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The Study of the Properties of Concrete Containing Waste Powder as a Fine Aggregate

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Abstract. Concrete production consumes much energy and large amounts of natural resources. It causes environmental, energy and economic losses. Cement industry contributes to production for about 7% of all CO_2 generated in the world. Every ton of cement production releases nearly one ton of CO_2 to atmosphere. Thus the concrete and cement industry changes the environment appearance and affects it to a great extent. On the other hand, there is an increase in demand and decrease in natural sources of concrete constituents, like sand. The use of rock dust as the replacement for natural sand will solve the problem of dust disposal. The present study shows the results of the research concerning the modification of concrete with waste dust. It is the waste from the preparation of aggregate used in asphalt mixture production. Concrete modification consists in that the powder waste is added to concrete as partial replacement of fine aggregate. Previous studies have shown that analysed waste has a beneficial effect on compressive strength, flexural strength as well as freeze resistance. The use of mineral powder as the partial substitution of fine aggregate allows for the effective management of industrial waste and improves some properties of concrete.

Keywords: concrete, compressive strength, waste management.

Conference topic: Environmental protection.

Introduction

Concrete is the most widely used man-made construction material in civil engineering applications such as buildings, roads, bridges, dams, power plants, flooring, etc. Compared to other building materials, concrete can be formed into a variety of shapes and sizes right at the construction site or in the form of precast elements. It enables any vision of the designer to be put into practice. Concrete is the most inexpensive and the most readily available material. The cost of concrete production is low compared to other engineered construction materials. Three major components of concrete, i.e. water, aggregate and cement, are available in every corner of the world. This enables concrete to be locally produced anywhere in the world, thus avoiding the transportation costs necessary for most other materials. The great advantage of concrete is its mechanical and physical properties. The concrete strength is commonly considered as the most valuable feature, but in many practical cases durability, impermeability and volume stability may in fact be much more important. It is essential that concrete should be capable of withstanding the conditions for which it has been designed throughout the life of structure (Neville 2011). According to Aïtcin (Aïtcin 2000), concrete is at the same time the result of a simple technology and a complex science that is beginning to be mastered, but not in all its details. In fact, the hardening of modern concrete results from reactions between amorphous or mineral products, water, more or less complex organic molecules, and with some mineral salts in some cases (Aïtcin 2000).

