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THE CEMENT COMPOSITES WITH MODIFIED RECYCLED ADDITION

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Abstract: In recent years, much emphasis is placed on environmental protection and respect for the resources which the Earth has given us. The paper presents the modern methods of recycling concrete. The outcomes of the authors' research on the cement composites with the supplement of old concrete added to the mixture are presented hereby.

Key words: concrete, recycling of concrete, fine-grained concrete, cement recycling, recycled addition.

1. Introduction

The increase in popularity of concrete as a construction material triggers the fact that this material becomes, a waste which one should get rid of. Nowadays all matters related to natural resources and environment conservation are of high importance. Concrete waste usually appears in form of debris. After the reinforcing steel is recovered (if it is possible), the debris usually ends up as road construction or ground leveling material. However, one should remember that debris could still contain valuable and useful aggregate (Ferrari et al., 2014), which after relevant processes, could be used to prepare new concrete. Technology of aggregate retrieving has been long and widely known and it was started in the USA and Japan. Many researches connected with recycled aggregate were carried out in these countries. Methods of concrete recycling are based on the secondary usage and the retrieval of aggregate. The rest of mortar after the recovery of the aggregate value can also be reused as an ingredient in cement composites. The paper presents selected results of a research on the behaviour of cement composites when the composition is modified by adding old cement to the mixture (Ferrari et al., 2014; Fischer et al., 2009).

2. Materials and Methods

The effective recycling is based on such fragmentation of concrete debris that during successive steps it is possible to retrieve useful aggregate. The most problems are caused by the removal of old grout which is made of original aggregate. This can be achieved by one of four methods: Heating and Rubbing Method (HRM), Mechanical Grinding Method (MGM), Screw Mill Method (SMM) and Gravity Classification Method (GCM). HRM is connected with usage of thermal container which is heated to 300°C. When exposed to high temperature small pieces (with diameter of 40–50 mm) of concrete became more fragile (as a result of dehydration adhesion between grout and aggregate is no more maintained) enabling to separate grout from aggregate (Fischer et al., 2009; Zajac and Golebiowska, 2010).

The process is carried out in tube mills and results in 35% of coarse aggregate, 21% of fine aggregate and 44% of dust to be received as an outcome. In MGM pieces of concrete are placed inside the mill between internal and external cylinders, where cement grout is rubbed off. In SMM pieces of concrete are placed into a cylinder where grout is rubbed off by an axially mounted screw. The process is repeated a couple of times, depending on the required quality of aggregate. The GCM is based on wet attrition of concrete debris. The mill contains crusher and grinding wheel mechanism which repeatedly moves pieces of concrete in water up and down in order to separate heavy grains of coarse aggregate from the lighter pieces of the grout, wood, etc. Recycling rate (percentage of high quality aggregate retrieved) of HRM and MGM is high and equals to 56% and 50%, respectively. The SMM and GCM are used only to retrieve coarse aggregate and their recycling rate is equal to 34-45% and 20%, respectively. Dust is received as a by-product of recycling and it is used as soil stabiliser. It is considered that dust could be also used for the purposes other than construction material production. The highest quality aggregate is received by using HRM. Coarse and fine aggregate retrieved in such a way is very similar to original one in terms of its physical and mechanical properties. This meets Japanese standards of natural aggregate. Currently aggregate is not

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industrially produced by HRM, because it is very energy consuming and it is connected with higher CO_2 emissions (Ferrari et al., 2014).

It is expected that due to high costs of HRM and MGM, and the lack of advanced dust utilization methods, HRM will be implemented in Japan in 2020 and the MGM in 2030. Expected amount of the annual production by HRM and MGM in 2030 will be equal to 17 mln and 60 mln tons, respectively, that is 8.4% and 29.7% of the entirely produced debris (Gastaldi et al., 2015)

3. Results of research

3.1. In-house survey characteristic on cement composites using a binder with recycling concrete

Designed mortar bars (4×4×16 cm). The mixture consisted of CEM I 42.5 R cement, CEN sand and water, in the following mass proportions: 1:3:0.5. The 25% of the cement mass was replaced by the recycled binder powder. The total of twelve series containing the same proportions of aforementioned components were carried out. The cubes (2×2×2 cm) from cement grout formed in age of about 3 months before destruction and calcinating process were used as a recycled powder binder. The binder was crushed and ground to silt fraction 0.063 mm (Fig. 1).

