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PROPERTIES EVALUATION OF GREEN MORTAR CONTAINING WASTE MATERIALS

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Graphical abstract

Abstract

The accumulation of massive waste has impacted human health and the city's appearance. As a result, there was a need to reduce waste by using by-products from industrial waste to replace cement, such as limestone, fly ash, silica fume, steel slag, and other minerals known as supplementary cementitious materials are produced environmentally and sustainably. This paper's purpose is to design a green mortar with the highest possible replacement of cement that has acceptable fresh and hardened characteristics. In this paper, three (SCMs), such as limestone powder (10%), calcined clay (0–35%), and slag (0–30%), were used to prepare ternary mixtures. The materials used in this research are available locally in Mosul, Iraq. The experimental studies were carried out for twelve mixes. The tests of flowability, flexural strength, compressive strength, dry density, ultrasonic pulse velocity, and water absorption on green mortar have been conducted. The cement was replaced 30% to 60% with a combination of ternary cement containing calcined clay, limestone, and slag in different replacement percentages than in other green mortar mixes. The results found that replacing OPC (30%), which contains 10% limestone, 10% steel slag, and 10% calcined clay, gives the highest compressive strength and flexure strength enhancement, which are 24% and 18% greater than the plain mortar after 28 days. When cement replacement was increased for ternary mixes, the result differed slightly from the plain mortar. Water absorption increased as the SCMs were increased. Dry density showed little effect.

Keywords: Limestone Powder. Calcined Clay. Slag. Green Mortar. Ternary Cement. Sustainably

1.0 INTRODUCTION

In the present context of climate change, limiting carbon dioxide emissions is one of our society's most urgent challenges in decreasing greenhouse gas emissions. Construction is among the world's most significant and oldest industries. At the same time, the binder material is the most utilized construction material among the various construction materials. Because concrete is really the second most used substance in the world after water, this has a substantial impact on the environment, particularly due to cement manufacturing [1]. As a result, ordinary Portland cement production has surpassed 4.1 billion tons annually in recent years [2]. Cement manufacturing consumes energy and produces carbon dioxide emissions despite the fact that CO_2 emissions from cement manufacturing account for approximately 8% of total global CO_2 emissions responsible for global climate change [3].

Research on alternate binders to limit the impact of the production of cement on resources and the associated CO_2 emissions in the manufacturing process [4]. Several research has focused on adding or replacing supplemental cementitious materials (SCMs) from cement. This is now one of the most cost-effective and practical solutions to decrease CO_2 emissions to manufacture green concrete and optimize resources by using alternate binders, especially in developing countries [5][6]. According to studies, SCMs can minimize carbon dioxide emissions by approximately 30%–40% [7]. Nowadays, industrial by-products such as steel slag, fly ash, and silica fume are widely accepted for reducing the cement content (the most CO2-intensive component) as a partial replacement. However, because of rising cement industry consumption, quality SCMs are expected to be scarce in the coming decades [8]. Consequently, several countries are more dependent on SCMs importation [9].

Furthermore, because SCMs are produced by heavy industries such as iron ore and coal manufacturing, not all countries have sufficient resources. Due to sustainability concerns and waste reuse, they are predicted to decrease in quantities [9]. The essential problem with the rising replacement levels of these materials (chiefly fly ash) has been the adverse effects on early age, like late setting and strength improvement in the concrete [10]. However, the production of steel iron (and thus slag) is concentrated in a comparatively little number of countries, so availability is even extra fixed in countries where demand for cement is rising [11]. Despite limestone being widely available, adding more than 10% limestone to cement leads to increased porosity and undesirable characteristics [12].

Recently, the problem of the non-availability of traditional SCMs compared to the increased demand for cement has led to the search for widely available alternatives in all countries. Clays have been found in plenty in all countries to meet the needs of massive demand for cement replacement materials. Research confirms that next to being calcined from 600 to 800 ◦C, calcined clay shows exceedingly pozzolanic reactive properties that refine the pore structure at an early age. [13–14].

