AN EXPERIMENTAL INVESTIGATION ON METAKAOLIN MODIFIED CONCRETE PAVER BLOCKS

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AN EXPERIMENTAL INVESTIGATION ON METAKAOLIN MODIFIED CONCRETE PAVER BLOCKS

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May 30, 2017

Supervisor's Certificate

This is to certify that the work presented in this thesis entitled "*An Experimental Investigation On Metakaolin Modified Concrete Paver Blocks*" by ''Govindapuram PrasannaJyothi '', RollNumber 215CE2022, is a record of original work carried out by her under my supervision and guidance in partial fulfilment of the requirements of the degree of Master of Technology in Structural Engineering. Neither this dissertation nor any part of it has been submitted for any degree or diploma to any institute or university in India or abroad.

(Prof. Asha Patel)

I dedicate my thesis to this great NATION.

Declaration of Originality

I, Govindapuram PrasannaJyothi, Roll Number 215CE2022 hereby declare that this thesis entitled "*An Experimental Investigation On Metakaolin Modified Concrete Paver Blocks"* represents my original work carried out as a postgraduate student of NIT Rourkela and, to the best of my knowledge, it contains no material previously published or written by another person, nor any material presented for the award of any other degree or diploma of NIT Rourkela or any other institution. Any contribution made to this research by others, with whom I have worked at NIT Rourkela or elsewhere, is explicitly acknowledged in the dissertation. Works of other authors cited in this dissertation have been duly acknowledged under the section "References". I have also submitted my original research records to the scrutiny committee for evaluation of my dissertation.

I am fully aware that in case of any non-compliance detected in future, the Senate of NIT Rourkela may withdraw the degree awarded to me on the basis of the present dissertation.

May 30, 2017 Govindapuram PrasannaJyothi

NIT Rourkela

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ABSTRACT

Concrete paver blocks are special pre-cast pieces of concrete blocks of non-interlocking or interlocking types, commonly used in exterior landscaping pavement applications. Properly designed and constructed paver blocks give excellent performance at locations where conventional pavement systems have lower service life due to a number of environmental, geological constraints. But with the use of high performance concrete they can be designed to sustain light, medium, heavy and very heavy traffic conditions under any constraints.
Modern concrete can be modified with addition of mineral admixtures which refine the microstructures of the concrete and enhance its physical properties and durability. Metakaolin, produced by controlled thermal treatment of kaolin, can be used as a concrete constituent, since it has pozzolanic properties. It is a highly efficient Pozzolana and react rapidly with the excess calcium hydroxide resulting from OPC hydration by a pozzolanic reaction, to produce calcium silicate hydrate and calcium alum inosilicate hydrates.

Hence the objective of the present work was 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 have been studied for various concrete mixes with varying percentages of Metakaolin.

Metakaolin was used as partial replacement of cement in the study and three percentages 5%.10% and 15% were adopted for determination of compressive strength, flexural strength and water absorption of zigzag, dumbel and I shape paver blocks. The mix with 10% replacement was found to give maximum compressive, flexural strength and minimum water absorption for all types of paver blocks.

To validate the above conclusion XRD, FESEM and EDS analysis of the MK modified mixes were done and found that addition of MK to concrete made microstructure very dense, thereby improving its properties

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CHAPTER 1

INTRODUCTION

1.1 General

Concrete is a product attained artificially by hardening the mixture of cement, sand, gravel and water in suitable quantities. As we know concrete is a composite material which is mostly used in construction industry all over the world. It is artificially attained by mixing the cementitious materials, aggregates and water in predetermined quantities. The word "concrete" is originated from the Latin word "concretus" which has the meaning to grow together to harden. The strength properties for the concrete depend upon the properties for constituent of material used and their combined action

In the manufacturing process of cement CO_2 gas emission is high, which results in damaging the natural environment and climatic conditions. To reduce the utilization of cement, partial standby of cement with some additional cementitious materials like Metakaolin (MK), bottom ash, rice husk ash, GGBS and silica fume etc., are used in concrete production. Metakaolin is a dehydroxylated form of the Kaolin clay mineral. Stones having the high percentage of kaolinite are called as the china clay (kaolin) was traditionally used as the manufacturing of the porcelain ceramic material. Metakaolin reacts with $Ca(OH)_2$ which is one of the by-product of hydration reaction of cement and its forms the C-S-H gel. This gel formation results in increasing strength and durability of the concrete. By replacing cement with MK increases the strength and durability and reduces the porosity in the concrete and reduces the permeability also.

1.2 Paver blocks

Concrete paver blocks were first used in Holland as substitution of paver blocks. These blocks were rectangular in shape and had almost the same size as the bricks. Since last fifty years the block shapes of paving blocks had been modified depending on the applications. Initially they were designed as non-interlocking or partially inter locking, then modified to fully interlocking shape types. These paver blocks are precast concrete units which are laid on a thin compacted bedding over a profiled base course to construct a pavement.

If non-interlocking or partially-interlocking paver blocks are used, then it is called Concrete Block Pavement (CBP) and if interlocking paver blocks are used the pavement is called 'Interlocking Concrete Block Pavement (ICBP).

These paving blocks being pre-cast units can be applied to any locations and do not depends on geological, environment conditions. They can be cast of any shapes and sizes to cater the need. They also offer speedy construction and can be designed to take care of light, medium and heavy traffic conditions safely.

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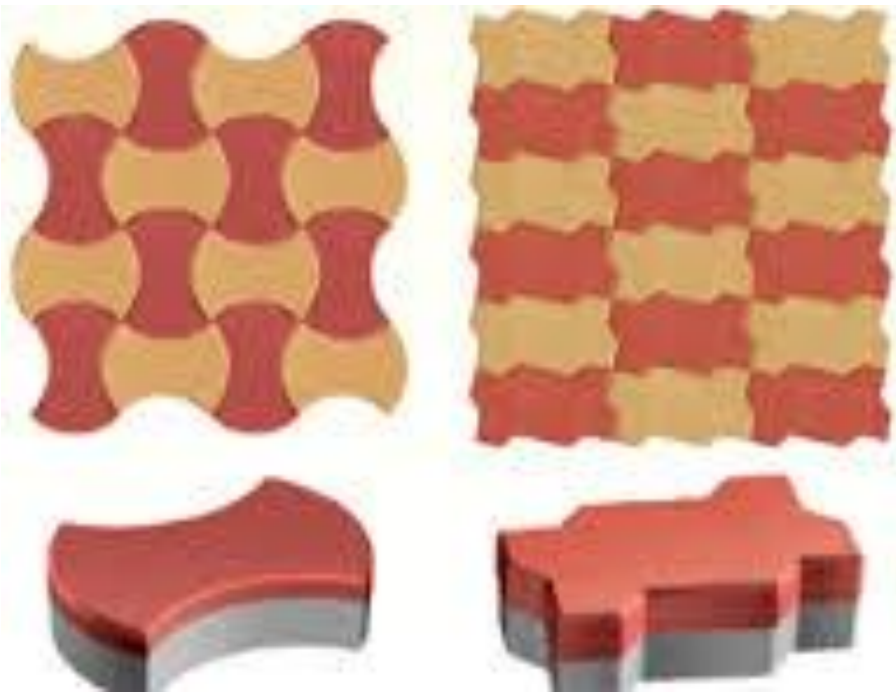


Fig 1.1 Paver Blocks

1.3 Materials

1.3.1 Cement

Ordinary Portland Cement (OPC) is the most common cement used in general concrete construction. It is used as a basic ingredient of concrete. Ordinary Portland Cement are classified as OPC-53, OPC-43, OPC-33 grades. The 43 grade OPC is the most popular general-purpose cement in India.

The four basic chemical compounds of OPC are tricalcium silicate (3CaO.SiO2), dicalcium silicate (2CaO.SiO2), tricalcium aluminate (3CaO.Al2O3) and tetra calcium aluminoferrite (4CaO. Al2O3.Fe2O3). Their relative percentage in cement derive the essential properties in the cement concrete mix. The chemical composition of OPC is shown in Table 1.2

Table 1.2 Chemical Composition of Cement

Chemicals	Mass (%)
CaO	60-67
SiO_2	17-25
Al_2O_3	3-8
Fe_2O_3	0.5-6
MgO	0.1-4

1.3.2 Metakaolin

Metakaolin is a highly reactive Pozzolana for use in concrete. It is not a by-product but a product that is manufactured for use by-product and is formed when china clay, the mineral kaolin, is heated to a temperature between 600 and 800ºC. Its quality is controlled during manufacture, resulting in a much less variable material than industrial Pozzolana that are by-products. First used in the 1960s for the construction of a number of large dams in Brazil, Metakaolin was successfully incorporated into the concrete with the original intention of suppressing any damage due to alkali-silica reaction.

