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PERFORMANCE EVALUATION OF CEMENT MORTAR CONTAINING CONSTRUCTION AND DEMOLITION WASTE AS SUPPLEMENTARY CEMENT MATERIALS

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The purpose of this study is to investigate the effect of fine powders from construction and demolition waste (CDW) as a replacement for cement on the properties of fresh and hardened cement paste and mortar. Specifically, the study focuses on three types of waste powders (WPs) which are: waste brick powder (WBP), waste concrete powder (WCP) and mixed waste powder (MWP). Each type of WP is used to replace 0 % to 15 % of cement. First, the milled powders are assessed in terms of their morphology (SEM) and composition (X-ray diffraction (XRD) and X-ray fluorescence (XRF)). Such an assessment is carried out based on consistency and setting time tests in order to examine the fresh behaviour of the cement pastes. Second, the mechanical properties, mineralogical and microstructural characteristics are evaluated in order to elucidate the effect of various WPs on the mortar samples. The results demonstrate that, according to the required standards, the use of each WP up to 15 % does not alter the mechanical properties of the cement mortar. However, the use of 5 % and 10 % WBP replacement levels was adequate for improving the strength. Thus, a 52.9 MPa maximum strength was achieved with this mix. Furthermore, the microstructure analyses indicate that the WBP and WMP show a denser mortar structure compared to the reference one. Consistent with the microstructural analyses, the mineralogy analysis reveals that the WBP and MWP have a significant impact on the hydration products of the elaborated mortars.

INTRODUCTION

Due to the growing world population and rapid urbanisation development, the demand for the production of construction materials has increased in the last few decades. Relatedly, since its invention, cement has been considered as the most widely used binding agent that is used in building materials. At an international level, the statistics indicate that the total annual cement production was higher (about 4.1 billion tonnes in 2020) compared to recent years [1].

In parallel, the rapid acceleration of the population and urbanisation is accompanied by a large amount of construction and demolition waste (CDW) produced annually on a global scale. It is estimated that three billion tonnes of CDW per year are produced in 40 countries worldwide [2]. Currently, the generation of high amounts of CDW as well as the massive production of cement constitute major sources of many socio-economic and environmental issues. Along with other economic sectors, the cement sector is a major contributor to the anthropogenic greenhouse gas emissions, especially carbon dioxide (CO_2) with approximately 7 % of the CO_2 global emissions [3, 4]. This will, in turn, increase global warming, causing other adverse effects, such as the acidification of water, health risks, drought, etc. [5, 6]. CDWs also constitute a direct cause of CO_2 emissions particularly through their transportation and treatment process. In line with such problems, many governments in the world are faced with the urgent need to establish new regulations and policies to reduce the environmental damage, especially those associated with waste disposal. For example, the Spanish Ministry of Public Works issued a code in the construction sector which reutilises 20 % of waste concrete [7] while the government in China implemented a law to fully utilise CDW or dispose of it harmlessly [8]. The office of Moroccan economic policies issued a decree about the building sector at the national level. This decree is meant to attain a CO_2 mitigation of approximately 8 % and energy conservation of 20 % by 2030 [9].

In this regard, many researchers have conducted several studies on the reuse of CDW. While most of the studies emphasised the possibility of using CDW as an aggregate for road applications [10, 11], others dealt with alternative solutions to re-utilise CDW as aggregates (coarse or fine) in cementitious materials (concrete or mortar) [12, 13, 14]. Nowadays, researchers are interested in using fine powder from CDW as a replacement for cement to improve the eco-efficiency of cementitious materials and, significantly, to ensure a more environmentally sustainable future. Schackow et al. [15] studied the impact of the partial substitution of cement by clay brick waste on mortar properties and concluded that 40 % of clay brick waste replacements provide better performance regarding the strength development and density. Another study by Ortega et al. [16] indicated that the use of waste brick from demolition debris up to 10 % improves the mechanical properties of mortar. Shao et al. [17] confirmed that the properties of mortar containing clay brick powder up to 20 % present better performance than the control mortar. The compressive strength of mortar with 20 % waste clay brick powder was 62.2 MPa, and the strength was increased by 4.2 % at 90 days compared to the reference mortar. It can be noted that those results are generally grounded on the pozzolanic effect of the waste brick's fine particles. As products of the pozzolanic reaction, additional C–S–H and C–A–H compounds would be formed, reducing the pore sizes. Thus, the microstructure became more compact.

Different scholars [18, 19] have also analysed the effect of waste clay brick on the properties of the mortar. On the other hand, being interested in the study of fine powders from concrete waste, some scholars reported that fine fractions of concrete waste could be reused after heat treatment, as an alternative raw material in the production of Portland clinker. Even though this method proved efficient in valorising concrete waste, it still remains costly. Another group of researchers aimed to evaluate the incorporation of fine concrete waste, as a cement replacement, in building materials (mortar and concrete). Oliveira et al. [20] studied the effect of using fine concrete waste as a cement replacement (0 %, 15 %, and 25 % by cement weight) on the mechanical and microstructural properties of composite materials. The results indicated that a 25 % substitution by fine concrete waste did not show significant changes in the mechanical performance compared to the conventional material. Other studies demonstrated that the amount of waste concrete powder should be limited to 15 % in the production of a cement mortar [21]. However, there is, until now, little literature about the use of waste concrete powder instead of cement in the production of cementitious materials.

CDW, reclaiming into fine powder as a supplementary cementitious material to substitute part of cement, is limited to the study of one type of waste, especially clay brick waste, because of its pozzolanic activity. However, CDW mainly stems from construction, rehabilitation and demolition sites. Their composition is, thus, very diverse. Despite their variability, concrete and brick waste account for the main components. The proportion of concrete and brick waste is more than 80 % of the total volume of the CDW [22]. In Morocco, about nine million tonnes of CDW are generated annually, of which concrete and brick waste are the main components [23]. Due to the fact that the country is one of the highest producers of ceramics, most masonry structures are built with red brick and concrete [24]. However, given that CDW is very rarely valorised, it is practically dumped in open landfills.