When clay, including kaolinite, is calcined, calcined clay is formed had been utilized as SCMs, which is basically an amorphous alumina silicate ($Al_2Si_2O_7$) that is rich in silicate and aluminate. That can react with $Ca(OH)_2$ as a traditional pozzolan to give CASH and CSH hydrates. In addition, the aluminate or silicate in the presence of calcined clay and slag reacts with the limestone ($CaCO_3$) to create a carbo-aluminate hydrate [9]. All those products fill the void and contribute to the improvement of characteristics (e.g., durability and strength) With this partial substitution, it is the potential to acquire good mechanical performance, especially at early ages [15]. Hence the addition of slag can decrease strength at an early age because of the low reactivity of slag. Limestone filler is commonly utilized in BFS-blended binary concrete to counter the major weakness of BFS-blended concrete [16].

Studies on cement mortar by Dawood and Abdual-kareem[17] reported that cement containing (30%, 35%, 40%, and 45%) steel slag reduces workability, which led to the addition of a superplasticizer to get the same flow and also concluded that the slag powder in the later age gave higher compressive strength to green mortar. Mohammed et al. [18] investigated the effects of green mortar properties that used calcined clay, fly ash, and limestone as SCMs and found the optimum calcining depending on strength activity index tests was 750ºC for calcined clay. They also concluded that the compressive strength was improved in mixes containing 10, 20, and 30 % calcined clay. Lin et al. [19] studied the mechanical properties of mixed cement with different percentages of limestone; a 10% substitute level increased the compressive strength compared to cement mortar and improved permeability and mechanical properties. Nair et al. [20] found that calcined clay in LC3 had increased superplasticizer need and showed several difficulties in maintaining fluidity for an extended period. Argın and Uzal [21] found that limestone addition improved the reactivity of calcined clays dependent on the calcination temperature, fineness, and nature of the clay. Limestone addition little reduced the water needed. Makhloufi et al. [22] observed that ordinary plotland cement, slag, limestone powder, and pozzolan quaternary mixed mortar had enhanced sulfate resistance to OPC mortar.

The major objectives of this paper are: to investigate the green mortar containing different percentages of ternary mixes using waste material locally available in Nineveh that contains calcined clay, limestone, and steel slag as cement replacement, determine the mechanical and physical characteristics of green mortar produced with suitable ternary replacements of blends and select the best green mortar mixture based on properties that suitable for construction application.

2.0 MATERIALS AND MIX PROPORTIONS

2.1 Cement

Using locally available cement, sustainable and green mortar mixes were produced. In this paper, ordinary portland Cement (OPC) type I was used r. It was obtained from the Baddosh factory, which is available locally in the Nineveh Governorate and is one of the cheapest types of cement available. Table 1 was shown physical properties, and Table 2 was shown chemical composition Iraqi Specifications No.5-2010[23] and according to ASTM C150 [24]

Table 1 Physical properties of OPC.

Tests	Results	Limitations of the ASTM C150-17	Limitations of the IQS No.5-2010
Initial Setting Time,	97 Min	≥ 45 Min	≥ 45 Min
Finish Setting Time,	240 Min	≤ 375 Min	≤ 600 Min
Fineness, (Blaine Test)	$310 M^2/Kg$	≥ $260 M^2/Kg$	≥ $230 M^2/Kg$
Compressive Strength (MPa) 3 Days 7 Days	16.71 MPa 24 MPa	≥ 12 MPa ≥ 19 MPa	≥ 15 MPa ≥ 23 MPa

*The test was conducted in the laboratories of Mosul Technical college.

Table 2 Chemical synthesis of OPC and SCMs measured with XRF.

Composition	Weight (%)			
	OPC	limestone	Slag	Calcined clay
Silicon dioxide (SiO_2)	21.87	12.2	43.52	50.4
Ferric oxid (Fe_2O_3)	2.41	1.1	17.8	7.55
Aluminum oxide(Al_2O_3)	6.29	1.61	12.61	22.5
Magnesium oxide(MgO)	3.42	2.4	1.49	3.36
Sulfate oxide(SO_3)	2.37	0.13	0.092	0.1
Calcium oxid (CaO)	62.3	49.53	24.53	12.5
Potassium oxide (K_2O)	0.44	0.36	0.99	0.51
Sodium oxide(Na_2O)	0.18	0.64	0.23	0.1
Loss of ignition (LOI)	0.94	31.50	1.21	3.01

*The test was conducted at Soran University

2.2 Sand

The river sand used in this paper supplied from the Kanhash region in Nineveh has been locally obtainable. The particles have been passed through the sieve (# 4) 4.75 mm. The specific gravity was 2.66, and the fineness modulus was 2.8 in identity with specifications ASTM C128 [25] and ASTM C33 [26].

