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ECOLOGICAL ASPECT OF WASTE CONCRETE FINES APPLICATION AS CEMENT REPLACEMENT IN FINE-GRAINED COMPOSITES

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ABSTRACT: Cement production is a very energy-intensive process which is responsible for around 5-8% of global carbon dioxide emission caused by human activity. Thus, replacing it with other materials is very beneficial for the environment. The paper presents the research on the use of a waste concrete fines which partially replaced cement in concretes. The fines was obtained in the thermal and mechanical treatment of concrete rubble. Then the research experiment considered the impact of two factors on selected physical and mechanical properties of the fine-grained concretes. These factors included: contents of the recycled fines (10, 20, 30% of cement's mass) and its grinding time (0, 30, 60min). The results confirmed that the right technology enables the recycled fines to substitute 20% of the cement's weight. Such activity allows energy saving compared to clinker and will also cover part of the ever-increasing cement demand – while protecting raw material.

KEY WORDS: waste concrete fines, recycling, ecological aspect, carbon dioxide emission

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Introduction

Contemporary society is increasingly paying close attention to the ecological aspects of life related to sustainable development, health, eating or the environment protection. Increasing environmental consciousness manifests, among others, in such selection of used materials and technologies to minimize the negative impact on the environment. Appropriate industrial solutions based on limitation of waste production and returning it to life cycle will protect non-renewable resources for the next generations according to sustainable development idea. Construction and demolition waste (C&DW) is one of the heaviest and most voluminous waste streams generated in the EU. It accounts for approximately 33% (821 million tons) of total waste generated (EC, 2015). In the EU, more than 200 million tons of this waste is produced every year, which gives around 500 kg per capita (Bio Intelligence Service, 2011). Figure 1 presents the amount of C&D waste generated in Poland in 2004–2013 and forecasts to 2022 (from 2014 year because so far there are no data).

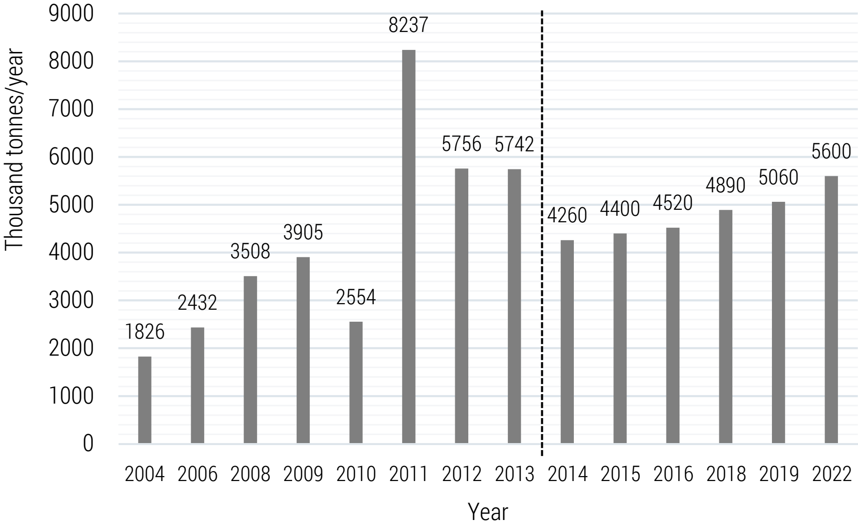


Figure 1. Amount of C&D waste generated in Poland and forecasts for generation to 2022
Source: (C&DW, 2015)

It is therefore necessary to change the material production technologies used in construction in a way reducing energy consumption and use of non-renewable raw materials. The revised Waste Framework Directive (EC, 2008) is an important step towards better material management and increasing resource efficiency in the EU. It proposed a hierarchy of waste management based primarily on waste preventing and reusing. The Directive has called on the member states to take necessary measures to reach a minimum target for reusing, recycling or recovering 70% of waste by 2020 (EC, 2008). Concrete is the most consumed material with 25 billion tons worldwide and 2.5 billion tonnes in the EU. After demolition generally is used for road bases, hole fillings or as coarse recycled aggregate for new concrete. However, when crushing concrete rubble or "cleaning" recycled aggregate from an old cement mortar to improve its properties, up to 30% of the fine fraction (sometimes even up to 65%) is produced. Because of many impurities and weak properties such fine fraction is not recommended to use as concrete component and usually ended up at landfills.