Based on the abovementioned considerations, most studies concentrated on one type of waste as a partial alternative to cement in construction materials. Nevertheless, studies of construction materials carried out from concrete and brick waste that account for the main components of CDW have not been well investigated. On the other hand, regarding the effect of each type of waste, there are conflicting results regarding the positive and negative impacts on the mortar's properties, which, therefore, requires more research. For this, the current study focuses on the feasibility of using fine powder from concrete and brick waste in different forms (separate and combined) as a replacement for cement to produce an eco-friendly cement mortar. The fresh, mechanical, mineralogical and microstructural properties of the mortar, containing fine powder from concrete and brick waste at different levels, were examined and compared. Finally, this research is meant to offer a sustainable and promising solution to minimise the environmental impacts from cement production and waste disposal, which is still a challenge facing the global industrial sector, especially in low-income countries.

EXPERIMENTAL

Materials

A type CPJ 55 Portland cement, compiled with the Moroccan standard NM 10.1004, was used for preparing the mortar mixes. It was provided by the Moroccan Lafarge Holcim Company. The chemical composition of the cement is given in Table 1 and its physical and mechanical characteristics are shown in Table 2. The fine

Table 1. Physical properties of the CPJ 55 cement.

Properties	Results obtained	Reference standard
Blaine fineness (cm^2·g^{-1})	3460	NM 10.1.005
Specific weight g·cm^{-3}	3.14	
Setting time; Initial IST (min)	155	
Setting time; Final FST (min)	250	
Soundness (mm)	0	
Residue on 45 µm sieve (%)	4	
2-day compressive strength (MPa)	≥ 20	
28-day compressive strength (MPa)	≥ 42.5	

Table 2. Chemical properties of the CPJ 55 cement.

Chemical composition	(%)
SiO_2	18.75
Al_2O_3	4.54
CaO	63.66
MgO	1.83
Fe_2O_3	3.26
K_2O	0.2
MnO	0.07
SO_3	2.18
TiO_2	0.37
Cl	0.01
Loss on Ignition (%)	4.48
Insoluble residue (%)	0.48

aggregates used in this investigation were natural sand with a maximum particle size of 2 mm (CEN EN 196-1). The specific gravity was 2.5 while the absorption was 0.2 %. The water used for the preparation of the mortars was tap water distributed by the Intercommunal Autonomous Water and Electricity Distribution Authority (RADEEF). It meets the standards of potability outlined in NM 10.1.353.

In this research, the waste powders (WPs) were divided into three types according to their nature and origin. Concrete waste was obtained from cylindrical concrete specimens (Ø 160 mm × H 211.1 mm), after performing specific mechanical tests for technological control. Because of poor management, such specimens are available in huge quantities in many civil engineering laboratories, which now cause a serious problem (Figure 1b-c). Ten samples were selected from the same engineering project with a compressive strength of around 32 MPa. The waste powder that was obtained from the latter will be hereafter denoted as WCP (waste concrete powder). The waste clay brick was collected from a construction site, in which the raw bricks come from a brickwork factory (Figure 1a), which will be termed as waste brick powder (WBP). The mixed waste powder (MWP) was obtained from the local waste management association in Sefrou (28 km southeast of the city of Fez, Morocco). MWP, the source of which is a pure mixture of leftover concrete and brick waste, was chosen to be representative of the main components of construction and demolition waste.

Figure 1. Types of construction and demolition waste (CDW) utilised in this research. Site of waste located in the city of Fez, Morocco: a) leftover brick waste; b) and c) landfill of concrete waste.

The preparation process of WPs is described as follows: First, the specimens were reduced to small fragments by using a crusher, in which only particles with diameters lower than 5 mm were selected. Second, the 5 mm fragments were put directly into a Los Angeles apparatus, containing steel balls (600 rpm). Finally, the WP was sieved through 45 µm. Different types of WPs are shown in Figure 2.

Figure 2. Binder materials used in this study: a) mixed waste powder; b) cement; c) waste concrete powder; d) waste brick powder.

The chemical composition of the cement and three WPs used are presented in Table 3. The main chemical components of the WBP are silica and alumina with 64.99 % and 19.67 %, respectively, while the main components of the WCP are lime and silica. The MWP is rich in silica, lime, alumina and other oxides. In compliance with ASTM C618 for pozzolans, both the WBP and MWP have an oxide element (Al_2O_3+Fe_2O_3+SiO_2) content higher than 70 %.

Mix proportions

In order to understand the influence of the WPs on mortar's performance, ten mortar mixtures were prepared in this study. The mortar mixtures were prepared with a binder: sand: water weight ratio of 1:3:0.5, based on the requirements stated in EN 196-1. For each type of WP, three mixtures were prepared using three different percentage substitutions of cement: 5 %, 10 %, and 15 % by weight (Table 4). A total of ten mixes including one reference mix and nine mixes were manufactured. For each mix, moulds with the size of 40 × 40 × 160 mm were used to evaluate the properties of the mortar, according to the standard EN 196-1. All the specimens were cured in a curing room with a temperature of 20 ± 1 °C and a relative humidity of 95 ± 5 % for 28 and 90 days.

Table 3. Chemical compositions and selected physical properties of the MWP, WBP, and WCP.

Parameters	Chemical compositions (%)									Loss on ignition (%)	Fineness (cm^2 g^{-1})
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	TiO_2		
MWP	44.87	16.40	9.04	23.18	2.31	1.40	0.82	0.15	0.76	1.07	3622
WBP	64.99	19.67	6.63	2.77	1.41	3.28	–	–	0.74	0.51	3667
WCP	26.55	11.20	4.21	50.30	1.10	0.77	1.64	2.37	0.20	1.66	3577

Table 4. Mix proportion of the specimens.

Designation	Waste powder (WP)	Binder:Sand:Water Weight	WP replacement (%)	Sand (g)	Binder (g)	WP (g)
Control	–	1:3:0.5	0	1350	450.0	0
WBP5	Red Brick waste	1:3:0.5	5	1350	427.5	22.5
WBP10		1:3:0.5	10	1350	405.0	45.0
WBP15		1:3:0.5	15	1350	382.5	67.5
MWP5	Concrete-brick waste	1:3:0.5	5	1350	427.5	22.5
MWP10		1:3:0.5	10	1350	405.0	45.0
MWP15		1:3:0.5	15	1350	382.5	67.5
WCP5	Concrete waste	1:3:0.5	5	1350	427.5	22.5
WCP10		1:3:0.5	10	1350	405.0	45.0
WCP15		1:3:0.5	15	1350	382.5	67.5

Figure 3. Procedure for the preparation of the WPs and equipment used in this paper at the National Center for Technical and Scientific Research (CNRST), Rabat, Morocco.

