ДГКС ASES | E-36
Kongres 2026
Congress 2026

doi: 10.67563/ASESCONF2026024P

Vladan Pantić[1], Slobodan Šupić[2], Mirjana Malešev[2], Vlastimir Radonjanin[2]

SHEAR STRENGTH OF SUSTAINABLE MASONRY MORTARS INCORPORATING CERAMIC WASTE POWDER

Summary: The construction industry is one of the largest consumers of non-renewable natural resources and a significant source of CO_2 emissions, which underscores the need to develop more sustainable materials that can reduce its negative environmental impact. In order to meet the requirements of the modern circular economy, this study investigates the potential application of locally available waste materials in the production of innovative, eco-friendlier masonry mortars. The eco-binder used as a supplementary cementitious material (SCM) was ceramic waste powder (CWP), generated during the manufacturing processes in the ceramic industry, with a cement replacement level up to 80%. The experimental program involved comprehensive characterization of the CWP to evaluate its suitability as an SCM, followed by testing of the fundamental properties of the developed masonry mortars. Furthermore, the performance of the eco-mortar within masonry assemblies was examined, with particular emphasis on assessing the initial shear strength of the mortar joint. The results indicate that ceramic waste powder can be effectively utilized as a partial cement substitute.

Keywords: circularity, masonry mortar, ceramic powder, shear strength

ČVRSTOĆA VEZE ODRŽIVIH MALTERA ZA ZIDANJE SA DODATKOM KERAMIČKOG OTPADNOG PRAHA

Rezime: Građevinska industrija predstavlja jednog od najvećih potrošača neobnovljivih prirodnih resursa i značajan je izvor emisije CO_2, što ukazuje na potrebu razvoja održivijih materijala koji mogu smanjiti njen negativan uticaj na životnu sredinu. U skladu sa principima savremene cirkularne ekonomije, u ovom radu ispituje se mogućnost primene lokalno dostupnih otpadnih materijala u proizvodnji inovativnih i ekološki prihvatljivijih maltera za zidanje. Kao ekološko vezivo, odnosno dodatni cementni materijal (SCM), korišćen je prah keramičkog otpada (CWP), nastao u procesu proizvodnje keramičkih proizvoda, pri čemu je ostvarena zamena cementa od 50%. Eksperimentalni program obuhvatio je detaljnu karakterizaciju praha keramičkog otpada radi procene njegove pogodnosti za primenu kao SCM-a. Pored toga, analizirane su performanse maltera u zidanim sklopovima, sa posebnim akcentom na određivanje početne čvrstoće smicanja, odnosno čvrstoće veze malterskog spoja. Dobijeni rezultati pokazuju da se prah keramičkog otpada može uspešno koristiti kao delimična zamena cementa.

Ključne reči: cirkularna ekonomija, malteri za zidanje, prah keramičkog otpada, čvrstoća veze.

[1] Faculty of technical sciences Novi Sad, University of Novi Sad, pantic_vladan@uns.ac.rs
[2] Faculty of technical sciences Novi Sad, University of Novi Sad

1. INTRODUCTION

The construction industry is one of the largest consumers of non-renewable natural resources and a significant source of CO_2 emissions, which necessitates the development of more sustainable materials capable of reducing its negative environmental footprint. Consequently, increasing attention is being directed towards the potential application of recycled materials derived from solid waste processing in the production of new construction products. In this context, the utilization of ceramic waste holds considerable potential for advancing sustainable production and circular economy principles in the construction sector. The use of locally sourced ceramic waste as a partial substitute for cement and natural aggregates in concrete and mortar can contribute to addressing significant environmental challenges.

Ceramic waste powder (CWP) is generated as a result of the demolition of masonry structures, the construction of new buildings, or manufacturing defects in the ceramic industry. According to data reported in the literature [1], more than 22 billion tons of this waste are produced globally on an annual basis, posing a serious. Numerous studies have investigated the potential use of ceramic waste in cement-based composites, either as an aggregate replacement or as a partial substitute for cement [2]-[5]. The results have generally indicated favourable pozzolanic activity of finely ground CWP and its positive contribution to the mechanical properties of the composite at later stages of hydration. While the beneficial effects of CWP have been extensively demonstrated in cement-based composites, its application in masonry mortars has received comparatively less attention. Among cement-based composites, masonry mortar represents a particularly important application, as its mechanical and bonding properties directly govern the structural performance of masonry assemblages.

