53rd Conference on Experimental Stress Analysis
Český Krumlov, Czech Republic, June 1–4, 2015


# Mechanical Properties of Refractory Composite with Various Cement Replacement Materials

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**Abstract:** This experimental program is aimed at investigation the effect of partial substitution of aluminous cement with environmentally friendly materials. Mechanical properties of new developed composites were investigated to determine satisfactory high temperature resistance. Environmentally friendly cement-based materials are an actual topic of interest and cement supplementary materials play an important role in the construction industry from economical, technological and ecological points of view. These materials are arising by the recycling of waste produced in the building industry or by the recycling of cast-off materials. For the purpose to produce suitable refractory material was chosen binder system based on aluminous cement. To reduce the costs and adverse effects on the environment was the binder system modified by finely ground ceramic powder and metashale. The investigation of composites was realized on the base of determination of mechanical properties after gradual thermal loading. Realized program confirmed good potential for practical utilization of ceramic powder and metashale as an aluminous cement replacement.

**Keywords:** Thermal Loading; Aluminous Cement; Ceramic Powder; Metashale; Mechanical Properties.

## 1 Introduction

Concrete materials should offer besides good workability, excellent mechanical properties and durability, also environmental and economic benefits.

In construction industry, the production of cement is one of the major producers of greenhouse gases, especially carbon dioxide ($CO_2$) due to the calcinations of limestone and other raw materials [1, 2] and high energy consumption of other productive processes. Hence, cement is a material which is commonly used in the construction industry as binder of concrete; it brings undesirable impact to the environment. Approximately one tonne of $CO_2$ released to the environment with one tonne of cement produced [2]. The percentage of $CO_2$ emission is increasing rapidly because cement production is increasing over the years. Therefore, $CO_2$ reduction has become the most concerned issue worldwide. There is a need of reducing the usage of cement by partial replacement with other materials [3, 4].

## 2 Materials for Cement Replacement

Besides cost reduction and enhancement of workability of fresh concrete, the use of pozzolans could help to improve the durability properties of concrete such as resistance to thermal cracking, alkali-aggregate expansion, and sulfate attack [1, 5].

A pozzolana is defined as a natural or artificial material which contains reactive silica [1]. A more detailed definition is given in [6] and pozzolans are defined as materials that have little or no cementitious ability by themselves, however, when finely milled and in the presence of moisture they will chemically react with alkalis to form cementing compounds. The silica in a pozzolan has to be amorphous or glassy, to be reactive [6]. Natural pozzolans are generally derived from volcanic rocks and minerals [1].

Tab. 1: Composition of studied composites.

| | Components [kg/m$^3$] | | | | | | |
|---|---|---|---|---|---|---|---|
| | Plasticizer | Water | Aluminous Cement | Metashale | 0/1 mm | Fireclay 1/2 mm | 2/4 mm |
| Ref | 16.20 | 200 | 900 | 0 | 520 | 140 | 320 |
| | Plasticizer | Water | Aluminous Cement | Ceramic Powder | 0/1 mm | Fireclay 0/1 mm | 2/4 mm |
| CP10 | 16.20 | 200 | 810 | 90 | 520 | 140 | 320 |
| CP20 | 16.20 | 200 | 720 | 180 | 520 | 140 | 320 |
| CP30 | 16.20 | 200 | 630 | 270 | 520 | 140 | 320 |
| | Plasticizer | Water | Aluminous Cement | Ceramic Powder | 0/1 mm | Fireclay 0/1 mm | 2/4 mm |
| MS10 | 16.20 | 200 | 810 | 90 | 520 | 140 | 320 |
| MS20 | 16.20 | 200 | 720 | 180 | 520 | 140 | 320 |
| MS30 | 16.20 | 200 | 630 | 270 | 520 | 140 | 320 |

Tab. 2: Chemical composition of binder components [8–10].

