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Properties of Green Concrete Mixes Containing Metakaolin, Micro Silica, Steel Slag, and Recycled Mosaic Tiles

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A B S T R A C T

Recently, the constructions industry begins to make concrete more sustainable, side by side, with making its high performance. This paper aims to investigate the effect of (Metakaolin and Micro Silica) when they replace cement by (8, 12 and 16) % and (6, 9 and 12) % respectively, recycled steel slag when replaces fine aggregate by (10, 20 and 30) %, and recycled mosaic tiles when replaces coarse aggregate by (33.33, 66.67 and 100) % each one another on the slump, density, absorption and compressive strength of concrete. The experimental results showed that the maximum reduction ratio of cement reach (17%) (8% of metakaolin and 9% Micro Silica) while the optimum percentage of mosaic tiles and steel slag is (100%) and (20%) respectively. The optimum percentages obtained are combining to produce three basic green mixes: 1) 17% (8% of Metakaolin and 9% of Micro Silica) only, (2) A mix containing 17% of (Metakaolin and of Micro Silica) plus 100% of recycled mosaic, (3) 17% of (Metakaolin and Micro Silica), 100% of recycled mosaic and 20% of slag. Compressive strength at (7, 28, and 60) days, modulus of rupture at (28) days, absorption, fresh and hardened density are investigated. The best improvement in compressive strength compared with reference concrete was recorded (20.06, 10.855 and 9.983) % at (7, 28 and 60) days respectively for the mix containing (17% of cementitious materials plus 100% of recycled mosaic) while the ultimate flexure strength (24) % appeared in green mix containing (17% of cementitious materials, 100% of recycled mosaic and 20% of slag). Generally, an inverse relationship between density and absorption in all trail mixes which are conducted.

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خصائص الخلطات الخرسانية الخضراء الحاوية على الميتاكاؤولين، المايكروسيليكا، خبث الحديد وبلاط الموزاييك معاد التدوير

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الخلاصة

في الآونة الأخيرة، بدأت الصناعات الانشائية بجعل الخرسانة اكثر استدامة، جنباً الى جنب، مع جعلها عالية الأداء. تهدف هذه الورقة البحثية الى دراسة تأثير كل من (الميتاكاؤولين والمايكروسيليكا) عندما يحلان كبديل عن السمنت بنسب (8، 12 و 16) % و(6، 9 و12) % على التوالي، خبث الحديد عندما يحل بديلاً عن الركام الناعم بنسب (10، 20 و30) % وكاشي الموزاييك معاد التدوير عندما يحل محل الركام الخشن بنسب (33.33، 66.67 و100) (%) كل استبدال على حدى على كل من الهطول، الكثافات المتصلبة، الامتصاص الكلي ومقاومة انضغاط الخرسانة بعمر(7 و28) يوم. أظهرت النتائج ان اقصى نسبة

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تخفيض للسمنت وصلت (١٧) % (٨% من الميتاكاؤولين و ٩% من المايكروسيليكا) بينما النسبة المثلى لبلاط الموزاييك المعاد تدويره وخبث الحديد بلغت (١٠٠) % و(٢٠) % على التوالي. تم خلط النسب المُثلى المُستحصلة لإنتاج ثلاث خلطات خضراء رئيسية: ١) (١٧) % من المواد السمنتية البوزولانية (٨ % من الميتاكاؤولين و ٩ % من المايكروسيليكا)، (٢) خلطة تحتوي على (١٧) % من المواد السمنتية البوزولانية (٨ % من الميتاكاؤولين و ٩ % من المايكروسيليكا) و(١٠٠) % من بلاط الموزاييك، (٣) خلطة تحتوي على (١٧) % من (الميتاكاؤولين والمايكروسيليكا)، (١٠٠) % من الموزاييك المُعاد تدويره و(٢٠) % من الخبث. تم دراسة كل من مقاومة الإنضغاط بأعمار (7، 28 و60) يوم، معامل الكسر بعمر (28) يوم، الامتصاص الكلي، الكثافة الطرية والمتصلبة. افضل تحسن بمقاومة الإنضغاط بلغ (20.06، 10.855 و9.983) % للأعمار (7، 28 و60) يوم على التوالي مقارنةً بالخرسانة المرجعية للخلطة المحتوية على (١٧) % من المواد السمنتية البوزولانية (الميتاكاؤولين والمايكروسيليكا) و (١٠٠) % من الموزاييك المُعاد تدويره ، بينما اقصى مقاومة انثناء (24) % (اعلى من تلك للخرسانة التقليدية) ظهرت في الخلطة الخضراء المحتوية على (١٧) % من المواد السمنتية البوزولانية و (١٠٠) % من الموزاييك المُعاد تدويره إضافةً الى (٢٠) % من الخبث. بصورة عامة، هناك علاقة عكسية بين الامتصاص والكثافة لكل الخلطات التجريبية التي أجريت.

الكلمات الدالة: المواد البوزولانية، االخرسانة الخضراء، خرسانة الركام معاد التدوير، خبث الحديد، الميتاكاؤلين، السليكا المايكروية.

1. INTRODUCTION

The concrete which uses (at least one of its components) a waste material, or it has been produced without any negative impact on the environment, or it has a sustainable life cycle, and high performance can define as green concrete [1]. Green concrete has several forms, including high-performance concrete, high-volume fly ash concrete, geopolymer concrete, and some lightweight concrete [2]. Supplementary cementitious materials (SCM) are the materials which have a chemical composition similar to that for Portland cement with different oxides percentages, for this reason, it is used as a substitution material for cement in green concrete and high-performance concrete. Since 1990, metakaolin (MK) proved that it was an active pozzolanic material when it was utilized in concrete. Metakaolin can be prepared by calcining pure kaolin with a high heating degree ranged between (700-900) ºC where pure kaolin loss about 14% from its hydroxyl water and became MK [3]. Throughout the hydration process, C_3S and C_2S react with water and produced 75% calcium silicates hydrate (C-S-H) and 25% calcium hydroxide ($Ca(OH)_2$) as final structure. The surplus calcium hydroxide reacts with Silica and Alumina which exist in pozzolanic material and thus producing addition CSH and C_2ASH_8, making the concrete more performance. Replacing natural aggregate (fine and coarse) by debris and industrial wastes also produced green mixes. Two billion tons/year of aggregate are needed and the quantity expected to be raised in the USA. For this challenge, it was necessary to conserve our natural aggregate resource. Hence, the use of natural aggregate has imposed taxes in many countries in Europe [4]. The amount of debris per year in all governorates of Iraq was estimated at 1,111,788 tons/year in 2005 [5-7]. According to the Ministry of Planning documents accompanying UN-habitat, there are about (10,793,121) tons of demolition wastes in AL-Mosul city located in various percentages and concentrated in the right bank of Tigris river district [8]. On the other hand, steel slag was subsisted as a by-product form from the accompanying impurities, which was floated as a liquid over iron or steel crude liquid in different melting furnaces. Al-Basra steel factory throws slag with an estimated reach of 60 million tons/year. At a rate (10- 15%) of the steel product, the slag was insulated and removed from the furnace [9-12]. Previous investigations showed that the optimum percentages of MK and silica fume in concrete were ranged between (9-10) percent [13-16]. According to Qasrawi et al. [17] investigation, the optimum replacement level of steel slag was ranged (15-30) % from the mass of fine aggregate. Many researchers study different types of demolition wastes in concrete (such as recycled concrete, ceramic, bricks, etc.), and that is not enough to cover all available debris. The main scope of the current paper is reducing cement's content and use one or more residues as aggregate alternatives in the same concrete mix and investigating these materials effects on some concrete's mechanical properties.