Test procedures

Consistency and setting time analysis

The consistency and setting time of the cement paste with the different WPs were measured using a manual Vicat apparatus, according to NM 10.1.005 which is identical to NF EN 196-3 (Figure 4). The standard consistency is defined as the status of the cement which permits the Vicat plunger to penetrate to a point 6 ± 1 mm from the bottom of the Vicat mould. Meanwhile, the test indicated that the reference cement paste should be prepared with a water/cement ratio equal to 0.285 to achieve a standard consistency.

The same procedure was also adopted to determine the initial setting time of the fresh mix, except that the Vicat plunger was replaced by a Vicat needle until a distance of 6 ± 3 mm. The final setting time was obtained by taking the time in which the needle cannot penetrate more than 0.5 mm from the summit of the mould. Determining the parameters of various fresh mixes is essential for their application *in situ*.

X-ray diffraction analysis (XRD)

The XRD patterns of the raw materials and mortar mixes were carried out by an X-Ray diffractometer (PANalytical X'Pert Pro), using Cu Kα1 radiation. The X-ray tube voltage and current parameters were operated at 45 kV and 40 mA. This analysis was performed in the National Center for Technical and Scientific Research (CNRST), Rabat, Morocco (Figure 3). PANalytical X'Pert HighScore Plus was also used.

Scanning Electron Microscopy (SEM)

Scanning Electron Microscopy (SEM) was used to investigate the microstructural characteristics of the different mortar mixes. The texture difference of each raw material was also identified by (SEM) before mixing.

Mechanical strength

The flexural and compressive strength of the cement mortars with a size of 40 × 40 × 160 mm was carried out following the standard EN 196-1. For each mortar mix, three specimens were measured to obtain an average value of the strength. The compressive strength R_c (MPa) is calculated as follows:

$$R_c = \frac{F_c}{A} \tag{1}$$

where: R_c is the compressive strength [MPa]; F_c is the maximum load at fracture [N]; A is the area of the platens (40 × 40 mm) [mm^2].

The flexural strength R_f (MPa) was measured using the equation below:

$$R_f = \frac{1.5 \times F_f \times l}{b \times b \times b} \tag{2}$$

where: F_f is the peak load (N); l is the distance between the supports (mm); b is the side of the prism (mm).

RESULTS AND DISCUSSION

Characterisation of the raw materials:

X-ray diffraction analysis

The mineral composition of each WP was determined by X-ray diffraction and is shown in Figure 4. The main compounds of the WCP and WMP are quartz (SiO_2), calcite ($CaCO_3$), and dolomite ($MgCa(CO_3)_2$). These phases were found to have the most intense peaks which appeared at 2θ = 26.75° (quartz), 2θ = 29.40° (calcite), and 2θ = 30.80° (dolomite). The XRD results for the WCP also revealed the presence of portlandite ($Ca(OH)_2$) which is released during cement hydration. However, quartz is mainly obtained from the natural fine aggregate used to manufacture the parent concrete. Similar phases were also found by previous authors [20, 25]. Quartz was observed to be the main crystalline phase present in the WBP, demonstrating the firing products of ceramic materials.

The cement diffractogram shows multiple peaks which are quartz (SiO_2), calcite ($CaCO_3$), alite (Ca_3SiO_5 or C_3S), belite (Ca_2SiO_4 or C_2S), and gypsum ($CaSO_4 \cdot 2H_2O$). From the characterisation results, it should be noted that the presence of silicon dioxide in the WPs may promote the pozzolanic reaction of the cementitious materials.

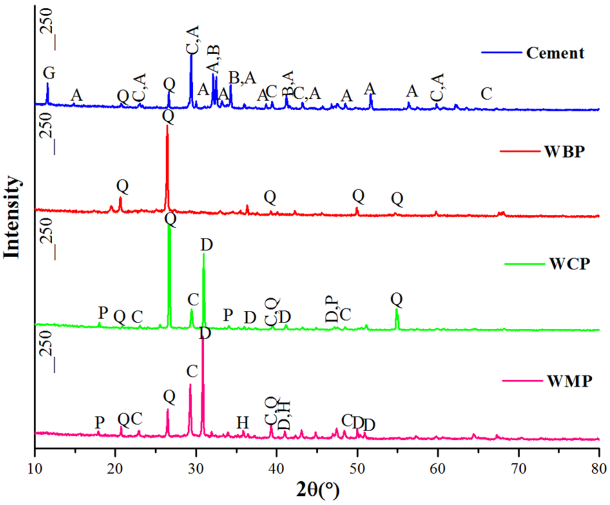
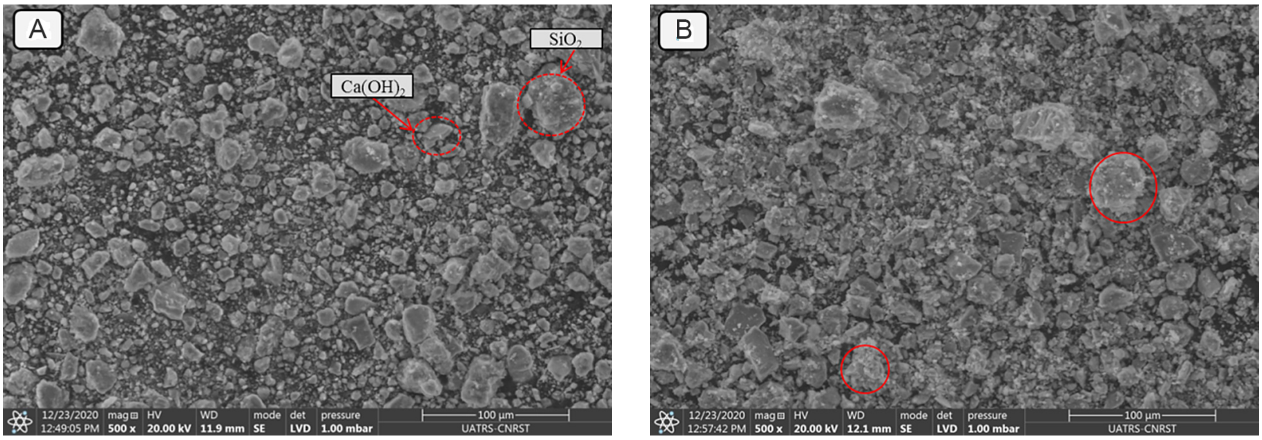


Figure 4. XRD diffractograms of the raw materials (Q – Quartz; C – Calcite; P – portlandite; D – dolomite; A – alite; B – belite; H – hematite; G – Gypsum).

