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Experimental Investigations of Some Clays Industrial Wastes as Recyclable Materials for the Production of Blended Cement

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ABSTRACT

This study deals with a comparative experimental investigation on the industrial waste clays as recyclable materials in blended cement production. In spite of the fact that waste of fired clay bricks (WFCBs), ground or broken bricks, waste of ceramic tiles (WCTs), and waste of vitrified clay pipes (WVCPs) are silicates solid waste, their recycling management has the best environmental, social, and economic aspects. The implementation of these wastes as recyclable materials in wall materials, mortar, and concrete are used as raw materials or cement additives as pozzolanic materials for rapid urbanization and improvement of construction and high pollution rates in the developing countries such as Egypt. A large amounts of these wastes has been produced from factories for producing clay bricks, ceramic tiles, and vitrified clay pipes, as well as construction operations, building improvement, and the demolition of old buildings. The mortar microscopic structures are observed by scanning electronic microscope (SEM), while hydrous minerals are studied using X-Ray Diffraction (XRD) as well as differential thermal analysis (DTA).These wastes, as artificial pozzolanic materials, rise the setting time of cement products. The average strength of compressive and flexural accelerates at early age slower than later age. The study aims to reduce construction solid waste and conserve raw material resources. These wastes are widespread in the Egyptian provinces, and there is very a little available information on their chemical composition and mineral components.

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التجارب المعملية لبعض مخلفات تصنيع الطين لإعادة استخدامها في إنتاج الأسمنت المخلوط

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الملخص

تتناول هذه الدراسة تجارب معملية على مخلفات التصنيع الطينى كمواد قابلة لإعادة التدوير فى إنتاج الأسمنت المخلوط، وهذه المخلفات عبارة عن مخلفات سيليكاتية صلبة وإدارتها لإعادة استخدامها فى إنتاج الأسمنت المخلوط لها مميزات بيئية وإقتصادية وإجتماعية عالية نظرا لعمليات التوسع والتطوير والتحسين العمراني والبنية التحتية للدول النامية ومنها مصر. ولهذا السبب تتوافر هذه المخلفات بكميات كبيرة من عمليات التصنيع والهدم والتطوير وتحتاج إلى دراسات كافية لمعرفة تركيبها الكيميائى والمعدنى. تم التأكيد بعد الفحص للمكونات المعدنية بواسطة المجهر الألكترونى وحيود الأشعة السينية من أن هذه المخلفات لها خاصية بوزولانية وأن إضافة هذه المخلفات تزيد من زمن الشك الأبتدائي والنهائي وقوة تحملها للضغط تزداد مع الوقت. وخلصت الدراسة إلى أن إستخدام هذه المخلفات لها تأثير إيجابي على البيئة والحفاظ على الموارد الخام الطبيعية الداخلة فى صناعة الأسمنت وإدارة هذه المخلفات لما لها من تأثير إيجابى اقتصاديا على الدول النامية فلا بد من وجود سياسات وإستراتيجيات تلبى وتخدم إعادة إستخدام هذه المخلفات.

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Introduction

In the late twentieth century, there was an increasing awareness of the overall impacts of cement manufacturing on the atmosphere. The impact of CO_2 has been considered one of the major factors affecting climate changes. The CO_2 is emitted as a result of cement production with amount reaching about 0.9 tonne per tonne of clinker production. Concrete production has an impact on climate as it accounts for 5-7% of total anthropogenic carbon dioxides emissions (Meyer, 2009). It is commonly known that the cement industry needs high energy consumption and emits a lot of greenhouse gases (Reddy et al., 2003). The energy consumption and carbon footprint of the building materials are effectively decreased by partial substitution of cementing materials by non-conventional binders. Ceramic wastes are used as partial replacement in blended cement and effects on of their physic-mechanical properties of produced concrete; it is found that the ideal partial replacement ratio by these wastes reaches up to 25% to produce light weight foamed concrete (Siong et al., 2022). The characteristics of blended cement containing up to 50% pulverized fired clay brick wastes are the superior properties values and it is concluded that the prepared mortar is attained at a level of 20% replacement by the waste after treatment time at 28 days (Oluwarotimi et al., 2019). The influence of pozzolanic activity on the properties of blended cement mortar at partial replacement of clay brick powder waste that was collected from a demolition place surrounds

