

# Compressive Strength and Ultrasonic Pulse Velocity of Concrete with Metakaolin

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**Abstract** The intention of the present study is to assess the possibility of using Metakaolin as a partial replacement of Portland Pozzolana Cement (PPC) in the concrete to improve its workability and compressive strength. It also explores the study on the connection between ultrasonic pulse velocity (UPV) on different replacement percentage of mineral metakaolin and compressive strength by using a compression testing machine for M40 grade of concrete. Concrete specimens were cast of size 150 mmx150 mm x150mm by partial replacing PPC with metakaolin in the range of 4% to 28 % by the weight of cement. For better consistency and workability the Visco-Flux superplasticizer was used. Usual procedure of water curing of specimens was done for 7, 28, and 90 days to determine the effect of curing time on strength. All 8 different mix specimens were tested for compressive strength and ultrasonic pulse velocity. It was observed that up to 24% metakaolin replacement the strength was increased but after that, the strength gets reduced as compared to the normal concrete and the optimum value of compressive strength was obtained at 16% metakaolin replacement. The increase in the UPV of test samples indicated the formation of the homogeneous structure due to the addition of metakaolin. So the use of metakaolin as a partial replacement of PPC in concrete is a good choice to reduce the cost of production and increase the strength of concrete. A mathematical model is generated by regression analysis in the form of an equation to correlate the compressive strength and ultrasonic pulse velocity.

**Keywords** MK (Metakaolin), Compressive Strength, Ultrasonic Pulse Velocity, Concrete

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## 1. Introduction

Utilisation of Metakaolin as a pozzolanic binder in concrete blend is widely increased. Metakaolin is very different from other pozzolanic material because it is not the by-product as manufactured underneath carefully controlled environments [1]. It is made by calcinations of kaolin, one of the extensively available natural mineral. Fine and white color kaolin clay has conventionally been applied as a coating for paper and in the porcelain production. Usually metakaolin mineral is oxides of Aluminum and Silicon with small amounts of oxides of Calcium, Iron, Magnesium, Titanium, etc. MK has a white shade, which makes it appealing to architectural programs together with color matching [2]. Metakaolin due to higher degree of pozzolanic reactive improves mechanical properties of concrete reducing the cement consumption. Previous studies discovered an enormous interest in metakaolin because it has both micro filler in addition to pozzolanic properties [2-4]. Also it improves strength of concrete particularly in early stages of hydration [5, 6]. Metakaolin has been successfully used for formation of high strength self-compacting concrete (HSSCC) and proved with the help of mathematical modeling [7]. Due to fineness of metakaolin dose of super plasticizer required is more in MK containing concretes [8]. Such concretes help in protecting the environment by reducing carbon dioxide (CO<sub>2</sub>) and other greenhouse gas emissions related with cement production.

These days the non destructive tests (NDT) like Ultrasonic pulse velocity test methods are used for examination of concrete quality. The basis of this method is the measurement of velocity propagation, which is closely related to mechanical properties and more directly relates to elastic modulus. The UPV portable device consists of a source/detector unit and a surface sensor, with an operating frequency range of 25 to 60 kHz [9]. In all non-destructive testing methods, concrete is assumed to be a homogeneous material. This test is used to determine whether there is any damage/rupture, material discontinuity and intensity within a given exposure time. The measurement value is obtained by measuring the propagation time of an ultrasonic pulse between transducers on opposite ends of a given material. Knowing the span and propagation time between the transducers, the pulse velocity can be quickly found by dividing the length or span by the propagation time (Eq. (1)). High strength indicates higher density, integrity and quality of the material [10]

$$V(x,t) = x/t \quad (1)$$

Where, V is the UPV value, x is the length of concrete specimen and t is the travel time. Many previous studies reported correlation between UPV and the compressive strength for a particular proportion concrete mix [1-5, 11-15] still, a relationship with a wide variation will be obtained if the required data of UPV and the compressive strength of different proportion concrete mixture are arrange and analyzed [11-15].

In this work, harden properties of compressive strength test and ultrasonic pulse velocity test were conducted on all the mixes; regression analysis is carried on the values obtained from the result of compressive strength test and ultrasonic pulse velocity test to check their interrelationship among them.