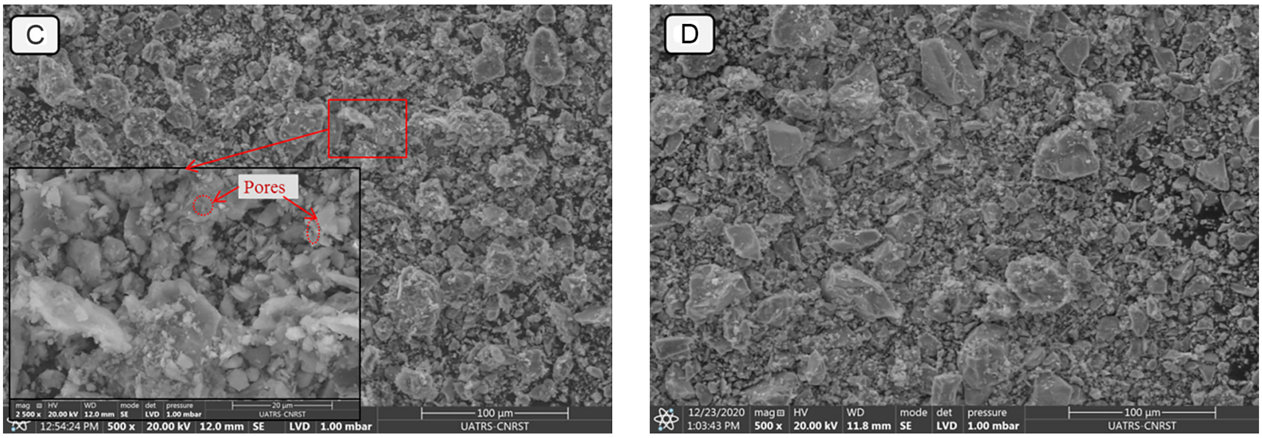
SEM analysis

The microstructure of the waste powder (WP) may affect the properties of the prepared mortar. Figure 5 show the micrographs obtained by scanning electron microscopy (SEM) of the WCP, WBP, MWP, and CPJ 55, respectively.

The micrographs (A), (B), (D) revealed that all the WPs have irregular shapes with a rough surface texture,



a) WCP b) MWP



c) WBP d) CPJ 55

Figure 5. SEM Micrographs of the WCP (a), MWP (b), WBP (c), and CPJ 55 (d).

which may be attributed to the crushing process. At higher magnification, the microstructural analysis of the WCP reveals the presence of SiO_2 and hydrated cement particles, such as ($Ca(OH)_2$) (Figure 5a, see the red mark). The latter is mostly derived from the hydration process of cement paste in the composition of the original concrete. Similar SEM results were reported by several other authors [22]. In terms of the WBP, there are some micropores in its microstructure, which may increase the water absorption and, thus, negatively impact the workability of the cement paste (Figure 5c). It was also observed that the MWP particles have an irregular shape with fine particles attached to the surface of the large ones (see the red circle in Figure 5b).

Characterisation of the cement pastes and mortar specimens

Standard consistency

The results indicate that adding WCP, WBP, and MWP requires a higher water demand to achieve a standard consistency than the control cement paste (Figure 6). The water demand for the control cement paste to attain a standard consistency was 28.5 %, and this value increases to around 31 % for a larger MWP incorporation. This effect can be attributed to the irregular shapes and rough surface differences of the WPs. The highest value in the case of the MWP may be due to the fine particles attached to their surface that increase the specific surface area, thus leading to higher water demand. The results of the microstructural analysis can clarify this matter. Zhao et al. [26] studied the effect of waste brick powder (WBP) on the consistency of cement paste. It was observed that the water demand of the WBP mixture increases as the WBP replacement ratio increases.

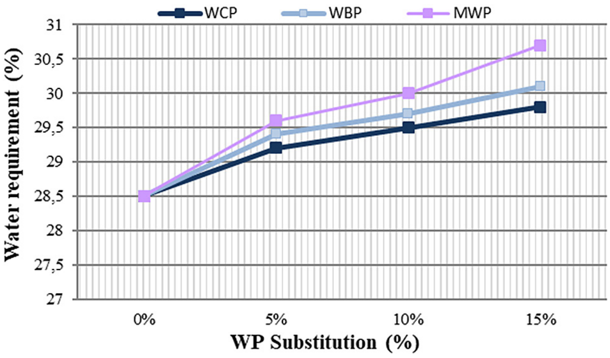


Figure 6. Water requirement of the blended cement pastes.

Setting times

Figure 7 presents the setting time results of the cement pastes incorporating the different WPs. The initial and final setting times of all blended cement paste was observed to be more retarded than the control cement paste. The latter had the lowest setting time, while that containing 15 % of WP had the highest. This effect is due to the incorporation of WP, which reduced the amount of hydration products, thus prolonging the setting times. The minor differences in the values of the blended paste's setting time can be attributed to the higher water-binder ratio that requires more time to achieve a stiff cement structure. The results agree with those previously reported by Kim et al. [21].

The requirement specifies that the initial setting time should not be less than 60 min and the final setting time should not be more than 720 min (12 h). Meanwhile, the results of setting times show that all the pastes fulfil the standard limits of NM 10.1.005.

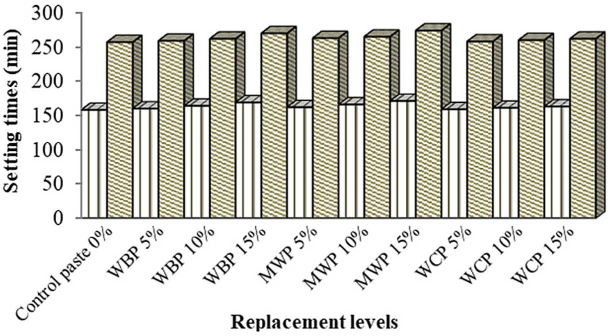


Figure 7. Setting time of the paste with the WCP, WBP, and MWP.

