ADVANCES IN MATERIALS SCIENCE, Vol. 23, No. 4 (78), December 2023

DOI: 10.2478/adms-2023-0026

Amar Mezidi[1], Salem Merabti[1], Smain Benyamina[1] and Mustapha Sadouki [1]

[1] *Acoustic and Civil Engineering Laboratory LAGC, Faculty of Sciences and Technology, University of Khemis Miliana, Algeria*

*s.merabti@univ-dbkm.dz

EFFECT OF SUBSTITUTING WHITE CEMENT WITH CERAMIC WASTE POWDERS (CWP) ON THE PERFORMANCE OF A MORTAR BASED ON CRUSHED SAND

ABSTRACT

The enormous quantities of ceramic waste lead us to its use in the construction field to solve both an environmental and an economic problem. The present study aims to recycle ceramic waste powders (CWP) to produce mortars. To this end, five crushed sand (CS) based mortar mixes with prismatic dimensions of 4x4x16 cm³ were prepared by partially replacing 0, 5, 10, 15, and 20% white cement with CWP. Tests were carried out to assess bulk density, compressive strength, and ultrasonic pulse velocity (UPV). The results obtained showed that increasing the proportion of ceramic waste powder (CWP) in mortar mixes led to a decrease in bulk density, compressive strength, and UPV in the different mortars. In addition, linear correlations were observed between the different variables studied.

Keywords: *white cement; ceramic waste powder; crushed sand; mortar; compressive strength; ultrasonic pulse velocity.*

INTRODUCTION

The global production of ceramics has a significant impact on waste generation. It is estimated that India produces 100 million tons of ceramics annually, of which 15 to 30% is considered waste [1], while China produces approximately 13 million tons of ceramic waste each year, accounting for 25% [2]. Around 22 billion tons of ceramic powder waste is generated worldwide annually [3]. These massive quantities of waste harm ecosystems [4], occupy agricultural land [2] and pollute soil, water, and air [5].

In recent years, many researchers have studied various uses of ceramic waste to manage its harmful impact on the environment [6-11]. In civil engineering, their utilization as a substitute for aggregates or as a replacement for cement with ceramic powders has been shown to significantly reduce CO2 emissions [12, 13]. These materials are considered durable and resistant to chemical attacks [13]. All ceramics are made from clays containing kaolinite, quartz, illite, etc. [14]. Lilesh Gautam et al. conducted a study in which they replaced up to 30% of the cement with ceramic powder and up to 40% of fine natural aggregates with ceramic aggregates to prepare self-compacting concrete mixes. The results showed that the

Received 02 August 2023; Received in revised form 30 August 2023; Accepted 15 October 2023

self-compacting concrete obtained exhibited less weight loss and improved compressive strength up to an optimal replacement level. Indeed, the self-compacting concrete demonstrated pozzolanic properties and superior filling properties [13].

The incorporation of ceramic waste in concrete production has also been studied. In a study conducted by Gautam et al. [15], it was demonstrated that preparing concrete using a combination of 10% ceramic waste powder (CWP) and 30% waste granite resulted in maximum strength. This research also revealed that this specific material combination exhibited minimal porosity, highlighting the effectiveness of this particular blend in concrete production. Chokkalingam et al. explored the influence of incorporating ceramic waste (CW) and granulated blast furnace slag (GBFS) in concrete. The results indicated that the optimal mix corresponded to a CW: GBFS ratio of 2:3 with a binder quantity of 450 kg/m^3 [16]. Other researchers have advanced that the incorporation of CWP in concrete production imparts pozzolanic properties to the material [10, 17]. De Almeida et al. studied the effect of substituting up to 100% of coarse aggregates with ceramic waste in the production of concrete. They found that the compressive strength was very good, even for the formulation with 100% ceramic waste (fc = 47.78 MPa). Additionally, formulations containing 25%, 75%, and 100% ceramic waste showed lower porosity compared to the reference concrete [18]. However, the study conducted by Wang et al. used up to 50% of waste ceramic polishing powder (CPP) [4], along with both freshwater and seawater for concrete production. The results indicate that increasing the concentration of CPP decreases the compressive strength of both concrete forms. In contrast to the sample without CPP, the chloride penetration resistance is higher for both types of concrete mixed with CPP. Furthermore, when compared to concrete mixed with seawater, concrete with a freshwater mix exhibits lower resistance to chloride penetration.