2. EXPERIMENTAL PROGRAM

2.1. Materials

2.1.1. Cement

Ordinary Portland cement (type I) which is known commercially as (ALMAS) was used in this study. The chemical composition and physical properties show that this type of cement conforms to the requirements of Iraqi Specification No. (5)-1984. These properties are illustrated in the Tables (1 and 2), respectively.

2.1.2. Aggregate

2.1.2.1. Natural Coarse Aggregate

Well-rounded natural gravel with nominal maximum size (5-14) mm from Tikrit city was used in this study. Sieve analysis and other properties are conformed Iraqi specification No.45/1984 and illustrated in Tables (3and 4), respectively.

2.1.2.2. Natural Fine Aggregate

In all concrete mixes, river sand from Al-Zawiya area at the north of Tikrit in Salah Uddin Government was used. Sieve analysis, specific gravity, absorption, and SO_3 content are conformed to Iraqi specification No.45/1984 and illustrated in Tables (5-6), respectively.

2.1.3. Recycled Aggregate

2.1.3.1. Recycled Mosaic Tiles Coarse Aggregate

Recycled mosaic tiles aggregate was obtained by crashing the tiles manually and recombining to obtain particles with a size similar to that for natural coarse aggregates by using sieve shaker. The crushed fractions were washed and immersed in tap water for 24 hours, then exposed to laboratory air for an hour and then kept in plastic bags to preserve the moisture content of the aggregate. Sieve analysis, physical and chemical properties of recycled mosaic coarse aggregate are conformed to the Iraqi specifications N0. 45-1984 and illustrated in Tables (7- 8), respectively. Plate 1 describes this recycled aggregate.

Table. 1.

Chemical Composition of Cement

Oxide Composition	Content (%)	Limit of Iraqi specification No.5/1984 [16]
CaO	57.65	-
Al2O3	4.4	-
SiO2	18.05	-
Fe2O3	4	-
MgO	3.8	5% (max.)
SO3	2.1	2.5% (max.)
Loss on Ignition, (L.O.I)	1.28	4% (max.)
Insoluble material	0.89	1.5% (max.)
Lime Saturation Factor, (L.S.F)	0.96	(0.66-1.02)
Main compounds		% by weight of Cement
C3S		56.183
C2S		9.442
C3A		4.9
C4AF		12.16

Table. 2.

Physical Properties of Cement.

Physical Properties	Test Results	Limit of Iraqi specification No. 5/1984 [18]
The initial setting, (hrs: min)	1:56	Not less than 45 min
The final setting, (hrs: min)	7:10	Not more than 10 hrs
Compressive strength (MPa) For 3 days	27.6	15 MPa lower limit
Compressive strength (MPa) For 7 days	36.15	23 MPa lower limit
Specific surface area (m^2/kg)	297	230 (Min.)

Table. 3.

Sieve Analysis of Natural coarse aggregate

Sieve size (mm)	Passing %	Limit of Iraqi specification No.45/1984 [19]
20	100	100
14	100	90-100
10	70.175	50-85
5	0.2	0-10
2.36	-	-

Table. 4.

Physical and Chemical Properties of Natural Coarse aggregate

Properties	**Specifications**	**Tests Results**	**Limits of (IQS No.45/1984)** [17]
Specific gravity (SSD)	(IQS No.31/1981) [20]	2.592	-
Absorption (%)	(IQS No.31/1981) [20]	0.45	-
Sulfate content (SO_3) (%)	(RGD No.500/1994) [21]	0.015	0.1 (Max.)

*SSD: saturated surface dry

Table .5.

Sieve Analysis of Fine aggregate

Sieve size (mm)	**Passing %**	**Limit of Iraqi specification No.45/1984 Zone(II)** [19]
10	100	100
4.75 mm (No. 4)	100	90 - 100
2.36 mm (No. 8)	81	75 - 100
1.18 mm (No. 16)	67.6	55 - 90
600 µm (No. 30)	54.8	35 - 59
300 µm (No. 50)	24.7	8 - 30
150 µm (No. 100)	4.7	0 - 10

Table. 6.

Physical and Chemical Properties of Fine Aggregate.

Properties	Specifications	Tests Results	Limits of (IQS No.45/1984) [19]
Specific gravity (SSD)	(IQS No.31/1981) [20]	2.67	-
Absorption (%)	(IQS No.31/1981) [208]	1	-
Sulfate content (as SO_3) (%)	(RGD No.500/1994) [21]	0.13	0.5 (Max.)
Properties	Specifications	Tests Results	Limits of (IQS No.45/1984) [19]

2.1.3.2. Electrical Arc Furnace Slag or Steel Slag (EAFS)

This waste was brought from (ALMAS) steel factory in Bazian district/Al-Sulaymaniyah province. Sieve analysis, chemical composition and physical properties are illustrated in Tables.9, 10 and 11. Plate.2 describes Steel Slag.

2.1.4.2. Metakaolin (MK)

A pozzolanic material was produced by the calcination process for pure kaolin clay at a temperature 700˚C. This fine admixture was exported from China. Tables (14- 15) illustrate the chemical composition and physical properties of Metakaolin which conformed to ASTM C 618-12a specification. Plate 4 shows the used Metakaolin powder.

Plate 1. Recycled Mosaic Tiles.

Table .7.

Sieve Analysis of Recycled Mosaic Tiles coarse aggregate

Sieve size (mm)	Passing %	Limit of Iraqi specification No.45/1984 [19]
20	100	100
14	100	90-100
10	57.25	50-85
5	0.85	0-10
2.36	-	-

Table. 8.

Physical and Chemical Properties of Recycled Mosaic Coarse Aggregate

Properties	Specifications	Tests Results	Limits of (IQS No.45/1984) [19]
Specific gravity (SSD)	(IQS No.31/1981) [20]	2.524	-
Absorption (%)	(IQS No.31/1981) [20]	4.877	-
Sulfate content (as SO_3) (%)	(RGD No.500/1994) [21]	0.03	0.1 (max.)

Table. 9.

Sieve Analysis of Steel Slag (EAFS)

Sieve size (mm)	Passing %	Limit of Iraqi specification No.45/1984 Zone(II) [17]
10	100	100
4.75 mm (No. 4)	100	90 - 100
2.36 mm (No. 8)	80.1	75 - 100
1.18 mm (No. 16)	66.04	55 - 90
600 µm (No. 30)	52.64	35 - 59
300 µm (No. 50)	21.14	8 - 30
150 µm (No. 100)	0.14	0 - 10

Table .10.

Chemical Composition of Steel Slag (EAFS).

Composition	Content (%)
CaO	29.05
Al2O3	9.41
SiO2	21.91
Fe2O3	4.28
MgO	4.01

Table. 11.

Physical Properties of EAFS

Property	Specification	Value
Color	-	Dark grey
Absorption (%)	(IQS No.31/1981) [20]	0.8
Specific gravity (SSD)	(IQS No.31/1981) [20]	3.7

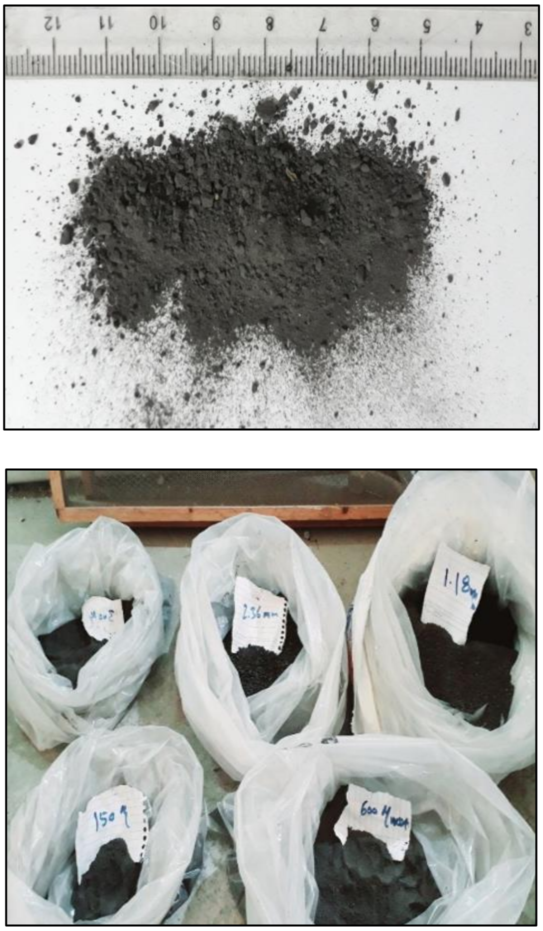


Plate.2. Recycled steel slag

Table .12.

