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REACTION TO FIRE OF MASONRY MORTAR BLENDED WITH ENVIRONMENTALLY-FRIENDLY MATERIALS

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Abstract

Sustainable development in the twenty-first century necessitates the strategic use of renewable, environmentally-friendly materials as well as inventive thinking. Hence, it is unavoidable to assess their performance and engineering properties to be accepted by the civil engineering community. Traditional masonry structures have relied heavily on conventional cement-lime mortars. Owing to enormous natural resources consumption (limestone and clay) and a large amount of CO_2 *discharged into the environment due to the thermal treatment of raw materials, these mortars might be classified as unfriendly in contemporary engineering practice. Therefore, in recent years, extensive research has been conducted on the application of various pozzolanic materials as a feasible option for developing new, alternative types of greener masonry mortars. However, just a few studies have addressed the fire behaviour aspect of masonry mortars, particularly those containing supplementary cementitious materials. This paper focuses on the reaction to fire of nine different masonry mortar mixtures incorporating locally accessible waste materials: ceramic waste powder, fly ash, and biomass ash, as cement substitutes. Non-combustibility and the gross heat of combustion tests were performed with the aim of categorizing investigated mortars into fire reaction classes. The results indicate that all mortar combinations meet the requirements for the A1 fire reaction class, while all blended mortars had lower mass loss and heat release in relation to the reference cement-lime mortars.*

Key words: *masonry mortar, fire reaction class, environmentally-friendly materials.*

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1. Introduction

Nowadays, sustainability involves the strategic use of renewable and environmentally acceptable building resources, such as waste materials produced as by-products of industry and agriculture.

To be accepted by the civil engineering community, sustainable materials must be evaluated for their performance and engineering properties. This includes assessing their durability, structural integrity, energy efficiency, thermal performance, and fire safety.

Fire safety represents one of seven basic requirements that construction products and buildings must satisfy for an economically reasonable working life, subject to normal maintenance (Zakon o građevinskim proizvodima No 83/2018), (Regulation (EU), No 305/2011). Preventing ignition and fire development by using building materials with adequate reaction to fire characteristics represents the first phase of passive fire protection (Martin, 2017). Reaction to fire is defined as "*a response of a product in contributing by its own decomposition to a fire to which it is exposed, under specified conditions*" (SRPS EN 13501-1: 2018).

Traditional masonry structures have relied heavily on conventional cement-lime mortars. Owing to enormous natural resources consumption (limestone and clay) and a large amount of CO_2 discharged into the environment due to the thermal treatment of raw materials, these mortars might be classified as unfriendly in contemporary engineering practice.

In recent years, extensive research has been conducted on the application of various pozzolanic materials as a feasible option for developing new, alternative types of greener masonry mortars. However, just a limited number of studies have addressed the fire behaviour aspect of masonry mortars, particularly those containing supplementary cementitious materials (SCMs). According to the findings of Mohit et al., ceramic waste powder as cement replacement improves the thermal resistance of mortar mixes (Mohit & Sharifi, 2019). Silica fume has a favourable effect on improving the fire performance of thermal-insulating mortar and can significantly mitigate the adverse effects of high-temperature deterioration, which is helpful for the fire performance of insulation mortars applied to building facades (Ding, 2023). Textile reinforced mortars can provide effective protection and prevent cracking of masonry due to fire (Estevan, 2023). High strength mortars that have equivalent residual strength after exposure to 700°C to that of control cement mortar specimens before exposure to high temperature can be produced by replacing cement with high-volume fly ash and using colloidal nanosilica (Ibrahim, 2012). Cement mortars with mineral wool from construction and demolition waste recycling can be a sustainable alternative to the commercial ones currently being used, improving mechanical-thermal behaviour after the fire and preventing the explosive behaviour of the mortars (Piña Ramírez, 2020). SCMs such as fly ash, ground granulated blast-furnace slag, silica fume, nanoclay, and nanosilica, preserve mechanical properties of the coating mortar at high temperatures and also reduce harmful effects of the expansion of $Ca(OH)_2$ at high temperatures and its deleterious effect during rehydration (Matias Martins, 2024).

