Behaviour of Metakaolin Modified Concrete Paver Blocks

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Abstract

The current study involves the experimental investigation on the mechanical properties of high strength concrete paver blocks prepared with concrete containing commercially available metakaolin as mineral additive. A concrete mix of M40 grade , suitable for making concrete paver blocks for medium traffic was designed following IS 15658:2006 . Three different shapes Zig Zag , Dumbbell and I-shape paver blocks were considered for the study. The effect of replacing cement partially by 5% ,10% and 15% of metakaolin were studied in terms of 7-days and 28-days of compressive strength, flexural strength, water absorption and abrasion resistance. The results were compared with mix without metakaolin referred as control mix..

The results indicated that addition of metakaolin improve all characteristics of the paver blocks of all types. The mix with 10% replacement was found to give maximum compressive, flexural strength , abrasion resistance and minimum water absorption characteristics . The further increased percentage of metakaolin were found to adversely affecting these characteristics due to dilution of Cement. Comparing with control mix 20% increase in compressive strength, 12% increase in flexural strength, 16 % increase in abrasion resistance and 30 % decrease in water absorption were observed for the mix with 10% metakaolin. The microscopic study of hydrated structure of metakaolin modified concrete mix were conducted through XRD ,FESEM and EDX techniques. The XRD and EDX analysis indicated higher percentage of strength giving silicates hydrates phase and the FESEM images showed more refined , compact, smooth and layered micro structure for metakaolin modified concrete mix. The microscopic study of hydrate structures of different mix justify the results obtained from mechanical tests.

Key Words: Interlocking Concrete Paver Blocks, Metakaolin, Abrasion Resistance, Water Absorption

Introduction

Concrete paver blocks are special pre-cast pieces of concrete blocks mainly used in exterior landscaping and pavement applications. The conventional paving systems generally suffer lower service life because of limitations imposed due to different environmental, geological, traffic conditions. The properly designed and constructed paver blocks give excellent performance under such conditions. The modern interlocking concrete paver blocks(ICPB) system have more advantages over conventional pavement system. They can be manufactured in any size , shape and color and easy to lay and repair. Since pre-cast ,they can be custom made in desired pattern with required mechanical properties . They are attractive and economical alternative to both flexible and rigid pavement system. With the use of high strength concrete they can be designed to sustain medium, heavy and very heavy traffic conditions under any possible constraints.

Ordinary Portland cement (OPC) is main ingredient of concrete blocks. It is known that process of manufacturing OPC liberates huge amount of CO_2 ,polluting the environment and causing greenhouse effect. Therefore, use of substitute materials replacing OPC partially or fully are needed to reduce the environment problem. Mineral admixtures are used as partial replacement of cement in concrete. They work as pozzolana and micro filler in the concrete matrix . Metakaolin (MK), $Al_2Si_2O_7$ is highly amorphous dehydrated product of naturally available kaolinite known as china clay, which is abundantly available in several parts of India. Metakaolin is produced by controlled thermal treatment of kaolin . It is a highly efficient Pozzolana and react rapidly with the calcium hydroxide resulting from OPC hydration, through pozzolanic reaction and produce extra calcium silicate hydrate and calcium aluminosilicate hydrates , the strength giving components in th mix.

Sufficient number of research works are available on metakaolin modified mortar and concrete.Zhang and Malhotra (1995) studied physical and chemical properties of metakaolin and its potential to be used as supplementary cementing material in concrete. The result of their study show that Mk is highly pozzolanic and improve mechanical properties like strength, durability of concrete. Khatib et al (1996) studied effect on pore size distribution and porosity of hydrated paste due to increasing percentage of Mk replacement. They found that upto 20% Mk replacement , water absorption reduces due to microstructure refinement and filler effect of Mk. Similar observations were obtained by Bredy et al.(1989),Sabir et al.(2001),Qian and Li (2001),Khatib and Clay(2004) .Effect of Mk replacement on fresh properties of cement and concrete was studied by Justice(2005) with respect to setting time and workability, He observed that Mk shorten setting time of cement and workability decreases with increasing % of Mk. This is supported by Khatib (2008),Bai and Gailius(2009).The effect of Mk on mechanical properties like compressive strength,flexural strength, resistance against acid attack,sulphate attack , freezing and thawing were studied by Khatib and Wild(1998),Beulah and Prahallada (2012),Shelorkar and Jadhao (2013), Aqeel Hatem Chkheiwer (2017), investigated properties of paver blocks made with silica fume, metakaolin and flyash as partial replacement of cement and compared the results. The compressive and abrasion resistance were found to increase with addition of these mineral additives to certain optimum values. FA was found to be best than MK and SF.The literature survey portray that metakaolin is effective SCM which improves early & later age strength and durability by reducing the permeability of concrete.