Nanjing, the pozzolanic activity was enhanced decrease with particle size clay brick powder (Yasong et al., 2020).The investigation about some Egyptian clay materials in vitrified clay pipes production reveals that these clay materials are appropriate for clay pipes production (El-Desoky et al., 2019). Based on the properties of produced fired clay bricks, the Egyptian Paleozoic raw building materials have been investigated with different mixes. The better mix has been assigned with 10% sand at burning temperature equal/or over 800°C (Adel et al,. 2022). Some Egyptian raw materials comprise quartz, kaolin, feldspar and bentonite for production of ceramic tiles, sintered between 1160 to 1260°C, and the main fired minerals are mullite, quartz and albite (Mohamed et al., 2021). However, pozzolans are of both natural or artificial origin. The natural pozzolans are of volcanic origin such as volcanic ash, pumice, zeolite, and tuffs. Artificial pozzolans are waste products formed from industry or heat treatments for clays such as metakaolin (MK), silica fume (SF), granulated blast furnace slag (GBFS), fly ash (FA), calcined clays or shales, and rice husk ash (RHA) as well as wastes of clays manufacturing (Hewlett, 1998, Soroka, 1979, Ramachandran et al., 1999 and Singh et al., 2001). The Romans are the first users for lime incorporating natural materials to produce highly durable hydraulic binders and are the oldest construction materials that used before cement invention at 1700's (Malinowski et al., 1991 and Spence et al., 1974). Pozzolanic reaction calcium hydroxide generated by calcium silicate hydrate and calcium aluminosilicates hydrate with wished durability and binding characteristics, pozzolans enhances the properties of blended cements, different clinker substitution levels can be published stand on the type and surface area of pozzolans and properties of theOrdinary Portland Cement (OPC) (Hewlett et al., 1998 and Ramachandran et al., 1999). It is widely believed that the calcined artificial pozzolans, such as calcined clays, at an ideal temperature of 800-850°C would produce the most pozzolanic reactivity (Wild et al., 1996). The fire behaviors of clays are controlled by their chemical and mineralogical constituents (Murat, 1983). A large amount of waste fired clay bricks WFCBs has been generated from the demolition of buildings, and according to statistics, the quantity of WFCBs generated from the demolition waste and building operations are about 50-70% and 30-50% respectively (Li , 2005). The worldwide annual production of bricks in 2015 was 1500 billion units and the annual demand for bricks is expected to increase continuously by 5-6% (Halblazig –Zig, 2014 and2019). A lot of researches have proposed that the use of WFCBs as pozzolanic materials in the blended cement improve some properties and minimize the production cost. Moreover, when cement clinker is partly replaced by WFCBs with different percentages (0-50 %), the strength value of mortar would be raised up to 10% cement replacement (Naceri et al., 2009, Cheng et al. and Tian 2014, Wang, 2012 and Ma, CT., 2009). When the percentage of WFCBs increased above 10%, the compressive strength of mortar had reduced (Wu XM, 2004). When cement clinker is partially replaced by clay brick waste, the strength accelerated slowly at early stage of hydration and setting time and water of consistency are increased (Lin et al., 2010 and Han et al., 2015).When the replacement level of calcined clay bricks waste is 20% from cement, it has estimated to reduction of CO_2 emissions by about 10% (Toledo et al., 2007). Incorporating OPC paste up to 25 % with Homra (ground fired defective clay bricks) improved the compressive strength when the dose of Homra is 20 wt%. Furthermore, the paste cement mix with Homra is thermally stable between 100ºC and 400°C, and additional C-S-H cement compounds resulted from pozzolanic reaction reduce the pore system (Heikal, 2000). Loss on ignition for different hardened paste cements is raised with increasing of Homra content as well as temperature increased. Also, the apparent porosity is raised while density decreased at temperature between 400 - 500ºC (Darweesh, 2017). Some of researches have provided that the use of waste ceramic tiles (WCTs) as pozzolanic materials can improve some engineering properties, and reduce the production cost. Incorporating OPC paste with (TCW) up to 35 wt% satisfy the strength activity index (SAI) fixed by fly ash limitations (Maria et al., 2016). Ceramic waste can be used as pozzolanic material to decrease CO2 emission and stabilize hydration heat up to 28 hours. The WCT addition consumes, partially, the CH by pozzolanic reaction effecting the decreasing of bothcompressive strength at early age and the porosity as well as specimen density (Viviana et al., 2019). Ground waste ceramic has applied in the blended cements (CEMII) with substitution ratio until 35%. The use of 5% replacement level by ground ceramic has no effect on the control paste and mortar cement, where the CH converted to CSH through the pozzolanic reaction of ceramic waste (Sadek, 2018). The addition of clay bricks as partial substitution for white cement led to reduce the whiteness of cement, delay setting time of blended cement and porosity. Moreover, it increases water content, compressive strength and density as a result of pozzolanic reactivity of fired clay bricks (Mohamed, 2022). Pozzolanic reactivity and compression strength value are improved more slowly at early stage due to the substitution of clinker with pozzolana. This is relatedto the rate of the pozzolanic reaction where it is really slow at early time (Massazza, 1993). At a later stage, the compressive strength increases due to the hydration precedes more new hydration products such as CSH and CASH causing rise in compressive strength value of blended cement pastes (Massazza, 1993 and Commite, 1994). The main objective of this study is to investigate the addition of some industrial wastes as partial replacement of cement clinker on the properties of blended cement mortars.

Materials methods and techniques

Starting rawmaterials

The used raw materials are: Ordinary Portland Cement Clinker (OPCC) delivered from Al-Arish Cement Company (ArCC); fired clay bricks (WFCBs) wastes collected from Mit Ghamr clay bricks; ceramic tiles (WCTs) wastes collected from Ceramic Cleopatra Group; vitrified clay pipes (WVCPs) wastes collected from Sweillem Clay Pipes Company; and gypsum has been extracted from gypsum quarry in Ras Sudr South Sinai. CEN Standard sand shipped in bags with 1350 ± 5g weight from France was used. Distilled water has been used.

Fig.1.Photographs showing industrial waste of landfills sites: (a) WFCBs beside a clay brick factory. (b) Construction area (c) Demolition area. (d) (WCTs) and (e) (WVCPs).

Methods and techniques

The studied industrial waste materials, ordinary Portland cement clinker and gypsum have crushed and grounded in ball mill to pass through a 200-mesh sieve size, then quartered. These are conducted in the Centralized Laboratories of the Housing and Building National Research Center (HBRC) and Nuclear Materials Authority (NMA) in Egypt. The prepared materials are analysed by X-ray florescence (XRF) of an Axios sequential spectrometer manufactured by PANalytical, Netherlands. The crystalline phases of clinker, studied industrial waste and selective treated specimens for determining hydration phases, are examined by XRD technique of a BRUER, Axs D8 ADVANCE A8, and using Germany Diffractometer at Nuclear Materials Authority (NMA) Laboratories. Clinker phases are estimated according to Bogue's equations (Robert, 1929). Calculation of water consistency and setting times of cement pastes have been measured according to the European Standard (BS EN 196-3). Setting times of cement pastes have been performed using Automatic VI vat Needle Apparatus (Toni SET Classic). Compressive and flexural strengths of the lab-made blended cement mortars are executed in Laboratories of Sinai Cement Company (SCC) and Laboratories of El-Arish Cement Company (ArCC) according to ASTM (C349-18) and ASTM (C348-21) respectively. Schimaduz DTA-50 (Co-Kyoto, Japan) thermal analyzer device is used to identify the hydration phases of cured blended mortars specimensand carried out in Nuclear Materials Authority (NMA) Laboratories. In order to describe the morphology and micro-structure of broken parts of hardened treated specimens of different mixes, the scanning electron microscope (SEM) is carried out using Model Quanta 250 FEG (Field Emission Gun), with magnification ×14 up to ×1,000,000, accelerating voltage 30 KV and resolution for Gun.1n)