Masonry structures are predominantly composite systems consisting of masonry units and mortar. Their use remains relatively widespread in developing countries, owing to the low cost of materials, local availability, and ease of construction. The shear strength between masonry units and mortar is of critical importance for reliable performance under various loading conditions. Numerous studies have focused on the investigation of shear bond strength and failure mechanisms at the brick-mortar interface, particularly in the context of incorporating novel ecological binders to produce green mortars.

Javed et al. [6] investigated the compressive strength and shear strength of masonry assemblies constructed using three different types of brick and three environmentally friendly mortars incorporating fly ash, sugarcane bagasse ash, and calcined clay, respectively. The results demonstrated that the calcined clay mortar achieved the highest shear strength, while mortars based on sugarcane bagasse ash exhibited superior performance at later curing ages, attributable to the slower strength development characteristic of this binder.

Murthi et al. [7] examined the compressive strength of masonry wallets and the shear strength of mortar joints incorporating supplementary cementitious materials - dolomite powder and silica fume - at two different mortar joint thicknesses of 12 mm and 18 mm. The results indicated that masonry assemblies constructed with blended cement mortars achieved strengths comparable to those constructed with conventional cement mortar, thereby confirming the feasibility of partial cement replacement with these materials.

Azimi Resketi and Toufigh [8] investigated the shear strength characteristics of masonry structures constructed using environmentally friendly materials, in which natural pozzolan "Taftan" and two types of rice husk ash were incorporated into the mortar mix. The use of these additions resulted in improved mortar ductility and increased deformation capacity at failure, while simultaneously reducing production costs and the environmental impact of the mortar.

In contrast to the extensive body of research on the application of CWP in concrete, its use in masonry mortars remains insufficiently explored. For this reason, the present study examined the influence of locally sourced ceramic waste powder on the properties of masonry mortar, including compressive and flexural strength, with particular emphasis placed on the determination of shear strength of the mortar joint. The aim of the investigation was to assess the feasibility of large-scale cement replacement - up to 80% - and to develop masonry mortars suitable for both structural and non-structural applications, while reducing the environmental impact and improving cost efficiency.

2. EXPERIMENTAL RESEARCH

2.1. MATERIALS

For the purposes of the experimental investigation, Portland cement (PC) of the grade CEM I 42.5R, manufactured at the "Holcim" plant in Beočin, was used as the primary binder. The cement has a Blaine specific surface area of 4,000 cm^2/g and a specific gravity of 3.1 g/cm^3.

As a supplementary cementitious material (SCM), ceramic waste powder was used, obtained by grinding waste generated during the production of ceramic products at the "NEXE Stražilovo" manufacturing facility in Petrovaradin, Serbia. The ceramic brick rubble was first coarsely crushed to a size appropriate for processing in the laboratory mill and subsequently finely ground for 6 h to attain the desired fineness (Figure 1). The adopted criterion was a specific surface area approximately equal to that of the cement. After grinding, a powder with a Blaine specific surface area of 13,815 cm^2/g - approximately three to four times higher than that of cement - and a specific gravity of 2.62 g/cm^3 was obtained.

(a) (b) (c)

Figure 1: (a) Ceramic waste. (b) Crushed clay blocks. (c) Ceramic waste powder

The results of the chemical composition analysis of PC and CWP are presented in Table 1. The chemical composition of the CWP was evaluated in accordance with the requirements defined by standard SRPS EN 450-1 [9], which stipulates that the minimum total content of the key oxides - SiO_2, Al_2O_3, and Fe_2O_3 - must be 70%. The combined proportion of these oxides in the ceramic powder amounts to 84%, thereby fully satisfying the aforementioned requirement. Furthermore, the reactive SiO_2 content is as high as 50%, significantly exceeding the lower threshold value of 25% prescribed by the same standard.