The results of this study indicated the possibility of using this concrete fines as partially cement replacement in concrete, what could manage, in the environmentally friendly way, many millions of tons of such waste produced annually in EU.

An overview of literature

Recycling of concrete rubble is one of the main ways of construction waste recovering. The last standard PN-EN 206, (2014) introduced the possibility of partial replacement of coarse natural aggregate by recycled concrete aggregate. However, during the rubble crushing process about 30% of the fine fraction (<4 mm) consists of cement mortar and pollution is produced additionally. Moreover, to improve the quality of recycled aggregates, various methods of separating the cement mortar from the aggregate grains are proposed (Ismail, 2013; Dosho, 2007). As a result 35% of high-quality coarse aggregate and 21% of fine aggregate is produced but 44% of fines contains a large amount of original mortar generally regarded as a waste material is also obtained (Dosho, 2007). However the ways of reusing that waste fines must be found immediately. For a last few years the researchers have been working on this issue. Gastaldi et al. (2015) and Schoon et al. (2015) have used different amount of the recycled fines (< 63μm) mainly for the production of a clinker and achieved promising long-term results. Shui et al. (2008) studied the possibility of re-hydration of the recycled mortar subjected to 800°C. Ahmari et al. (2012) proposed the possibility of producing a new geopolymer binder based on powder from the recycled concrete.

In present article fine waste material obtained from the production of high quality recycled aggregates was used as a partial replacement for Portland cement. For this purpose special thermal-mechanical treatment method of concrete rubble, based on patent application (P.417362) was tested.

The world demand for cement is about 4160.0 million tonnes and is constantly growing. Portland clinker is produced through a combustion process: first calcium carbonate from the quarry is calcined to lime; then this lime is combined with clay to produce clinker. This process requires thermal energy, e.g. 2.9 GJ/t clinker with the best available technology. The CO_2 emission related to both calcination and combustion is ~ 830 kg CO_2/t clinker produced. Cement production is a very energy-intensive process which is responsible for around 5-8% of global CO_2 emission caused by human activity with a growing tendency (Błaszczyński and Król, 2014; WRI, 2005). Taking into account the fact that the world produces billions of tons of cement annually, it is easy to imagine damages caused in the environment. Thus, the introduction of alternative binders from waste and their use as a cement additive or replacement will contribute to minimizing negative impacts on the natural environment by reducing pollutant emissions and the efficient use of waste.

The aim of this study is to determine the possibility of using the recycled concrete fines after thermal-mechanical treatment as partially cement replacement in the fine-grained concretes and analysis the beneficial impact of such activity on the environment. The fine-grained concrete recipe is based on the reactive powder concrete (RPC) composition, which contains 700-1200 kg/m^3 of cement.

Research methods

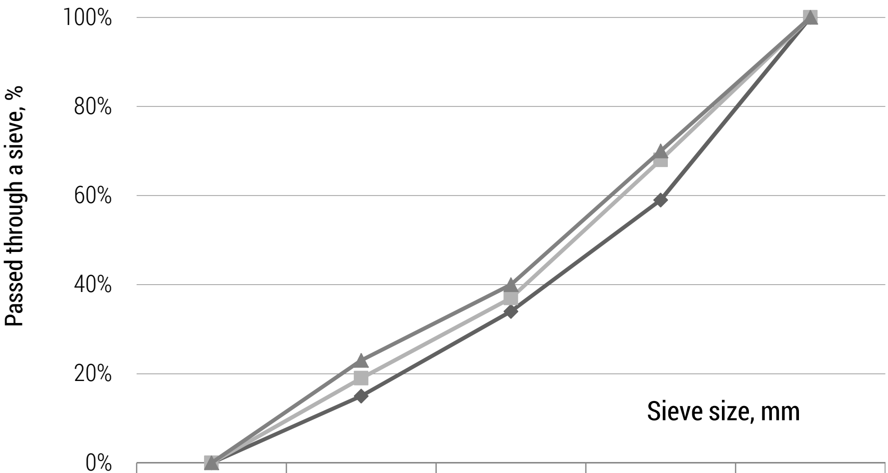
To conduct the research were used: Portland cement CEM I 42.5R, standard sand fraction 0/1 mm, CHRYSO Fluid Optima 350 additive and silica fume. The recycled fines was obtained by processing cement mortar separated from concrete rubble. In the first stage concrete rubble was subjected to pre-grinding in a jaw crusher in order to obtain coarse aggregate and then special thermal-mechanical treatment, based on patent application (P.417362, 2016) for mortar separating was used. Roasting temperature in the experiment was set at 650^{o}C according to patent guidelines. The recycled material was roasted for one hour in a pre-heated furnace in order to weaken the adhesion of the cement mortar to the aggregate grains and recover binding properties of the dehydrated paste phases.

