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THE ROLE OF MICROFILLERS IN SHAPING THE SULPHUR CONCRETE PERFORMANCE

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Abstract

The article presents the research results of sulphur concrete – the material that is created at high temperature as a mixture of a sulphur binder with aggregate and microfillers. While it has very interesting properties, it is not as appreciated as it should be.

The aim of this paper is also to encourage a deeper insight into the presented material, and the use of its hidden potential. Sulphur concrete is not new a product of modern technology – it has been known for decades, but new applications are still being found. The paper focuses mostly on the impact of the microfillers used on some properties of the concrete. In the research, the microfillers used were: fly ash, microsilica and zeolite. The article presents the microfillers' influence on the growing kinetics of compressive and flexural strength and the effects of abrasion on the sulphur concrete. The lab tests were carried out after 3, 7 and 28 days. The most noticeable was the positive influence of the fly ash on concrete performance. The microfillers that influenced the material's microstructure were also presented.

Introduction

The popularity of sulphur concrete in the domestic literature is scarce, almost non-existent for such an interesting material. The concrete is made by the means of mixing (at the temperature of 135°C) sulphur binder, aggregate and in some cases several types of microfillers, which task is to modify the properties. The technology of sulphur concrete production is much more similar to asphalt concrete production than to cement concrete. Sulphur

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concrete in the building industry is not considered as a new generation product. It was applied for the first time in the first half of the 20th century and up till now has been thoroughly investigated in many articles, research studies and publications where its properties have been presented. The first mix recipe was prepared by Canadians and Americans from *the Sulphur Institute* in the 1970s. **(**VROOM at al 1974**).** The main advantage of the concrete that it gain strength very quickly. Elements made with sulphur concrete reach its designed strength after several hours but in most cases they are ready and stable after 2–3 hours, depending on the surrounding temperature. What is more, the concrete sulphur is characterised by its complete resistance to aggressive corrosive factors. Even in the 20th century, several researchers (FARAŃSKI 1999, LOOV et al. 1974, MALHOTRA 1979, ORŁOWSKI 1992) presented, that in order to obtain the composite that would be resistant to chemical corrosion, the sulphur can be successfully applied as a binder. For this reason it is perfect when applied in radioactive and toxic waste tanks, pens for animals, sewers and many other uses (KUŚ, ROGALA 2004, CZARNECKI at al 1994, ŻARKIEWICZ 1996). Its high resistance to abrasion is also an important feature. It is more resistant to rutting leading to its use in road surfaces in the United States of America (DRIVER 2012). In spite of appearances, the costs of producing a cubic meter of sulphur concrete is comparable to cement concrete. The issue of costs was investigated by Americans in 1970s when they calculated that producing concrete based on sulphur binder can be 20% cheaper when compared to traditional concrete (*it is influenced by the price of sulphur, which ranges from several US dollars to several dozens US dollars per ton depending on the location).* In Poland, the phenomenon was looked into by the company of „SIARKOPOL" company in the 1990s. Nowadays the only sulphur concrete products are made by „MARBETWIL", a company which is located in Bielsko Biała with a factory in Gliwice (FARAŃSKI 1999).

The basic aim of this research is a presentation of the strength performance and physical (density) of sulphur concrete composites with various microfillers.

The scope and methodology of the research

In the Faculty of Technical Sciences at UWM in Olsztyn has been conducted research concerning into the of sulphur concrete in different biologically or chemically aggressive environments (CIAK 2007, CIAK, HARASYMIUK 2013). The research on the modification possibilities of sulphur concrete by using different microfillers have been also carried out.

The paper presents the research results of the modified sulphur concrete with a mixture of microfillers such as: fly ash (FA) from electrofilters, microsilica (MS) with 99.8% content of SiO_2 and zeolite (Z) with 62.1% content of SiO_2. Ground elementary sulphur with 99.98% content of sulphur (Fig. 1) was used as a binder. The last ingredient was 0/2 sand with the granulation presented on the Figure 2.