The paper focuses on the reaction to fire of nine different masonry mortar mixtures incorporating locally accessible waste materials: ceramic waste powder, fly ash, and biomass ash, as cement substitutes. Non-combustibility and the gross heat of combustion (calorific value) tests were performed with the aim of categorizing investigated mortars into fire reaction classes.

2. Materials and methods

2.1 Materials

Portland Cement (PC), produced by the Lafarge cement plant in Vojvodina, was used. The cement has a Blaine fineness of 4.000 cm^2/g and a density of 3.1 g/cm^3.

Fly ash (FA), corn cob ash (CCA), and ceramic waste powder (CWP) were used as SCMs in the cement-lime masonry mortars.

FA was provided by the thermal power plant Nikola Tesla B in Obrenovac, Serbia.

CCA was collected from ALMEX-IPOK in Zrenjanin, Serbia. This starch factory uses biomass waste, i.e. corn cobs, as an energy source and generates substantial amounts of CCA as a by-product.

CWP was produced from ceramic manufacturing waste, consisting of damaged clay hollow blocks discarded in the production facility NEXE Stražilovo in Petrovaradin.

As the fineness of FA was satisfying, no additional mechanical processing was necessary, while CCA and CWP had to be additionally ground in the lab ball mill up to the appropriate level of fineness.

The results of testing the chemical composition of SCMs are summarized in Table 1.

Table 1: Chemical compositions of SCMs

	FA	**CCA**	**CWP**
SiO_2	53.64	45.76	60.86
Al_2O_3	25.74	5.91	16.38
Fe_2O_3	7.36	3.37	6.81
Na_2O	0.30	0.00	0.77
K_2O	1.48	13.10	2.39
MgO	3.09	8.30	3.89
CaO	7.15	14.08	9.38
SO_3	2.75	1.26	0.80
P_2O_5	0.06	2.81	0.14
Content Cl	0.01	0.50	0.002
Reactive SiO_2	48.16	38.21	50.26

Owing to the favourable chemical composition, when it comes to SCMs, all tested materials displayed positive pozzolanicity, whereas FA and CWP showed a pozzolanic activity of Class 10, while CCA demonstrated a pozzolanic activity of Class 5, in line with SRPS B.C1.018:2015. All SCMs met the requirements regarding the activity index in accordance with SRPS EN 450-1:2014.

River sand was employed as fine aggregate in the production of mortar. Its specific gravity was determined to be 2.3 g/cm^3 and its fineness modulus to be 0.97.

Masonry mortar was prepared with tap water.

2.2 Methods

The chemical composition of raw materials was analysed in accordance with SRPS EN 196-2:2015 and ISO 29581-2:2010.

Non-combustibility and the gross heat of combustion (calorific value) tests were performed according to SRPS EN ISO 1182:2021 and SRPS EN ISO 1716:2018 standards.

Fire classification of masonry mortars into fire reaction classes was carried out according to SRPS EN 13501-1:2018.

2.3 Mixing and proportioning of mortars

Nine different mortar mixtures were used in the experimental investigation. The mixing ratios of reference cement-lime mortar (C) were: 1:0.7:4.2, and 1:1:4 (cement/lime/sand), by volume. In the remaining mixtures, substantial amount of cement (up to 60%) was replaced by FA, CCA, or CWP for each mixing ratio by volume. The mixing ratios and the levels of cement substitution were chosen based on the previous laboratory trials.

The water-to-binder ratio (w/b) was adjusted aiming to achieve the required workability of masonry mortar (175±10 mm), as prescribed by SRPS EN 1015-2:2008.

The labels and quantities of component components for each masonry mortar are shown in **Error! Reference source not found.**.

