal Government Engineering College Haveri.

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Abstract

Over the past several decades, the use of fly ash in concrete has had a successful track record. The performance benefits fly ash provides to mechanical and durability properties of concrete have been well researched and documented in actual structures. Currently, fly ash is used in more than 50% of all ready mixed concrete placed in the United States, yet many design professionals continue to remain overly restrictive when it comes to using fly ash in concrete. Metakaolin has the highest content of siliceous, so it is also called High Reactivity Metakaolin (HRM). During the cement hydration process, water reacts with Portland cement and forms calcium-silicate hydrate (CSH). The by-product of this reaction is the formation of calcium hydroxide (lime). This lime has weak link in concrete, and hence reduces the effect of the CSH. When metakaolin is added in the hydration process, it reacts with the free lime to form additional CSH material, thereby making the concrete stronger and more durable.
The main objective of this research work is to study the properties of high volume fly ash and metakaolin blends in concrete by replacing 50% of cement by fly ash and metakaolin. The strength characteristics of high volume fly ash and metakaolin concrete such as compressive strength, tensile strength, impact strength and shear strength are studied. Along with this the water absorption and sorptivity properties are also studied. The study is made on M30 grade of concrete.

1. Introduction

The application of concrete in construction is as old as the days of Greek and Roman civilization. But for numerous reasons, the concrete construction industry is not sustainable. It consumes a lot of virgin materials and the principal raw material of concrete i.e. cement is responsible for green house gas emissions causing a threat to environment through global warming. Therefore, the industry has seen various types of concrete and is in search of a solution to sustainable development. Infrastructural growth has witnessed many forms of concrete like, high strength concrete, high performance concrete, self compacting concrete and the latest in the series is high volume fly ash concrete (HVFC).
Fly ash is an industrial by-product, generated from combustion of coal in the thermal power plants. The increasing scarcity of raw materials and an urgent need to protect the environment against pollution has accentuated the significance of developing new building materials based on industrial waste generated from coal fired thermal power station which creates unmanageable disposal problems due to its potential to pollute the environment.
Metakaolin differs from other supplementary cementitious materials like fly ash, slag or silica fume, in that it is not a by-product of an industrial process; it is manufactured for specific purpose under controlled conditions. Metakaolin is fine, natural white clay made by heating kaolin to temperatures between 650^{o}C-900°C. This treatment, called calcination, radically modifies the particle structure making it a highly reactive, amorphous pozzolana.

The relative fineness of metakaolin can result in decreased slump, but the use of water reducing admixtures or use in combination with fly ash in ternary mixes can compensate for this. Slumps of 125 to 180 mm have been achieved with metakaolin at water-cementitious materials ratio (w/cm) of 0.36 to 0.38, using high-range water- reducing admixture.

Recently, there has been a growing interest in the utilization of high-reactivity metakaolin (MK) as a supplementary cementitious material in concrete industry. Metakaolin is an ultrafine pozzolana, produced by calcining purified kaolinite clay at a temperature ranging from 650 to 900^0 C to drive off the chemically bound water and destroy the crystalline structure. Unlike industrial by-products such as fly ash, silica fume, and blast-furnace slag, Metakaolin is refined carefully to lighten its color, remove inert impurity, and control particle size. The particle size of metakaolin is generally less than that of cement particles, though not as fine as silica fume. Moreover, the use of metakaolin in concrete in its present form is relatively a new concept. Recent works have shown that the inclusion of metakaolin greatly influenced the mechanical and durability properties of concrete. It has also been demonstrated that concrete mixture incorporating high-reactivity metakaolin gave comparable performance to silica fume mixtures in terms of strength, permeability, and chemical resistance. The utilization of this material is also environmentally friendly since it helps in reducing the CO_2 emission to the atmosphere by the minimization of the Portland cement consumption.

When water is added in to cement, chemical reaction takes place and due to this hydration lime is generated. Out of that 25% of lime remains intact on surface and overtime it would be susceptible to the effect of weathering and loss of strength and durability. To overcome this effect, pozzolanic material i.e. siliceous material that develops any hydraulic cementitious properties in the presence of lime is added into OPC which reacts with free lime and convert it to calcium silicate hydrate (C-S-H) which gives strength to concrete and also make it durable.

Activated fly ash (type F) is an industrial waste and metakaolin is easily available with low cost compared to silica fume if both these materials are used as a pozzolanic material to replace OPC in concrete can reduce the amount of cement used thereby reducing the emission of CO_2. All these materials are finer, particles are glassy which help in reducing amount of water and help to increase workability. By using this mineral admixture, eco friendly concrete can be developed.

2. Materials and methodology

2.1 Materials

The binder materials used in mixes were ordinary Portland cement (OPC) 43 grade conforming to IS: 8112 – 1989, low calcium, class F dry fly ash from the silos of Raichur thermal power station conforming to IS: 3812 (Part 1) – 2003 and metakaolin derived from the thermal activation of kaolin clay at about 750 - 800^0C.

Locally available river sand belonging to zone II of IS 383-1970 was used. Locally available crushed aggregates confirming to IS 383-1970 was used. Water fit for drinking and commercially available high performance super plasticizing admixture, Conplast SP430; conforming to ASTM C 494 (1992) were used in this experimentation.

2.2 Methodology

- Separately mix the cementitious materials (cement, fly ash and metakaolin).
- Dry mix the sand and cementitious materials.
- Add coarse aggregate to it and dry mix it thoroughly to achieve a homogenous mix.
- Add the calculated quantity of water to the dry mix with one percent of super plasticizer and mix thoroughly to get homogeneous mix.
- Moulds are cleaned and lightly oiled to the inner surface of the mould to prevent any bonding reaction between the mould and the sample.
- Place the moulds on the vibrating table and put the wet concrete mix inside the moulds in three layers.
- Vibrate the concrete both through table vibration and by hand compacting using tamping rod.
- Vibration should not be more, otherwise segregation will takes place.
- After filling the moulds with wet concrete, level the surface and give the designation to each specimen.
- Demould the specimen after 24 hours.
- Demoulded specimens are then kept for 28 days of curing in water.
- Tests on hardened concrete after 28 days of curing are conducted

- Compressive strength test on 150mmX150mmX150mm cube.
- Tensile strength test on 150mmϕX300mmL cylinder.
- Flexural strength test on 100mmX100mmX500mm beam.
- Impact strength test on 150mmϕX60mmL cylinder.
- Shear strength test on L shaped specimen.
- Water absorption and sorptivity tests.