The compressive and flexural strengths of the WP based mortars at different curing ages (28 and 90 days) are reported in Figures 8 and 9, respectively. As shown in Figure 8, the compressive strength of all the blended mortars at 28 days decreases with a further increase in the WP replacement ratio, especially with WCP. Mortar mixes with WCP had the minimum compressive strength, which was about 9.8 %, 11.3 %, and 16 % of the control mortar. This may be due to that WCP consists mainly of non-reactive powders [21].

Generally, the reduction of the early compressive strength of all the mortar mixes can be explained by the addition of the WPs, which results in a low amount of cement and, therefore, retards the formation of hydration products. The latter has a significant effect on strength development, which elucidates the results of the compressive tests [27].

This finding is consistent with previous studies [28, 29] indicating that the compressive strength of mortar mixtures decreased with an increasing WP content, especially in the early curing days. However, all the mortar specimens showed a compressive strength gain from 28 to 90 days, implying a continuous hydration process. Notably, the 90-day compressive strength of the mortars with WBP had the highest values compared with that with the other type of WPs. This can be attributed to the potential pozzolanic activity of the waste brick materials. The presence of SiO_2 and Al_2O_3 in the WBP may react with the $Ca(OH)_2$ released during the cement hydration and form additional hydration products, such as calcium silicate hydrates (C–S–H), and aluminates (C–A–H), which, in turn, improve the mechanical strength.

The development of the compressive strength for all the mixtures is consistent with that of the flexural strength, except the mix containing 5 % and 10 % of MWP (Figure 9). It can be noticed that mortars with MWP showed a relatively comparable flexural strength as those of the control mortars. This could be associated with the difference between the MWP's particle shapes and the other WPs. The MWP is irregular in shape with a high aspect ratio and fine particles, leading to an increase in the adhesion among the particles.

However, the mechanical properties of the mortars were found to decrease with a further increase in the WP replacement percentage to 15 %. This indicates that the filler effect cannot compensate for the dilution effect caused by the large incorporation of WPs.

From the above, it can be concluded that the type and content of the WP both obviously impact the compressive and flexural strength. Although a decrease in the compressive strength was observed when the WCP, WBP, and MWP replacements were 15 %, the produced mortars meet the minimum mechanical strength requirements of

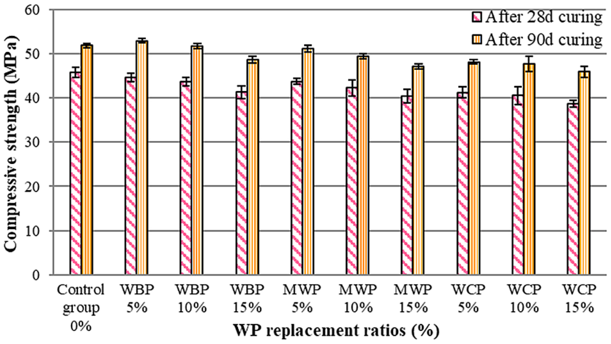


Figure 8. Compressive strength results of the mortars mixes.

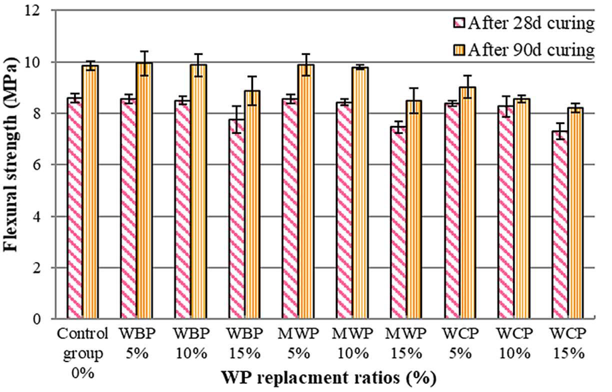


Figure 9. Flexural strength results of the mortars mixes.

the EN 998-2 regulations for cement mortar. As a result, using eco-friendly waste powder from CDW to prepare cement mortar is feasible.

Micro-structural analysis:

In order to determine the microstructure of the blended mortar, several images were taken with the Scanning Electron Microscope (SEM) at the National Center for Technical and Scientific Research (CNRST), Rabat, Morocco. The SEM morphology of the control specimens without the WPs and specimens with WPs are shown in Figures 10, 11, 12, and 13.

The image of the control specimen shows more pores than the WBP and the MWP blended mortar (Figure 10). Simultaneously, the SEM micrographs presented in Figures 11b,c and 12b,c illustrate that the specimens with WBP possess a more refined and denser microstructure than the control specimen. Hexagonal and lamellar portlandite ($Ca(OH)_2$) crystals are clearly observed in the controlled hardened paste (Figure 10b). Most of those hexagonal crystals are eroded in the paste with WBP (Figure 11b,c). Moreover, hydration products, such as ettringite and C–S–H gel, can be both observed in SEM micrographs (Figure 11, 12, and 13). However, the C–S–H gel is predominant in the hardened paste with WBP, thus, forming a compact and dense microstructure. This can be explained by the pozzolanic reaction of the WBP in which the hydration products can grow into the micropores, thus improving the microstructure's cement matrix. With regard to the MWP micrographs, Figure 12 shows a relatively dense microstructure as compared to the control one. This may be due to the MWP's fine particles which will increase their fineness and, thus, improve the pore structure of the cement matrix. The use of WBP and MWP does not compromise the microstructure performance of the cement matrix, the types of hydration products in the paste were the same. The authors [30, 31] indicated that the addition of ground ceramic waste decreases the pore size in a cement's microstructure.

XRD analysis

Figure 14 presents the XRD patterns of the CM (control mortar), MBP (mortar with waste brick powder), MCP (mortar with waste concrete powder), and MWP (mortar with mixed waste brick and concrete powder) samples. The principal compounds identified in the control mortar and mortars with the different waste powders are quartz (SiO_2), calcite ($CaCO_3$) and portlandite ($Ca(OH)_2$). The latter is the only main hydration product observed in all the mortar mixtures, which appears at 18.15°, 34.25° and 50.96°, respectively. No X-ray spectrum, such as C–S–H was detected, which may be related to its amorphous structure (C–S–H gels). Similar XRD results were also obtained in previous studies [26, 32, and 33].