Mix Composition and Mortar specimens preparation

In order to investigate the effect of industrial wastes on the properties of OPCC, thirteen mixes namely C.0 (blank mix), (C.1-C.12) are designed for study and sand: cement: water ratio, which is 3: 1: 0.5 (Table. 1). To process the experimental work, the mix ingredients have been ground, then mixed in an electrical mixer for 3 minutes, and water has been added and re-mixed until a homogeneous paste was achieved. Then, the cement mortar is poured in 40×40×160 mm steel prism molds. The molds are carefully vibrated to remove the air bubbles. The fresh mortar is maintained in the molds inside a humidity cabinet at 20°C and relative humidity at least 90% for 24 hours before demolding. The hardened specimens are demolded and treated in water tank at the room ambient conditions till the testing times of 7 and 28 days. At the end of curing period, a series of test is carried out to determine selected properties of the hardened blended cement mortar specimens in terms of compressive and flexural strengths tests. The averages of tests on three repeated specimens are calculated.

Table 1: Compositions and properties of the studied mixes (wt.%) incorporating industrial wastes

Mix No.	OPCC	WFCBs	WCTs	WVCPs
C.0	95	-	-	-
C.1	85	10	-	-
C.2	80	15	-	-
C.3	75	20	-	-
C.4	70	25	-	-
C.5	85	-	10	-
C.6	80	-	15	-
C.7	75	-	20	-
C.8	70	-	25	-
C.9	85	-	-	10
C.10	80	-	-	15
C.11	75	-	-	20

Results and Discussion

Chemical characteristics

The oxides compositions of the OPCC sample (Table .2) reveals that the sample is composed primarily of CaO, SiO_2 as well as Al_2O_3 and Fe_2O_3. The calculated clinker phases in decreasing order of abundance are C_3S, C_2S, C_4AF and C_3A. All studied industrial wastes show that the major elemental oxides are SiO_2, Al_2O_3 as well as Fe_2O_3. CaO is recorded as a minor amount (about 5%) in WFCB and WCT. The composition of gypsum sample shows that the most common chemical composition of gypsum deposits is SO_3 and CaO. The comparative study between standard eligible criteria (BS 8615-1:2019) for pozzolanic activity and present results (Table .3)reflect that all studied wastes achieved all listed parameters for pozzolanic materials.

Table 2: The chemical composition (wt. %) in terms of oxide content, loss on ignition, clinker phase and free lime for the studied materials.

Oxides	OPCC	WFCBs	WCTs	WVCPs
SiO_2	21.30	63.64	62.55	59.90
Al_2O_3	5.88	18.17	16.22	26.60
Fe_2O_3	4.23	5.56	7.65	8.08
CaO	66.00	4.92	5.38	0.20
MgO	1.25	1.32	0.88	0.40
SO_3	0.69	1.50	1.40	1.20
K_2O	0.20	1.37	2.45	1.24
Na_2O	0.29	0.90	2.11	0.43
TiO_2	0.03	0.94	0.74	1.74
Cl	0.04	0.07	0.05	0.08
P_2O_5	0.08	0.22	0.32	0.13
LOI	0.20	1.46	0.30	0.20

Ordinary Portland cement clinker (OPCC), waste of fired clay bricks (WFCBs), waste of ceramic tiles (WCTs), waste of vitrified clay pipes (WVCPs), free lime (FL), alite (C_3S), (C_2S) belite, aluminate (C_3A) and ferrite (C_4AF).

Table 3:Comparative results between standard eligible criteria for pozzolanic materials according (BS 8615-1:2019) and the used industrial wastes.

BS 8615-1:2019			Wastes used		
Property	Result	Test method	WFCBs	WCTs	WVCPs
Loss on ignition	≤ 7.0%	BS EN 196-2	1.45	0.30	0.20
Chloride content	≤ 0.1%	BS EN 196-2	0.07	0.05	0.08
Sulfate content	≤ 3.0%	BS EN 196-2	1.5	1.40	1.20
Free calcium oxide	≤ 1.5 %	BS EN 451-2	0.2	0.00	0.00
Sum of oxides (SiO_2+Al_2O_3+Fe_2O_3)	≥ 70.0%	BS EN 196-2	87.37	86.42	95.3
Magnesium oxide	≤ 4.0%	BS EN 196-2	1.32	2.45	1.20
Reactive calcium oxide	≤ 10.0%	BS EN 196-2	4.92	5.38	0.40

Waste of fired clay bricks (WFCBs), waste of ceramic tiles (WCTs), waste of vitrified clay pipes (WVCPs).

Mineralogical compositions

Mineralogical composition of the used materials (OPCC, WFCBs, WCTs and WVCPs) and selected hardened mortars of different mixes (C.0, C.1, C.3, C.5, C.7, C.9 and C.11) are illustrated in XRD patterns (Figs.2 and 3). The XRD pattern of OPCC sample matched with its chemical phase's composition. The XRD pattern of WFCB sample shows that it is composed manly of quartz (SiO_2) and sanidine ($KAlSi_3O_8$). Mineralogically, the WCTs sample is composed of well-crystalized quartz and vaterite ($CaCO_3$) that may be formed from the hydration of stored cement and found by water vapor and air for prolonged contact (Ewa et al., 2003). Vaterite is unstable $CaCO_3$ polymorphs and mostly water soluble and is gradually changes to calcite (Per, 2003). Also, poorly crystallized form of mullite ($Al_2O_3.SiO_2$) phase (highly temperature mineral) is detected. The XRD pattern of WVCPs sample illustrates that the sample is mainly composed of quartz and cristobalite (SiO_2) and minor amount of mullite phase. XRD pattern (Fig. 3) revealed that blank mortar is composed mainly of quartz and hydration phases of tobermorite $Ca5Si_6O_{16}(OH)_2.4H_2O$ {calcium silicate hydrate, (CSH)} and {portlandite $Ca(OH)_2$,(CH pozzolanic activity increased (hydration phases) and CH decreased due to its consumption in the CASH formation)}. The results prove that as industrial waste increased, the cement clinker amount decreased and pozzolanic activity increased (hydration phases) and CH decreased due to its consumption in the CASH formation.