When used to replace cement at levels of 5 to 10% by weight, the concrete produced is generally more cohesive and less likely to bleed. As a result, pumping and finishing processes require less effort. The compressive strength of hardened concrete is also increased at this level of replacement.

Slightly higher replacement levels (up to 20%) produce a cement matrix that has low porosity and permeability. This results in improvements to resistance of the hardened concrete to attack by sulfates, chloride ions and other aggressive substances, such as mineral and organic acids. Freeze/ thaw resistance is improved and the risk of damage resulting from the effects of impact or abrasion is reduced for Metakaolin concrete that has been finished and cured properly.

Table 1.4 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

1.3.3 Pozzolanic reaction of Metakaolin

Metakaolin acts like pozzolana. It reacts with CH hydrates and form secondary CSH gel along with calcium aluminate hydrates and calcium aluminosilicate hydrate gels. They are of cementitious nature. The get deposited on primary CSH gel and form compact and smooth plates like structure. Metakaolin also act like filler and fill the voids between the hydrate plates hence increasing density of hydrated mass

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].

1.4 Objective of present investigation

- The main objective of this project is to investigate the potential use of Metakaolin as a partial replacement of cement in paver blocks of different shapes.
- The study involves experimental results to determine mechanical properties of MK modified paver blocks.
- The study further extended to XRD, FESEM and EDS analysis

1.5 Organization of the Thesis

The work undertaken for the research work has been presented in 5 chapters.

Chapter 1 **"Introduction"** discusses about the materials used, importance of the topic and aim of the present investigation.

Chapter 2 **"Literature Review"** includes the historical background of the study and relevant retrospective research.

Chapter 3 **"Experimental Programme"** includes the material properties, mix design and testing procedure concrete in fresh and hardened state.

Chapter 4 **"Results and Discussion"** describes the analysis of test results.

Chapter 5 **"Conclusion and Scope for Future Study"** it includes various conclusion based upon study and scope of the work for future researchers.

CHAPTER 2

LITERATURE REVIEW

Satyendra Dubey et al. (2015) aimed to study effect of Metakaolin on compressive strength of concrete. For M_{25} grade of concrete by replacing cement with 0, 5, 10, 15% MK. The results to showed that 10% MK is the optimum % replacement and the other % of MK such as 5 and 15% also showed that considerable increase in strength characteristics of the concrete when compared with conventional concrete.

Nikhil K and Ajay A.H (2015) studied the valuation of Strength of Plain Cement Concrete with Partial substitute of Cement by MK. In this study they observed replacement of cement with MK and fly ash at 0%, 5%, 10% and 15% for 7days and 28 days for M_{20} and M_{25}. And these results compared with the conventional concrete. Finally, they concluded that up to 15% replacement cement with MK and fly ash strength is increasing, beyond strength was decreased. Therefore, it is always better to use 10% for good results.

Yogesh R. Suryawanshi et al. (2015) studied the Compressive Strength for the Concrete by using the Metakaolin. In their research study they investigated the effects of MK & Super plasticizer on the strength properties of M_{35} grade concrete. Their research program is designed to find the compressive strength of concrete by partially substituting the cement with MK in concrete production. The replacement levels of cement by MK are selected as 0%, 4%, 8%, 12%, 16% and 20% for constant water-cement ratio of 0.43. For all the mixes compressive strength is found at 3, 7, 28. Current experimental study shows that 12% substitute of cement by MK gives the higher strength. MK increases the compressive strength for the concrete more than 10%.

Naresh Kumar (2014) aimed to investigate on A Study of MK and SF used in various Cement Concrete blocks. In his research work effect of MK and Silica Fume is used through compressive and flexural strength of concrete. MK and SF are used as cement substitute materials at 5%, 10%

and 15% by mass and keeping W/C ratio as 0.42. Compressive and flexural strengths observed at 7 and 28 days of curing. Finally, he concluded that replacement of MK increases the compressive strength at all stages of curing, however optimal replacement is 10% and increased strength about 1.66 to 2.05% higher than the plain concrete. Replacement of the MK also increases the flexural strength at all stages of curing, however optimal dose is 10% and increased strength about 1.5% higher than the plain concrete.

Sai Kumar A.V.S, Krishna Rao.B (2014) aimed to study on strength of concrete with partial replacement of cement with quarry dust and MK. This paper dealt at constant replacement of fine aggregate(FA) with 25% Robo sand by varying MK percentage as 2.5,5,7.5,10%. The results showed that all properties are reached target man strength and flexural strength is at 28 days with percentage replacement of cement with MK. And split tensile strength also increases at 28 days with percentage replacement of cement with MK up to 10%.

Nazeer M et al. (2014) aimed to study the assessment of Strength Studies on Metakaolin Blended with High-Volume Concrete. Generally, the addition of Pozzolana to concrete will improve some properties like Workability, Later age strength and Resistance to sulfate and Chloride attacks. In their research work 50% of cement was replaced with Class-F MK and 0%, 5%, 10%, 15% and 20% of Metakaolin is also replaced in place of cement for M_{30} grade concrete mix. From this research study they concluded as addition of MK and SF in concrete reduces the Workability. Mechanical properties for example compressive strength, split tensile strength and modulus of elasticity shows diminishing trend with the increasing of MK. The declined in workability of high-volume MK concrete changed with the addition of MK shall be expressed as a function of MK content in the mix.

Nova John (2013) studied the Strength Properties of MK Admixed Concrete. In this study they studied the strength properties for M_{30} concrete at 0%, 5%, 10%, 15%, 20%. Finally, they concluded that MK gives faster early age strength and mix with 15% is superior to all other mixes. The usage of supplementary cementitious material like MK concrete can compensate for environmental and economic issues caused by cement industry.

Patil B.B and Kumar P.D (2012) aimed to study the strength and durability properties of High functioning Concrete incorporating High Reactive MK. This rich Performance of Concrete is the recent trend in the concrete industry. In this study the paper dealt with strength, durability and workability of M_{60} grade High Performance Concrete at different percentages of MK. Finally, they concluded that 7.5% replacement is better and good environmental resistance.

Sanjay N. Patil et al. (2012) aimed to study the Literature Review on Metakaolin effect on Concrete with title as Metakaolin- Pozzolanic Material for the Cement in High Strength Concrete. In the paper they concluded that optimal percentage is attained by replacing 7% to 15% of cement with MK and the benefits are not realized until at least 10% MK is used. Compressive strength of concrete with MK after 28 days can increases up to 20%. As the percentage of MK increases workability is decreases, it seems to require dosage of super-plasticizer to ensure longer period of workability.

Kim et al. (2007) aimed to study the strength and durability views of high strength concrete using Korean MK. In their research investigation they used Metakaolin as 5%, 10%, 15% and 20% replacement with cement. Finally, the conclusions made by them is, there is no significant effect of Metakaolin on the flexural strength or split tensile strength for replacement levels of 5 to 15%. However, there appears to be slight decreases in strength in the 20% replacement proportion at ages less than 28 days. At 10% replacement of Metakaolin there is significant amount of strength is increased in all mixes at all the stages. And finally they concluded that 10% MK can be usable in concrete manufacturing in Korea.

Koli Nishikant et al. (2016) carried out a study on feasibility of waste glass inclusion as partial FA replacement systems. Properties of concrete incorporating waste glass as partial substitution for FA amounts of 15%, 30% and 45% were investigated. The waste glass material used was obtained from waste collectors. The results obtained show clearly that glass enhances the compressive strength properties of the final concrete product. The study indicated that waste glass can effectively be used as fine aggregate replacement (up to 45%) without substantial change in strength. Study concluded that Density of concrete decreased with increase in waste glass content thus making concrete light weight in nature and percentage of water absorption also decreases. The compressive strength increases with increasing the glass parentage from 15% to 30% replacement of glass and after 45% waste glass replacement onwards the strength is decreases. Strength reductions observed may be due to the internal voids of waste glass.