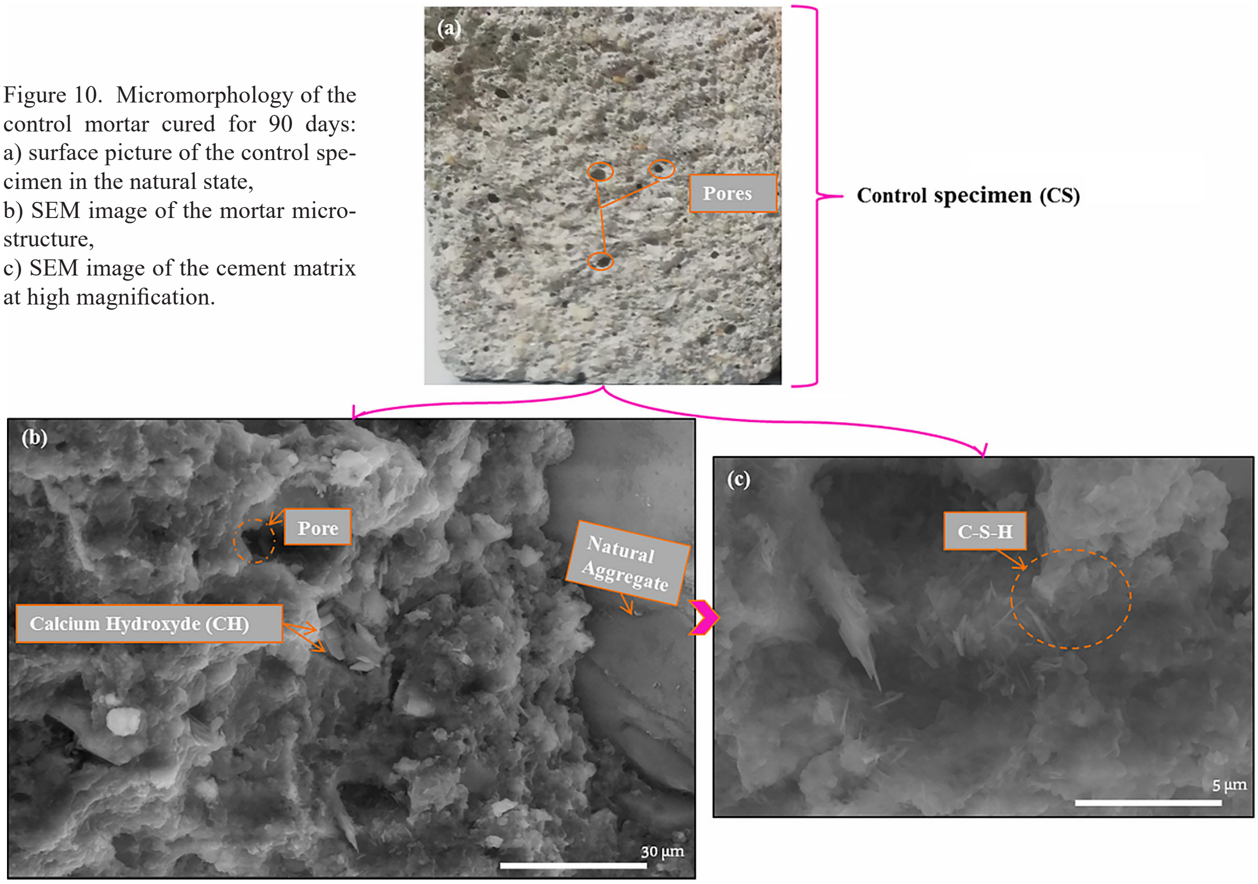


Figure 10. Micromorphology of the control mortar cured for 90 days:
a) surface picture of the control specimen in the natural state,
b) SEM image of the mortar microstructure,
c) SEM image of the cement matrix at high magnification.