Then material was placed in the Los Angeles drum for separation the old cement mortar from the aggregate's surface. After 1000 revolutions the drum's content was sieved (sieve size – 4mm) to separate the coarse aggregate. The remaining mortar was re-sieved (sieve size – 0.5 mm) to separate the concrete fines used for further examination. Next after grounding in a mill for: 0 min, 30 min and 60 min specific surface area and skeletal density were examined (table 1) and the sieve analysis was performed (figure 2).

Table 1. The properties of the recycled concrete fines and cement

Properties	Recycled concrete fines in depend on grinding time, min			Cement CEM I 42.5R
	0	30	60	
Skeletal density acc. EN 1097–7 [cm³/g]	2.76			3.05
Specific surface area acc. EN 196-6 [cm²/g]	2 086	2 674	3 162	3 400

Source: author's own work.



	0	0,063	0,125	0,25	0,5
0 min	0%	15%	34%	59%	100%
30 min	0%	19%	37%	68%	100%
60 min	0%	23%	40%	70%	100%

Figure 2. Grain size curves of the obtained recycled powders

Source: author's own work.

Prolonged grinding of the concrete fines increases mainly dust faction <0.063 mm. Next cylindrical samples (3 cm – diameter and 3.5 cm – height) were prepared and after 28 days of curing chosen physical-mechanical properties like compressive strength, water absorption, density and water capillarity of composites were conducted.

Research experiment and results

In order to determine the influence of the recycled fines on selected properties of fine-grained composites I planned a research experiment consisting of 9 basic and one control series without recycled fines (No 10). The experiment included two factors (X_1, X_2):

X_1 – the content of the recycled fines: 10; 20; 30% of the cement mass,

X_2 – grinding time of the recycled fines: 0 min; 30 min; 60 min.

Final recipe of the concrete mix with a starting cement content of 900 kg/m^3, which corresponds to reactive powder concretes is presented in table 2. Next, the moulded samples were pressed for 10min with a force of 250 kN.

Table 2. Recipes of concrete mixes per 1 m^3

Composition	Control	X_1=10%	X_1=20%	X_1=30%
Cement CEM I 42.5 R [kg/m^3]	900	810	720	630
Recycled fines [kg/m^3]	-	90	180	270
Silica fume [kg/m^3]	225	225	225	225
w/c	0.30	0.33	0.38	0.43
w/s	0.24	0.24	0.24	0.24
Water [dm^3/m^3]	270	270	270	270
Superplasticiser [dm^3/m^3]	22.5	22.5	22.5	22.5
Standard sand 0/1mm [kg/m^3]	834.5	834.5	834.5	834.5

Source: author's own work.

Table 3 shows the average results of the compressive strength tests after 28 days of curing ($f_{cm,28}$), water absorption (WA), density (D) and the water capillarity (Cap).

Figures 3a-d show a graphical interpretation of the obtained results.

Table 3. The average test results of composite properties

Series n°	Variable values		Composite properties			
	X_1	X_2	$f_{cm,28}$	WA	D	Cap
	[%]	[min]	[MPa]	[%]	[kg/m³]	[%]
1	10	0	75.21	2.86	2389.37	0.83
2	20	0	68.67	3.29	2361.93	0.95
3	30	0	63.77	3.36	2334.49	1.07
4	10	30	79.11	2.16	2407.15	0.80
5	20	30	81.87	2.46	2379.71	0.95
6	30	30	66.65	2.49	2352.27	1.00
7	10	60	89.55	1.55	2424.93	0.75
8	20	60	88.53	1.93	2397.49	0.85
9	30	60	69.53	1.95	2370.05	0.94
10	0	0	71.90	1.68	2430.63	0.66

Source: author's own work.

