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PERFORMANCE OF TERNARY CEMENT MORTAR USING STEEL SLAG, FLY ASH, AND METAKAOLIN

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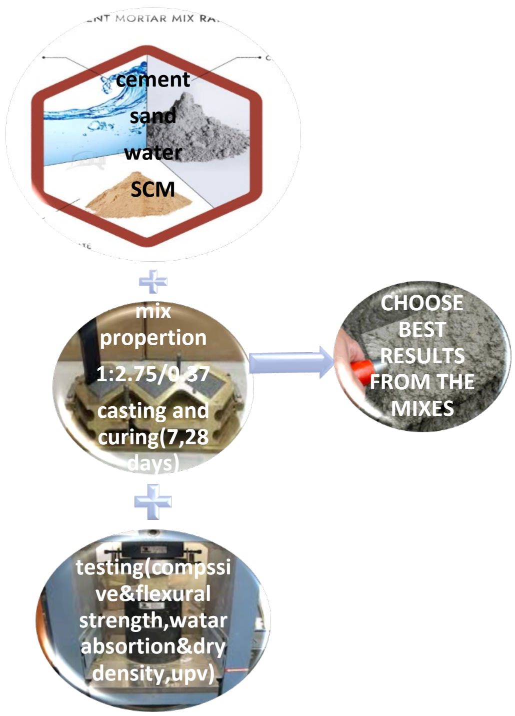
Graphical abstract



Abstract

Green mortar is a mortar that is environmentally friendly and that uses waste materials or by-products to reduce CO_2 emissions that are produced during cement production. This study aims to produce a new type of green mortar by using ternary cement mixes with acceptable fresh and hardened properties. The materials used were metakaolin (10-20%), slag (15-30%), and fly ash (10-20%). The experimental work was divided into two steps. Firstly, metakaolin was replaced with various percentages of 10%, 15%, and 20%, and then the optimum percentage having the highest compressive strength was chosen to use in ternary mixes. Secondly, cement was replaced with a ternary mix (slag, fly ash, and metakaolin) with a replacement ratio of 40% and 50%. Properties were studied flowability, compressive strength, flexural strength, water absorption, dry density, ultra-sonic plus velocity test, The results show that using metakaolin as a partial replacement for cement decreased flowability and increased superplasticizer dosage. From the results can conclude the use of ternary mixes decreased the workability of mixes and increased the dosage of superplasticizers to 1.8% at 50% replacement of cement. The results of compressive strength showed an increase of 50.6% after replacing 10% metakaolin at 7 days and 17.35% after replacing ternary mixes with 15% slag, 15% fly ash, and 10% metakaolin, while flexural strength increased by 26.47% after replacing the same percent of metakaolin and by 10.4% after replacing a ternary mix with the same percent of materials. The results show that using 10% metakaolin decreased water absorption by 28.75% while increasing slag increased water absorption in ternary mixes. The results for dry density slightly decreased or increased with the increased replacement of ternary cement mixes from 1.2% to 0.33% compared with the control mix. The UPV test result increased by 5.4% in ternary cement mixes, and when replacing metakaolin with 10% and 15%, it increased UPV by 5.7% and 5.2%, respectively, at 28 days.

Keywords: Green mortar, steel slag, fly ash, metakaolin, ternary cement mortar.

1.0 INTRODUCTION

Sustainable development has become increasingly common over the last few years. This has amorphous connotations, and many governments, companies, and establishments are adopting it as politics [1–3]. The notion of sustainability has been applied to describe a type of development, famous as sustainable development [4]. According to the World Committee on Climate and Development, sustainability is known as "sustainable development" that meets the needs of the present without compromising the ability of future descents to meet their own requirements [5].

The fast evolution of construction in the world requires the use of very good materials, especially concrete and mortar building materials. The continued and uncontrolled use of materials eventually leads to the depletion of pure material stocks such as aggregate and cement. Also Cement production accounts for 2.4% of total global CO_2 emissions from factories [6]. One of most problem activities stressed the engineers and scientists linked to concrete factory aims at a high percent replacement of clinker in cement with by-products raw materials, that possible of improvement of cement quality and durability of mortar [7].

