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Some Properties of Concrete Containing High Fraction Volume of Metakaolin

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ABSTRACT

In this research, a study has been made on the effect of high fractional volume of replacement Metakaolin that results from grinding and burning the local kaolin from (Doeakhla zone / west of Baghdad / Iraq) with fineness of 18000 cm^2/gm., and with temperature 700°C for one hour, on some properties of concrete (compressive strength, splitting tensile strength, flexural strength, modulus of elasticity, density, absorption and drying shrinkage). Also, non-destructive tests have been made (Schmidt rebound hummer and Ultrasonic pulse velocity). In this study, ten concrete mixes have been used in two Groups to get a compressive strength 40 N/mm^2 at 28 days. In Group A, the percentage replace of Metakaolin have been changed from (0-70) % by weight of cement with percent increment equal to 10% for each mix, and change the maximum size of aggregates to determine the effect of changing the surface area of aggregate as variable on the properties of concrete-containing Metakaolin, The tests for all mixes were made at ages ranged from 1 day to 90 days after mixing and replacement a dosage of superplasticizer by water content of the mix to make a constant workability with slump 50±5mm. The aim of this research is to find a type of concrete that can be used in dams as one of the types of mass concrete, concluded from this research that replacing 70% Metakaolin instead of cement mixing the compressive strength aged 90 days less than the 63%, splitting strength at 28 days less than 27%, flexural strength at 28 days less than about 27%, the modulus of elasticity at 28 days less than 54%, density of less than about 8% at 28 days, the absorption rate increases about 27% and drying shrinkage $1.65 * 10^{-4}$ at 60 days when compared all these tests with the reference concrete.

Keywords: Concrete, Metakaolin, Superplasticizer.

بعض خواص الخرسانة المحتوية على نسبة عالية من الميتاكاؤولين

الخلاصة

يشمل البحث دراسة تاثيرالنسب العالية من إستبدال الميتاكاؤولين الناتج من طحن وحرق الكاؤولين المحلي من منطقة دويخله / غربي بغداد/ العراق وبنعومة 18000 سم^2 \غم وبدرجة حرارة 700° سيليزية لمدة ساعة واحدة على بعض خواص الخرسانة (مقاومة الانضغاط ، مقاومة الشد الغير مباشر (الانفلاقي)، مقاومة الانثناء ، معامل المرونة، الكثافة، الامتصاص، انكماش الجفاف) واجراء الفحوصات اللاإتلافية للخرسانه (مطرقة الارتداد السطحي والموجات الفوق الصوتية). إستعملت في هذه الدراسة 10 خلطات خرسانية للحصول على مقاومة انضغاط 40 نت\ملم^2 تم فيها تغيير نسب الميتاكاؤولين وكالتالي من (0-70)% من وزن الاسمنت وبنسبة زيادة قدرها 10% لكل خلطة، وبتغيير المقاس الاقصى للركام لمعرفة مدى تاثير تغيير المساحة السطحية للركام كمتغير آخرعلى خواص الخرسانة المحتوية على الميتاكاؤولين، أجريت الفحوصات بأعمار تتراوح من اليوم الاول الى 90 يوماً بعد الخلط وباستبدال جزء من ماء الخلط بالملدن المتفوق للحصول على قابلية تشغيل ثابته للخرسانه بفحص الهطول 50±5ملم. ان الهدف من هذا البحث هو ايجاد نوع جديد من انواع الخرسانه يمكن استخدامه في السدود كأحد انواع الخرسانه الكثيفة. استنتج من هذا البحث انه باستبدال 70% ميتاكاؤولين بدلا من الاسمنت فان مقاومة الانضغاط بعمر 90 يوماً تقل بمقدار 63%، ومقاومة الانشطار بعمر 28 يوماً تقل بمقدار 27% ، ومقاومة الانثناء بعمر 28 يوماً تقل حوالي 27% ومعامل المرونه بعمر 28 يوماً تقل بمقدار 54%، والكثافة تقل حوالي 8 % بعمر 28 يوماً، وان نسبة الامتصاص تزداد حوالي 27%، بينما انكماش الجفاف فانه يقل بمقدار 1.65* 10^{-4} بعمر 60 يوماً وذلك بمقارنة نتائج الفحوصات مع خرسانه غير حاوية على الميتاكاؤولين.

INTRODUCTION

Supplementary cementitious materials are finely ground solid materials that are used to replace part of the cement in a concrete mixture. The term pozzolan refers to a silecious material which, in finely divided form and in the presence of water, will react chemically with calcium hydroxide $Ca(OH)_2$ to form cementitious compounds. Kaolinite is the mineralogical term that is applicable to kaolin clays. Kaolinite is defined as a common mineral, hydrated aluminum disilicate, the most common constituent of kaolin, Metakaolin (MK) has been studied because of its high pozzolanic properties, Unlike other pozzolans, it is a primary product not a secondary product or byproduct, which is formed by the dehydroxylation of kaolin produser upon heating in the temperature range of 700–800°C, The raw material input in the manufacture of metakaolin ($Al_2Si_2O_7$) is kaolin. Calcium hydroxide can be virtually eliminated from the cement matrix by using sufficient adapted metakaolin concentrations. MK is being used to produce high strength, high performance concrete with improved durability. The use of MK as part of binders for concrete has been increasing throughout the world, particularly in the production of high strength and high performance concrete, in this thesis study the behavior and properties of concrete containing a large proportion of MK replaced instead of cement content of the mix.

Objective of the Study

The purpose of this research is to determine the effect of high rates of replacement Metakaolin instead of cement used in the mix on some properties of concrete and thus use existing Kaolin in Iraq as raw materials in the production of a type of mass concrete, **Marawan(2013)**.

EXPERIMENTAL WORK

Materials

Cement

Ordinary Portland cement (OPC) manufactured in the north of Iraq with trade mark of (Al-mass) has been used throughout this investigation. It has been stored in airtight plastic containers to avoid the exposure to atmospheric conditions. Its physical properties and chemical composition are given in Tables (1) & (2), respectively. The test results show that the cement conforms to the provisions of **Iraqi specification No. 5/1984**.

