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Use of Recycled Ceramic Powder as a Green Alternative in Mortar-Based Cementitious Composites

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Abstract

Recognizing material waste as a significant global concern has influenced both the environment and the construction industry. The utilization of ceramic waste as a recycled material in construction projects has gained attention as an effective and sustainable approach to address environmental issues. This study examines the use of waste ceramic tile powder (WCTP) as a supplementary material in cement mortars to decrease the amount of cement required. WCTP was used in place of cement at percentages of 5%, 10%, and 20%. Four different mix designs were created and tested for the study, yielding a total of 48 specimens. Numerous investigations were carried out, including flow table evaluations, measures of dry density, assessments of compressive and flexural strengths, X-ray diffraction, and SEM-EDX testing. The objective of these investigations was to evaluate the specimens' mechanical and physical characteristics as a whole. The findings showed that using ceramic powder in place of some cement might enhance the properties of the mortar. The compressive and flexural strengths of the mortar were notably impacted by replacing 10% of the cement content with ceramic powder. The inclusion of ceramic powder significantly enhanced the mortar's microstructure interface, according to SEM-EDX studies. In the end, the utilization of ceramic powder was found to have a substantial positive impact on the environment by reducing waste.

Keywords: Waste Ceramic Powder; Strengths; FE-SEM; EDX; Microstructure.

1. Introduction

Utilizing waste materials instead of typical construction materials in civil infrastructure and buildings could measure in reducing greenhouse gas emissions and the use of natural resources [1]. Reducing the consumption of natural resources and ensuring proper recycling of industrial waste are effective solutions for both economic development and environmental cleanliness. The development and movement of waste items that result in insignificant environmental consequences must be prevented [2]. By repurposing and using solid waste in the manufacturing of construction material, it is possible to make goods that are both more environmentally friendly and economically viable. These materials must either be cost-effective alternatives or offer ecological benefits that justify their use. In order to assess the sustainability of ceramic waste powder mortar in comparison to regular mortar, it is essential to consider measurements such as greenhouse gas emissions, production costs, and energy consumption associated with mortar manufacturing [3]. The vast quantities of ceramic waste prompt use to employ it in the

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construction industry to address both environmental and economic concerns [4]. Ceramic powder can be utilized and reused in concrete as cementitious materials [5-7] and aggregate substitutes [8-10]. Early studies have been conducted mostly for the characterization of WCTP with great care in its composition [11]. The mineralogy of the powders [12], particle size distribution [13], and physical properties [14]. These base studies bring out an enlightening record of the particular characteristics that allow for WCTP to be different from the conventional construction material. Modern research has paid due concern to the potential of WCTP as supplementary material in the areas of construction and geotechnical engineering, among others [15-17].

Aksoylu et al. [18] conducted experiments using different percentages of CP (10%, 20%, and 30%). They found that incorporating up to 10% of CP, which is the optimal substitution ratio, boosted the compressive and flexural strengths of concrete. This is because CP served as both a filler and a pozzolanic reactive material. This was also approved with Taher et al. [19] according to their analysis, a cement replacement ratio of 10% is superior to a CWP replacement ratio of 20%. Ebrahimi et al. [20] on the same topic. The optimal substitution rate was 10–20%. Tawfik et al. [21] examined the influence of different amounts of cement replacement with waste ceramic (WCP) and brick powder (WBP) ranging from 0-15% on the parameters of high-strength concrete. Research findings suggest that replacing 15% of cement with WCP or WBP in concrete manufacturing leads to environmental benefits, as it reduces specific energy consumption by 13.1%. Samai et al. [22] illustrated the effects of substituting cement in mortar with ceramic waste. A deterrent percentage of ceramic powder, ranging from 0 to 60 percent of the cement's weight, was utilized. They discovered that 40% provided the most strength. In their study, Li et al. [23] used micro ceramic powder as a supplemental material. They found that substituting 20% of cement with micro ceramic powder resulted in a 9.5% economic advantage in concrete manufacturing and a 6.62% reduction in specific energy consumption during cement production. More studies were made to examine the impact of WCTP on the microstructure of concrete and mortar in particular view of its potential to bring improved material performance [24-26].

According to Nasr et al. [27], the SEM data showed that replacing cement with CWP enhanced the microstructure of the mortar and increased the density of the ITZ. This further enhances the performance and hence gives more strength, hence likely to increase the resilience and life span of the structure. Reducing the frequency of maintenance or replacement, this conforms to the objective of promoting durable infrastructure in the light of sustainability. If WCTP were applied and combined with building materials, all of these would contribute to mitigating the overall carbon emissions generated by construction projects. Therefore, replacing some of the cement, normally with a smaller carbon footprint, could help to reduce the environmental impact of making concrete with it [28]. Moreover, there may be financial advantages to using WCTP in construction materials. In construction projects, it could result in cost savings, particularly in areas where industrial by product disposal expenses are substantial. Prior studies in the literature have examined the performance of waste materials in concrete. Various investigations have been conducted, yielding differing conclusions regarding the amount of ceramic addition as a substitute. The purpose of this essay is to clarify the environmental effects of disposing of ceramic tile in landfills and to emphasize the benefits of recycling and finding other applications as more sustainable disposal solutions.

2. Research Significance

The utilization of discarded ceramic tiles in construction applications is presently recognized as a crucial objective in civil and environmental engineering, notably in the context of scholarly investigations focusing on construction materials. The utilization of waste ceramic material as an additional powder in cement mortars not only enhances the mechanical properties of the mortars but also plays a pivotal role in safeguarding the environment against issues arising from its significant deposition. Thus, the current investigations present a substantial study to achieve the abovementioned objectives, specifically with regard to the mechanical characteristics and the configuration of pore structures. Figure 1 depicts the flowchart illustrating the research methodology.

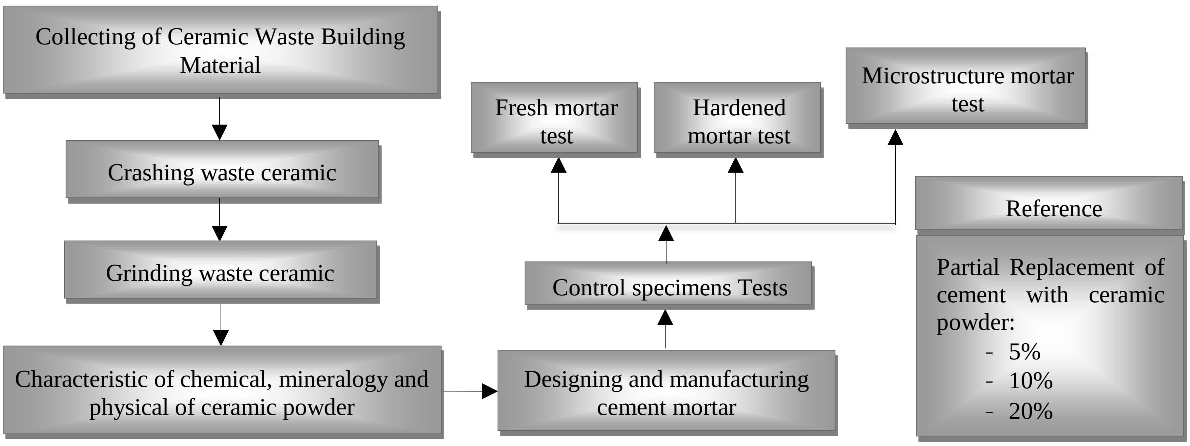

Figure 1. The flowchart of the research methodology

3. Material Properties

The characteristics and behaviors displayed by various types of materials are crucial for understanding how they will perform under different conditions and in various applications. The materials used in this study included cement, Waste Ceramic Tile (WCT), natural sand, water, and a superplasticizer admixture.