Chemical Composition of Micro Silica Table 1

Oxide Composition	Content (%)	Limit of ASTM C 1240-3a specification [22]
CaO	2.61	-
Al2O3	4.02	-
SiO2	91.7	85% (min.)
Fe2O3	0.31	-
MgO	0.097	-
SO3	0.74	-
Loss on Ignition, (L.O.I)	3.21	6% (max.)
Activity index % (7days)	122.3	105% (min.)

Table. 13.

Physical Properties of Micro Silica.

Property	Test method	Value
State	amorphous	Sub-micron powder
Color	-	Grey to medium grey powder
Specific Gravity	-	2.1 to 2.4
Specify Surface Area (m2/kg)	-	15000
Bulk Density	-	500 to 700 kg/m3

Plate 3. Micro Silica (MS)

Table 14.

Metakaolin Chemical Composition

Oxide composition	Content (%)	Limit of ASTM C 618-12a specification [23]
CaO	0.26	-
Al2O3	33.27	-
SiO2	44.73	-
Fe2O3	1.18	-
Al2O3+SiO2+Fe2O3	79.18	70% (min.)
MgO	1.14	-
SO3	2.36	4% (max.)
Loss on Ignition, (L.O.I)	4.9	10% (max.)
Insoluble material	1.21	-

Table 15.

Physical Properties of Metakaolin

Property	Value	Limit of ASTM C 618-12a specification [21]
state	powdered	-
color	White to Cream	-
Specific Gravity	2.5	-
Blaine fineness, (m2/kg)	560	-
Activity index % (7 days)	90.6	75% (min.)
(28 days)	93.51	

Plate.4. Metakaolin Powder

2.1.5. Chemical Admixtures

2.1.5.1. High Range Water Reducing Admixture (HRWRA*)*

Mega flow 500 is a special carboxylic ether polymer with long lateral chains. It can be used in a concrete mixture containing Granulator Ground Blast Slag (GGBS), Micro Silica, Fly ash, Metakaolin, etc. this admixture was conformed with ASTM C494 [24].

2.2. Mixtures details

With constant w/c ratio (0.505) and without any Superplasticizers addition, Metakaolin (MK) with three ratio (8, 12 and 16) %, Micro Silica (MS) with (6, 9 and 12) %, incorporate Metakaolin-Micro Silica, fine Steel Slag aggregate with (10, 20 and 30) %, and coarse Recycled Mosaic with (33.33, 66.67 and 100) % have replaced the main components of concrete each one another. Then three green mixtures (with a different dosage of superplasticizers to improve workability for each mixture) are produced: (1) (MK8S9) only cement is replaced by 17 % (8% metakaolin and 9 % Micro Silica). (2) (MK8S9K10) a combination of cementitious materials (8% metakaolin and 9 % Micro Silica) and 100% recycled Mosaic tiles. (3) (MK8S9K10SL2) a combination of cementitious materials (8% metakaolin and 9 % Micro Silica), 100 % of recycled Mosaic tiles, and 20 % of steel slag. Tables (16-17) show the first phase mixtures details and the final three green mixes. Fig.1 shows the mixes' symbols details.

2.3. Mixing Process

All trails were mixed by electrical mixer (0.07 m^3) capacity with rotation speed (23 cycles/min) and according to ASTM C192m-15 [25].

2.4. Concrete tests:

2.4.1. Slump Test (workability)

This test was carried out according to ASTM C143/C143M-15 [26] for all mixes to determine the fluidity of plastic concrete.

2.4.2. Fresh density

For reference and the final six mixes, fresh density was measured according to ASTM C138/ C138M-01a [27].

2.4.3. Compressive Strength

An average of three cubes (150) mm was used to determine the compressive strength of concrete according to (BS 1881: part 116, 1983) [28].

2.4.4. Air Dry and Oven-Dried Density

The average of three cylinders (100 ×200) mm was tested to check densities and absorption according to (BS1881: part144, 1983 for density and ASTM C642-03a (2003) for total absorption) [29][30] at 28 days in the whole study.

2.4.5. Modulus of Rupture (fr)

For evaluating modulus of rupture of concrete, prism (100×100×500) mm with Third-Point Loading was used according to ASTM C78/C78m-15a [31].

Table. 16.
First-Phase Mixes Details

Mix	Water (kg)	Cement (kg)	MS (kg)	MK (kg)	Fine aggregate (kg)		Coarse aggregate (kg)	
					Sand	EAFS	Gravel	Mosaic
REF	176.6	378.22	0	0	804.7	0	910	0
MK1	176.6	347.96	0	30.26	804.7	0	910	0
MK2	176.6	332.83	0	45.39	804.7	0	910	0
MK3	176.6	317.705	0	60.515	804.7	0	910	0
MS1	176.6	355.53	22.69	0	804.7	0	910	0
MS2	176.6	344.18	34.04	0	804.7	0	910	0
MS3	176.6	332.83	45.39	0	804.7	0	910	0
MK1MS1	176.6	325.27	22.69	30.26	804.7	0	910	0
MK2MS1	176.6	310.14	22.69	45.39	804.7	0	910	0
MK3MS1	176.6	295.01	22.69	60.52	804.7	0	910	0
MK4MS1	176.6	298.79	22.69	56.74	804.7	0	910	0
MK1MS2	176.6	313.92	34.04	30.26	804.7	0	910	0
MK2MS2	176.6	298.8	34.04	45.38	804.7	0	910	0
MK3MS2	176.6	283.66	34.04	60.52	804.7	0	910	0
MK1MS3	176.6	302.576	45.39	30.26	804.7	0	910	0
MK2MS3	176.6	287.45	45.39	45.38	804.7	0	910	0
MK3MS3	176.6	272.32	45.39	60.51	804.7	0	910	0
K3	176.6	378.22	0	0	804.7	0	606.67	303.33
K6	176.6	378.22	0	0	804.7	0	303.33	606.67
K10	176.6	378.22	0	0	804.7	0	0	910
SL1	176.6	378.22	0	0	724.24	80.47	910	0
SL2	176.6	378.22	0	0	643.76	160.94	910	0
SL3	176.6	378.22	0	0	563.29	241.41	910	0

Ingredients for cubic meter

Table. 17.
Final Adopted Green Mixes Details

MK8S9K10SL2	MK8S9K10	MK8S9	REF	Mix	
176.6	176.6	176.6	176.6	Water (kg)	
313.92	313.92	313.92	378.22	Cement (kg)	
34.04	34.04	34.04	0	Micro Silica (kg)	
30.26	30.26	30.26	0	Metakaolin (kg)	
3.67	3.56	1.78	0	HRWRA (kg)	
643.7	804.7	804.7	804.7	Sand (kg)	Fine aggregate
160.9	0	0	0	Steel Slag (kg)	
0	0	910	910	Gravel (kg)	Coarse aggregate (kg)
910	910	0	0	Recycled Mosaic (kg)	