Vishal and Mishra A.K (2016) conducted a parametric experimental study on paver bricks made of waste steel aggregate. Waste steel bearing balls are included in concrete of paver bricks in different rates. Elastic rubber Pads are additionally utilized underneath the paver bricks. Compressive strength and Impact strength of paver bricks with different rates of waste steel aggregate and utilizing elastic Rubber Pads is carried out. Test results demonstrate that mix of utilizing elastic Rubber Pads and including different rates of waste steel aggregate in paver bricks gives up to 50% more strength than common paver bricks.

Dixit N and Jayeshkumar R (2014) in their study, Cement is partially substituted by used foundry sand to determine the strength of ICPB. The substitution is carried out at 10%, 20%, 30%, 40% and 50% and tested for their compressive and flexural strength after 7, 14 and 28 days curing period. water absorption test has been determined at 28 days. It has been concluded from their study at extent of 50 % replacement of cement the compressive strength of 23.48 N/mm^2 is achieved. And by increasing proportions of replacement, Water absorptions is also decreased along with the compressive strength. At maximum replacement 50%, water absorption is found to be 2% with compressive strength of 23.48 N/mm^2 .

Navya G and Venkateswara Rao J (2014) in this study investigating the compressive strength, water absorption and flexural strength of paving blocks were determined by adding Polyester fibers in the top 20mm thickness. Polyester fibers were added in percentages of 0.1%, 0.2%, 0.3%, 0.4% and 0.5% in volume of concrete. The compressive, flexural strength and water absorption test were examined at the end of 7 and 28 days. The test results show that addition of polyester fiber by 0.4% paving block attains maximum compressive, flexural strengths and minimum water absorption at 7 and 28 days. Results show that adding of fibers even up to 50% of top layer thickness compressive and flexural strengths are increasing.

Khandve P.V and Rathi A.S (2016) In this study attempt has been made to use kota stone industry waste as replacement for course aggregate used for manufacturing of traditional concrete paving blocks. Varying percentage of kota stone waste aggregates is considered and paving blocks Sare tested for water absorption, compressive strength and splitting tensile strength. The results shown that maximum 50 % of replacement of traditional aggregate with kota stone waste aggregate is possible for optimum results. Using waste material is reducing the cost of manufacturing and also solving the problem of disposal of construction waste and thus helping in protecting environment.

CHAPTER 3

EXPERIMENTAL PROGRAMME

3.1 General

The process to select the mixing materials and their appropriate quantities is done through mix design. There are ways to find the concrete mix design. The methods which are using in India are in accordance with the BIS. The main objective of the concrete mix design is to find the appropriate proportion in which the concrete ingredients like cement, water, fine aggregate and coarse aggregate should be mixed to provide the specified strength, durability and workability and possibly meet other requirements according to IS: 456-2000. IS: 10262-2009 code which gives the guidelines for the nominal concrete mix designs.

This chapter deals with the properties of the material used and methodology for evolving concrete mixes with Metakaolin in varying percentages. The main objective of this research study was the assessment of the mechanical properties in terms of compressive strength, flexural strength and water absorption of concrete. The materials used for this research work and experiments performed on concrete specimens have been discussed in this chapter.

3.2 Material and Their Properties

3.2.1 Cement

The physical properties of the cement used in present research work i.e. Ordinary Portland Cement of 43-Grade of Ultratech brand confirming to IS 8112: 2013. Physical properties and chemical composition was determined and given in Table No.3.1 and 3.2

Fig 3.1 OPC cement (43grade)

Table 3.1 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 3.2 Chemical composition OPC used

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

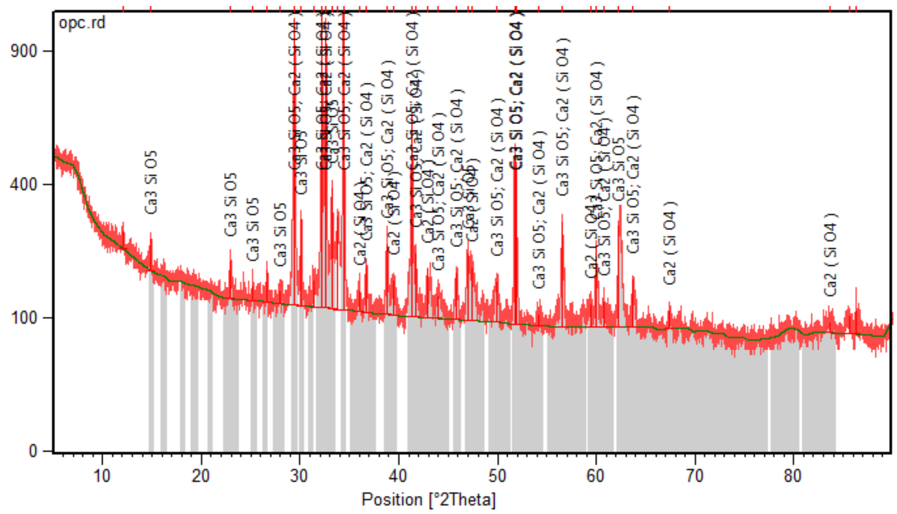


Fig 3.2 XRD pattern of OPC

3.2.2 Metakaolin

Metakaolin is procured from the Kaolin Industries Vadodara. Physical properties and chemical composition was determined and given in Table No.3.3 and Table No.3.4

Table 3.3 Physical Properties of Metakaolin

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

Table 3.4 Chemical composition of Metakaolin

Chemicals	Mass %
SiO_2	61.88
Al_2O_3	27.69
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.3.3 Kaolin Mineral

Fig.3.4 Metakaolin Powder

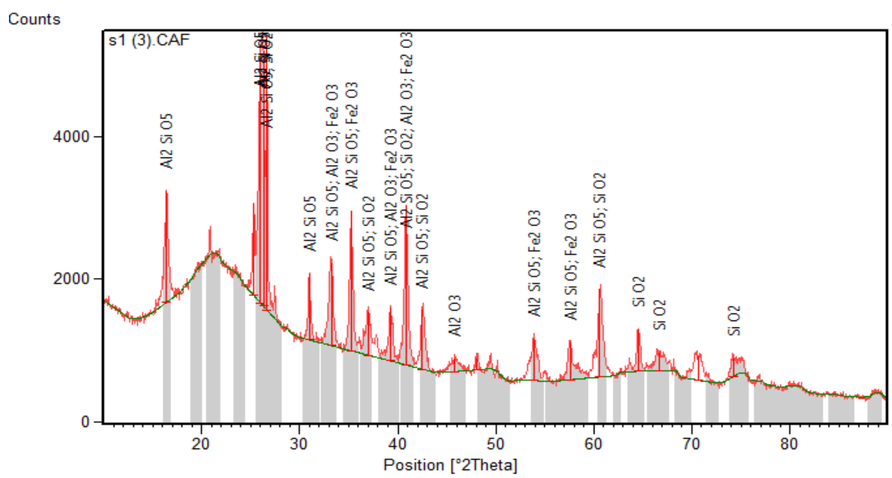


Fig 3.5 XRD pattern of Metakaolin

3.2.3 Natural Fine Aggregate

Locally available river coarse sand is used as a fine aggregate. The sieve analysis and physical properties of fine aggregate have been shown in the table below. Fine aggregate (sand) conforms to Grading Zone-III as per **IS: 383-1970**.

Wight of Sample Taken=1000gms.