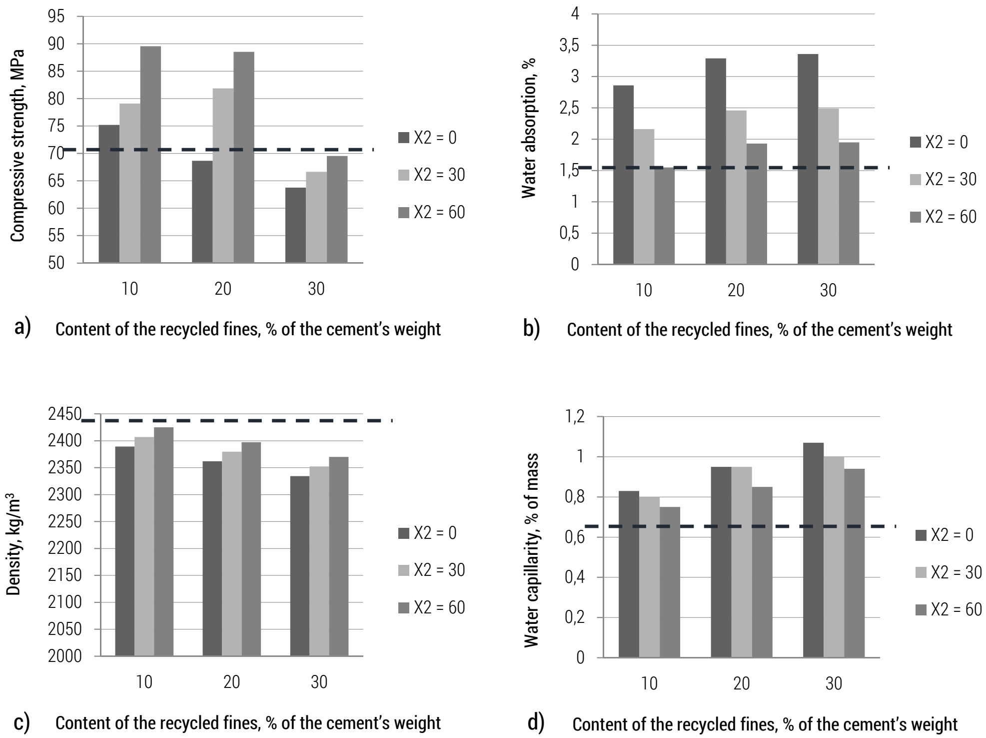


Figure 3. Graphs of changes in composite properties depending on X_1 and X_2 variables (a – compressive strength, b – water absorption, c – density, d – water capillarity)

Source: author's own work.

The above analyses show that two variables considered in the experiment had a significant influence on the tested concrete properties. An increase of the recycled fines from 10% to 30% in concrete caused a 15-22% loss of compressive strength (depending on the grinding time). Grinding the fines for 60min resulted in the fragmentation and an increase of grain content to 0.063mm (Figure 2), which probably improved packing of designed aggregate granulation. It led to the strength growth by about 23% when 20% of concrete fines were used in compare to control concrete. At a temperature of 650^{o}C portlandite dehydroxylation was occurred, resulting in calcium oxide was formed, which in contact with water hydrated again. Such a significant improvement in compressive strength when concrete fines was used is partly puzzling and may be due to the small size of the test specimens. But the general trend is visible and indicates the possibility of using recycled fines as a substitute for cement after proper treatment. Fines grinding time has a beneficial effect on composite water absorption, similar to the control, and on water capillarity due to the increase of the smallest fraction improving the tightness of the concrete structure. An increase in the recycled fines content from 10% to 30% caused a rise in water absorption by 17% and 26% at a grinding time of 0 min and 60 min respectively. This is probably due to a higher porosity of the recycled material and different grain size from the cement. A similar relationship was observed when the water capillarity was tested. Figure 4c concludes that both the content of the recycled powder and the grinding time do not significantly affect the concrete density. As the content of fines increased, the density of the composite decreased slightly (about 2%) because the material has a lower density compared to cement (table 1). The conclusion is that the longer grinding od fines positively affects the material's structure. It improves particle packing in the sample what developed concrete properties. To reduce the adverse effect of the presence of recycled fines in concrete is proposed to apply it in an amount of 20% of cement mass.

