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THE USE OF FINE WASTE MATERIAL FOR THE FUTURE OF SUSTAINABLE CONSTRUCTION

Katarzyna Kalinowska-Wichrowska

Department of Construction and Road Engineering
Bialystok University of Technology

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Abstract

The article presents data regarding scale of current production of cement and its future of sustainable construction. In the time of sustainability and Union Directives which rightly impose the reduction of emission of greenhouse gases the solution has been proposed that may in some extent contribute to reducing the cement consumption by using properly prepared recycling binder as its substitute. Some results of own research have been presented, connected with the possibility of using the waste material in form of properly processed cement grout as a partial substitute of cement in the cement composites. Due to high content of contaminants in the industrial secondary binder, which might interfere with the uniformity of results, it has been decided to obtain the recycling binder in the laboratory conditions. The secondary mineral material has been obtained in the process of multi-stage disintegration of prepared laboratory samples, made from cement grouts. The prepared material has been analysed for content of dust fraction and pozzolana activity. The obtained results have revealed that in assumed conditions of recycling binder processing it may be successfully used as cement substitute in the cement composites.

Introduction

Higher number of people and economic growth imposes an additional load on already limited natural resources and will require maintaining of actions aimed for neutralization of influence on the climate changes. As a key component

Correspondence: Katarzyna Kalinowska-Wichrowska, Katedra Budownictwa i Inżynierii Drogowej, Wydział Budownictwa i Inżynierii Środowiskowej, Politechnika Białostocka, ul. Wiejska 45A, 15-351 Bialystok, e-mail: k.kalinowska@pb.edu.pl

of concrete, the cement plays crucial role in the resource management, therefore the problem of reuse of old grout is an object of research of many scientists due to concrete recycling and recycled materials in the context of their efficient management and environment protection (BOŁTRYK, KALINOWSKA-WICHROWSKA 2016, KALINOWSKA-WICHROWSKA 2017b, DUAN, POON 2014).

With increasing use of concrete, the demand for cement and aggregates rises. Earth resources protection and high energy consumption while cement production imposes need to re-use concrete components through recycling. It is estimated that the concrete industry consumes about 11 billion tons of natural aggregate per year (JIN, CHEN 2015) and the cement industry is responsible for about 5% of anthropogenic CO_2 emissions in the world (*Rola cementu…* 2016).Construction waste represent around 25–30% of all waste generated in the European Union. They consist of many materials, including: brick debris, concrete, gypsum, etc., which can be subjected to the recovery process (ZAJĄC, GOŁĘBIOWSKA 2014). The percentage of recycling and re-use varies greatly across Member States. In Spain, for example, only 14% of rubbish waste is recycled. Other countries with a very high level of recycling, such as: the Netherlands, Denmark, Estonia, Germany, for which recycling rates are respectively 92%, 86%, 80% and 75% (Eurostat, online 2016).

The goal of research undertaken in this article is to demonstrate the possibility of reuse of binder obtained from concrete recycling as the cement substitute in the cement composites. Reduction of amount of used cement coming from the factory (where most of CO_2 is emitted to the atmosphere during clinker baking) limits emission of that gas (KALINOWSKA-WICHROWSKA 2017a).

BRAGA et al. (2012) analysed the behaviour of cement mortars using small recycled particles as a substitute for natural sand. In these studies, 15% of the necessary natural sand was replaced with recycled sand. An increase in compressive strength was observed, with a simultaneous decrease in the modulus of elasticity and increased water absorption, as compared to traditional cement mortars.

ZENGFENG et al. (2015) observed the effect of saturation of the fine fraction of recycling aggregates on mechanical properties, properties of fresh mortar and the material transition zone. The results showed that mortars made with dry aggregate from recycled materials show better compressive properties than saturated recycled aggregates due to the thinner transition zone. An increase in compressive strength of composites with dry fine aggregate was also observed from recycling.