Fine Aggregate

AL-Ekhaider natural sand (Southern West of Baghdad/Iraq) of 4.75 mm with grading limits in zone 3 was used throughout this work. Tables (3) illustrate the sieve analysis of the fine aggregate. Results indicated that the fine aggregate grading and the sulfate content were within the requirements of the **Iraqi specification No.45/1984**. Table (4) illustrates the specific gravity, sulfate content and absorption of the fine aggregate used in this investigation.

Coarse Aggregate

Crushed aggregate of 10 mm and 37.5 mm maximum size was used. It was obtained from AL-Nebai source (Northern west of Baghdad/Iraq). Tables (5) and (6), shows the grading of coarse aggregate which conforms to the British Standard Specification. The specific gravity, sulfate content and absorption of coarse aggregate are illustrated in Table (7).

Water

Drinking tap water is used for mixing and curing for all of the experimental work.

High Range Water Reducing Admixture

Superplasticizer (Structure 520 type A) according to **ASTM C494-04** was used as a high range water reducing admixture throughout this work. Table (8), illustrates its properties according to the manufacturer sheet. It is recommended by the manufacture to be used from (0.60-3.0) L/100 kg of cementitious material, which is used as a high performance concrete superplasticizer based on polycarboxylate technology.

Mineral Admixture Metakaolin (MK)

Metakaolin (MK) results from this dehydroxylation and disorder exhibits pozzolanic properties. The Iraqi kaolin clay brought from Dwekhla region / in Al Romadi desert in West of Baghdad/Iraq, used as a mineral admixture. In this work this material was used after burning converted to metakaolin by calcinations process to convert crystalline clay to an amorphous phase, the calcinations temperature and time of calcinations adopted in this work are 700°C for 1hr., respectively. Surface area (Blaine method) and specific gravity of MK, are (18000 cm^2/gm, and 2.62), respectively. The chemical composition of MK is shown in Table (9), Table (10) presents the pozzolan chemical requirements, and Table (11) shows the physical requirements of pozzolan according to **ASTM C618 -06**. X-ray diffraction has been used to determine the types of clay composition (kaolinite and Metakaolin).

Concrete Mixes

Design compressive strength of the two references mix (40N/mm^2) at 28 days curing age and with a constant water/cement ratio and workability about 50±5 mm without adding superplasticizer to reference mix. And began to add superplasticizers when began of add (MK) to the mix and increase it when increase the dosage of MK that's replacement by cement content of the mix. This research containing two

Groups A and B. For designing the mixes, Concrete Mix Design Program - Weight Method, SI Units, and Non-Air-Entrained Concrete. Group A: Have 8 mixes respect with the percentage of MK (0, 10, 20, 30, 40, 50, 60 and 70) % replacement by cement content of the mix, Constant (water / cement) ratio 0.47 and maximum size of aggregate is 10 mm, constant coarse and fine aggregate content and the cementetious materials are constant, but the cement content is variable in each mix respect with the percent of MK that replacement by it, Water content is 228 L/m^3, The proportion of the mix, (cementitious materials: sand: gravel) is (1:1.6:2.2). Group B: Have 2 mixes respect with the percentage of MK (0 and 50) % replacement by cement content of the mix. Constant (water / cement) ratio 0.55 and maximum size of aggregate is 37.5 mm, constant coarse and fine aggregate content and the cementetious materials is constant but the cement content is variable in each mix respect by dosage of MK that replacement by it. Water content is 216 L/m^3, the proportion of the mix, (cementitious materials: sand: gravel) is (1:2.4:2.7).

Mixing of Concrete

Sufficient mixing is necessary to achieve desirable concrete performance and homogeneity. In mixes, extending mixing time is necessary both to fully disperse the MK, and to allow the HRWRA agent to develop its full potential. All trial mixes were performed in rotary mixer of 0.01m^3 or 0.1m^3 capacities, while the mixes of specimens were performed in a rotary mixer of 0.1m^3. The MK and cement were mixed in dry state for about 1 minute to disperse metakaolin particles throughout the cement particles, then the sand and gravel were added and the mixture was mixed for 1 minute. The superplasticizer dissolved in water, and the solution of water and HRWRA was gradually added during the mixing process, then the whole mixture was mixed for 2 minutes. The mixer was stopped, and mixing was manually continued, especially for the portions not reached by the blades of the mixer. The mixer was then operated for 1 minute to attain reasonable fluidity.

Preparation of Specimens

Before casting, all molds were well cleaned and their internal surfaces were lightly oiled to avoid the adhesion of hardened concrete to the internal surface of the molds.

All specimens were filled with the mix in 50 mm height layers. Each layer was compacted by external table vibrator for approximately 20 seconds to minimize the air voids and to get well compacted concrete. The top surface of the molds was leveled, and the specimens were covered with nylon sheets to prevent the loss of moisture. After 24 hours, the specimens were taken out of the molds, marked and then cured.

Curing

The specimens were demolded and immersed in pool containing tap water at room temperature until testing, except the drying shrinkage specimens.

RESULTS AND DISCUSSIONS

Workability of mixes

In Group A in CA0MK mix no SP. added to the reference mix. While in CA10MK mix using 2145 ml/m^3, its about 0.44 L/100kg cementitious materials was used to get the slump 50mm, and increase this dosage with increase MK content when increase the fine materials in the mix. In mixes (CA20MK, CA30MK, CA40MK, CA50MK, CA60MK, and CA70MK) increase the dosage of SP. was (47, 80, 133, 200, 300, and 400) %, respectively, from the first dosage in mix (CA10MK) as explained in Table (12) and Fig. (1). While in Group B, no SP added to the reference mix (CB0MK), and (1.3) L/100kg cementitious materials was used for the mix (CB50MK).

