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AN EXPERIMENTAL INVESTIGATION ON METAKAOLIN MODIFIED CONCRETE PAVER BLOCKS

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Abstract— **Concrete pavers are distinctive precast concrete block elements of interlocking or non-interlocking type, commonly used in outdoor paving applications. Properly created and engineered pavers perform excellently in places where standard paving systems have a reduced lifespan due to various environmental factors and geological constraints. However, by using high-performance concrete, they are designed to withstand light, medium and heavy loads and very heavy traffic conditions under all restrictions. Fashionable concrete is transformed by the addition of mineral admixtures that refine the concrete's microstructure and improve its physical properties. The objective of the present work is to evaluate the performance of concrete modified with Metakaolin for paver blocks for use in pavements and other application areas. As compressive, flexural strengths and water absorption are the most significant properties for concrete paver blocks the same will be studied for various concrete mixes with varying percentages of Metakaolin.**

Keywords— Compressive Strength, Concrete paver blocks, Flexural strengths, Metakaolin, Water absorption etc.

I. Introduction

In Concrete can be a product obtained in an unnatural way by hardening a mixture of cement, sand, gravel and water in acceptable quantities. Concrete is known to be a material commonly used in the housing industry around the world. It is achieved artificially by combining the substances of the building material, aggregate and water in predetermined amounts. The word "concrete" comes from the Latin word "concretus", which means "to develop", "to put together". The strength properties of concrete depend on the properties of the fabric components used and their interaction. within the cement manufacturing process, the greenhouse gas emission is high, which ends in uRocks that have too high a mineral content are so named because clay (kaolin) was historically used to make the ceramic material. Metakaolin reacts with Ca(OH)2, which is one of the by-products of the association reaction. cement and forms the CSH gel. This gelation eventually increases the strength and robustness of the concrete. Replacing MK with cement increases strength and durability and reduces porosity in the concrete and also reduces permeability.

II. MATERIALS and METHODOLOGY

A. Cement

The physical properties of the cement used in the present research work, .Ultratech brand ordinary Portland cement, Class 43, which certifies IS 8112:2013. Physical properties and chemical composition were determined and are given in Tables Nos. 3 and 4.

Fig 1 OPC cement (43 grade)

Table no. 1 Physical properties of Ordinary Portland Cement

S. No	Property	Test Results	Standard values according to IS: 8112-1989
1	Fineness	3%	< 10 %
2	Normal Consistency	29%	26%-33%
3	Specific Gravity	3.14	3.14-3.15
4	Initial setting time	92 min.	>30 min.
5	Final setting time	186 min.	< 600 min.

Table 2 Chemical properties of Ordinary Portland Cement

Chemicals	Mass (%)
CaO	63.21
SiO_2	21.16
Al_2O_3	4.71
Fe_2O_3	1.89
MgO	0.48

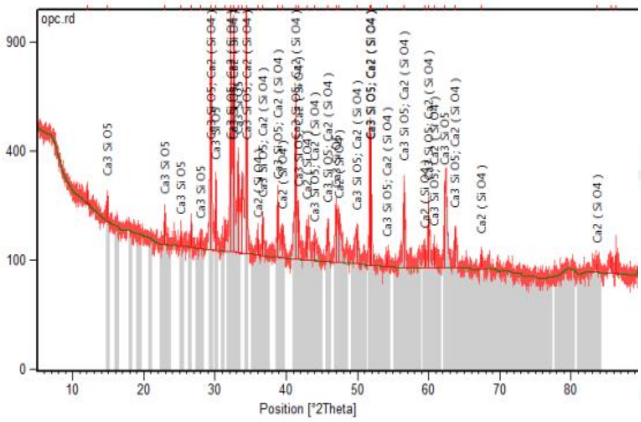

Fig 2 XRD pattern of OPC

B. Metakaolin

Metakaolin is purchased from Kaolin Industries Vadodara. Physical properties and chemical composition were determined and are reported in Table3 and Table 4.

Table 3 Physical Properties of Metakaolin

S.No	Property	Value
1	Particle shape	Spherical
2	Color	White

Table 4 Chemical composition of Metakaolin

Chemical Composition	Mass (%)
SiO_2	61.88
Al_2O_3	27.96
Fe_2O_3	1.41
CaO	0.78
MgO	0.56

Pozzolanic reaction of Metakaolin is as follows :-

Cement + Water = Primary CSH gel [Cementitious] + Ca (OH)2 [NonCementitious]

Ca(OH)2+Metakaolin = Calcium Aluminate hydrate(C4AH13) [Cementitious]

+ Calcium Aluminosilicate hydrate (C2ASH8) [Cementitious].
+ secondary CSH gel [Cementitious].