Object and methodology of own research

Characteristics of raw materials

Cement CEM I 42,5R and corresponding to the requirements of standard PN-EN 197-1 Cement – Part 1: Composition, specifications and conformity criteria for common cements. Only the fine aggregate in form of standardized sand has been used for the tests.

Recycling binder

The experiment has been realized with use of secondary binder obtained as a result of processing of previously prepared laboratory samples of cement mortars. The recycling mortars have been prepared from cement, sand and water in moulds 40×40×160 mm (according to PN-EN 196-7: 2009 Methods of testing cement – Part 7: Methods of taking and preparing samples of cement, where w/c ratio equalled 0.5). After 28 days of curing in the water conditions the samples of cement mortars have waited for another 6 months in air-dry conditions. Then they have been crushed in the jaw crusher to dimensions of approx. 10–20 mm. In such form they have been placed in the thermal furnace to be subjected to baking in temperatures defined in the experiment plan. After that process the material has been remilled for approx. 20 minutes in micro Deval drum to obtained as high specific surface as possible. During another milling the whole charge consisted of fraction <0.125 cm and the specific surface oscillated in range of 3,800–4,000 cm^2/g.

In the next step, the recipe of cement composites has been assumed as for standard mortars according to PN-EN 196-7: 2009 Methods of testing cement – Part 7: Methods of taking and preparing samples of cement, where w/c ratio = 0.5. For forming of beams 40×40×160 mm the Portland cement CEM I 42.5R has been used, which 25% of cement has been replaced with recycling material. After 28 days of curing in water conditions the samples have been subjected to compression tests. The test results are presented in section 4.

Test methodology

- Compression strength of cement composites with recycling material:

The compression strength testing has been realized for 6 randomly selected beams 4×4×16 cm from each batch according to standard PN-EN 196-1:2006 Methods of testing cement – Part 1: Determination of strength.

• The pozzolana activity has been determined according to standard PN-EN 450-1:2009. Fly ash for concrete. Part 1: Definition, specifications and conformity criteria.

• The percent content of individual sizes of particles in the recycling material after the thermal and mechanical processing has been determined with use of set of sieves.

Research experiment

Experiment plan

In order to determine the influence of thermal processing of recycling mortar on selected properties of cement composites the research experiment has been planned, consisting of 3 basic batches and 1 control batch (no. 4 – not consisting the recycling mortar binder).In the experiment factor (X_1) have been taken into consideration, each of three variation levels:

• X_1 – baking temperature of recycling binder (400, 650, 800°C).

The baking time of material has been assumed as constant and it amounted to 60 minutes.

The experiment plan including coded values of variables is presented in Table 1.

Table 1

Plan of research experiment

Batch no.	X_1 – baking temperature [°C]	
1	–1	400
	–1	400
	–1	400
2	0	650
	0	650
	0	650
3	+1	800
	+1	800
	+1	800
4	control batch	

Realization and curing of samples

Batches have been realized with use of automatic laboratory mixer. First the loose components have been weighed and mixed for 5 minutes, then water has been added and mixing lasted another 10 minutes. Such prepared amount of

material has been placed in the steel mould allowing for simultaneous forming of three samples of dimensions 40×40×160 mm. Then the samples in the mould have been consolidated on the vibration table. After removing from the mould the samples have been placed in the water basin of temperature of 20°C until realization of proper tests.

Results of tests and discussion

As described above, the recycling material after the baking process has been subjected to remilling in the planetary mill down to the specific surface similar to that of cement 42.5 R, and those processes might have with temperature had the significant impact on pozzolana effect. The Figure 1 shows grading curve for the recycling material baked in 650°C and subjected to remilling.