Testing of the pozzolanic properties confirmed that the ceramic waste powder belongs to pozzolanic activity class 10. Further evidence of pozzolanic reactivity is provided by the activity index, with values after 28 and 90 days reaching 99% and 105%, respectively, thereby fully meeting the requirements of standard SRPS EN 450-1 [9].

Table 1: Chemical composition of PC and CWP

	LOI	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	K_2O	MgO	CaO	SO_3	P_2O_5	Reactive SiO_2
PC	/	17,34	4,53	20,64	0,20	0,59	1,93	50,26	3,06	0,00	/
CWP	3,3	60,86	16,38	6,81	0,77	2,39	3,89	9,38	0,80	0,14	50.26

2.2. METHODS

The chemical composition of the waste materials was determined by XRF analysis in accordance with standards SRPS EN 196-2 [10] and ISO 29581-2 [11].

Pozzolanic activity and activity index were tested on specimens prepared in accordance with the procedure given in standards SRPS B.C1.018 [12] and SRPS EN 450-1 [9].

Compressive strength and flexural strength were determined in accordance with standard SRPS EN 1015-11 [13] on prismatic specimens with dimensions of 40×40×160 mm.

Testing of the initial shear strength of the mortar joint was carried out in accordance with standard SRPS EN 1052-3 [14]. Standard-format ceramic bricks were used for the preparation of the test assemblies. For each mortar mixture, six masonry specimens were prepared. Following fabrication, the specimens were cured under laboratory conditions for 28 days prior to testing.

2.3. MIXING AND PROPORTIONING OF MORTARS

The experimental program comprised four distinct mortar mixtures. The control mixture (C2) was a cement-lime mortar prepared with a volume ratio of 1:0.7:4.2 (cement:lime:sand). In the three remaining mixtures, a portion of the cement was replaced by CWP at substitution levels of 50%, 60%, and 80% by volume. The water-to-binder ratio (w/b) was adjusted aiming to achieve the required workability of masonry mortar (175±10mm), as prescribed by SRPS EN 1015-2 [15].

The designations of each mixture, along with the corresponding quantities of constituent materials, are summarized in Table 2.

Table 2: Mixture designations and constituent material quantities

Mortar	m_c (g)	m_l (g)	m_s (g)	m_{cwp}(g)	w/b	m_w (g)
C2	193.7	59.2	1350	/	1.05	265.6
CWP2-50	96.9	59.2	1350	74.2	1.20	276.3
CWP2-60	77.5	59.2	1350	89.0	1.20	270.9
CWP2-80	38.7	59.2	1350	118.7	1.25	270.8

m_c-mass of cement; m_l-mass of lime; m_s-mass of sand; m_{cwp}-mass of CWP; m_w-mass of water; w/b-water to binder ratio

The following photographs illustrate the specimen preparation procedure for the determination of the mortar joint shear strength. The specimens were constructed using three bricks bonded with cement mortar, with a controlled joint thickness of 10 mm. Immediately after construction, each specimen was pre-compressed with a uniformly distributed load providing a vertical stress between 2.0×10^{-3} N/mm² and 5.0×10^{-3} N/mm².

Figure 2: Sample preparation for testing shear strength

3. TEST RESULTS AND DISCUSSION

3.1. COMPRESSIVE STRENGTH

The results of the compressive strength testing at the ages of 28 and 90 days are presented graphically in the following figure.