Fig. 3 Kaolin Mineral

Fig. 4 Mertakaolin power

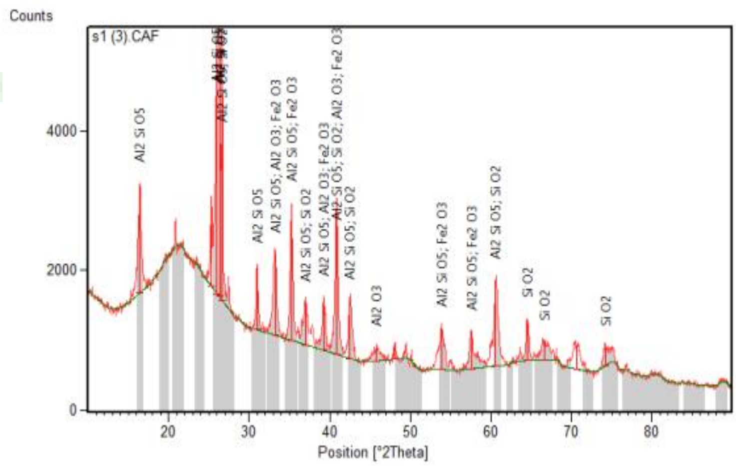

Fig.5 XRD pattern of Metakaolin

C. Natural Fine Aggregate

Coarse stream sand that is available regionally is used as a fine aggregate. The sieve analysis and physical properties

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of the fine aggregate are shown in the following table. The fine aggregate (sand) corresponds to the Zone III classification according to IS: 3831970.

Weight of Sample Taken =1000gms.

Table 5 Sieve analysis of fine aggregate

S.No	IS Sieve Size (mm)	Retained Weight (gms)	% Weight Retained	Cumulative % Retained	% finer
1	4.75	16	1.6	1.6	98.4
2	2.36	28	2.8	4.4	95.6
3	1.18	97	9.7	14.1	85.6
4	0.6	282	28.2	42.3	57.7
5	0.3	221	22.1	64.4	35.6
6	0.15	331	33.1	99.5	0.5
7	Pan	20	0.2	99.7	0.3

Table 6 Physical properties of fine aggregate

S.No	*Property*	*Observed Value*
1	Water absorption (%)	0.515
2	Fineness Modulus	3.757
3	Specific gravity	2.64

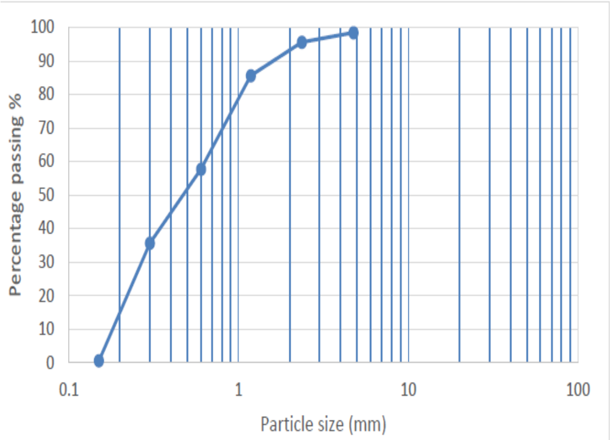

Fig 6 Particle size distribution of fine aggregate

D. Coarse Aggregate

Locally available aggregates is used as a coarse aggregate. The sieve analysis and physical properties of coarse aggregate have been shown in the table below

Weight of Sample Taken=5000gms.

