Mustansiriyah Journal of Materials Engineering and Sustainability
Vol. 02, No. 02, 2026, Pages 01-10
https://mjmes.uomustansiriyah.edu.iq/
Research Article

DOI: https://doi.org/10.31272/mjmes.v2i2.25

ISSN: 3079-9899 (Print)
ISSN: 3079-9902 (Online)

Sustainable Cement Mortar Incorporating Silica Fume and Recycled Ceramic Floor Waste: Mechanical, Fresh, and Ultrasonic Performance

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Article Info

Received	12/06/2026
Revised	22/06/2026
Accepted	25/06/2026
Published	1/07/2026

Abstract

The growing production of industrial by-products and the growing amount of construction and demolition waste have created a range of environmental problems associated with natural resource exhaustion and overburdened landfills. As far as construction and demolition waste is concerned, components such as silica fume and ceramic floor waste have shown some promising features in terms of physical and chemical compatibility with cement-based compositions. The present study focuses on evaluating the effects of using SF as a cement replacement material and CW as a fine aggregate substitute on the performance properties of cement mortar. Altogether, 13 mixes were tested: one control mix, four SF mixes (5%, 10%, 15%, and 20% by weight of cement), four CW mixes (10%, 20%, 30%, and 40% by weight of sand), and four combined SF-CW mixes (10% SF with 10%, 20%, 30%, and 40% CW). Flow tests, setting time determination, compressive strength, flexural strength, and ultrasonic pulse velocity tests were performed, along with scanning electron microscopy. The results showed that the optimal single substitution was 10% SF, reaching a compressive strength of 51.1 MPa, which represents net increase 9 MPa compared to the control specimen (42.1 MPa). The highest compressive (56.1 MPa), flexural (7.5 MPa), and UPV (4.614 km/s) values were observed for the SFC20 composition (10% SF + 20% CW), which indicated a synergetic effect in terms of the density of the material. An increase in both replacements resulted in a decrease in workability.

Keywords: Cement Mortar; Silica Fume; Ceramic Waste; Compressive Strength; Ultrasonic Pulse Velocity; Sustainable Construction

1. Introduction

The construction sector is one of the most resource-consuming industries in the world. It consumes considerable amounts of OPC and natural aggregates annually. In addition to being very resource-consuming, the production of OPC alone accounts for approximately 5-8% of CO_2 emissions globally, thus posing a huge risk to environmental sustainability [1]. The issue of construction and demolition waste has become extremely urgent nowadays, which has led to numerous legislative initiatives aimed at C&D waste utilization and management [2].

Silica fume (SF) is known as a waste material generated in the course of silicon and ferrosilicon alloy fabrication. It contains mostly amorphous silicon dioxide (SiO_2) particles with diameters not exceeding 1 µm and possesses a highly pozzolanic nature. Therefore, a second pozzolanic reaction occurs when SF and $Ca(OH)_2$ react and release additional C-S-H gel, thus increasing densification, decreasing porosity, and improving the mechanical properties of cement-based materials [3,4]. Many studies have confirmed that optimal SF replacement rates of 5-15% significantly improve the compressive and bending strengths of mortar and concrete [5,6].

Ceramic floor waste (CW) accounts for a considerable part of C&D waste owing to the extensive use of ceramic tiles in domestic and commercial construction projects. They are very stable and durable materials, do not absorb moisture, and are resistant to weathering and chemical corrosion; thus, their disposal in landfills poses a serious problem [7]. However, crushing of ceramic waste and its size grading can be utilized to replace natural fine aggregates in cement mortars and concretes, and many researchers have confirmed that CW content ranging from 20% to 30% improves mortar mechanical properties, whereas higher amounts deteriorate them [8,9].

Despite the extensive literature devoted to SF and CW separately, few studies have investigated the effects of these SCMs used together. Thus, it is possible to hypothesize that the combination of mechanical interlocking provided by CW and increased densification owing to the pozzolanic effect of SF can create synergistic interactions. To investigate such interactions and to determine the optimal replacement levels for SF and CW in mortar mixes, this study explores the fresh state properties, mechanical characteristics, and non-destructive properties of mortar mixes with SF and CW.