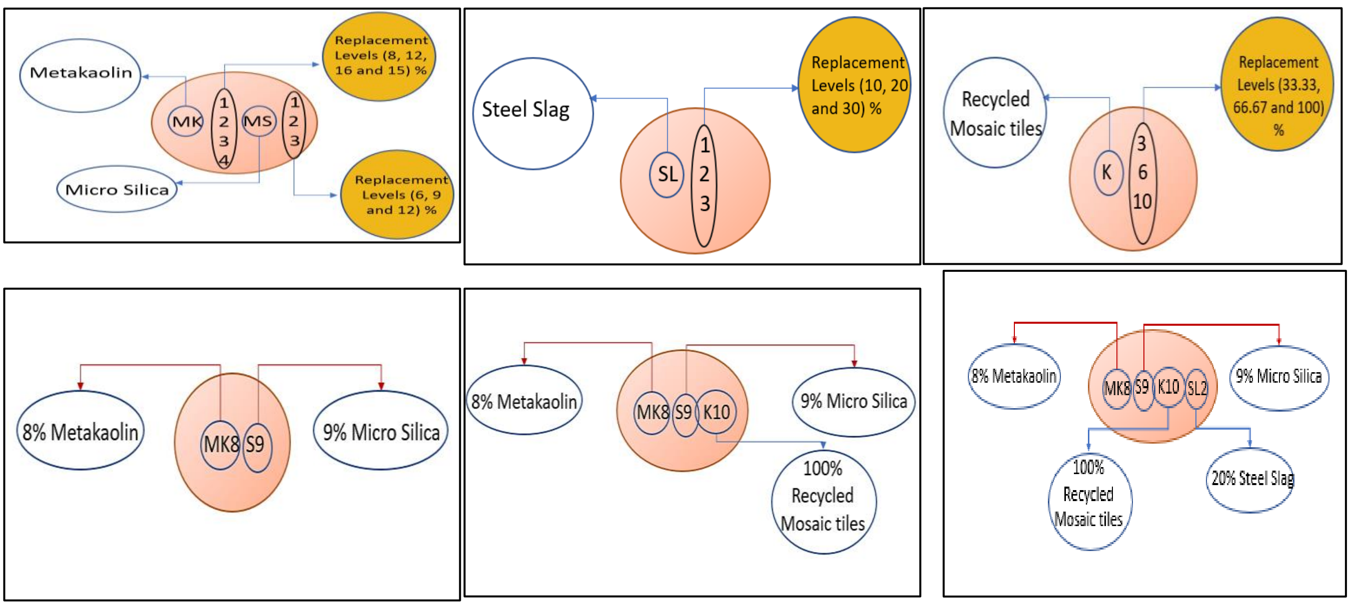
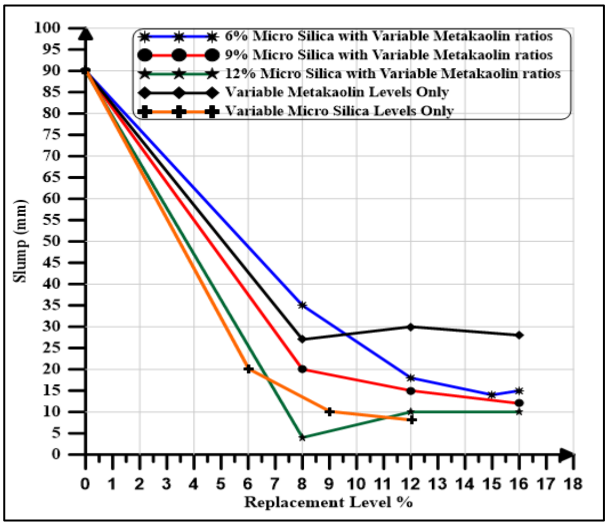


Fig.1. Mixes Symbols Details

3. RESULTS AND DISCUSSION

3.1. Slump Test

Generally, all trails indicate a dropping in workability for different reasons due to the replaced material nature. It is observed that when Metakaolin (MK) replaces cement partially, slump is decreased by (70, 66.7, 68.9) % for (8, 12 and 16) % respectively. Also, when Micro Silica (MS) replaces cement partially at a rate (6, 9 and 12) %, the workability reduces by (77.78, 88.9 and 91.1) % respectively. The combination between (12) % of Micro Silica and (8) % of Metakaolin record the ultimate reduction in slump (95.6) %. This decrease in workability is due to the ultra-fine of Micro Silica and Metakaolin grains which fill the voids in cement paste and thus concrete becomes more cohesive and difficult to finish. Also, Micro Silica (MS) and MK have spherical particles that are working as ball-bearing when concrete supplied by pumping or impact by vibration [1]. For Recycled Mosaic tiles, the slump is dropped by (50 and 72.2) % at replacement levels (66.67 and 100) % while replaced 33.33% of natural coarse aggregate by Mosaic does not affect workability. This reduction is caused by many factors such as moisture content of aggregate, shape, texture, particle size and absorption of recycled aggregate [32]. Also, Steel Slag decreases slump by (3.33, 16.67 and 27.8) % when it is replaced sand partially by (10, 20 and 30) % and this reduction is due to the angularity shape of slag particles which is tie up the fluidity of fresh concrete and this conforms with [16] investigation. Fig.2 shows slump test results.



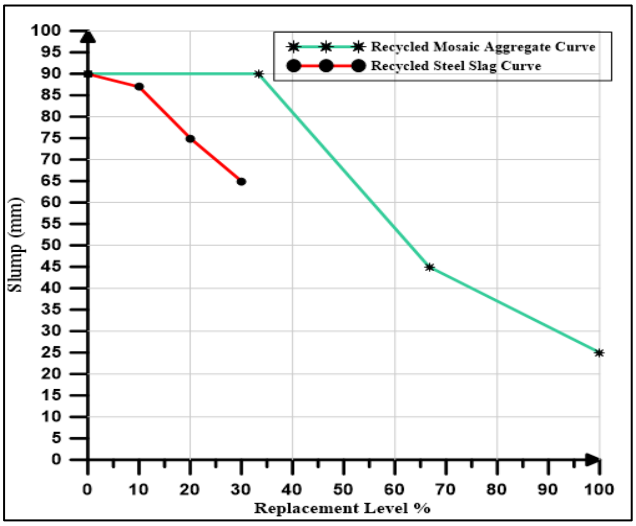


Fig.2. Slump Test Results.

3.2. Air dry, Oven-dried Density and Absorption

Results show that as Metakaolin demand increases, air and oven-dried density decrease. On the other hand, absorption increase as the metakaolin replacement level increases up to (16) % which represents the maximum increase in absorption. For Micro silica, opposite variation occurs whereas the enhancement in replacement percentage increases air and oven-dried density and decreases total absorption at 28 days. The combination between Metakaolin and Micro Silica also affects air and oven-dried density by increasing it as Micro Silica demand increasing with constant metakaolin replacement level and so that for absorption which decreasing as a result to densities variations. The maximum enhancement recorded was at (16) % of MK and (12) % of Micro Silica. This variation in densities and absorption is caused by the hydration process and pozzolanic reactivity whereas the increase in the interaction between Ca $(OH)_2$ produced form hydration with Silica and Alumina caused voids less than plain concrete and the finer grains of these Pozzolanic materials which makes concrete more cohesive when filling voids between cement particles. The substitution of Recycled Mosaic tiles (33.33, 66.67 and 100) % by natural coarse aggregate reduces density and absorption linearly by (1.667, 2.445 and 2.935) % for air-dry density, (0.102, 0.916 and 1.842) % for oven-dried density and for absorption by (85.33, 84.051 and 80.24) %. These results are formed due to the specific gravity of recycled Mosaic tiles particles (less than that for natural coarse aggregate) for density reduction while the absorption dropping is formed due to the reduction in voids between coarse aggregate particles which have small sizes (large quantity of the same sizes compared to those for natural gravel) work as filler occupy the voids and make concrete less permeable. Steel Slag also decreases absorption significantly and hence enhances density. The ratios (10, 20 and 30) % of steel slag by weight of sand affect the absorption, air dry density and oven-dried density by ((-76, -76.84 and -72.1) %, (1.185, 2.69 and -0.88) % and (2.622, 4.163 and 0.46) % respectively. The high specific gravity of slag rises the concrete density while the cementitious nature of steel slag and its fine particles drop absorption significantly. Density and absorption results are illustrated in figures (3-4), respectively.