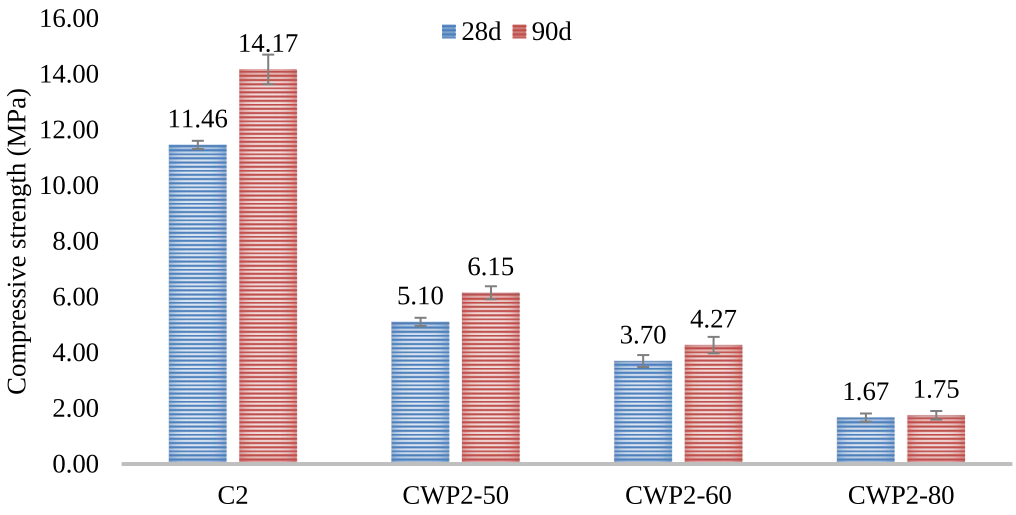

Figure 3: The compressive strength results of the mortars

Compared to the reference mixture C2, the partial replacement of cement with CWP led to a reduction in compressive strength. The compressive strength of mixtures CWP2-50, CWP2-60, and CWP2-80 decreased by 55%, 68%, and 85%, respectively. This reduction can be attributed to the increase in the effective water-to-binder (w/b) ratio inherent to blended mortar systems. An elevated w/b ratio promotes greater porosity and permeability within the hardened matrix, which in turn adversely affects the mechanical performance of the mortar.

At 90 days, mortars containing CWP showed a moderate increase in compressive strength of between 5% and 20% relative to the 28-day results, which can be attributed to the continued pozzolanic reaction of the ceramic waste powder.

In accordance with SRPS EN 998-2 [16], masonry mortars are classified into strength classes based on their mean compressive strength. Eurocode 6 and Eurocode 8 prescribe a minimum mortar compressive strength of 5 MPa (strength class M5) for load-bearing masonry structures. The mean compressive strength values and the corresponding strength class achieved by each mortar mixture are presented in Table 3.

Based on the compressive strength results, the reference mortar (C2) and mixture CWP2-50 comply with the requirements for structural masonry mortar. Mixture CWP2-60 is suitable for use in non-load-bearing masonry, while CWP2-80 is appropriate only for plastering mortars.

Table 3: Class of masonry mortars based on compressive strength

Mortar	C2	CWP2-50	CWP2-60	CWP2-80
Compressive strength 28d (MPa)	11.46	5.10	3.7	1.67
Class	**10**	**5**	**2.5**	**1**

3.2. FLEXURAL STRENGTH

The flexural strength results followed a similar decreasing trend to that observed for compressive strength. The flexural strength values of the mortar specimens at 28 days are presented graphically in the following figure.