Table 7 Physical properties of coarse aggregate

S.No	Property	Observed Value
1	Water absorption (%)	0.8
2	Fineness Modulus	5.2
3	Specific gravity	2.71

Table 8 Sieve analysis of coarse aggregate

S.No	Sieve Size (mm)	Retained Weight (gms)	Percentage Retained Weight	Cumulative Percentage Retained	% Finer
1	10	560	11.2	11.2	88.8
2	4.75	4370	87.4	98.6	1.4
3	2.36	70	1.4	100	0
4	1.18	0	0	100	0
5	0.6	0	0	100	0
6	0.3	0	0	100	0
7	0.15	0	0	100	0
8	Pan	0	0	100	0

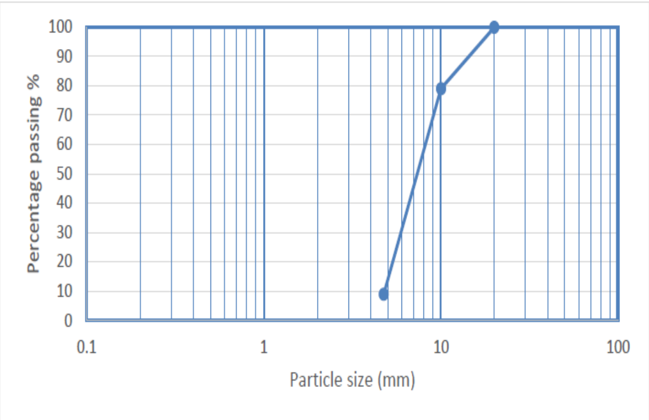

Fig 7 Particle size distribution of coarse aggregate

E. Water

The water must be free from organic and harmful contaminants. Drinking water is considered the most satisfactory for concrete according to Section 5.4 of IS: 4562000 Manufacture of Concrete and the Natural Process of Concrete Pattern.

III. CONCRETE MIX DESIGN

A. Mix Design

The mixed style is complete for the present study. In general, low slump dry mixes are required for the manufacture of molded concrete pavers. The design of the combine was in IS code 10262:2009 hot water management mix for impacted concrete M40 and the specification given in code IS 15658:2006

Stipulations for proportioning :-

Grade of concrete - M40 (medium traffic as per IS 15658:2006 table 1)

Cement – Ordinary Portland cement (43 grade)

Cement content – minimum 400kg/m^3 and maximum 450 kg/m^3

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Aggregate size - Angular aggregate of maximum size is 10 mm
W/C quantitative relation - 0.35
Slump worth - zero (IS code 15658:2008)
Condition of exposure – Mild
Admixture – super plasticisers

- **Mix Design process**

Target strength:
Mean target strength ft = f_{ck} + 0.825s (as per IS 15658-2006 table 3)
Standard deviation s = 5 N/mm^2 from table IS 456
So the target strength = 40 + 0.825 × 5 = 44.125 N/mm^2

- **Water-Cement ratio:**

As per IS 456, table no 5 the maximum water to cement ratio to be considered is 0.35

- **Water content**

For 10 mm maximum size of the aggregate with 0 to 25mm slump the required water is 208 lit from IS 10262-2009 Table 1. 30% water is reduced for super plasticizer. so required water is: 208 × 0.7= 145.6 kg

- **Cement content**

W/C = 0.35, cement = 148/0.35 = 416 kg,
Minimum cement content required as per IS 456 -2000, 360 kg/m^3

- **Calculation of volume of coarse and fine aggregate proportion**

Fine aggregate of zone III, W/C = 0.5, the volume of 10mm coarse aggregate is 0.48. But for the w/c ratio of 0.35 after correction the volume of CA is 0.51.
Volume of fine aggregate = 1 - 0.51 = 0.49

Mix calculations

Sg of cement = 3.15
Sg of fine aggregate = 2.71
Sg of coarse aggregate = 2.64
For 1m^3 volume of concrete

Cement volume = cement weight / (Density of cement)
= 416 / (3.15 × 1000) = 0.1364 m^3

Volume of water = weight of water/ (density of water)
= 145.6/(1 × 1000) = 0.145 m^3

All in aggregate volume = Total volume – volume of cement – volume of water
= 1 - (0.1364 + 0.145) = 0.7186 m^3

Coarse aggregate weight = All in aggregate volume × coarse aggregate volume × Density of coarse aggregate
= 0.7186 × 0.51 × 2.7 × 1000
= 989.51 kg
Weight of fine aggregate = All in aggregate volume × Fine Aggregate Volume × Fine aggregate density
= 0.7186 × 0.49 × 2.64 × 1000
= 929.58 kg.

While replacing cement with MK first cementitious material is increased 10 percent, then the materials are calculated.

