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EVALUATING AGGREGATE CONTENT AND ITS EFFECT ON CLAY MORTAR PERFORMANCE

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Abstract

The most commonly used material in the construction sector is arguably cement, the production of which generates massive amounts of greenhouse gases, contributing approximately 5-8% of global CO_2 emissions. A potential solution in this context is the use of inorganic binders from local sources, a trend that is gaining momentum in research studies within the construction materials industry. Clay-based masonry mortar represents a viable, eco-friendly, and cost-effective solution, with its components being abundantly available worldwide. Clay has demonstrated its effectiveness as a binder over centuries. In its natural, calcined, or modified forms, clay serves as an important alternative to cement, offering sustainable material development at lower costs and with reduced environmental impact. Clay is a sedimentary rock, whose main ingredient is aluminium silicate, characterized by its colloidal appearance and binding properties. The primary feature of clay is its ability to absorb large amounts of water, transforming into a pasty, ductile mass that can be easily shaped into any form.

Key words: *clay composite, local materials, mortar.*

INTRODUCTION

Global demand for cement and concrete products has increased significantly in recent years, due to the development of economies and the continuous growth of the world population (Kouakou et al., 2009; Berriel et al., 2016). According to the report published by CEMBUREAU (2023), in 2022 about 4.1 billion tons of cement were produced, the largest share being attributed to China - 51.1%.

The total quantity of cement that was imported in 2022 to Europe increased almost fourfold compared to 2016, the values of the quantities of imported tons are illustrated in Figure 1 (Andrew, 2018). Romania has witnessed a 459% increase in cement imports during this period, from 204,264 t in 2016 to 1,142,932 t in 2022 (CEMBUREAU, 2023). This has contributed to the expansion of various concrete-related industries, from the extraction of raw materials to the increased consumption of fossil fuels for material processing and cement production (Memon et al., 2012). At the same time, it should be noted that the impact of increased demand is reflected in the increase in cement prices by over 150% in the last decade and threatens significant environmental impacts, phenomena that need to be mitigated (Ahmad et al., 2011). Thus, improving the sustainability of the construction sector has become a major concern for researchers in this field.

A significant percentage of construction materials contain cement, which represents a hydraulic binder developed through an energy-intensive process. Cement production process emits large amounts of greenhouse gases and contributes approximately 5-8% to global CO_2 emissions.

According to estimates, this share could reach 10-15% if stringent measures are not taken to decarbonize the construction industry (Schneider et al., 2011). In this regard, significant progress has been made in the field of making construction products more efficient and there is a considerable increase in the level of involvement, awareness and engagement in projects to reduce environmental impact

(Kajaste et al., 2016). The automation of lime production in modern kilns and the use of alternative fuel resources represent an important step towards reducing energy consumption and CO_2 emissions (Deja et al., 2010), but these solutions are being outpaced by the exponential growth of demand, which is driving the development of new ways to reduce environmental impact and costs.

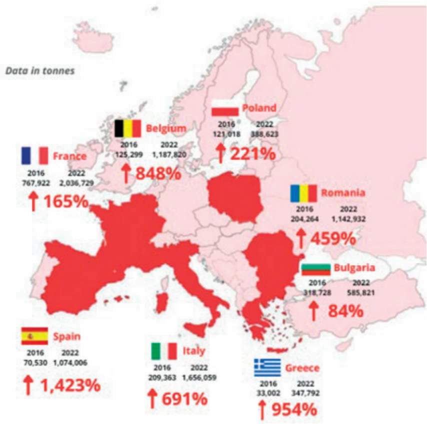

Figure 1. Quantity of tons of cement imported into Europe (CEMBUREAU, 2023)

Among the classic solutions to reduce the need for cement in the shrinkage materials industry, one can mention the partial substitution of cement by using industrial by-products such as fly ash and blast furnace slag, but its applicability is limited by the generation capacity of power plants or blast furnace industries (Alujas et al., 2015; Teklay et al., 2016).

Currently, in the construction sector, there is a growing demand for sustainable materials and products, with ecological characteristics, obtained through non-polluting processes and with increasingly lower energy consumption (Mircea et al., 2021). In order to gain a secure market, being in competition with traditional construction materials/products, made through energy-consuming and polluting processes, materials with ecological properties must have comparable or superior characteristics and durability (Calatan et al., 2020).

The use of natural materials in the production of various construction products is one of the solutions with high potential to achieve the aforementioned goals, and clay is one of these materials (Hegyi et al., 2023).

Clay represents a natural, sustainable, cheap and widely available material worldwide. Since the earliest times of the development of human civilization, clay has been used to obtain various materials and products for construction, either with a non-structural role, such as clay walls and floors, or even with a structural role, namely tiles for making roofs, bricks or clay blocks (Hegyi et al., 2016).

Clay is a sedimentary rock, whose main ingredient is aluminium silicate, characterized by its colloidal appearance and binding properties. The primary feature of clay is its ability to absorb large amounts of water, transforming into a pasty, ductile mass that can be easily shaped into any form (Petcu et al., 2023).