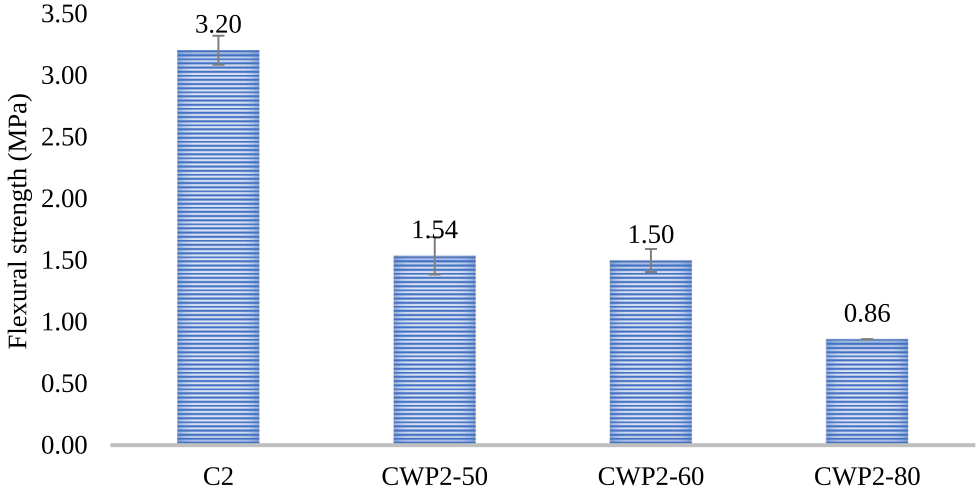

Figure 4: The flexural strength results of the mortars

The incorporation of CWP as a cement substitute resulted in a significant reduction in flexural strength. At 28 days, mixtures CWP2-50, CWP2-60, and CWP2-80 achieved approximately 52%, 53%, and 73% lower flexural strength compared to the reference mixture, respectively. It should be noted, however, that flexural strength is not a property of primary importance for masonry mortars, and accordingly, no specific criteria are prescribed in the relevant regulations.

3.3. SHEAR STRENGTH

The shear strength of the mortar joint was determined in accordance with SRPS EN 1052-3 [14], Procedure B. Since the reference mortar (C2) and mixture CWP2-50 satisfied the minimum compressive strength requirements for structural masonry mortars, only these two mixtures were selected for the shear bond strength tests. The schematic representation of the force distribution and the appearance of the specimen during testing are shown in Figure 5.

Figure 5: Shear strength testing of mortar joints

Testing was performed on a hydraulic press with a capacity of 1000 kN, at a shear stress rate of 0.1 N/(mm^2·min), within the range of 0.1 to 0.4 N/(mm^2·min) prescribed by the standard. The load was applied through a ball hinge placed in the centre of the top central steel plate, ensuring uniform force distribution across the specimen.

The reference mixture C2 exhibited a mean initial shear strength of 0.154 MPa. The mixture CWP2-50, in which 50% of the cement was replaced by ceramic waste powder, yielded a mean value of 0.153 MPa and a standard deviation of 0.038 MPa. It can be observed that the partial substitution of cement with CWP did not result in a statistically significant reduction in initial shear strength, as the mean values obtained for both mixtures are virtually identical. The graphical representation of the test results is presented in the following figure.

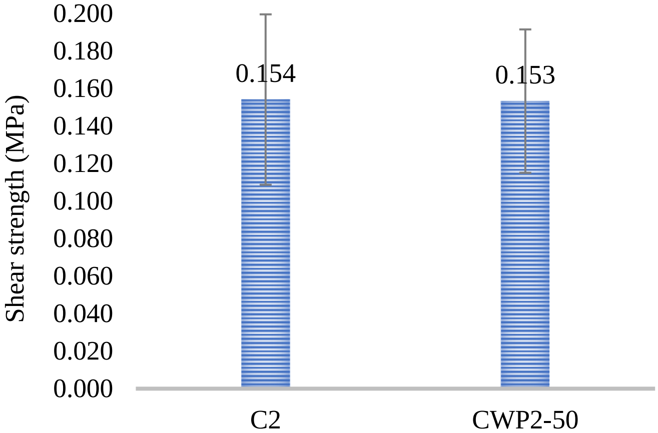

Figure 6: The shear strength results of the mortars

According to the requirements of SRPS EN 998-2 [16], the characteristic initial shear strength of the mortar joint shall not be less than 0.15 MPa for general-purpose mortars. As both investigated mixtures satisfy this criterion, it can be concluded that the partial replacement of cement with ceramic waste powder does not adversely affect this mechanical property.

The dominant failure mode observed across the tested specimens was shear failure at the unit/mortar bond interface, whereby the mortar remained adhered to one masonry unit or was divided between the two unit faces, as defined in Annex A of SRPS EN 1052-3 [14]. Representative examples of the observed failure mode are illustrated in Figure 7.

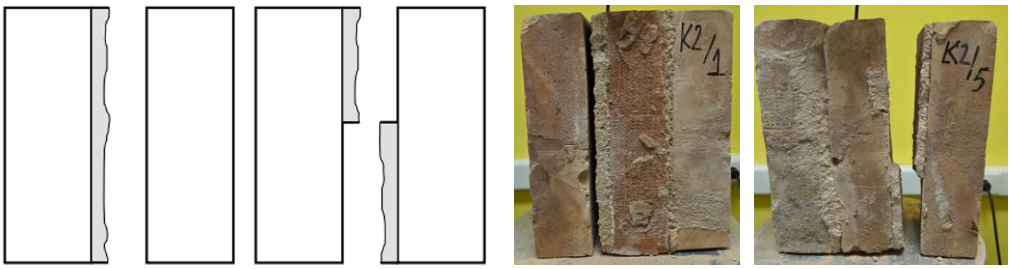

Figure 7: Failure pattern of masonry samples

4. CONCLUSIONS

The principal findings of the present study can be summarized as follows:

- Chemical analysis of CWP revealed a relatively high content of amorphous silica, which positively influences pozzolanic activity and is reflected in a high activity index, confirming the suitability of CWP as a supplementary cementitious material.

