# Improvement of Concrete Paving Blocks Properties by Mineral Additions

**Aqeel Hatem Chkheiwer**
*Basrah University /Engineering College /Civil Eng. Department*
aqeelhateem@gmail.com

## Abstract

This research presents the results of experimental work on the various properties concrete paving blocks (CPB) made with concrete containing different mineral additions.in this study, three types of mineral additions;Fly Ash (FA),Metakaolin (MK) and Silica Fume (SF) were used. Thirteen concretes mixes were cast at a water/binder ratio of 0.45 with 0, 5, 10,15and 20% cement replaced by either Fly ash,Metakaolin or Silica Fume. Theconcrete mixes were tested for slump, compressive strength, water absorption, and abrasion resistance.Metakaolin-contained concrete showed a better workability than fly ash and silica fume concrete. As the replacement level wasincreased, the 28-days compressive strength of the CPB containing MK increased similarly to that of the silica fume-containedCPB up to 20% replacement ratio. The replacement ratio of MK and SF from 5 to 20 % reduced water absorptionof CPB from5 to 19 than that of control mix. The increase in replacement ratio of MK andSF from 5 to 20 % leads to increasing abrasion resistance from 8 to 18% that of control mix.

**Keywords: Concrete Paving Blocks**, Mineral**Additions, Silica Fume,Fly Ash, Metakaolin**

## الخلاصة

في هذه الدراسة تم عرضنتائج البحث العملي لمختلف خصائص كتل الرصف الخرسانية المصنوعة من خرسانة احتوت على مضافات المعدنية مختلفة. في هذه الدراسة قد استخدمت ثلاثة أنواع من المضافات المعدنية وهي الرماد المتطاير والميتاكوئلين وغبار السليكا.تم إعداد وفحص ثلاثة عشر خلطة الخرسانية بنسبة الماء إلى الاسمنت 0.45 مع نسبة استبدال 0، 5، 10، 15 و 20٪ من وزن الاسمنت لكل من المضافات المعدنية الثلاث. تم اختبار الخرسانة للهطول، ومقاومة الانضغاط، وامتصاص الماء ومقاومة التآكل. وأظهرت النتائج ان الخرسانة الحاوية على الميتاكوئليناعطتقابلية تشغيل أفضل من الخارسانة الحاوية على الرماد المتطاير وغبار السيليكا. كلما زادت نسبة الاستبدال، تزداد مقاومة الانضغاط بعمر 28 يوم للخرسانة الحاوية على الميتاكوئلين وتلك الحاوية على غبار السيليكا بنفس المقدار تقريبا حتى نسبة استبدال 20٪.ان استبدال الاسمنت بالميتاكولين وغبار السليكا بنسبة 5 إلى 19%أدىإلى تقليل نسبة امتصاص لطابوق الرصف الخرساني من 5 إلى 20 % مقارنة بالخلطة المرجعية.وقد ادت زيادة نسبة الاستبدال لمادتي الميتاكوئلين وغبار السليكا من 5 إلى 20% من وزن الاسمنتإلى زيادة مقاومة التآكل للخرسانة من 8 إلى 18 %.

الكلمات المفتاحية :- طابوق الرصف الخرساني ،مضافات معدنية ، غبارالسليكا ،ماء متطاير ، الميتاكوئلين .

## 1-Introduction

Interlocking Pavers (concrete paving blocks (CPB)) are the modern day solutionfor low cost outdoor application.Paver block is solid, reinforcedpre-cast cement concrete paving units used in the surface course of pavement. They are high strength concrete precastelements in various shapes, sizes &colors to suit the imagination of landscape architects & nature's essence.By improvingits compressive strength it can be used in heavy traffic area also. Interlocking pavers are manufactured concrete productthat is individually placed in a variety of patterns and shapes as per the requirement[Kashiyani*et al.*(2013)]**.** The strength, durability and aesthetically pleasing surface of pavers have made CPB ideal for many commercial, municipal and industrial applications**.**