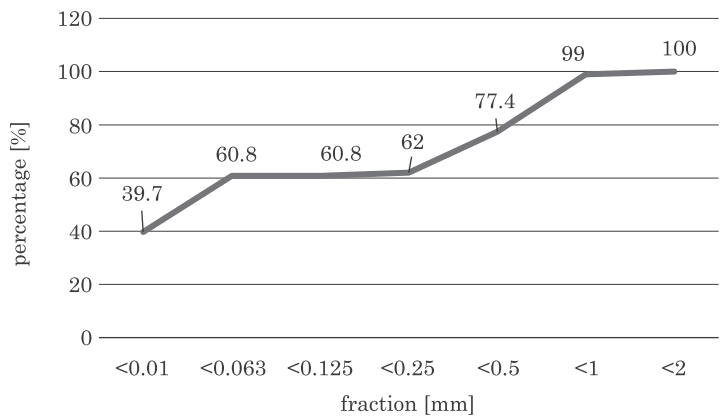

Fig. 1. Percentage content of individual particle sizes in recycling mortar binder (650°C)

Diversification of particle sizes in old grout (as proven by the strength results) does not impair the properties of composites. About 61% of the material have fraction less than 0.125 mm and 0.063 mm. High content of silty fractions indicates the effectiveness of the milling process. It should be noted that with the material's baked in temperature at 800°C and further milling, it became compacting material and deposited on the walls of the grinder. From the point of view of using technology in the industry it would be a disqualifying factor. The photos of the recycled mortar resulting from roasting debris at 650°C taken using the scanning technique are showed below (Fig. 2).

The results of compressive strength and pozzolana shown in Figure 3. The highest results of compression strength have been obtained for the composites including the recycling additive subjected to thermal processing in 650°C (batches 2).

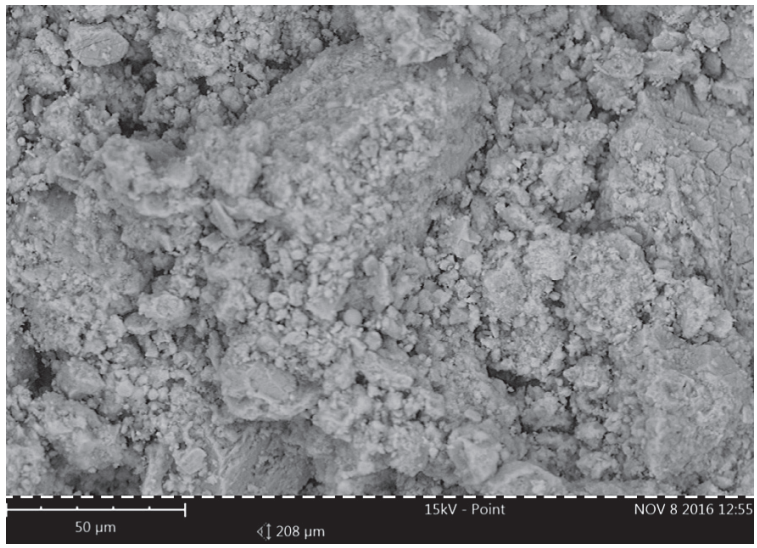

Fig. 2. SEM photo of recycling mortar (after thermal process in 650°C)

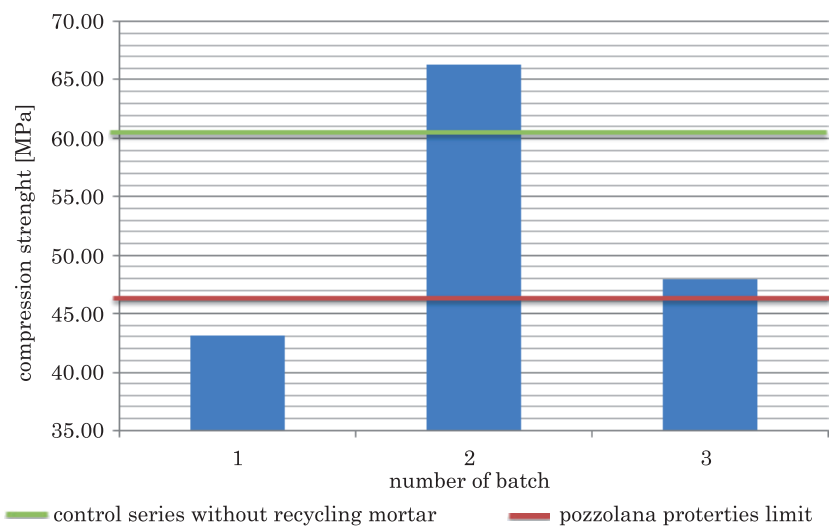

Fig. 3. The results of compression strength for cement composites with addition of recycling binder mortar