Thermal properties of the hardened blended cement mortars

DTA/TG patterns are used to identify the essential hydrate products shaped by their mass of loss (CSH, CH, C) for the different prepared cements (Alp et al., 2009 and Barbara et al., 2016). The DTA and TGA thermograms patterns (Fig. 4) of selected hardened blended cement mortar specimens (C.0, C.1, C.3, C.5, C.7, C.9 and C11) are treated for 28 days show the existence of the endothermic peaks at 51, 96, 473, 481, 493, 634, 700, 718, 722, and 731°C. The endothermic peaks lower than 200°C are generally caused by the dehydration, (free water), tobermorite phase (CSH gel) as well as calcium aluminosilicate hydrate (CASH). It is companied with loss of mass percentages 2, 2, 2.5, 2.2, 2.7, 2.3 and 2.6 (%) for C.0, C.1, C.3, C.5, C.7, C.9, and C.11 respectively. The endothermic peaks between 470° C to 500° C describe the dehydroxylation of $Ca(OH)_2$ (portlandite). It is associated with loss of mass equal 1.8, 1.2, 0.8, 1.15, 0.7, 1.1 and 0.9 (%) for C.0, C.1, C.3, C.5, C.7, C.9 and C.11 respectively.

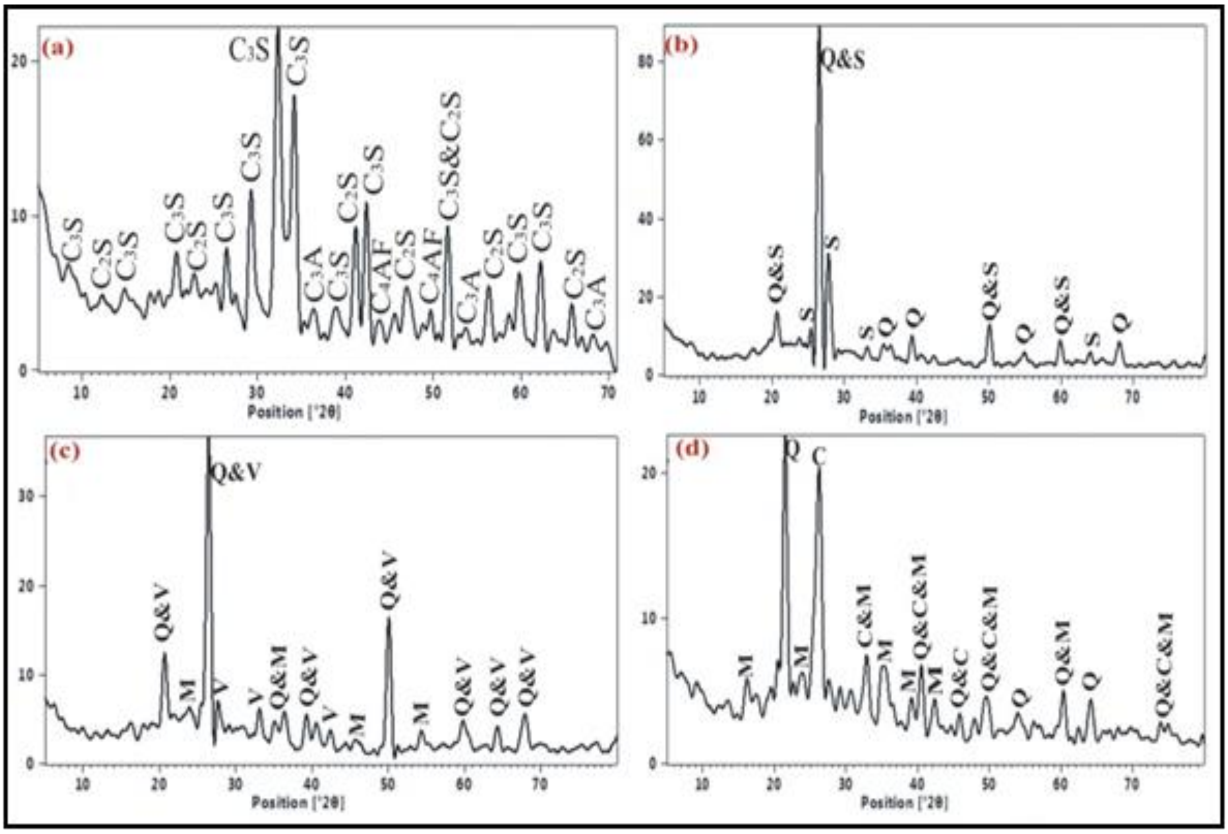

Fig.2. XRD patterns of clinker (a) (WFCBs) (b) (WCTs) (c) (WVCPs) (d) Q: quartz (SiO2) C3S: Alite. C2S: Belite, C3A: Aluminate, C4AF: Ferrite, M: mullite (Al2O3.SiO2), S: sanidine (K Al Si3O8), V: vaterite (CaCO3), C: cristobalite (SiO2).