3. Experimental results

3.1 Mix design

The mix design is conducted for 43 grade ordinary Portland cement as per High volume fly ash concrete technology best practice guidelines and IS 10262: 1982.

For one cubic meter of concrete, the mixture proportions arrived at are as follows:

Water	=	145.0kg
Cement	=	207.5kg
FA & MK	=	207.5kg
Coarse aggregate	=	1122.95kg
Fine aggregate	=	609.4kg
W/C	=	0.35

The mix proportion for M 30 grade concrete arrived at is

1:1.47:2.7:0.35

3.2 Test results

Following tables gives the test results and regression model for compressive strength split tensile strength, flexural strength, shear strength, impact strength, water absorption and sorptivity of high volume fly ash and metakaolin blended concrete by replacing 50% of cement in different percentages of blends such as, (50%FA+0%MK), (45%FA+5%MK), (40%FA+10%MK), (35%FA+15%MK), (30%FA+20%MK), (25%FA+25%MK), (20%FA+30%MK), (15%FA+35%MK), (10%FA+40%MK), (5%FA+45%MK), (0%FA+50%MK).

Table 3.1 Test results compressive strength

Percentage replacement of cement by different blends	Compressive strength (MPa)	Percentage increase or decrease of compressive strength w.r.t reference mix	Analytical values of compressive strength using obtained regression model equation (MPa)
(50%FA+0%MK) (Reference mix)	37.3	-	37.53
(45%FA+5%MK)	37.7	+0.4	38.57
(40%FA+10%MK)	39.11	+1.81	39.26
(35%FA+15%MK)	40.88	+3.58	39.6
(30%FA+20%MK)	41.33	+4.03	39.59
(25%FA+25%MK)	39.55	+2.25	39.23
(20%FA+30%MK)	37.33	+0.03	38.52
(15%FA+35%MK)	36.44	- 0.86	37.46
(10%FA+40%MK)	35.11	- 2.19	36.05
(5%FA+45%MK)	34.22	- 3.08	34.29
(0%FA+50%MK)	33.33	- 3.97	32.18