3.1. Cement

Cement is a crucial building material that plays a fundamental role in the construction industry worldwide. It is a powdery substance made by calcining lime and clay, forming a paste when mixed with water. This paste gradually hardens into a solid mass. Portland cement, composed of clinker, gypsum, and other additives, is the most prevalent type. Clinker, the key ingredient, is produced by heating a mixture of limestone and clay to extremely high temperatures in a kiln. The resulting clinker is ground into a fine powder, and gypsum is added to control the setting time when water is introduced. In the current investigation, cement mortar was produced using Portland cement (Type-I) compliant with IQS standards (IQS-1984) [29]. Table 1 displays the chemical and physical characteristics of utilized cement.

Table 1. Chemical and physical characteristics of utilized cement

Chemical composition	Cement (%)
Loss on ignition	2.33
SiO_2	20.44
Al_2O_3	5.28
Fe_2O_3	4.88
SO_3	2.15
CaO	61.64
MgO	3.9
Specific surface area (cm^2/gm)	436

3.2. Waste Ceramic Tiles (WCT) and Ceramic Powder (CP)

Waste Ceramic Tiles (WCT) refer to tiles that are discarded or no longer suitable for their intended purpose. This waste can originate from various sources, including construction and renovation projects, manufacturing processes, or breakage during transportation and installation. Notwithstanding their long-lasting nature, the disposal of waste tiles poses significant environmental obstacles, thereby demanding the implementation of sustainable management strategies. The WCTS were crushed into a fine powder known as Ceramic Powder (CP) after being granulated to the desired size of particles.

A finely powdered mixture of ceramic components, ceramic powder is frequently utilized as a raw material for a variety of purposes. Ceramic powders are essential to many applications. They are typically made of finely ground particles of inorganic materials like alumina, clay, silicon carbide, zirconia, and other ceramics. Another way to get Ceramic Powder (CP), is by crushing waste ceramic tiles. This process involves transforming discarded or unusable ceramic tiles into fine particles, contributing to sustainable practices in the ceramics industry. The grinding process not only provides an environmentally responsible way to manage waste, but also offers the potential for creating new materials or incorporating recycled content into existing products. In this study, waste ceramic tiles (Iranian origin) were granulated to particle sizes of approximately 19 mm. Ceramic granules were then pulverized into a powder, as illustrated in Figure 2.

Figure 2. Transferring of Waste Ceramic Tiles (WCT) to Ceramic Powder (CP)

The chemical and physical properties of the obtained ceramic powder are listed in Table 2. These properties were compared with the specifications of ASTM C618 [30], as indicated in Table 3. Based on this table, it is clearly seen that the WCT has appropriate conditions for an ideal pozzolana, according to the ASTM C618 recommendation.

Table 2. Chemical and physical properties of WCT

Chemical composition	WCT (%)
Loss on ignition	0.75
SiO_2	65.18
Al_2O_3	24.09
Fe_2O_3	2.94
SO_3	1.46
CaO	2.35
MgO	1.71
Specific surface area (cm^2/gm)	4614

Table 3. Properties of WCT compared to ASTM C618

Properties	Cement powder %	ASTM C618
$SiO_2 + Al_2O_3 + Fe_2O_3$	92.21	> 70%
MgO	1.71	< 5%
SO_3	1.46	< 3%
Loss on ignition	0.75	< 10%f

X-ray diffraction (XRD) is a technique used for analyzing the crystal structure of materials, and in this context, it is applied to the ceramic powder. It was implemented by Aeris Research Edition - Panalytical Company. SEM-EDX is a method that combines electron microscopy with X-ray spectroscopy to provide information about the elemental composition of a sample, and in this study. The graph represented in Figure 3 shows the X-ray diffraction (XRD) results of the applied ceramic powder. This results in the clear patterns of diffraction, which are generated by different formations of crystal at precise 2theta angles. Herein, the X-RD pattern indicates the presence of SiO_2 quartz; the major peak intensity in the range of angles at an elevated position is observed within 21–28. More importantly, the information on the existence of SiO_2 quartz in the sample is critical to pursue in the crystalline structure of the material. Scientists use XR-D patterns for identifying and classifying the crystalline phases that are present inherently in the material under study. These peaks confirm the existence of crystalline or amorphous particles of the studied ceramic powder. The obtained results are in conformation with the conclusions presented by Samadi et al. [22]. The ceramic powder employed in this investigation seems to be semi-crystalline, based on the XRD measures. Figure 4 represents the particle size distribution of the material.