Materials for cement replacement are widely available and can be used to replace Portland cement in the production of green mortar [6]. These materials are replacements for cement materials or pozzolans. Metakaolin (China clay), ceramic powder, brick powder, industrial wastes (i.e. fly ash, silica fume, blast furnace particles), [8]. Fly ash is a secondary material created by burning pulverized coal to create electricity. Fly ash particles usually have a spherical shape and their sizes range from 0.5 µm to 100 µm [9]. The properties of fly ash can change from power plant to power plant because of the differences in the sources of the used coal. There are two types of fly ash found in ASTM C 618. These are known as Class F and Class C. Class F is fly ash, which is normally produced from burning bituminous coal, while Class C is produced from the burning of subbituminous coal and lignite [10]. Slag (S) is a secondary material of the blast furnaces employed in the production of iron at a high temperature. The ore of iron is converted to iron, and the residue materials are slag that floats on the fused iron surface [11]. Slag is like in chemical composition to cement [12]. Therefore, using slag as a partial replacement for cement is a useful way to reuse slag, rather than weeding it out [13].

Metakaolin's main raw material input in the production of metakaolin is kaolin clay. Kaolin clay is a very fine, white clay mineral used in the manufacture of porcelain [14]. When use metakaolin as a partial replacement of cement in concrete or mortar, metakaolin reacts with calcium hydroxide $Ca(OH)_2$ it is one of secondary product result from hydration of cement and produce an additional C-S-H gel which increased strength of concrete or mortar [15,16].

The goals of this study are to produce a new type of green mortar by using by-product materials or waste materials locally available, like fly ash, slag, and metakaolin, as partial replacements for cement and to design suitable ternary mixes prepared by the optimum percentage of cementitious materials as partial replacements for cement that can be used for structural applications. Also, we studied the effects of various percent's of blended materials, ranging from 40 to 50% of fly ash, slag, and metakaolin, on cement mortar's fresh, physical, and mechanical properties.

2.0 MATERIALS AND EXPERIMENTAL WORK

2.1 Cement(C)

The cement obtained was ordinary Portland cement Type I from the Badoush Expansion Cement Factory in Mosul. The cement type satisfied the IQS: 5/1984 [17] specification guidelines. A chemical analysis of cement is shown in Table 1, while physical characteristics are shown in Table 2.

Table 1 The chemical composition of ordinary Portland cement

Constituents	Content percent(%)	Limits of IQS 5/1984
CaO	62.5	-
SiO_2	20.91	-
Al_2O_3	5.96	-
Mgo	3.8	≥5.0%
Fe_2O_3	2.53	-
SO_3	2.32	≥2.8%
L.O.I	1.45	≥4.0%
C_3S	39.5	-
C_2S	30.16	-
C_3A	11.5	-
C_4AF	7.7	-

Table 2 Physical characteristics of ordinary Portland cement

Test	Produced cement	Limits of IQS 5/1984
Initial setting time (min)	143	min 45
Final setting time [min]	175.5	max 600
Blain fineness [cm^2/g]	3100	more than 2300
Compressive strength [N/mm^2] 3 days 7 days	 31.64 39.3	 ≥16 ≥24

2.2 Fine Aggregate(SA)

The fine aggregate used in this study was natural river sand and was obtained from the Kanhash region in Mosul, Iraq. The used sand was passed through Sieve No. 4, the specific gravity was 2.66, the absorption was 1%, and the fineness modulus was 2.703. The sand grading analysis conforms to IQS 45/1984 [18].

2.3 Water(W)

In this research, it was done using tap water. The water used must be free from oil, acid, alkali, organics, and other matter that affects the mixes. In curing samples, use the same condition of mixing water.

2.4 Superplasticizer(SP)

Sika Company in Mosul supplied a high-range water reducer, viscocrete 5930, type F. The superplasticizer was used to obtain the desired flowability of the mixes. The chemical composition of the superplasticizer meets the requirements of ASTM C494 [19].

2.5 Steel Slag(S)

An iron ore factory waste byproduct is mixed at high temperatures and produced as a secondary product [20]. In this research, the slag used was rounded up from a steel factory in Zakho, Iraq. Slag was passed through sieve No. 325 (0.045µ) and used as a partial replacement of cement. The specific gravity of slag was 2.9 and the fineness was 550 kg/m^2. The strength activity index was measured according to ASTM C618 [21] and gave 80% at 28 days.

2.6 Fly Ash (FA)

In this research, we used fly ash type F, which has low calcium content. The fly ash passing through sieve No. 325 (0.045µ) is 85%. Chemical and physical properties meet the requirements of natural pozzolan type N according to the ASTM C618 standard [21]. The specific gravity of fly ash was 2.42 and the fineness was 495 kg/m^2. The strength activity index was measured according to ASTM C618 [21] and was at 84% after 28 days.