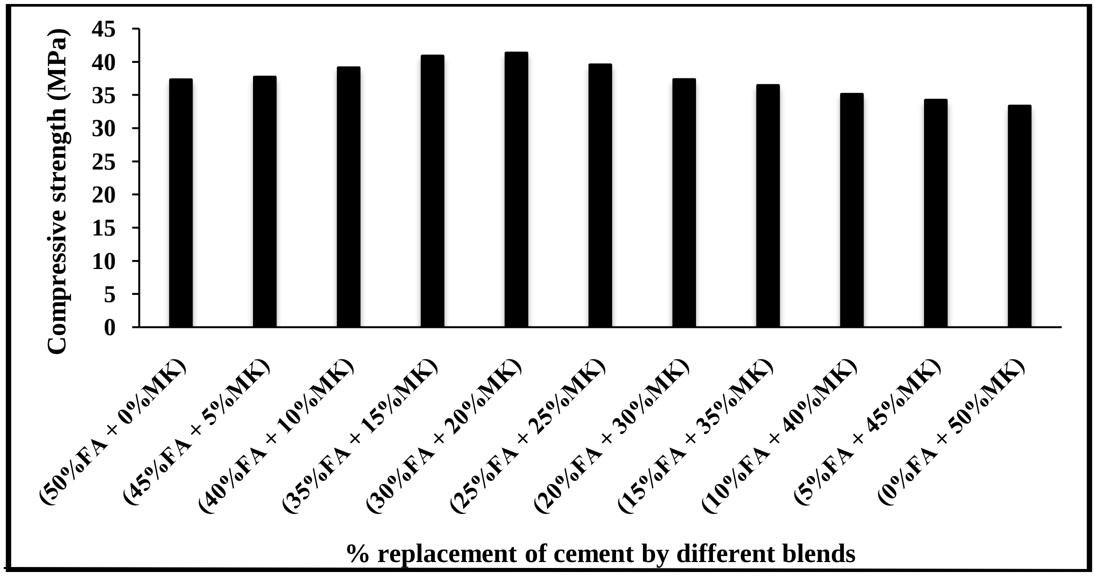

Fig 3.1 Variation of compressive strength

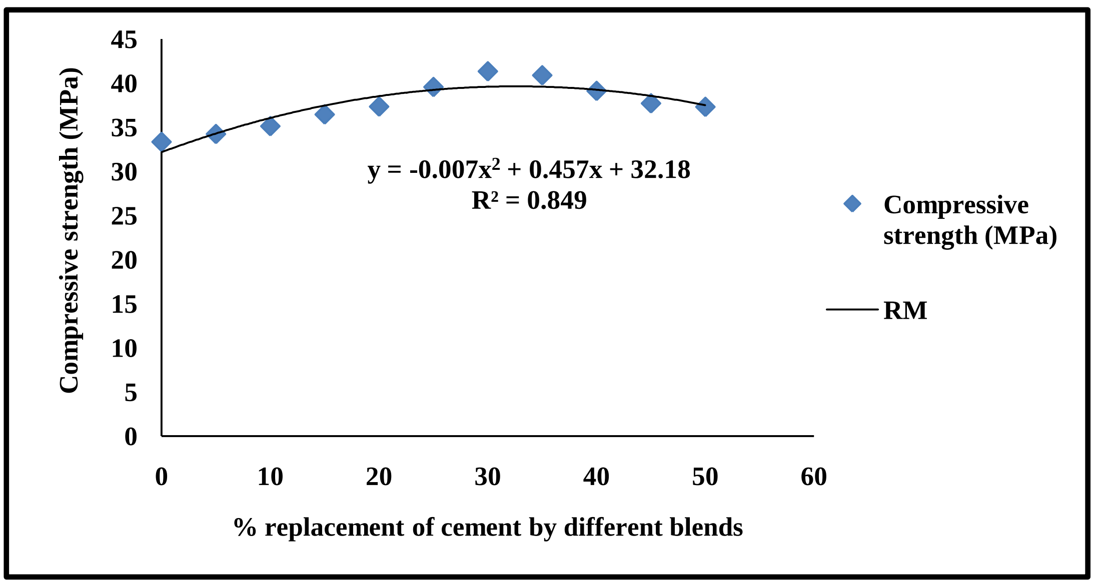

Fig. 3.2 Regression model of compressive strength

Table 3.2 Test results of split tensile strength

Percentage replacement of cement by different blends	Split tensile strength (MPa)	Percentage increase or decrease of split tensile strength w.r.t reference mix	Analytical values of split tensile strength using obtained regression model equation (MPa)
(50%FA + 0%MK) (Reference mix)	3.39	-	4.952
(45%FA + 5%MK)	3.49	+0.1	4.787
(40%FA + 10%MK)	3.54	+0.15	4.622
(35%FA + 15%MK)	3.63	+0.24	4.457
(30%FA + 20%MK)	3.87	+0.48	4.292
(25%FA + 25%MK)	3.82	+0.43	4.127
(20%FA + 30%MK)	3.68	+0.29	3.962
(15%FA + 35%MK)	3.58	+0.19	3.797
(10%FA + 40%MK)	3.54	+0.15	3.632
(5%FA + 45%MK)	3.44	+0.05	3.467
(0%FA + 50%MK)	3.35	- 0.04	3.302

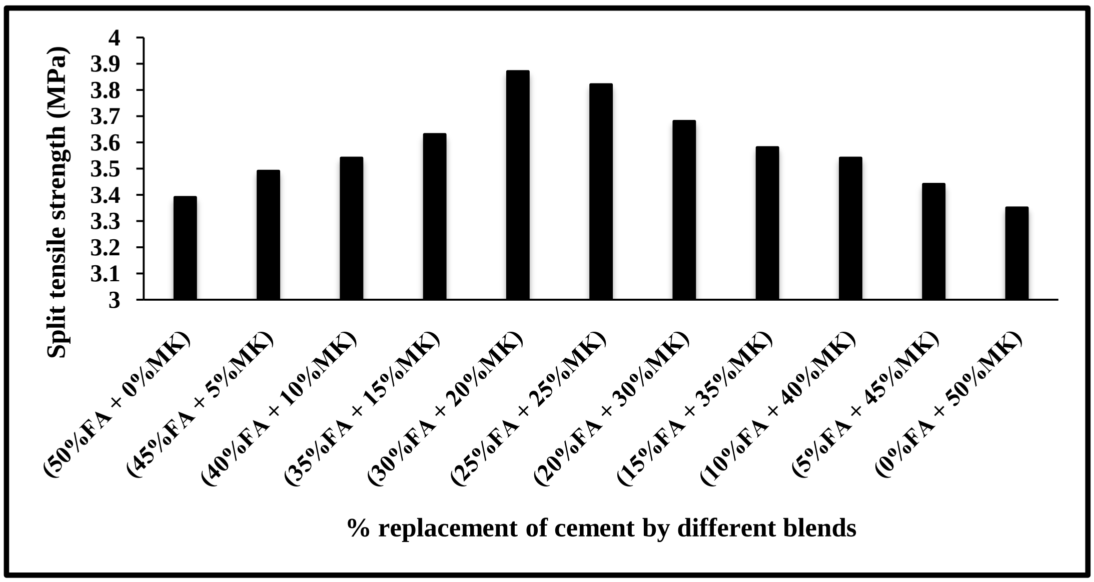

Fig 3.3 Variation of split tensile strength

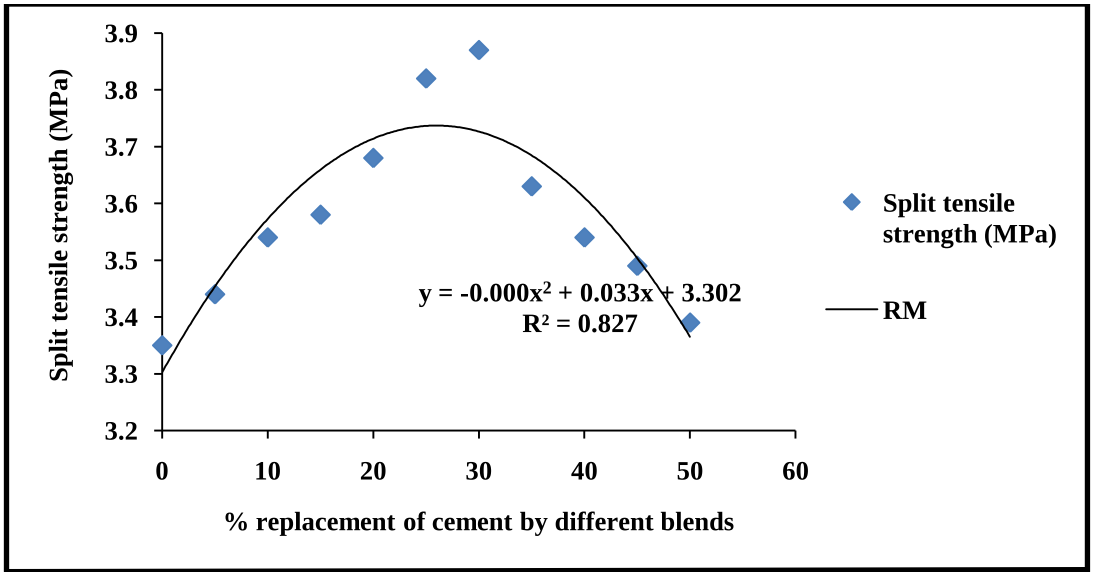

Fig. 3.4 Regression model of split tensile strength

Table 3.3 Test results of flexural strength

Percentage replacement of cement by different blends	Flexural strength (MPa)	Percentage increase or decrease of flexural strength w.r.t reference mix	Analytical values of flexural strength using obtained regression model equation (MPa)
(50%FA + 0%MK) (Reference mix)	5.27	-	5.92
(45%FA + 5%MK)	5.53	+0.26	6.24
(40%FA + 10%MK)	6	+0.73	6.45
(35%FA + 15%MK)	6.47	+1.2	6.57
(30%FA + 20%MK)	6.6	+1.33	6.58
(25%FA + 25%MK)	6.4	+1.13	6.49
(20%FA + 30%MK)	6.07	+0.8	6.31
(15%FA + 35%MK)	5.93	+0.66	6.03
(10%FA + 40%MK)	5.33	+0.06	5.64
(5%FA + 45%MK)	5	-0.27	5.16
(0%FA + 50%MK)	4.87	-0.4	4.57