Table 3.5 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 3.6 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

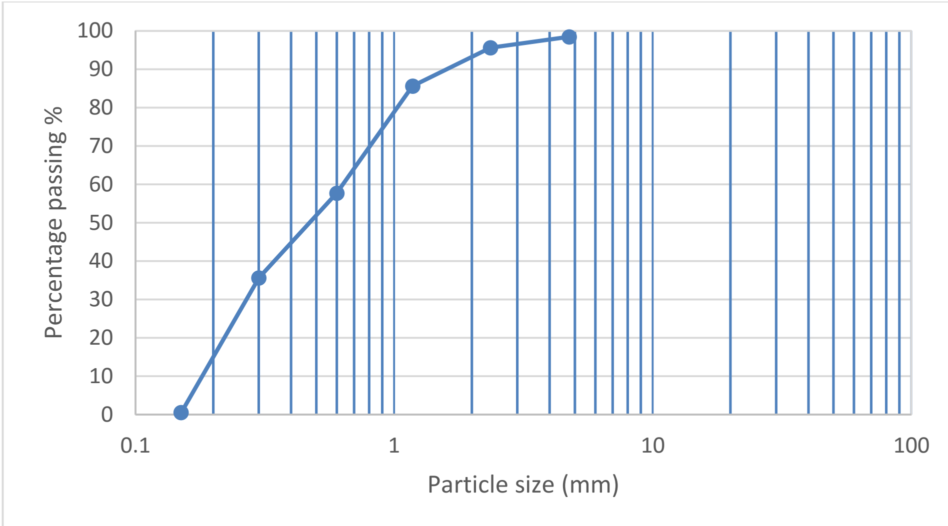


Fig 3.6 Particle size distribution of fine aggregate

3.2.4 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

Wight of Sample Taken=5000gms.

Table 3.7 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 3.8 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

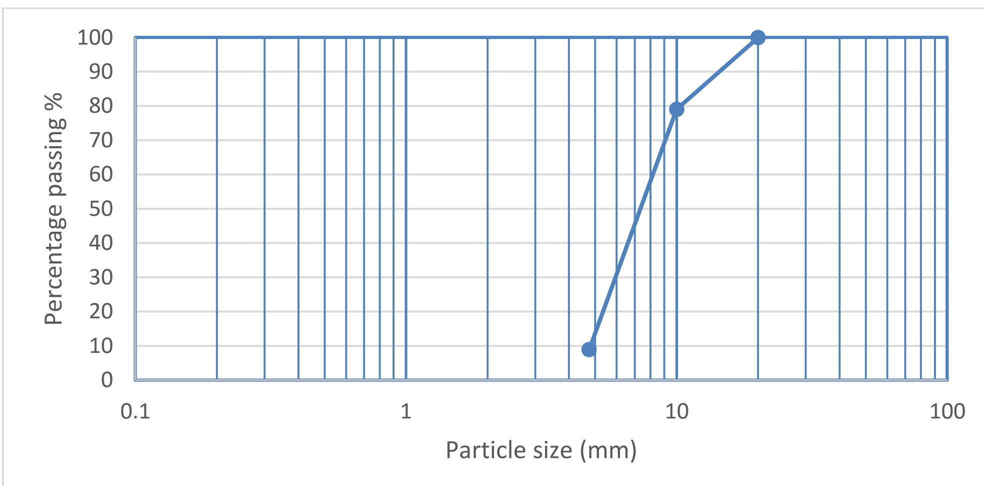


Fig 3.7 Particle size distribution of coarse aggregate

3.2.5 Water

The water should be free from organic and deleterious impurities. The potable water is generally considered satisfactory for the concrete as per clause 5.4 of IS: 456-2000. Tap water available in the laboratory was used for production of concrete and curing of the concrete specimens.

3.3 Concrete Mix Design

3.3.1 Mix Design

Mix design is done for the present study. Generally, for the manufacture of precast concrete paver blocks needs dry, low slump mixes. Mix design was done for control mix of M40 grade of concrete by using the IS code 10262: 2009 and specification given in the IS code 15658: 2006

3.3.2. 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

Aggregate size - Angular aggregate of maximum size is 10 mm

W/C ratio - 0.35

Slump value - zero (IS code 15658:2008)

Condition of exposure – Mild

Admixture – superplasticisers

3.3.3 Mix Design process

Target strength:

Mean target strength $f_t = f_{ck} + 0.825s$ (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

3.3.4 Water-Cement ratio:

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

3.3.4.1 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

3.3.4.2 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

3.3.5 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

3.3.6 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.

Mix design: 1:2.58:2.68

3.4 Manufacturing of paver block

Cement, sand, coarse aggregate, water and superplasticisers were mixed thoroughly in the concrete mixer. Then it was filled in the rubber paver mould of different shapes and different thickness. All the filled paver moulds were vibrated using table vibrator. After casting all the specimens were completed with a steel trowel and it was kept for 24 hours. After 24 hours they were remoulded from the paver moulds and kept in the water tank for water curing. The same procedure was done for 5%,10% and15% replacement of cement with metakaolin. To know the effect of standby of cement with metakaolin, compressive strength, flexural strength, were done on the paver block.

Table 3.9 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

3.5 Testing of Paver block

3.5.1 Compressive strength

As per IS 15658: 2006, compressive strength of paver block was determined at 7 and 28 day using universal testing machine (UTM). Minimum 3 samples were tested for 7 and 28 day strength. The average strength of 3 samples at 28 days were taken as compressive strength of paver block. The apparent compressive strength of paver block was multiplied with correction factor as it is mentioned in IS 15658: 2006 of table 5 Annex D to get corrected compressive strength of paver block.

Table 3.10 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

Fig 3.8 Compressive testing machine of paver block

3.5.2 Flexural strength

Flexural strength of paver blocks for control mix and for different 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 3.9 Flexural strength test conducted by using Universal Testing Machine

3.5.3 FESEM and EDX

To investigate the effect of Metakaolin on the microstructure of concrete various techniques such as spectroscopy, X-ray powder diffraction (XRD), Field Emission Scanning Electron Microscope (FESEM) are used.

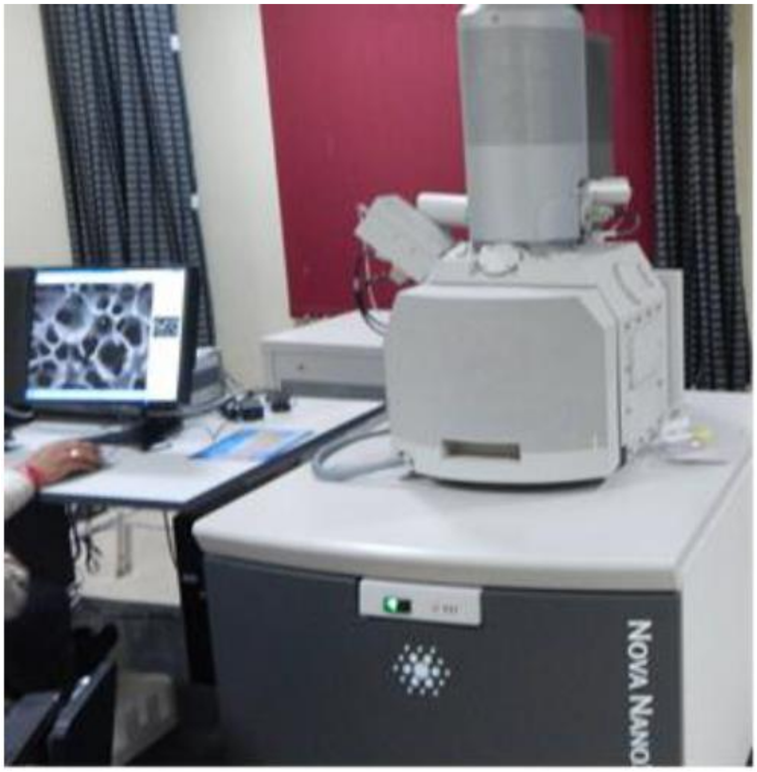


Fig 3.10 FESEM apparatus

SEM micrographs are obtained using FESEM apparatus. During the examination, the accelerating voltage is kept at a range of 20 kV. Mineral components of the isolates are further characterized by Energy Dispersive X-ray Spectroscopy (EDX) analysis.

3.5.4 XRD Spectroscopy

Ultimate X-ray diffract meter with a Cu anode (40 kV and 30 mA) and scanning from 5^0 to 80^0 is used for XRD spectra. The samples are taken from the inner part of the block, well crushed and sieved. The components of the sample are identified by comparing them with standards established by the international center for diffraction data.

Fig 3.11 Multipurpose X-ray diffraction system (Rigaku ULTIMA IV)

CHAPTER 4

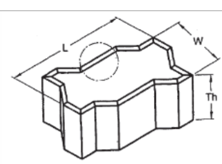
RESULTS AND DISCUSSION

4.1 General

The results obtained from experiments conducted on concrete paving blocks have been discussed in this chapter. A comparison of results has been made to evaluate the effect of the partial replacement of the cement by Metakaolin in concrete mixes to determine the mechanical properties at the age of 7 days and 28 days.