The most important material in concrete production is cement. The consumption of cement and thus concrete, increases day by day along with the growth of urbanization and industrialization and due to new developments in construction technologies, population growing, increasing of living standard, etc. According to Cembureau (CEMBUREAU 2015) and Portland Cement Association (CEMENT 2015) data, world cement consumption grows constantly. The total world production of cement was about 4.0 billion tonnes in 2013, 4.3 in 2014 and about 4.6 billion tonnes in 2015. Cement consumption is expected to grow 3.7 percent in 2016, and remain near 4 percent of growth during 2017-2018. It can therefore be estimated that annual production of concrete is about 15 billion m^3, on the premise that 300 kg of cement (on average) are used to produce 1 m^3 of concrete. This is roughly 2.0 m^3 concrete *per capita* annually. Taking this into account, it can be assumed that concrete is the second substance that is consumed in the world after water (Aïtcin 2000). Therefore it is not surprising that concrete industry plays an important role in infrastructure development and economic growth and also faces many challenges due to environmental concerns and sustainability issues (Mishra, Siddiqui 2014). Concrete production consumes much energy and large amounts of natural resources. It causes environmental, energy and economic losses as it exploits 50% of raw material, 40% of total energy, as well as generates 50% of total waste (Anik *et al.* 1996; Behera *et al.* 2014). Cement industry contributes to production of about 7% of all CO_2 generated in the world (Malhotra 2000). Every ton of cement production releases nearly one ton of CO_2 to atmosphere (van Oss, Padovani 2003). Thus the concrete and cement industry changes the environment appearance and influences it very much. Therefore it has become very important for construction industry to focus on minimizing the environmental impact, reducing energy consumption and limiting CO_2 emission. The need to meet these challenges has spurred an interest in the development of a blended Portland cement in which the amount of clinker is reduced and partially replaced with mineral additives – supplementary cementitious materials (SCMs). There are three main types of SCMs (Kurdowski 2014): (1) hydraulic materials when mixed with water produce essentially the same products as the principal products formed when Portland cement hydrates, mainly calcium silicate hydrate (C-S-H phase); (2) puzzolanic materials which in the presence of moisture react with calcium hydroxide at ambient temperature and form compounds possessing cementitious properties; (3) fillers are usually chemically inert and have a beneficial effect on some properties of concrete. Supplementary cementitious materials are mainly by-products of industrial production, such as silica fume (SF), fly ash (FA), granulated blast furnace slag (GBFS), stone powders and others. As a SCMs can be also used natural minerals like zeolite (Markiv *et al.* 2016). The average amount of clinker in cement declined from 85% in 2003 to 77% in 2010, and it is expected to decrease further to 71% in the future. At the same time the use of SCM is increasing (Juenger, Siddique 2015). SCMs affect cement hydration process by impact on cement hydration kinetics and composition of C-S-H phase (Juenger, Siddique 2015; Neeraj 2012; Laibao *et al.* 2013; Franus *et al.* 2015). Due to pozzolanic activity and the filling effect, SCMs contribute to the strength increase of cement mortar and concrete (Neeraj 2012; Saraya 2014; Laibao *et al.* 2013; Borosnyói 2016; Paris *et al.* 2016; Bilim 2011), enhance the freeze-thaw resistance (Borosnyói 2016; Paris *et al.* 2016; Bilim 2011), decrease porosity and permeability (Neeraj 2012; Borosnyói 2016; Paris *et al.* 2016; Bilim 2011) and thus improve durability of concrete (Borosnyói 2016; Paris *et al.* 2016; Bilim 2011; Lollini *et al.* 2016).

Concrete industry is one of the major consumers of natural resources. There is an increase in demand and decrease in natural sources of concrete constituents, like fine aggregate (sand). Thus there is a need to identify new sources of fine aggregate. On the other hand, large quantities of fine material (dust) are generated as by-products of stone crushers in quarries and during processing rocks into aggregate used in concrete industry. This fine material can be emitted into the surrounding atmosphere. The handling and disposal of dust is a severe environmental problem since it is detrimental to environment: it contributes to a great extent to the accumulation and harmful dispersion in air, water and soil of fine solid particles (Galetakis, Soultana 2016). Many researchers have studied the applicability of waste mineral powder in mortar and concrete production. The addition of marble dust (Neeraj 2012), basalt powder (Laibao *et al.* 2013; Saraya 2014; Dobiszewska *et al.* 2016a, 2016b), granite powder (Arivumangai, Felixkala 2014) or limestone powder (Saraya 2014; Galetakis, Soultana 2016) positively affects the strength of cement mortar and concrete as well as durability of concrete. The use of waste powder as partial replacement for natural sand allows for the effective management of industrial waste and improves some properties of mortar and concrete.

The present study shows the results of research concerning the modification of concrete with waste basalt powder. It is waste coming from the preparation of aggregate used in asphalt mixture production. Concrete modification consists in that the powder waste is added to a concrete as partial replacement of fine aggregate. Previous studies have shown that analysed waste has a beneficial effect on compressive strength, flexural strength and freeze resistance also.