2.7 Metakaolin(M)

Natural white, fine kaolinite clay was obtained from a factory located in Bagdad. Metakaolin was used as a partial replacement for cement after passing through sieve No. 325 (0.045). The specific gravity of metakaolin was 2.52 and the fineness was 14.3 cm^2/gm. The strength activity index was measured according to ASTM C618 [21] and gave 86% at 28 days and 80% at 7 days.

2.8 Mix Proportion

The mixing steps were first blending cement, sand, and metakaolin only with three percent; 10%, 15%, and 20%; and then weighting cement and sand according to the mix proportion (1:2.75) and mixing it for three minutes to ensure homogeneity of the mix. After adding the amount of water and mixing, the superplasticizer was added to the remaining water and mixed for another 3 minutes. After completing the mixing, the flow was measured according to ASTM C-1437[22] to determine the workability of the mixes. Choose the optimum percentage of mixed metakaolin and blend it with slag and fly ash. Table 3 show the mix proportion for all mixes.

The second step was casting ternary cement mixes that have slag, fly ash, and metakaolin with cement replacements of 40% and 50%.

The fresh mix is then cast in molds that have dimensions for compressive strength at 7- and 28-days casting 6 cubes each have a size of 50*50*50 mm in two layers, compact each layer 36 strokes, and for flexural strength at 7 and 28 days, 3 prisms each have a size of 40*40*160 mm in two layers, compact each one 12 strokes. For water adsorption, ultrasonic pulse velocity and dry density were cast in three cubes of 70.7×70.7×70.7mm and tested after 28 days. The use of 0.37 of w/b ratio and SP (1.0-1.8) %by the weight of cement has been used for all mixes to maintain the workability by the range of 110 ±5 mm.

Mixes consist of control mix and M1, with a 10% replacement of cement by metakaolin only. Then, for each M2 and M3, repeat the mixes with metakaolin replacing 15% and 20% of the cement, respectively. Ternary mixes were cast with fly ash, slag, and metakaolin replacing 40-50% of the cement.M4 mix with 40% steel slag replacement, 10% fly ash, and 10% metakaolin. M5 mix with 40% steel slag, 15% fly ash, and 10% metakaolin replacement. M6 mixture with 40% steel slag, 10% fly ash, and 15% metakaolin. Mix with a 50% replacement of cement made of 20% steel slag, 15% fly ash, and 15% metakaolin. 50% replacement of cement by 25% steel slag, 15% fly ash, and 10% metakaolin. The specimens were demolded after 24hrs and put in a curing tank according to ASTM C192 tank have a temperature of 23±2 ^{o}c until the testing day.

Table 3 Mix proportion for the green mortar in kg/m^3

index	C	SA	W	FA	S	M	SP (%)
M0	500	1375	255	0	0	0	0
M1	450	1375	185	0	0	50	1
M2	425	1375	185	0	0	75	1.1
M3	400	1375	185	0	0	100	1.2
M4	300	1375	185	50	100	50	1.7
M5	300	1375	185	75	75	50	1.65
M6	300	1375	185	50	75	75	1.7
M7	250	1375	185	75	100	75	1.7
M8	250	1375	185	75	125	50	1.8
M9	250	1375	185	50	150	50	1.8

3.0 RESULTS AND DISCUSSION

3.1 Flowability

According to the ASTM C-1437 [22] test method, the flowability was measured in fresh mortar after complete mixing, and the flow was fixed at 110 mm. For this reason, we need to use high-range water reducers (superplasticizers) to solve the high-water demand problem in fresh mixes [23]. The effect of adding pozzolanic materials as partial replacement on flowability was noted when increasing replaced materials like slag or metakaolin; the flow decreased, so to achieve the flowability of the control mix 110±5mm, it was necessary to add superplasticizer to the mixes. Fly ash has little effect on flowability and enhances the workability of fresh mortar because of the spherical shape of its particles and its smooth surface [24, 25]. Wassem et.al.the same results was noted at the research on the behaiver of fly ash at workability as increse amount of fly ash workability enhanced[26] .Therefore, by adding 10% to 15% of fly ash at M4 and M5, the dosage of superplasticizer was fixed at 1.7%. The flow decreases with increased replacement of 40% and 50%. Therefore, by adding 10% to 15% of fly ash at M4 and M5, the dosage of superplasticizer was fixed at 1.7.Table 4 display flowability results.