One reference mix M0 of M40 grade was prepared without addition of Metakaolin and three more mixes M1, M2 and M3 were prepared with Metakaolin of varying amounts 5%,10% and 15% used as partial replacement of cement respectively. Three different shapes of paver blocks, Zigzag, I shaped, and Dumbel shaped were adopted for the study. Eight specimens of each type of paver blocks were cast and cured for 7days and 28 days.

Table 4.1 Details of Paver Blocks of different shapes

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
			

4.2 Compressive strength

As per IS 15658: 2006, compressive strength of paver block was determined at 7 and 28 day using Universal testing machine (UTM). Minimum 3 samples were tested for each 7days and 28 day strength. The apparent compressive strength of paver block was multiplied with correction factor as it is mentioned in IS 15658: 2006 to get corrected compressive strength of paver block.

- Correction factor for 80mm thickness is ***1.12***

Table 4.2 7-days Compressive strength result MPa

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

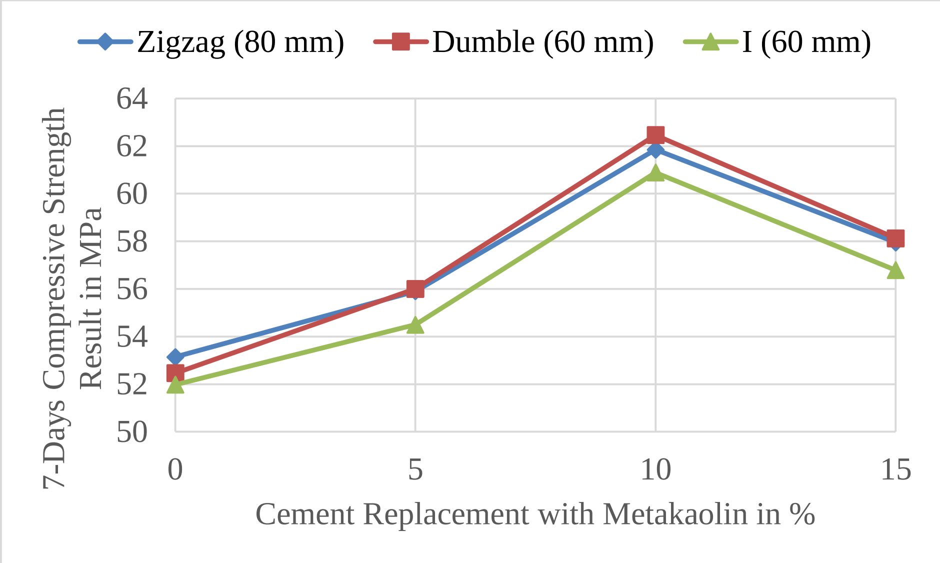


Fig: 4.1 7- days Compressive strength result MPa

Table 4.3 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

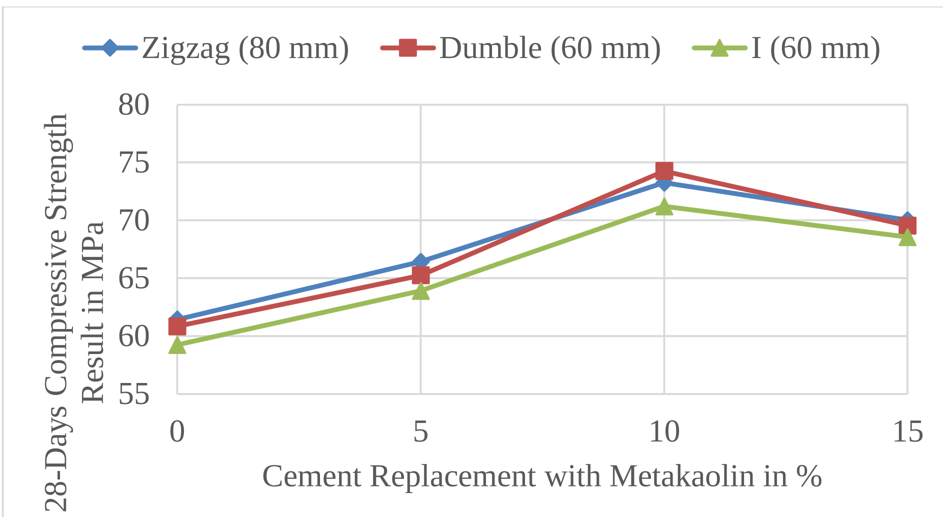


Fig: 4.2 28-days Compressive strength result MPa

- It was observed that 7-days and 28-days' compressive strength of all shapes of paver blocks had increased due to incorporation of Metakaolin compared to control mix M0. Mix with 10% Metakaolin exhibited maximum strength gain. Compared with I-shape Zigzag and Dumbel shape gave more strength and their behavior were almost same.
- Compared with control mix maximum percentage increase in 7 days compressive strength for M10 mix was 17.14 % found with I shape, 19.06% with Dumbel shape and 16.39% with zigzag shape. Similarly maximum percentage increase in 28 days compressive strength was observed as 20.21% with I shape, 22.1 with Dumbel shape and 19.22 was with zigzag shape.

- Maximum percentage increase were obtained for Dumbel shape then I shape and lowest for zigzag shape.
- For Dumbel shape 7.25% increase in strength were found with 5% MK, 22.1% increase with 10% MK and 14.32 % increase with 15 % MK as partial replacement. The same trend was shown for other shapes.

4.3 Flexural strength

Flexural strength or breaking load of paver blocks for control mix and for different 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