2.3 Water

Tap water was used to mix the components. Oils, organic material, and other potentially harmful components should not be present in the water used in the mixing and curing.

2.4 Steel Slag

Slag is a by-product produced as a remaining product from Industry. When coke, limestone, and iron ore are blended at high temperatures. Slag has been gained from the local industrialization factory in Zakho, Iraq. Slag particles have passed through the sieve (#325) 45 µm and retained on sieve No. 325 of 4 %. The strength activity index for slag at 28 days was 80 %, according to ASTM C989 [27]. The specific gravity was 2.9, and fineness of 550 m^2/Kg.

2.5 Limestone Powder

A by-product from waste industrial resulting from cutting and mining stone locally available in the Mosul factories. The natural limestone is brought from the shakhan region. The physical properties of specific gravity (2.7), fineness of 390 m^2/kg , retained on sieve No. 325, 6 %, and strength activity index for limestone was 86% at 28 days according to ASTM C618[28].

2.6 Superplasticizer

High range water reducing admixture was used manufactured by Sika Company for admixtures of type ViscoCrete®� 5930 superplasticizer was used to the required workability [29]. The superplasticizer Type F specifications according to ASTM C494 [30].

2.7 Calcined Clay

Natural clay had been brought from located of Mosul city. the clay was crushed into small particles and grinding by Los Angelos. After grinding the clay, calcination was by heating the clay in furnace-type Prothern 442 . The temperature of the furnace was increased from room temperature to 750ºC with a stable heating rate of 15ºC/min, maintaining the fixed temperature for an hour. after calcination had been cooled furnace and exposed to additional grinding for calcined clay to increase the fineness particles up to becomes less than 45 µm. The particles had been passed through a sieve (# 325) and retained on sieve No. 325 of 3 %. The strength activity index for calcined clay was 119% at 28 days, according to ASTM C618[28]. The surface area was 530 m^2/kg, and the specific gravity was 2.44 .

2.8 Mix Proportions

Table 3 shows the proportions of cement paste and cementitious materials. Green mortar has been used to prepare mixes. In this paper, 12 mixtures were prepared to produce green mortar. All (M0 to M12) mixes have been prepared with a binder to a fine aggregate ratio of 1:2.75. The sand was used in a surface saturated dry (SSD) state in each mixes. While, the water/binder (w/b) ratio has been used at 0.37 with various dosages of superplasticizer for obtaining suitable workability, except for the control mixes (reference mortar) without using a superplasticizer (w/c) ratio of 0.51. The specimens of this paper contain eleven ternary mixes to produce green mortar. The cement was replaced up to 60% by the weight of cement in ternary mixes, as illustrated in Table 3.

The mixing process was done by manually blending the cement, slag, limestone, calcined clay, and sand in accordance with mixes proportions for 3 min to ensure the uniformity of the mix. The high-range water reducer was added to part of the blending water and stirred by the manufacturer's order. Subsequently, the water and the superplasticizer were added to the mixes, and the blending continued for three extra minutes. After the blending procedure was completed, a flow test was carried out to determine the workability for each mix in this paper in accordance with ASTM C1437 [31]. The superplasticizer was added to maintain the flow ratio. Then, six 50 mmx50 mmx50 mm cubes for each blend were cast, three cubes by each age group at 7 and 28 days, Six prisms of 40 mm× 40mm × 160 mm have as been cast for the flexural test, three prisme by each age group at7 and 28 days. Three cubes of 70.7mm × 70.7mm × 70.7 mm were cast for the ultrasonic pulse velocity (UPV), dry density, and water absorption tests at 28 days of the total casting of 51 cubes. The molds were opened after 24 hours and then submerged the samples into tank water at 23 ±2ºC for curing according to ASTM C 192 [32].

Table 3 Mix proportions for ternary mixes of GM.