## 2. Materials Used

### 2.1. Cement

PPC confirming by (IS 1489:1991). Initial and final setting time is 136 minutes and 210 minutes respectively, soundness 0.5 mm and 28 days compressive strength is 55.60 N/mm<sup>2</sup>. Chemical Properties of PPC are as given in Table 1.

**Table 1.** Chemical properties of cement

Sr. No.	Contents	Requirements as per IS 1489( Part I): 1991	Results
1	% Magnesia	Not more than 6.0 %	1.1
2	% Insoluble Residue	[X+4.0(100-X)/100] Max. (X is % Pozzolana in PPC)	27.0
3	% Sulphur Calculated As SO <sub>3</sub>	Not more than 3.0 %	2.3
4	% Loss On Ignition	Not more than 5.0 %	2.0
5	% Chloride	-	0.022

### 2.2. Metakaolin

Metakaolin, quality enhancing pozzolana in amorphous powder form was marketed by the 20 Micron Ltd. at Vadodara, Gujarat with physical and chemical properties given in Table 2.

**Table 2.** Chemical and Physical properties of Metakaolin

Properties	Contents	Results (% by mass)
Chemical properties	SiO <sub>2</sub>	53
	Al <sub>2</sub> O <sub>3</sub>	43
	Fe <sub>2</sub> O <sub>3</sub>	1.2
	CaO	0.5
	Na <sub>2</sub> O	0.12
	MgO	0.4
	K <sub>2</sub> O	0.53
	L.O.I.	0.4
Physical properties	TiO <sub>2</sub>	2.27
	Surface area (m <sup>2</sup> /kg)	16800
	Specific gravity	2.6

### 2.3. Fine and Coarse Aggregate

The fine aggregate used in the experimentation is locally available river sand complying with zone- II of IS 383(2016). The crushed stone were obtained from the local quarry was used as coarse aggregate. The coarse aggregates used in the experimentation were of 20mm and 10 mm and tested as per IS: 2386-1963 (I, II and III) specifications.

### 2.4. Superplasticizer

To give the additional desired properties, a superplasticizer Visco Flux-2230+ was used for casting specimens of all the mixes. It conforms to IS: 9103-1999 and has a specific gravity of 1.1.

### 2.5. Water

In experimentation fresh portable tap water which is free from acid concentration and organic substance is used for concrete mixing and for curing.

## 3. Concrete Mix Proportion and Casting of Specimen

The design mix proportion for M40 grade concrete as per standard was given in IS 10262:2009 and IS 456: 2000 was (1:1.69:3.1) of binder 400 kg/m<sup>3</sup>. The mix with water cement ratio 0.38 and the proportion of coarse aggregate (20mm): (10mm) was 60:40. The different proportion of concrete mix components was used to improve workability

of ppc with metakaolin concrete with proper dose of super plasticizer. All eight concrete mixes were used to cast 9 specimens per test series. The mixes were prepared by varying percentage of metakaolin from 0 to 28 with the interval of 4%. The standard 150 mm cubes were casted for compressive strength test. For the mixing of concrete the electrical laboratory concrete mixer were used. Initially for first two minutes dry mixing was done and latter for one minute wet mixing of concrete. After casting molds were allowed to dry for 24 hours at room temperature. The specimen were demolded and kept in water tank for curing for 7, 28 and 90 days age. Table 3 reports the concrete mix proportions.

150x150x150 mm as per IS 516:1959 by compressive strength machine of capacity of 2000KN. At all ages of curing compressive strength was performed.

### 4. Experimental Investigations

#### 4.1. Compressive Strength

The compression Test is done on cube of size

#### 4.1.1. Effect of Metakaolin on Cube Compressive Strength and UPV Values

The effect of addition of metakaolin as a replacement material to cement in concrete in various percentages, the compressive strength is increased significantly. The metakaolin is added in 4%, 8%, 12%, 16%, 20%, 24% and 28% by weight of cementitious material. The test is performed after completion of 7, 28 and 90 days of curing. The maximum compressive strength is found at 16% replacement of cement by metakaolin. It shows increment up to 10% over control concrete with a standard deviation of 4.15%. The variation of change in compressive strength in percentage is shown in Figure 1.