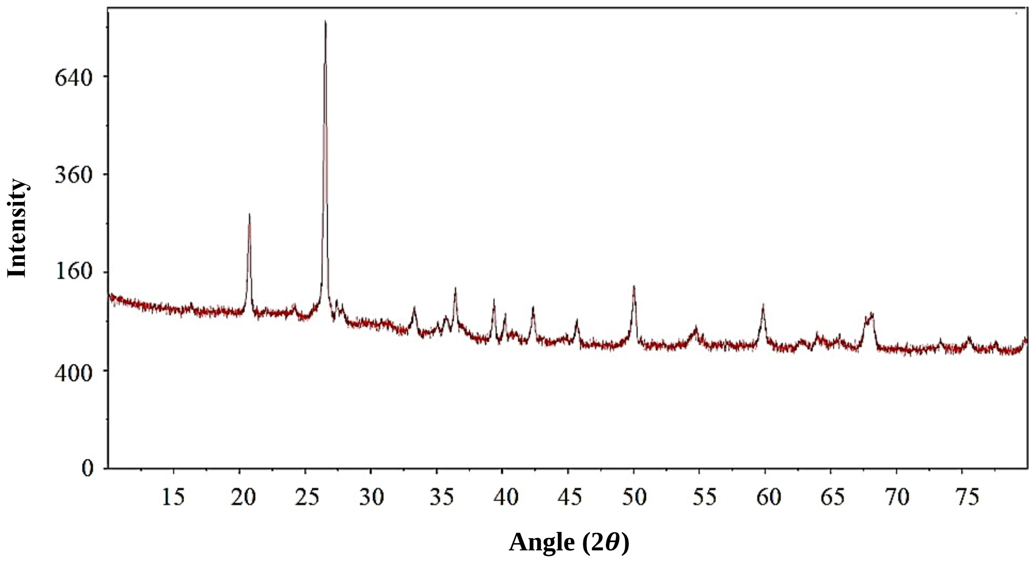

Figure 3. X-ray diffraction (XRD) of the used ceramic powder

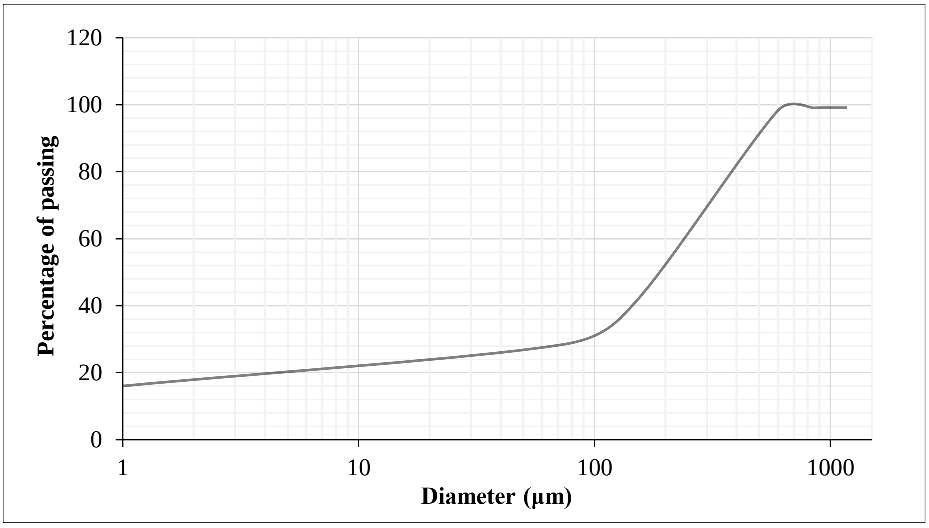

Figure 4. Particle size distribution of the ceramic powder

3.3. Natural Sand

Sand is a granular material made up of mineral and rock particles that have been finely divided. It is a diverse range of ecosystems encompassing deserts, rivers, and coastlines. Depending on the parent stone and the geological conditions that led to its development, the chemical makeup of natural sand might differ considerably. Sand is a crucial substance extensively employed in the formulation of mortar and concrete, holding a significant position in the process of mix design. In the current study, natural Iraqi sand was used. The fine aggregate, passing through the 1.18 mm sieve size, was used in the mortar mixture. This study carried out an SEM test on the used sand, and the result was monitored, as shown in Figure 5. It can be observed that the sand particles have an angular appearance.

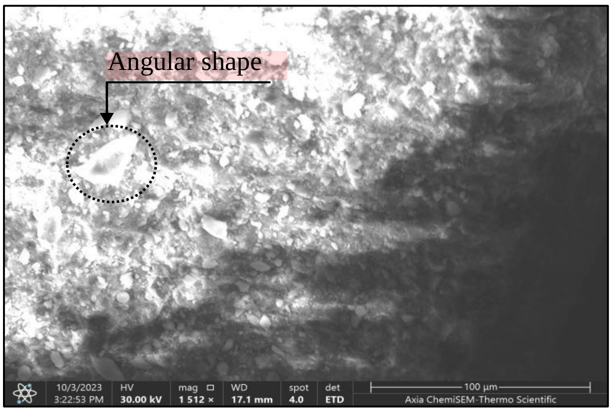

Figure 5. The SEM test of the used sand

Based on the SEM-EDX test, the mineral composition of the sand was listed in Table 4, specifying the weight and atomic percentage of each component. The EDX spectrum of the mineral composition of the sand was also introduced, as shown in Figure 6. Furthermore, the SEM elemental mapping of the tested sand was demonstrated, as depicted in Figure 7. It can be observed that the percentage of calcium is high. This is evidence that the type of utilized sand is calcium sand, which mainly consists of calcium carbonate.

Table 4. Mineral composition of the used sand

Element	Weight (%)	Weight Error (%)	Atomic (%)	Atomic Error (%)
C	6.0	0.1	10.1	0.1
O	51.1	0.3	65.3	0.4
Na	0.2	0.0	0.2	0.0
Mg	1.6	0.0	1.3	0.0
Al	2.5	0.0	1.9	0.0
Si	7.6	0.0	5.5	0.0
S	0.2	0.0	0.1	0.0
Ca	28.8	0.1	14.7	0.1
Fe	2.0	0.1	0.7	0.0