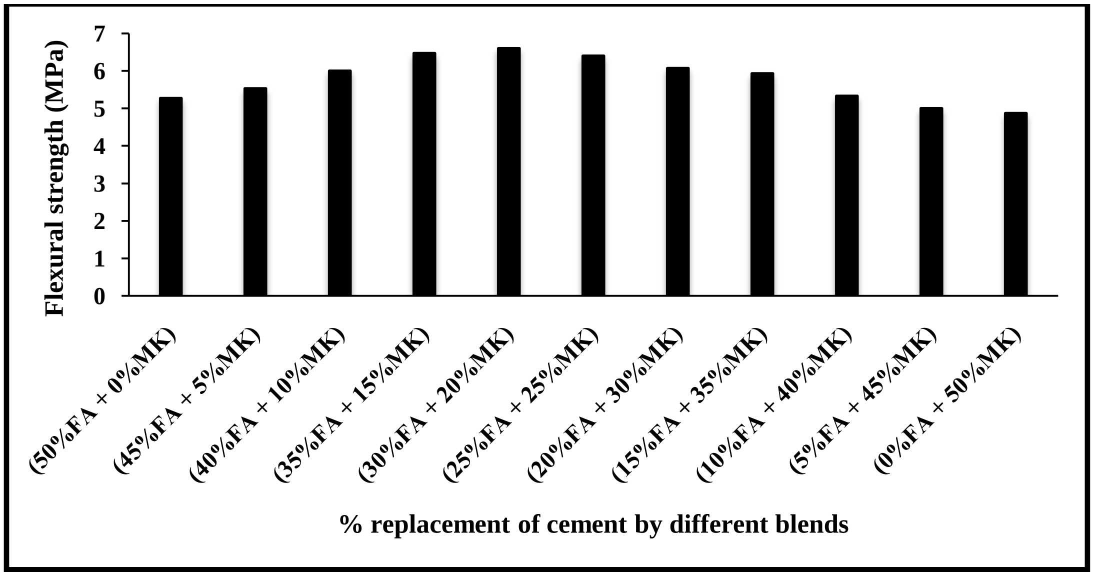

Fig 3.5 Variation of flexural strength

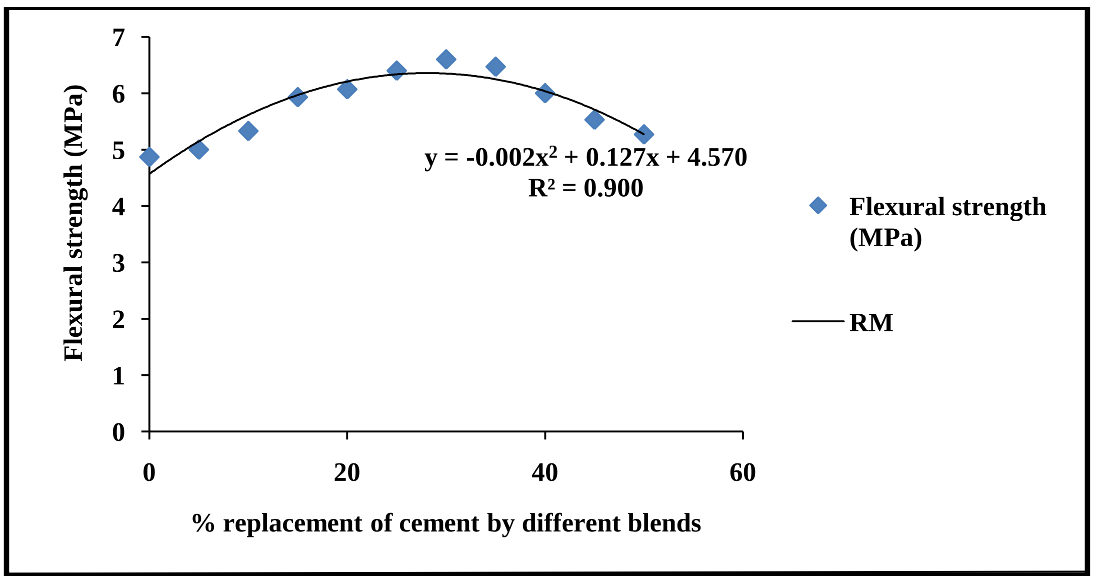

Fig. 3.6 Regression model of flexural strength

Table 3.4 Test results of shear strength

Percentage replacement of cement by different blends	Shear strength (MPa)	Percentage increase or decrease of shear strength w.r.t reference mix	Analytical values of shear strength using obtained regression model equation (MPa)
(50%FA + 0%MK) (Reference mix)	3.52	-	5.144
(45%FA + 5%MK)	3.72	+0.2	5.354
(40%FA + 10%MK)	3.89	+0.37	5.464
(35%FA + 15%MK)	4.83	+1.31	5.474
(30%FA + 20%MK)	5.6	+2.08	5.384
(25%FA + 25%MK)	5	+1.48	5.194
(20%FA + 30%MK)	4.44	+0.92	4.904
(15%FA + 35%MK)	3.89	+0.37	4.514
(10%FA + 40%MK)	3.6	+0.08	4.024
(5%FA + 45%MK)	3.33	-0.19	3.434
(0%FA + 50%MK)	3.15	-0.37	2.744