B. Mix design: 1:2.58:2.68

Manufacturing of paver block

Cement, sand, coarse aggregate, water and superplasticizer were mixed together in the concrete mixer. They were then stuffed into the rubber mold of the paver in different shapes and thicknesses. In casting, all samples were finished with a steel trowel and did not break for twenty-four hours. after 24 hours they were recast from the paver molds and kept in the tank with water to harden. an equivalent process was in serious trouble 5%, 10% and 15% replacement of cement with metakaolin. to know the result of the readiness of the cement with metakaolin, compressive strength, flexural strength, they were carried out in

Table 9 Paver block details

SI No.	Shape	Thickness (mm)	Plan Area (m^2)	Length (cm)	Width (cm)
1	Zigzag	80	0.0285	23.5	12.5
2	"I" shape	60	0.033	22.5	12.5
3	Dumbel	60	0.036	26.5	11

C. Testing of Paver block

Compressive strength

According to IS 15658:2006, the compressive strength of the paving stone is determined after seven and twenty-eight days in the Universal Abuse Testing Machine (UTM). At least 3 samples were tested for strength after 7 and 28 days. The combined strength of three samples after 28 days was taken as the compressive strength of the paver. The apparent compressive strength of the paving stone increased with the correction problem as it is mentioned in IS 15658:2006 from Table 5, Annex D to require a corrected compressive strength of the paving stone.

Table 10 Correction Factor for Thickness of Paver Block for Calculation of Compressive Strength

S.No	Paver block thickness(mm)	Correction factor
1	60	1
2	80	1.12

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Fig 8 Compressive testing machine of paver block

D. Flexural strength

Flexural strength of paver blocks for control mix and for various percentage of sand and cement replacement with MK were done as per IS 15658: 2006. The flexural strength of paver block calculated as follows:

$$F_b = 3Pl / 2bd^2$$

Where:

F_b= Flexural strength in N/mm^2,

P = Breaking load in N,

l = Distance between centre to centre of supporting rollers,

b = Average breadth of block measured in both faces

Fig 9 Flexural strength test conducted by using Universal Testing Machine

E. FESEM and EDX

To analyze the results of metakaolin in the microstructure of the concrete, different techniques are used, such as: B. Spectroscopy, the optical powder X-ray phenomenon (XRD) and the scanning emission microscope (FESEM). To analyze the results of metakaolin in the microstructure of the concrete, different techniques are used, such as: B. Spectroscopy, the optical powder X-ray phenomenon (XRD) and the scanning emission microscope (FESEM).

F. XRD Spectroscopy

A separate final X-ray meter with a copper anode (single potential 40 and thirty mA) and 50 to 800 scans is used for the XRD spectra. Samples are taken from within the block, crushed and well sieved. Samples are known by being tested against standards established by the International Center for Optical Phenomena Data.

Fig 10 Multipurpose X-ray diffraction system (Rigaku ULTIMA IV).

IV. RESULTS AND DISCUSSION

A comparison of results was made to measure the effects of partially replacing cement with metakaolin in concrete harvesters to determine mechanical properties at seven days and twenty-eight days.

A reference mix M0 of grade M40 was prepared without the addition of metakaolin and 3 additional mixes M1, geld stock and geld stock were prepared with metakaolin in different amounts of 5%, 10% and 15%, each used as a partial replacement of cement. Three completely different shapes of cobblestones, zigzag, I-shape and dumb-shape, were adopted for the study. Eight samples of each grade of cobblestone blocks were forged and cured for 7 days and 28 days.

Shape	Zigzag	I-shape	Dumbel
Thickness(mm)	80	60	60
Plane Area(m^2)	0.0285	0.033	0.036
Length	23.5	22.5	26.5
Width	12.5	12.5	11

Fig 11 (7 days) Compressive strength result

Table 11 (7-days) Compressive strength result MPa

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Tests Performed	Materials used
Compressive strength	Paver block of Zigzag (80 mm), Dumbel (60 mm), I-shape (60 mm) having Metakaolin [0%, 5%, 10%, 15%]
Flexural strength	Paver block of Zigzag (80 mm) Dumbel (60 mm) I-shape (60 mm) having Metakaolin [0%, 5%, 10%, 15%]
Water absorption	Paver block of Zigzag (80 mm) Dumbel (60 mm) I-shape (60 mm) having Metakaolin [0%, 5%, 10%, 15%].