Regarding mortars, Mohit et al. found that cement mortar containing 10% ceramic powder exhibited the highest compressive strength. In contrast, the ternary cement mortar containing 30% ceramic powder showed the lowest compressive strength [14]. In another study, Sharif et al. investigated the acid resistance and microstructural properties of cement mortars containing ceramic waste powder (CWP). The amount of CWP added to the mixture reached 25% as a substitute for cement. Specimens were immersed in a sulfuric acid solution (pH=1.5) for 28, 42, and 56 days. The results showed that incorporating ceramic powder as a cement substitute provided superior acid resistance to the mortar. In addition, the researchers observed a reduction in pore and void content due to the substitution of cement with ceramic powder [19]. In their studies, Steiner et al. replaced cement with ceramic polishing residues (PR) up to 40% of the total cement weight. The researchers reported that the obtained mortars showed a high level of pozzolanic activity, reaching 111%. The compressive strength after 120 days of curing was 41.5 MPa when using 25% ceramic powder, resulting in a reduction of compressive strength by 10 to 15% [20]. Similar findings were observed for the use of ceramic tile waste as a cement replacement. Indeed, the mortars obtained exhibited pozzolanic properties, and the addition of 35% ceramic tile waste complied with cement standards [21]. In a study conducted by Ebrahimi et al., two binders were used separately: cement and lime [22]. Cement was partially replaced up to 60%, and lime up to 80%, with ceramic waste powder (CWP). The experimental results showed that the incorporation of 50% CWP in the cementitious mortar had no adverse effect on its strength. Moreover, for lime-based mortar, a substitution rate of 70% with CWP improved both compressive strength and tensile strength. However, the study by Alsaif revealed a considerable degradation of these properties with the addition of 20% CWP [23]. Nayana and Rakesh used crushed ceramic waste and micro-silica. Mortar mixes were prepared by incorporating 5% and 10% micro-silica, and 15%, 30%, and 50% ceramic waste as substitutes for cement and sand, respectively. An increase of 20.78%

was observed with 15% ceramic waste and 10% micro-silica. Due to reduced porosity, they recorded a reduction of 1.17% in water absorption rate and 11.96% in sorptivity for the mix containing 15% ceramic waste. In addition, they found that the mortar containing 15% ceramic waste exhibited low expansion [24]. AlArab et al. studied mortars containing ceramic waste powder (CWP) and ground granulated blast furnace slag (BFS) as substitutes for cement. The obtained mortars showed an improvement in both strength and thermal conductivity [25].

Many studies have been conducted on the effect of waste aggregates and ceramic powders on the behavior of various types of concretes and mortars. However, there is a lack of non-destructive testing to assess the properties of materials containing ceramic waste. Non-destructive testing methods are increasingly used as a reliable alternative for determining mechanical strength. In our study, we chose to use ultrasonic testing. These tests will allow us, on the one hand, to determine the speed of propagation and, on the other hand, to estimate the compressive strength of the mortar containing up to 20% ceramic waste powder. The measurement of the ultrasonic velocity will be carried out on different sample thicknesses. In addition, we carried out a correlation between the different parameters studied to highlight the relationship between the speed of propagation of ultrasound and the quality of the mortar containing ceramic waste powders.

MATERIALS AND METHODOLOGY

Materials used

Portland cement type CEM II/B-L 42.5 N according to EN 197-1 [26], with a fineness of 4500 cm^2/g and a density of 3150 kg/m^3 was used. The sand used is crushed sand from local quarries with a fraction of less than 3.15 mm. The physical characteristics of this sand are presented in Table 1. Figure 1 shows the size distribution of crushed sand.