Table 4 Flowability results

index	C(%)	S(%)	FA(%)	M(%)	w/b	Flow (mm)	SP(%)
M0	100	0	0	0	0.51	108	0
M1	90	0	0	10	0.37	113	1.0
M2	85	0	0	15	0.37	109	1.1
M3	80	0	0	20	0.37	112	1.2
M4	60	20	10	10	0.37	113	1.7
M5	60	15	15	10	0.37	106	1.65
M6	60	15	10	15	0.37	109	1.7
M7	50	20	15	15	0.37	114	1.7
M8	50	25	15	10	0.37	107	1.8
M9	50	30	10	10	0.37	111	1.8

The flowability of control mix M0 is achieved by adding only water, which has a water to binder ratio of 0.51. The other mixes, M1 to M8, have a reduced water to binder ratio of 0.37, and a dosage of superplasticizers is added to maintain the flowability of the mixes.

The flowability was decreased with increased slag and metakaolin percent’s due to the high fineness of pozzolanic materials adsorbing more water [26].

In M1, M2, M3 the superplasticizers dosage increases by 10% for each 5% of metakaolin this was happened due to the high surface area and small particle size of metakaolin this lead to increase water demand and absorb water [26]., also because of chemical activity was lead to more consumption of water [27]. The results was same of research that use metakaolin noted shawkat and dawood released increased in water demand led to decreased workability [28].

To achieve the desired workability in M4, M5, and M6, it contains 40% replacement of ternary cement mixes, so the superplasticizer dosage ranges from 1.65-1.7% by weight of cement.The flowability was greatly reduced in M7, M8, and M9 that contained 50% replacement of ternary cement mixes, so the superplasticizer dosage ranged from 1.7-1.8%. The high dosage of superplasticizer added is due to the fineness of pozzolanic materials being greater than cement fineness, which leads to adsorbing more water as Karakuzu et.al shows in the research [28].

The results show that as cement was replaced with pozzolanic materials (fly ash, slag, and metakaolin), the flowability of green mortar decreased.

3.2 Compressive Strength

The compressive strength of all ternary mixes and mixes containing metakaolin only was tested at 7, 28 days according to ASTM C109 [29], as shown in Table 5.

Table 5 Compressive strength results for ternary mortar at 7 and 28 days

mix	C(%)	S(%)	FA(%)	M(%)	C 7	C 28
M0	100	0	0	0	24.5	34
M1	90	0	0	10	36.9	40.45
M2	85	0	0	15	33.6	38.23
M3	80	0	0	20	30.1	35.6
M4	60	20	10	10	28.6	36.1
M5	60	15	15	10	27.7	39.9
M6	60	15	10	15	25.3	33.2
M7	50	20	15	15	26.3	32.7
M8	50	25	15	10	25.7	31.3
M9	50	30	10	10	23.6	28.23

The mix contains fly ash, slag, and metakaolin with cement replacements of 40% and 50%. All ternary mixes have a high dosage of superplasticizer to improve the workability of the mortar. Figure 1 show effect of metakaolin on strength.

The compression test indicates that the partial replacement of cement with metakaolin increased the compressive strength of green mortar that contains metakaolin. The development is higher than the reference mix. The compressive strength increased with increased replacement. The optimum percent of metakaolin was 10%. The results show that replacing 10% metakaolin increased strength by 50.6% at 7 days and 18.9% at 28 days, while replacing 15% metakaolin increased strength by 37% at 7 days and 12.4% at 28 days, and replacing 20% metakaolin increased strength by 22.8% at 7 days and 4.7% at 28 days, which is attributed to the filler effect and metakaolin's pozzolanic reaction with Ca(OH) to result in C-S-H [30]. The chemical composition of metakaolin and the high percentages of silicate (SiO_2) and alumina (Al_2O_3) react with calcium hydroxide to form calcium aluminate silicate hydrates (C-S-A-H). This product improves early strength [31].Some recent research also that using metakolain showed increased in compressive strength when used percent low than 15%[28].