3.3. Compressive Strength

Generally, the compressive strength results indicate a significant decrease as replacement levels of Metakaolin and Micro Silica increase. At 8% of Metakaolin, maximum compressive strength is recorded (12.121 and 2.56) % increasing at (7 and 28 days), respectively compared to control and this conforms with previous investigations whose found that the best replacement percentage of Metakaolin is ranged between (9-10) % [15-18]. While substitute Micro Silica by (12) % rise strength by (7.923 and 0.46)% at 7 and 28 days respectively but replaces cement by (9) % increases strength at 28 days by (1.355) % with a reduction reach (1.243) % at 7 days similar to some previous studies whose reported that the optimum ratio of Micro Silica ranges between (9 to 12) % [13, 33, 34]. The combination between Metakaolin and Micro Silica decreases compressive strength in most of the replacement percentages except mixtures containing (8 % Metakaolin and 9% Micro Silica), which is recorded an enhancement (0.291) % at 28 days and a reduction about (1.592) % at age 7 days. This dropping or rising may be attributed to the hydration process, which accelerated or decelerated, the pozzolanic reactivity (produce C-S-H more/less than plain mix) and physically when fine particles of Metakaolin and Micro Silica fill voids between cement particles causing concrete more performance than conventional. The replacement of natural gravel by (33.33, 66.67 and 100) % of recycled Mosaic tiles enhance compressive strength linearly by (10.13, 14.823 and 21.9) % and (10.133, 12.827 and 16.89) % at 7 and 28 days respectively. This increase may be due to the interlocking action which resulted from the angular shape of sharp particles or the strong bond between aggregate particles which content old cement mortar (white and ordinary cement under high pressure) and new mortar and thus, strengthen compressive strength of recycled aggregate concrete. A variation in strength (2.255, 7.698 and -15.06) % occurs when Steel Slag replaces sand partially by (10, 20, and 30) % at 7 days whilst compressive strength varies by (0.79, 4.421 and -8.654) % at 28 days. Consequently, (20) % of Steel Slag gives the best strength at 7 and 28 days, which exceeds reference concrete. This behavior of strength may be due to the angularity of steel slag particles compared to rounded natural sand particles and the low pozzolanic effect of steel slag which accelerates or decelerates the hydration process. Table.18 illustrates this phase results. Compressive strength results are shown in Fig.5. Plate.8 shows compressive strength failure.

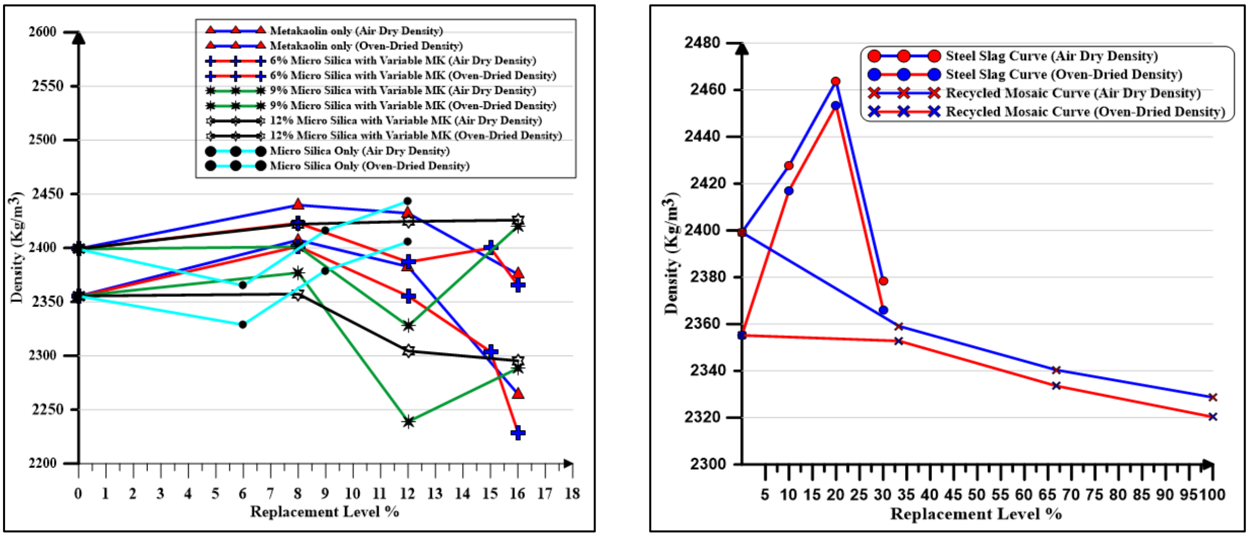


Fig.3. Density Results.