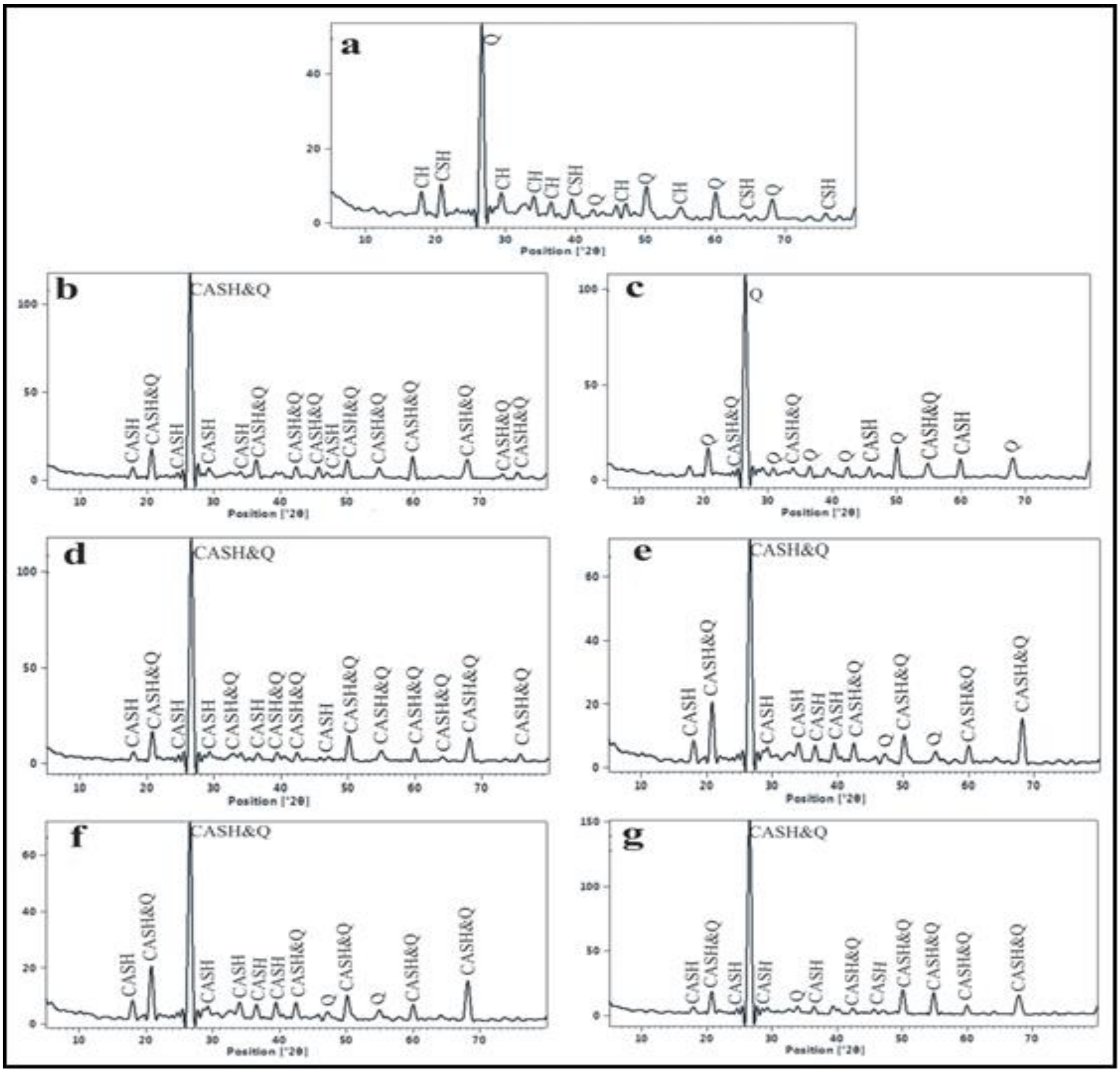

Fig.3. XRD patterns of hardened mortar specimens cured for 28 days, blank mortar (a) 10 Wt.% (WFCBs) (b) 20 Wt.% (WFCBs) (c) 10 Wt.% (WCTs) (d) 20 Wt.% (WCTs) (e) 10 Wt.% (WVCPs) (f) and 20 Wt.% (WVCPs) (g) . Q: quartz, CH: portlandite, CSH: Calcium silicate hydrate (tobermorite) and CASH: calcium aluminate silicate hydrated.

Whereas the broad exothermic peaks effect ranges from 630 Cº to 750 Cº is referred to calcination of calcium carbonate. It is companied with a remarkable loss of mass about 7.6, 5.6, 6.7, 7.5, 8.2, 5.8 and 6.2(%) for C.0, C.1, C.3, C.5, C.7, C.9, and C.11 respectively. The results reflect that the peak field and content of portlandite (CH) of all the studied blended cement mortars is smaller than the blank mortar. It is a result of pozzolanic reactions between studied wastes and cement matrix leading to (CH) consumption (Eloy et al., 2020 and Anjaneya et al.,2021).