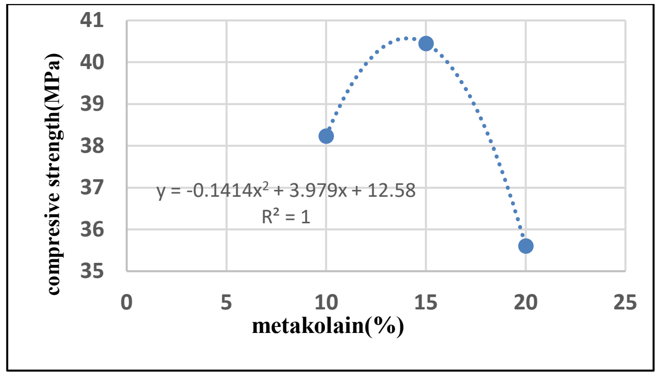


Figure 1 Relationship between Compressive Strength at 28 days with Percent replacement of Metakaolin (%) for all mixes

The compressive strength at 7 and 28 days for ternary mixes in M4, M5, M6, M7, and M8 increased by 16.7%, 13%, 7.34%, and 4.89% at 7 days, respectively, and mixes M4, M5 increased by 6.1% and 17.35%, respectively, at 28 days because of a chemical reaction between the SCM material and the spherical shape of fly ash particles. SIO_2 and Al_2O_3 in metakaolin and CaO in slag have a strong effect on strength [32].The compressive strength of M8 was reduced by 3.68% after 7 days and by 2.4%, 3.83%, 8%, and 17% in M6, M7, M8, and M9 after 28 days due to the high percentage of slag powder, which contains 30%, and slag gives strength at a later age as showed in other research also the effect of slag was noted at later age[13].

Relative (%) $=\frac{M*}{M0} \times 100$

Where:M*=compressive strength of any mix

M0=compressive strength of reference mix

The relationship between relative and compressive strength at 28 days for all mixes is shown in figure 2.

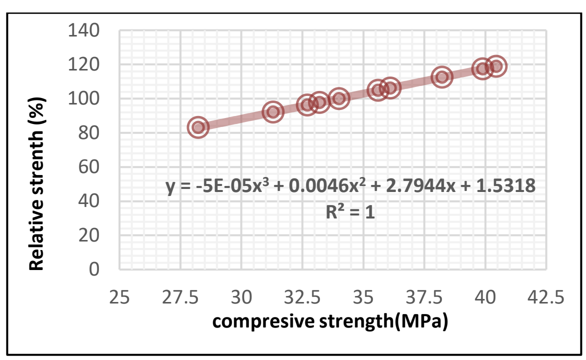


Figure 2 Relationship between compressive strength and relative compressive strength (%) at 28 days

3.3 Flexural Strength

Flexural strength was tested at 7,28 days for all ternary mixes and mixes containing metakaolin only as a partial replacement for cement, according to ASTM C348 [32]. Table 6 shows the flexural strength results for mixes.

Table 6 Flexural strength results for ternary mortar at 7 and 28 days

mix	C(%)	S (%)	FA (%)	M (%)	f7	f28
M0	100	0	0	0	6.8	8.15
M1	90	0	0	10	8.6	9.1
M2	85	0	0	15	8.15	8.7
M3	80	0	0	20	7.5	8.2
M4	60	20	10	10	7	8.6
M5	60	15	15	10	7.2	9
M6	60	15	10	15	7	8
M7	50	20	15	15	7.1	7.9
M8	50	25	15	10	7.1	7.7
M9	50	30	10	10	6.7	7.3

At 7 and 28 days, the flexural strength of all mixtures ranged between 6.9 and 9.1 MPa.

In M1, M2, and M3 that contain metakaolin only as a partial replacement of cement, the flexural strength increased by 26.47%, 19.85%, and 10.3%, respectively, at 7 days compared with the control mix, and increased by 11.65%, 6.74%, and 0.61% at 28 days compared with the control mix; the most development was noted at 10-15% by the weight of cement [33]. This increase in flexural strength is due to metakaolin particles filling the voids between cement particles, accelerating the hydration of cement and the pozzolanic reaction of metakaolin as noted in research and other reseach[35]. The poor performance was 20%, compared to 15% and 10%.

In M4,M5,M6,M7,M8 the flexural strength increased by ,2.9% ,5.8%,2.9% ,4.41%,4.41% respectively at 7 days and M4,M5 increased 5.5%,10.4% at 28 days the results was smaller to recent research that use pozzlanic materials as they found that the flexural strength increased for two reasons: the first was related to the fineness of the pozzolanic material because fine material fills the voids between the particles and improves the density of the mortar, so the strength increased [34], and the second was the reaction of the pozzolanic material with Ca(OH) free lubricate during cement hydration, which increased the strength of mixtures [35]. As a result, it can be noted that the improvement in flexural strength was less than the improvement in compressive strength.