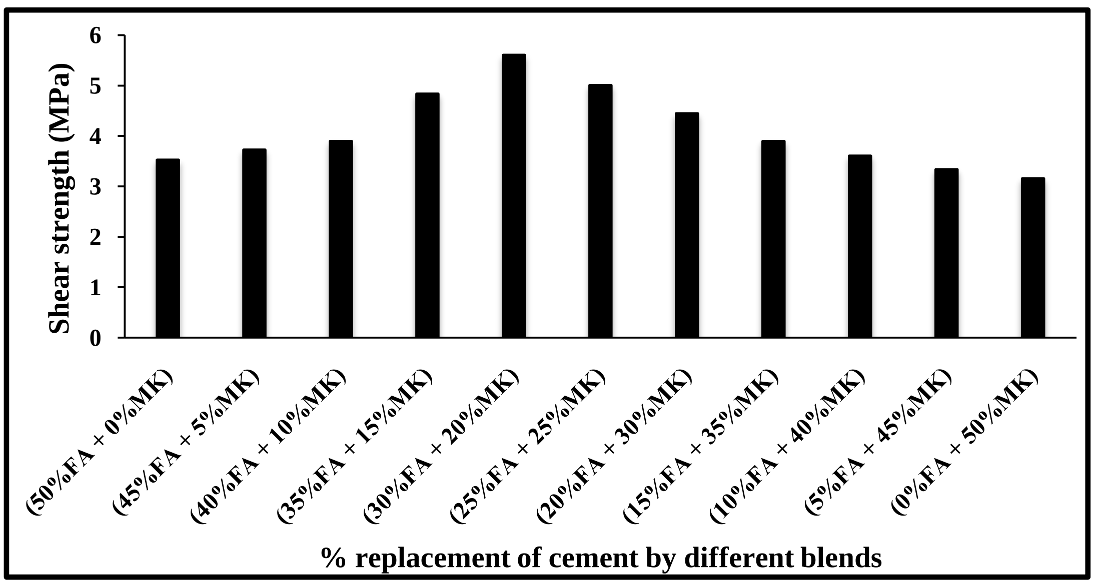

Fig 3.7 Variation of shear strength

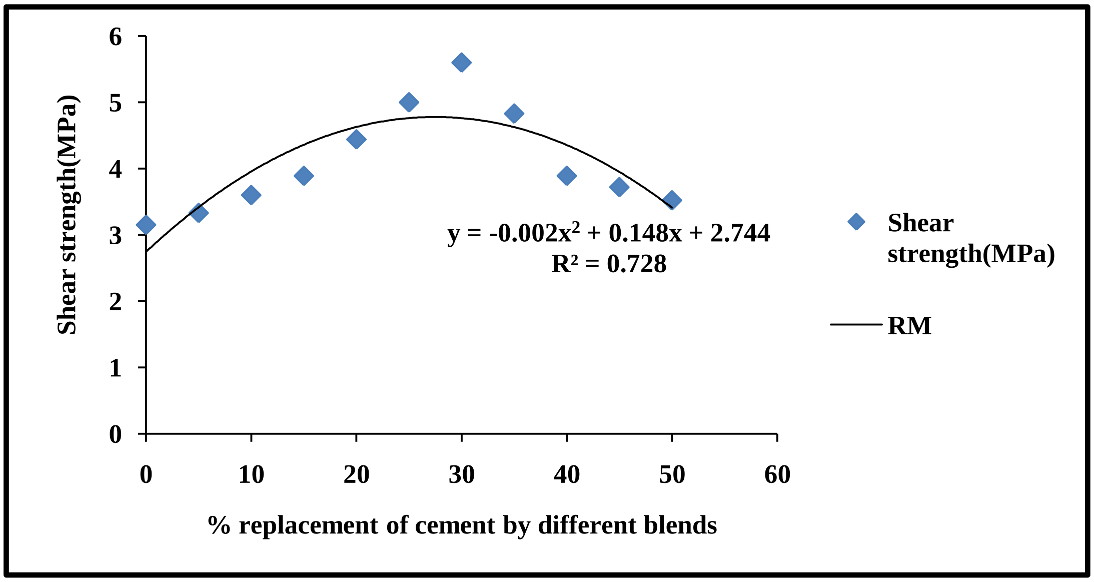

Fig. 3.8 Regression model of shear strength

Table 3.5 Test results of Impact strength for N1 number of blows

Percentage replacement of cement by different blends	Impact strength for first crack (N-m)	Percentage increase or decrease of impact strength for first crack w.r.t reference mix	Analytical values of impact strength for first crack using obtained regression model equation (N-m)	Impact strength for final failure (N-m)	Percentage increase or decrease of impact strength for final failure w.r.t reference mix	Analytical values of impact strength for final failure using obtained regression model equation (N-m)
(50%FA+0%MK) (Reference mix)	1.989	-	3.55	2.084	-	3.727
(45%FA+5%MK)	2.180	+0.191	3.75	2.310	+0.226	3.922
(40%FA+10%MK)	2.392	+0.403	3.85	2.536	+0.452	4.017
(35%FA+15%MK)	2.646	+0.657	3.90	2.804	+0.720	4.012
(30%FA+20%MK)	4.367	+2.378	3.75	4.504	+2.420	3.907
(25%FA+25%MK)	3.839	+1.850	3.55	3.990	+1.906	3.702
(20%FA+30%MK)	2.440	+0.451	3.25	2.550	+0.466	3.397
(15%FA+35%MK)	2.132	+0.143	2.85	2.262	+0.178	2.992
(10%FA+40%MK)	1.858	-0.131	2.35	1.974	-0.110	2.487
(5%FA+45%MK)	1.837	-0.152	1.75	1.954	-0.130	1.882
(0%FA+50%MK)	1.398	-0.591	1.049	1.556	-0.528	1.177