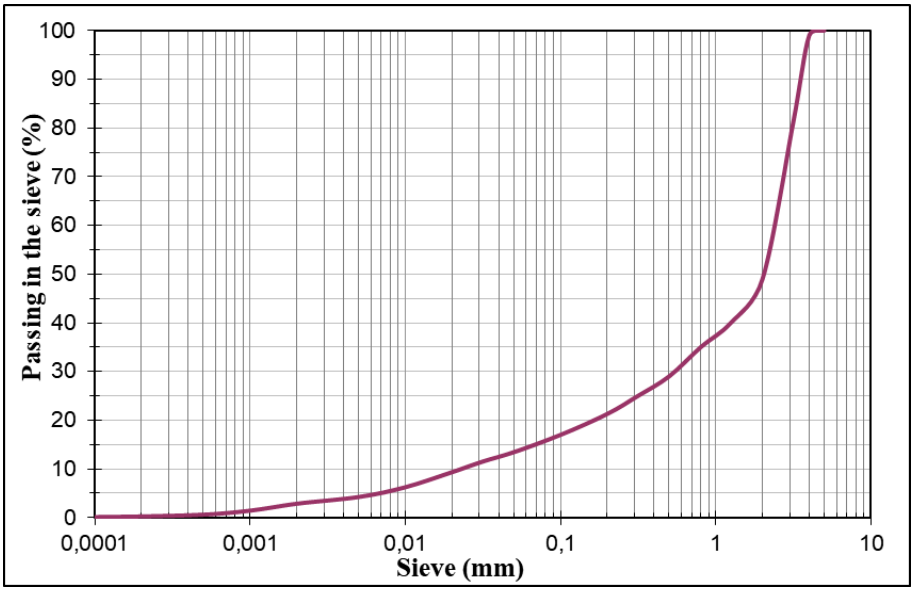


Fig. 1. Grain size distribution of crushed sand

Table 1. *Physical properties of crushed sand*

Physical properties	Crushed sand (CS)
Bulk density (g/cm^3)	1.72
Absolute density (g/cm^3)	2.54
Modulus of finesse (%)	3.15
Water absorption (%)	0.38
Sight sand equivalent (%)	71.00
Piston sand equivalent (%)	69.00

After collection, sanitary ceramic waste is washed, crushed, sieved through an 80 μm sieve, and prepared in powder form (CWP). They are characterized by an apparent density of 0.38 g/cm^3. The recycling protocol for these powders is shown in Figure 2.



Fig. 2. Process for obtaining CWP

Tests carried out

Five mixes of prismatic dimensions (4x4x16) cm^3, in compliance with EN 196-1, were produced [27], in which the cement was partially replaced by 0%, 5%, 10%, 15%, and 20% ceramic waste powders (CWP). Table 2 shows the detailed composition of these mortars.

Table 2. *Components of different mortars*

Mixtures	Cement (g)	CS (g)	Water (g)	CWP (g)	W/C
0% PC	450.0	1350	306	0	0.68
5% PC	427.5	1350	290.7	22.5	0.68
10% PC	405.0	1350	275.4	45.0	0.68
15% PC	382.5	1350	260.1	67.5	0.68
20% PC	360.0	1350	244.8	90.0	0.68

After the mortars had been formulated, density and compressive strength tests were carried out. However, the UPV propagation test complies with ASTM-C597 [28]. Figure 3 shows the experimental setup for the UPV test.



Fig 3. UPV test

RESULTS AND DISCUSSION

Figure 4 shows the effect of ceramic waste powders (CWP) on the density of different mortar mixes. The results show that as the percentage of CWP increases, the mass density decreases. It was found that an increase in CWP from 0 to 20% in the mortars induced a linear decrease in density from 592.2 to 572.5 kg/m^3, with a variation deviation of 3.37% and a coefficient of determination R^2 = 0.86. Several authors [1, 6, 29] have also found that concrete density decreases with an increasing percentage of CWP. They explained this decrease by the density of the ceramic, which is lower than that of the substituted cement.