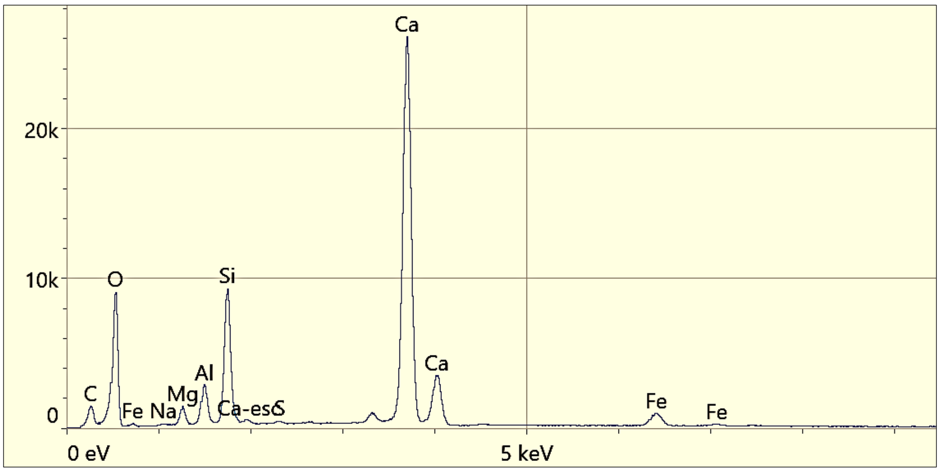

Figure 6. The EDX spectrum of the mineral composition of the tested sand

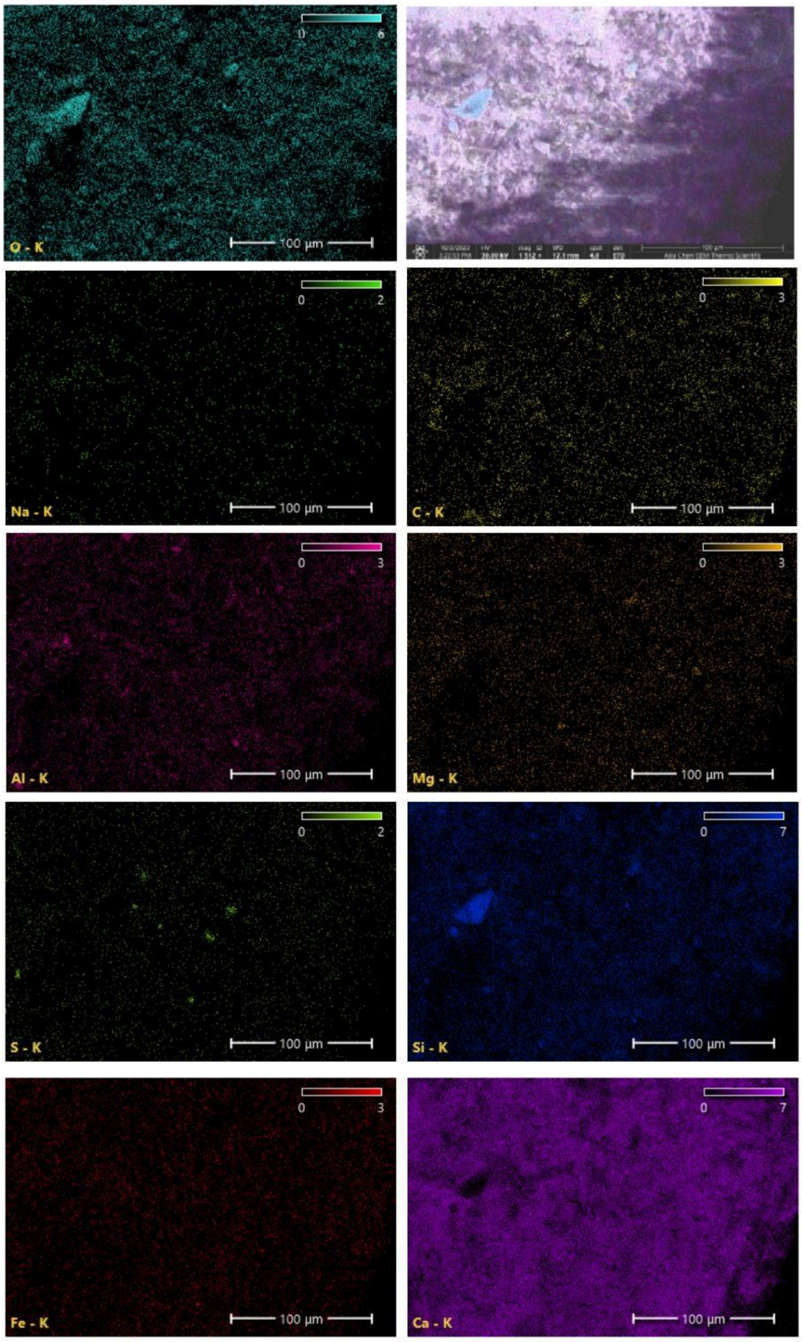

Figure 7. The SEM elemental mapping of the tested sand.

3.4. Water

The presence of water is crucial in determining the composition of mortar, influencing its workability, strength, and long-term durability. Within mortar mix design, the water-to-cement ratio stands out as a fundamental factor, exerting a substantial influence on the characteristics of the resulting mortar. Tap water was used in the current study.

3.5. Superplasticizer (SP) Admixture

Superplasticizers (SP), also known as high-range water reducers, are chemical admixtures used in concrete mixtures to improve the workability and flow of the concrete without sacrificing its strength. These admixtures are particularly useful in situations where high-strength concrete with a low water-cement ratio is required, as they allow for the reduction of water content while maintaining workability. The BETONAC®1030 (Polycarboxylate Ether), which complies with ASTM C-494 [31], Type F, was used in this study. The characteristics of the used superplasticizer are listed in Table 5.

Table 5. The characteristics of the used Superplasticizer

Appearance	Transparent or Light Brown Liquid
Calcium Chloride	Nil
Viscosity	450 CPs at 20°C
Density	1.10 ± 0.02 gm/ml

4. Mortar Mix Design

Mortar mix design is a process of selecting the proportions of ingredients for a mortar to achieve the desired properties in the desired product. The mix design is crucial to ensure that the mortar meets the performance requirements for strength; workability, durability, and other relevant properties. The designed mortar in the current study is a mixture of ordinary Portland cement, sand, Ceramic Powder (CP), water, and superplasticizer. The designed mortar consists of four mixes, including a control mixture and three different mixtures. The control mixture (C-M) does not have ceramic powder; however, the other mixes have different percentages of ceramic powder (as an alternative cementitious material). The second mixture (CP-5), contains 25 grams of ceramic powder, replacing 5% of the cement in the reference mixture. The third mixture (CP-10), contains 50 grams of ceramic powder, replacing 10% of the cement in the reference mixture. The fourth mixture (CP-20), contains 100 grams of ceramic powder, replacing 20% of the cement in the reference mixture. The remaining variables were fixed to be the same values in all mixtures, to obtain the real effect of the replaced ceramic powder on the results. These variables include the water quantity, sand quantity, superplasticizer (SP) percentage, and water/binder (w/b) percentage. The used mortar mix designs are listed in Table 6.

Table 6. Mortar mix design

Mix Design	Water (ml)	Sand (gm)	SP (%)	w/b (%)	Cement (gm)	CP (gm)	CP/cement (%)
C-M	242	1375	4.78	0. 484	500	0	0
CP-5	242	1375	4.78	0. 484	475	25	5
CP-10	242	1375	4.78	0. 484	450	50	10
CP-20	242	1375	4.78	0. 484	400	100	20

5. Cast and Test of Specimens

A total of 48 specimens were cast and tested in this study, as shown in Figure 8. Twenty-four specimens were cast as cubes with dimensions of 50 mm × 50 mm × 50 mm, and another 24 specimens were cast as prisms with dimensions of 160 mm × 40 mm × 40 mm. The investigations were conducted in three stages: fresh tests, hardening tests, and microstructure tests. In the fresh tests, mortar workability was examined using a flow table test—a technique for assessing the flow of fresh mortars. This test was conducted in accordance with ASTM C1437 [32].

Figure 8. The cast of current study

Figure 9 shows the flow table test implemented in this study. The specimens were cured for 28 days by placing them in a water tank, and then hardening tests were conducted. In the hardening tests, the compressive and flexural strengths of specimens were investigated at the twenty-eighth day. Figure 10 illustrates the setup for the compressive and flexural tests. It's important to note that the dry density of cubes was determined using an oven at temperatures of 100 - 105 °C. The purpose of these dry density measurements is to assess the impact of the CP ratio on the density of the tested mortar. Figure 11 displays the cubes placed in the oven used for the measurements.