Since limited research is available on effect of Mk on performance of concrete paver blocks the aim of the present work is to evaluate the performance of metakaolin modified concrete paver blocks of three different shapes. Zigzag (80mm thick), Dumbbell (60mm thick) and I-shape (60 mm thick) paver blocks were considered for the study.The effect of replacing cement partially by 5%, 10% and 15% of metakaolin were studied in terms of 7-days and 28-days of compressive strength, flexural strength, water absorption and abrasion resistance of different concrete paver blocks. The results were compared with the control mix without Mk. To categorize the change in the microstructure of hydrated paste of concrete for increasing Mk replacement a thorough analysis were conducted by using XRD, EDX and FESEM techniques.

Experimental Program

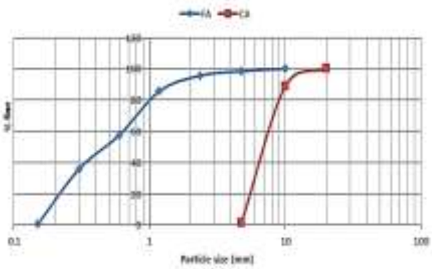
Materials

In the investigation 43-Grade OPC of Ultratech brand confirming to IS 8112: 2013 were used. Metakaolin is procured from the Kaolin Industries Vadodara. Locally available river sand confirming to zone III (IS 383-1970) and basalt coarse aggregate of 10mm size were used for mix preparation. Chemical composition of OPC and Mk were determined through chemical analysis method in Structural Engineering Lab. of NIT, Rourkela and given in Table 1. The sieve analysis were carried out for fine and coarse aggregate and practical size distribution diagram is shown in Fig.1.The XRD analysis of OPC and Mk were performed and X-Ray difractogram of OPC and metakaolin are shown in Fig.2. The XRD pattern of OPC shows calcium silicates as the main mineral and of metakaolin shows quartz and alumina-silicate phase as the main minerals . The physical properties of cement, fine and coarse aggregate are summarized and given in Table 2.

Table 1. Chemical composition of OPC & Mk

Chemicals	OPC (Mass %)	MK (Mass %)
CaO	64.24	0.82
SiO_2	20.25	62.08
Al_2O_3	5.62	27.71
Fe_2O_3	1.89	1.23
MgO	0.46	0.52

Fig.1.Grading Curves of CA &FA



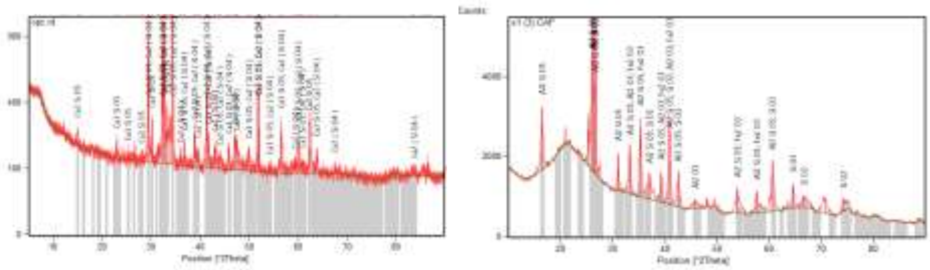


Fig.2. XRD Patterns of OPC and Metakaolin

Concrete Mix Design

Mix design was done for control mix of M40 grade of concrete following IS 10262:2009 .It is the minimum grade for medium traffic specified in IS 15658:2006.