Ecological aspect of cement replacement by waste concrete fines

Above test results of physical and mechanical properties of cementitious composites indicate that it is possible to replace Portland cement by waste fines of up to 20% of its weight. However, this requires the use of a suitable thermal-mechanical treatment, in particular a high temperature in which the hydrated cement in waste partially recover its binding capacity. In table 4 stages of the production processes of Portland cement and recycled concrete fines were presented.

Table 4. Production processes of Portland cement and recycled concrete fines

Kind of binder	
Portland cement	Recycled concrete fines
Stage of the production process	
Extraction of raw materials	Selective demolition of the building – concrete rubble
Crushing / Grinding	Preliminary crushing
Correction of composition	Essential crushing
Homogenization	Roasting in temp. 650°C
Roasting in temp. up to 1450°C	Mechanical treatment – separation cement mortar <4 mm
Grinding in a ball mill	Grinding in a ball mill
Storage and packaging	Storage and packaging

Source: author's own work.

As can be seen in table 4, the production processes of Portland cement and recycled concrete fines consist of similar steps, in spite of their different origin. However, determining the amount of energy that consumes production of 1t of recycled fines is quite difficult, because so far, this process is carried out on a laboratory scale and not industrial. On the other hand, it may be provided that the amount of energy should be reduced as compared with the cement production. It is due to much lower roasting temperature needed for recycling fines treatment. In addition, greenhouse gases, mainly carbon dioxide, are emitted during the production process of clinker binder. When clinker is roasted, decarbonisation of calcium carbonate ($CaCO_3$) into calcium oxide occurs. Carbon dioxide in the amount of 510 kg to 610 kg per 1 ton of cement is by-product (Błaszczyński, Król, 2014). In the concrete fines production process, when the roasting temperature of 650°C is used, dehydroxylation of calcium hydroxide $Ca(OH)_2$ takes place which results in calcium oxide and water vapor (1):

$$Ca(OH)_2 \xrightarrow{650^{o}C} CaO + \uparrow H_2O$$

The decomposition of calcium carbonate with CO_2 emission takes place at about 800°C (Krzywobłocka-Laurów, 1998). Thus, it can be assumed that the production process of concrete fines consumes less than a half of energy needed to clinker production and does not contribute to by-products formation such as carbon dioxide. The development of effective management methods at each stage of waste production allows to return such secondary materials into circulation. This results in ecological and economic benefits and improves the raw material-product balance. Recycling of concrete waste fines will allow energy saving compared to clinker and will also cover part of the ever-increasing cement demand – while protecting raw material.

Conclusions

Cement production is a very energy-intensive process, so replacing it with other materials is very beneficial for the environment. The waste fines used instead of cement was obtained in the thermo-mechanical processing of concrete rubble. Because of roasting at 650°C, the cement paste in concrete became partially dehydrated, which activated the cement's binding capacity. The influence of two factors like the content of the recycled fines and its grinding time on selected physical and mechanical properties of concretes were analysed. I found out that in most cases the grinding time of the recycled fines and its content significantly affected the obtained results. The best results especially for compressive strength were observed, when recycled fines in an amount up to 20% of cement mass was applied. Particularly advantageous effect was obtained when grinding powder for 60min was used because it had a specific surface area similar to that of cement (3400 cm^2/g). Therefore I can concluded that the results presented in paper are promising and this way should be developed. Proposed solution on one hand allows to manage part of fines waste, on the other hand supports the sustainable development idea by saving the natural resources and reducing the CO_2 emission and energy needed for cement production process.

The author is also conducting research into the possibility of using this material as a pozzolanic additive for cement composites.

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