Table 3. Concrete Mix proportion

Sr. No.	Concrete mix	PPC:MK	Metakaolin %	Total binder (kg/ m <sup>3</sup> )	PPC (kg/ m <sup>3</sup> )	Metakaolin (kg/ m <sup>3</sup> )	Aggregate		W/C	SP %
							Fine (kg/ m <sup>3</sup> )	Coarse (kg/ m <sup>3</sup> )		
1	S1	1.00:0.00	0	400	400	0	679	1258	0.38	0.55
2	S2	0.96:0.04	4	400	384	16	679	1258	0.38	0.55
3	S3	0.92:0.08	8	400	368	32	679	1258	0.38	0.6
4	S4	0.88:0.12	12	400	352	48	679	1258	0.38	0.65
5	S5	0.84:0.16	16	400	336	64	679	1258	0.38	0.7
6	S6	0.80:0.20	20	400	320	80	679	1258	0.38	0.75
7	S7	0.76:0.24	24	400	304	96	679	1258	0.38	0.8
8	S8	0.72:0.28	28	400	288	112	679	1258	0.38	0.85

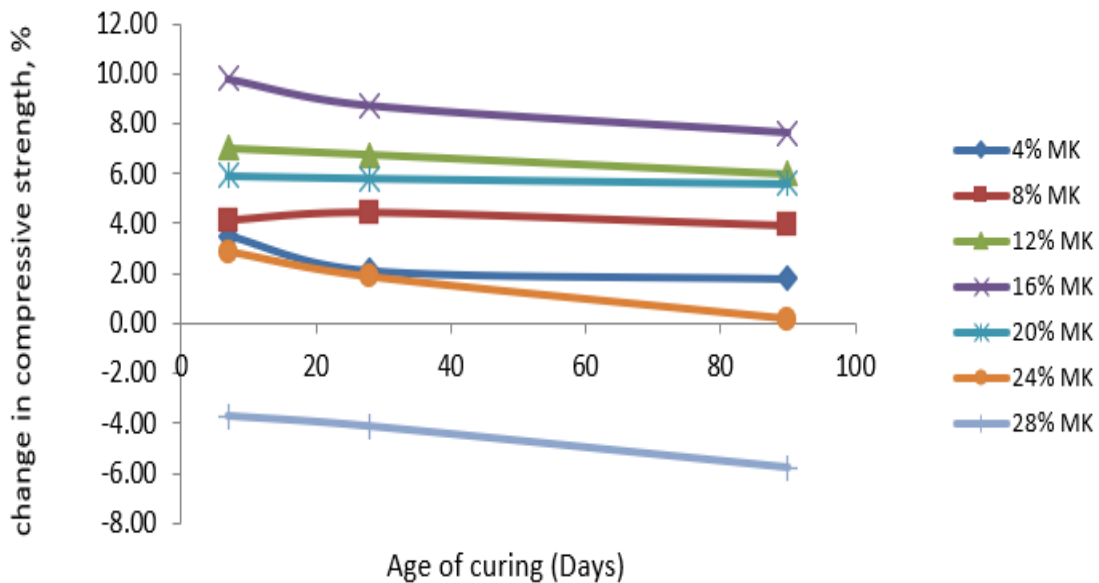


Figure 1. Variation of change in compressive strength of M40 concrete with MK percentages