Mix	Metakaolin (%)	Zigzag (80 mm)	Dumbel (60 mm)	I-shape (60 mm)
M0	0	53.14	52.46	51.98
M1	5	55.9	56	54.5
M2	10	61.85	62.46	60.89
M3	15	57.95	58.13	56.79

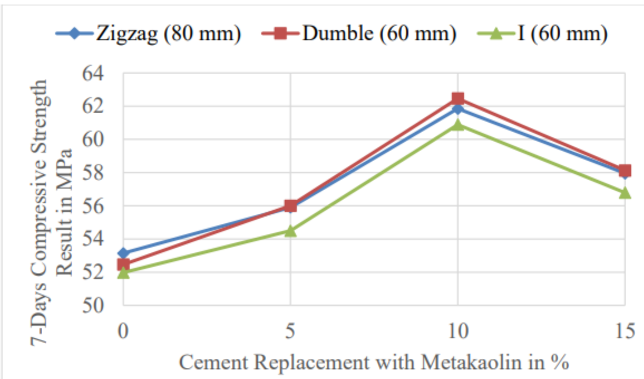

Table **12 (28-days) Compressive strength result MPa**

Mix	Metakaolin (%)	Zigzag (80 mm)	Dumbel (60 mm)	I-shape (60 mm)
M0	0	61.43	60.83	59.23
M1	5	66.42	65.24	63.9
M2	10	73.24	74.26	71.2
M3	15	70.01	69.54	68.54

Table 13 (7-days) Flexure strength result MPa

Mix	Metakaolin (%)	Zigzag (80 mm)	Dumbel (60 mm)	I-shape (60 mm)
M0	0	5.21	5.02	4.89
M1	5	5.65	5.79	5.6
M2	10	6.2	6.42	6.1
M3	15	5.61	5.59	5.5

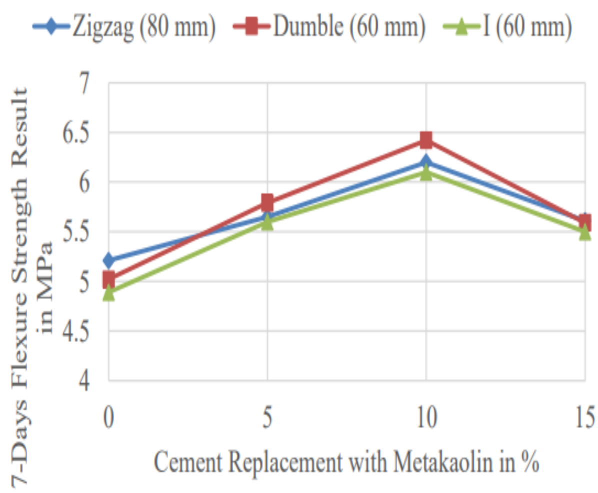

Fig no. 12 (7- days) flexure strength MPa

Table 14 (28-days) Flexure strength result MPa

Mix	Metakaolin (%)	Zigzag (80 mm)	Dumbel (60 mm)	I-shape (60 mm)
M0	0	7.22	7.04	6.99
M1	5	7.56	7.34	7.29
M2	10	7.84	7.9	7.77
M3	15	7.68	7.57	7.39

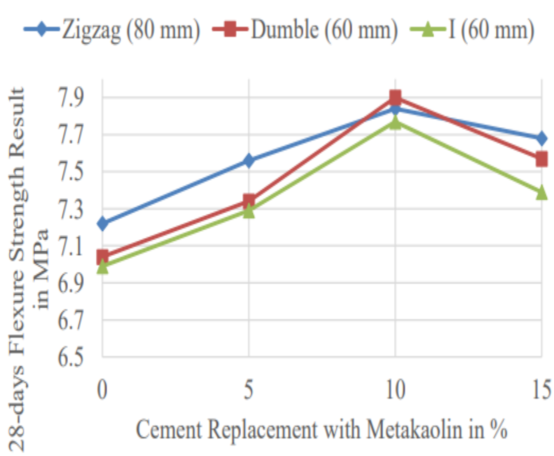

Fig no. 13 (28 days) Flexure strength result MPa

Table 15 Cement replacement Vs. Water absorption

Mix	Metakaolin (%)	Zigzag (80 mm)	Dumbel (60 mm)	I-shape (60 mm)
M0	0	2.3	2.1	2.2
M1	5	2.45	2.4	2.5
M2	10	1.6	1.9	1.8
M3	15	2.2	2.2	2.1