Fly ash (FA), a by-product of coal combustion, is widely usedas a cementitious and pozzolanic ingredient in Portland cement concrete. Silica fume(SF) is a by-product resulting from the reduction ofhigh-purity quartz with coal or coke and wood chips in anelectric arc furnace during the production of silicon metal orferrosilicon alloys .Metakaolin(MK)It is produced by calcining purified kaolinite clay at a specifictemperature range to drive off the chemically bound water inthe interstices of kaolin and destroy the crystalline structure,which effectively converts the material to the MK phase,which is an amorphous aluminosilicate. Unlike industrialby-products, such as silica fume (SF) and fly ash (FA), MK is refined carefully to lighten its color, remove inertimpurities, and control particle size. Mineral additions typically incorporated into concrete to replace 5 to20 wt% of cement.Metakaolinwas found to improve concrete properties while offeringgood workability. Concrete with MK requires 25 to 35% lesshigh-range water-reducing admixture than concrete with silicafume to achieve a comparable slump of 12 to 18 cm at a water/binder ratio of 0.36 to 0.38 [ACI 234R-2 (2000), Caldarone*et al.*(1994)].

Mall *et al.* (2015) found that replacement of cement by Fly Ash up to 25% by weight has a negligible effect on the reduction of any physical and mechanical properties of CPB like compressive strength, flexural strength etc.The results showed that at 25% fly ash is partially replaced with OPC give higher strength as compared to conventional mix i.e., is 0%. Then at 25% fly ash give economic value as compared to conventional mix i.e., is 0%. The water absorption decreased as Fly Ash replacement ratio increased up to 15 %. In the same time, Singh*et al.* (2015) concluded that for all types of cement, the compressive strength and flexural strength of CPB increased with increase of fly ash replacement up to 20% of weight of cement. Butthe water absorption reduced with increase in replacement ratio from 0to 40%.

There is less information about the properties of concrete paving blocks containing mineral additions, however, than for other mineral admixture-modifiedconcretes, and the available conclusions are somewhatcontradictory. The objectives of the study were to investigatesystematically the effect of mineral additions on the properties of concrete paving blocksat various replacement amounts, including workability, compressivestrength, water absorption, and abrasion resistance.

**2. Research Significance**

Mineral additions (FA, MK, SF) are a supplementary cementing materialsdeveloped recently for high-performance concrete. Althoughsome works have reported that it improves concrete properties,information about the properties of concrete paving blocks with high reactivity supplementary mineral additions is still limited and somewhat contradictory, whichretards its application in the construction practice. This studysystematically investigated the effect of FA,MK and SF on concrete paving blocksproperties;strength and water absorption as wellas abrasion resistanceto find the optimum of mineral additions to cement ratioreplacement ratio which produces the best interlock and concrete block properties. These results are compared with thoseof concrete made with sulfate resistance cement. The conclusions of this study are very important information in range of improvement of concrete interlock pavement technology.

## 3.EXPERIMENTAL WORK

In order to find the most appropriate mix with mineral additions for the strength, and abrasion properties of CPB, twelve concrete mixtures were cast using 0, 5, 10, 15 and 20%by weight replacement of cement with FA, MK orSF, at a water/binder ratio of 0.45 and a sand-to-total aggregateratio of 40%. The mixtures were marked as SRC, FA5, FA10, FA15, FA20, MK5,MK10, MK15,MK20, SF5, SF10,SF15 and SF20, respectively. For all ofthe mixtures, the ratio of binder (including cement, SF,FA and MK)to sand and to gravel was kept constantat 1:1.81:2.70. All mixtures contained 1.0% superplasticizer(SP) by weight of binder. The details of the mixture proportions are presented in Table (1).