Although there is significant evidence for the separate application of silica fume and ceramic waste to cementitious material mixtures, only a few studies have examined the joint application of both in mortars. Joint replacement with both pozzolanic densification from silica fume and enhanced mechanical interlocking from ceramic particles may result in certain synergies in terms of mortar performance enhancement. Thus, the combination of both additives in mortar might not only improve its fresh and hardened properties, but also help to meet the goals of sustainable development and circular economy. This will provide an efficient way to decrease the environmental footprint of cement mortar manufacturing, eliminate ceramic waste disposal, and reduce the extraction of natural fine aggregates [1, 2, 7, 10].

In the context of this problem, the current research is intended to examine the effect of silica fume used as a partial replacement for cement and ceramic waste taken from recycled ceramic floor tiles as a partial replacement for fine aggregates on the behavior of cement mortar. Specifically, the work aims to analyze the properties of mortars, such as fresh properties, mechanical properties and UPV. In addition, the current study should help in identifying the optimal levels of cement and aggregate replacement by silica fume and ceramic waste, respectively.

2. Experimental Program

2.1 Materials

2.1.1 Ordinary Portland Cement

Type-I Ordinary Portland Cement (OPC), in accordance with the specifications of ASTM C150 [11], was used in this study. The specific gravity of the cement was 3.15, and the fineness of the cement was approximately 3,500 cm²/g according to the Blaine test results. Chemical analysis was conducted to confirm that the cement complied with the standards for CaO, SiO_2, Al_2O_3, and SO_3 contents.

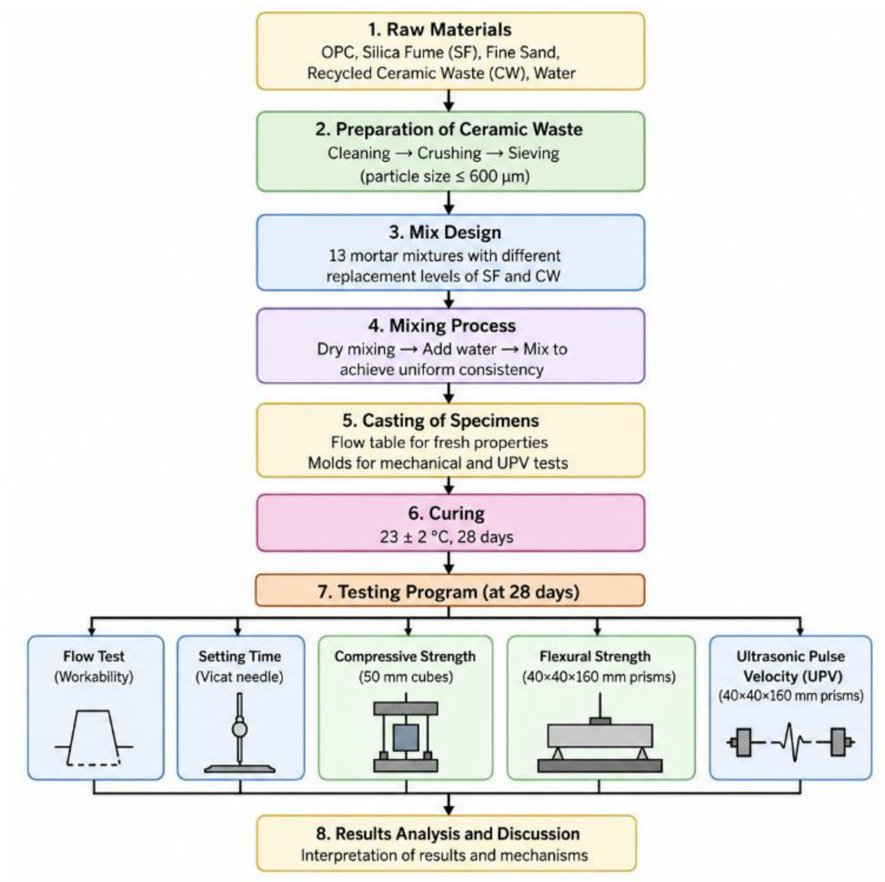

Figure 1. Flow chart of the experiment.

2.1.2 Natural Fine Aggregate

Natural river sand with a specific gravity of 2.65, water absorption rate of 0.8%, and fineness modulus of 2.7, was used as the natural fine aggregate. The sand grading curve conformed to the ASTM C33 [12] standards for fine aggregate gradations. Prior to use, the sand underwent washing, drying, and sieving to remove contaminants and moisture content.