Figure 9. The flow table test implemented in this study

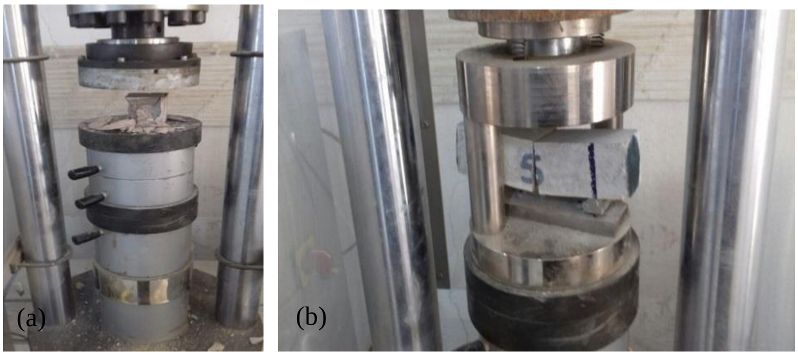

Figure 10. The setup of the specimens: (a) compressive and (b) flexural tests

Figure 11. The tested cubes in the used oven

6. Results and Discussion

6.1. Workability of Mortars

The mortar workability of mixes was tested using the slump test, conducted in accordance with ASTM C1437 [32]. The flow table values of various mortar mixes are presented in Figure 12, with each mixture representing a specific mortar mix design. According to this figure, it can be observed that the flow table values of the mixtures ranged between 200 and 276 mm. The slump values of C-M, CP-5, CP-10, and CP-20 were 267.5 mm, 263 mm, 276 mm, and 200 mm, respectively. In comparison with the control mixture, the slump value was reduced by about 34 % when 20% of the cement was replaced with ceramic powder. This result may be attributed to the high-water absorption properties of ceramic waste, which reduce the amount of available water and subsequently decrease the mixture workability as mentioned by Pal et al., 2021 [33]. Alsaif [34] reported that, through cement substitutions, the majority of properties in fresh and hardened mixtures, in particular, their workability and compressive strength, are degraded with CWP by an additional 20%. This conclusion is consistent with the current results.

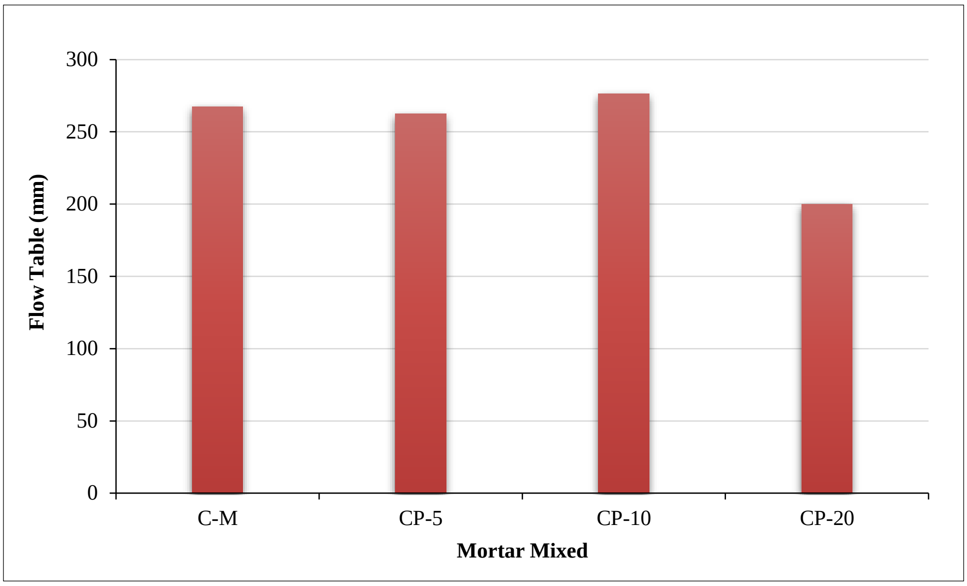

Figure 12. The flow table of the tested mortar mixes

6.2. Dry Bulk Density (DBD) of Mortars

The DBD of all mortar mixtures was experimentally tested, and the outcomes are presented in Figure 13. Each mix design represents the average of three mortar specimens. In general, it is clear that the addition of CP to the mortar, has a significant effect on the mortar's DBD. The DBD of the mortar decreased with the addition of CP, and this reduction depends on the added CP ratio. Compared to the control mix, the DBD of the mortar decreased by 3.6 %, 4.1 %, and 4 % when the added CP ratios were 5%, 10%, and 20%, respectively. It is noted that the density of the mixture did not decrease uniformly as the percentage of added CP increased. The reason for this is that cement particles have a density relatively higher than CP as indicated by Mohit and Sharifi [35]. It may be concluded from these results that there is a limited level for the percentage of added CP; exceeding this level leads to a reversal in the performance of the mixture.

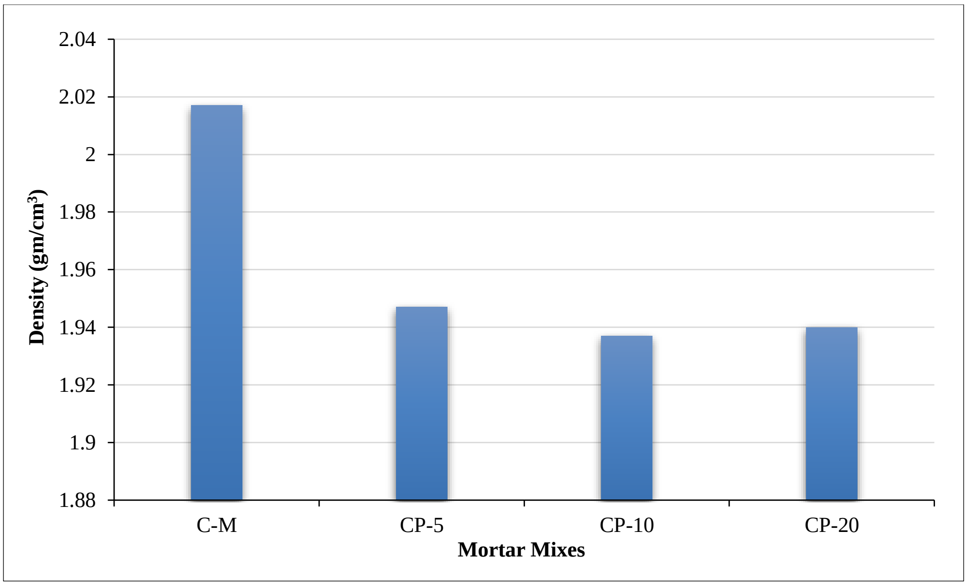

Figure 13. The DBD of the tested mortar mixes

6.3. Compressive Strength of Mortars

The compressive strengths of mortars were tested using Techno-test (300 kN) machine in the current study. All tests were carried out after the curing process for 28 days. The results are explained in Figure 14, with each mix design representing the average of three mortar specimens.