**Table (1)Mix proportions of all mixtures Kg/m$^3$**

| Mix symbol | FA | MK | SF | Cement | Water | SP | Sand | Gravel |
|---|---|---|---|---|---|---|---|---|
| SRC | 0 | 0 | 0 | 400 | 180 | 4.00 | 725 | 1090 |
| FA 5 | 20 | 0 | 0 | 380 | 180 | 4.00 | 725 | 1090 |
| FA10 | 40 | 0 | 0 | 360 | 180 | 4.00 | 725 | 1090 |
| FA15 | 60 | 0 | 0 | 340 | 180 | 4.00 | 725 | 1090 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| FA20 | 80 | 0 | 0 | 320 | 180 | 4.00 | 725 | 1090 |
| MK 5 | 0 | 20 | 0 | 380 | 180 | 4.00 | 725 | 1090 |
| MK10 | 0 | 40 | 0 | 360 | 180 | 4.00 | 725 | 1090 |
| MK15 | 0 | 60 | 0 | 340 | 180 | 4.00 | 725 | 1090 |
| MK20 | 0 | 80 | 0 | 320 | 180 | 4.00 | 725 | 1090 |
| SF 5 | 0 | 0 | 20 | 380 | 180 | 4.00 | 725 | 1090 |
| SF10 | 0 | 0 | 40 | 360 | 180 | 4.00 | 725 | 1090 |
| SF15 | 0 | 0 | 60 | 340 | 180 | 4.00 | 725 | 1090 |
| SF20 | 0 | 0 | 80 | 320 | 180 | 4.00 | 725 | 1090 |

The cement used in this research was sulfate resistance cementmanufactured locally, complying with Iraqi standard No.5 (1984), with a specific gravity of 3.15 and aspecific area of 385 $m^2$/kg.The Fly Ash class F-type, with specific gravity of 2.25, a specific surface area of 320 $m^2$/kg, and an average particle size of 2.25 µm .The high-reactivity MK, which was locallymanufactured, had a specific gravity of 2.56, a specific surface area of11* $10^4$ $m^2$/kg, and an average particle size of 2.24µm. TheSF was a commercially available product with a specificgravity of 2.26 and an average particle size of 0.1 µm. Thechemical compositions of cement and these three powders are listed inTable (2). The coarse aggregate was (9.25-2.36) mm crushed gravelwith a specific gravity of 2.62 and absorption of0.7%. The fine aggregate had a specific gravity of 2.66, anabsorption of 1.2%, and a fineness modulus of 2.80,both fine and coarse aggregate had grading complied with ASTM C33 (2003) as seen in Table(3).The water used in this study for the preparation of concrete mixes and specimens curing was tab water, free of acids, organic matter, suspended solids, alkalis and impurities which when present may have adverse effect on the strength of concrete.To increase the Compressive Strength, reduced the consumption of water and maintain the slump value a poly carboxylic ether based superplasticizer complying with ASTM494-type G (2004)was used.

**Table (2) Chemical composition and color of cementitious materials**

| Chemicals | Cement | Fly Ash | Metakaolin | Silica Fume |
|---|---|---|---|---|
| $SiO_2$ | 20.70 | 53.30 | 51.2 | 92.9 |
| $Al_2O_3$ | 5.18 | 10.20 | 45.3 | 0.69 |
| $Fe_2O_3$ | 2.30 | 4.50 | 0.60 | 1.25 |
| MgO | 3.90 | 1.20 | --- | 1.73 |
| CaO | 64.3 | 1.66 | 0.05 | 0.40 |
| $Na_2O$ | 0.50 | 0.20 | 0.21 | 0.43 |
| $K_2O$ | 0.30 | 0.65 | 0.16 | 1.19 |
| $SO_3$ | 2.40 | 0.35 | --- | ---- |
| LOI | 1.63 | 1.33 | 0.51 | 1.18 |
| Color | Gray | Light Gray | White | Dark gray |