Mechanical Properties

Compressive Strength

This section focuses on the compressive strength performance of concrete containing Metakaolin (MK). Compressive strength is the most important property of concrete, since the first consideration in structural design that the structural elements must be capable of carrying the imposed loads. Compressive strength characteristic is also important, because it is related to several other important properties which are more difficult to measure directly. The response of concrete to applied stress depends not only on the stress type but also on how a combination of various factors affects the porosity of the different structural components of concrete. The factors include properties and proportions of materials in the concrete mixture, degree of compaction, and conditions of curing **ASTM C143-04**. The relationship between (water/cement) ratio and the percentage of Metakaolin that replaces with cement content of the mix is undoubtedly the most important factor because, independently of other factors, it affects the porosity of both the cement mortar matrix and the interfacial transition zone between the matrix and the coarse aggregate **Mehta (2006)**. Table (13) and (14) shows the results of compressive strength of all types of concrete mixes at various ages. In general, the results demonstrate that all concrete mixes exhibit continuous increase in compressive strength with increasing in curing age, this increase in the compressive strength of these specimens is due to the continuity of hydration process which forms a new hydration product within the concrete, as shown in Fig. (2).

Splitting Tensile Strength

The splitting test is rather simple to perform; it does not require other equipment than that needed for the compression test, and gives approximately similar value to the actual tensile strength of concrete, **Neville (1997)**. In general the tensile strength of concrete is much lower than the compressive strength, because of the ease with which cracks can propagate under tensile loads and is usually not considered in design (it is often assumed to be zero). However, it is an important property, since cracking in concrete is generally due to the tensile stresses that occur under load, or due to environmental changes. The failure of concrete in tension is governed by microcracking, associated particularly with the interfacial region between the aggregate particles and the cement paste, which is called an interfacial transition zone (ITZ).

The load applied (compressive force) on the cylindrical concrete specimen induces tensile and shear stresses on the aggregate particles inside the specimen, generating the bond failure between the aggregate particles and the cement paste, **Cristian (2003)**. Concrete specimens containing different percentages of MK as a partial replacement by weight of cement have been used to study their effect on the behavior of concrete under splitting tensile stresses. The results of splitting tensile strength for all mixes are shown in Table (15). The tensile strength of concrete with a low porosity interfacial transition zone will continue to be weak as long as large numbers of oriented crystals of calcium hydroxide are present there. The size and concentration of calcium hydroxide crystals in interfacial transition zone can be reduced by chemical reactions when either a pozzolanic admixture or a reactive aggregate is presented, **Mehta (2006).** In general, the splitting tensile strength of concrete contained Metakaolin as a mineral admixture increases with the progress of age as shown in Figure (3). This is due to the continuity of hydration process. These results are due to the pozzolanic reaction which reduces the microcracking and strengthens the transition zone through the pore size and grain size refinement processes. This is in agreement with other results of **O'Neil (2002).** The pozzolanic reaction is also accompanied by a reduction in the total volume and size of capillary pores an effect that is equally important for the enhancement of strength, **Mehta (2006)**. The effect of MK on the splitting tensile strength of specimens is more active on age of 28 days as compared with the 7 days age. This behavior is due to the low pozzolanic activity of MK at early age and through the time due to the pozzolanic activity of MK. The addition of MK increases the hydration production and filling the pore and improving the mechanical properties. These results are in a good agreement with other results of **Ghazwan (2009)**.

Flexural Strength (Modulus of Rupture)

The flexural tensile strength mixes was determined, and the results presented in Table (16) and Figure (4), indicate that there is an increase in the flexural tensile strength due to replacement (0-30) % MK with the cement content at 7 and 28 days, respectively. This is because of using MK as cement replacement materials in concrete improves the strengths of concrete due to the more consumption of $Ca(OH)_2$, better pore refinement, micro filling action, early gain of strength, and higher pozzolanic reaction. In both Groups A and B using (MK) between (30-50) % leads to reducing the flexural tensile strength results because of reducing the binder materials, and (MK) does not work just as a pozzolanic materials but also works to fill the capillary pores of the mix by fine particles, makes a bleeding in the surface of the specimens (the reduction of flexural is due to reduction of the cement content of the mix) and increase the filler materials. The use of (MK) between (50-70)% makes a high drop in flexural strength corresponding to its reference, because of its work as a type of fine aggregate, and that leads to increase the ratio of aggregate to cement content of the mix. In general, the modulus of rupture results for all mixes increased with increase its age.

Static Modulus of Elasticity(E)

The static modulus of elasticity is defined as the secant in the stress-strain curve at the point corresponding to 40% of the maximum strength, **Mesdah (2002)**. Results of static modulus of elasticity for all dosage of Metakaolin concrete mixes are presented in Table (17).

The behavior of the mixes which contain mineral admixtures is mainly attributed to the influence of MK on the interfacial zone and the bond in composite material. The elastic behavior of concrete depends on the bond strength, density of the interfacial zone, and on densities and void contents of the concrete, **Neville (1997)**.

In general, the reduction of modulus of elasticity is due to increase the percent of high fraction volume of Metakaolin in all mixes (increase the ratio of aggregate to cement content), as shown in Figure (5). this behavior is ascribed to the reduction of cement content of the mix. Figure (5) explain the comparison of all mixes on the dynamic modulus of elasticity at 7 and 28 days for Group A and Group B, respectively.

Density Test

Metakaolin concrete mixes showed a decrease in dry bulk density relative to their reference concrete. The percentage decrease in dry bulk density results when the percentage of metakaolin increases. The result Show that the percentages decrease in the density of concrete mixes with Metakaolin replacement of (10, 20, 30, 40, 50, 60 and 70) % by weight of cement are (1.2, 2.5, 3.3, 3.8, 4.5, 6.9, and 8.2) % respectively, relative to the reference mix (CA0MK). For Group B in mix (CB50MK), the density decreases about 4.4% from the reference (CB0MK).The percentage of density decreased when the percentage of metakaolin in the mix increased, because the specific gravity of cement is (3.14), while the specific gravity of MK is (2.62), the 28 day dry bulk density results for all types of concrete are presented in Table (19) and Figure (6).