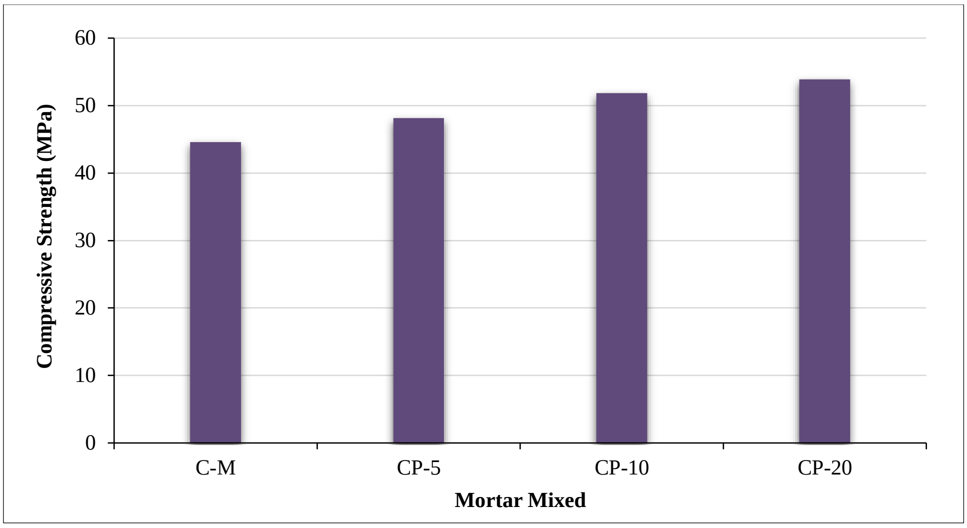

Figure 14. The compressive strengths of the tested mortar mixes

It can be observed that the addition of CP has an influence on the compressive strength of the mortar. The compressive strength of the mortar increased with the addition of CP, and this increment depends on the added CP ratio, this aligns with the viewpoint of both Al-Khafaji & Behaya [36] and Al-Fakih et al. [37]. The fine ceramic powder composed of silica and alumina stages reacts with calcium hydroxide discharged amid lime hydration to make calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH) through pozzolanic reaction [38]

Compared to the control mix, the compressive strength of the mortar increased by 7 %, 14 %, and 17 % when the added CP ratios were 5%, 10%, and 20%, respectively. This increment may occur due to the pozzolanic reaction in the mixture, where the added CP accelerates the pozzolanic reaction that mainly affects the strength characteristics. Also, it is noteworthy that the added CP becomes more active when CH is released; consequently, the compressive strength of the mortar is improved as indicated by Jamil et al. [35].

6.4. Flexural Strength of Mortars

The flexural strengths of mortars were tested using the same machine used in the compressive strength test. The tests were conducted after the curing process for 28 days. The experimental findings are illustrated in Figure 15. Overall, it is observed that the addition of CP to the mortar has an effect on the flexural strength. The flexural strength of the mortar was enhanced when it contained CP, and this enhancement relies on the ratio of the added CP. In comparison to the reference mixture, the flexural strength of the mortar was enhanced by 14 %, 17 %, and 7 % when the ratios of the added CP were 5%, 10%, and 20%, respectively. It is noticed that the addition of CP to the mortar, enhanced the flexural strength; however, this enhancement was not directly proportional to the increase in the percentage of added CP. This is attributed to the nature of cementitious materials. The strength of cementitious materials is reduced when alumina levels are too high as indicated by Nazari & Riahi [40]. Therefore, the flexural strength of the CP-20 mix design dropped when the composition of alumina (Al_2O_3) increased as a result of an increase in the amount of ceramic. Based on these results, it can be concluded that the performance of the mixture is limited by the percentage of added CP.

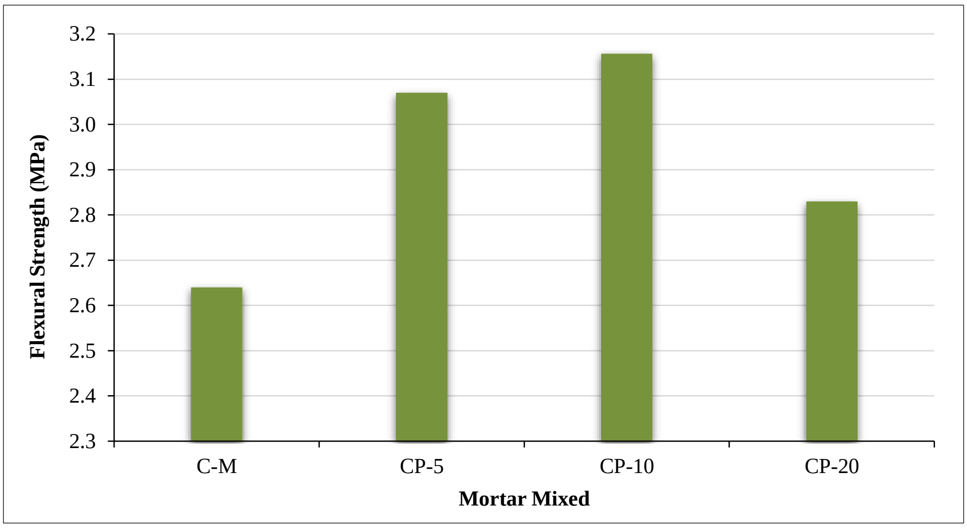

Figure 15. The flexural strengths of the tested mortar mixes

6.5. FE- SEM and EDX Tests of Mortars

The microstructure of a material can affect its physical properties, including strength, toughness, and hardness. This study conducted two types of microstructure tests, namely FE-SEM and EDX tests. The FE-SEM and EDX tests were performed for only two mix designs: the control mix design (C-M) and the CP-10 mix design. The SEM-EDX tests were conducted after the curing process for 28 days. Figures 16 and 17 depict the SEM test results for the C-M and CP-10 mix designs, respectively. From these micrographs, the presence of amorphous C-S-H can be clearly observed. Comparing the two mix designs, it is evident that the CP-10 mix design has a denser microstructure than the C-M mix design. This is because the capillary pores of the CP-10 mix design are smaller than those of the C-M mix design. The lower level of hydration in the C-M mix design is insufficient to completely fill the specimen's capillary pores. Consequently, CP can considerably enhance the hydration of cement. This coincides with the results obtained by Ouyang et al. [41], which reported that the CWP-hydration interface is significantly enhanced at late curing age because of the hydration reaction of CWP.