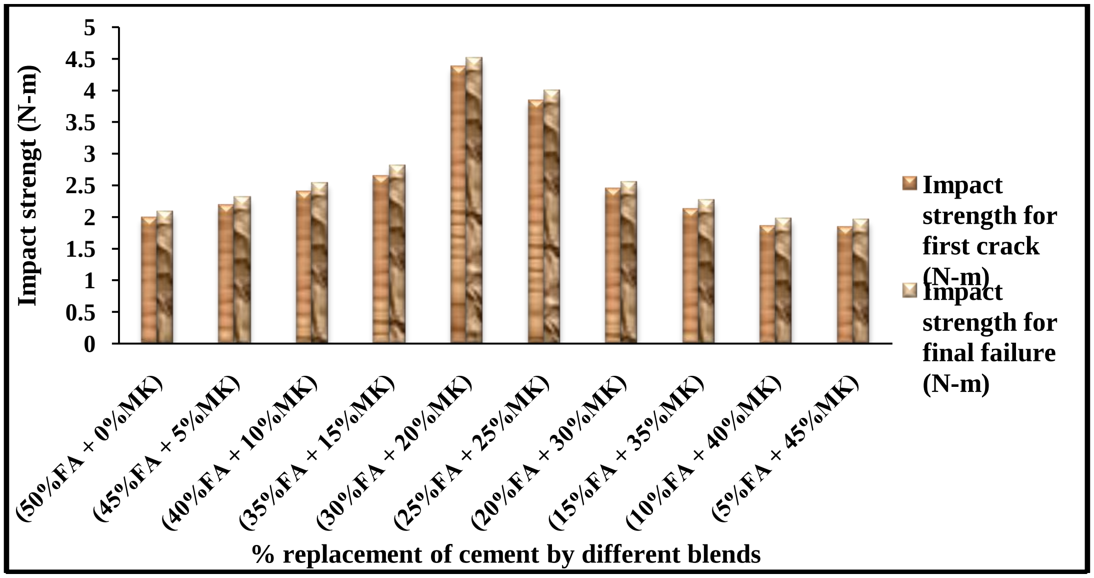

Fig 3.9 Variation of impact strength

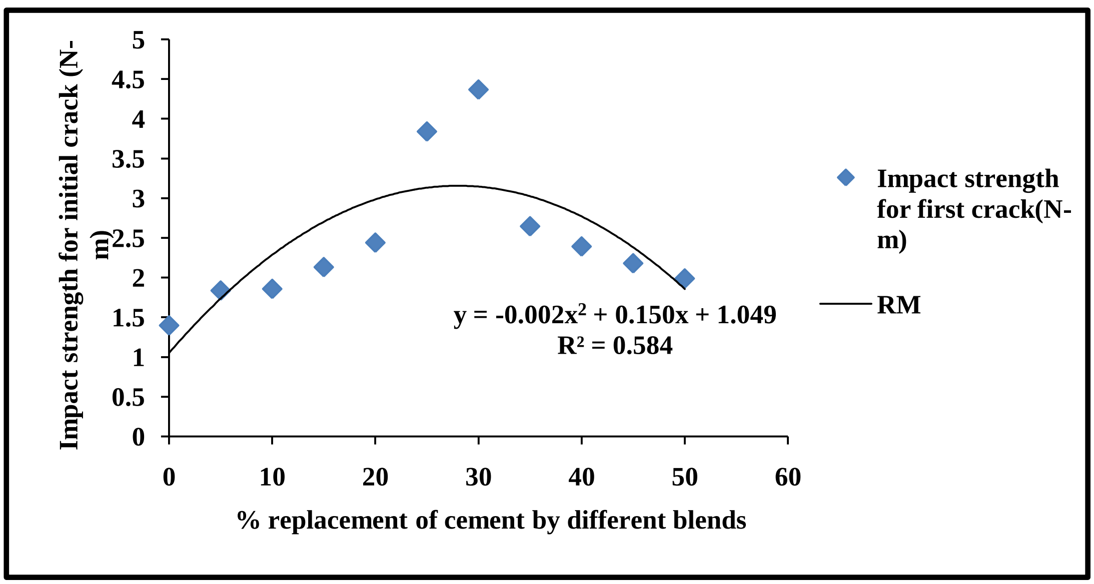

Fig. 3.10 Regression model for initial crack

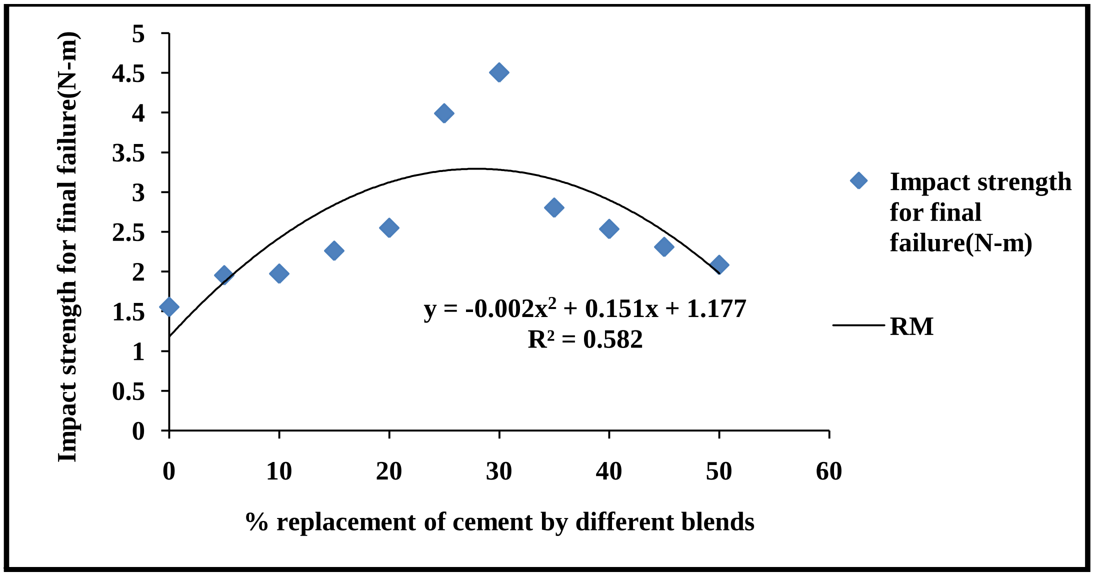

Fig. 3.11 Regression model for final failure

Table 3.6 Test results of water absorption

% Replacement of cement by different blends	Average percentage water absorption	Percentage increase or decrease of water absorption w.r.t reference mix	Analytical values of water absorption using obtained regression model equation (%)
(50%FA + 0% MK) (Reference mix)	0.835	-	0.559
(45%FA + 5%MK)	0.823	-0.012	0.599
(40%FA + 10MK)	0.810	-0.025	0.639
(35%FA + 15%MK)	0.771	-0.064	0.679
(30%FA + 20%MK)	0.712	-0.123	0.719
(25%FA + 25%MK)	0.859	+0.024	0.759
(20%FA + 30%MK)	0.873	+0.038	0.799
(15%FA + 35%MK)	0.889	+0.054	0.839
(10%FA + 40%MK)	0.892	+0.057	0.879
(5%FA + 45%MK)	0.921	+0.086	0.919
(0%FA + 50%MK)	0.932	+0.097	0.959