Water Absorption Test

The results of the total absorption of various types of concrete mixes are presented in Table (18) and Fig. (7).The results generally indicate that all concrete mixes exhibit continuous reduction in the total absorption values with the use normal dosage of pozzolanic material. This is attributed to continuous pores filling process which is associated with proceeding hydration. The dosage of metakaolin between (0-30) % improvement of the water absorption of concrete is due to the combined action of MK in this dosage as a pozzolanic material which reacts with $Ca(OH)_2$ liberated during the hydration of cement to form calcium silicate and calcium aluminates hydrates, which leads to reduction of the porosity of MK concrete. It also functions as filler and results pozzolanic materials occupy space that would otherwise be occupied by water. This action leads to a reduction in the total porosity of the concrete mixes. These results agree with these of other researchers, **Khalid & Luma (2008)**. The partial replacement of cement with MK reduces the water penetration into concrete by capillary action. The water absorption of concrete by total immersion, however, is slightly increased in metakaolin concrete. $Ca(OH)_2$ crystal is produced due to the hydration reaction between cement and water. It is hexagonal and is arrayed in the interfacial transition zone (ITZ) between the aggregates and binding paste matrix, produceing C-S-H (gel). Namely, the $Ca(OH)_2$ crystal can be absorbed. Then, the size and amount of the calcium hydroxide crystals is reduced. The CSH gel fills the voids to improve the density of the interfacial transition zone and the binding paste matrix. While, high dosage of MK (30-70) % leads to increase water absorption due to reduction of the cement paste in the mix by increasing the (aggregate / cement) ratio because high percentage of MK work as a type of fine aggregate.

Drying Shrinkage Test

Results of drying shrinkage of various dosage of high fraction volume of metakaolin up to 70% replacement by cement content are presented in Table (20) and Figure (8). These figures show the effect of MK on the drying shrinkage of concrete in all mixes at different curing ages. The results show high drying shrinkage at early ages. This is due to rapid loss of moisture from the surface of the specimens. The rate of drying shrinkage decreases with time depending on the moisture movement of concrete. The results showed that the drying shrinkage increase when the dosage of metakaolin increased.

In general the drying shrinkage decreases with increasing the age of the specimen, the maximum percentage of drying shrinkage was at early ages and reduces gradually at later ages.

Non - destructive Tests

Schmidt Rebound Hammer Test (SRH)

Hardness is one of many factors connected with the quality of concrete , Schmidt rebound hammer built on impacting the concrete surface with a specified mass activated by a standard amount of energy. The test is based on the principle that the rebound of an elastic mass depends on the hardness of the surface upon which it impinges and, in this case, will provide information about a surface layer of the concrete defined as no more than (5 cm) depth. The rebound hammer test is one of the most common non-destructive approaches due to its simplicity. It is fast and easy to perform. Therefore, the rebound hammer test can be considered as a successful method for checking the uniformity of concrete in structures, to assess the mechanical properties of concrete for removal of formworks and early safe prestressing, since the prediction of concrete strength, especially at early ages is very important to accelerate the construction schedule and reduce the unexpected failures, **Nergiz (2006)**. As mentioned earlier , the test affected by several factors, such as mix proportions of concrete type, the percentage of metakaolin that replaced by cement content of the mix and maximum size of aggregate in the mix and witness of the concrete surface. The values of the rebound number measurements for all mixes at different curing ages are presented in Table (21) and plotted in Figure (9), the test results showed that the rebound number measurement for all specimens cured in water increases with the increase in age up to 90 days.

Ultrasonic Pulse Velocity Test (UPV Test)

This test is based on the principle that the velocity of an ultrasonic pulse through any material depends upon its elastic properties, comparatively higher velocity is obtained when concrete quality is good in terms of density, uniformity, and homogeneity. Because of the velocity of the pulses is almost independent on the geometry of the material through which they pass and depends only on its elastic properties, thus pulse velocity is a very desirable technique for investigating structural concrete in the laboratory. The values of ultrasonic pulse velocity measurements for all mixes at different curing ages are presented in Table (22) and plotted in Figure (10). The obtained test results confirm that the ultrasonic pulse velocity increases with age at a decreasing rate. The pattern is similar to the increase of concrete strength with age. This behavior is mainly attributed to the increase in the density of concrete with age and the reduction in points of discontinuity. The ultrasonic pulse velocity increased faster than compressive strength, this increase was rapid in the first 7 days and continued at a slower rate until it reaches the 90 days.

CONCLUSIONS

This study is conducted to investigate some properties of concrete have a specified compressive strength 40N/mm^2, and the effect of replacement MK up to 70% by weight of cement content in the mix depends on materials, mix proportion, methods of testing and the results of this investigation. The following conclusion can be drawn:

1-It is possible to get the same workability in the mixes with the same (w/c or w/cm) ratio when increased the dosage of MK by adding SP to the mixes and increasing SP dosage with increasing MK. In Group A, in mixes when replacement (10%MK) by 10% of cement content, (0.44) L/100 kg cementitious material was used. In mixes (20%MK, 30%MK, 40%MK, 50%MK, 60%MK and 70%MK), the percentage of increasing SP is from 46.6 to 400) %. While in Group B, (1.30) L/100 kg cementitious material was used for the mix containing (50%MK).

2-The percentage increase or decrease of the compressive strength results at 90 days for all mixes in Group A (10%MK, 20%MK, 30%MK, 40%MK, 50%MK ,60%MK and 70%MK) with respect to its reference are from +5.6 to -63%. Where as in Group B, the compressive strength result of (50%MK) decreased by (36) % from its reference.