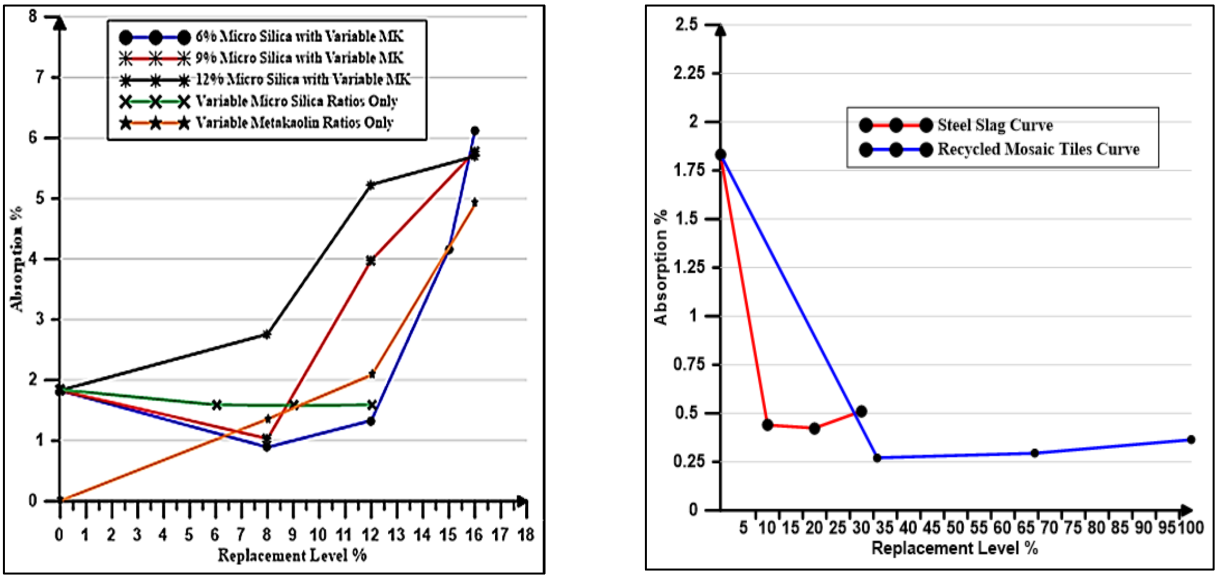


Fig.4. Absorption Results

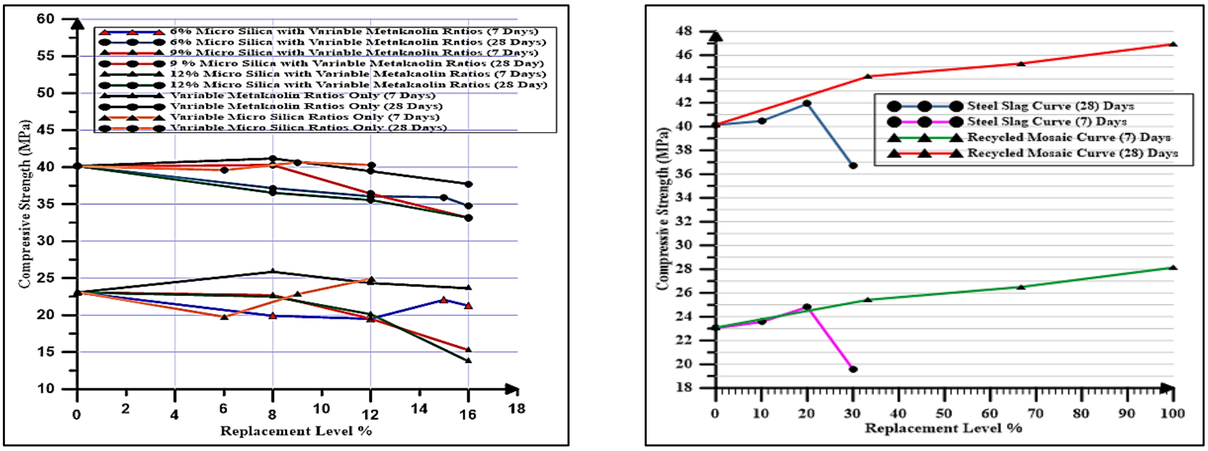


Fig. 5. Compressive Strength Test Results

Table 18.

Phase-One Results

Mix	Slump (mm)	Air dry density (kg/m^3)	Oven-dried density (kg/m^3)	Absorption %	Compressive Strength, (MPa)	
					7 Days	28 Days
REF	90	2399.21	2355.3	1.831	23.059	40.147
MK1	27	2439.8	2407.3	1.35	25.854	41.175
MK2	30	2432.2	2382.7	2.077	24.333	39.447
MK3	28	2375.6	2264.6	4.902	23.629	37.725
MS1	20	2365.53	2328.7	1.582	19.704	39.653
MS2	10	2416.3	2378.9	1.574	22.772	40.691
MS3	8	2443.6	2405.5	1.581	24.886	40.332
MK1MS1	35	2423.11	2401.6	0.892	19.898	37.155
MK2MS1	18	2387.06	2355.7	1.333	19.5	36.047
MK3MS1	15	2365.333	2229.14	6.11	21.26	34.75
MK4MS1	14	2400	2304.1	4.162	22.055	35.93
MK1MS2	20	2401.383	2376.8	1.035	22.692	40.264
MK2MS2	15	2327.8	2238.7	3.98	19.511	36.408
MK3MS2	12	2420.44	2288.3	5.775	15.259	33.143
MK1MS3	4	2422.12	2357.04	2.761	22.498	36.521
MK2MS3	10	2424.69	2304.2	5.23	20.104	35.547
MK3MS3	10	2425.88	2295.11	5.7	13.739	33.171
K3	90	2359.21	2352.89	0.27	25.395	44.215
K6	45	2340.54	2333.73	0.292	26.477	45.297
K10	25	2328.79	2320.4	0.362	28.108	46.928
SL1	87	2427.643	2417.03	0.44	23.579	40.464
SL2	75	2463.72	2453.32	0.424	24.834	41.922
SL3	65	2378.2	2366.1	0.511	19.587	36.675

Plate.5. Compressive Strength Failure

3.4. Green Concrete Mixes Properties

After studied the variation in some properties for each replaced material on concrete, three green concrete mixes will be produced, examined for some properties and compared with reference concrete. Table.19 illustrates these green mixes properties.

3.4.1. Fresh Density

A slight decrease in fresh density (0.933) % when cement replaces by (8) % Metakaolin and (9) % Micro Silica. It may be attributed to the low specific gravity of Micro Silica and Metakaolin compared to cement's specific gravity. Green concrete contains Micro Silica, Metakaolin, and recycled Mosaic tiles had fresh density less than conventional by (6.268) %. The lower specific gravity of Mosaic tiles compared to that for natural coarse aggregate is the main reason for this dropping. The combination between Micro Silica, Metakaolin, recycled Mosaic tiles, and Steel Slag has a fresh density higher than conventional by (1.561) %. As evident, the replacement of natural sand by steel slag increases the fresh density. Fig.6 shows fresh density test results.

3.4.2 Air dry, Oven-dried density and Absorption

At 28 days, densities of green concrete containing (8% of Metakaolin and 9% of Micro Silica) are dropped by (2 and 0.847) % for air dry and oven-dried density respectively. Also, the total absorption reduces by (63.03) %. This may be attributed to the hydration process produces (C-S-H) less quantity compared to reference causing a decrease in density, but the reduction in absorption may be due to the ultra-fine particles that fill voids between cement particles. For (MK8S9K10) green mix, A reduction occurs in this new concrete's air dry and oven-dried density at 28 days by (6.819) % and (5.47) % respectively. Total absorption also decreases by (77.72) %. Although steel slag increases the density of concrete, when Metakaolin and Micro Silica replace cement, recycled Mosaic tiles replace natural coarse aggregate, air, and oven-dried density are decreased slightly by (1.346 and 0.039) % respectively. Also, total absorption is dropped significantly by (71.054) %. Figures (7-8-9) show air-dry, oven-dried density, and absorption results of the green mixtures.

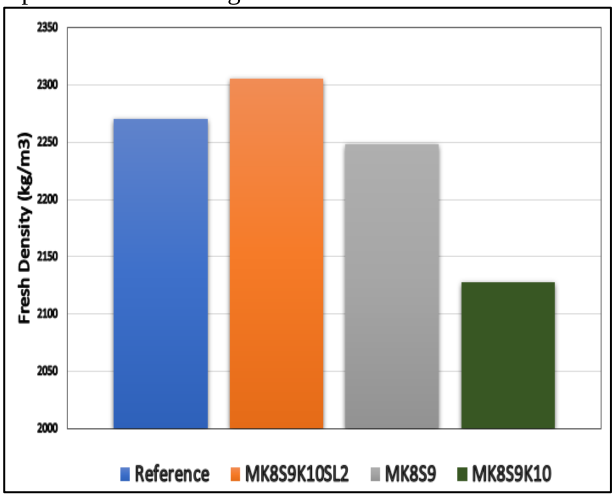


Fig. 6. Fresh Density Test Results.

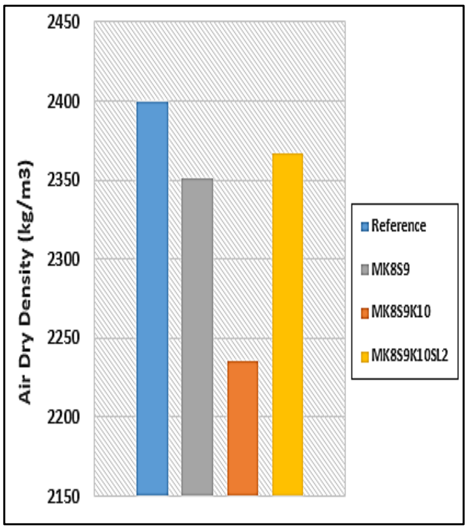


Fig. 7. Air-Dry Density Results

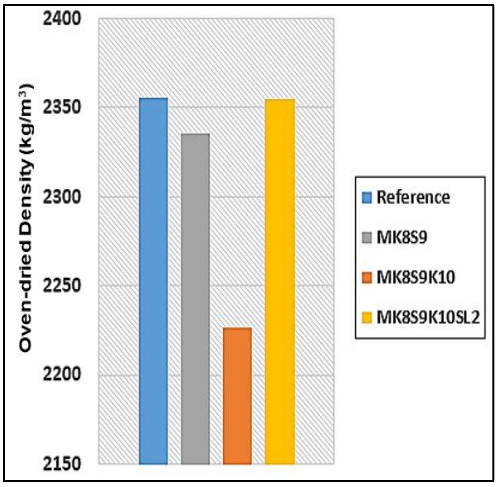


Fig. 8. Oven-dried Density Results.