The flexural strengths of M9 decreased by 1.5% at 7 days, and in M6, M7, M8, and M9, they increased by 2%, 3%, 5.5%, and 10.4%, respectively, at 28 days. The decreases in flexural strength resulting also noted in some research from the high replacement of cement were due to decreases in C_2S and C_3S in cement composition due to the effect of pozzolanic materials [40]. The relationship between compressive strength and flexural strength at 7 and 28 days is shown in Figures 3 and 4.

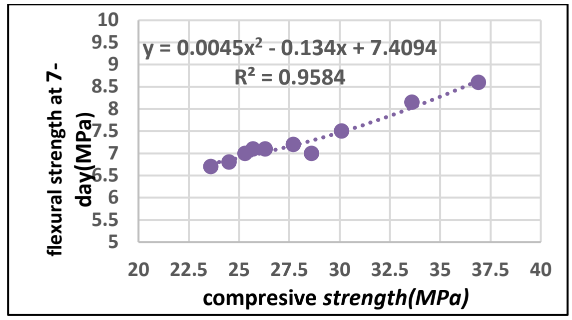


Figure 3 Relationship between compressive strength with flexural strength (MPa) at 7 days

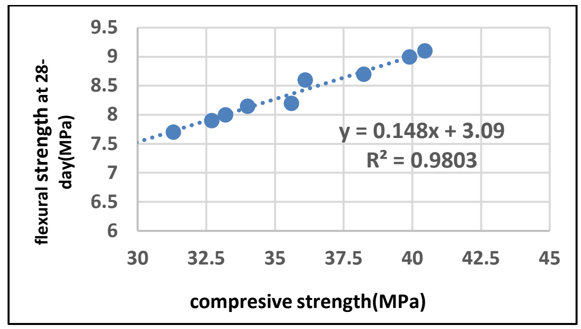


Figure 4 Relationship between compressive strength with flexural strength (MPa) at 28 days

3.4 Ultrasonic Pulse Velocity

According to ASTM C597 [37], the ultrasonic pulse velocity was tested for all mixes in green mortar at 28 days that contain metakaolin only and ternary mixes that contain metakaolin, slag, and fly ash as a partial replacement of cement. Table 7 shows the ultrasonic pulse velocity results for green mortar.

Table 7 Ultrasonic pulse velocity results in green mortar at 28 days

Mix	C (%)	S(%)	FA(%)	M(%)	UPV (m/sec)
M0	100	0	0	0	3850
M1	90	0	0	10	4050
M2	85	0	0	15	4070
M3	80	0	0	20	3895
M4	60	20	10	10	4000
M5	60	15	15	10	4060
M6	60	15	10	15	3840
M7	50	20	15	15	3840
M8	50	25	15	10	3760
M9	50	30	10	10	3670

As shown in Table 7, for the mixes M1, M2, and M3 that contain metakaolin only as a partial replacement of cement, the reading increased with increased metakaolin content: for 10%, the reading increased by 5.2%; for 15%, by 5.7%; and for 20%, by 1.1% compared with the control mix. This slightly increases in relation to the density of mortar and the transportation of UPV waves through the materials [38]. Some research also noted replacement of metakaolin resulted in fewer voids due to the fineness of the material and a more uniform structure [39], hence the UPV was increased. According to the results, the UPV reading increased by 3.8%, or 5.4%, in M4, which contains 20% slag, 10% fly ash, and 10% metakaolin, and in M5, which contains 15% slag, 15% fly ash, and the same metakaolin content, which increases fly ash content and decreases slag content, the UPV reading increased by 3.8%, or 5.4%. Dense media facilitate the transport of UPV waves [41]. In M6, M7, M8, and M9, the UPV reading decreased by 0.35%, 0.35%, 2.3%, and 4.67%, respectively, compared with the control mix. The reading was decreased with increased replacement of slag because it has a low activity index and increasing replacement ratios lead to less uniform structure and more porosity, so the UPV reading is decreased [38]. The regression analysis between compressive strength and ultrasonic pulse velocity tests is shown in figure 5.