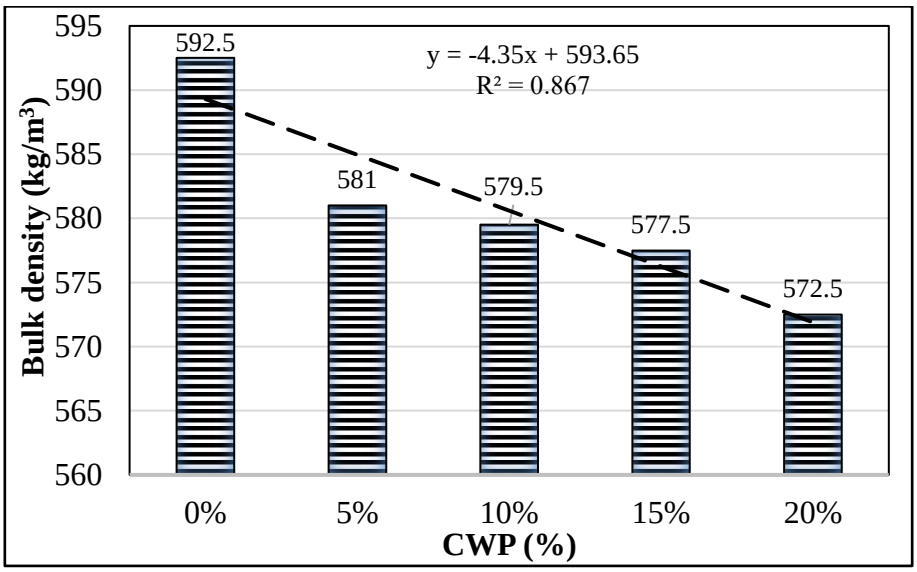
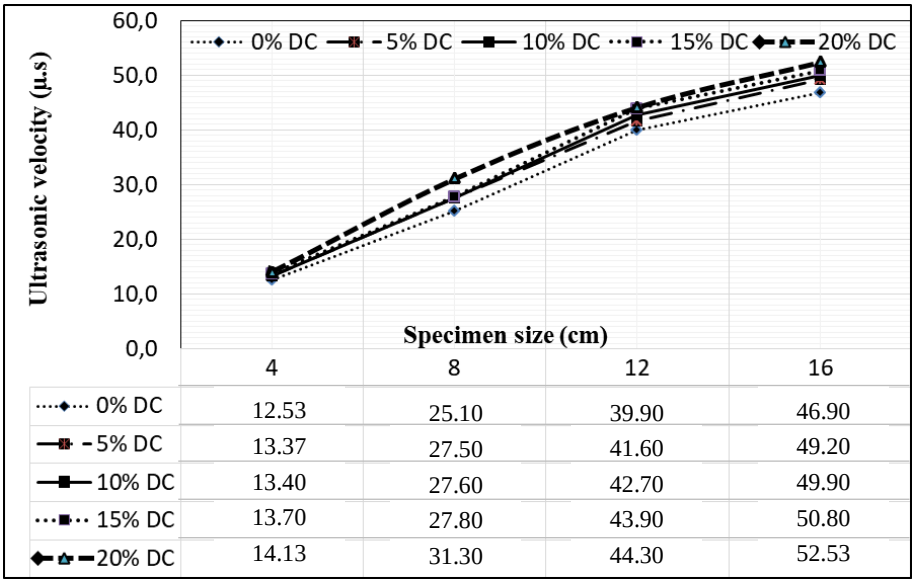


Fig. 4. Variation of density with the percentage of ceramic waste powders

The results for ultrasonic velocity as a function of specimen dimensions are shown in Figure 5. The results clearly show that increasing specimen thickness from 4 to 16 cm for

different percentages of ceramic waste contributes to a 35% increase in ultrasonic mortar velocity for all mortar types. This can be explained by the distance at which ultrasonic pulse velocity propagates as the distance increases, so does the propagation velocity.



	4	8	12	16
0% DC	12.53	25.10	39.90	46.90
5% DC	13.37	27.50	41.60	49.20
10% DC	13.40	27.60	42.70	49.90
15% DC	13.70	27.80	43.90	50.80
20% DC	14.13	31.30	44.30	52.53

Fig. 5. Ultrasonic velocity with the specimen sizes

The ultrasonic velocity as a function of the rate of substitution of cement by ceramic waste is shown in Figure 6. It is observed that increasing the rate of cement replacement by ceramic waste in mortar mixes from 0 to 20% results in an increase in ultrasonic velocity from 12.53 µ.s to 14.13 µ.s. This increase is mainly attributed to the lower compactness of ceramic waste compared to the replaced cement.