Index	(kg/m³)					%	
	Cement	Calcined Clay	Limestone	Slag	sand	w/b	Sp
M_0	500	0	0	0	1375	0.51	0
M1	350	50	50	50	1375	0.37	1.38
M2	300	100	50	50	1375	0.37	1.5
M3	300	50	50	100	1375	0.37	1.55
M4	250	125	50	75	1375	0.37	1.75
M5	250	150	50	50	1375	0.37	1.7
M6	250	75	50	125	1375	0.37	1.75
M7	250	100	50	100	1375	0.37	1.7
M8	250	50	50	150	1375	0.37	1.8
M9	225	150	50	75	1375	0.37	1.8
M10	200	150	50	100	1375	0.37	1.8
M11	200	175	50	75	1375	0.37	1.8

3.0 RESULTS AND DISCUSSION

3.1 Flowability

The flowability tests were carried out in accordance with ASTM C-1437 [31]. As shown in Table 4, the partial cement substitution several ternary mixes that contained (limestone, calcined clay, and slag) with an added different percentage of the superplasticizer to reduce water demand in the compounds except for the plain mix. Consequently, when cement is replaced to achieve the ideal flowability of 110%±5%, This research used a ViscoCrete®-5930 superplasticizer composed of polycarboxylate to high-range water reducer demand to achieve the same flowability as the plain mix [18] [13]. The results indicated that the dosage in M1 decreased, which contained 30% of the ternary mixture (limestone, calcined clay, and slag) by replacing cement. This could be associated result the addition of limestone powder as a supplementary cementitious material that has improved the flowability of green mortar [33]. This is due to contained limestone's high proportion of $CaCo_3$ in aqueous suspension; the OH^- groups bond together the Ca^{2+} ions on the surface of limestone particles, enhancing an electrostatic repulsion effect due to CO_3^- ions having a negative charge. This minimizes inter-particle adhesion and, as a result, enhances cementitious material flowability [34][35]. Previous studies have shown that using limestone powder as a replacement for cement in certain percentages enhances the flow efficiency of fresh mortar and concrete mixes [33] according to Table 4.

The flow test results showed that when compared to M2, which contained 40% of ternary cement (10% limestone, 20% calcined clay, and 10% slag), the dosage of superplasticizer was increased by 3% in M3, which contained 40% of the ternary mixture (10% limestone, 10% calcined clay, and 20% slag) due to the replacement of cement. This could be attributed to the high fineness of slag particles compared to other SCMs particles and OPC, the particle shape of sharp edges, and the gruff surface of the slag particles that affect increased water demand and increased dosage [17]. In other mixes, when there was an increase, the replacement of cement that contained SCMs in ternary mixtures to produce green mortar. The superplasticizer has been added to the dosage. This led to an increased dosage and a fixed of 1.8 % for M8, M9, M10, and M11. This was due to the high fineness of ternary mixes that contained limestone that had a surface area of 390 m²/kg, calcined clay that had a surface area of 530 m²/ kg, and slag that had a surface area of 550m2/kg when compared of cement particles that had a surface area 310m²/kg. In summary, slag and calcined clay decreased the flow of the pastes, and the influence of calcined clay was more significant in flow. The pastes with 35% CC exhibited a significant drop

in flow spread diameter, equal to 105 %, and fixed the superplasticizer dosage of 1.8.

Table 4 Flowability results for serval ternary mixes to produce green mortar

Index	%						
	Cement	Calcined Clay	Limestone	Slag	w/b	Sp	Flow
M_0	100	0	0	0	0.51	0	110
M1	70	10	10	10	0.37	1.38	108
M2	60	20	10	10	0.37	1.5	108
M3	60	10	10	20	0.37	1.55	107
M4	50	25	10	15	0.37	1.75	109
M5	50	30	10	10	0.37	1.7	109
M6	50	15	10	25	0.37	1.75	108
M7	50	20	10	20	0.37	1.7	107
M8	50	10	10	30	0.37	1.8	106
M9	45	30	10	15	0.37	1.8	105
M10	40	30	10	20	0.37	1.8	105
M11	40	35	10	15	0.37	1.8	105

3.2 Compressive Strength

The compression strength test results were carried out by ASTM C109/C109M [36]. Table 5 above showed that the superplasticizer (ViscoCrete®� 5930) was added to all ternary mixtures to improve compressive strength and enhance workability to decrease water demand. Except for M_0 (plain mortar). The results obtained in the compressive strength test for green mortar mix at 7 days and 28 days are presented in Table 5.The compressive strength at 28 days in M1, which contained 30% replacement of cement (10% limestone, 10% calcined clay, and 10% slag), increased by 24% compared to plain mix. This was due to the presence of limestone powder in addition to mixes that could react alumina or silicate in calcined clay and more alumina presence of slag to form carbo-aluminate hydrates CSH and CASH. All these components contribute to the development of the strength and fill the pores, resulting in the formation of a dense microstructure and the presence superplasticizer [37]. While increasing the participation of more limestone particles, the early reaction is faster in the hydration reaction during the early stage.