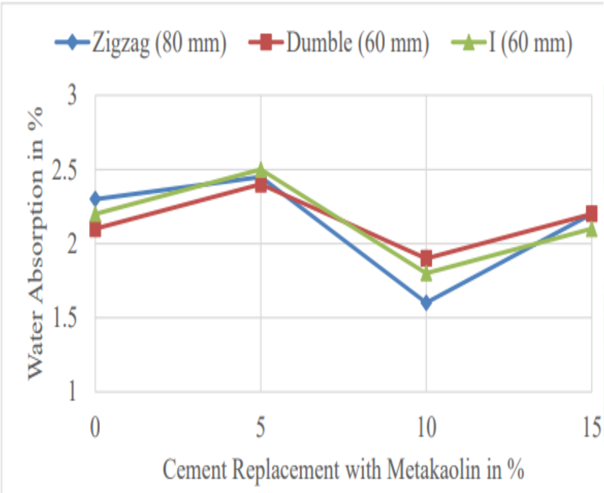

Fig 14 Cement replacement Vs water absorption

A. FESEM and EDS Analysis

FESEM analysis was carried out to provide information about the particle morphology and crystal growth of hydrated paste for mixes with varying percentage of Metakaolin.

M0 (Control Mix)

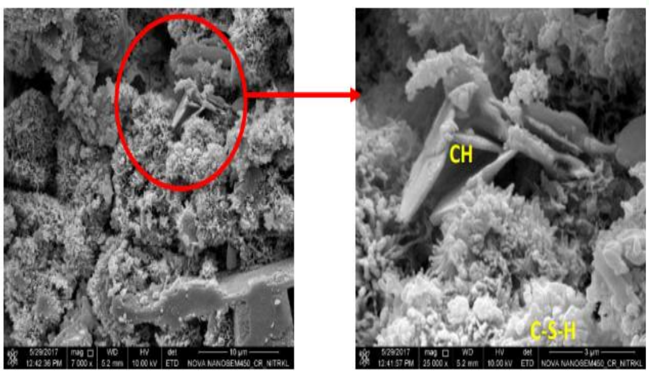

Fig 15 FESEM image of control mix

The micro structure of hydrated cement paste is characterized by presence of the CSH gel, CH plates, ettringite, pores.

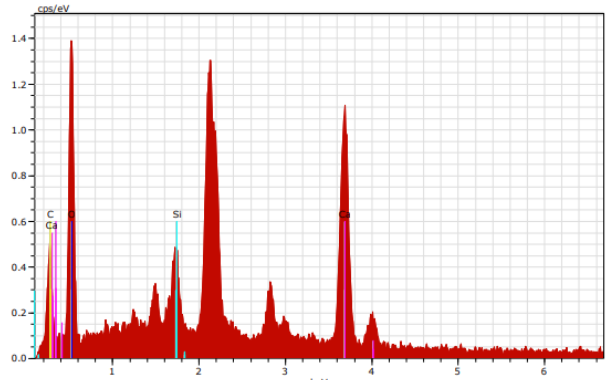

Fig 16 EDS analysis of control mix

M1 (5% Metakaolin)

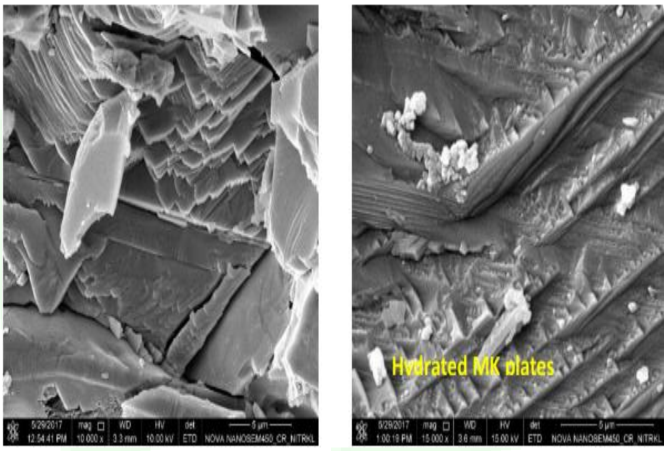

Fig 17 FESEM image of MI mix

Due to the pozzolanic reaction between MK and CH throughout the association process, secondary calcium silicate hydrate (CSH gel) is formed, which deposits on and between the first layers of the CSH gel, forming an additional small compact and hissing structure. The SEM image in the figure shows the comparatively densely layered hydrated metakaolin plate with smooth surfaces. The amorphous portion of the hydrated cement paste can be seen between and at the edges of the hydrated MK plates. You can see the pores and voids in the layer.