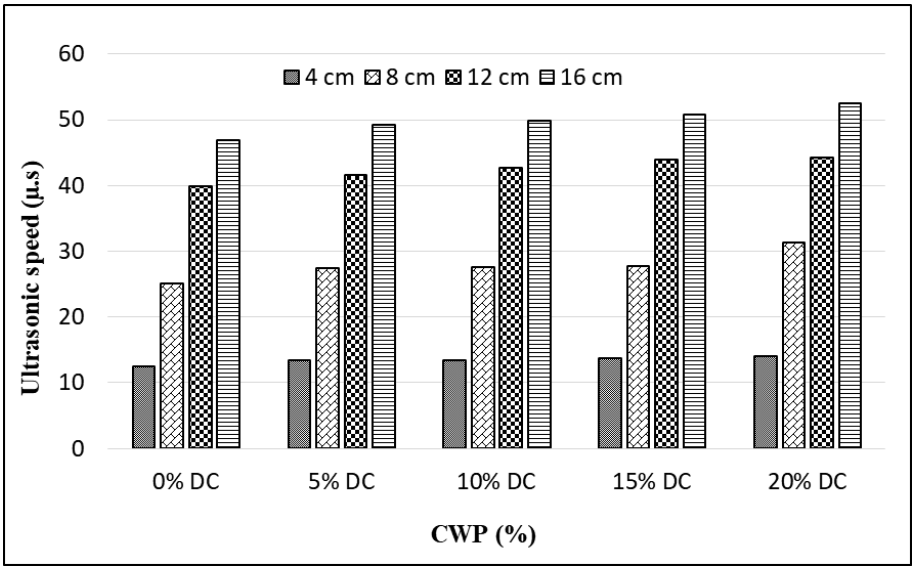


Fig. 6. Variation of ultrasonic velocity with the percentage of ceramic waste powders

Figure 7 shows that mortars based on ceramic waste are weaker than control mortars, where replacing cement with 20% ceramic waste results in a reduction in compressive strength from 53.94 MPa to 41.12 MPa. This reduction may be linked to the weak pozzolanic effect of ceramic waste compared with cement.

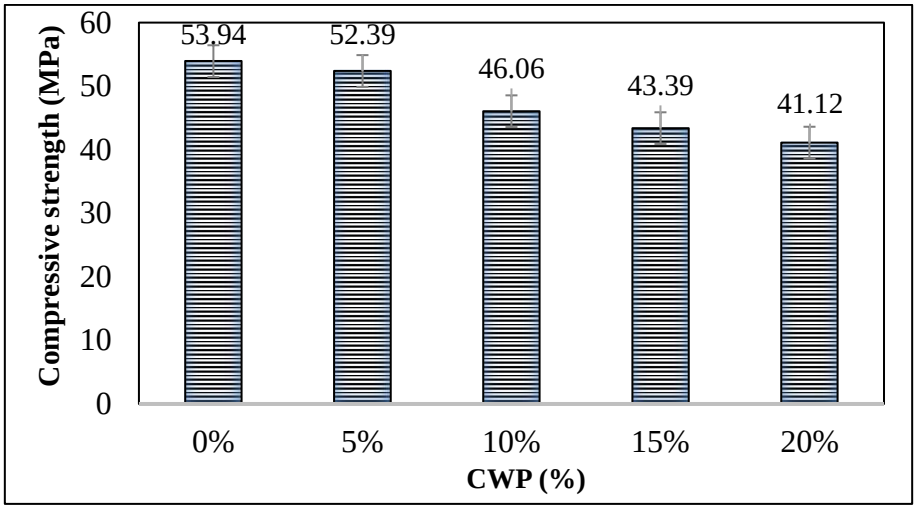


Fig. 7. Compressive strength with the percentage of ceramic waste powders

Figure 8 shows the correlation curve established between the crushing compressive strengths "Rc" and the corresponding ultrasonic velocities "V". The expression proposed for this correlation is a linear relationship given by equation (1), with a correlation coefficient: $R^2 = 0.80$.

$$R = -3.46\ V + 57.7 \quad (1)$$

From this figure, we can conclude that there is a good correlation between the compressive strengths by crushing and the corresponding ultrasonic speeds for all the mortars tested. In this respect, it can be said that the results obtained by ultrasound converge well with those obtained by direct crushing.