Characteristics of waste basalt powder

Asphalt mixture production leads to formation of significant amounts of by-product in the form of mineral powder. The quantity of this waste powder is about 5% of aggregate mass used to production of asphalt mixture. It can be estimated that about 25–30 thousand tons of waste powder has been produced per year in Kuyavian-Pomeranian Voivodeship in Poland. Utilization of this waste is a problem in Asphalt Batch Mix Plant, which can use a small amount of the powder in asphalt mixture production. But huge amount of this waste is collected on landfills or used in land reclamation. Natural aggregate used in asphalt mixture production is dried at the temperature of about 200°C. An exhaust leaves the dryer with a particles of powder. Coarser fractions of powder are collected in a special separator but very fine fractions deposit in a filter of the dryer. This very fine material is treated as a waste, by-product. Properties of this powder depend on the type of aggregate used in production. Mineral powder used in this study is the origin of basalt hence it is defined as a basalt powder. The grading curve of basalt powder is shown in Fig. 1, and the chemical composition is given in Table 1. The specific gravity of powder is 2.84 g/cm^3 and Blaine specific surface is 3700 cm^2/g. Studied basalt powder represents a modal type of grading. The particle diameters are in the range of 2 to 300 μm. The largest volume, ie. ca. 36%, are occupied by particles of about 17.51 μm in diameter. Chemical composition is typical for basalt rock, ie. silica and alumina oxide dominate, which is in 57% and calcium and iron oxide. The scanning electron microscope (SEM) image of the basalt powder is given in Fig. 2 and XRD diffractogram is given in Fig. 3. Basalt powder particles have rough surface and angular shape. In mineralogical composition, the plagioclase, pyroxene and amphibole dominate.

Table 1. Chemical composition of powder basalt PB

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	Cl^-	LOI
	[%]									
PB	45.64	11.28	13.13	13.54	5.06	0.34	0.50	2.85	0.048	7.63

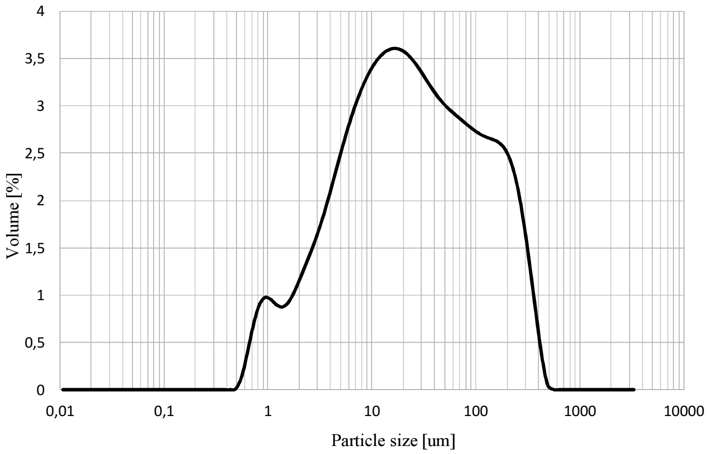

Fig. 1. The grading curve of basalt powder

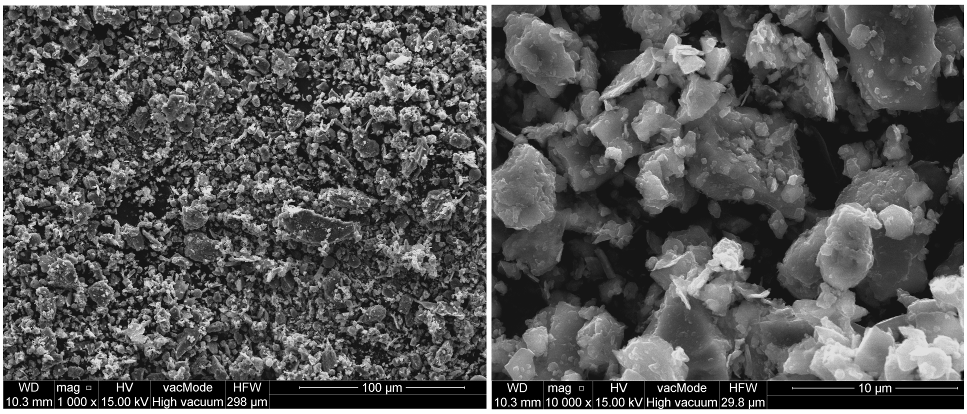

Fig. 2. The scanning electron microscope (SEM) image of the basalt powder at 1000 x mag. (left) and 10000 x mag. (right)