In addition, the hydraulic nature of slag that contains calcium oxide (CaO) in a high percentage does not require much calcium hydroxide during hydration in the later stages due to converting CaO to $Ca(OH)_2$ [15].

When the replacement equivalent of cement of 40% by ternary mixes of green mortar in M2 and M3, the compressive strength in 28 days in M2 was 41.8 MPa higher than in M3, which was 39.5 MPa, as shown in Table (5).This was attributed to the high proportion of calcined clay in the M2 that contained a high percentage of silicate compared to slag. In addition to pozzolanic activity, calcined clay enhanced the refined pore structure [16]. At 28 days, the compressive strength in M4 of ternary mixes that contained 50% ternary cement (10% limestone, 25% calcined clay, and 15% slag) increased by 3% when compared with the plain mixes. This is attributed to the chemical composition and activity of pozzolanic clay, which is higher than slag and limestone, which could enhance the hydration rate of the mix, in addition to SCM particles finer than cement particles [37][38][39].

Table 5 Compressive strength results for ternary mixes to produce green mortar

Index	%				Compressive Strength (MPa)	
	Cement	Calcined Clay	Limestone	Slag	7	28
					Days	
M_0	100	0	0	0	24.5	35.2
M1	70	10	10	10	33	43.5
M2	60	20	10	10	31	41.8
M3	60	10	10	20	30	39.5
M4	50	25	10	15	23	36.5
M5	50	30	10	10	21.6	34.5
M6	50	15	10	25	21.8	33.1
M7	50	20	10	20	20.2	32.8
M8	50	10	10	30	21.3	31.7
M9	45	30	10	15	20	29
M10	40	30	10	20	18.5	25
M11	40	35	10	15	17.5	22

Figure 1 observed increase in replacement in cement leads to a decrease in available C_2S and C_3S components, which are the essential ingredients of the cement composite [40]. Moreover, the compressive strength in M2 mixes was higher than in M5 mixes when increasing calcined clay due to calcined clay containing a higher percentage of aluminates and silicate than slag, and reduced $Ca(OH)_2$ when reducing cement content that reaction with aluminates and silicate to form CASH which helps improve strength in early and later age [39] [40]. When increasing the replacement of cement by 50 %, 55%, and 60%., the green mortar was reduced by 2%, 6%, 7%, 10%, 18%, 29%, and 38% in M5, M6, M7, M8, M9, M10, and M11 mixes, respectively. As a result, the availability of calcium hydroxide for the pozzolanic reaction was reduced when the replacement of cement up to 60% [41]. From the results as observed, SCMs can improve cement hydration. This improvement to the filling and dilution influence; the pozzolanic reaction of calcined clay and slag with $Ca(OH)_2$ in the later phase may also a contributing factor. Consequently, ternary blended green pastes with three materials can effectively stimulate the cement reaction and significantly positively influence the long-period durability of green concrete.

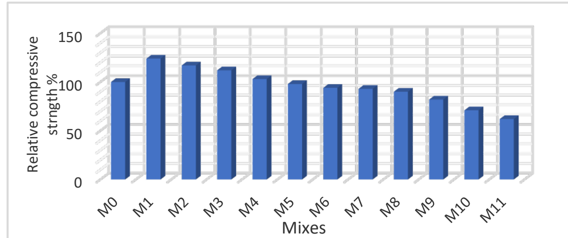

Figure 1 Relative compressive strength (%) at 28 days.

3.3 Flexural Strength Test

The flexural strength test results were carried out by ASTM C-348 [42]. The results were obtained in the flexural strength test for green mortar mix at 7 days and 28 days, as illustrated in Table 6. At 28 days, the flexural strength of ternary blends in M1, M2, M3, and M4 increased by 18%, 12%, 10%, and 5%, respectively, when compared with cement mortar.

This has been attributed to the higher proportion of crystalline silica and alumina during the addition of more pure calcined clays and slag that reacted with $Ca(OH)_2$ for the formation of C-A-S-H gel that blocked porous had, resulting in the densification of the microstructure and improved flexural strength [43][44]. From the result was observed that calcined clay when to increase up to 25 % in ternary cement of replacement of cement and in addition to the presence of a specific SP dosage. The flexural strength was increased when compared to plain mortar. This was due to high activity strength compared to other SCMs The flexural strengths have decreased with increased cement replacement in M5-M11 mixes, as shown in Figure 2. That was due to the reduced calcium hydroxide that reacted with pozzolanic materials, forming a porous mixture . While most specimens experience decreased flexural strength with a higher percentage of steel slag .