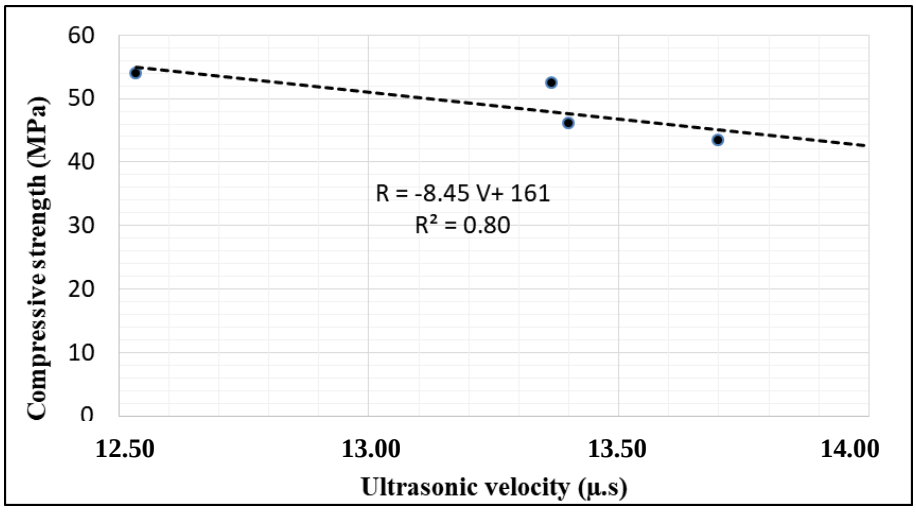


Fig. 8. Relationship between compressive strength and ultrasonic velocity

A correlation curve between the compressive strength (Rc) and density (D) of the different mortar mixes is shown in Figure 9. This correlation is expressed by a linear relationship given by equation (2), and a correlation coefficient: $R^2 = 0.96$.

$$R = -3.47\ D + 161 \quad (2)$$

According to this good correlation between resistance and density, we can say that crushing resistance can be estimated or predicted through density.

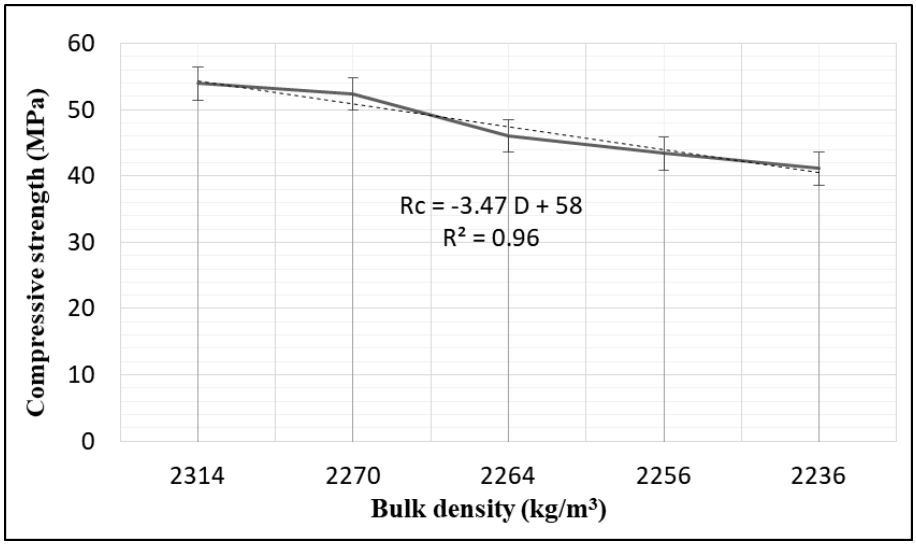


Fig. 9. Relationship between compressive strength and density

Figure 10 shows that there is a linear relationship between mortar density (D) and ultrasonic propagation velocity (V). The curve shows that the lower the mortar density, the lower the ultrasonic velocity. The correlation between these two parameters is represented by equation (3), and the correlation coefficient: $R^2 = 0.98$.

$$D = -48.8\ V + 2923.2 \quad (3)$$

The results found are related to the density of the mortar: the more porous it is, the slower the propagation of UPV.