2.1.3 Silica Fume

ASTM C1240 [13]-standardized densified silica fume was used as a partial replacement for cement. Silica fume contained more than 90% amorphous SiO_2 by weight and featured average particle diameters ranging between 0.1 and 0.3 µm, while its specific surface area exceeded 15,000 m^2/kg.

2.1.4 Ceramic Tile Waste

All ceramic waste used within this study has been collected from one single demolition site with the intention of reducing variation in the composition and material properties of the debris. Once collected, underwent manual cleaning to eliminate adhesives and mechanical crushing using a jaw crusher, followed by sieving with standard sieves to obtain natural fine aggregate equivalent particles. The specific gravity and water absorption rate of ceramic waste were measured as 2.45 and 2.1%, respectively, which is higher than that of natural sand owing to the micro-porosity of the ceramic tile surface.

2.1.5 Water

Tap water without any harmful substances was used during the mixing and curing processes conforming to ASTM C1602 [15].

2.1.6 Superplasticizer

A PCE-based high-range water-reducing admixture (Sika® ViscoCrete®-180 GS) was utilized to maintain the required workability of the mortar mixtures.

2.2 Mix Proportions

A total of thirteen cement mortar mixtures were prepared with a constant water-to-binder ratio (w/b) of 0.485 and a cement-to-sand ratio of 1:2.75. The reference mixture (REF) served as the control specimen and contained neither silica fume (SF) nor ceramic waste (CW). Four mixtures were produced by partially replacing cement with SF at replacement proportion of 5%, 10%, 15%, and 20%. Another four mixtures were prepared by partial substituting sand with CW at proportion of 10%, 20%, 30%, and 40%. Furthermore, four blended mixtures were developed incorporating a fixed SF content of 10% together with CW replacement levels of 10%, 20%, 30%, and 40%. This experimental program enabled the evaluation of the individual and combined effects of SF and CW on the properties of cement mortar. No changes were done on the mixing water for the purpose of accommodating the increased amount of water that ceramic waste aggregate can absorb as an aggregate. All of the mixtures were made with a constant water-to-binder ratio of 0.485 in order that only the addition of ceramic waste aggregate and silica fume had an impact on the performance of the mortar

Figure 2. Raw materials before and after crushing.

Table 1. Mix proportions of all mortar mixtures.

Mix ID	Mixture Description	SF (g)	CW (g)	Cement (g)	Sand (g)	w/b Ratio	Superplasticizer
REF	Reference Mix	0	0	1000	2750	0.485	1.4
SF5	5% SF	50	0	950	2750	0.485	1.4
SF10	10% SF	100	0	900	2750	0.485	1.4
SF15	15% SF	150	0	850	2750	0.485	1.4
SF20	20% SF	200	0	800	2750	0.485	1.4
C10	10% CW	0	275	1000	2475	0.485	1.4
C20	20% CW	0	550	1000	2200	0.485	1.4
C30	30% CW	0	825	1000	1925	0.485	1.4
C40	40% CW	0	1100	1000	1650	0.485	1.4
SFC10	10% SF + 10% CW	100	275	900	2475	0.485	1.4
SFC20	10% SF + 20% CW	100	550	900	2200	0.485	1.4
SFC30	10% SF + 30% CW	100	825	900	1925	0.485	1.4
SFC40	10% SF + 40% CW	100	1100	900	1650	0.485	1.4

*Note: Silica fume replacement was performed by the mass of cement, and ceramic waste replacement was performed by the fine aggregate.

All mixtures were formulated with the same constant dosage of polycarboxylate ether (PCE) superplasticizer (1.4% by mass of the binder) based upon the results of preliminary trials with trial batches to determine an adequate amount to provide satisfactory workability without segregation in the reference mortar. The superplasticizer content was kept constant across the mixtures to provide a constant basis for comparison and allow for independent evaluation of the effect of silica fume and ceramic waste replacement levels upon the properties of the mortars.

3. Specimen Preparation

Prior to mixing, the natural sand and ceramic waste aggregates were oven-dried and stored under laboratory conditions. Therefore, the moisture content of the aggregates was assumed to be negligible during mixture preparation.

The mortar was manufactured according to ASTM C305 [16]. Cement, silica fume (if included), sand, and ceramic wastes (if included) were mixed dry in a laboratory blender for two minutes. Water was slowly added, and mixing was further conducted for another three minutes.