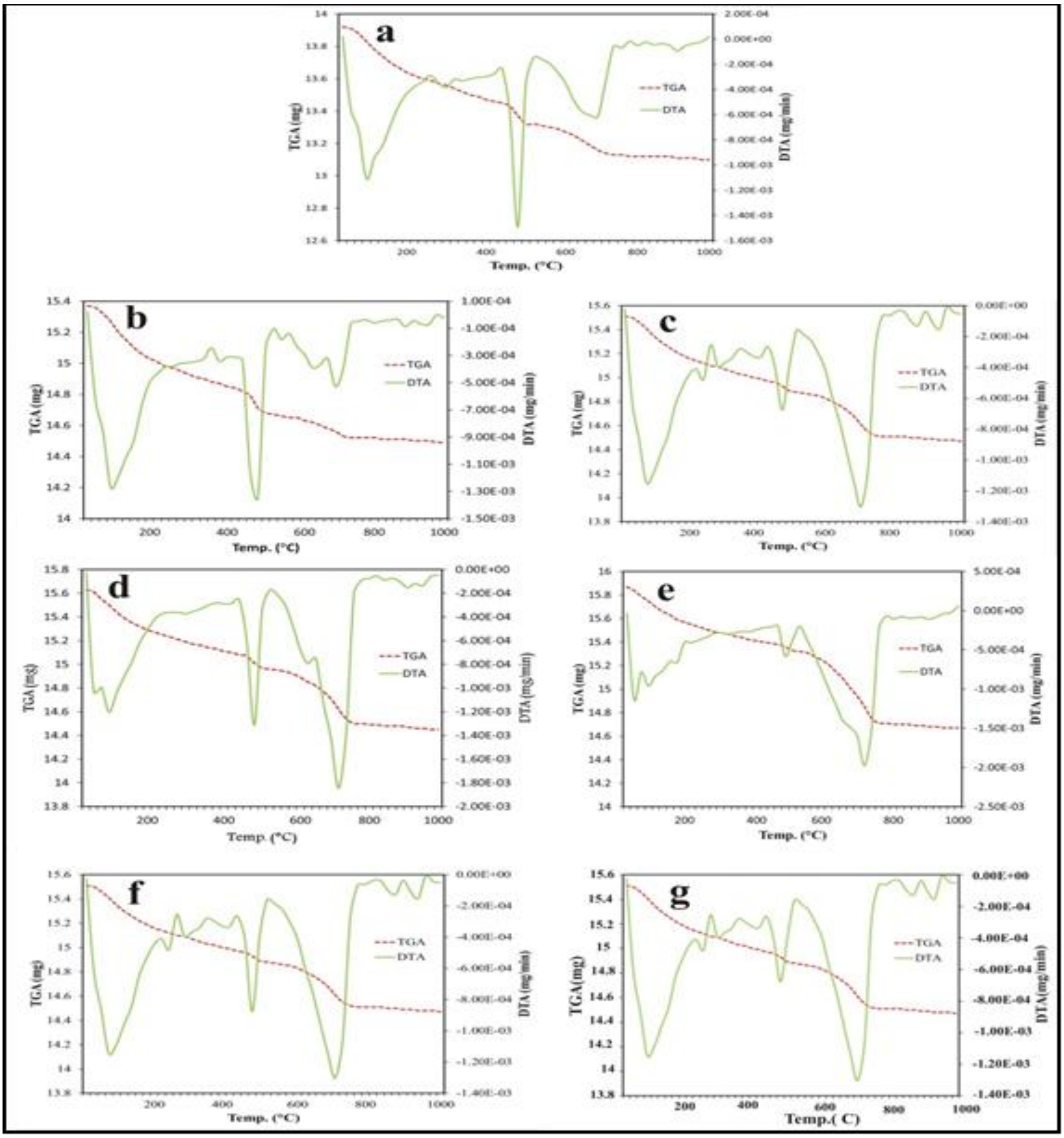

Fig.4. DTA and TGA thermograms of mortar specimens cured for 28 days, blank mortar (a) 10 Wt.% (WFCBs) (b) 20 Wt.% (WFCBs) (c) 10 Wt.% (WCTs) (d) 20 Wt.% (WCTs) (e) 10 Wt.% (WVCPs) (f) and 20 Wt.% (WVCPs) (g).

SEM of the studied materials and hardened blended cement mortars

The microstructure of the used materials and some selected 28 days cured hardened blank mortar specimen and blended cured cement mortar specimens (C.0, C.1, C.3, C.5, C.7, C.9, and C11) are shown in figures (5 and 6) respectively. The compounds and quality of the clinker samples can be investigated carefully using the energy dispersive x-ray spectrometry technique (EDAX) to establish chemical composition and semi-quantitative distribution of the distinguished minerals in the clinker samples (Wickert, 1984). The microstructure of the studied clinker sample tested by SEM Figure (5a) reveals that the main phases are alite (hexagonal crystal), belite phases (rounded grains in clusters form) and the interstitial phases of aluminate and ferrite phases (irregular to lath-like crystal shape). The irregular shape, porous surface, and rough texture can be observed in the studied industrial waste materials (Fig. 5b-5d). Hematite appears as a pseudo-cubes, mosaic texture, and irregular randomly oriented crystal form. Quartz is an angular roughly crystals form (Depeng et al., 2022). Cristobalite is octahedral crystal form of fused silica. Mullite is elongated acicular prismatic crystal form (Farouk et al., 2019 and Lee et al., 2008). The SEM micrographs of the investigated blank hardened mortar and some selected hardened blended cement mortar specimens (C.0, C.1, C.3, C.5, C.7, C.9, C11) treated for 28 days (Fig. 6) illustrate that quartz and hydration phases, of ettringite crystal as needle-like form, amorphous products (CSH-gel), CH portlandite (elongated hexagonal crystals). In all investigated blended cement mortars, portlandite and free lime were consumed CASH formation (like honeycomb-texture). That may be owing to pozzolanic reaction between at the expense of industrial waste materials and CH (Awoyera et al., 2017, Shigeta et al., 2018, Franus et al., 2015, Kunal et al., 2016 and Myers et al., 2015). The low Ca/Al ratio for prepared blended cement compared to OPC is contributed to formation of CASH (Guangxiang et al., 2023). XRD and TGAdata match with SEM results. The EDX analyses indicate that the addition of these pozzolanic materials in all mortar leads to the increasing of Si and Al peaks specially by the increase the (10-25%) substitution level compared to the blank mortar specimen.