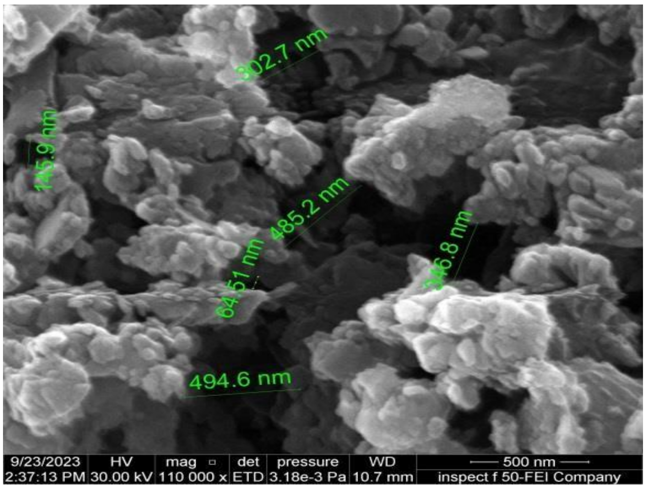

Figure 16. The SEM test of C-M mix design

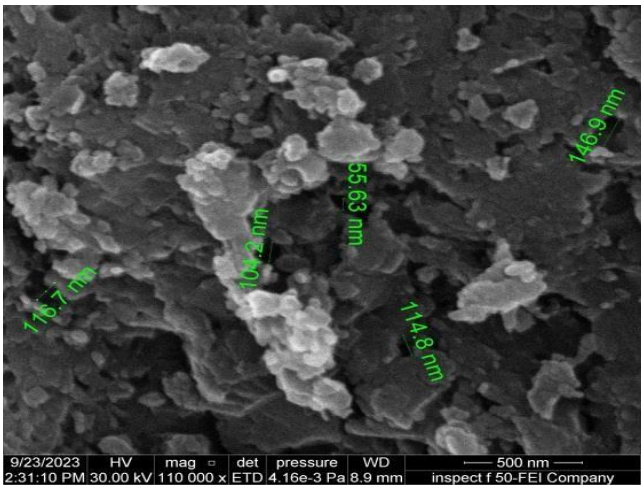

Figure 17. The SEM test of CP-10 mix design

According to Hu et al. [42], a Ca/Si ratio below 1.7 suggests the presence of C-S-H, while a Ca/Si ratio exceeding 1.7 suggests the existence of CH. Additionally, based on that study, a Ca/Si ratio around 3 indicates the partially hydrated areas of calcium trisilicate, and a Ca/Si ratio significantly greater than 3 signifies zones abundant in CH. As the Ca/Si ratio rises, the quantity of CH also increases, while a decrease in the Ca/Si ratio corresponds to an increase in the amount of C-S-H. These ranges were adopted in the current study to specify whether the CH or C-S-H percentage is predominant in the mortar. Based on the SEM-EDX test, the mineral composition of the C-M mix design was depicted in Figure 18 and listed in Table 7, specifying the weight and atomic percentage of each component. The EDX analysis of the specimens aimed to determine the Ca/Si ratio in various areas. Additionally, the SEM elemental mapping of the C-M mix design was demonstrated in Figure 19. According to these tests, it was found that the Ca/Si ratios of the C-M and CP-10 mix designs were 3.024 and 3.022, respectively. The difference was very small (0.002), which may be attributed to the quality of the sand used, containing a high percentage of calcium, as indicated by the SEM-EDX test for the tested sand.

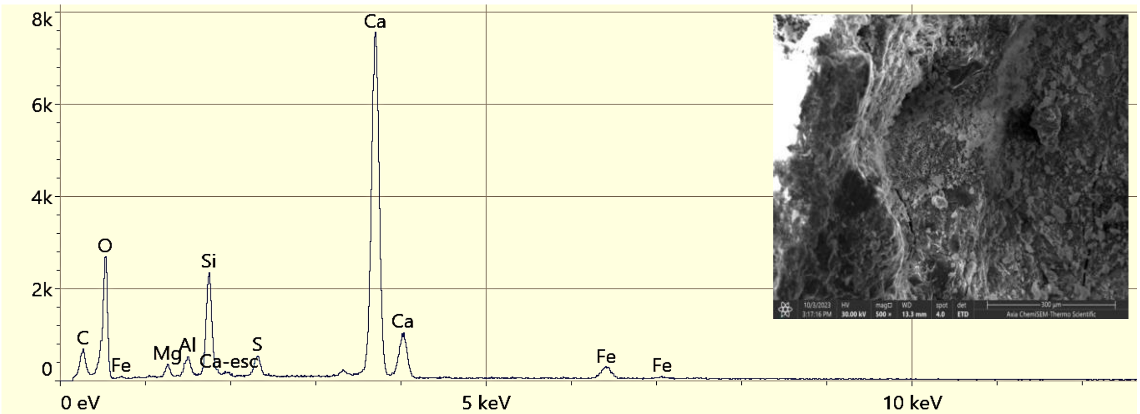

Figure 18. The SEM-EDX test of C-M mix design

Table 7. Mineral composition of C-M mix design

Element	Weight (%)	Weight Error (%)	Atomic (%)	Atomic Error (%)
C	B10.2	0.2	16.5	0.3
O	52.4	0.5	63.6	0.6
Mg	1.1	0.1	0.9	0.1
Al	1.4	0.0	1.0	0.0
Si	5.9	0.1	4.1	0.0
S	1.3	0.0	0.8	0.0
Ca	25.7	0.1	12.4	0.1
Fe	1.9	0.1	0.7	0.0

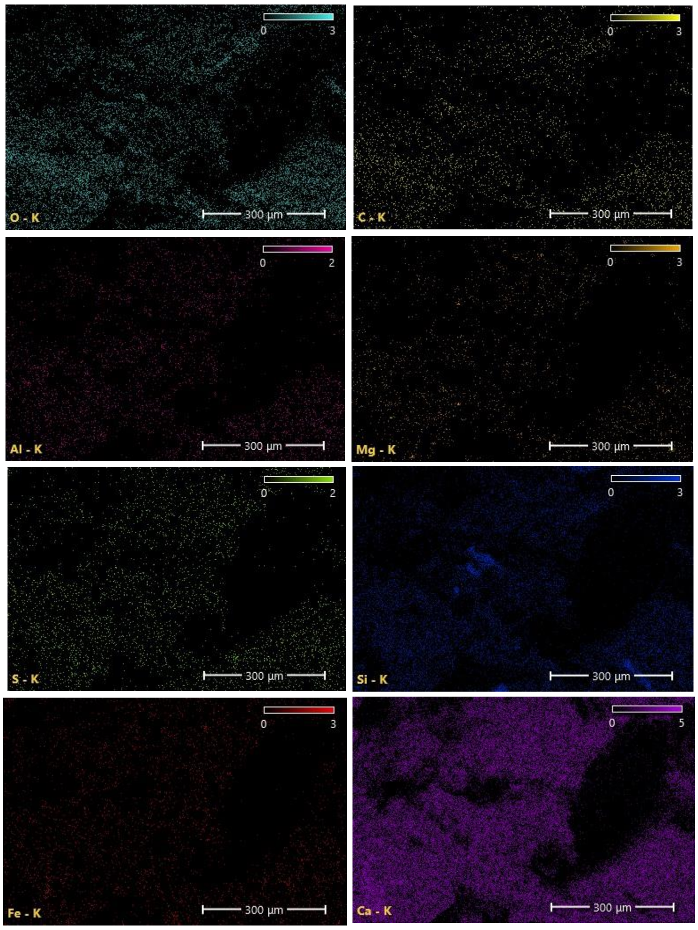

Figure 19. The SEM elemental mapping of C-M mix design

For the CP-10 mix design, the SEM-EDX test and SEM elemental mapping were depicted in Figures 20 and 21and listed in Table 8. The EDX spectrum shows a reduction in the Ca/Si ratio for the specimens of this mix design, aligning with the development of the microstructure. The decline in percentage is attributed to the utilization of calcium hydroxide (CH) through the pozzolanic reaction, coupled with the formation of silica resulting in C-S-H gel.