Fresh mortar was immediately placed in 50 mm cube molds for compression tests and 40 mm × 40 mm × 160 mm prism molds for flexural tests and UPV measurements. The specimens were made in two lifts and compacted in each lift using a vibrating table and tamping rod. In addition, the surface was leveled after removing the excess mortar. The molded specimens were wrapped with polyethylene foil and placed under controlled environmental conditions at 23 ± 2°C for 24 h. Following the curing process, the specimens were tested in a 28-day-old condition by complete submersion in water maintained at 23 ± 2°C.

For each of the 13 mortar mixtures, three 50 mm cube specimens were prepared for compressive strength testing and three prism specimens (40 mm × 40 mm × 160 mm) were prepared for flexural strength and UPV measurements. Accordingly, a total of 39 cube specimens and 39 prism specimens were tested. In addition, setting time and flow table tests were performed in triplicate for each mixture, and the reported values represent the average of three measurements.

4. Testing Procedures

4.1 Initial and Final Setting Time

Setting-time tests were conducted on cement pastes incorporating silica fume, ceramic waste, and their combinations with respect to their initial and final setting times. These tests were performed using a Vicat needle apparatus and complied with the standard ASTM C191 [17]. Three replicates were performed for each mixture, and the average values are presented herein. The purpose of the test was to determine the influence of SF and CW on the hydration and stiffening behavior of the cement paste.

4.2 Workability (Flow Table Test)

The workability of the mortars was measured using the flow table test in accordance with the standard ASTM C1437 [18]. The flow percentage was determined based on measurements taken after 25 table drops, with the results expressed as the percentage of the initial mortar base diameter. This is a useful method for directly estimating the effect of SF and CW incorporation on the deformability of fresh-state mortar. Although a PCE-based superplasticizer (Sika® ViscoCrete®-

180 GS) was used at 1.4% of binder weight, the flow values decreased with increasing silica fume and ceramic waste contents because of the high surface area of silica fume and the higher water absorption and rough texture of ceramic waste particles.

4.3 Compressive Strength

Compressive strength tests were performed on 50 mm cube mortar specimens. Tests were performed in accordance with the standard ASTM C109 [19]. Testing was performed on day 28 of the curing period using a universal testing machine at a constant load rate of 900 N/s. Three specimens were tested per mixture, and the average values are presented here. Compressive strength is the main mechanical property of mortar mixtures [5].

4.4 Flexural Strength

Flexural (modulus of rupture) tests were performed on 40 mm × 40 mm × 160 mm prism mortar specimens. This test was performed in accordance with the standard ASTM C348 [20], and the specimen dimensions met the 3:1 span-to-depth requirement for three-point bending tests. Three replicates were tested per mortar mixture, and the average values are presented below. The flexural strength test complements the compressive strength test by providing data on tensile strength and crack resistance [6].

4.5 Ultrasonic Pulse Velocity (UPV)

Ultrasonic pulse velocity measurements were performed in accordance with the ASTM C597 standard [21]. A set of two 54 kHz transducers were used to perform the tests in the direct transmission mode. The UPV test is a nondestructive test to indirectly assess the quality and homogeneity of the concrete microstructure in terms of density. Higher UPV values usually indicate denser microstructures with fewer pores [22].

5. Results and Discussion

The experimental results on the workability, setting time, mechanical performance, and ultrasonic pulse velocity (UPV) of all mortar mixtures that contain silica fume (SF), ceramic floor waste (CW), and their combination are presented in the following sections. As seen from the data presented, the presence of both materials was found to substantially affect the workability, setting time, mechanical performance, and ultrasonic pulse velocity of all mortar mixes tested. In general, higher contents of silica fume and ceramic waste decreased workability as a result of the higher specific surface area of silica fume and roughness of ceramic particles. At the same time, silica fume accelerated the setting process, while ceramic waste extended the setting times. Mechanical testing results revealed that moderate contents of both materials positively affected the compressive and flexural strengths of the mortar owing to the pozzolanic effect of silica fume and higher particle interlocking as a result of ceramic waste. The combination of both materials resulted in a better performance in terms of the above-mentioned parameters. In particular, the SFC20 mix exhibited the highest compressive and flexural strengths and the highest UPV. However, too high a content led to poorer performance because of the higher porosity and decreased matrix cohesion.