Table 2. Physical Properties of Cement ,FA Coarse Aggregates

Materials	Properties	Test Results
Cement	Fineness	3%
	Normal Consistency	32%
	Specific Gravity	3.14
	Initial Setting Time	90 min.
	Final Setting Time	185 min.
Sand (FA)	Water Absorption	0.52 %
	Fineness Modulus	3.74
	Specific Gravity	2.67
Coarse Aggregate	Water Absorption	0.8%
	Fineness Modulus	5.2
	Specific Gravity	2.71

Table3. Details of Paver blocks

Shape mm	Zig-zag	Dum bell	I-shape
Thick-ness	80	60	60
Length	235	265	225
Width	125	110	125
Area (m^2)	0.028	0.036	0.033

The mix proportion adopted was 1:2.58:2.68 with water cement ratio 0.35 and 0.6% of superplasticizer(Conplast SP430 G8 of FOSROC brand) to achieve a slump value of 10 mm. The mix were prepared in a power driven mixer ,then filled in rubber moulds of different types of paver blocks.The details of the Paver Blocks are given in Table 3. After thorough compaction on vibration table, the filled and leveled moulds were left for 24 hours at room temperature . After this the specimens were placed in water tank for curing for 28 days. The same procedure were adopted for other mixes prepared with 5%,10% and 15% MK as replacement of cement. The inclusion of MK in mix was observed to slightly increasing the admixture demand to obtained the desired workability.

Test Results and Discussion

1. Compressive Strength

The paver blocks were tested for 7-days and 28-days compressive strength by using UTM in accordance with IS 15658 Annex D.

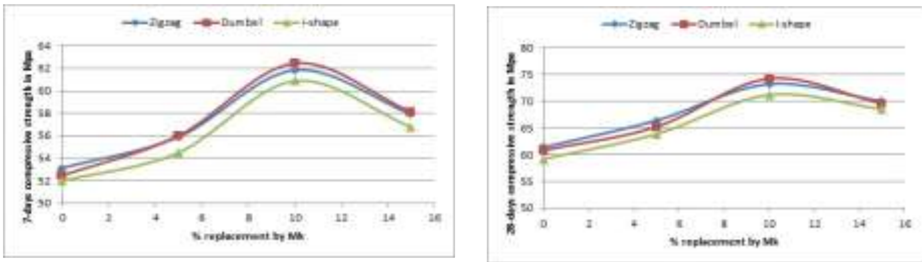


Fig.3 Percentage replacement by Mk Vs Compressive strength

The average of three for each type of paver blocks , was reported as compressive strength. The test set-up is shown in Fig 7(a). The values of compressive strength are plotted against percentage replacement with metakaolin for three types of paver blocks is presented in Fig 3. The results for all types of paving blocks exhibit improvement in compressive strength due to replacement of cement with Mk. The mix M2 with 10% Mk gave maximum strength. Compared to control mix 16%,19% 17% increase in 7-days compressive strength and 19% 22% and 20% increase in 28 days compressive strength were observed for Zigzag, Dumbbell and I shape paver blocks respectively.

2. Flexural strength

The central point loading method was used to determine the flexural strength of paver blocks at the age of 7-days and 28-days following IS 15658 Annex G. The flexural strength was calculated by using equation

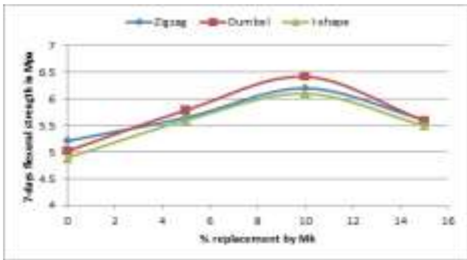
$\boldsymbol{F_b = \frac{3Pl}{2bd^2}}$ where F_b= flexural strength in N/mm^2

P = breaking load in N,

l = distance between centre /centre of supporting rollers

b = average breadth of block measured in both faces.

The test set-up under UTM for flexural strength is shown in Fig.7 (b). The results obtained at 7-days and 28-day s are plotted against the Mk % and shown in Fig.4.