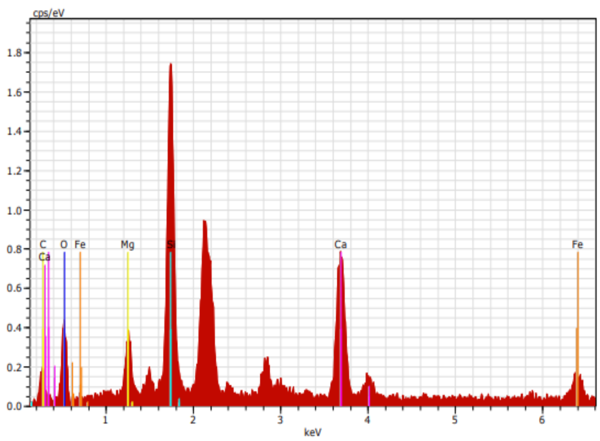

Fig 18 EDS analysis of MI mix

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M2 (10% replacement)

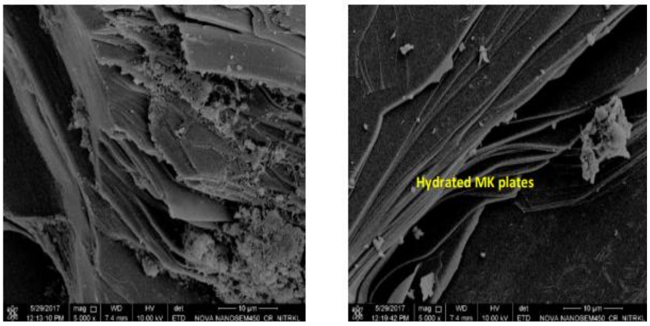

Fig 19 FESEM image of M2 mix

The sample shows a higher compactness, the layered HCP structures got sealed with Metakaolin particles due to reaction resulted in smoother compact surface with smaller pores.

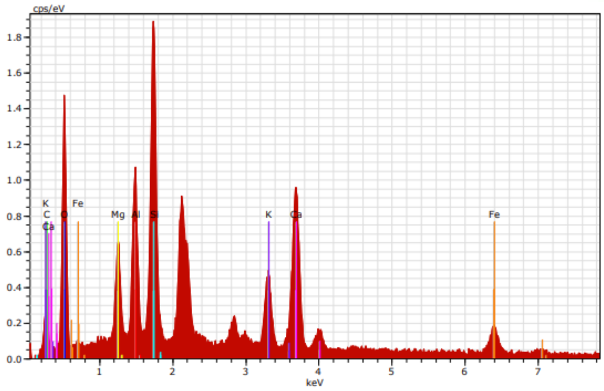

Fig 20 EDS analysis of M2 mix

M3(15% replacement)

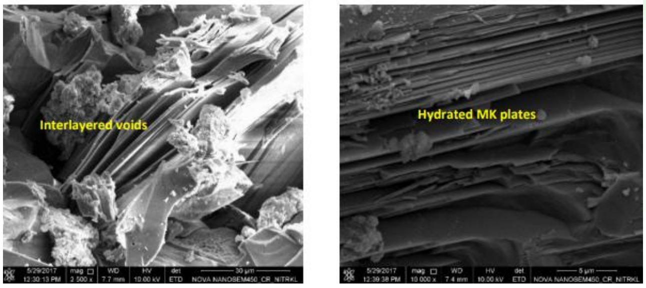

Fig 21 FESEM images of M3 mix

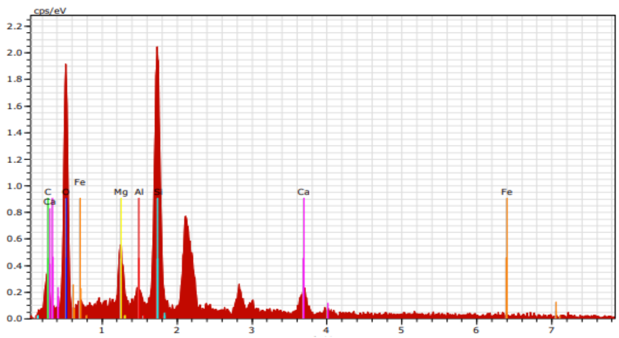

Fig 22 EDS analysis of M3 mix

B. EDS

Analysis EDS is Energy Dispersive X-ray Spectroscopy. It is a characterization technique that provides the elemental composition of various constituents in a material. The abscissa of the EDX spectrum indicates the ionization energy and the ordinate indicates the counts. The higher the count for a particular item, the greater its presence at that point or area of interest.