**Table (2) Grading of coarse and fine aggregate**

| Coarse aggregate 9.5-2.36 mm | | | Fine aggregate | | |
|---|---|---|---|---|---|
| Sieve size mm | Passing (%) | ASTM C33-03 limits | Sieve size mm | Passing (%) | ASTM C33-03 limits |
| 12.5 | 100 | 100 | 9.5 | 100 | 100 |
| 9.5 | 90 | 85-100 | 4.75 | 96 | 95-100 |
| 4.75 | 25 | 10-30 | 2.36 | 85 | 80-100 |
| 2.36 | 2 | 0-10 | 1.18 | 70 | 50-85 |

| | | | | | |
|---|---|---|---|---|---|
| 1.18 | 0 | 0-5 | 0.60 | 44 | 25-60 |
| | | | 0.30 | 20 | 5-30 |
| | | | 0.15 | 4 | 0-10 |

Immediately after the concrete have been thoroughly mixed, the slump test on fresh concrete mixtures was carried out according BSEN12350-2- part 2 (2009). The specimens with150 mm in length, 150mm width and 60 mm in thickness were casted in molds and compacted with vibrated table. All samples are demolded after 24 hrs, marked and cured in water until 28 days of age.

For each mix, at 28days of age, ten specimens for compressivestrength and five specimens for waterabsorption were tested in accordance withIraqi standard No.1606 (2002).Abrasion test is very important test for the concrete interlock. To assess this property, five specimens were tested according to BS EN1338 (2003) specificationby using wearing machineas illustrated in Fig.(1), the groove length in each abrasion specimen was measured and the average of five results was calculated.

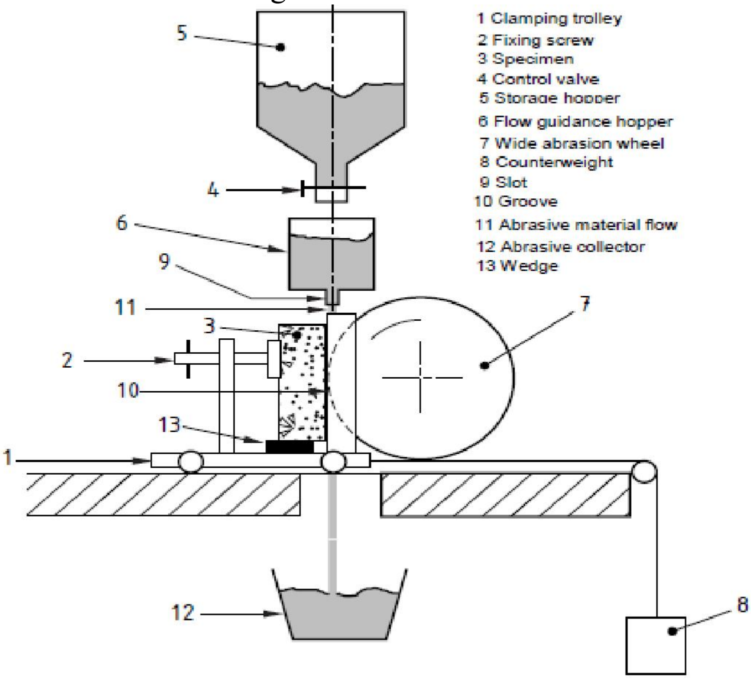


**Figure (1) Principle of wearing machine** [11]

## 4. RESULTS AND DISCUSSIONS

Table (4) summarized the test results of all mixes.Results of fresh and hardened concrete with partial replacement of mineral additions are discussed incomparison with those of normal concrete made with sulfate resistance cement in following sections.