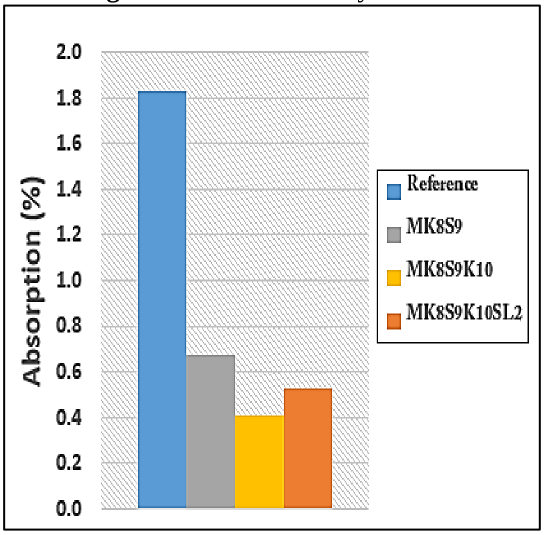


Fig. 9. Absorption Results

3.4.3. Compressive Strength (f_{cu})

The compressive strength decreases at 7 and 28 days by (1.995 and 0.115) %, respectively, while compressive strength at 60 days improves by (5.24) %. This compressive strength development indicates that the pozzolanic reactivity of Micro Silica increases as curing age increases and this may be attributed to the enhancement of Ca $(OH)_2$ as curing age enhances which is produced from the hydration process, the high Silica content in Micro Silica which is interacted with Ca $(OH)_2$ and thus produces additional (C-S-H) fill the voids in cement paste making the concrete more cohesive. At 7, 28, and 60 days, compressive strength increases by (20.06, 10.855, and 9.983) %, respectively. The combination of recycled Mosaic tiles and cement replaced materials increase compressive strength at all ages. The results causing this improvement may be attributed to the pozzolanic reactivity, micro particles which reducing the voids between cement's particles, strong old mortar, and angularity shape, which is caused by the interlocking of recycled Mosaic particles. When this incorporation assembles in the concrete mix, the compressive strength increases significantly by (12.511, 5.831, and 4.05) % at (7, 28, and 60) days, respectively. See Fig.10.

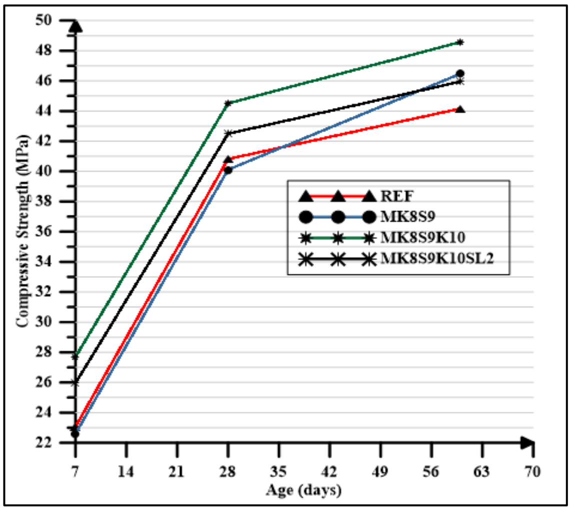


Fig. 10. Compressive Strength Results.

3.4.4 Modulus of Rupture (fr)

An enhancement (2.434) % in modulus of rupture at 28 days occurs when Micro Silica and Metakaolin replace cement this may be attributed to final hydration products, and it reacts with the silica and alumina in pozzolanic materials which produced less C-S-H causing voids more than reference and thus decreasing concrete's flexure strength. It is evident that the modulus of rupture of (MK8S9K10) also increases by (6) % more than conventional due to the interlocking between the recycled coarse aggregate particles as a result from angular particles shape and rough texture. As the compressive strength of the green mix (MK8S9K10SL2) improves, modulus of rupture also enhances by (24) % more than reference. Many reasons for this enhancement, such as recycled aggregate interlocking in addition to the effect of steel slag low pozzolanic reactivity (because of its low fines grains) results are shown in Fig.11.

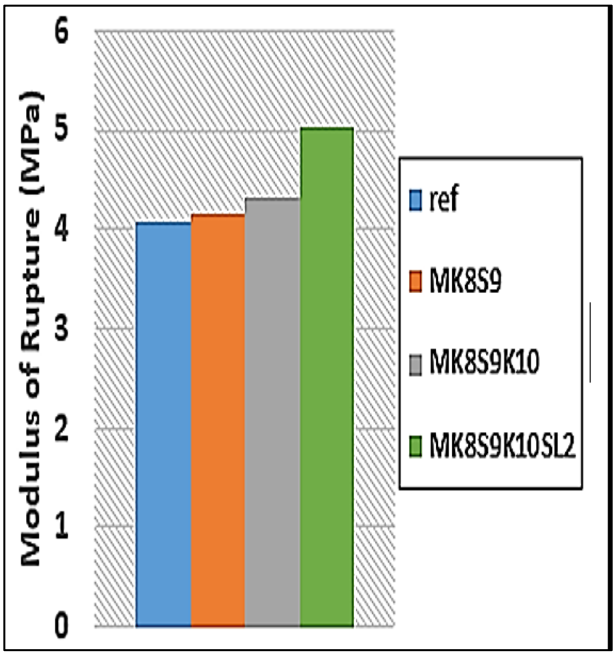


Fig. 11. Modulus of Rupture Results.

Table 19.

Green Mixtures Properties.

Test	Age	Reference	MK8S9	Difference From ref. (%)	MK8S9K10	Difference From ref. (%)	MK8S9K10SL2	Difference From ref. (%)
Fresh density (kg/m^3)	-	2270	2248.82	-0.933	2127.7	-6.268	2305.43	1.561
Air dry density (kg/m^3)	28	2399.208	2351.25	-2	2235.6	-6.819	2366.91	-1.346
Oven-dried density, (kg/m^3)	28	2355.281	2335.33	-0.847	2226.5	-5.47	2354.37	-0.039
Absorption (%)	28	1.831	0.677	-63.03	0.408	-77.72	0.53	-71.054
Compressive strength, (MPa)	7	23.06	22.6	-1.995	27.685	20.06	25.945	12.511
	28	40.147	40.101	-0.115	44.505	10.855	42.488	5.831
	60	44.157	46.472	5.24	48.565	9.983	45.945	4.05
Modulus of Rupture, (MPa)	28	4.068	4.167	2.434	4.312	6	5.044	24

4. CONCLUSION

A set of conclusions are observed depending on this experimental work:

1. When cement replaced by pozzolanic materials which have particles finer than its grains, slump is dropped significantly. The maximum reduction in slump reach (95.6) % when cement replaced partially by (8% MK and 12% MS) while the maximum is decreasing in slump reach (72.2 and 27.8) % for (100 and 30) % of recycled mosaic and steel slag respectively.

2. The use of fine slag increased density up to 4.163% for oven-dried density at 20% replacement level from the mass of sand while the use of recycled mosaic decreased the oven-dried density by (0.102, 0.916, and 1.842) % for (33.33, 66.67 and 100) % respectively. The maximum density which obtained when (8%) of cement mass replaced by MK was (1.692 and 2.21) % for air and oven-dried density respectively while the maximum reduction in absorption which recorded was (51.28) % when cement replaced partially by (14) % of MK (8%) and MS (6%) respectively. For recycled mosaic and steel slag, the maximum reduction in absorption reach (85.33 and 76.85) % compared with the reference. For the three green mixes which being produced, the maximum reduction in density (air and oven-dried density) and absorption was (6.819, 5.469 and 77.71) % respectively when concrete mix containing (8% of MK, 9% of MS and 100% of recycled mosaic).