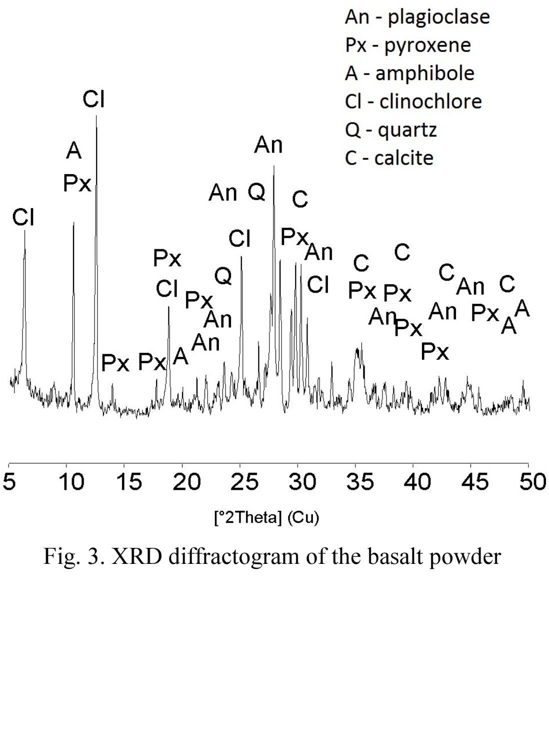

Fig. 3. XRD diffractogram of the basalt powder

Experimental program

General procedures

The main objective of the study aimed to examine the effect of waste powder basalt on the some properties of concrete. A comparison was made between reference concrete devoid of powder basalt and those containing different amounts of powder waste. Three concrete mixtures were prepared, replacing 0%, 10% and 20% of fine aggregate (sand) by powder basalt, in terms of mass. They are named respectively B0 (reference concrete), B1 and B2. Concrete mixture proportion is given in Table 2. The water/cement ratio was maintained constant at 0.44. To determine the effect of applying different amount of waste powder on concrete, consistency, air content and workability of concrete mixture, as well as compressive and splitting tensile strength, freeze resistance and water absorption were investigated.

Table 2. Concrete mixture proportion

Concrete	Cement	FA	CA 2/8 mm	CA 8/16 mm	Powder basalt	Water	SP	P	AE
	[kg/m^3]								
B0	350	685	487	631	0	153	2.1	1.8	0.5
B1		616	486	630	69		2.3	1.9	1.0
B2		548	485	629	137		2.5	2.1	2.1

Materials and method

Concrete mixtures were produced with High-Sulphate-Resistant cement CEM I 42.5 HSR. Natural river sand with a 2.0 mm maximum size was used as a fine aggregate (FA) and a gravel – as a coarse aggregate (CA) with a 16.0 mm maximum size. Coarse aggregates were classified into two different grain groups as 2–8 mm and 8–16 mm. Concrete mixtures were modified by chemical admixtures; Plasticiser (P), Superplasiciser (SP) and Air Entraining (AE).

All concrete mixtures were prepared using a laboratory mixer. The workability of the concrete mixtures was verified by a slump test conducted in different period of time, ie. 7, 30 and 60 minutes, according to EN-12350-2. Air content was measured by pressure method according to EN-12350-7. The EN-12390-3 and EN-12390-6 methods were employed to determine the compressive and splitting tensile strength respectively. The compressive strength and splitting tensile strength value after 28 days were determined using cubic samples of 150x150x150 mm. To determine frost resistance and water absorption, the Polish standard PN-B-06250:1988 was employed. Frost resistance was measured by comparison between the values of compressive strength of samples stored in the water and compressive strength of samples periodically frozen (150 freeze-thaw cycles). The weight loss of sample mass was also measured. To determine water absorption of concrete, specimens were dried in an oven at the temperature of approximately 105°C until they reached a constant weight. Then the samples were immersed in water until they reached constant weight. Absorptivity index was determined as an increase in weight of the sample saturated with water relative to the weight of dried sample to the constant weight.