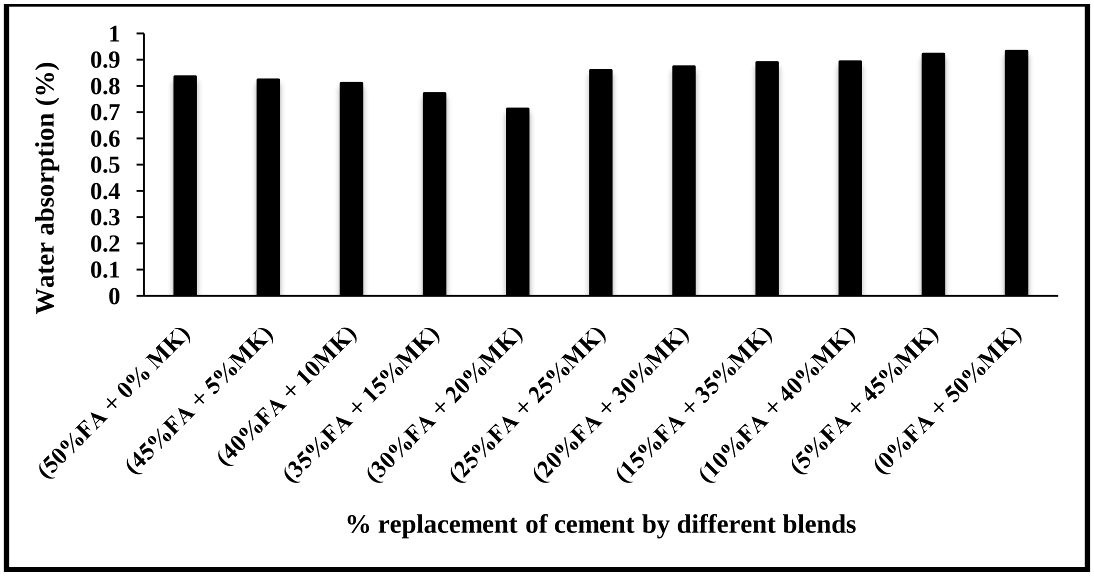

Fig. 3.12 Regression model of water absorption

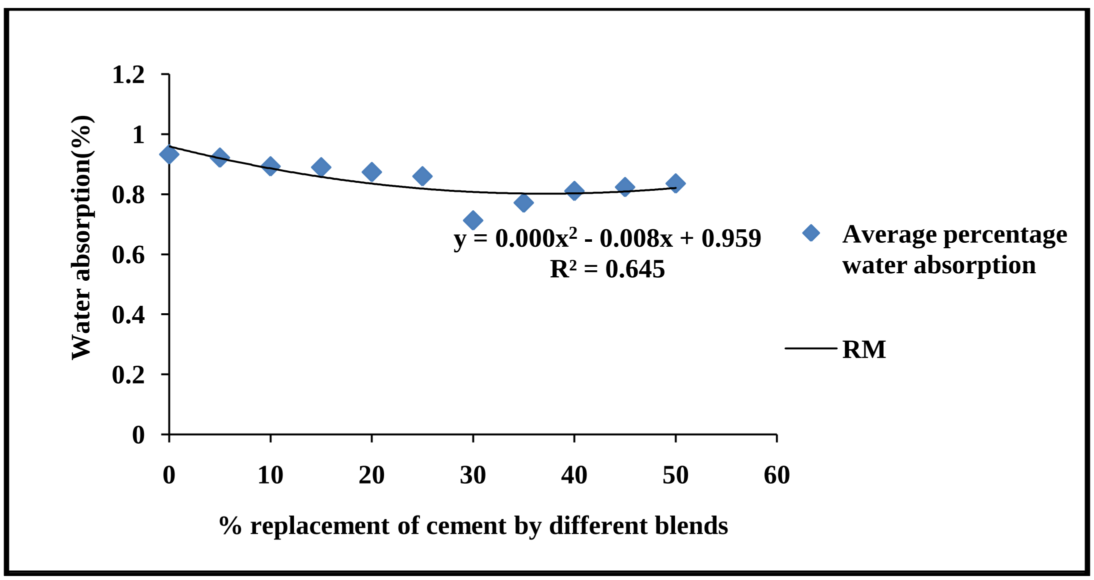

Fig 3.13Variation of water absorption

Table 3.7 Test results of sorptivity

% Replacement of cement by different blends	Sorptivity (mm/min$^{0.5}$)	Percentage increase or decrease of soroptivity w.r.t reference mix	Analytical values of sorptivity (mm/min$^{0.5}$)
(50%FA + 0% MK) (Reference mix)	0.438	-	0.05
(45%FA + 5%MK)	0.424	-0.014	0.11
(40%FA + 10MK)	0.41	-0.028	0.17
(35%FA + 15%MK)	0.396	-0.042	0.23
(30%FA + 20%MK)	0.368	-0.017	0.29
(25%FA + 25%MK)	0.438	0	0.35
(20%FA + 30%MK)	0.495	+0.057	0.41
(15%FA + 35%MK)	0.537	+0.099	0.47
(10%FA + 40%MK)	0.566	+0.128	0.53
(5%FA + 45%MK)	0.594	+0.156	0.59
(0%FA + 50%MK)	0.622	+0.184	0.65