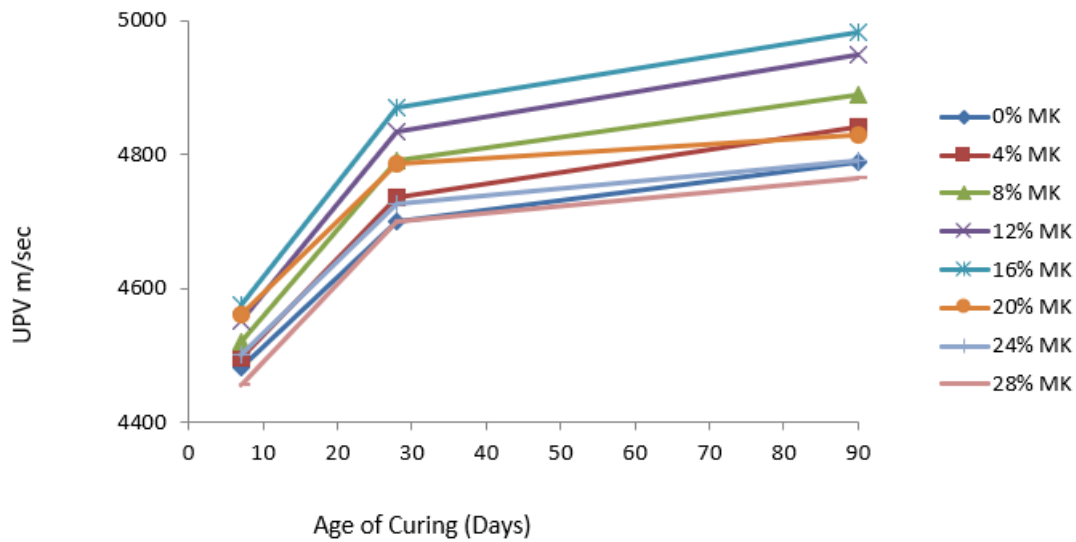


Figure 2. Variation of ultrasonic pulse velocity of M40 concrete with different MK%

It was found that gain in compressive strength for all mixes with MK % 0 to 24. At 28 % MK replacement compressive strength was less than the control mix. Early age, 7 days strength gain is more as compare to 28 and 90 days strength. Percentage gain in 7 days compressive strength was 3.48%, 4.14%, 7.02%, 9.81%, 5.91% and 2.88% for 4% to 28% Mk replacement respectively. After 90 days curing gain in strength was 1.8%, 3.93%, 5.98%, 7.6%, 5.59% and 0.17% for 4% to 28% MK replacement respectively. The UPV test result of all specimens is shown in figure 2. The range of UPV values is between 4482m/sec to 4993m/sec. It was observed that as MK % increases UPV values also increases at all curing ages. Curing age also increased UPV value for all the mixes. Reduction in UPV values was observed after certain limit of MK replacement.

**4.2. Compressive Strength and Ultrasonic Pulse Velocity Relationship**

Taking into account the correlation between the compressive strength and UPV value of all concrete mixtures, the UPV and compressive strength of all concrete mixtures with a curing time of 7 to 90 days are plotted in Figure 3. The final relationship between the two is shown in Figure 3. The correlation coefficient ( $R^2$ ) is 0.947, indicating that 94.7% of the variation in compressive strength value has a linear relationship with the UPV shown in Figure 3.

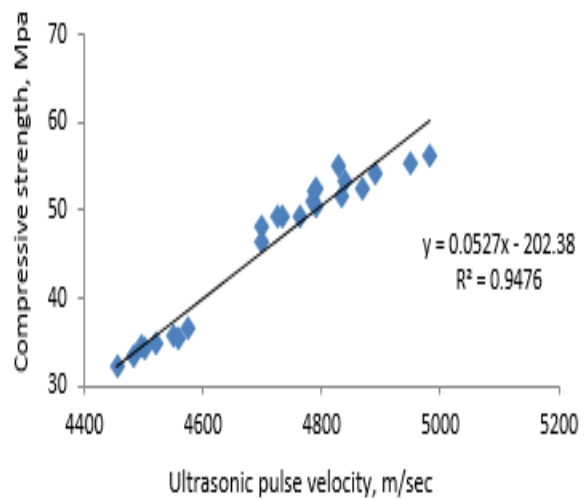


Figure 3. Relationship between cube compressive strength of M40 concrete and UPV

For the all results it had been found the subsequent model between compressive strength ( $f_c$  in MPa) and UPV ( $V$  in m/s):

$$f_c = 0.052V - 202.3 \tag{2}$$

Mathematical models for MK replacement percentage varying from 0% to 28% with the interval of 4 % as shown in figure 4 gives the justification for the general equation (2) of M40 concrete.