Result and analysis

Fresh concrete

Fresh concrete properties are given in a Table 3. From results of the study it can be concluded that, as the percentage of powder basalt increases the slump of concrete mixture and air content decrease. The powder basalt has much higher specific surface than sand which was replaced by dust. Therefore with the increase of powder content, the fineness of aggregate increases thereby increasing specific surface of aggregate particles. As a result, more water is required to wet surfaces of all particles and workability decreases. Powder basalt acts as a filler material and fills the voids in concrete mixture, hence the air content decreases with the increase in basalt powder content. The filling effect also contributes to the increase in density of concrete mixture.

Table 3. Properties of fresh concrete

Concrete	Slump [mm]			Air content [%]			Density [kg/m^3]
	7 min.	30 min.	60 min.	7 min.	30 min.	60 min.	
B0	220	170	150	5.2	5.1	5.2	2306
B1	220	180	100	6.2	5.4	5.2	2325
B2	220	100	0	5.2	4.0	–	2319

Hardened concrete

The most important property of hardened concrete is the compressive strength. The relationship between the compressive strength of concrete at 28 days and the basalt powder content is presented in Fig. 4. It can be seen that the addition of powder basalt as a replacement of fine aggregate (sand) slightly affects compressive strength. The 28-day compressive strength increases with the increase in powder basalt content to maximum of 53 MPa at a powder basalt content of 20%. This increase can be related to higher concentration of hydrated cement compounds within the available space to occupy (Neville 2011). Powder material acts as a filler. The porosity is reduced because the large pores in concrete are filled with basalt powder (Dobiszewska *et al.* 2016a). This leads to better compaction and the densification of structure of hardened concrete. Splitting tensile strength of concrete showed relatively the same trend as with compressive strength. The maximum splitting strength value was obtained with 0% and 10% content as a replacement of sand. The results of splitting tensile strength are presented in Fig. 5. The increase in the splitting tensile strength can be attributed to the rough texture and angular shape of basalt powder particle which leads to creation of better bonding between paste and aggregate particles as well as the filler effect of powder.

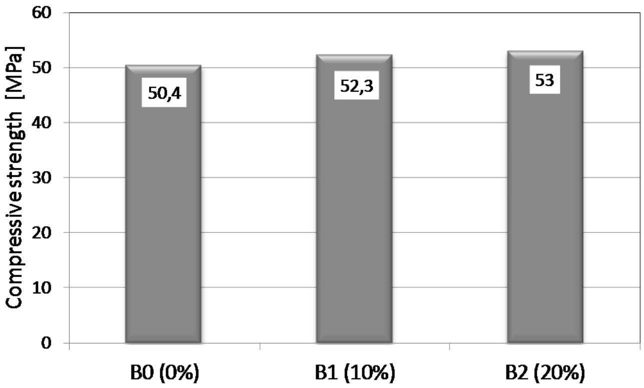

Fig. 4. Compressive strength of concrete at 28 days with different powder content

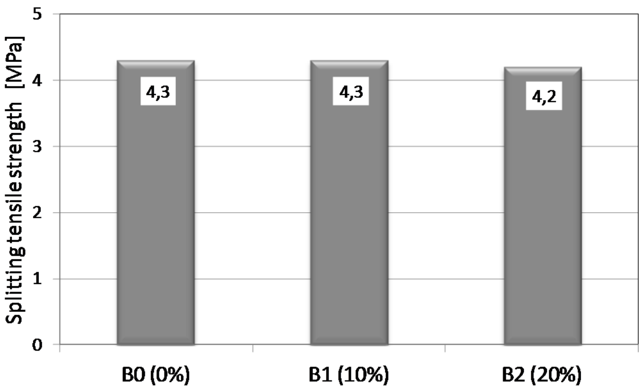

Fig. 5. Splitting tensile strength of concrete after 28 days with different powder content