Table 6 Flexural strength result of GM

Index	%				Flexural Strength (MPa)	
	Cement	Calcined Clay	Limestone	Slag	7	28
					Days	
M_0	100	0	0	0	6.5	8.2
M1	70	10	10	10	8	9.7
M2	60	20	10	10	7.6	9.2
M3	60	10	10	20	7.5	9
M4	50	25	10	15	6.3	8.6
M5	50	30	10	10	6.1	8.1
M6	50	15	10	25	6	8
M7	50	20	10	20	5.8	7.9
M8	50	10	10	30	6.1	7.4
M9	45	30	10	15	5.6	7.2
M10	40	30	10	20	5.4	6.2
M11	40	35	10	15	5.2	5.8

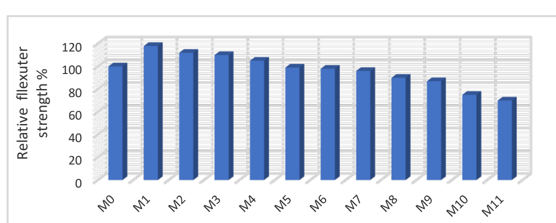

Figure 2 Relative flexure strength (%) for ternary mixes at 28 days

As shown in Figures 3 and 4, the regression analysis for all ternary mixes shows sturdy relationships between compressive and flexural strength.

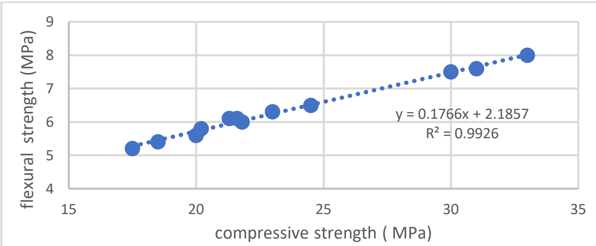

Figure 3 Relation between compressive strength and flexural strength at 7 days

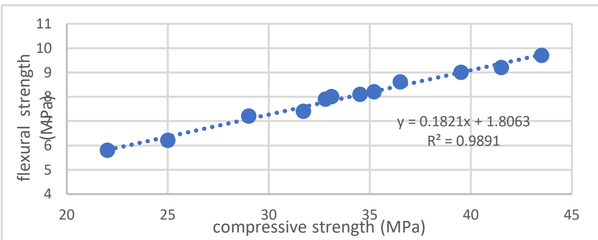

Figure 4 Relation between compressive strength and flexural strength at 28 days.

3.4 Ultrasonic Pulse Velocity

The UPV test results were carried out in accordance with ASTM C-597[45] for green mortar. The test has been done for cube mortar that dimension (70.7*70.7*70.7) mm at 28 days for all mixes. as illustrated in Table 7 and Figure 5.

Other hands, the wave's speed had increased utilizing the UPV test for ternary mixes in M1, M2, M3, and M4 increased by 14%,12%,11%and 1%when compared to plain mixes. This can be attributed to the pozzolanic reaction of SCMs that contained (calcined clay, limestone, and slag), which led to the formation of C–S–H and carbo aluminates helped to improve density and also decreased pores, as shown in Figure 8 [46].

Table 7 Ultrasonic pulse velocity results for ternary mixes at 28 days

Index	%				m/s
	Cement	Calcined Clay	Limestone	Slag	Ultrasonic Pulse Velocity
M_0	100	0	0	0	3901
M1	70	10	10	10	4450
M2	60	20	10	10	4370
M3	60	10	10	20	4364
M4	50	25	10	15	3950
M5	50	30	10	10	3870
M6	50	15	10	25	3850
M7	50	20	10	20	3770
M8	50	10	10	30	3740
M9	45	30	10	15	3660
M10	40	30	10	20	3220
M11	40	35	10	15	3100

At 28 days, when the increased replacement of cement in M5-11 by ternary mixes of green mortar, the wave's speed had decreased due to low cement content in the mixes and the chemical reactions for component material for mixing and formation of a porous structure that affected the wave[47]. Previous research by Godinho et al. [48] have proved that compressive and UPV are extremely correlated. Figure 6 shows a linear relationship between UPV and compressive strength at 28 days; the value of R2 was 0.97.