| | $Al_2O_3$ [%] | CaO [%] | $SiO_2$ [%] | $Fe_2O_3$ [%] | MgO [%] | LOI [%] | Blaine [m$^2$/kg] |
|---|---|---|---|---|---|---|---|
| Secar71 | 70.80 | 27.50 | 0.58 | 0.42 | 0.21 | 0.49 | 381 |
| Ceramic Powder | 20.26 | 10.92 | 50.73 | 6.36 | 4.75 | 6.98 | 336 |
| Metashale | 41.90 | 0.13 | 52.90 | 1.08 | 0.18 | 3.81 | 306 |

Composite binder based on aluminous cement in this research is represented with the Secar71 produced by the company Kerneos Inc. The composition of all studied mixtures is clearly shown in Tab. 1. As already mentioned, considerable disadvantage of aluminous cement is its energy consumption of its production. Therefore, for the purpose of reducing the negative impact on the environment was used fine ground ceramic powder and metashale as the partial substitution of the cement. The ceramic powder is a waste material with pozzolanic properties, which is generated by grinding of advanced hollow bricks blocks. Also metashale is a pozzolanic material originated by the calcination of clay materials [1]. Shale is a natural material of which the main component is mineral kaolinite [6, 7].

The chemical composition and specific surface area [m$^2$/kg] measured by Blaine apparatus of Secar71 and cement replacement materials is shown in Tab. 2.

## 3 Findings

The mechanical properties in this experiment were obtained by the static measurement of specimens with dimensions of 40 × 40 × 160 mm$^3$. Reference specimens formed solely composites with aluminous cement as a binder. Following specimens' testing consisted of composites divided on six groups with 10, 20 and 30 % of cement replacement, which was represented by ceramic powder (CP) or metashale (MS). It was observed, that the finely ground ceramic powder and metashale addition positively complements the grading curve of the aggregate, which results in increasing the viscosity of the mixture. This effect helps to improve the aggregates suspension, preventing coarse aggregate segregation and keeping the mixture homogenous [11].

Following text presents results of measuring of flexural strength $f_{tm}$ [MPa], compressive strength $f_{cm}$ [MPa] and bulk density $\rho$ [kg/m$^3$], see Tab. 3. All these values are presented after drying at 105 °C and after exposure to 600 °C and 1000 °C. According to manufacturing technology for monolithic refractories based on hydraulic bond, after cement composites maturity it is necessary to carry out a drying procedure and the first firing [12].

Tab. 3: Results of measured properties.

| | $\rho$ [kg/m$^3$] | | | f$_{tm}$[MPa] | | | f$_{cm}$[MPa] | | |
|---|---|---|---|---|---|---|---|---|---|
| | 105 °C | 600 °C | 1000 °C | 105 °C | 600 °C | 1000 °C | 105 °C | 600 °C | 1000 °C |
| Ref | 2351 | 2226 | 2182 | 15.5 | 13.8 | 8.7 | 119.3 | 112.8 | 75.6 |
| CP10 | 2289 | 2149 | 2154 | 14.1 | 12.2 | 7.0 | 113.5 | 98.0 | 65.0 |
| CP20 | 2214 | 2056 | 2035 | 13.4 | 11.5 | 6.1 | 105.2 | 84.5 | 62.4 |
| CP30 | 2161 | 1988 | 1990 | 16.4 | 11.2 | 8.5 | 102.8 | 85.6 | 68.7 |
| MS10 | 2314 | 2125 | 2088 | 18.6 | 13.4 | 9.0 | 121.5 | 107.0 | 64.6 |
| MS20 | 2314 | 2154 | 2095 | 17.3 | 14.5 | 9.3 | 118.5 | 107.5 | 66.6 |
| MS30 | 2320 | 2171 | 2101 | 21.3 | 14.9 | 10.3 | 125.3 | 112.9 | 69.3 |

We can observe the gradual decline of bulk density due to effect of high temperature, when moisture and physically bounded water is evaporated first. Increase of temperature leads to further decrease of bulk density which is caused by partial chemical decomposition of hydration products. The highest values of bulk density can be observed at the reference specimens without cement replacement.

Relative values of studied mechanical properties are shown in Fig. 1 and Fig. 2, there is also well demonstrated potential of applied cement supplementary materials for the refractory composites production. Reached substitution of used cement brings' an extensive environmental benefits.