Effect of the powder basalt on the frost resistance of concrete was estimated on a basis of determination of compressive strength of samples periodically frozen and thawed (150 cycles), and resistance of concrete to surface exfoliation in the presence of salt solution. The results are presented in Fig. 6 and 7. All examined samples of concrete fulfil the requirements for frost resistant concrete, ie. (1) decrease of the compressive strength of concrete after freeze-thaw cycles is lower than 20% (in comparison to samples stored in water) and (2) decrease of weight of samples after freeze-thaw cycles is lower than 5%. The value of compressive strength of reference samples and samples with 10% addition of powder basalt remained practically unchanged with respect to the compressive strength of samples stored in the water. With the increase in the powder basalt content, loss of weight of samples decreases.

The addition of powder basalt slightly affects the water absorptivity of concrete. The value of water absorption of B0, B1 and B2 concrete is 4.52%, 4.61% and 4.73% respectively.

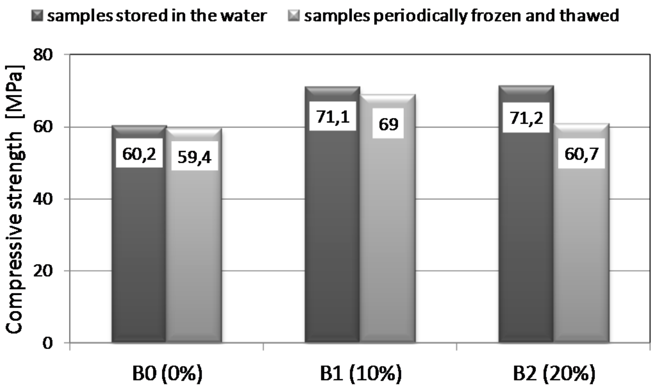

Fig. 6. Compressive strength of periodically frozen and thawed concrete after 28 days with different powder content

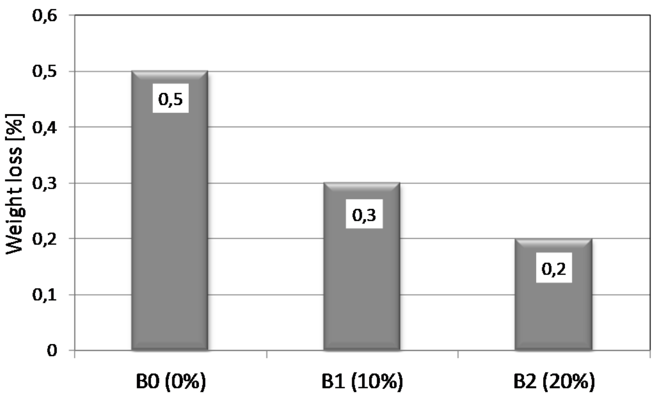

Fig. 7. Weight loss of periodically frozen and thawed samples of concrete after 28 days with different powder content

Conclusions

Growing demand for natural resources used for building materials production led to intensification of research concerning the possibility of using by-products. Powder basalt positively affects compressive strength while splitting tensile strength is not worsened. The increase in compressive strength is attributed to the fact that basalt acts as a filler and densifies the concrete matrix. Concrete with powder basalt addition meets requirements of frost resistant concrete. Although the decrease in compressive strength of periodically frozen and thawed concrete with addition of 20% powder basalt is the highest (ca. 14%), it is worth noticing that compressive strength of all frozen samples produced with basalt powder is higher than the compressive strength of reference samples stored in water. The review of the literature shows that the effect of basalt powder on the properties of concrete is not only physical corresponding to reduction in voids and thus porosity (filler effect) but also chemical, ie. basalt has potential pozzolanic activity (Laibao *et al*. 2013; Saraya 2014). Incorporation of waste basalt powder into concrete as a replacement of fine aggregate is environmentally friendly and economically feasible.

Disclosure statement

Authors do not have any competing financial, professional, or personal interests from other parties.

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