Table 4.4 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

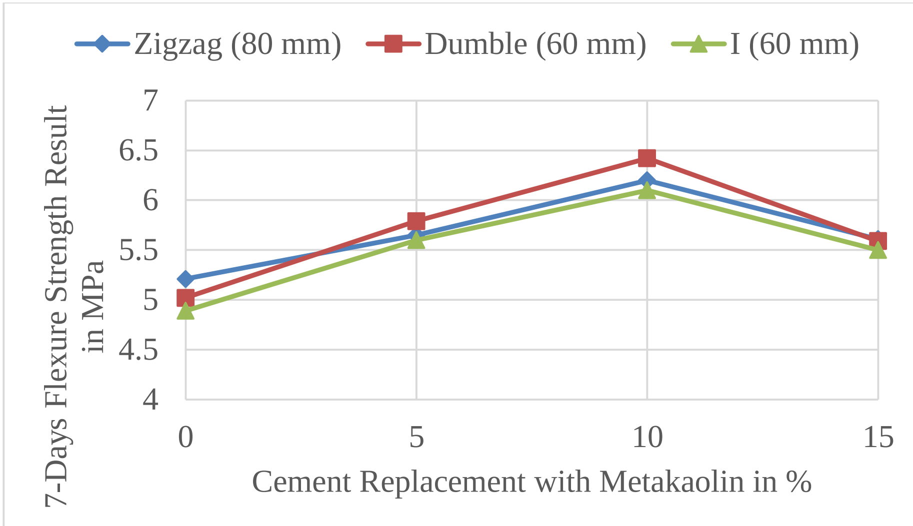


Fig: 4.4 7-days Flexure strength result MPa

Table 4.5 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

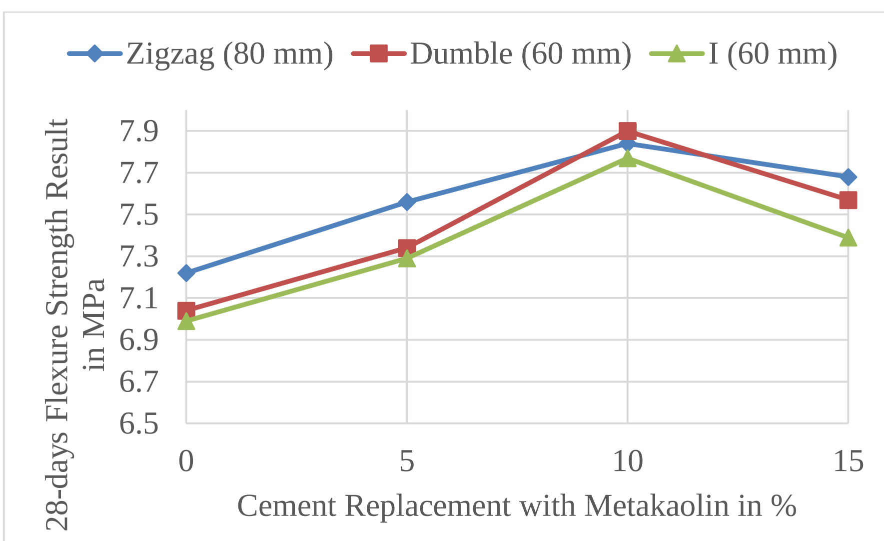


Fig: 4.4 28-days Flexure strength result MPa

- It was observed that 7-days and 28 days Flexure strength of all shapes of paver blocks had increased due to incorporation of Metakaolin compared to control mix M0. Mix with 10% Metakaolin exhibited maximum strength gain. When compared with I-shape Zigzag and Dumbel shape gave more strength and their behavior were almost same.
- Compared with control mix maximum percentage increase in 7 days Flexure strength for M10 mix was 18.1 % found with I shape, 15.06% with Dumbel shape and 12.39% with zigzag shape. Similarly maximum percentage increase in 28 days Flexure strength was observed as 11.11% with I shape, 12.4% with Dumbel shape and 8.7% was with zigzag shape.
- Maximum percentage increase were obtained for Dumbel shape then I shape and lowest for zigzag shape.
- For Dumbel shape 4.25% increase in strength were found with 5% MK, 12.4.1% increase with 10% MK and 9.32 % increase with 15 % MK as partial replacement. The same trend was shown for other shapes.

4.4 Water absorption

The test Results of water absorption test are tabulated in the Table 4.6. It is observed from Table4.6, water absorption of paver blocks of all the shapes are increasing up to 5 percentage replacement and again decreasing at 10 percentage of cement replacement. But maximum decrease in water absorption occur at 10% replacement of cement. For 5% cement replacement water absorption for all the shapes of paver blocks are more than control mix. The maximum water absorption occur at 5% replacement which is less than 6% specified in IS 15658-2006 as maximum limit.

% Water Absorption = [(WW – DW) / DW] x 100

Where, WW = Wet Weight of paver block,

DW = Dry Weight of paver block

Table 4.6 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

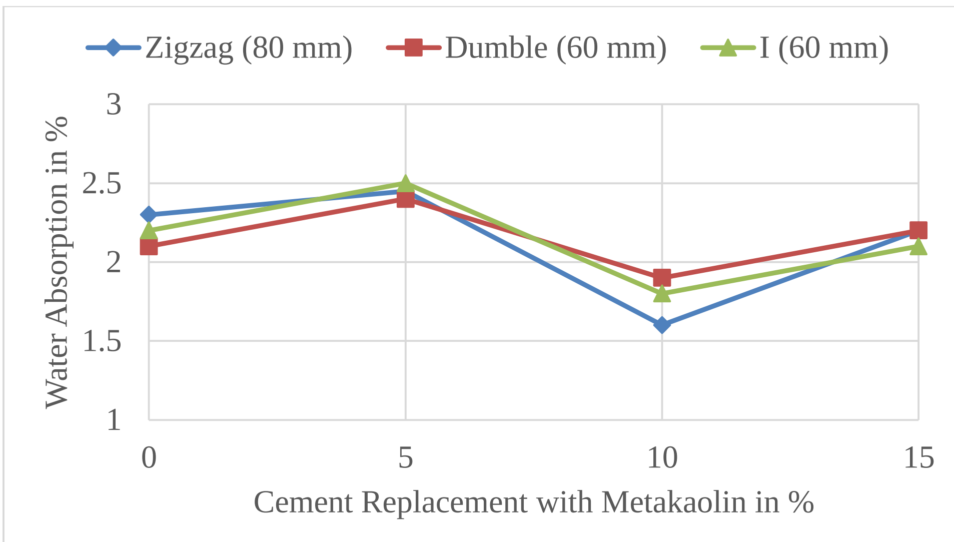


Fig 4.5 cement replacement Vs. water absorption

4.5 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)

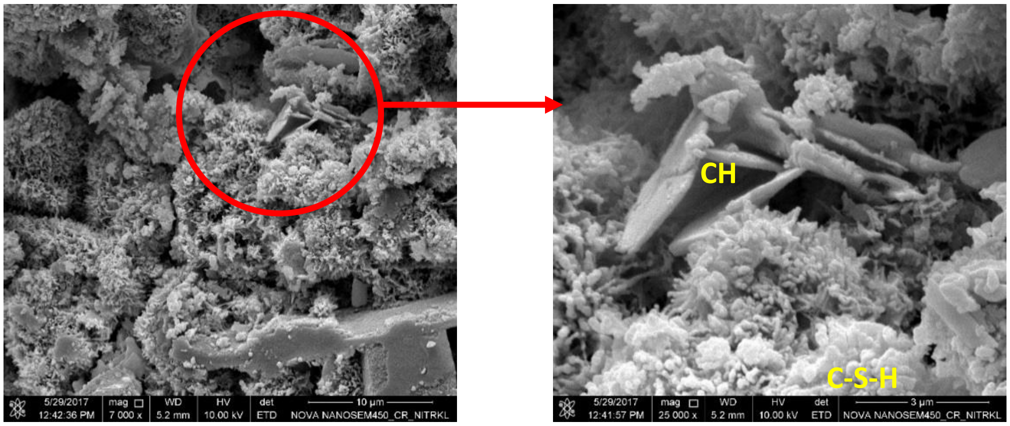


Fig No 4.6 FESEM image of control mix

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

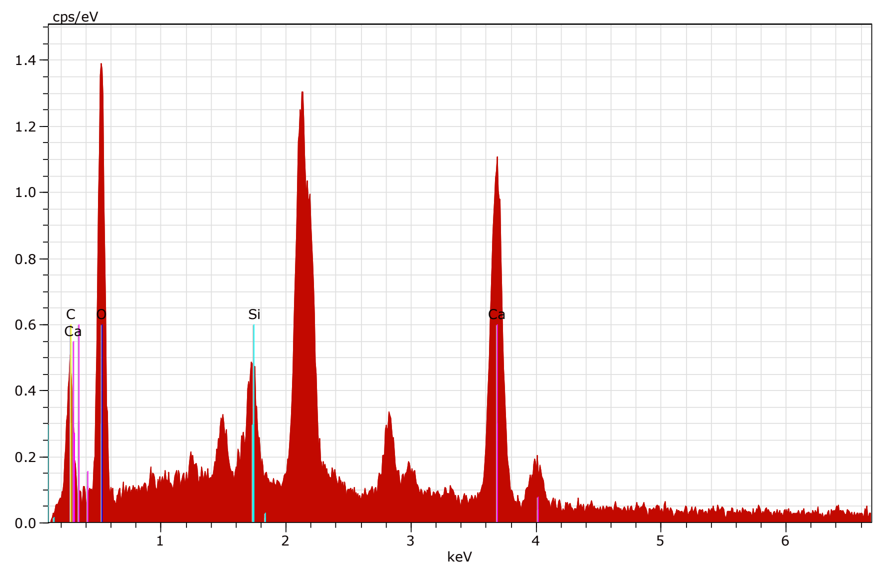


Fig No 4.7 EDS analysis of control mix

M1 (5% Metakaolin)

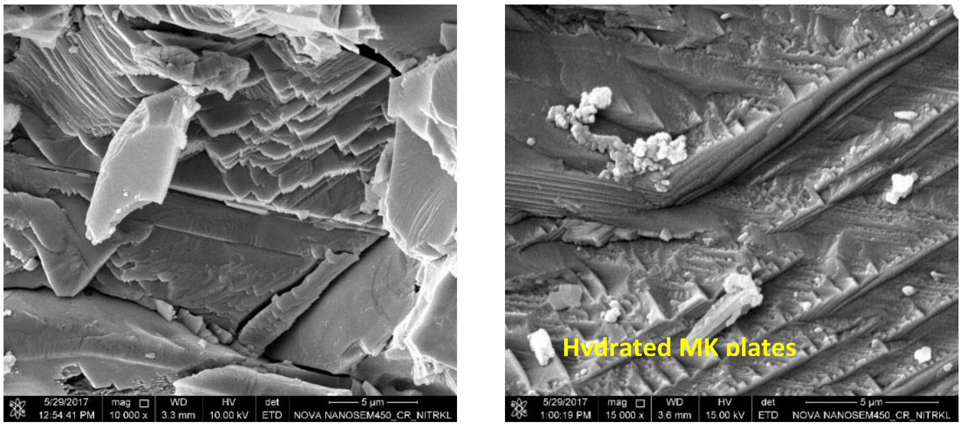


Fig No 4.8 FESEM image of M1 mix

Due to pozzolanic reaction between MK and CH during hydration process secondary calcium-silicate-hydrate (CSH gel) forms which get deposited on and in between the primary CSH gel layers forming a more compact and smooth micro structure.