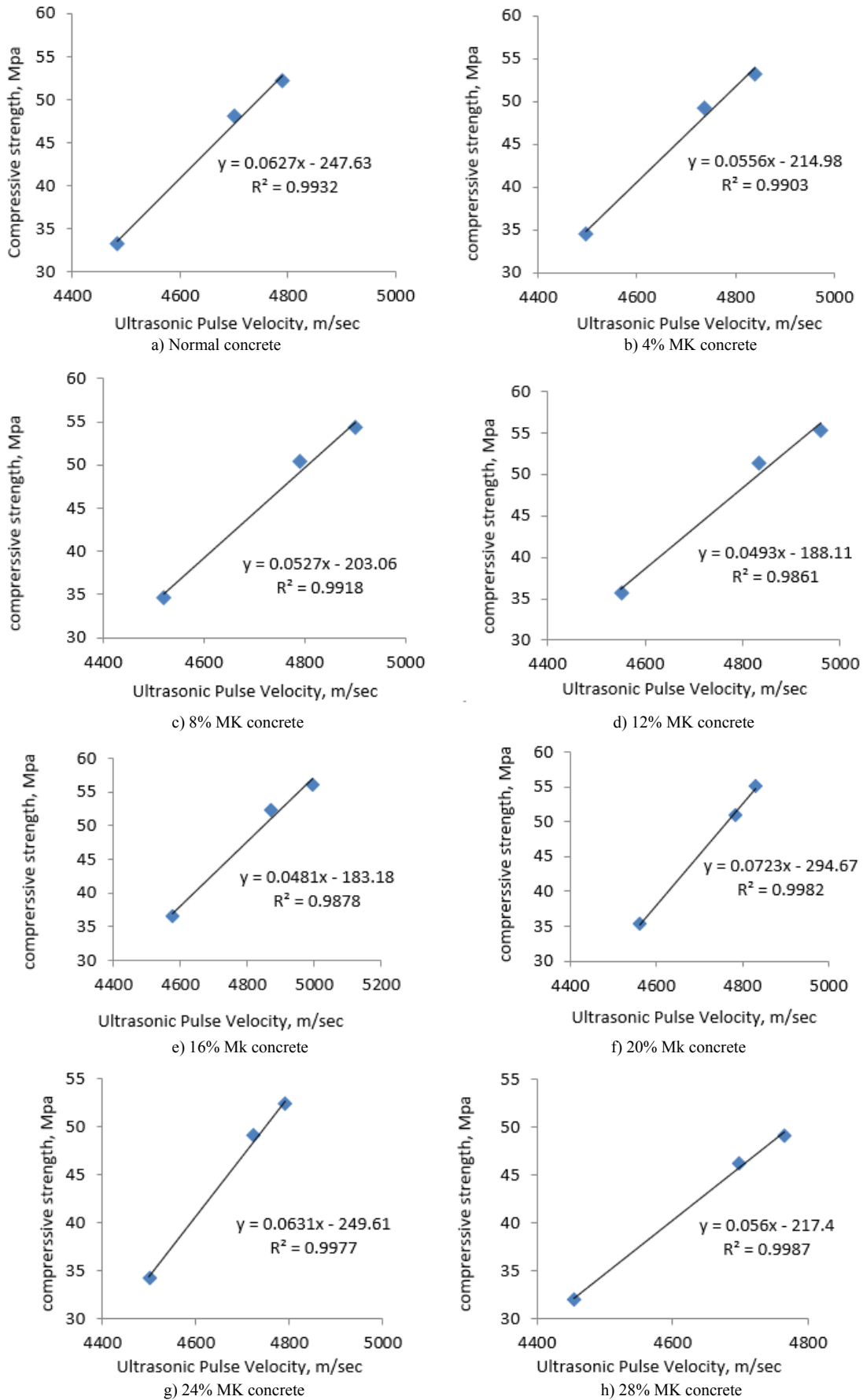


Figure 4. (a-h) Relationship between concrete cube compressive strength and Ultrasonic Pulse Velocity for M 40 concrete.

For individual model for MK replacement 4%, 8%, 12%, 16%, 20%, 24% and 28% a linear relationship was also observed with the correlation coefficient 0.99, 0.991, 0.986, 0.987, 0.998, 0.997 and 0.998 respectively.

## 5. Conclusions

1. Addition of MK in the range of 4 to 24% had improved the compressive strength of normal concrete.
2. Early age compressive strength gain was more almost in all curing levels of MK concrete.
3. For all the MK mix Ultrasonic pulse velocity value was observed to be increase as the age of curing was increased.
4. Generalized equation between compressive strength range 35 MPa to 55 MPa and ultrasonic pulse velocity gives the good agreement between experimental and predicted values.
5. The model for different percentage of MK concrete can be used to calculate the compressive strength of concrete.

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