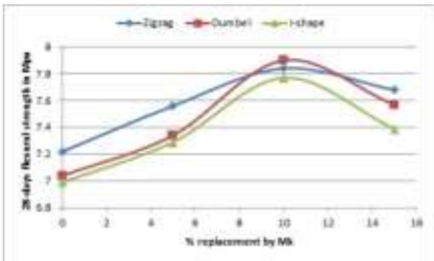


Fig.4 Percentage replacement by Mk Vs Flexural strength

The average of three specimens was taken as flexural strength. Paver blocks prepared with M2 (10% Mk) gave maximum strength for all types. With respect to control mix for M2 mix 19%,28% , 24.7% increase in 7-days and 8%,12% and 11% increase in 28-days flexural strength were observed for Zigzag, Dumbbell and I-shape paver blocks respectively. The early age strength gain is more prominent compared to 28-days strength.

3. Water Absorption

The water absorption of the concrete blocks were determined at 28 days according to IS: 15658 Annex C. Initially, each specimen was immersed in water for 24 hrs. Then it was surface dried and its weight was taken in saturated condition and noted as W_s. After this, the specimen was oven-dried at 105± 5°C for not less than 24 h, and its dry weight was recorded as W_d . The percentage of water absorption were calculated by Equations

$$\text{Water absorption (\%)} = [(W_s – W_d)/ W_d] \times 100$$

The average value of two samples was considered as result. Min water absorption was obtained for M2 mix with 10% Mk for all types of Paver Blocks. Maximum water absorption was observed for mix M1 with 5% Mk which was more than the control mix. The absorption of M3 was observed to be almost equal to control mix . The graph between % replacement by Mk and water absorption is shown in Fig 5. In any case percentage absorption had not increased the limiting 6% value specified in IS: 15658 for paver blocks.

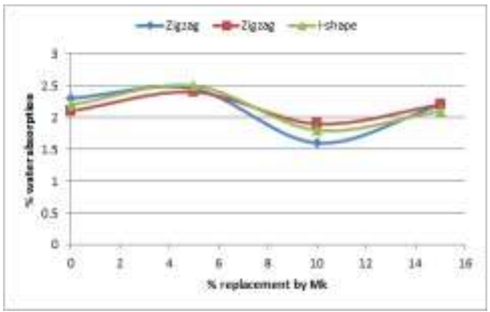


Fig.5 Percentage replacement by Mk Vs % Water absorption

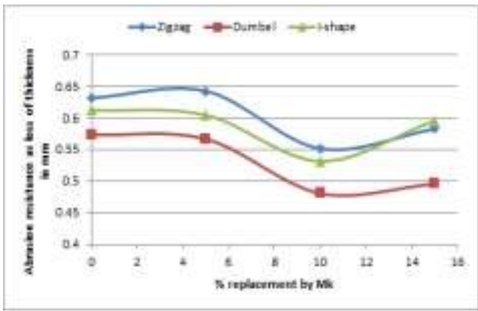


Fig.6. Percentage Replacement by Mk Vs Abrasion resistance

4. Abrasion Resistance

Abrasion testing machine shown in Fig.7(c), confirming to IS 1237 is used to determine Abrasion resistance of concrete block. Square shaped specimen of size 71+_ 0.5 mm was cut from the paving blocks. The specimen was oven dried to constant mass at 105^{o}C. Density of the specimen' PR' is determined prior to test by measuring volume and weight as per IS 15658. The wearing surface of specimen is ground as per the procedure given in IS 15658 Annex E. The abrasive wear of the specimen after 16 cycles (22 revolutions per cycle) of testing shall be calculated as the mean loss in specimen volume, Δv, from the equation:

$$\Delta \mathbf{v} = \frac{\Delta \mathbf{m}}{\mathbf{PR}}$$

where Δv = loss in volume after 16 cycle, in mm^3;

Δm = loss in mass after 16 cycles, in g

PR = density of the specimen in g/mm^3**.**

The abrasion resistance was represented as average loss of thickness in mm and its variation with Mk replacement is shown in the graph in Fig 6. Abrasion resistance of M1 mix with 5% was found to decrease indicating more wear even more than the control mix. M2 mix indicated maximum resistance among all.The trend shows increase in wear for M1, then decrease in wear for M2 then again increase in wear for M3 with increasing percentage of Mk for all type of Paver blocks

5. Microscopic Study

The advanced techniques like XRD, EDX and FESEM were conducted on all mix after 60 days to explore the effect of different percentage of Mk in con. mix at micro level.