3-For splitting strength results at 28 days for the mixes in Group A (10%MK, 20%MK, 30%MK, 40%MK, 50%MK, 60%MK and 70%MK), the percentage increase or decrease with respect to its reference is from +5.4 to -27%. While in Group B, the percentage decrease of splitting strength result of the mix (50%MK) is (18.4) %.

4-The percentage increase or decrease of flexural strength results at 28 days for all mixes in Group A (10%MK, 20%MK, 30%MK, 40%MK, 50%MK ,60%MK and 70%MK) with respect to its reference is from +5.9 to -27.4%. Where as in Group B, the flexural strength result of (50%MK) decreased by (19) % from its reference.

5-Regarding the static modulus of elasticity results at 28 days for the mixes in Group A (10%MK, 20%MK, 30%MK, 40%MK, 50%MK ,60%MK and 70%MK) the percentage increased or decreased with respect to its reference is from +2.7 to -53.7%. While in Group B, the percentage decrease of static modulus of elasticity result of the mix (50%MK) is (27.7) %, with respect to its reference.

6-For density test results, all mixes at 28 days are decreased with respect to its reference, the mixes in Group A are (10%MK, 20%MK, 30%MK, 40%MK, 50%MK, 60%MK and 70%MK), the percentage of decrease is from 1.2 to 8.1%, while the percentage of decrease in Group B of the mix (50%MK) is (4.4) %.

7-The percentage of water absorption test results at 28 days for all mixes in Group A (10%MK, 20%MK, 30%MK, 40%MK, 50%MK ,60%MK and 70%MK) are decreased or increased from -14.9 to +26.9% with respect to its reference. While in Group B, the mix (50%MK) increased water absorption result to about (16.9) % from its reference.

8-In drying shrinkage test results, all mixes are reduced in length at 60 days with respect to their length at 1 day, in both Groups A and B, the mixes are (10%MK, 20%MK, 30%MK, 40%MK, 50%MK , 60%MK, 70%MK, REFERENCE 2 and 50%MK), the linear drying shrinkage decrease is from $1.65*10^{-4}$ to $2.05\% *10^{-4}$.

9-The results of rebound number at 90 days for the mixes of Group A are increased or decreased with respect to its reference , mixes of Group A are (10%MK, 20%MK, 30%MK, 40%MK, 50%MK ,60%MK and 70%MK) and their percentages are from +9.2 to -44.7%, while the mix of Group B (50%MK) has a decrease of the rebound number result about (25.7)% with respect to its reference.

10-For the ultrasonic pulse velocity test results at 90 days for the mixes in Group A (10%MK, 20%MK, 30%MK, 40%MK, 50%MK ,60%MK and 70%MK), the percentage increase or decrease with respect to their reference is from +4.1 to -14.6%. While in Group B, the percentage decrease of ultrasonic pulse velocity test result of the mix (50%MK) is (8.1) % with respect to its reference.

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Table (1) Physical properties for Type I cement (OPC)*.

Physical properties	Test results	Limit of Iraq specification No.(5) _ 1984
Specific surface area m^2/kg	277	≥230
Setting time Initial setting time, hrs: min Final setting time, hrs: min	1:50 7:10	≥45 min. ≤ 10 hrs.
Compressive strength 3 days N/mm^2 7 days N/mm^2	 21.8 32.4	 ≥15 ≥23

*Physical analysis has been conducted by the National Center For Construction Laboratories and Researches

Table (2) Chemical oxide analysis, weight %, for type I cement (OPC)*.

Oxide	% by weight	Limits of Iraq specification No.(5) _ 1984
CaO	62.3	__
SiO_2	20.1	__
Al_2O_3	5.98	—
Fe_2O_3	3.08	__
MgO	2.31	<5
SO_3	2.01	< 2.8
Na_2O	0.28	$Na_2O + 0.658\ K_2O \leq 0.6$
K_2O	0.51	
Insoluble Residue (I.R)	1.03	<1.5
Loss on ignition (L.O.I.)	2.4	<4.0
Main Compounds		
C_3S	50.77	__
C_2S	19.55	__
C_3A	10.34	__
C_4AF	9.48	__

*Chemical analysis has been conducted by the National Center for Construction Laboratories and Researches

Table (3) Grading of fine aggregate (sand)*.

Sieve size (mm)	Cumulative passing %	Limits of Iraqi specification No.45/1984 zone 3
10	100	100
4.75	100	90-100
2.36	91.7	85-100
1.18	83.1	75-100
0.60	62.7	60-79
0.30	24	12-40
0.15	4.25	0-10
Fineness modulus =2.33		

*Laboratories in Department of Building and Construction in the University of Technology

Table (4) Some properties of fine aggregate (sand)*.

Physical properties	Test results	Limits of Iraqi specification No.45/1984
Specific gravity	2.64	-
Sulfate content	0.3	≤0.5%
Absorption	1.1	-

Table (5) Grading of coarse aggregate (10 mm) maximum size*

Sieve size (mm)	Cumulative passing %	British Standard specification
14	100	100
10	88.6	85-100
5	10.8	0-25
2.36	0	0-5

Table (6) Grading of coarse aggregate (37.5 mm) maximum size*.

Sieve size (mm)	Cumulative passing %	British Standard specification (5-40)
50	100	100
40	100	95-100
20	42.6	35-70
14	---	---
10	28.7	10-40
5	0	0-5

*Laboratories in Department of Building and Construction in the University of Technology

Table (7) Some properties of coarse aggregate*

Physical properties	Test results	Limits of Iraqi specification No.45/1984
Specific gravity	2.630	-
Sulfate content	0.06%	≤ 0.1%
Absorption	0.63%	-

*National Center for Construction Laboratories and Researches

Table (8) Properties of the superplasticizer (SP 520 'S)*

Appearance	Light brown colored liquid
Specific gravity	1.235 at 25±2°C
Chloride content	Nil
Flash point	N/A
pH value	6.5
S.G at 20 °C	1.100
Alkali content	Typically less than 1.5gm Na_2O equivalent per liter admixture

*By SP producer

Table (9) Chemical analysis specify of MK*.