The SEM image in Figure illustrates the relatively dense, layered hydrated Metakaolin plate with smooth surfaces. The amorphous phase of hydrated cement paste can also be seen in between and at the edges of the hydrated MK plates. The interlayer pores and voids can be observed.

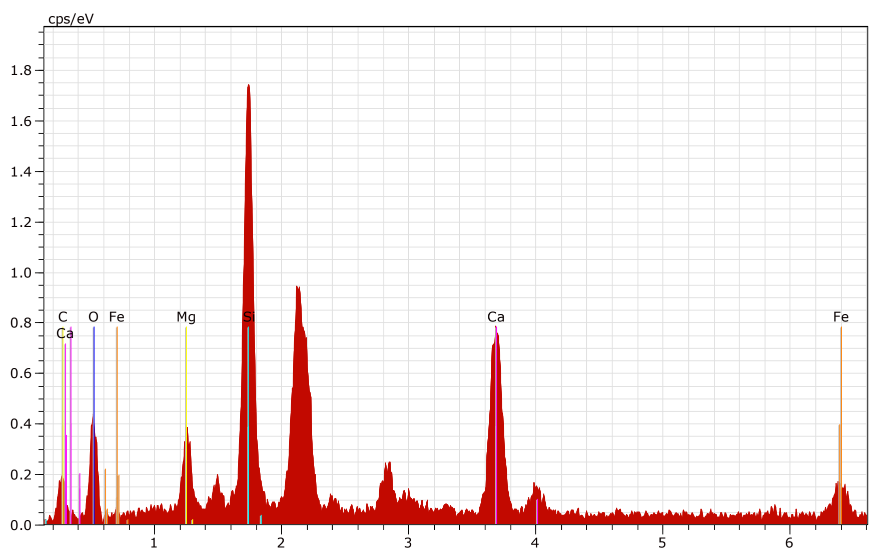


Fig No 4.9 EDS analysis of M1 mix

M2 (10% replacement)

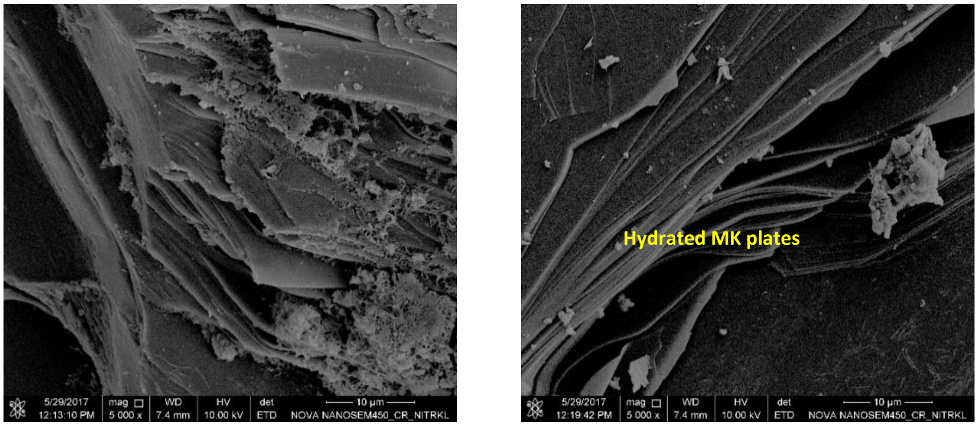


Fig No4.10 FESEM images of M2 mix

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.

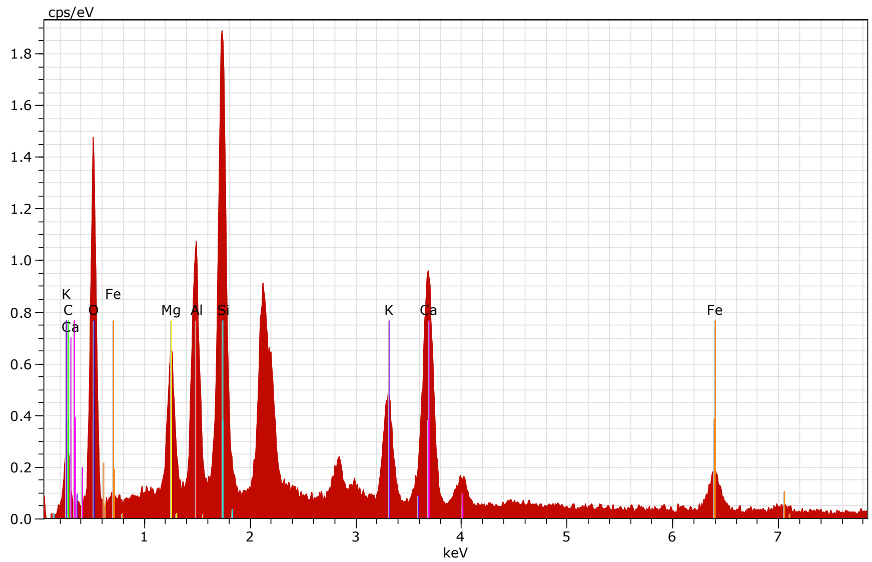


Fig No 4.11 EDS analysis of M2mix

M3(15% replacement)

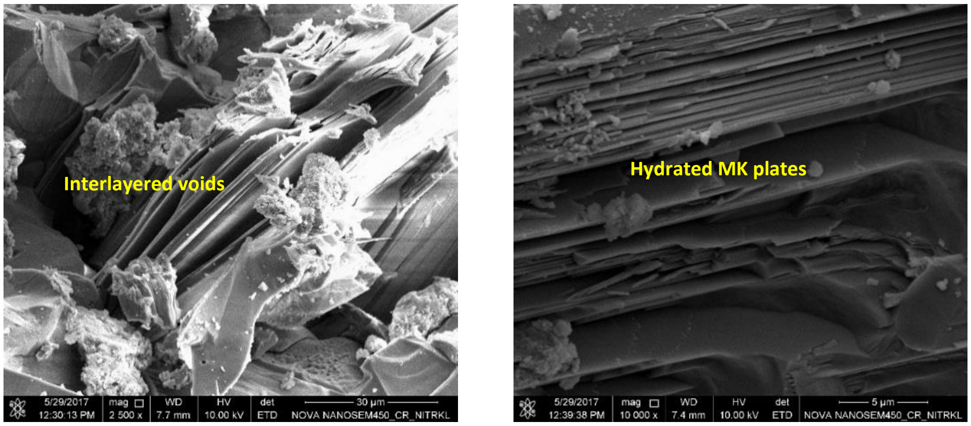


Fig No4.12 FESEM images of M3 mix

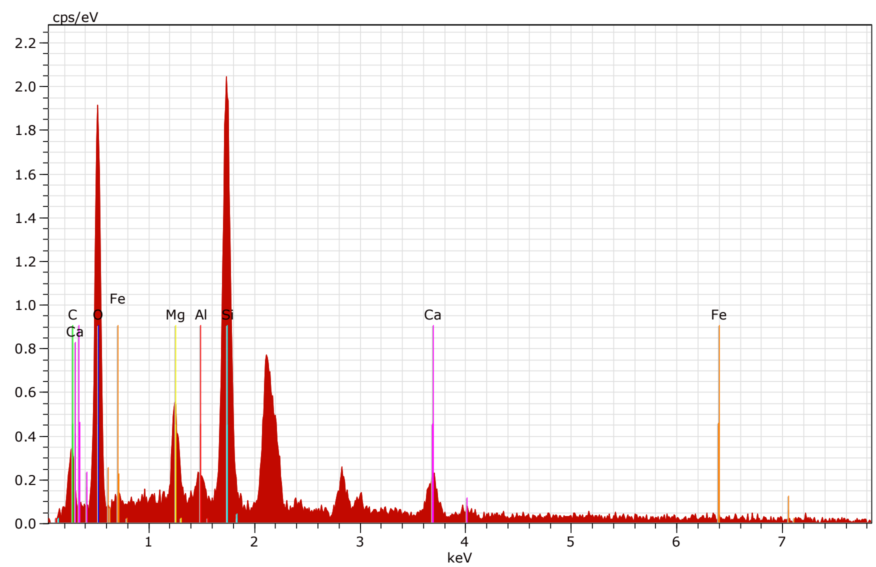


Fig No 4.13 EDS analysis of M3mix

- The specimen shows compactness and smoothness with more and large capillary pores. Large number of unreacted Metakaolin were also observed in between the hydrated layers.
- From the above images we can observe that the more voids are present between the hydrated MK plates and also some unhydrated MK particles can be seen.
- Because of this reason the mix with 15% metakaolin gave less strength.