Table 2: Labels and component materials quantities for designed masonry mortars

Mortar	m_c (g)	m_l (g)	m_s (g)	m_{SCM}(g)	w/b	m_w (g)
C2	193.7	59.2	1350	/	1.05	265.6
FA2-50	96.9	59.2	1350	59.6	1.25	269.5
CCA2-50	96.9	59.2	1350	68.7	1.18	265.2
CWP2-50	96.9	59.2	1350	74.2	1.20	276.3
C3	201.8	92.5	1350	/	0.90	264.9
FA3-50	100.9	92.5	1350	62.0	1.05	268.2
CCA3-50	100.9	92.5	1350	71.6	1.00	265.0
CCA3-60	80.7	92.5	1350	85.9	1.03	266.9
CWP3-50	100.9	92.5	1350	77.3	1.00	270.7
m_c-mass of cement; m_l-mass of lime; m_s-mass of sand; m_{scm}-mass of SCM; m_w-mass of water; w/b-water to binder ratio.						

3. Test results and discussion

3.1 Non combustibility test

The cylindrical test specimens, five of each series, having a diameter of (45±2) mm and a height of (50±3) mm, were prepared, as illustrated in Figure 1.

Figure 1: Test specimens, prepared for combustibility test

The specimens were dried in a ventilated oven maintained at (60±5)°, for 24h, and cooled to ambient temperature prior to testing. The test lasts 30 minutes, and the sample is exposed to a temperature of (750±5) °C in hot furnace. The mass, before and after the test for each specimen was recorded.

The result of the measurement is the mass loss of the samples in percentages after the combustion process. Figure 2 shows the mass loss in nine different masonry mortar mixtures.

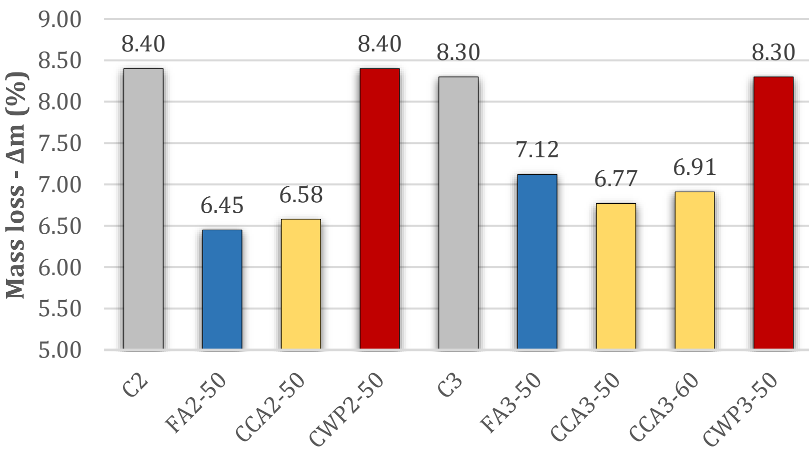

Figure 2: Mass loss of test specimens after the combustion process

The test findings revealed that reference cement mortars and mortars with CWP have the highest mass loss, ranging from 8.3 to 8.4%. Masonry mortars blended with FA and CCA displayed the lowest values of mass loss, ranging from 6.4 to 7.1%.

All tested masonry mortars met the requirements for non-homogeneous materials categorized in A1 fire reaction class (Δm≤50%), according to SRPS EN 13501-1:2018 mass loss classification criterion.

Figure 3 depicts the specimen following the combustion process. The majority of test specimens retained their cylindrical shape following the test; nonetheless, their structure was friable and prone to collapse. It should be emphasized that no persistent blazing or consistent blue-coloured luminous gas zones were detected during the test. All evaluated specimens showed no sustained flame, indicating that all mortar combinations met the threshold for the A1 fire reaction class (t_f=0s).