In the following step of analysis an experiment was planned to examine how using recycled binder relates to compressive strength of concrete mortar after 28 days under laboratory conditions. Twelve series were carried out containing different proportions of aforementioned components. Experiment was designed in accordance to theory of experimental research, in which all 12 concrete mixtures were designed with three independent variables coded on three different levels: -1, 0, 1 (Tab. 1.), which:

- X_1 – time calcination of recycled binder powder (30, 60, 90) minutes,
- X_2 – temperature calcination of recycled binder powder(550°C, 650°C, 750°C),
- X_3 – ratio water - cement (0.35; 0.45; 0.55).

Examination of compressive strength after 28 days has been carried out randomly selected samples. The results of compressive strength of concrete, treated by ordinary and then maturing low-pressure infusion under test conditions during 28 days, are presented in Fig. 2.

The highest strength at the level of 48.20 MPa was obtained by series number 1. The recycled binder powder was calcinated in 750°C by 30 minutes. The lowest compressive strength rate equal to 23.6 MPa was obtained by series number 6 (calcinated in 550°C by 60 minutes). Addition of recycled binder cement/powder resulted (series 1) in small decrease in the compressive strength rate in relation to samples without addition of recycled powder/cement (the strength of control sample with new cement 42.5R is about 40 MPa).

Fig. 1. Material for the recycled binder powder during milling.

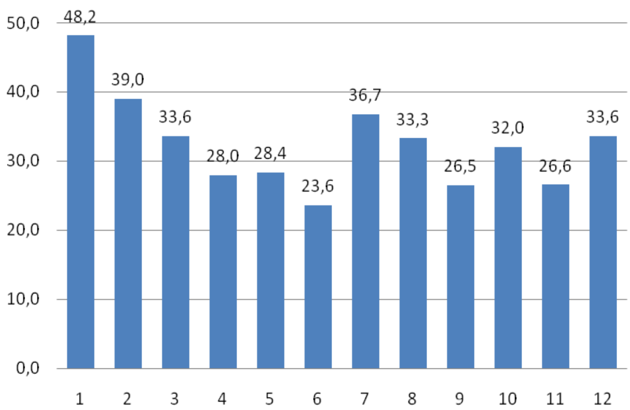

Fig. 2. Average test results of the compressive strength of concrete after 28 days of curing in the laboratory conditions, series: 1-12, in MPa.

Tab. 1. The plan of the experiment (coded and real value) for each series.

Number of series	Real value			Coded value		
	Time of calcination	Temperature of calcination	Ratio w/c	X_1	X_2	X_3
1	30	750	0.45	-1	1	0
2	60	650	0.35	0	0	-1
3	90	750	0.35	1	1	-1
4	30	550	0.55	-1	-1	1
5	90	750	0.55	1	1	1
6	60	550	0.45	0	-1	0
7	30	750	0.55	-1	1	1
8	30	550	0.35	-1	-1	-1
9	90	550	0.55	1	-1	1
10	90	550	0.35	1	-1	-1
11	90	650	0.45	1	0	0
12	30	750	0.35	-1	1	-1

3.2. Research pozzolanic properties of the produced powder recycling

As pozzolans determine the siliceous material or silica-alumina, which is in particulate form and in the presence of moisture chemically reacts with calcium hydroxide to form a compound of binding properties. Technologically very important feature of the pozzolanic material is fragmented and the content of the vitreous – their reactivity increases with increasing fragmentation and the amount of amorphous silica. Pozzolans as a material of some latent binding properties alone does not harden when mixed with water, and finely ground, react with calcium hydroxide in an aqueous medium at ambient temperature. Hydrated calcium silicates, so-called "C-S-H phase" are the product of this reaction. It is the main product of hydration of Portland clinker minerals-calcium silicates.

To detect the pozzolanic properties of the recycled powder 3 samples (in two parts) concrete mortar bars were is designed (4×4×16 cm). The mixture of 3 samples consisted of CEM I 42.5 R cement, CEN sand and water, in the following mass proportions: 1:3:0.5. The next 3 samples consisted the 25% of the cement mass were replaced by the recycled binder powder.