5.1 FESEM Analysis

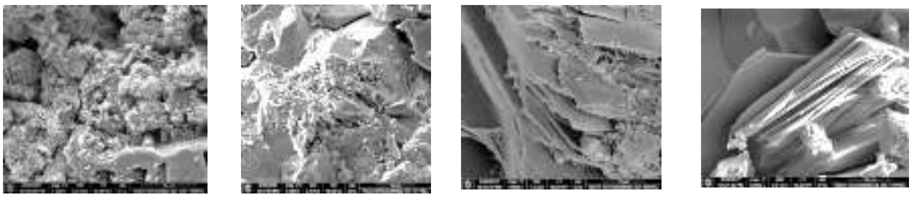
Field emission scanning electron microscopy provides elemental and topographical information at magnification as high as 300,000 x. It gives information about particle

Fig 7.a Fig 7.b Fig 7.c

Fig.7. Test Set up for Compressive, Flexural Strength & Abrasion Resistance

morphology and crystal growth of hydrated paste of different mix. Fig. 9 show the SEM images obtained from the broken surface of the specimens of different mixes at age of 60 days using system magnifications of 5000x .

The micro structure of hydrated cement paste of control mix M0 is characterized by presence of CSH gel, CH plates, ettringite, pores etc. can be seen as loosely packed with each other. Relatively dense, compact, layered crystalline microstructure with interlayer pores and voids was observed for Mk modified mix. Mix M1 with 5% shows smooth crystalline structure with cracks and voids.The mix M2 with 10% MK shows a



M0 M1 M2 M3

Fig.9 SEM images of different mix with 5000x magnifications

higher compactness in layered crystalline structures and ettringite, whereas the M3 mix with 15% shows compact, layered crystalline structure with larger voids and number of un-reacted metakaolin in between the hydrated layers.

5.2 EDX Analysis

EDX , the Energy dispersive X-ray Spectroscopy is a characterization technique that provides elemental composition of hydrated paste. They are obtained from examination of an area on SEM micrograph. 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 area of interest. The X-ray spectrum of the different mix are shown in the Fig. 10.

EDX spectra for mix M0 shows high composition of Ca ,O and lower Si indicate CSH gel phase. EDX spectra of M1 shows high composition of Si and relative Ca and small O indicating consumption of CH through pozzolanic reaction. Higher composition of Si indicates increase in Si due to incorporation of Mk in the mix.

EDX spectra of M2 shows high composition of Si and relative Ca, Al and O indicating primary products CSH CASH and ettringite phase. EDX spectra of M3 shows high Si, O and relative Ca ,Al indicate CASH gel and higher Si due to higher percentage of Mk in the mix indicating full consumption of CH in the mix.

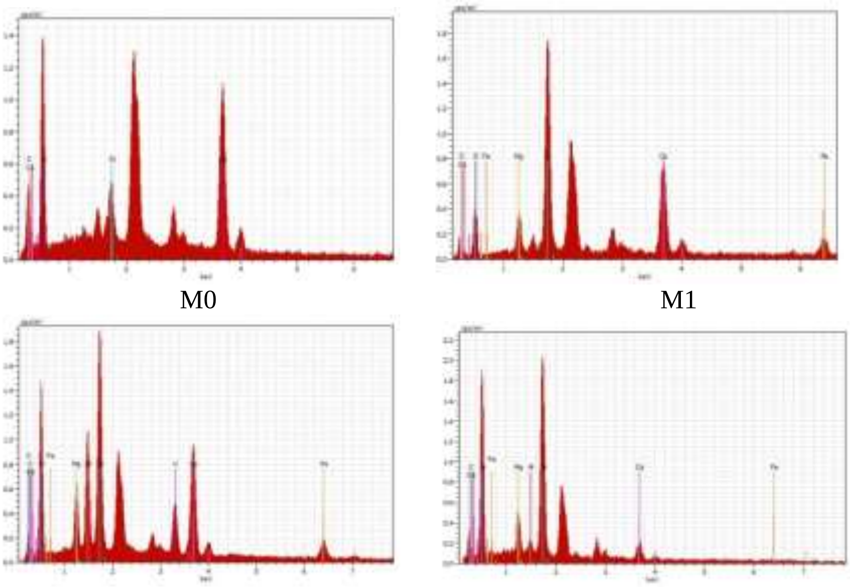


Fig.10 EDX Spectra of different mix

Higher count of Si in Mk modified mixes indicates dilution of cement. It was observed that with increasing percentage of Mk in the mix Si count got increased and Ca count got decreased due to consumption in pozzolanic reaction and formation of CSH and CASH gel .