- With respect to compressive strength, mixture CWP2-50 satisfied the requirements for structural masonry applications (class M5), while the remaining mortar mixtures attained strength rendering them suitable for use in non-load-bearing elements.
- The partial replacement of cement with ceramic waste powder did not adversely affect the shear bond strength of the mortar joint. Both the reference mixture and the CWP2-50 mixture met the minimum characteristic initial shear strength of 0.15 MPa prescribed by SRPS EN 998-2 for general-purpose mortars, demonstrating that up to 50% cement substitution can be achieved without compromising this mechanical property.
- Overall, the results indicate that CWP represents a viable and sustainable alternative to PC in masonry mortar production, contributing to the reduction of cement consumption and the valorization of industrial waste in the construction sector.

REFERENCES

[1] J. Yang, P. Jiang, R. Nassar, S. A. Suhail, M. Sufian, A. F. Deifalla, Experimental investigation and AI prediction modelling of ceramic waste powder concrete – An approach towards sustainable construction, Journal of Materials Research and Technology, 23, 2023.

[2] M. Ebrahimi, A. Eslami, I. Hajirasouliha, M. Ramezanpour, K. Pilakoutas, 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.

[3] M. N. Lam, D. Nguyen, D. Nguyen, Potential use of clay brick waste powder and ceramic waste aggregate in mortar, Construction and Building Materials, 313, 2021, 125516.

[4] A. Tokareva, S. Kaassamani, D. Waldmann, Using ceramic demolition wastes for CO2-reduced cement production, Construction and Building Materials, 426, 2024, 135980.

[5] S. Šupić, M. Malešev, V. Pantić, I. Lukić, V. Radonjanin, M. Ognjanović, G. Broćeta, Environmentally friendly masonry mortar blended with fly ash, corn cob ash or ceramic waste powder, Materials, 16, 2023, 6725.

[6] K. Javed, M. Irfan-ul-Hassan, M. A. Farooq, M. B. Sharif, Detailed investigation of compressive and bond strength for sustainable brick masonry developed by using various types of bricks and green mortars, Journal of Building Engineering, 84, 2024, 108477.

[7] P. Murthi, Md. Akib, Md. Imran, S. Ahmed, V. Prasanna, Studies on the strength variation of brick masonry using novel blended masonry mortar mixes and mortar thickness, Materials Today: Proceedings, 39, 2021, 126-130.

[8] N. Azimi Resketi, V. Toufigh, Enhancement of brick-mortar shear bond strength using environmental friendly mortars, Construction and Building Materials, 195, 2019, 28-40.

[9] SRPS EN 450-1:2014, Fly ash for concrete : Definition, specifications and conformity criteria.

[10] SRPS EN 196-2:2015, Methods of testing cement - Part 2: Chemical analysis of cement.

[11] ISO 29581-2:2010, Cement - Test methods: Chemical analysis by X-ray fluorescence.

[12] SRPS B.C1.018-2015, Non-metallic mineral raws - Pozzolanic materials - Constituents for cement production - Classification, technical conditions and test methods.

[13] SRPS EN 1015-11:2019, Methods of test for mortar for masonry - Part 11: Determination of flexural and compressive strength of hardened mortar.

[14] SRPS EN 1052-3:2010, Methods of test for masonry : Determination of initial shear strength.

[15] SRPS EN 1015-2:2008, Methods of test for mortar for masonry - Part 2: Bulk sampling of mortars and preparation of test mortars.

[16] SRPS EN 998-2:2017, Specification for mortar for masonry — Part 2: Masonry mortar.