Clay-based construction materials and products are increasingly used at the national level, with the benefits of clay recognized not only for the technical characteristics it imparts to construction materials and products but also for its contribution to enhancing the durability of construction elements over time. The growing adoption of clay in Romanian construction, alongside other traditional natural materials, reflects the industry's alignment with sustainable development principles through the application of environmentally friendly technologies. Additionally, it supports the creation of a healthier environment and contributes to reducing climate change caused directly by human activities.

This study evaluates the influence of aggregate content on the performance of clay-based mortar which can be used to create eco masonry for sustainable buildings.

MATERIALS AND METHODS

The clay composite utilized in this study was prepared using locally sourced materials, including sand fractions of 0-1 mm and 0-4 mm, coarse aggregates of 4-8 mm, and clayey soil characterized by a composition of 53% clay, 44% silt, and 3% sand. The water content required for each formulation was determined experimentally to achieve optimal workability. The compositions analysed in the study are detailed in Table 1.

Table 1. Tested clay compositions

`Constituents	Units	R1	R2	R3
Sand 0-1	g	439	366	293
Sand 0-4	g	4578	3851	3052
Aggregates 4-8 mm	g	4204	3503	2803
Clay soil	g	6148	7684	9221
Water/clay soil ratio		0.52	0.48	0.52
Clay soil/aggregates ratio		0.40	0.50	0.60

The consistency of the fresh mixture was evaluated in accordance with the standard SR EN 1015-3:2001/A2:2007, which specifies the procedure for determining the consistency of masonry mortars using the flow table method. As illustrated in Figure 2, the test involved placing a conical mould on a circular table and filling it with the fresh clay-based mortar in two layers. Each layer was compacted using a standardized metal tamper. Following the removal of the mould, 15 consecutive drops of the table were performed within 15 seconds, after which the average spread diameter of the sample was measured.

Figure 2. Determination of the consistency of the fresh clay mixture

The fresh clay mortar was then cast into standardized metallic moulds with dimensions of 160 × 40 × 40 mm (Figure 3). After a curing period of three days, the specimens were demoulded and stored under controlled laboratory conditions at a temperature of 20 ± 2°C and relative humidity of 65 ± 5% until testing at 28 days.
The performance of the hardened clay mortar was assessed based on density, flexural strength, and compressive strength. The density of the material was influenced by the granulometric distribution, which governed the packing efficiency of the particles and the proportion of voids within the composite.

Figure 3. Casting fresh clay mixture in metal moulds

The internal structure of the clay-based material played a significant role in determining its mechanical performance and durability, as extensively examined in previous studies under various operational conditions.
The density of the hardened mixture was determined with the relationship:

$$D = \frac{m}{V} \quad (1)$$

where:
D - density of hardened mixture, kg/m^3;
m - mass of the specimen, kg;
V - volume determined by measurement, m^3.
Flexural strength testing was conducted according to the SR EN 1015-11:2020 standard, which outlines the procedures for evaluating the mechanical performance of hardened masonry mortars. The specimens were positioned on support rollers, and a controlled load was applied at a rate of 10-50 N/s until failure occurred within a time frame of 30 to 90 seconds. The flexural strength was determined using the following equation:

$$R_f = \frac{1.5 \cdot F_f \cdot l}{bd^2} \quad (2)$$

where:
R_f - bending strength, MPa;
b - prism width, mm;
d - prism height, mm;
F_f - load applied in the middle of the prism at rupture, N;
l - distance between the support rollers, mm.
Compressive strength, a fundamental parameter in the assessment of mortars, was also determined in accordance with SR EN 1015-11:2020. The test was conducted on the halves of the specimens obtained from the flexural strength test. Prior to testing, the specimens

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were measured to ensure dimensional accuracy, and their surfaces were verified for parallelism to minimize experimental errors. The load-bearing surfaces of the testing apparatus were cleaned using a dry textile before securing the samples. The specimens were positioned to ensure uniform load distribution, with a clearance of 16 ± 1 mm from the nearest support edge. The compressive load was applied gradually, within a controlled range of 50 N/s to 500 kN/s, ensuring failure occurred within 30 to 90 seconds.

Compressive strength was determined with the formula:

$$R_c = \frac{F_C}{1600} \quad (3)$$

where:

R_c - compressive strength, MPa;

F_c - maximum load at the moment of rupture, N;

1600 - area of the plates (40 x 40 mm), mm^2.

RESULTS AND DISCUSSIONS

The clay-based mortar formulations achieved optimal workability at a spread diameter of 105 ± 1 mm. As illustrated in Figure 4, mixtures with a lower spread exhibited reduced cohesion and workability, forming a stiff, low-fluidity mass. In contrast, mixtures with excessive spread exhibited a paste-like consistency with excessive stickiness.