In the following step an experiment was planned to examine compressive strength of concrete mortar after 28 days under laboratory conditions (one of method to checked the pozzolana effect in concrete). The tensile test results are shown in Table 2. The pozzolana index was calculated using the formula:

$$WAP = \frac{f_{cb}}{f_{ck}} \quad (1)$$

where: *WAP* is the pozzolana index in %, f_{cb} is the average of compressive strenght samples of test series (part -2) in MPa and f_{ck} is the average of compressive strenght samples of control series (part -1) in MPa.

If the WAP index is more than 75%, the material should be classified as a pozzolanic.

The results showed in Table 2 confirmed the thesis of established the pozzolanic properties in tested powder. The WAP index is about 82% and it is by 7% more than value required. The properly prepared recycled binder powder used an amount of 25% by weight mass *t* of cement can be successfully used as the pozzolanic addition. The fragmentation of the powder particles is influenced on the pozzolanic effect. Using the Blain Apparatus, the surface area surveyed powders was examined. The outcomes of the specific surface measures carried out with the Blain Apparatus for the particular concrete binders are shown in Fig. 3.

Tab. 2. The results of average compressive strenght and pozzolana index (WAP).

The number of series	The average compressive strength [MPa]	WAP (index of pozzolana effect) [%]
Part-1 (3 samples)	49.61	81.95
Part-2 (3 samples)	40.65	

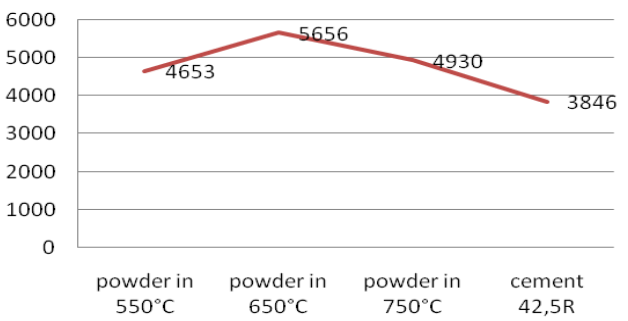

Fig. 3. The surface area of the different binders according to Blaine, in cm^2/g.

As is apparent from measurements, the calcination of recycled powder are affected on the growth of the specific surface area. The largest surface area of the calcined powder was achieved at a temperature of 650°C. It has been observed that the roasting process caused an increase in surface area in relation to the specific surface of the cement 42.5R (in 650°C – the best value – about the surface area about 1.5 times more than cement 42.5R). The all of remaining respondents binder does meet the standards, because the normalised value for cement 42.5R is about 4000 cm^2/g.

4. Conclusions

The results clearly leads to the conclusion that the compressive strength of mortars made strictly dependent on the type of binder recycled, that the temperature and time of calcination also *w/c* ratio. The greatest strength obtained for series 1 (roasting in 750°C by 30 min and *w/c* = 0.45) and amounted to 48.16 MPa. The lowest value of strength for the series 6 (calcined at 550°C by 60 min and *w/c* = 0.45). The difference amounted to 51.08%.

Grind size of the binder recycling was proved so effective and was observed high specific surface higher than the pure cement subjected to analysis. The highest average specific surface area was obtained for a series of calcined 650°C. The smallest surface area while was observed with calcination binder recycling in 550°C. All resulting surfaces were found to be higher than the cement surface 42.5, which binder recycling created and given by the manufacturer. The difference between the largest specific surface area obtained by the roasting binder 650°C for 60 min, and the surface area of the cement was 47%. It was also observed that increasing the temperature of 100°C was resulted in an apparent decrease in surface area of up to 13.40% and 24.30% reduction.

The selected of analysis of research shows that 25% of calcinated recycled powder content could be effective pozzolana addition in cement composites.

Due to aforementioned conclusions further research is recommended to test the application of recycling binder content in newly designed concretes. Whereas, the process of recycling of concrete certainly may be considered as the future and new direction in scope of modern construction.

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KOMPOZYTY CEMENTOWE Z MODYFIKOWANYM DODATKIEM RECYKLINGOWYM

Streszczenie: W ostatnich latach duży nacisk kładzie się na ochronę środowiska i poszanowania zasobów naturalnych, które daje nam Ziemia. W artykule omówiono technologie recyklingu betonu z naciskiem na jego potrzebę i znaczenie tego procesu w obecnych warunkach. W artykule przedstawiono rezultaty badań własnych nad kompozytami cementowymi, w których zastosowano dodatki odzyskane ze starego betonu.