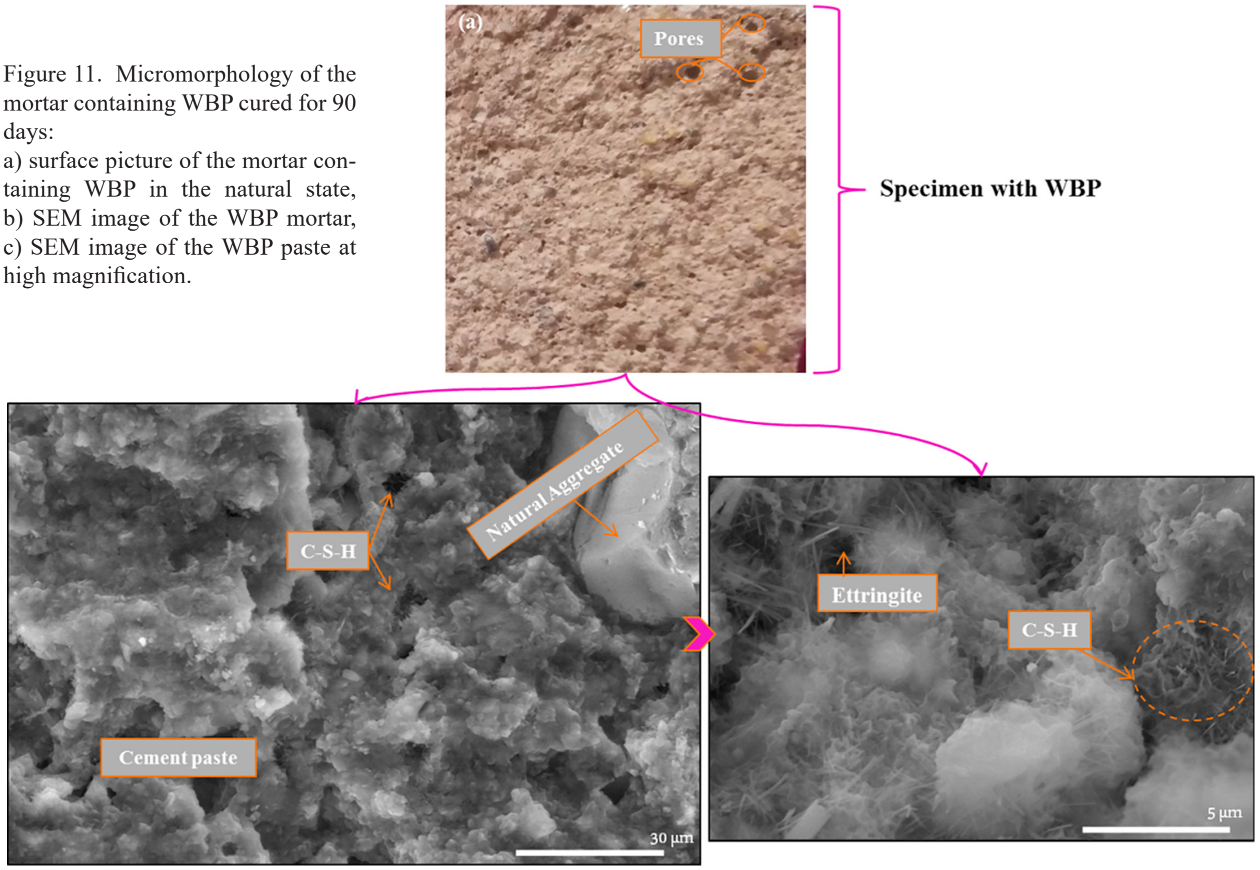


Figure 11. Micromorphology of the mortar containing WBP cured for 90 days:
a) surface picture of the mortar containing WBP in the natural state,
b) SEM image of the WBP mortar,
c) SEM image of the WBP paste at high magnification.

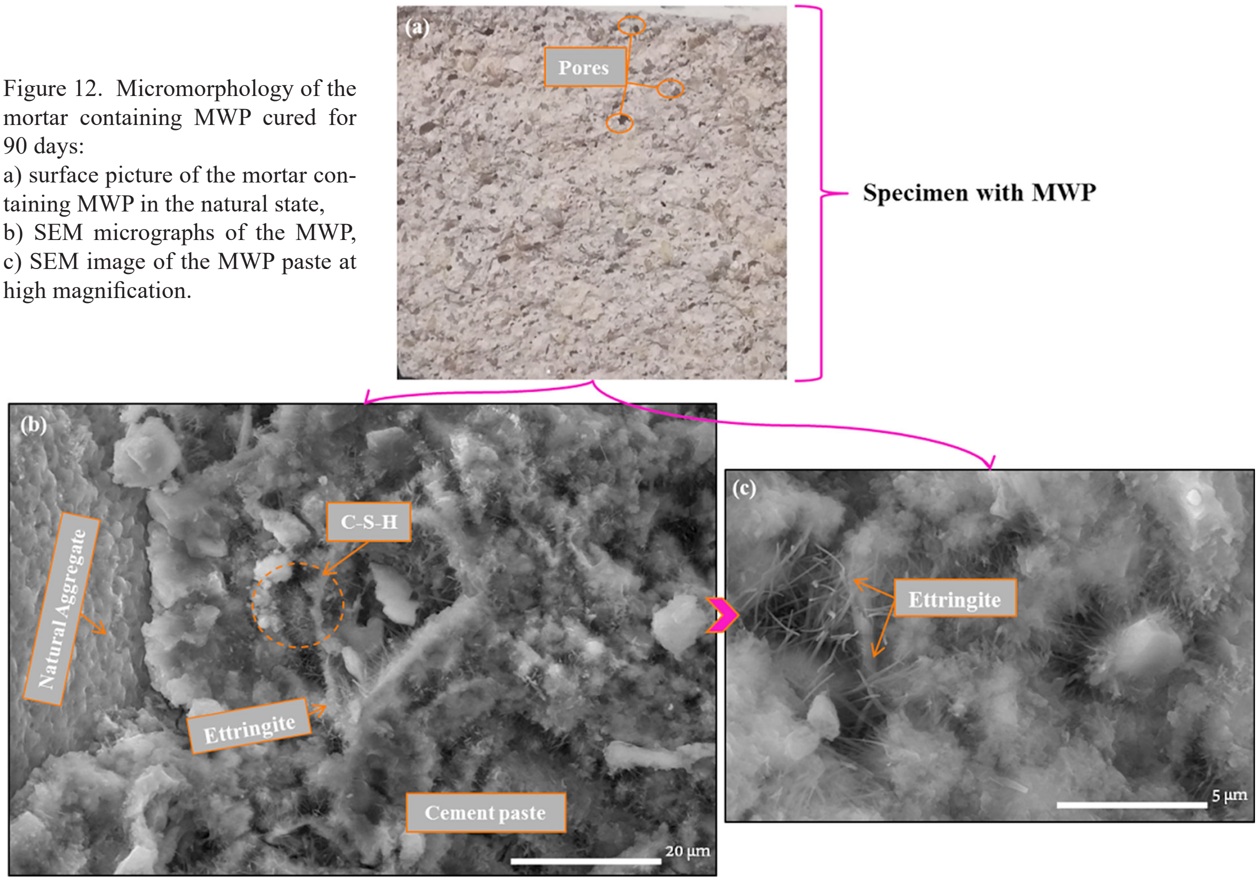


Figure 12. Micromorphology of the mortar containing MWP cured for 90 days:
a) surface picture of the mortar containing MWP in the natural state,
b) SEM micrographs of the MWP,
c) SEM image of the MWP paste at high magnification.