5.1 Workability (Flow)

The flow percentage was used to determine the workability in the fresh state, as shown in Table 2. It can be noted that the reference sample (REF) possessed flow properties equal to 110%, which was in accordance with the desired consistency for standard cement mortar. Workability showed a progressive decrease in dependence on silica fume content; thus, SF5 had 106%, while SF20 had 92%. The reason behind such a result may lie in the extremely large specific surface area of silica fume particles (greater than 15,000 m²/kg). Such properties lead to an increased water demand by the mixture, leaving less available water for particle lubrication. In addition, the ultrafine nature of particles causes more inter-particle friction and thus leads to less fluidity [3,5].

Such tendencies were also found when analyzing the workability of ceramic waste mixtures. The flow decreased from 108% at C10 to 94% at C40. One should assume that this tendency resulted from the relatively rough texture and high water absorption in comparison with river sand. The latter leads to a lower w/c ratio and reduced effectiveness of the lubrication process [8]. Mixes composed of both SF and CW materials (SF-CW) showed the lowest level of workability. Thus, SFC40 had the lowest value of flow among all examined samples (86%) as shown in Figure 3. The reason for this result was the combined influence of the SF high specific surface area and CW high water absorption. Despite this, all 13 mixtures possessed flow values ranging from 86% to 110%, and it was still sufficient for proper work without segregation and bleeding [18].

The reduction in flowability can be attributed to the increased surface area requiring wetting, as well as the absorption of mixing water by ceramic particles, which reduces the amount of free water available for lubrication.

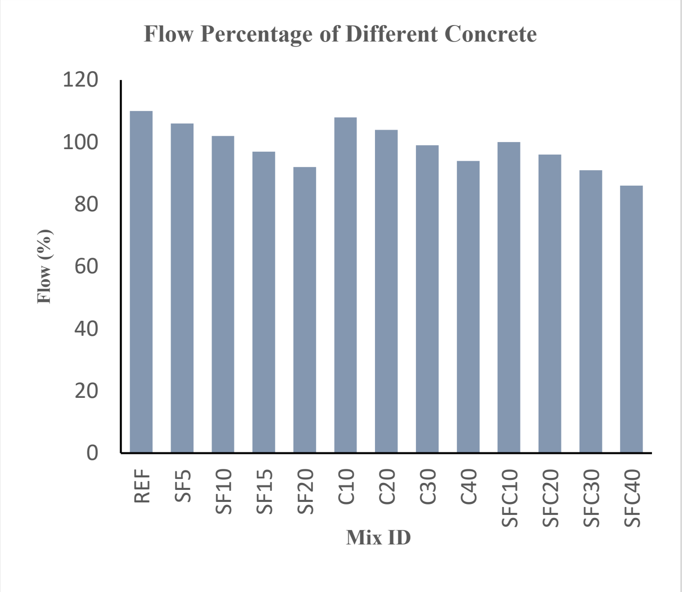

Figure 3. Flow percentage of different mortar mixtures.

5.2 Setting Time

The setting time measurements of the investigated mixes are recorded in Table 2. The reference mix demonstrated an IST of 125 min and an FST of 220 min. The use of silica fume resulted in the gradual acceleration of both parameters. The IST decreased from 125 to 108 min, whereas the FST was reduced from 220 to 192 min. The acceleration of both parameters is a proven property of silica fume that is associated with its high pozzolanic reactivity and nucleation ability: ultrafine SF particles become nuclei for C-S-H formation, thereby accelerating cement hydration [14, 24]. Moreover, the secondary pozzolanic reaction involving SF and $Ca(OH)_2$ contributes to the quick depletion of calcium hydroxide and further cement dissolution.

In contrast, ceramic waste resulted in an increase in both parameters, as shown in Figure 4. IST was observed to range from 128 min at C10 to 141 min at C40, whereas FST increased from 225 min to 245 min. Such behavior may be explained by the high-water absorption ability of ceramics, which lowers the availability of free water during the initial stage of hydration and thus reduces the effective w/c in the vicinity of cement particles [8, 9]. The limited pozzolanic reactivity of ceramic waste compared to SF implies that no significant nucleation occurs during the hydration processes.

The combination of SF with CW showed that mixing had opposite effects on IST and FST. Thus, the IST ranged from 121 to 135 min, and the FST varied from 214 to 236 min.

The acceleration caused by silica fume is associated with its nucleation effect, which promotes earlier formation of hydration products, whereas ceramic waste may delay hydration due to temporary water absorption and slower release of absorbed water.

