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Mechanical Fracture Parameters of Cement Based Mortars with Waste Glass Powder

Hana Šimonová[a,*], Jana Zahálková[a], Pavla Rovnaníková[a], Patrik Bayer[a], Zbyněk Keršner[a], Pavel Schmid[a]

[a]*Brno University of Technology, Faculty of Civil Engineering, Veveří 331/95, 602 00 Brno, Czech Republic*

Abstract

Glass is an amorphous solid substance with pozzolanic properties that can be used as a partial substitute for ordinary Portland cement (OPC) in cement based composites. In the research conducted for this paper, the PC was partially replaced by fine-ground waste laboratory borosilicate glass (in mixtures where 5, 10, 15 and 20 % by mass was substituted). Beam specimens with the dimensions 40 × 40 × 160 mm were prepared from each mixture. After demoulding, the specimens were kept under standard laboratory conditions. Basic tests were conducted at the age of 7, 28, 56, and 90 days: the compressive (f_c) and flexural (f_f) strengths were determined according to the ČSN EN 1015-11 standard. Specimens were also subjected to fracture testing at the age of 28 days. The beam specimens with an initial central edge notch were tested in three-point bending. Load vs. displacement diagrams were recorded and modulus of elasticity (E), fracture toughness (K_{Ic}^e) and fracture energy (G_F^*) were determined. It was found, that strength increased with specimen age: at the age 28 days this increase was 12–33 % in case of f_c, and 6–15 % as regards f_f. The values obtained for almost all the parameters decreased with the increasing dosage of glass as a replacement for cement: compared to a reference composite this decrease was 22–40 % in the case of f_c, 24–28 % for f_f, 3–5 % for E, 9–29 % for K_{Ic}^e, and 30–50 % for G_F^*; exceptions were recorded for glass replacement doses of 5 and 10 %, where increases of 2–6 % for f_c and 8–10 % for E were obtained.

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Keywords: Mortar; cement; glass powder; fracture test.

* Corresponding author. Tel.: +420 541 147 381.
E-mail address: simonova.h@fce.vutbr.cz

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1. Introduction

Presently, great emphasis is being placed on protecting the environment through reductions in carbon dioxide emissions. Carbon dioxide is produced during combustion processes, as well as due to other activities. Large quantities of CO_2 are also produced by the lime and cement industries, which both manufacture the energy intensive products (lime and cement production is carried out at temperatures above 1000°C). The effort to reduce CO_2 emissions is leading to the use of supplementary cementitious materials (SCMs) as partial substitutes for Portland cement. SCMs are natural or technogenic materials of a pozzolanic character, such as fly ash, burnt clays, zeolites, diatomite, etc. Pozzolanic activity requires the presence of amorphous SiO_2. Glass is an amorphous material with SiO_2 content; it reacts with calcium hydroxide formed through cement hydration. Calcium silicate hydrate products are formed during a pozzolanic reaction [1−4]. The topic of this study was the verification of options of ground glass as a partial replacement for cement in pastes; the waste glass came from broken equipment and glassware from chemical laboratories.

2. Materials and methods

Portland cement CEM I 42.5 R (Českomoravský cement, a. s., Radotín Cement Works), fine-ground waste laboratory borosilicate glass (see Tab. 1 for chemical composition and Fig. 1 for micrographs), standard sand with a grain size within the range of 0–2.5 mm, and mixing water were used to produce test specimens with nominal dimensions of 40 × 40 × 160 mm. The glass grains have an irregular shape with size between 1 to 10 µm. After demoulding, the specimens were immersed in water bath at a temperature of 21 ± 1°C. The pozzolanic activity of 719 mg $Ca(OH)_2$ / 1 g of used glass was measured by the modified Chapelle test. The grain size of the glass ranged from 0.1 to 700 µm (d_{10} = 7.44 µm, d_{50} = 63.71 µm, d_{90} = 333.50 µm). A water/binder ratio was chosen that achieved a fresh cement mortar consistency of 160 ± 5 mm when tested on a shaking table in accordance with Czech standard ČSN EN 1015-3 [5].

Mechanical tests were conducted when the specimens reached the age of 7, 28, 56 and 90 days. Basic mechanical properties were tested according to ČSN EN 1015-11 [6]: bulk density, compressive strength (f_c), and flexural strength (f_f). Mixtures/mortars in which the cement was replaced by 5 to 20 % of waste chemical glass by cement weight are marked DSM. The results are compared below with those gained for a reference composite, which is designated REF. The proportional compositions of all mixtures are shown in Tab. 2.

Table 1. Chemical composition of fine-ground waste laboratory borosilicate glass.

	B_2O_3	SiO_2	Al_2O_3	Fe_2O_3	K_2O	Na_2O
Content [%]	10.5	78.5	2.94	0.186	1.09	4.55

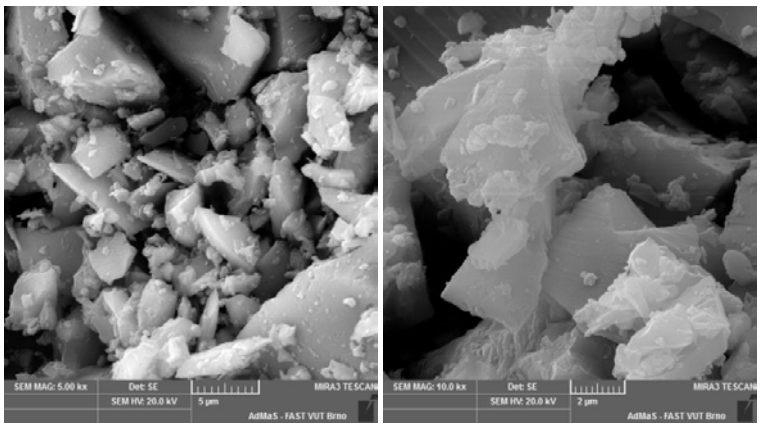

Fig. 1. Micrographs of waste chemical glass.