Figure 3: Test specimens after the combustion process

3.2 The gross heat of combustion

Heat of combustion (calorific value, Q) is defined as “thermal energy produced by combustion of unit mass of a given substance” (expresed in MJ/kg). Gross heat of combustion (PCS) represents “heat of combustion of a substance when the combustion is complete and any produced water is entirely condensed under specified conditions” [SRPS EN ISO 1716:2018].

Five test specimens of each mortar combination were broken and burned under standardized conditions, in a bomb calorimeter. The gross heat of combustion was calculated based on the observed temperature rise, taking into account heat loss and the latent heat of vaporization of water.

Figure 4 shows the average values of the gross heat of combustion computed from measurements on three specimens of each mortar type.

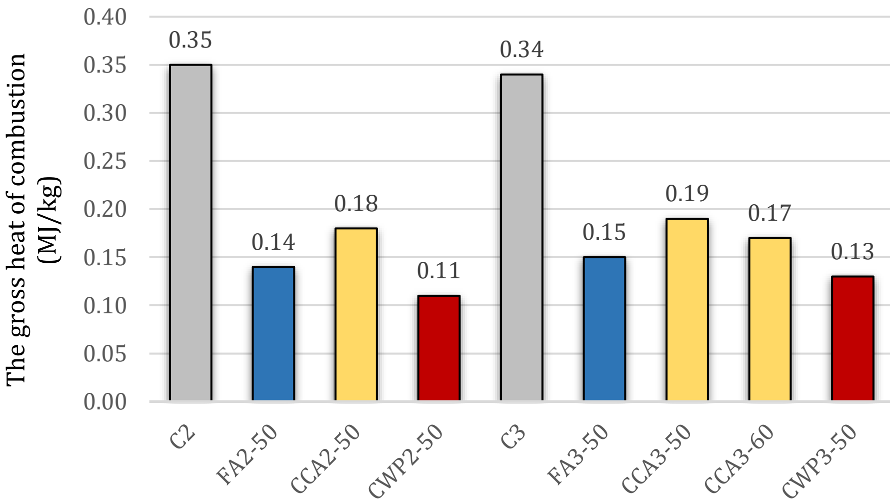

Figure 4: The gross heat of combustion of masonry mortars

The obtained results indicate that reference cement mortars are characterized by the highest heat release values. All mortar types containing SCMs demonstrated lower values of heat release, with minimal variances between them.

Based on the classification criterion related to the gross heat of combustion, specified in SRPS EN 13501-1, all tested masonry mortars met the requirements for non-homogeneous products classified in A1 fire reaction class (PCS≤2.0 MJ/kg).

4. Conclusions

Reaction to fire test is used to evaluate the contribution of a material and building elements to fire growth. In this experimental research, innovative mortar mixtures were prepared with locally available environmentally friendly materials, derived as by-products from industry and agriculture: corn cob ash, ceramic waste powder, and fly ash. Nine different masonry mortar formulations were designed, produced and subjected to the fire reaction test, whereas non-combustibility and gross heat of release were determined. The main findings of this study are briefly listed below.

- Regarding non-combustibility test, all masonry mortars met the requirements for non-homogeneous materials categorized in A1 fire reaction class (Δm≤50%). With this regard, mortars blended with fly ash and corn cob ash displayed superior performance (the lowest mass loss).
- All evaluated specimens showed no sustained flame, indicating that all mortar combinations met the threshold for the A1 fire reaction class (t_f=0s).

- SCM-blended mortars demonstrated lower values of gross heat release, in relation to the reference cement-lime mortar. Nevertheless, all tested masonry mortars met the requirements for non-homogeneous products classified in A1 fire reaction class (PCS≤2.0 MJ/kg).

It can be stated that novel, environmentally friendly masonry mortars, produced with higher share of locally accessible waste materials, satisfy requirements regarding A1 fire reaction class and may, thus, be effectively utilized as integrated part of fire-rated masonry structures.

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