5.3 XRD Analysis

X-ray diffraction (XRD) is an technique used for phase identification of a material. Replacement ofcement with metakolin dilutes OPC by increasing amount of silica ,alumina etc. compounds in the binder. The available calcium hydroxide (CH) for pozzolanic reaction depends mainly on lime concentration in the mix .The XRD pattern of mix are shown in the Fig. 11. The high peaks in the XRD pattern indicate crystalline form of SiO_2 and CH and weak and smaller peaks characterised CSH gel and gelignite hydrate (C_2ASH_8). The magnitude of weaker peaks can be related to formation of strength giving CSH, C_2ASH_8 phase in hydrates. The patterns are clearly depicting the increase in weak and smaller peaks with increasing percentage of Mk in the mix indicating increases in gel formation. The higher number of smaller weak corresponds to M2 mix with 10% Mk. This may denote maximum utilisation of CH through pozzolanic reaction. Pattern for M3 with 15% Mk indicate more of smaller peaks but relatively higher Q peaks representing Silica indicating unconsumed metakaolin .Pattern for M1 shows less of smaller peaks and high peak for Si and C indicating presence of silica and unconsumed CH in the mix.

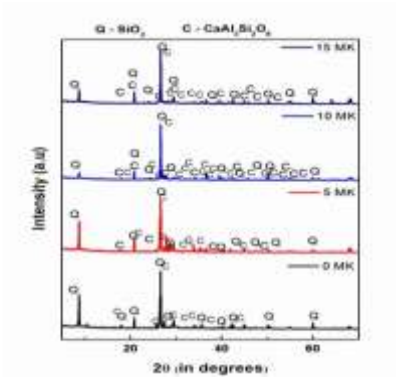


Fig.11 XRD Spectrum of Different Mix

Conclusions

1. It was observed that use of metakaolin as partial replacement of cement is effective in improving compressive strength, flexural strength ,abrasion resistance and durability of concrete paver blocks of all types.
2. This improvement is upto an optimum percentage of Mk as replacement ,which is found as 10% for the current study. Beyond this optimum percentage, decline in these properties were observed.
3. Maximum 20% increase in compressive strength after 7-days and 28-days , 28% increase in 7-days flexural strength and 12% increase in 28-days flexural strength,30% decrease in water absorption and 16% increase in abrasion resistance were observed for the paver blocks.
4. The microscopic observations of hydrated paste of Mk modified mix by FESEM images revealed that metakaolin in concrete forms dense microstructure. The plate like hydrates formed smooth layered and compacted microstructure. Owing to this strength characteristics and durability of the mix has improved.
5. The EDX spectre provided knowledge of elemental composition of hydrates of different mix through the counts of different elements . The relative quantitative measure of Si and Ca hydrates in different mix, giving insight knowledge of consumption of metakaolin in different mixes
6. The XRD patterns of the mixes revealed that Q (quartz) and C (CASH+CSH hydrates) form very strong peaks . The reduction in C peaks accompanied with increase in Si peaks on the graphs indicated consumption of calcium hydroxide in pozzolanic reaction and dilution of OPC due to replacement by metakaolin.

The general conclusion is an optimum quantity of metakaolin used as partial replacement of cement can remarkably improve strength characteristics of high strength concrete paver blocks of all types . The metakaolin through the pozzolanic reaction form extra strength giving compounds and refine the micro structure in compact crystalline form. This imparts better strength and resistance against abrasion and less water absorption, which are the requisite properties for any paver blocks Also replacing a part of cement leads to minimising cement consumption for a green and better environment.

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