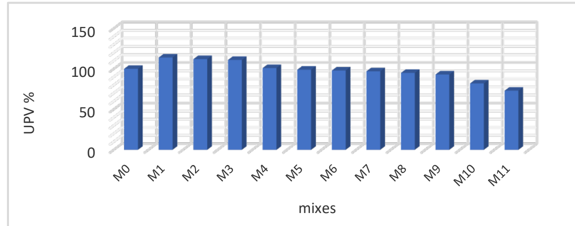

Figure 5 Relative UPV result (%) at 28 day

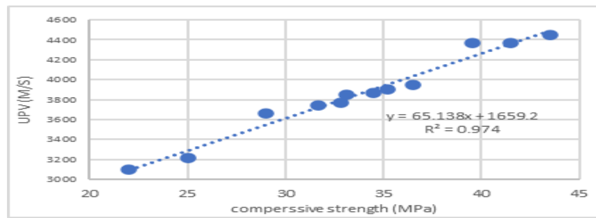

Figure 6. The linear relationship between compressive strength and UPV

3.5 Dry Density

Table 8 shows test results archived on cube mortar (70.7*70.7*70.7) mm at 28 days. The test was implemented in accordance of ASTM C-642 [49].

Table 8. Dry density results for ternary mixes of green mortar at 28 days

Index	%				Kg/m3
	Cement	Calcined Clay	Limestone	Slag	Dry Density
M_0	100	0	0	0	2246
M1	70	10	10	10	2277
M2	60	20	10	10	2273
M3	60	10	10	20	2269
M4	50	25	10	15	2250
M5	50	30	10	10	2242
M6	50	15	10	25	2236
M7	50	20	10	20	2230
M8	50	10	10	30	2225
M9	45	30	10	15	2220
M10	40	30	10	20	2216
M11	40	35	10	15	2200

From the Table above, it could be noticed that the dry density for green mortar has increased in ternary mixes M1-M4 when cement is replaced by 1.38%-0.17%, as shown in Figure 7. This was due to the SCMs being present in the mixture, which was finer than cement. However, the fineness of limestone 390 m^2/kg, calcined clay 530 m^2/kg, and slag 550 m^2/kg refinement of the pores due to the higher pozzolanic action of calcined clay, the hydraulic nature of slag, and also. The presence of limestone was reacted with calcium hydroxide formation; CSH and CASH can fill space and reduce the volume of pores in the matrix. That led to increased density [50][51]. On the contrary, the dry density has decreased for mixes M5-M11 when cement replacement increases up to 60%. The density had decreased by (0.8-3.1)%. This is due to the addition of calcined clay, slag, and limestone having significant effects on the structure and the formation of the C-(A)-S-H gel. The silicates and aluminate increased during the hydration, decreasing Ca $(OH)_2$; for this reason, the chemical composition of (CASH) is influenced. This change has affected the density of the green mortar [52].