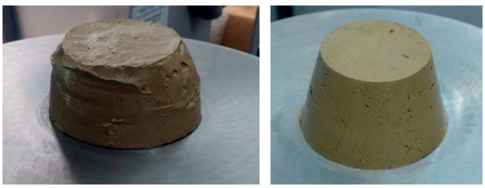

Figure 4. Different consistency of the fresh clay mixture

Density of clay mortar

Higher-density clay mixtures displayed a more compact internal structure, with enhanced particle bonding and lower porosity, whereas lower-density mixtures exhibited improved thermal properties. The uniformity of the clay mortar mixtures was confirmed by the low coefficient of variation (COV), which remained below 1%, indicating a consistent internal structure. The mean density values at 28 days were 1914 kg/m³ for recipe R1 (COV = 0.24), 1939 kg/m³ for R2 (COV = 0.08), and 1961 kg/m³ for R3 (COV = 0.24). The increase in aggregate content led to higher densities due to the greater specific weight of the aggregates compared to the clay matrix, promoting a denser packing arrangement where fine clay particles occupied the voids between aggregates. The aggregate distribution for recipe R2 is depicted in Figure 5.

Figure 5. Aggregate distribution for R2

Flexural Strength

The flexural strength results, determined in accordance with SR EN 1015-11:2020, ranged from 1.06 MPa for recipe R1 (50% clay) to 1.17 MPa for recipe R3 (60% clay). The correlation between density and flexural strength at 28 days is presented in Figure 6. The binding role of clay was evident, as its proportion directly influenced the mechanical performance.

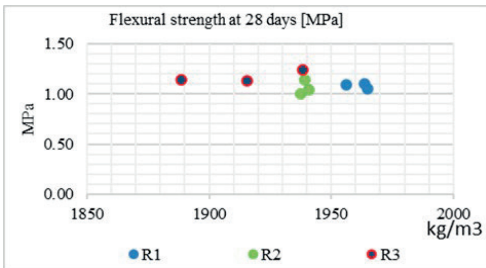

Figure 6. Correlation between density and flexural strength at 28 days

To achieve optimal strength, the clay content must be sufficient to completely coat the aggregate surfaces, facilitating the development of a cohesive and structurally stable matrix. The increased flexural strength observed in mixtures with higher clay content can be attributed to the formation of silico-aluminate bonds, which enhance the mechanical integrity of the composite. The failure mode of the specimens under flexural testing is shown in Figure 7. The coefficient of variation for flexural strength ranged from 2.19% to 6.53%, further confirming the homogeneity of the material.

Figure 7. The mode of failure of the sample subjected to bending

Compressive Strength

Compressive strength was evaluated using the prism halves obtained from the flexural strength test (Figure 8). The failure mechanism of the material under uniaxial compression was associated with the transverse tensile stresses generated at the aggregate-matrix interface. The primary factors influencing compressive strength included the quality and proportion of the constituent materials, adhesion between the clay matrix and aggregates, compaction state, curing conditions, and specimen age.

Figure 8. Compressive strength of the prism halves

The average compressive strengths recorded at 28 days were 2.98 MPa for R1 (40% clay), 3.72 MPa for R2 (50% clay), and 3.79 MPa for R3 (60% clay), with coefficients of variation ranging from 4.22% to 5.77%. The distribution of compressive strength results is shown in Figure 9. The results indicated that the recipe R3, containing 60% clay marked highest compressive strength, representing a 27% increase compared to the Recipe R1 with 40% clay content. The higher clay content contributed to improved compressive strength due to enhanced bonding between the matrix and aggregates. However, excessive clay content may lead to reduced permeability, which could affect the long-term durability of the material.

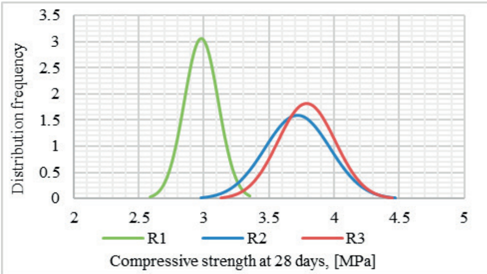

Figure 9. Distribution of 28-day compressive strength results

CONCLUSIONS

The increasing demand for sustainable materials and products in the construction sector contributes to the development of environmentally friendly materials, which contribute to reducing the consumption of natural resources, increasing the energy efficiency of buildings and protecting the environment.

Preliminary results have marked a promising performance of the prototypes, confirming their potential to replace traditional masonry mortar with a high ecological footprint. In addition, the use of local and economically accessible materials supports the development of a circular economy, while contributing to the sustainability of rural communities and reducing production costs

Thus, following the analysis of the results obtained, the R3 recipe containing 60% of the total amount of aggregates showed superior results, both in the case of flexural strength - 1.17 MPa, with a coefficient of variation of

5.19%, and in the case of compressive strength - 3.79 MPa, and a coefficient of variation of 5.77%.

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