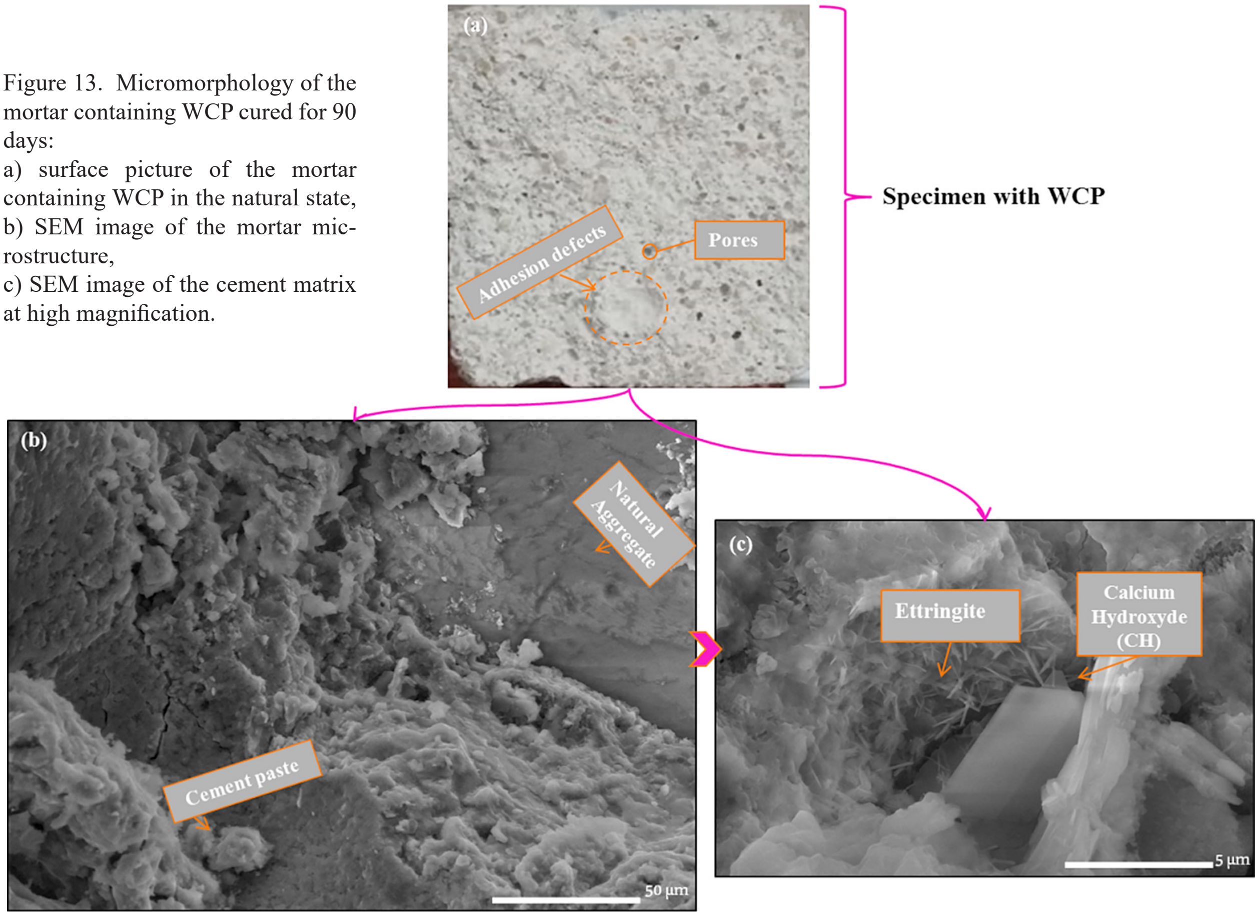


Figure 13. Micromorphology of the mortar containing WCP cured for 90 days:
a) surface picture of the mortar containing WCP in the natural state,
b) SEM image of the mortar microstructure,
c) SEM image of the cement matrix at high magnification.

The intensity peaks of minerals vary relatively with the WP types used. As it is shown in Figure14, the intense peak corresponded to the quartz mineral, due to the presence of natural silica sand in the mixture, in which the main characteristic peaks appeared at around 21.0° and 26.79° respectively. The peak of this mineral shows almost the same intensity in all the mortar mixes, as compared to the control mortar. For the $Ca(OH)_2$ mineral, the intensity peak was relatively lower in the case of the MBP and MWP mortar mix (very tiny peaks as shown in Figure 14), which suggests its consumption via a pozzolanic reaction.

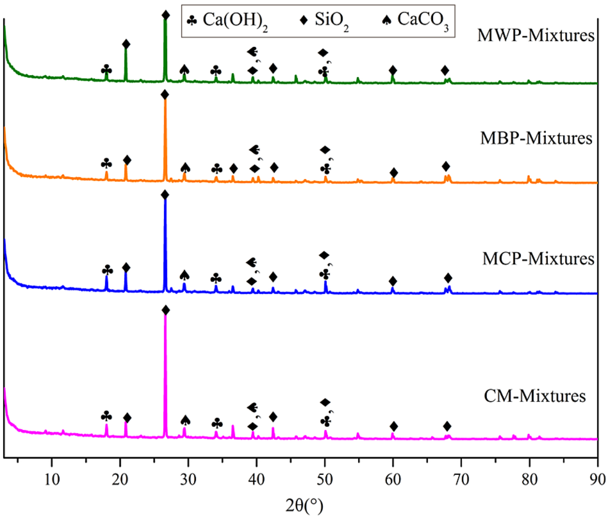


Figure 14. XRD results of the mortars with different WPs.

The reactive compounds of WBP (SiO_2 and Al_2O_3) may react with calcium hydroxide $Ca(OH)_2$ to produce new hydration products. These compounds are responsible for the hardened and stable structure of the mortar. The author [Ma et al., 2020] also concluded that the pozzolanic reaction in mortars containing WBP is related to the amount of portlandite in the pastes; they noted a decrease in the intensity peak of $Ca(OH)_2$. Compared with the pattern of the control mortar, the incorporation of WPs leads to little changes in the mineral phases at a later age.

CONCLUSIONS

This study presents experimental results on the use of different types of construction and demolition waste as supplementary cementitious materials (SCMs) in a cement mortar. Different mortar mixes were prepared by replacing 0 %, 5 %, 10 %, and 15 % of cement with waste powders (WPs), and samples were tested after moist curing for 28 and 90 days.

Based on the results of this experimental investigation, the following conclusions can be drawn:

- The consistency of the cement pastes increased considerably with a WP high content, owing to its high surface area and high levels of water demand. Consistent with the SEM images, the WP particles are irregular in shape with a rough texture and porous surface that also causes an increase in the water demand.
- The WP generally retarded the setting times of the cement paste compared to the reference ones. However, all the blended cement pastes fulfil the standard limits, which were found to begin after 60 minutes and completed after 274 minutes.
- The WBP5, WBP10, and MWP5 mortars showed higher mechanical performances compared to those of the control mortars at later ages. This is attributed to the pozzolanic and filler effect of the WP's fine particles. Hence, the highest value of compressive strength was obtained at 52.9 MPa for the WBP5 mixes.
- The SEM results demonstrated that the mortars with WBP have a higher microstructure refinement compared to the control ones, which is confirmed by the slow formation of additional C–S–H phases. Moreover, the XRD analyses showed that the incorporation of WBP and MWP affect the amount of hydration products formed.

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