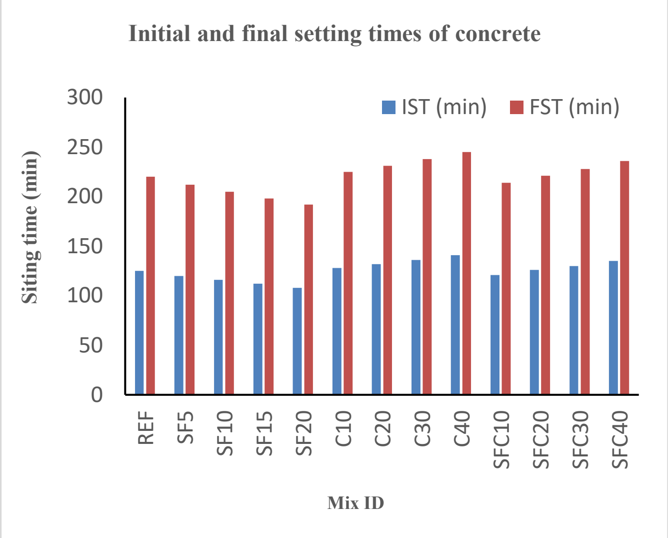

Figure 4. Initial and final setting times of the investigated mixes.

5.3 Compressive Strength

The results of the 28-day compressive strength test for all mixtures are provided in Table 2. It can be seen that all tested materials show positive improvement in strength parameters until they reach their maximum values, after which they drop significantly. The compressive strength of the reference material is 42.1 MPa. Increasing the SF level improves the compressive strength until reaching 51.1 MPa at the SF10 level, a 21.4% gain over the reference. This improvement in strength parameters may be explained by the pozzolanic reaction with the formation of additional C-S-H gel due to SF reactions with $Ca(OH)_2$; micro-filling effect when ultrafine particles occupy spaces between other particles and improve ITZ properties [3,4,14].

With a further increase in the SF content, the compressive strength drops to 49.3 MPa (SF15) and even more – to 45.7 MPa (SF20). The latter was predicted according to results reported in other literature [5,6], as a higher amount of water is needed for higher SF content, causing the agglomeration of ultrafine SF and its dilution of clinker content, which cannot maintain a proper hydration process, resulting in increasing micro-porosity and decreasing compressive strength [5,6].

The reduction in mechanical performance at higher replacement levels can be attributed to the dilution effect caused by reduced cement content, agglomeration of ultrafine silica fume particles, and decreased particle packing efficiency. In addition, the higher water absorption and porosity of ceramic waste particles may weaken the aggregate–paste interface and increase microstructural heterogeneity. As a result, the beneficial effects observed at moderate replacement levels become less significant at higher substitution rates, leading to lower compressive and flexural strengths.

Mixtures with ceramic waste replacement showed insignificant improvements in compressive strength, with the C10 (44.3 MPa) and C20 (46.7 MPa) mixtures having better parameters than the reference mixture. Such results are caused by the additional mechanical interaction of ceramic particles due to their rough surface, as well as the partial pozzolanic activity of ceramic waste due to its amorphous silica and alumina content, which can react with $Ca(OH)_2$ in an alkaline environment [7,9]. In the case of higher replacement levels – 30 and 40%–the compressive strengths of C30 and C40 are lower than that of the reference material, which may be caused by the higher water absorption of ceramic particles, which leads to additional porosity and a weak interface between the aggregate and cementitious paste [8].

SFC mixtures demonstrated the best results of all the materials used. 52.9 MPa for SFC10 and record high of 56.1 MPa – representing a 33.3% improvement over reference – was recorded for SFC20; however, at higher CW substitution rates of 30% and 40% strength decreased to 51.8 and 47.5 MPa respectively. The superior performance of the SFC20 mixture confirms the good synergistic interaction between silica fume and ceramic waste: SF provides densification of the matrix owing to additional C-S-H gel formation and void filling, whereas ceramic particles (20%) provide efficient mechanical interlocking of particles [6, 9, 23].

This positive interaction phenomenon can be explained by the way silica fume works in conjunction with ceramic debris to act as an addition to the mortar matrix. The use of silica fume creates a better pore structure through its use as both a filler and pozzolanic material; both of these functions provide additional C-S-H gel in the matrix thereby, lowering the porosity of that matrix. Additionally, due to the coarser texture of the ceramic debris when compared to natural sand, the mechanical interlock is enhanced through improved aggregate-to-paste bond strength as well as providing more effective mechanical load transfer throughout the mortar. The superior performance exhibited by the SFC20 mix in both compressive and flexural strengths and UPV values supports this explanation.