Chemical content	Oxide content %	ASTM C816 Limitation
SiO_2	55.22	Min 70%
Al_2O_3	32.38	
Fe_2O_3	1.54	
MgO	0.41	
CaO	2.24	
SO_3	2.85	Max 4%
L.O.I	3.35	Max 10

*Chemical analysis has been conducted by the National Center for Construction Laboratories and Researches

Table (10) Chemical requirements of pozzolan.

Oxide composition	Limitation according to ASTM C618 – 06 %	MK %
(SiO_2+AlO_3+Fe_2O_3), min.	70	89.14
SO_3, max.	4	2.85
Loss on ignition, max.	10	3.35

Table (11) Physical requirements of pozzolan *.

Physical properties	Limitation of pozzolan according to ASTM C618- 06	MK
Strength activity index with Portland Cement at 28 days (%)	75% at min.	138
Flow (%)	110±5	110
Specific gravity	-	2.62

* Physical analysis has been conducted by the National Center

Table (12) Superplasticizers dosage for all types of concrete mixes.

Group	Symbol of Mix	% of MK	Cementitious material content (kg/m^3)		HRWRA (ml/m^3)	w/c or w/cm ratio
			Cement	MK		
A	CA0MK	0	485.0	0.0	0	0.47
	CA10MK	10	436.5	48.5	2145	0.47
	CA20MK	20	388.0	97.0	3145	0.47
	CA30MK	30	339.5	145.5	3860	0.47
	CA40MK	40	291.0	194.0	5000	0.47
	CA50MK	50	242.5	242.5	6430	0.47
	CA60MK	60	194.0	291.0	8570	0.47
	CA70MK	70	145.5	339.5	10715	0.47
B	CB0MK	0	393.0	0.0	0	0.55
	CB50MK	50	196.5	196.5	6250	0.55

Table (13) Compressive strength for all mixes Cube specimens.

Group	Symbol of mix	% of MK	w/c or w/cm ratio	Compressive strength (N/mm^2)				% increase or decrease for 90 days
				7 days	28 days	60 days	90 days	
A	CA0MK	0	0.47	32.1	39.5	41.5	42.7	-
	CA10MK	10	0.47	34.4	41.4	43.1	45.1	+5.6
	CA20MK	20	0.47	32.5	39.7	42.4	46.4	+8.7
	CA30MK	30	0.47	32.7	38.9	40.4	43.8	+2.6
	CA40MK	40	0.47	28.3	34.5	35.8	36.6	-14.3
	CA50MK	50	0.47	24.1	29.3	31.4	32.8	-23.2
	CA60MK	60	0.47	18.8	22.1	23.6	27.6	-35.4
	CA70MK	70	0.47	11.9	13.5	15.2	15.8	-63.0
B	CB0MK	0	0.55	32.2	39.3	41.5	42.0	-
	CB50MK	50	0.55	19.9	24.0	25.7	26.9	-35.9

Table (14) Compressive strength for all mixes Cylinders specimens.

Group	Symbol of mix	% of MK	w/c or w/cm ratio	Compressive strength (N/mm^2)		
				7 days	28 days	90 days
A	CA0MK	0	0.47	26.3	30.8	33.4
	CA10MK	10	0.47	28.4	33.9	36.7
	CA20MK	20	0.47	29.3	34.5	37.3
	CA30MK	30	0.47	27.4	32.2	34.8
	CA40MK	40	0.47	23.1	28.5	30.8
	CA50MK	50	0.47	18.6	23.9	25.8
	CA60MK	60	0.47	12.4	18.6	20.1
	CA70MK	70	0.47	8.2	12.9	14
B	CB0MK	0	0.55	30.7	35.3	38.2
	CB50MK	50	0.55	15.6	20.3	22.1

Table (15) Splitting strength results for all mixes.

Group	Symbol of mix	% of MK	(w/c) or (w/cm) ratio	Splitting Tensile Strength (N/mm^2)		% increase or decrease at 28 days
				7 days	28 days	
A	CA0MK	0	0.47	2.9	3.7	-
	CA10MK	10	0.47	3.3	3.9	+5.4
	CA20MK	20	0.47	3.4	3.8	+2.7
	CA30MK	30	0.47	2.9	3.6	-2.7
	CA40MK	40	0.47	2.6	3.4	-8.1
	CA50MK	50	0.47	2.3	3.2	-13.5
	CA60MK	60	0.47	2.1	3.0	-18.9
	CA70MK	70	0.47	1.8	2.7	-27.0
B	CB0MK	0	0.55	3.3	3.8	-
	CB50MK	50	0.55	2.6	3.1	-18.4

Table (16) Flexural strength results for all mixes.

Group	Symbol of mix	% of MK	(w/c) or (w/cm) ratio	Flexural Strength (N/mm^2)		% increase or decrease at 28 days
				7 days	28 days	
A	CA0MK	0	**0.47**	**7.5**	**8.4**	**-**
	CA10MK	10	**0.47**	**7.4**	**8.9**	**+6.0**
	CA20MK	20	**0.47**	**7.5**	**9.1**	**+8.3**
	CA30MK	30	**0.47**	**7.4**	**8.4**	**0.0**
	CA40MK	40	**0.47**	**6.9**	**7.9**	**-6.0**
	CA50MK	50	**0.47**	**6.3**	**7.0**	**-16.7**
	CA60MK	60	**0.47**	**5.9**	**6.7**	**-20.2**
	CA70MK	70	**0.47**	**5.1**	**6.1**	**-27.4**
B	CB0MK	0	**0.55**	**7.5**	**8.4**	**-**
	CB50MK	50	**0.55**	**5.9**	**6.8**	**-19.0**

Table (17) Static modulus of elasticity for all mixes

Group	Symbol of mix	% of MK	w/c or w/cm ratio	Static modulus of elasticity, (N/mm^2) *10^3	
				7 days	28 days
A	CA0MK	0	0.47	24.8	29.6
	CA10MK	10	0.47	28.1	30.4
	CA20MK	20	0.47	28.6	31.2
	CA30MK	30	0.47	27.6	30.5
	CA40MK	40	0.47	22.0	25.6
	CA50MK	50	0.47	18.8	22.2
	CA60MK	60	0.47	17.6	19.1
	CA70MK	70	0.47	11.8	13.7
B	CB0MK	0	0.55	25.5	29.9
	CB50MK	50	0.55	18.2	21.6

Table (18) Results of water absorption for all mixes.