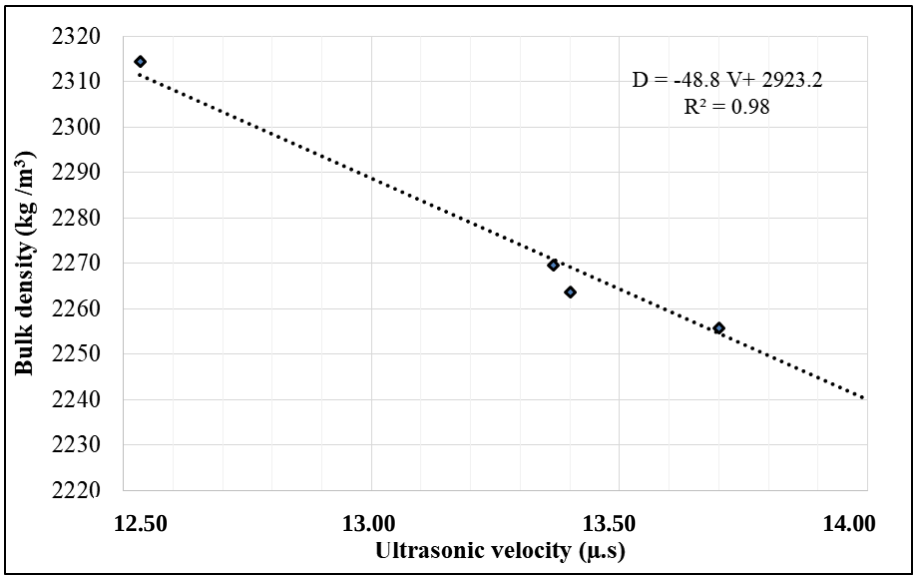


Fig. 10. Density as a function of ultrasonic velocity

CONCLUSIONS

This study outlines the importance of using ceramic waste powders as a partial cement substitute in crushed sand-based mortar building materials. Based on the tests carried out and the results obtained, several conclusions can be drawn:

- Ceramic waste powders have the potential to partially replace cement in mortar preparation;
- Increasing the mass replacement rate of cement by ceramic waste powders from 0 to 20% leads to a reduction in mortar bulk density;
- Varying the thickness of test specimens from 4 to 16 cm contributes to a 35% increase in the ultrasonic speed of mortars for different percentages of ceramic waste powders;
- Cement replacement of 0-20% ceramic waste powders in mortar mixes promotes an 11% increase in ultrasonic velocity, resulting in a 23% reduction in compressive strength at 28 days of storage;
- A good correlation between compressive strength and ultrasonic velocity was recorded (R^2=0.80);
- Linear relationships between compressive strength and density, mortar density, and ultrasonic pulse velocity propagation, were established;
- The results show that ceramic waste powders can be used to make mortar as a partial replacement for white cement.

REFERENCES

1. Yarramsetty B.B., Goud E S.K., Geddada Y: Study of concrete behavior by partial replacement of cement with Ceramic Waste Powder in the presence of Sisal fiber. Materials Today: Proceedings 2023.
2. Li L., Liu W., You Q., Chen M., Zeng Q., Zhou C., Zhang M: Relationships between microstructure and transport properties in mortar containing recycled ceramic powder. Journal of Cleaner Production 263(2020) 121384.
3. El-Dieb, A.S., Taha, M.R., Abu-Eishah, S.I. The use of ceramic waste powder (CWP) in making eco-friendly concretes. Ceramic Materials: Synthesis, Characterization, Applications and Recycling (2019) IntechOpen.
4. Wang S., Nguyen V.T., Xiu Z., Han W: Test research on the effect of waste ceramic polishing powder on the compressive strength and chloride penetration resistance of seawater concrete. Construction and Building Materials 386(2023) 131590.
5. Yang J., Jiang P., Nassar R.U.D., Suhail S.A., Sufian M., Deifalla A.F: Experimental investigation and AI prediction modelling of ceramic waste powder concrete-An approach towards sustainable construction. Journal of Materials Research and Technology 23(2023) 3676e3696.
6. Medina C., Sánchez de Rojas M.I., Frías M: Properties of recycled ceramic aggregate concretes: Water Resistance. Cement and Concrete Composites 40(2013) 21-29.
7. Medina C., Sánchez de Rojas M.I., Thomas C., Polanco J.A., Frías M : Durability of recycled concrete made with recycled ceramic sanitary ware aggregate. Inter-indicator relationships. Construction and Building Materials 105(2016) 48-486.