Table16 EDS analysis of different mixes

Mix	Si (% wt)	Ca (%wt)
M0	1.60	13.98
M1	8.02	8.75
M2	6.48	8.01
M3	11.18	2.84

4.6 X-Ray diffraction spectrometry Analysis

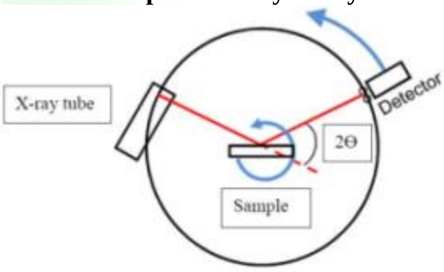

Fig.23 Schematic of working of X-ray diffraction system

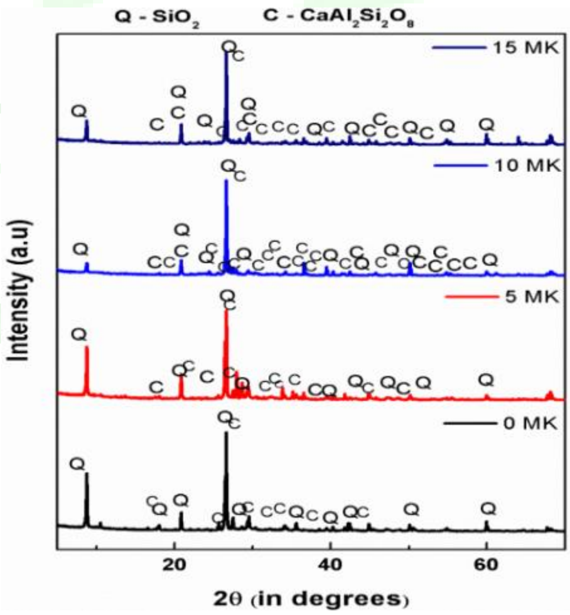

Fig 24 XRD pattern

Similar observations were found in XRD analysis of pools. A smaller alphabetic character peak was determined for the 10-MK mixture, indicating higher Q consumption in pozzolanic reactions that form a large amount of CSH gel, indicated by the C number, within the 15 -MK blend. The Q peak shows a higher proportion of unreacted MK. The 5MK mixture showed a higher peak for Q and a lower count for C, which could result in incomplete pozzolanic reactions.

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V. CONCLUSION

The following conclusions are made.

1.The compressive strength of paving blocks of all shapes and thickness after seven and twenty-eight days definitely increases with an increasing proportion of MK cement substitute up to 10%. The 7-day compressive strength of the paver for all shapes exceeds the target strength required up to 15 days after replacement. The maximum compressive strength for all shapes is replaced in addition to 10%. Most compressive Concrete with metakaolin also showed higher strength in relation to water absorption.

2. Flexural strength increases as cement replacement increases by up to 10% more than when 15% replacement is more than control concrete and more than 5% replacement overall. The flexural strength at 7 and 28 days increases up to 10% replacement, at which point it decreases as the replacement ratio increases. together about 4.5 MPa for all shapes needed for a rigid concrete pavement.

3. The use of metakaolin as a partial replacement for cement increases mechanical properties such as compressive strength, flexural strength of concrete.

4. Concrete with Metakaolin also exhibited higher strength in terms of water absorption. It has been clearly established that 10% metakaolin, used as a partial replacement for cement, improves theoverall properties of concrete pavers. The compressive strength of all types of paving stones was determined for an increase of 20% in 28 days. An 11% increase in 28-day flexural strength was observed for all types of pavers.

5. The maximum strength gain was observed with the dumbbell shaped cobblestone blocks.

6. Metakaolin imparts a characteristic glassy white color to pavers which increases reflectivity making it acceptable for certain applications such as swimming pools, roofing, etc. to also enhance the beauty of fine arts. Due to the lower porosity, suitable for use on industrial floors, parking lots, bridge decks, etc. Microscopic observations carried out by FESEM revealed that metakaolin forms a dense structure in concrete, mainly thanks to the increase in the amount of associated goods that CSH, CAH and money correspond, and their subsequent accumulation in the accessible pores, which confer greater strength and lower permeability.XRD and EDX analysis confirm tip.

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