Group	Symbol of mix	% of MK	w/c or w/cm ratio	Absorption (%), 28 days	% change of absorption
A	CA0MK	0	0.47	6.7	-
	CA10MK	10	0.47	5.7	-14.9
	CA20MK	20	0.47	4.8	-28.4
	CA30MK	30	0.47	6.0	-10.4
	CA40MK	40	0.47	7.2	+7.5
	CA50MK	50	0.47	7.5	+11.9
	CA60MK	60	0.47	7.9	+17.9
	CA70MK	70	0.47	8.5	+26.9
B	CB0MK	0	0.55	7.1	-
	CB50MK	50	0.55	8.3	+16.9

Table (19) Density for all mixes.

Group	Symbol of Mix	% MK	w/c or w/cm ratio	Density (kg/m^3) at 28 days	% of Decrease
A	CA0MK	0	0.47	2440	-
	CA10MK	10	0.47	2410	1.2
	CA20MK	20	0.47	2380	2.5
	CA30MK	30	0.47	2360	3.3
	CA40MK	40	0.47	2350	3.7
	CA50MK	50	0.47	2330	4.5
	CA60MK	60	0.47	2270	7.0
	CA70MK	70	0.47	2240	8.2
B	CB0MK	0	0.55	2480	-
	CB50MK	50	0.55	2370	4.4

Table (20) The linear drying shrinkage of all specimens.

Group	Symbol of mix	% of MK	w/c or w/cm ratio	Length (285+(X * 10^{-6})) mm (X)				
				1 day	7 days	14 days	28 days	60 days
A	CA0MK	0	0.47	800	465	430	350	330
	CA10MK	10	0.47	700	370	345	260	240
	CA20MK	20	0.47	770	460	440	315	300
	CA30MK	30	0.47	860	540	500	375	355
	CA40MK	40	0.47	725	310	285	225	210
	CA50MK	50	0.47	830	400	360	295	280
	CA60MK	60	0.47	770	240	200	190	180
	CA70MK	70	0.47	870	395	315	275	240
B	CB0MK	0	0.55	780	445	400	325	310
	CB50MK	50	0.55	935	480	425	370	350

Table (21) Results of Rebound number of all mixes.

Group	Symbol of mix	% of MK	Rebound number			
			7 days	28 days	60 days	90 days
A	CA0MK	0	33.3	40.1	40.9	42.3
	CA10MK	10	36.0	43.8	44.4	46.2
	CA20MK	20	32.5	39.5	40.5	41.7
	CA30MK	30	26.2	31.9	32.5	33.9
	CA40MK	40	25.5	31.0	31.9	32.6
	CA50MK	50	24.6	29.9	30.6	31.2
	CA60MK	60	21.6	25.9	26.6	27.2
	CA70MK	70	18.1	22.4	22.9	23.4
B	CB0MK	0	32.0	38.9	39.7	41.1
	CB50MK	50	23.1	28.9	29.5	30.5

Table (22) Results of Ultrasonic Pulse Velocity of all mixes .

Group	Symbol of mix	% of MK	Ultrasonic Pulse Velocity (km/sec)			
			7 days	28 days	60 days	90 days
A	CA0MK	0	3.9	4.7	4.8	4.8
	CA10MK	10	4.0	4.8	4.9	5.0
	CA20MK	20	4.1	4.6	4.7	4.8
	CA30MK	30	3.8	4.6	4.6	4.7
	CA40MK	40	3.6	4.4	4.5	4.6
	CA50MK	50	3.5	4.3	4.4	4.4
	CA60MK	60	3.3	4.2	4.3	4.3
	CA70MK	70	3.1	4.0	4.1	4.1
B	CB0MK	0	3.9	4.7	4.8	4.9
	CB50MK	50	3.6	4.3	4.4	4.5