5.4 Flexural Strength

As in the case of compressive strength, the behavior of flexural strength also showed patterns largely similar to each other (see Table 2). The flexural strength in the reference mixture was found to be 6.1 MPa. The use of silica fume resulted in improved flexural strength until SF10 (up to 7.1 MPa), after which there was a decrease in SF15 (6.8 MPa) and SF20 (6.3 MPa). Flexural strength is especially dependent on microstructure enhancement in the ITZ region, since it plays the most significant role in the cracking process in the case of bending [6]. The pozzolanic reaction in SF results in a reduction in the concentration of $Ca(OH)_2$ crystals in the aggregate-paste contact area, leading to better interfacial bonding and, hence, improved flexural strength.

For ceramic waste mixes, C20 provided the maximum flexural strength (6.6 MPa), whereas C40 yielded the minimum result among all mixes (5.5 MPa), below the reference as shown in Figure 5. This trend follows the compressive strength, where moderate amounts of ceramic waste were beneficial owing to the increased surface roughness and aggregate-paste interaction. In contrast, increased content raised the probability of crack appearance. The results coincide with those reported previously in studies concerning the addition of ceramic aggregates into mortar [7,8].

A similar tendency was noted for SF and CW mixed together; specifically, SFC20 yielded the highest flexural strength (7.5 MPa), while SFC40 also performed slightly better than the reference (6.4 MPa). The results prove that a combination of increased paste density and increased aggregate roughness provides an extremely strong structure that is resistant to cracking [23].

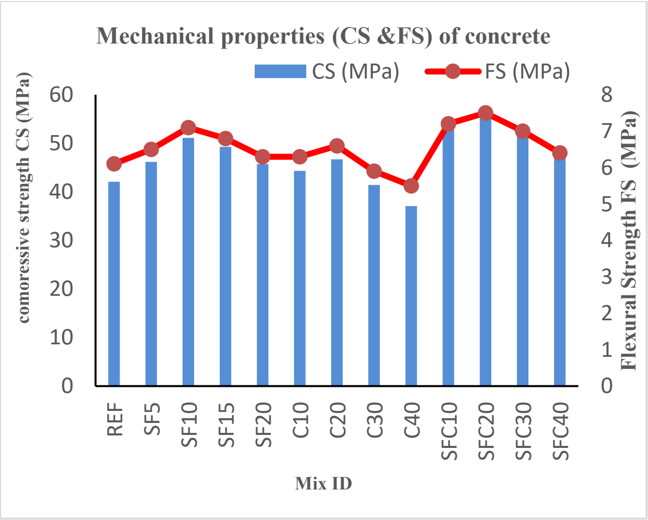

Figure 5. Compressive and flexural strengths of mortar mixtures at 28 days.

5.5 Ultrasonic Pulse Velocity (UPV)

The UPV measurements provided a non-destructive evaluation of the internal quality and uniformity of the mortar samples. Based on the classification standards, a UPV greater than 4.5 km/s represents excellent concrete quality, 3.5–4.5 km/s represents good quality, while below 3.0 km/s means poor quality [22]. All mixtures tested in this study had UPV within good and excellent ranges.

The UPV reading for the reference mixture was 4.15 km/s. The UPV readings increased with silica fume addition up to SF10 (4.447 km/s), after which they began to decrease for SF15 (4.392 km/s) and SF20 (4.248 km/s) as shown in Figure 6. The increase in UPV with increasing addition is due to the microfiller and pozzolanic action of SF. The latter reduces the internal porosity, thereby improving the continuity of the solid phases through which the ultrasonic waves travel [21, 22]. The reduction with a further increase is due to the higher microporosity caused by agglomeration and the higher water requirement.

Of the ceramic waste mortar mixtures, C20 showed the highest UPV (4.314 km/s), whereas the C40 mortar had the lowest reading (3.891 km/s). The latter result can be explained by the increase in internal porosity with a higher replacement percentage, hence disrupting the pathways for wave propagation. The combination mortar mixtures gave the highest UPV readings, where SFC20 registered 4.614 km/s, which represents an excellent quality mortar mix. A high correlation between the UPV and compressive strength was found across the 13 mixes in this study, which is in agreement with the well-known correlation between the two variables [22].