8. Mohit M and Sharifi Y: Thermal and microstructure properties of cement mortar containing ceramic waste powder as alternative cementitious materials. Construction and Building Materials 223(2019) 643-656.
9. Nowak A.P., Trzciński K., Lisowska-Oleksiak A: Electrochemical Characterization of Gelatine Derived Ceramics. Advances in Materials Science 14(2014) 75-81.
10. Wu J., Li Z., Wen G., Gao Z., Li Y., Zhao Y: Friction mechanism analysis of copper-based composites reinforced with ball-milled and modified composite ceramic powders. Wear (2023) 204959.
11. Ying H., Ding G., ZhaoJ., Wang J., Liu Z., Zhou M., Ye J: Properties of PSN-PZT piezoelectric ceramic powder prepared by fast solid-phase reaction method. Materials Today Communications 35(2023) 106086.
12. Miller S.A., Horvath A., Monteiro P.J.M: Readily implementable techniques can cut annual CO_2 emissions from the production of concrete by over 20%. Environmental Research Letters 11(2016) 074029.
13. Gautam L., Bansal S., Sharma K. V., Kalla P: Bone-china ceramic powder and granite industrial by-product waste in self-compacting concrete: A durability assessment with statistical validation. Structures 54(2023) 837-856.
14. Mohit M., Haftbaradaran H., Riahi H.T: Investigating the ternary cement containing Portland cement, ceramic waste powder, and limestone. Construction and Building Materials 369(2023) 130596.
15. Gautam L., Jain J.K., Jain A., Kalla P: Valorization of bone-china ceramic powder waste along with granite waste in self-compacting concrete. Construction and Building Materials 315(2022) 125730.
16. Chokkalingam P., El-Hassan H., El-Dieb A., El-Mir A: Multi-response optimization of ceramic waste geopolymer concrete using BWM and TOPSIS-based taguchi methods. Journal of Materials Research and Technology 21(2022) 4824-4845.
17. Uysal M., Aygörmez Y., Canpolat O., Cosgun T., Kuranlı Ö.F: Investigation of using waste marble powder, brick powder, ceramic powder, glass powder, and rice husk ash as eco-friendly aggregate in sustainable red mud-metakaolin based geopolymer composites. Construction and Building Materials 361(2022) 129718.
18. De Almeida D.H., Freitas Grillo R.H., Maestrelli S.C., Del Rover C: Properties of concrete manufactured with use of ceramic sanitary ware waste as aggregate. Revista Matéria 24(2019).
19. Sharifi Y., Ranjbar A., Mohit M: Acid resistance of cement mortars incorporating ceramic waste powder as cement replacement. ACI Materials Journal 117(2020).
20. Steiner L.R., Bernardin A.M., Pelisser F: Effectiveness of ceramic tile polishing residues as supplementary cementitious materials for cement mortars. Sustainable Materials and Technologies 4(2015) 30-35.
21. Ay, N., Unal. M: The use of waste ceramic tile in cement production. Cement and Concrete Research 30(2000) 497-499.
22. Ebrahimi M., Eslami A, Hajirasouliha I., Ramezanpour M., Pilakoutas K: Effect of ceramic waste powder as a binder replacement on the properties of cement- and lime-based mortars. Construction and Building Materials 379(2023) 131146.
23. Alsaif A: Utilization of ceramic waste as partially cement substitute – A review. Construction and Building Materials 300(2021) 124009.

24. Nayana, A.M., Rakesh, P: Strength and durability study on cement mortar with ceramic waste and micro-silica. Materials Today: Proceedings 5(2018) 24780–24791.

25. Al Arab A., Hamad B., Chehab G., Assaad J.J: Use of ceramic-waste powder as value-added pozzolanic material with improved thermal properties. Journal of Materials in Civil Engineering 32 (2020).

26. EN 197-1 Cement Part 1: Composition, specifications and conformity criteria for common cements. European Committee for Standardization. 2000.

27. EN 196-1: Methods of testing cement - Part 1: Determination of strength. 2016.

28. ASTM-C597. Standard test method for pulse velocity through concrete, Annual Book of ASTM Standards. 2016.

29. Pitarch A.M., Reig L., Tomás A E: López F.J: Effect of Tiles, Bricks and Ceramic Sanitary-Ware Recycled Aggregates on Structural Concrete Properties. Waste and Biomass Valorization 10(2019).