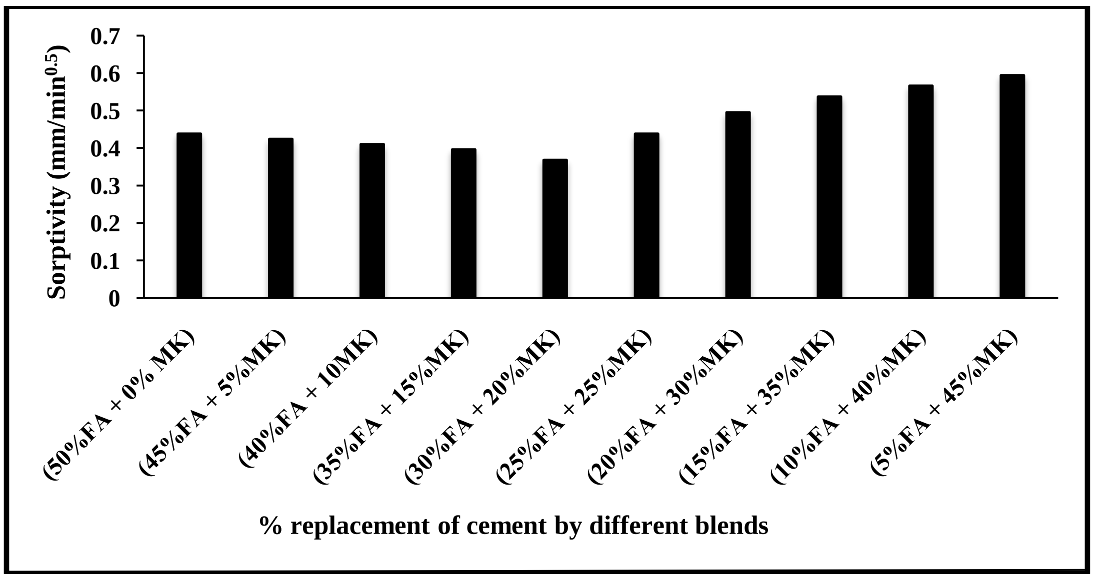

Fig 3.14 Variation of sorptivity

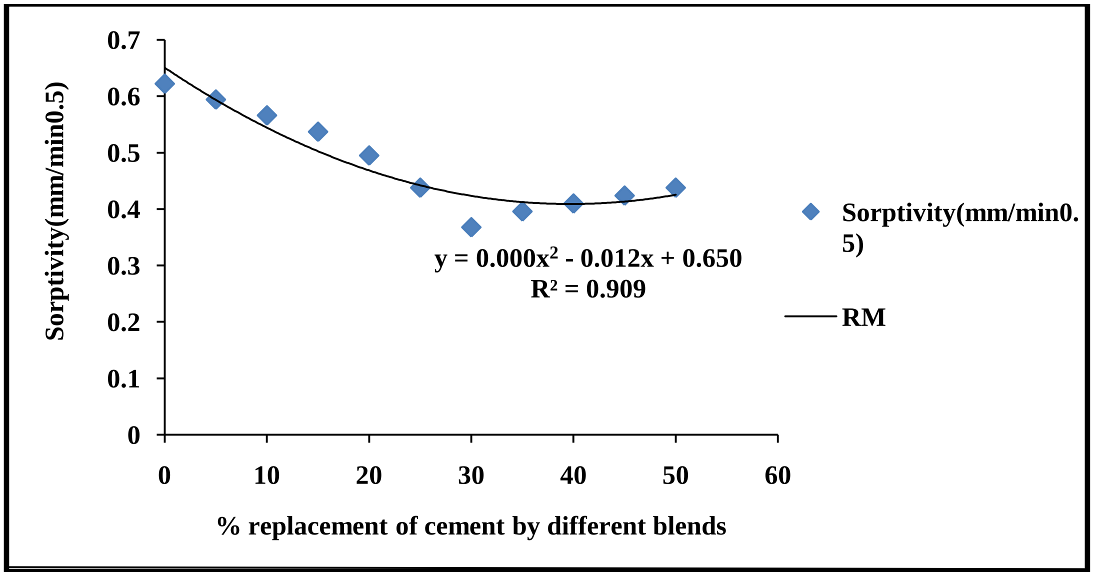

Fig. 3.15 Regression model of sorptivity

4. Observations and discussions

It is observed that the compressive strength, split tensile strength, flexural strength, shear strength and impact strength for initial crack and final failure of high volume fly ash and metakaolin blended concrete go on increasing as the metakaolin percentage in it increases up to 20%. Thereafter the strength starts decreasing. Thus, the compressive strength, split tensile strength, flexural strength, shear strength and impact strength for initial crack and final failure of high volume fly ash and metakaolin blended concrete show higher value at (30%FA + 20%MK). Also it is observed that at this combination the percentage increase in the corresponding strengths are 4.03%, 0.48%, 1.33%, 2.08%, 2.38% and 2.42% respectively. This is due to the fact that at (30%FA + 20%MK), both fly ash and metakaolin blends may have the rich silica content which will assist in imparting higher strength to the concrete. Also it is due to the fact of filler effect. Thus it can be concluded that the higher strength for high volume fly ash and metakaolin blended concrete can be obtained with a combination of (30%FA + 20%MK).

It is observed that the compressive strength, split tensile strength, flexural strength, shear strength and impact strength for initial crack and final failure of high volume fly ash and metakaolin blended concrete show almost equal corresponding values at (50%FA+0%MK) and (20%FA+30%MK), (50%FA+0%MK) and (5%FA+45%MK), (50%FA+0%MK) and (10%FA+40%MK), (50%FA+0%MK) and (10%FA+40%MK), (50%FA+0%MK) and (10%FA+40%MK) respectively. This may be due to the fact that at the above said combination probably the pore structure is such that it responds in the same way for the application of load. This is the reason why the corresponding strengths are equal at both the above said combinations. Thus it can be concluded that the compressive strength, split tensile strength, flexural strength, shear strength and impact strength for initial crack and final failure of high volume fly ash and metakaolin blended concrete are almost equal correspondingly at (50%FA+0%MK) and (20%FA+30%MK), (50%FA+0%MK) and (5%FA+45%MK), (50%FA+0%MK) and (10%FA+40%MK), (50%FA+0%MK) and (10%FA+40%MK), (50%FA+0%MK) and (10%FA+40%MK) respectively.

It is observed that the water absorption and sorptivity of high volume fly ash and metakaolin blended concrete go on decreasing as the metakaolin percentage in it increases up to 20%. Thereafter the water absorption and sorptivity starts increasing. Thus, the water absorption and sorptivity of high volume fly ash and metakaolin blended concrete show least value at (30%FA+20%MK). Also it is observed that at this combination the percentage decrease in the water absorption and sorptivity is 0.123% and 0.017% respectively. This is due to the fact that at (30%FA+20%MK), both fly ash and metakaolin blends may have the rich silica content which will undergo the reaction with cement thereby increasing the water tightness. Thus it can be concluded that the least value of water absorption and sorptivity for high volume fly ash and metakaolin blended concrete can be obtained with a combination of (30%FA+20%MK).

5. Conclusions

- Higher compressive strength, split tensile strength, flexural strength, shear strength and impact strength for initial crack and final failure for high volume fly ash and metakaolin blended concrete can be obtained with a combination of (30%FA+20%MK).
- The compressive strength, split tensile strength, flexural strength, shear strength and impact strength for initial crack and final failure of high volume fly ash and metakaolin blended concrete show almost equal corresponding values at (50%FA+0%MK) and (20%FA+30%MK), (50%FA+0%MK) and (5%FA+45%MK), (50%FA+0%MK) and (10%FA+40%MK), (50%FA+0%MK) and (10%FA+40%MK), (50%FA+0%MK) and (10%FA+40%MK) respectively.
- Least value of water absorption and sorptivity for high volume fly ash and metakaolin blended concrete can be obtained with a combination of (30%FA+20%MK).
- The different strength values obtained from the experimental results and analytical calculations (regression analysis) almost match for all the different cases.

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