The increase in UPV is consistent with the development of a denser and more homogeneous microstructure. Reduced porosity and improved continuity of the solid phase facilitate faster transmission of ultrasonic waves through the mortar matrix.

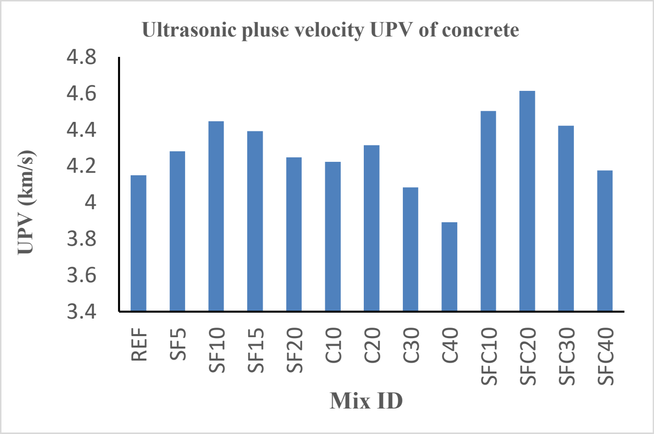

Figure 6. Ultrasonic Pulse Velocity (UPV) results for different mixes.

6. Conclusions

The results of the current work lead to the following conclusions.

1. Workability showed a progressive decrease with rising silica fume and ceramic waste substitution levels due to the large specific surface area of SF, rough texture, and high-water absorption rate of CW. The flow of all mixes stayed in an acceptable range (86-110%).
2. Owing to the high pozzolanic activity and nucleation effect, silica fume shortened the initial and final setting times, whereas ceramic waste extended the setting times owing to the lower amount of available water in the mixture.
3. Silica fume content of 10% (SF10) resulted in maximal compressive strength (51.1 MPa) and flexural strength (7.1 MPa) as compared with the reference. These values are higher than those of the reference by 21.4% and 16.4%, respectively.
4. At moderate (10-20%) levels, ceramic waste increased the compressive strength and flexural strength via mechanical interlocking. Above 30% replacement levels of CW, the mortar demonstrated lower compressive and flexural strengths than those of the reference mixture.
5. The most successful combination was the mixture SFC20 (10% SF + 20% CW), which provided the greatest values of compressive strength (56 MPa), flexural strength (7.5 MPa), and UPV (4.614 km/s) among all other investigated mixes.
6. From an economic perspective, the utilization of silica fume and recycled ceramic waste may contribute to reducing the consumption of conventional cement and natural aggregates. Ceramic waste is generally available at low cost as a construction and demolition by-product, while silica fume is an industrial by-product that can partially replace cement. Although transportation and processing costs should be considered, the combined use of these materials has the potential to lower material costs and landfill disposal requirements while improving mortar performance.
7. The research results indicate that using both ceramic waste from construction and silica fume together can result in increased strength and durability for making mortar. The improved mechanical properties achieved by blending these two materials have the potential to be utilized as masonry mortars, rendering applications, repair materials, etc., because they have greater strength and durability than traditional mortars used in cement-based products. By using industrial waste and construction waste, we can also decrease the amount of cement consumed, conserve natural aggregates, reduce the amount of landfill waste and promote a circular economy in the construction industry.

The present study focused on the conventional 28-day evaluation period commonly used for cement-based materials. Future research is recommended to investigate the long-term performance of mortar mixtures containing silica fume and ceramic waste at later ages, including strength development and durability characteristics.

Future studies may focus on developing empirical predictive models relating silica fume and ceramic waste replacement levels to the mechanical properties of mortar mixtures. Such models could enhance the practical application of these sustainable materials in mixture design and performance prediction.

Acknowledgements

The authors acknowledge Mustansiriyah University (www.uomustansiriyah.edu.iq) in Baghdad, Iraq, for its support in this research.

Conflict of interest

"The authors declare that there are no conflicts of interest regarding the publication of this manuscript".

Author Contribution Statement

All authors contributed to writing and editing the manuscript. Rafla Abbas Abduljabbar, Dalia Adil Rasool, Amer Hameed Majeed proposed the research problem and supervised the work. All authors participated in preparing the introduction, structuring the manuscript, discussing the findings, and finalizing the paper.

Data Availability

Data available by the authors upon request.

AI Declaration Statement

The authors confirm that the manuscript has been written without the assistance of generative AI or AI-based writing tools.

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