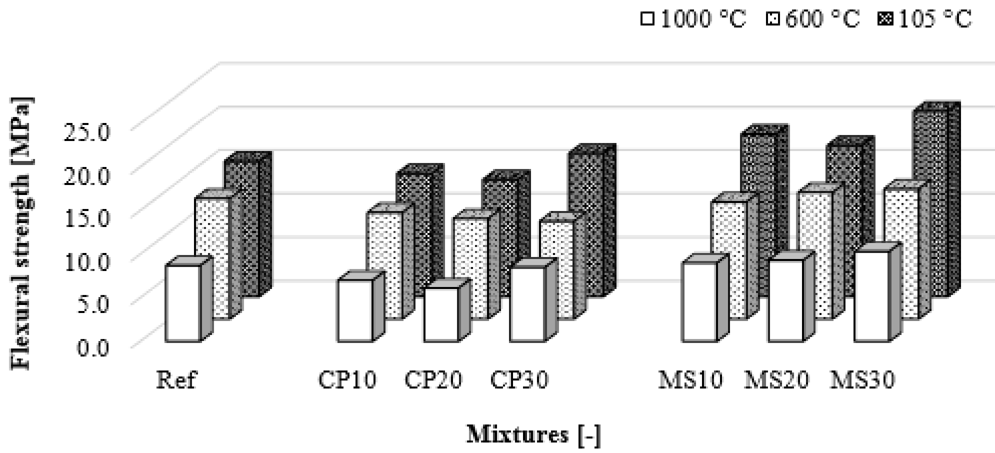


Fig. 1: Relative values of residual flexural strength.

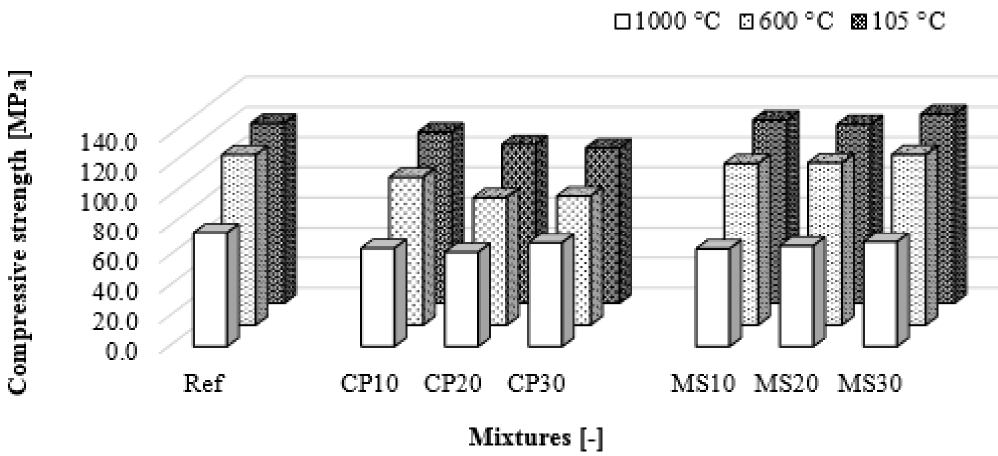


Fig. 2: Relative values of residual compressive strength.

Based on the provided experiments we can conclude, that the most suitable is the cement substitution of 270 kg/m$^3$ of metashale (30 % of aluminous cement weight) in terms of flexural and compressive strength and residual strength after effect of high temperature. Graphical representation of reached results well describe stability of developed refractory composites with 270 kg/m$^3$content of metashale. After 600 °C the $f_{tm}$ decreases to 70.0 % of original value, while the $f_{cm}$ decreases to 90.1 % of original value. Situation after 1000 °C continues in the same trend (48.4 % of original values in case of flexural strength and 55.3 % for compressive strength).

## Acknowledgement

The authors gratefully acknowledge the support provided by the Czech Science Foundation under the project No. P104/12/0791: Fibre-Reinforced Cement Composites for High Temperature Applications.

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