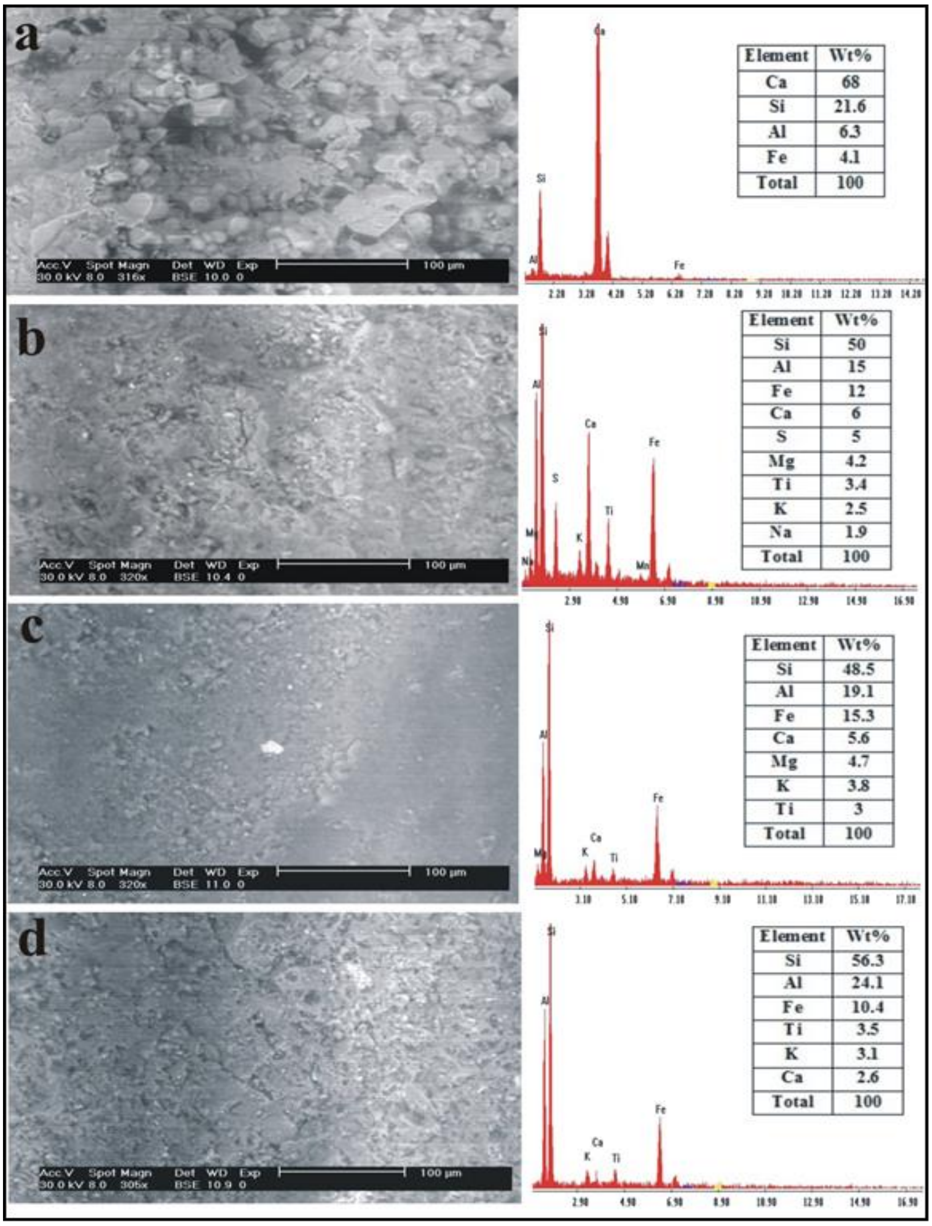

Fig.5. SEM micrographs shows microstructure (a) clinker; (b) (WFCBs); (c) (WCTs); (d) (WVCPs) and its EDX spot micro-analyses

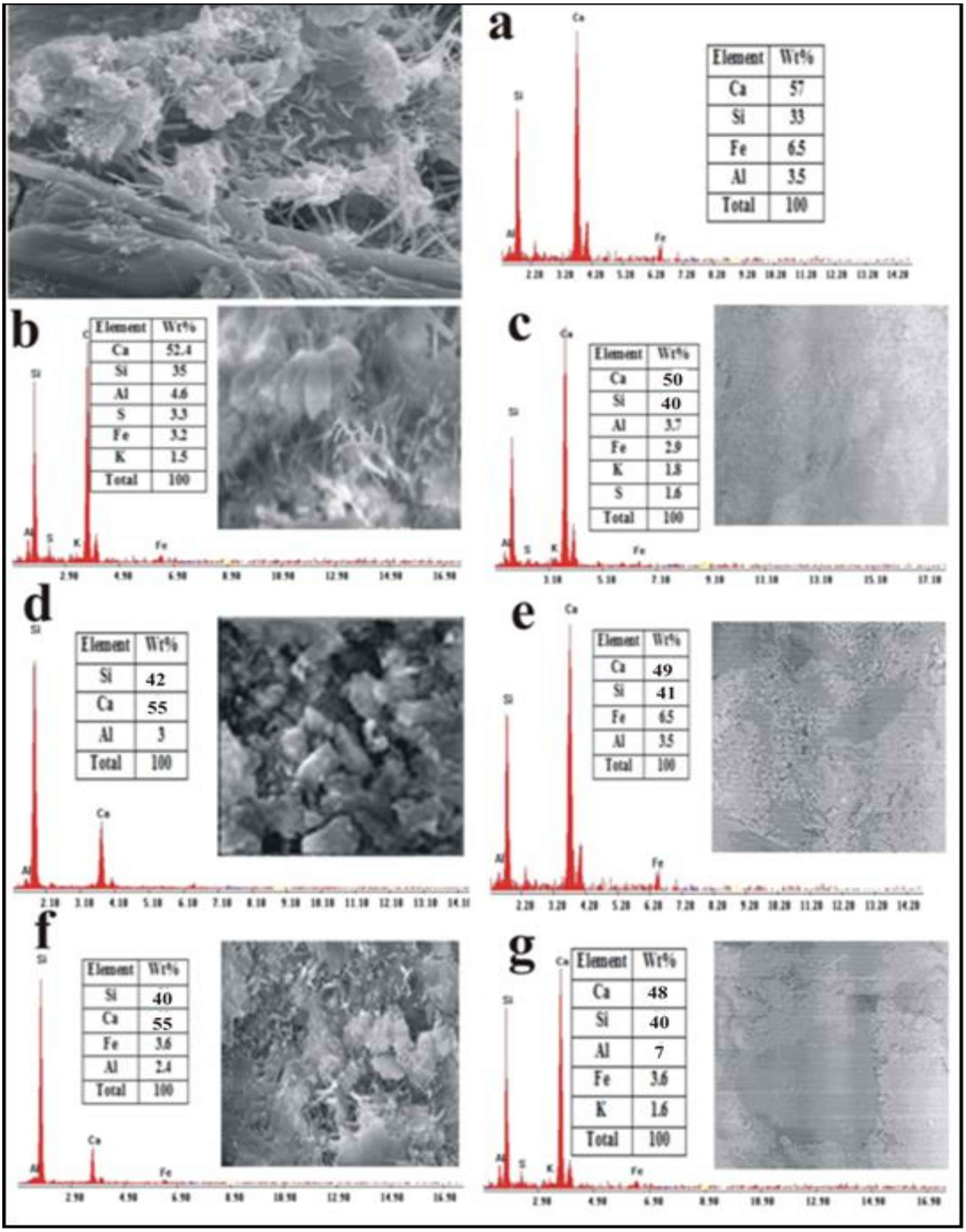

Fig.6. SEM micrograph shows microstructure of hardened cement mortars cured for 28 days (a) blank, (b) 10 Wt. % (WFCBs); (c) 20 Wt.% (WFCBs), (d) 10 wt.% (WCTs), (e) 20 wt.%(WCTs), (f) 10 wt. % (WVCPs), (g) 20 wt. % (WVCPs) and its EDX spot micro-analyses