**Table (4) Test results of all mixes**

| Mix symbol | Slump mm | Compressive strength*MPa | Water ** absorption % | Abrasion resistance *** (groove lengthmm) |
|---|---|---|---|---|
| SRC | 180 | 38.5 | 4.0 | 19.5 |
| FA 5 | 180 | 40.0 | 3.9 | 19.0 |
| FA10 | 185 | 39.0 | 3.7 | 19.3 |
| FA15 | 171 | 37.4 | 3.3 | 19.7 |
| FA20 | 152 | 35.5 | 3.3 | 19.8 |

| | | | | |
|---|---|---|---|---|
| MK 5 | 184 | 44.3 | 3.8 | 18.0 |
| MK10 | 190 | 46.4 | 3.4 | 17.4 |
| MK15 | 181 | 51.7 | 3.0 | 16.0 |
| MK20 | 170 | 52.4 | 3.2 | 16.0 |
| SF 5 | 171 | 43 | 3.6 | 18.6 |
| SF10 | 130 | 46.2 | 3.0 | 17.2 |
| SF15 | 116 | 50.8 | 2.9 | 16.3 |
| SF20 | 110 | 52.3 | 2.8 | 16.0 |
| * a value of compressive strength represents average of ten test specimens<br>** a value of water absorption represents average of five test specimens<br>*** a value of groove length represents average of five test specimens | | | | |

## 4.1 Slump

The effect of FA, MK or SF on the slump of concrete at differentreplacement levels is shown in Fig. (2). It can be seen that MKshowed a much better workability than did FA and SF for the givenmixture proportions. Indeed, concrete mixtures with 5 to10% MK had a higher slump than the SRC mix.Even when the replacement ratio of MK was increased to15 and 20 %, the slump was decreased by 3 and8%respectively and was still greater than 160 mm. For FA mixture, at replacement level 5% ,the slump value of was still equal to slump of control mix and then decreased gradually as the ratio increased to 20% as seen in Fig(2). For SF mix,the slump value exhibited only a small decrease at the replacementlevel of 5%. However, it decreased almost linearly withan increase of SF content to 20%. That means the concrete mixtures modified by MK requiredless high-range water-reducing admixture than FA and SF mixturesto achieve similar workability at the same water/binder ratio.This reduction in superplasticizer demandmay result in less tendency for surface tearing during finishingoperations and lead to an overall better finishability. In addition, the MK-modified mixtures may be more economical becauseof a lower dosage of superplasticizer.In addition**,** theworkability was substantially increased for mixtures containingMK, with greater increase being experienced as the MKreplacement level increased up to 10%.