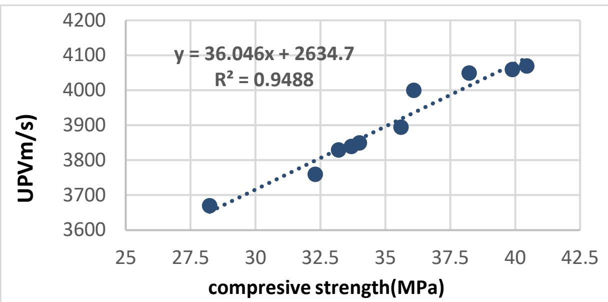


Figure 5 Relationship between compressive strength and ultrasonic pulse velocity test at 28 days

3.5 Dry Density

According to ASTM C642 [42], the dry density was determined for all mixes that contain metakaolin only and ternary mixes that contain metakaolin, slag, and fly ash as a partial replacement of cement at 28 days. Table 8 shows dry density results for all mixes on green mortar.

mix	C(%)	FA (%)	S(%)	M(%)	Dry density (kg/m³)
M0	100	0	0	0	2243
M1	90	0	0	10	2270
M2	85	0	0	15	2258
M3	80	0	0	20	2248
M4	60	10	20	10	2250
M5	60	15	15	10	2268
M6	60	10	15	15	2230
M7	50	15	20	15	2227
M8	50	15	25	10	2221
M9	50	10	30	10	2215

Table 8 Dry density results in green mortar at 28 days

The dry density increased slightly with increased material replacement in M1, M2, M3, M4, and M5; the increment ranged from 1.2% at M1 to 0.22 at M3 that contain metakaolin only as a partial replacement of cement; this is due to the fact that metakaolin has a very high fineness, so particles will fill the voids between the materials, resulting in an increase in the dry density of mortar [43].

Dry density decreased with increased slag replacement ratio, which decreased ranging from 0.57 at M6 to 1.25% at M9, where M6 has 15% of slag and M9 has 30% of slag, which means with increased slag content, the dry density was slightly decreased because slag particles have a rough, sharp edge shape that creates more pores, which decreases bonding and makes structure randomly, which decreases dry density also the research noted the behavior of steel slag depended on shape of particle [44].

The relationship between compressive strength and dry density was determined in Figure 6.

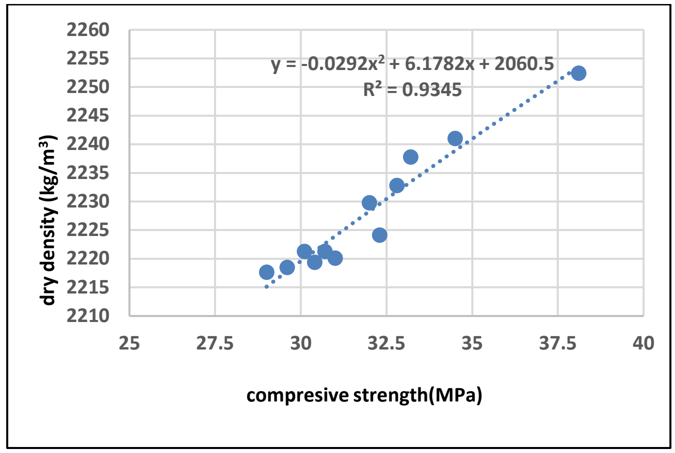


Figure 6 Relationship between compressive strength and dry density test

3.6 Water Absorption

According to ASTM C642 [42], water absorption was determined at 28 days for all mixes containing metakaolin only and ternary mixes (slag, fly ash, and metakaolin). Table 9 shows the water absorption results.

Table 9 Water absorption results in green mortar at 28 days

mix	C (%)	FA (%)	S(%	M (%)	Water absorption (%)
M0	100	0	0	0	4
M1	90	0	0	10	2.85
M2	85	0	0	15	3
M3	80	0	0	20	3.3
M4	60	10	20	10	3.2
M5	60	15	15	10	2.9
M6	60	10	15	15	4.2
M7	50	15	20	15	4.1
M8	50	15	25	10	4.5
M9	50	10	30	10	5.1

The water absorption in M1, M2, M3, M4, and M5 decreased with increased replacement of materials; the decrement ranged from 28.75% at M1 to 17.5 at M3, which contained metakaolin only as a partial replacement of cement due to the reduction of pore volume, which may be due to the pozzolanic reaction products from the hydration of fly ash and metakaolin that fill the pores. In the second case, reduction of pore volume was caused by the high pozzolanic reactivity of materials (metakaolin), the small dimensions of metakaolin particles, and their pore-filling effect (filling the pore space between the cement grains) as show in research using fly ash and metakaolin as partial replacement of cement [43]. The regression analysis between dry density and water absorption, is shown in Figure 7.