3. It is reported that the use of 8% Metakaolin as cement's replaced material gives the maximum compressive strength (12.12 and 2.56) % higher than reference at 7 and 28 days, respectively. While the maximum replacement level which cement can replace without any losses in strength is 17% (8% Metakaolin and 9% Micro Silica). When recycled Mosaic tiles replaced by the natural coarse aggregate, the compressive strength increased linearly up to (100) % which gives an increment reach (16.89) % at 28 days. Also, replacing sand partially by steel slag increased the compressive strength at (10 and 20) % replacement ratios but decreased at (30) %. The ultimate enhancement in the compressive strength which obtained was (20.06, 10.855, and 9.983) % at (7, 28, and 60) days respectively, for the green mix containing (8% of MK, 9% of MS and 100% of recycled mosaic).

4. The increasing in modulus of rupture of final adopted green mixes at 28 days was (2.434, 6 and 24) % compared with plain concrete for green mixes containing ((8% Metakaolin and 9% Micro Silica) only, (8% Metakaolin (MK) and 9% Micro Silica (MS)) and (100) % recycled Mosaic tiles and (8% Metakaolin, 9% Micro Silica, 100% of recycled Mosaic tiles and 20% of Steel Slag)) respectively.

REFERENCES

[1] Obla KH. What is green concrete. *The Indian Concrete Journal* 2009). **24:** 26-28.

[2] Liew K, Sojobi A, Zhang L. Green concrete: Prospects and challenges. *Construction and Building Materials* 2017 **156**: 1063-1095.

[3] Hassan AA, Lachemi M, Hossain KM. Effect of metakaolin and silica fume on the durability of self-consolidating concrete. *Cement and Concrete Composites* 2012; **34** (6): 801-807.

[4] Malešev M, Radonjanin V, Marinković S. Recycled concrete as aggregate for structural concrete production. *Sustainability* 2010; **2**(5): 1204-1225.

[5] Abdul-Rahman MB, Ali AA, Younus AM. Effecting of Steel Fibers and Fly Ash on the Properties of Concrete. *Tikrit Journal of Engineering Sciences* 2018; **25**(4), 30-36.

[6] Abd.alrazaak TK. Construction Wastes: problem and solution. *Conference Journal of the Department of Planning and technical pursuance-Iraqi Environment Ministry*. 2012; (In Arabic).

[7] Jumaa'h MM, Kamil B, Baghabra OS. Mechanical and Structural Properties of a Lightweight Concrete with Different Types of Recycling Coarse Aggregate. *Tikrit Journal of Engineering Sciences* 2019; **26** (1): 33-40.

[8] Noaman AS. Utilization of Construction Waste in Reconstruction of War-Destroyed Projects. MSc thesis, University of Baghdad, Iraq: 2019.

[9] Al-Amoudi O, Rasheeduzzafar MM, Abduljauwad S. Influence of chloride ions on sulphate deterioration in plain and blended cements. *Magazine of Concrete Research* 1994; **46** (167): 113-123.

[10] Al-Gahtani AS, Rasheeduzzafar, Al-Saadoun SS (1994.). Rebar Corrosion of Slag Furnace Cement. *Journal of Materials in Civil Engineering Structures* 1994; **6**(2): 223-239.

[11] Alonso M, Sainz E, Lopez F, Medina J. Devitrification of granulated blast furnace slag and slag derived glass powders. *Journal of materials science letters*, 1994; **13**(22): 1602-1607.

[12] Yoda A. Properties of concrete using ground granulated blast-furnace slag as additive for concrete. Zairyo. *Journal of the Society of Materials Science*, Japan, 1994; **43** (491): 943-948.

[13] Shah Bhavanaben K, Gajjar M. (2011). Can Metakaoline Replace Silicafume. *National Conference on Recent Trends in Engineering and Technology*. .B.V.M. Engineering College, V. V. Nagar, Gujarat, India, 13-14 May.

[14] Poon CS, Kou S, Lam L. (2006). Compressive strength, chloride diffusivity and pore structure of high performance metakaolin and silica fume concrete. *Construction and Building Materials 2006;* **20** (10): 858-865.

[15] Poon CS, Lam L, Kou S, Wong YL, Wong R. Rate of Pozzolanic Reaction of Metakaolin in High-Performance Cement Pastes. *Cement and Concrete Research* 2001; **31** (9): 1301-1306.

[16] Qasrawi H, Shalabi F, Asi I. (2009). Use of low CaO unprocessed steel slag in concrete as fine aggregate. *Construction and Building Materials* 2009; **23** (2): 1118-1125.

[17] Iraqi Standard No. 5 for year of (1984) and Amendments No.1 and No.2 for year of (2010), "Portland Cement". Central Organization for Standardization and Quality Control, 8 pages, Baghdad.

[18] Iraqi Standard No. 30 for year of (1984), "Determination Size and Shape of Aggregate Particles". Central Organization for Standardization and Quality Control, l9 pages, Baghdad.

[19] Iraqi Standard No. 45 for year of (1984) and amendment No.2, "Natural Aggregate used for Concrete and Construction". Central Organization for Standardization and Quality Control, 4 pages, Baghdad.

[20] Iraqi Standard No. 3l for year of (1981), "Determination Density, Relative Density (Specific Gravity), Water Absorption, and Voids in Aggregate". Central Organization for Standardization and Quality Control, 8 pages, Baghdad.

[21] Iraqi Reference Guide Directory No.500 for year of (1994), "Sulfate Content Test of Aggregate". Central Organization for Standardization and Quality Control, Baghdad.

[22] ASTM C1240 - 03, (2004), "Standard Specification for Use of Silica Fume as a Mineral Admixture in Hydraulic-Cement Concrete, Mortar, and Grout". Annual Book of ASTM Standards, Vol.04.02, pp. l-6.

[23] ASTM C618 - 12a (2012), "Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete": American Society for Testing and Materials.

[24] ASTM C494, (2004), "Standard Specification for Chemical Admixtures for Concrete". Annual Book of ASTM Standards, Vol.04.02, pp.1-5.

[25] ASTM C192/C192M - 15 "Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory": American Society for Testing and Materials.

[26] ASTM C143/C143M-15 (2015), "Standard Test Method for Slump of hydraulic-Cement Concrete", American Society for Testing and Material International.

[27] ASTM C138 / C138M-17a, Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete, ASTM International, West Conshohocken, PA, 2017

[28] BS 1881: Part 116, (1983), "Method for Determination of Compressive Strength of Concrete Cubes". British Standards.

[29] BS 1881: Part 144, (1983), "Methods for Determination of density of hardened Concrete". British Standards. Incorporating amendents No.1 and No.2.

[30] ASTM C642 - 03a, "Standard Test Method for Density, Absorption, and Voids in Hardened Concrete", Annual Book of ASTM Standards, American Society for Testing and Materials, Vol. 04-02, 2003.

[31] ASTM C78/C78m-15a, (2002), "Standard Test Method for Flexural Strength of Concrete" American Society for Testing and Materials.

[32] Debieb F, Courard L, Kenai S, Degeimbre R. (2009). Roller compacted concrete with contaminated recycled aggregates. *Construction and Building Materials* 2009; **23** (11): 3382-3387.

[33] Ghutke VS. Bhandari PS. (2014). Influence of Silica Fume on Concrete. *International Conference on Advances in Engineering & Technology* 2014; (2320-334X), 44-47.

[34] Kumar R, Dhaka EJ. (2016). "Partial replacement of cement with silica fume and its effects on concrete properties. *International Journal for Technology Research in Engineering*. 2016; **4** (1): 86-88.