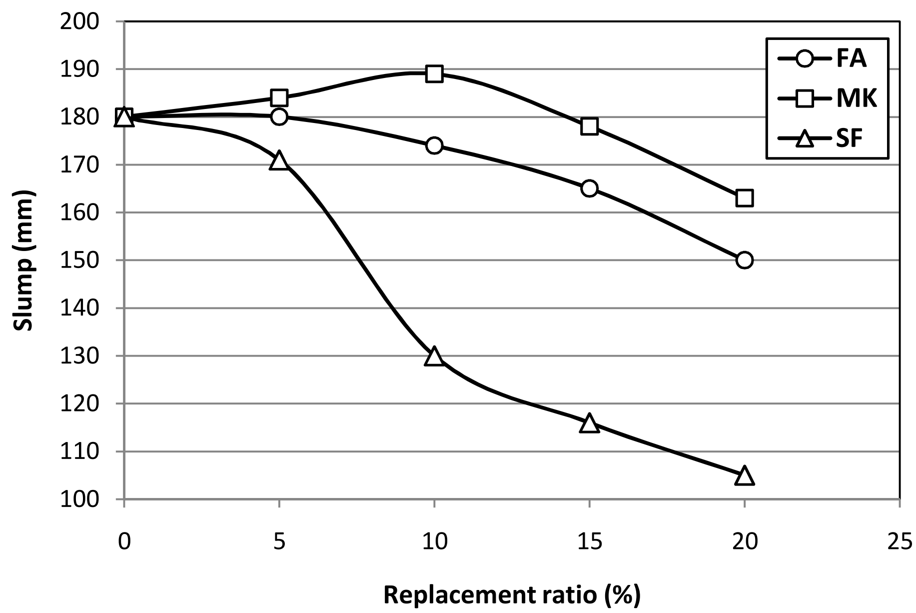


**Figure (2) Effect of mineral additions on slump at different replacement ratios by weight of cement**

## 4.2Compressive strength

Fig.(3) demonstrates the effect of mineral additions on the 28-daycompressive strength at different replacement ratios. It is clear from Fig. (3)That, atthe same replacement ratio, MK increased concrete strength to almost the same extent (approximately 11 to 36%)as SF did. By increasing the replacement level from 5 to 20%,the strengthening effect of MK increased.Concrete mixture with 5 % FA had a higher compressive than the SRC mix. When the replacement ratio of FA was increased from 5%to 20%, the compressive strength decreased but was still greater than that of SRC mix up to10%. From Table (4) it can observed that, the compressive strengths of the concretemixtures FA5andFA10 approximately 4, 2 % higher than that of SRCmix respectively. But the mixes containing FA from 15 to20 %, the compressive strengths of the CPB reduced 3 to 8% than that of SRC respectively. The compressive strengths of the concretemixtures MK5, MK10, MK15and MK20 were approximately 15, 21,34 and 36% higher than that of SRCmix at 28 days. The compressive strengths of the concretemixtures SF5, SF10, SF15and SF20 were approximately 12, 24, 32and 36 % higher than that of SRCmix at 28 days.

As per Iraqi standard No.1606 (2002), compressive strength of concrete Paving Block should be greater than 30, 35, 55MPafor high, medium and light loading degrees respectively. But minimum compressive strength among all mixes was found to be 35.5 MPa, which compliedtherequirement of medium loading degree.

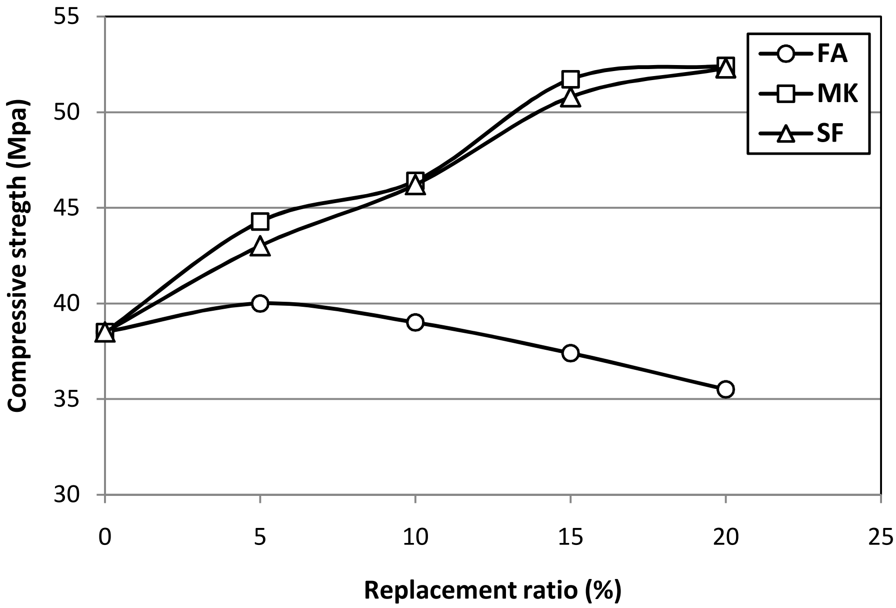


**Figure (3) Effect of mineral additions on 28-days compressive strength at different replacement ratios by weight of cement**

## 4.3 WaterAbsorption

Fig.(4)reveals the effect of FA, MK or SF with different replacement levelson the water absorption of CPB. From Fig.(4) it can be seen that atall replacement levels, the mineral additions decreasedwater absorption of CPB compared with SRC mix. At the same replacement ratio,The SF mix showed water absorption less than of MK and FA. It is clear from Table (4) that, the water absorption of the concretemixtures FA5, FA10, FA15 and FA20was approximately 2, 17,and 7and 45% less than that of SRCmix.The concretemixtures MK5, MK10, MK15and MK20 exhibited lower water absorption5, 15,25 and 25% compared withSRCmix. The water absorption of SF5, SF10, SF15and SF20 were approximately 10, 25,28 and 30% higher than that of SRCmix.