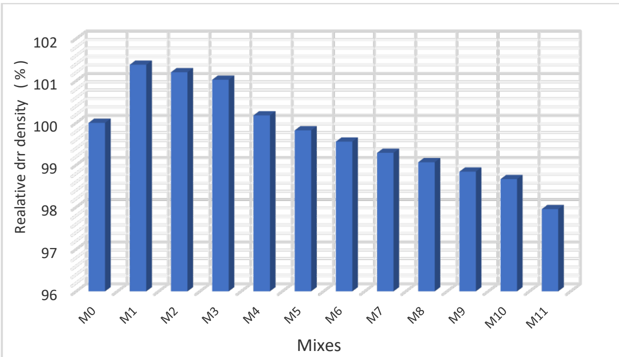

Figure 7 Relative dry density at 28 days

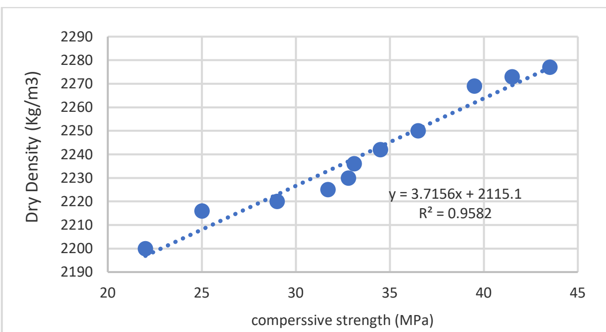

Figure 8 Relation between compressive strength and dry density at 28 days

3.6 Water Absorption (%)

Table 9 shows test results that have been achieved on cube mortar (70.7*70.7*70.7) mm at 28 days. The test was implemented in accordance of ASTM C-642 [49]. The water absorption has decreased in ternary mixes M1-M5 when cement is replaced by (29-5.26) %, as shown in Figure 9 and explained in the previous section[53]. Because there is an inverse relationship between density and absorption, as shown in Figure 10. The water absorption increased in M6,M7,M8,M9,M10andM11by5.2%,10.5%,15%,18%,21% and 26% when compared the reference mortar. The hydrated product produced by the pozzolanic reaction has several properties to the hydrated product produced by the hydraulic reaction because of the difference in their chemical compositions [54]. The result noted that water absorption decreased when the calcined clay content increased up to 25% in ternary cement due to the high-activity chemical compound. While the water absorption increased when increased slag content caused low activity and shape of the particle [55].

Table 9. Water Absorption for Ternary Mixes of Green Mortar.

Index	%				
	Cement	Calcined Clay	Limestone	Slag	Water Absorption
M_0	100	0	0	0	3.8
M1	70	10	10	10	2.7
M2	60	20	10	10	2.8
M3	60	10	10	20	3
M4	50	25	10	15	3.3
M5	50	30	10	10	3.6
M6	50	15	10	25	4
M7	50	20	10	20	4.2
M8	50	10	10	30	4.4
M9	45	30	10	15	4.5
M10	40	30	10	20	4.6
M11	40	35	10	15	4.8

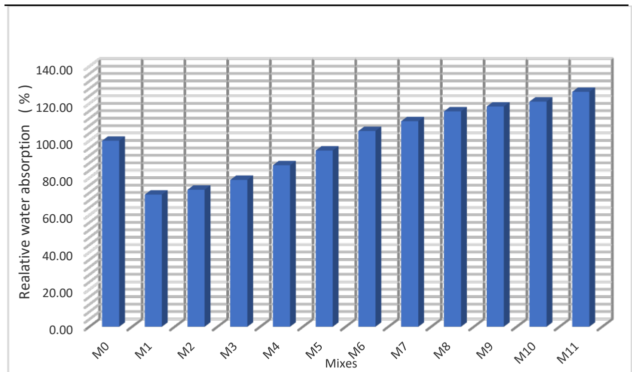

Figure 9 Relative water absorption % at 28 days.

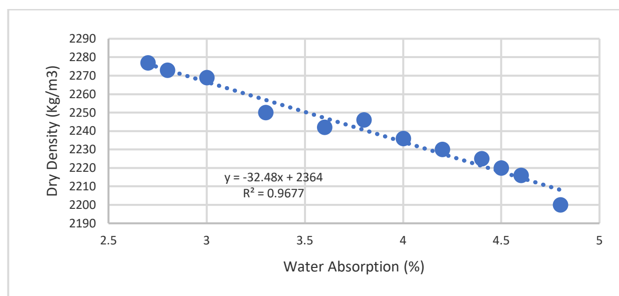

Figure 10 The relation between water absorption % and dry density at 28 days.

4.0 CONCLUSION

In this paper, ternary cement was produced of calcined clay, limestone powder, and slag in different proportions when was replaced of cement up to 60%, which are considered three widely used supplementary cementitious materials. The following points provide a summary of the conclusions based on the test results:

1. The addition of limestone powder, calcined clay, and slag as partial cement replacement decreases flowability properties, so an increased dosage of superplasticizer in the fresh properties of green mortar is needed.

2. When replacement of 30% of cement by ternary cement that contains (10% limestone, 10 % calcined clay, and 10% slag) with the presence of a certain dosage of superplasticizer provides the greatest improvement in compressive strength between other ternary mixes and increases compressive strength by about 24%, while flexural strength increases by 18% at 28 days.
3. The dry density for ternary mixes is shown a little different compared to the plain mortar.
4. The wave speed during the UPV increases that contain (10% limestone+10%calcined clay and 10% slag) by 14% ternary cement compared to the plain mortar.
5. The ternary mixes decrease water absorption by 28% when replacing 30% cement compared to plain mix. When the SCMs are increased that water absorption also increases.

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