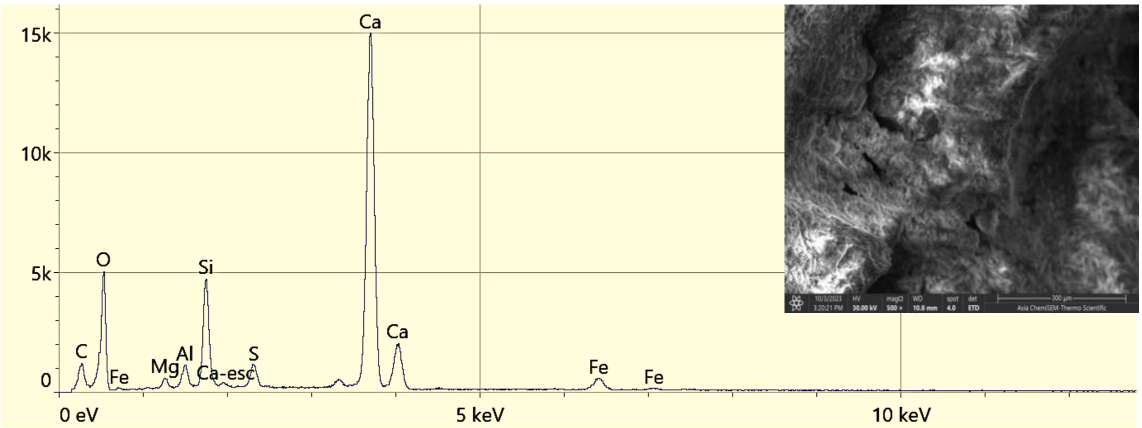

Figure 20. The SEM-EDX test of CP-10 mix design

Table 8. mineral composition of CP-10 mix design

Element	Weight (%)	Weight Error (%)	Atomic (%)	Atomic Error (%)
C	9.5	0.1	15.6	0.2
O	50.6	0.4	62.7	0.5
Mg	1.0	0.0	0.8	0.0
Al	1.6	0.0	1.2	0.0
Si	6.4	0.1	4.5	0.0
S	1.5	0.0	0.9	0.0
Ca	27.4	0.1	13.6	0.1
Fe	2.0	0.1	0.7	0.0

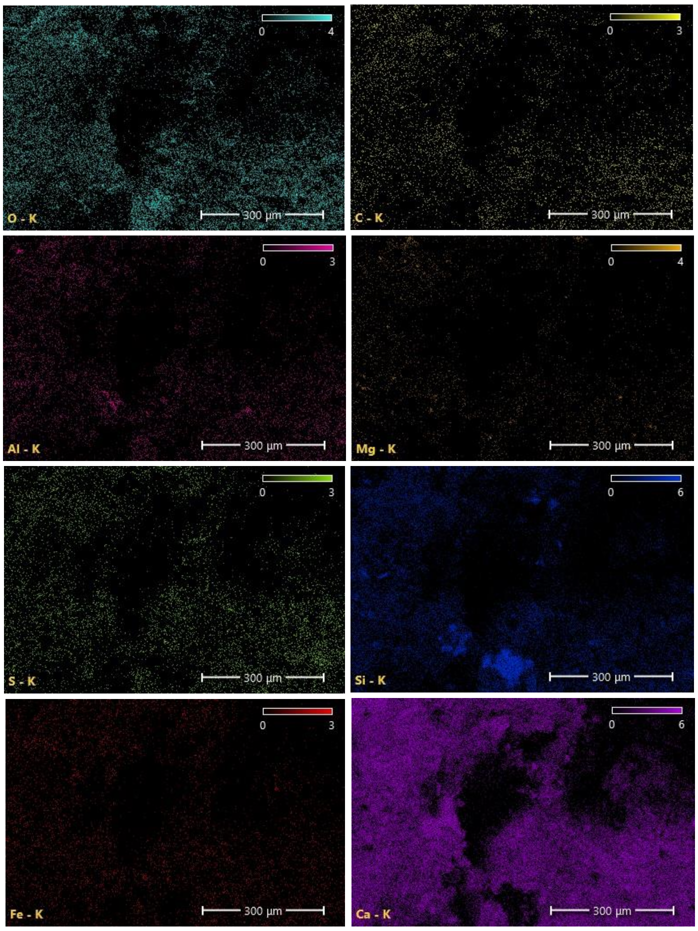

Figure 21. The SEM elemental mapping of CP-10 mix design

These results confirm previous study by Kunther et al. [43]; they concluded that the compressive strengths of the C–S–H pastes increase for decreasing Ca/Si ratio for all synthesized samples and testing ages. The Ca/Si ratio of C–S–H gel produced as a result of the pozzolanic reaction is lower than the one produced through Portland cement hydration. The C–S–H that is formed during the hydration of alite in plain Portland cement has an average Ca/Si ratio of around 1.7–1.8 as presented by Elyasigorji et al. [44]. In the present study, the percentage of a significant amount of calcium in the sand led to a rise in the calcium percentage, potentially influencing the specific Ca/ Si ratio.

7. Conclusion

The following research considered the suitability of mortars produced incorporating CWP as a cement replacement. The research involved various assessments, including X-ray diffraction tests, SEM-EDX tests, compressive and flexural strengths, dry density, and flow table measurements, to evaluate the mechanical and physical properties of the specimens. Based on the outcomes obtained from the current study, the properties of mortar can be enhanced by substituting a certain proportion of cement with ceramic powder. There was a considerable impact on the dry bulk density of specimens containing CWP as cement replacement. However, the density of the mortar is inversely proportional to the ratio of the added ceramic powder.

A significant reduction in density was observed when 20% ceramic powder was used as a replacement for cement. The addition of CP has an influence on the compressive strength of the mortar. The compressive strength of the mortar increased with the addition of CP, and this increment depends on the added CP ratio. However, there is a significant effect on the compressive and flexural strengths of mortar when 10% of the cement content is replaced with ceramic powder. Based on the SEM-EDX tests, the added ceramic powder significantly improved the interface microstructure of the mortar. The difference in Ca/Si ratios between C-M and CP-10 mix designs was very small (0.002), possibly attributable to the quality of the sand used, which contains a high percentage of calcium. The specimens from the CP-10 mix design showed a decrease in the Ca/Si ratio, corresponding to the development of the microstructure. This reduction is attributed to the utilization of calcium hydroxide (CH) in the pozzolanic reaction. Finally, the use of ceramic powder plays an important role in enhancing the environment by reducing waste.

8. Declarations

8.1. Author Contributions

Conceptualization, L.A.G.Z., M.Z.Y., and L.K.S.; methodology, L.A.G.Z., M.Z.Y., and L.K.S.; formal analysis, L.A.G.Z., M.Z.Y., and L.K.S.; investigation, L.A.G.Z.; resources, L.A.G.Z., M.Z.Y., and L.K.S.; data curation, M.M.S.; writing—original draft preparation, L.A.G.Z.; writing—review, L.A.G.Z., M.Z.Y., R.K.S.A., and L.K.S.; visualization, L.A.G.Z.; supervision, L.A.G.Z.; project administration, L.A.G.Z., M.Z.Y., and L.K.S. All authors have read and agreed to the published version of the manuscript.

8.2. Data Availability Statement

The data presented in this study are available in the article.

8.3. Funding

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8.4. Acknowledgements

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8.5. Conflicts of Interest

The authors declare no conflict of interest.

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