As per Iraqi standard No.1606 (2002), water absorption of Concrete Paving Block should be less than 6, 7, and 10% for high, medium and light loading degrees respectively. But maximum water absorption among all mixesis found to be 4.0 %,which is much less than the requirement for all loadingdegrees.

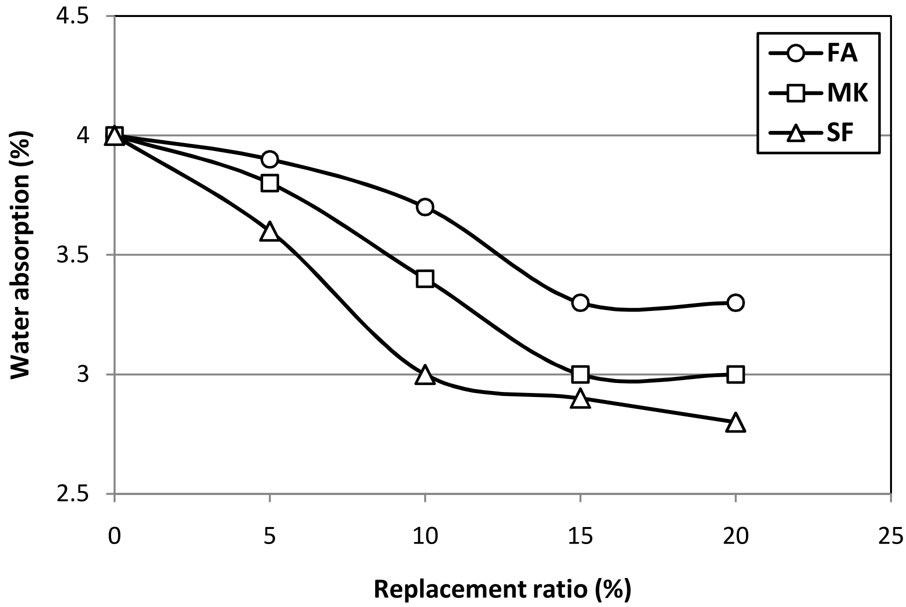


**Figure (4) Effect of mineral additions on water absorption at different replacement ratios by weight of cement**

## 4.4 Abrasion

Fig.(5)illustrates the effect ofincrease replacement ratio of FA, MK or SFwith on the abrasion resistance o CPB from observation the extension and reduction of groove length of the tested specimens. It can be observed from Fig.(5)that, in the case of fly ash, the effect of this mineral addition on abrasion resistance improvement of CPB is not pronounced as in the case of MK and SF. This can be justified from the relatively large values of groove length.The increase in replacement ratio of MK and SF leaded to decreasing groove length approximately at a same path. For AF mixes, by increasing the replacement ratioto 5%,the groove lengthdecreased 3% than that of SRC mix. After this ratio,the groove length increased as replacement ratio increase.The groove lengths of the concretemixtures MK5, MK10, MK15and MK20 were approximately 8, 11,18and 18 % lower than that of controlmix. The concrete blocksSF5, SF10, SF15 and SF20showed decrease in groove length 5, 12, 17 and 18% compared with SRCmix.

As per BS EN1338(2003)specification groove length of concrete Paving Block should be less than 20 mm. But maximumgroove length for all mixes was found to be 19.8 mm.

## 5. Conclusions

The effect of FA, MK or SF on the workability, compressive strength, water absorption, and abrasion resistance of concrete were investigated and compared in this study, the conclusions from this study can be drawn as following:

1. For the given mixture proportions, MK offers better workability than does SF and FA.
2. The strength of the MK-modified concrete increased at all ages. The increase in the strength was similar to that of the SF-modified concrete.
3. The replacement partially of cement by MK or SF in concrete mix can reduce water absorption rate significantly, with the SF concrete performing somewhat better.