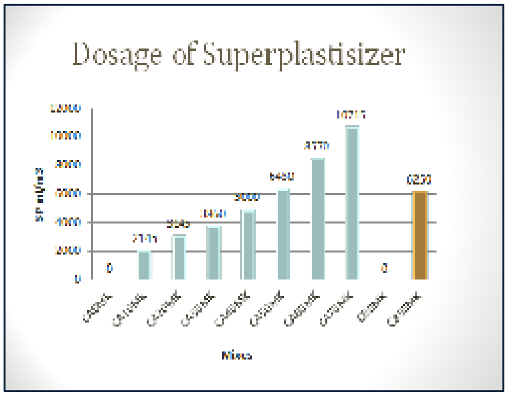


Figure. (1): Superplasticizers dosage of all mixes in Groups A & B

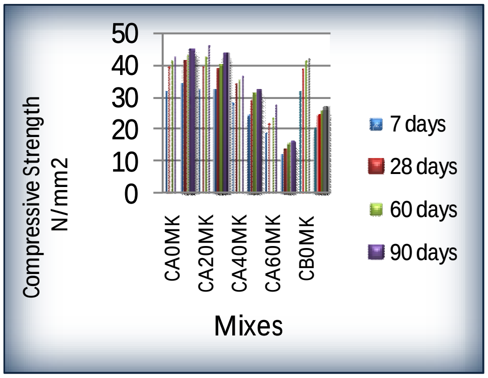


Figure. (2): Compressive strength of all mixes in Groups A & B

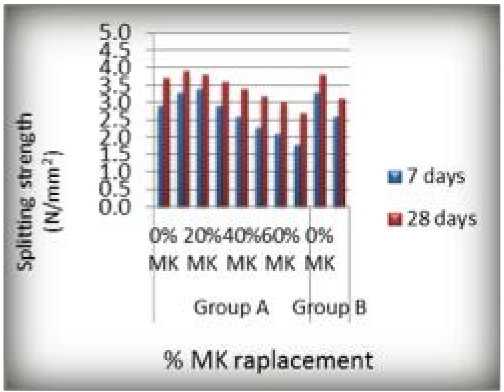


Figure.(3): Splitting strength development for all mixes in Group A and B

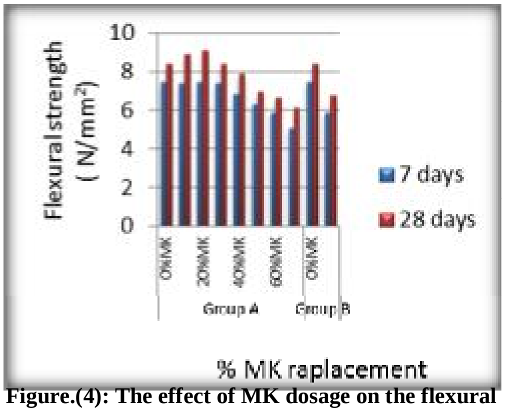
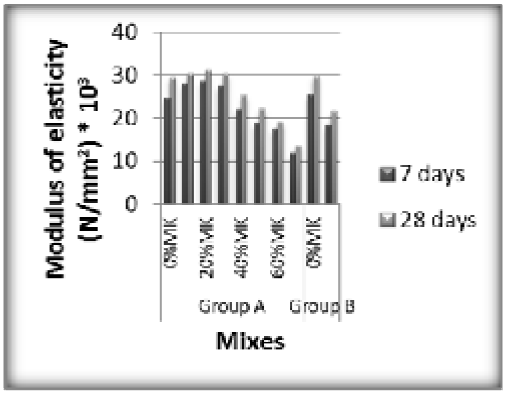


Figure.(4): The effect of MK dosage on the flexural strength in Group A and B



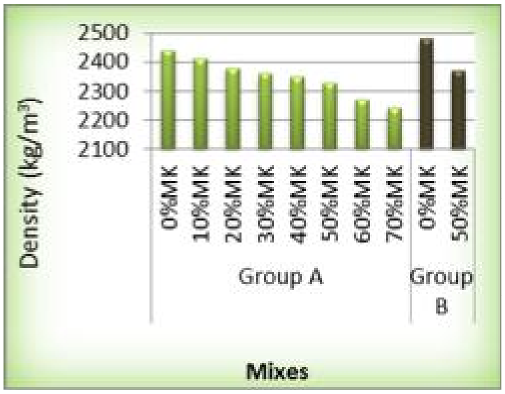
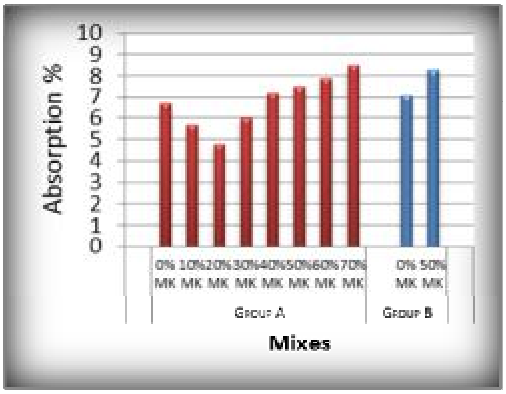


Figure. (5): The comparison for all on the static modulus of elasticity at 7&28 days

Figure. (6): Density test results for all mixes at 28 days age



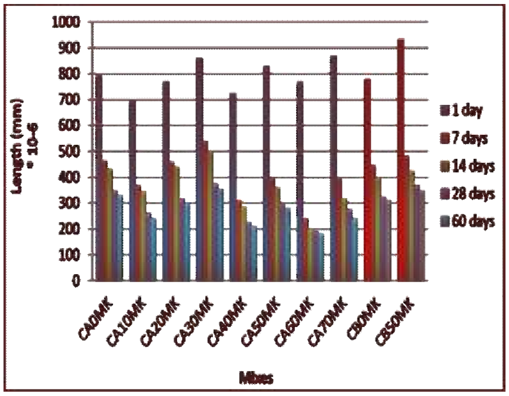


Figure. (7): Water absorption test results for all mixes at 28 days age

Figure. (8): Drying shrinkage of all mixes and Groups

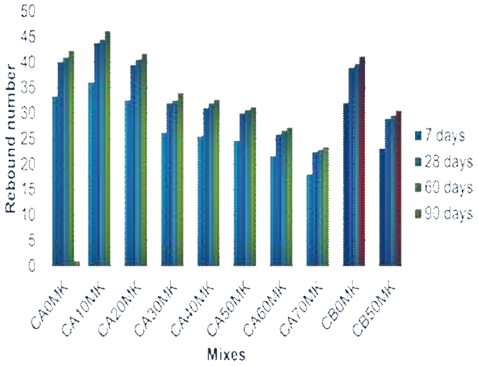


Figure. (9): Rebound number test results for all mixes and Groups

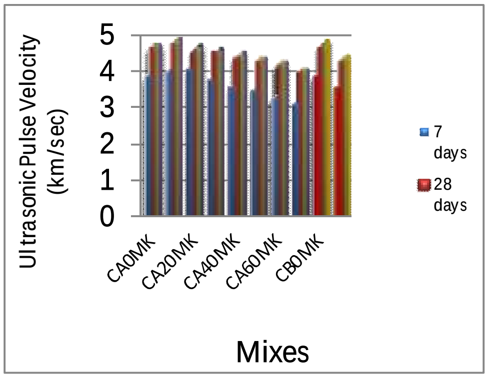


Figure. (10): ultrasonic pulse velocity test of all mixes and Groups