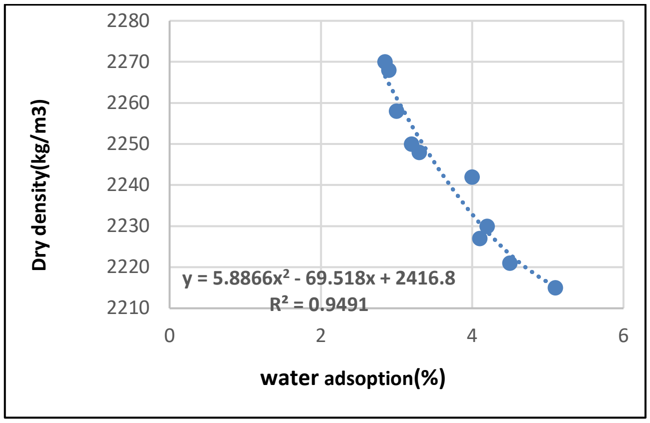


Figure 7 Relationship between water absorption and dry density test

Water absorption increased in M6, M7, M8, and M9 by 5%, 2.5%, 12.5%, and 27.5%, respectively, for these mixes because of the filler influence incorporated with a high hydraulic and pozzolanic activity. The pore structure in the mix was changed through the reactions of steel slag with water (the later hydraulic reaction) and calcium hydroxide (Ca (OH)), produced during the hydration of cement (the pozzolanic reaction) [46] Then the pores were filled with the additional C-S-H products instead of calcium hydroxide, leading to decreased permeability. Also, due to the improved workability and lowered w/b ratio, a denser structure of steel slag blends was successfully achieved, leading to reduced water absorption as this agree with the research on the properties of steel slag showed [44].

The regression analysis between water absorption and compressive strength is shown in Figure 8.

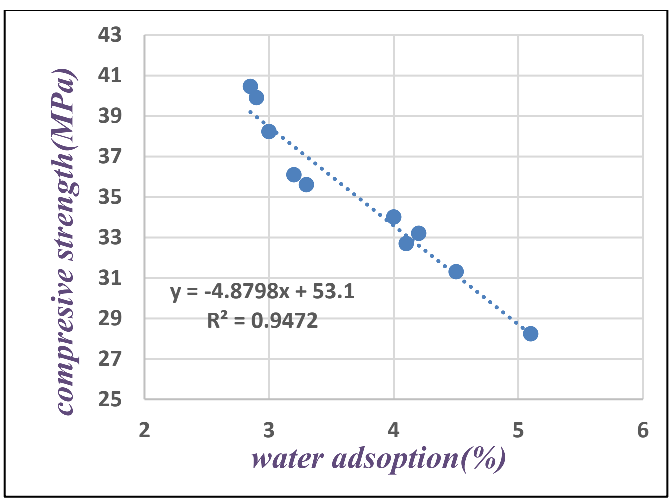


Figure 8 Relationship between water absorption (%) and compressive strength test

4.0 CONCLUSION

From this study of ternary blended cement mortar that contains slag, fly ash, and metakaolin to produce sustainable green mortar, the results obtained from the tests can be summarized as the following:

1. Utilizing fly ash as a supplementary cementitious material enhances the flowability of green mortar and incorporating slag and metakaolin decreases the flow by 5%. Metakaolin increases the dosage of superplasticizer by 10%. The dosage of superplasticizer increases 10% when the replacement of ternary cement is increased by 10%.
2.The compressive strength is improves at an early age when metakaolin is used as a partial replacement of cement by less than 20% and increases compressive strength by 22.5-50% at 7 days. A suitable combination of 15% fly ash, 15% slag, and 10% metakaolin in green mortar increases compressive strength by 17.35% at 28 days and 13% at 7 days compared to the control mix.
3.When replaced with 10% metakaolin, flexural strength increases by 26.47% at 7 days and 11.65% at 28 days. Ternary mixes of 15% slag, 15% fly ash, and 10% metakaolin increase flexural strength by 5.8% at 7 days and 10.4% at 28 days.
4.At 28 days, replacing ternary cement with slag, fly ash, and metakaolin increases wave speed by 5.4%, and replacing metakaolin increases wave speed by 5.2%, 5.2%, and 5.2% when replaced with 10% and 15%, respectively.
5.The dry density slightly decreases or increases with the increase of ternary cement mixes to 50% compared with the control mix.
6. Using 10% of metakaolin as a partial substitute for cement reduces water absorption by 28.75%. In ternary blended cement mixes, where the replacement ratio is 50%, the increased water absorption is 27.5%.

The recommended mix proportions of ternary blend is use 15% of fly ash,15% slag with 10% metakaolin will give suitable mechanical properties.

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