4.The increase in replacement ratio of MK, FA and SF leads to increasing abrasion resistance

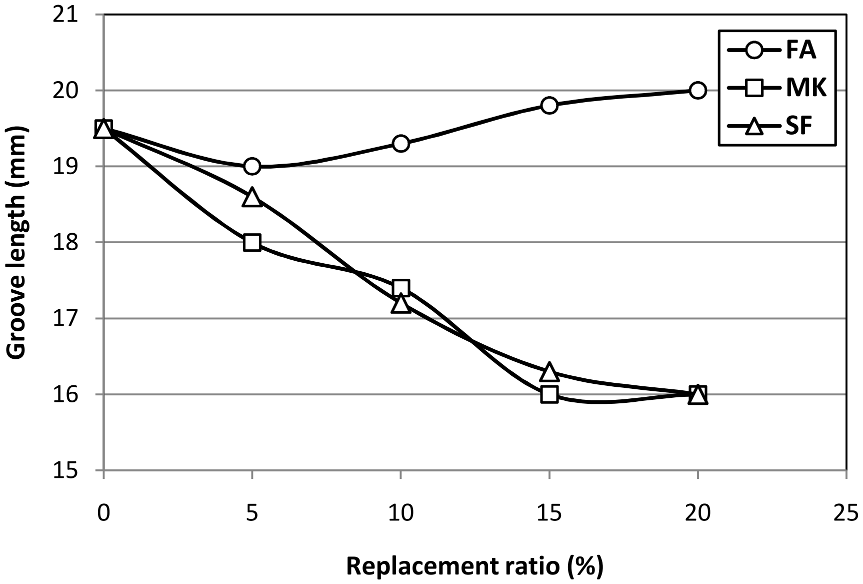


**Figure (5) Effect of mineral additions on Groove length at different replacement ratios by weight of cement**

## 6. References

ACI 234R-2-96"Guide for the Use of Silica Fume in Concrete", reported by ACI Committee 234, reapproved 2000.

ASTM C33-03, "Standard Specification for Concrete Aggregates", ASTM International, American Society of Testing Materials, USA. Vol. 4.2, 2003.

ASTM C494-04, "Standard specification for Chemical Admixtures for Concrete", ASTM International, American Society of Testing Materials, USA.Vol.4.2, 2004.

BS EN 12350-2-2009 part 2 specification, "Slump Test", European Committee for Standardization, 2009.

BS EN1338-2003 specification"Concrete Paving Blocks, Requirements and Test Methods", European Committee for Standardization, 2003.

Caldarone, M. A., Gruber, K. A., and Burg, R. G., "High-Reactivity Metakaolin: A New Generation Mineral Admixture," *Concrete International,* V. 16, No. 11, Nov. 1994, pp. 37-40.

Iraqi Standards No.5/1984, "Ordinary Portland cement", Ministry of Housing and Construction, Baghdad, 2004.

Iraqi standard No.1606, "Concrete Paving Blocks", Ministry of Housing and Construction, Baghdad, 2002.

Kashiyani B. K., Pitroda J. and Shah B. K. , "Effect of Polypropylene Fibers on Abrasion Resistance and Flexural Strength for Interlocking Paver Block"International Journal of Engineering Trends and Technology (IJETT) ,Vol.4, Issue5, May 2013, pp.1837-1843.

Mall R., Shrama S. and Pate R.D., "Studies of the Properties of Paver Block using Fly Ash" International Journal for Scientific Research & Development Vol. 2, Issue 10, and 2014 pp.59-64.

Singh, M., Mehla, P. and Kumar, A., "An Experimental Investigation on Precast Cement Concrete Paver Blocks using Fly ash", International Journal of Enhanced Research in Science Technology & Engineering. Vol. 4 Issue 6, June-2015, pp: (395-402).