Phyco-mechanical properties of the studied cement pastes and hardened blended cement mortar specimens

The setting time of blank and blended cement pastes and water of consistency are given in table (4). The water of consistency increased with the increasing of replacement ratio of clinker by industrial wastes. Also, setting times of the blended cement paste increases with the waste replacement ratio. Occasionally, the replacement of clinker by clays industrial wastes delays the setting time of cement. This is as a result of the little pozzolanic behavior of studied waste at early time of curing (Taha et al., 1981). These wastes possess high concentration of SiO_2, Al_2O_3, Fe_2O_3, K_2O and Na_2O compared to clinker (Hamdy et al., 2011). The increasing of water consistency of the studied industrial waste materials powder may be due to their active surface area. The porosity is reduced by the filling of some pores by hydration products (Hamdy et al., 2011 and Kae et al., 2010). The added water is increased with increasing of waste amount, so the setting times are increased (Marangu et al., 2018). The average strength results of the prepared 7 and 28 days cured specimens (Table .1) with replacement ratios of (10, 15, 20 and 25 wt. %) for the clinker cement (Table .4) revealed that a significant gradually decrease in the compressive strength with increasing the replacement ratio of the studied industrial waste materials. These results match with several published data as (Peng et al. 2022) ,(Bahforouz et al. 2020), (Vejmlkova et al. 2014) and (Heidari et al. 2013). The highest value of the compressive strength (C5 = 40.5 MPa) is recorded with the replacement ratio of 10% WCTs and the lowest value of compressive strength (C12 = 33MPa) is noticed at a replacement ratio of 25% for WVCPs. At the late ages of curing at 28 days, the compressive strength of blank mortar is greater than all studied hardened blended cement mortars and mortar contained 10% (WCTs) has a higher value (C5 = 54.9 MPa) comparable to the lower value that recorded in mortar containing 25% (WCTs; C7 = 43 MPa). These results match with Juarez et al. (2021) and Chania et al. (2017). The flexural strength, specimens that contain 10% (WCTs; C5 = 9.8 MPa) have higher flexural strength at the later stage of curing at 28 days compared to the blank mortar (Cailos et al., 2020). It is can note that the compressive strength value of mortars is proportionate to its flexural strength, where the higher flexural strength is related to the higher compressive strength. The SAI strength activity index is defined as the is ration of the compressive strength value of blended cement mortar including a pozzolana, divided by the compressive strength value of a blank cement mortar,where subjected to same curing conditions according to ASTM (C0311-11B).The SAI increases with decreasing replacement ratio and enhances with increasing curing time. Except the mortar replacement level 25% (73%) from WCTs, and 25% (74.5%) from WVCPs, all replacement levels of the industrial waste in this study are similar to the strength index recognized by fly ash limitations greater than 75% of (Maria et al. 2016). The results show that the strength of blended cement mortars values came closer to the blank mortar (with no wastes) if the amount of dose from recyclable waste industrial materials is less than 10% wt.. The recorded data displayed a rising in setting time leading to rising in the compressive strength. Also, compressive strength of prepared blended cement mortars are enhanced with increasing curing time.

Table 4: Physic-mechanical testing of the studied hardened blended cement mortars

Mix No.	Initial setting time (min.)	Final setting time (hr.)	Water Consis-tency%	Average Strength (MPa) 7days Flexural	7days Compressive	28days Flexural	28days Compressive	SAI% ≥ 75 % At 28 days
C.0	85	140	26	9	46.8	10.3	58.4	100
C.1	112	155	27.6	8	40.2	9.2	54.3	93
C.2	113	157	27.2	7	38.7	8.1	50.5	86
C.3	114	159	27	6.8	36.3	7.5	48.9	83
C.4	116	162	26.8	6.4	34.4	7.2	46	78
C.5	125	190	26.8	8.3	40.5	9.8	54.9	94
C.6	120	180	27	7.1	37	9	50	85
C.7	105	170	27.2	7.7	35.2	8.2	45.5	77
C.8	100	165	27.5	6.3	32.8	7.7	43	73
C.9	105	150	26.8	8.5	39.5	9	52.9	90.5
C.10	112	160	27	7.6	37.9	8	49.8	85
C.11	120	170	27.3	7.1	35.8	7.5	46.9	80
C.12	128	180	27.8	6.1	33	7.1	43.5	74.5

(SAI %) Strength activity index (ASTM C311/C311M-22).

Conclusions

Nowadays, the development of recyclable materials as raw materials in the cement industry as well as the studied materials in Egyptian emerging economy is facing many challenges, such as theses varying in resources, chemical, mineralogical composition, and industrial processes. These industrial wastes require more efforts from researchers, technical centers, current policies, strategies, and laws from governments to stimulate their reuse.

Based on the laboratory investigations and the obtained data it can conclude that:

1. The studied industrial clay wastes have a potential use for producing pozzolanic blended cement. These wastes have chemical and mineral compositions that are suitable for reacting with portlandite to form the cementing compounds as (CASH) by pozzolanic reaction.
2. Utilization of the investigated industrial wastes as recyclable materials to from blended cement contributes to the mitigation of CO_2 footprint as an environmental concern, cost reduction of cement production as financial concern and the preservation of natural resources of cement industry as social concern.
3. The compressive strength of the studied blended cement mortars came closer to the blank cement mortar (with no wastes) with recyclable materials less than 10%.
4. The studied wastes lack waste management in terms of limiting their quantities, collecting them at a collection point, defining, classifying, sorting them chemically, and treating them mechanically, i.e., reducing their sizes to conform to cement, concrete and construction codes, transporting them to factories, and providing continuous supply to cement factories.

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