The values of obtained strength in those batches are higher results for the control batch (4) without the recycling additive, increased by 10%. According to test method described in PN-EN 450-1:2009 the tested material reveals the pozzolana properties when the compression strength of composite containing 25% of material substituting the cement is 75% of control sample.

In tested composites all strength results for batches, where the recycling material has been subjected to baking in 650°C, had revealed the pozzolana properties (in figure red line shows pozzolana veneer). Only in batches where the thermal processing of recycling material was 400°C (batch 1) and 800°C (batch 3) the pozzolana properties have not been activated. It is assumed that in such range of temperatures 300–500°C there is still significant amount of not decomposed portlandite present and in range 750–800°C there is a breakdown of calcium carbonate into carbon dioxide and a significant amount of inactive calcium oxide (KRZYWOBŁOCKA-LAURÓW 1998). As results shows applying too high temperature of baking decreases pozzolana activity in recycled binder mortars.

Figure 4 shows a composite scanning photo using a recyclable mortar as a cement substitute. The structure of the cement matrix is identical to that of a classic composite made exclusively on cement. The portlandit clusters were not observed, which could indicate an incomplete pozzolanic reaction. The C-S-H phase which fills the structure of the composite is visible in the Figure 4.

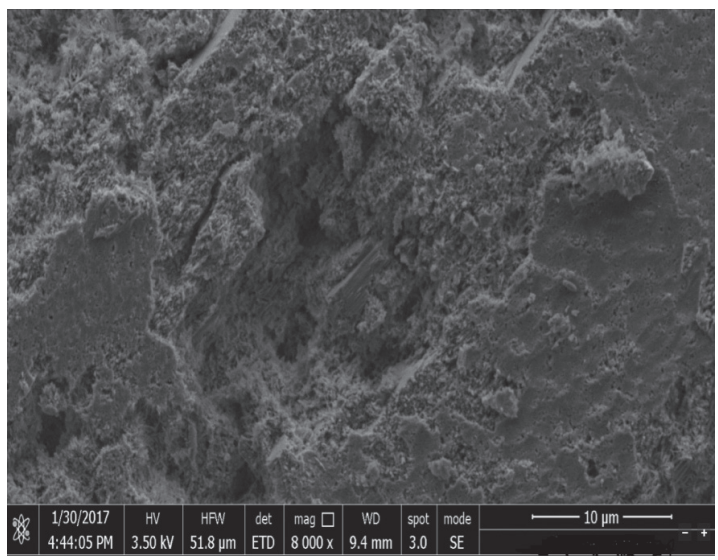

Fig. 4. SEM photos of breakthroughs of samples made using a recycling mortar, visible phase C-S-H

Summary

The article presents the possibility of effective utilization of recycling mortar in cement composites.

The presented results of tests have confirmed that after specific suitable thermal processing the tested recycling material reveals the pozzolana properties

in composites and improves compression strength values. The optimum strength parameters and the highest level of pozzolana activity index have been obtained for the baking temperature of 650°C. Increasing the processing temperature by 150°C (to 800°C) deteriorates of strength and pozzolana parameters. The suitability of tested material as an active additive is also significantly influenced by the milling degree, close to specific surface of cement.

In realized tests the assumed of baking temperature of recycling material had high influence on the composite strength properties. As the tests results show, the recycling material produced in such way may be successfully used as an alternative for cement or in the future as fillers or other type II additives for cementitious composites.

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