4.5.1 EDS Analysis

EDS is energy dispersive X-ray spectroscopy. It is a characterization technique that provides elemental composition of various constituent elements in a material. The abscissa of the EDX spectrum indicates the ionization energy and ordinate indicates the counts. Higher the counts of a particular element, higher will be its presence at that point or area of interest.

Table 4.7 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

- EDS analysis of control mix with OPC M0 gave higher count of Ca (13.98%) and less count of Si (1.60%) indicating higher percentage of CSH gel.
- The mix with 5% Metakaolin M1 showed increase in Si count (8.02%) due to addition of Metakaolin and reduction in Ca count (8.75%) due to consumption of CH in forming secondary CSH gel.
- The Mix with 10% Metakaolin M2 exhibited further reduction in Si count (6.48%) which may be due to higher consumption of Si to form more secondary CSH gel forming more compact microstructure and thereby providing more strength.
- The mix with 15% M3 showed smaller count of Ca (2.84%) which may be due to consumption of higher CH in pozzolanic reaction and gave higher count of Si (11.18%) which may be due to addition of higher quantity of Metakaolin and presence of un hydrated Metakaolin particles owing to non-availability of enough CH for further hydration.

At M0 control mix the percentage of Si is less and Ca is more due to addition of Metakaolin the percentage of Si increase. In M1 with 5% replacement of Metakaolin percentage of Si increases which take part in the pozzolanic reaction. And the same thing is continuing with M10 where the more Si is reacting and forms more C-S-H gel. This result is verified with the experimental result by testing the different thickness of paver blocks.

4.6X-Ray diffraction spectrometry Analysis

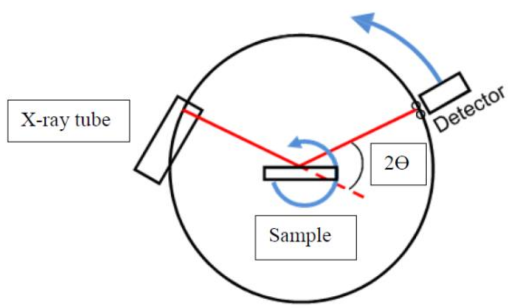


Fig 4.14 Schematic of working of X-ray diffraction system

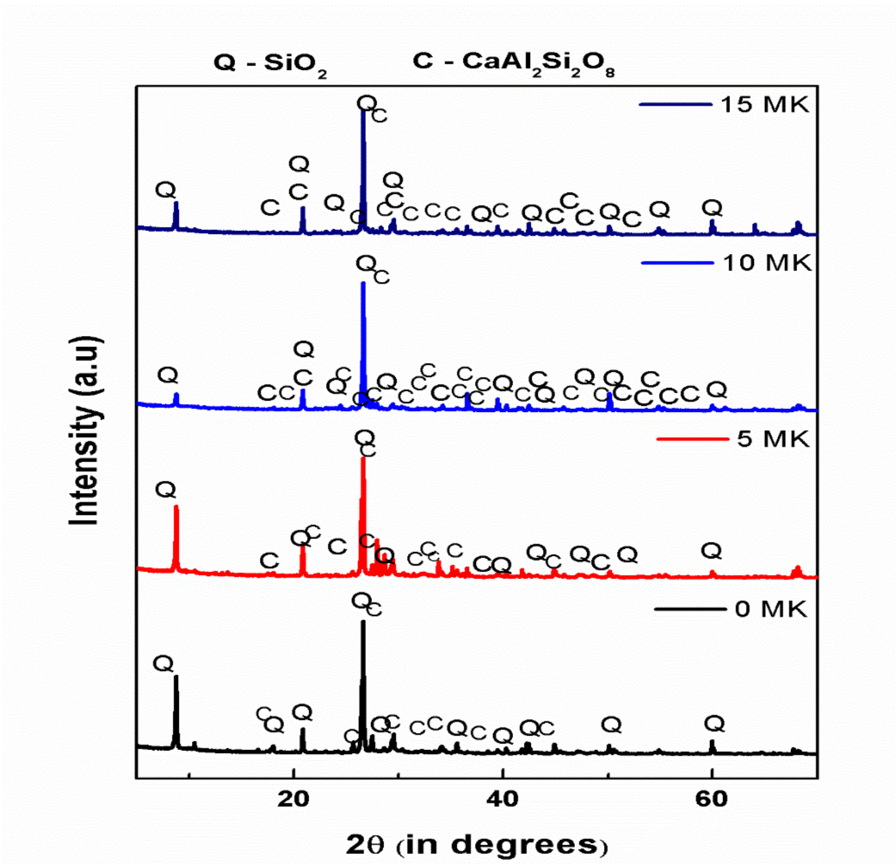


Fig 4.15 XRD pattern of different mixes.

The similar observations were found from XRD analysis of mixes.

Smaller peak for Q was observed for 10MK mix indicating higher consumption of Q in pozzolanic reactions forming more CSH gel which is indicated by C count, in the 15MK mix Q peak is more indicating higher percentage of unreacted MK. The 5MK mix showed higher peak for Q and lesser count of C, this may be due to incomplete pozzolanic reactions.

CHAPTER 5

CONCLUSION

The aim of the present research work is to determine the mechanical properties of concrete with MK as the admixture for M_{40}grade of concrete Paver blocks. On the basis of experimental investigation of the present research study, the following conclusions have been drawn.

1. It is observed that compressive strength of paver block for all the shape and thickness at 7 and 28 days are increased as percentage of cement replacement with MK increases up to 10%. . 7 days compressive strength of paver block for all the shapes are more than required target strength up to 15% cement replacement. The maximum compressive strength for all the shapes are more at 10% of replacement. The maximum compressive strength of Dumbel (60mm) thickness at 10% replacement is 74.26 MPa which is about 23% more than that of control concrete.
2. Flexural strength is increasing as cement replacement increases up to 10% after that for 15% cement replacement it is more than control concrete and also more than 5% replacement. 7-day and 28-day flexural strength is increases up to 10 % replacement after that it decreases as percentage of replacement increases. Even though there is decrease in flexural strength at 28 days after 10% replacement of cement the flexural strength at 15% replacement also more than 4.5MPa for all the shapes which is required strength for rigid concrete pavement.

3. Use of Metakaolin as partial replacement of cement increases mechanical properties like compressive strength, flexural strength of concrete.
4. Concrete with Metakaolin also exhibited better durability in terms of water absorption.
5. It was observed that 10 percent Metakaolin used as partial replacement of cement improve overall properties of concrete paver blocks.

6. About 20% increase in 28-days compressive strength were observed for all types of paver blocks.
7. About 11% increase in 28-days flexural strength were observed for all types of paver blocks.
8. The maximum strength gain was observed for Dumbel shape paver blocks.
9. Metakaolin imparts distinct glassy white color to paver blocks which increase the reflectivity and makes it suitable for specific applications like in swimming pools, roofs etc. to enhance architectural beauty also.
10. Less permeability makes it suitable to be used in industrial floors, parking garages, bridge decks etc.
11. The microscopic observations by FESEM revealed that Metakaolin in concrete forms dense structure mainly due to the increase of the amount of hydration products such as CSH, CAH and CASH and their later accumulation within the available pores giving high strength and less permeability.
12. The XRD and EDX analysis confirms the above observations.

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