Fig. 1. Materials used in the researches: *a* - sulphur, *b* – fly ash, *c* – microsilica, *d* – zeolite
Source: Fig. *b* – Photographs taken by D. JANKOWSKI

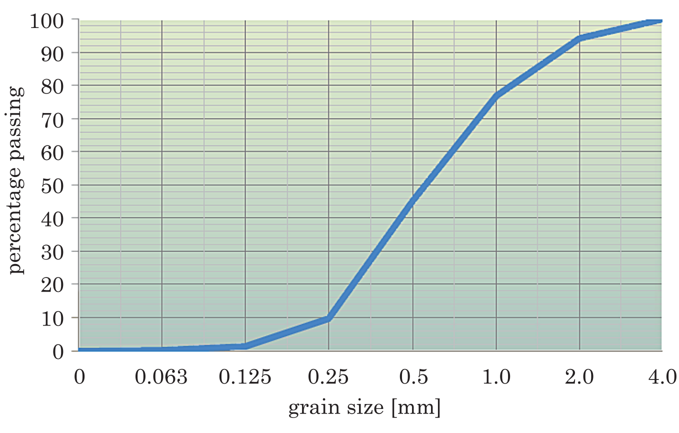

Fig. 2. Granulation of sand used in the research

The percentage shares of particular ingredients of the sulphur concrete mix which is presented in figure 3 was established by the following trials.

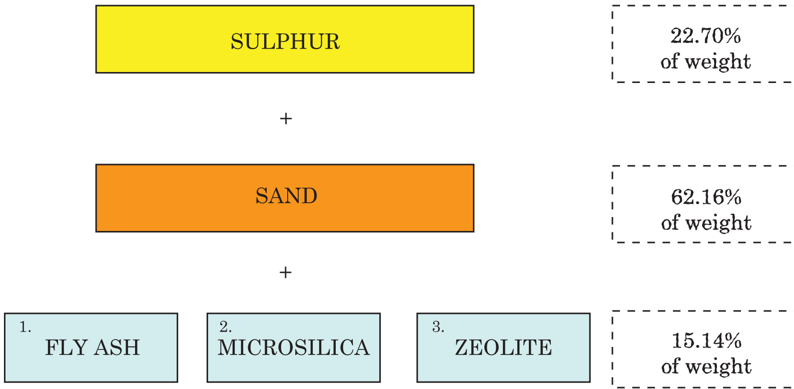

Fig. 3. Composition of sulphur concrete

Samples (100×100×100 mm and 40×40×160 mm) were prepared in an automatic agitator (Fig. 4) where melted sulphur was mixed with previously heated ingredients (sand and one of the microfillers). The temperature of the mix was 130-140°C. After obtaining uniform, smooth consistency, the mix was poured into casts (also previously heated to the proper temperature), then it is thickened with vibrations and finally stripped after several minutes (Fig. 4).

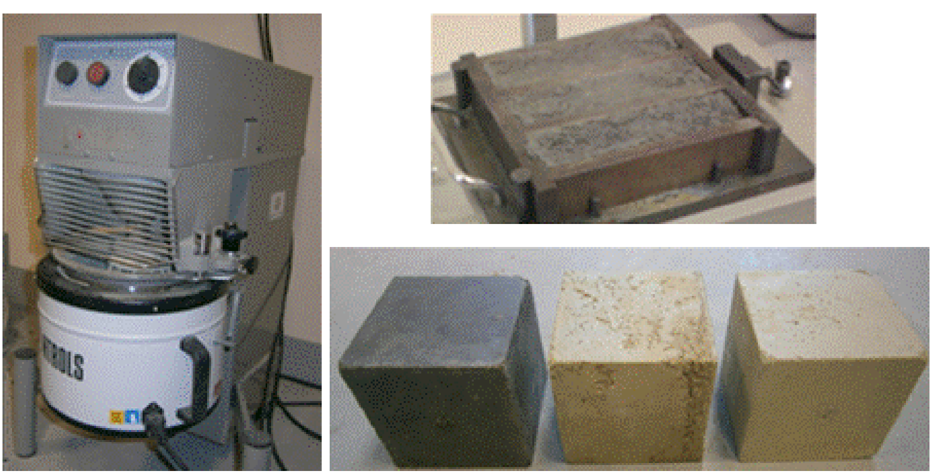

Fig. 4. Agitator for bitumen used in the research (on the left); Trigeminal cast filled with the sulphur concrete mix and a sample (100×100×100 mm) of the sulphur concrete with a mixture of fly ash, microsilica and zeolite (on the right)
Source: Photograph taken by D. JANKOWSKI

Fig. 5. Strength press ADVANTEST Controls
Source: Photograph taken by D. KOZŁOWSKI

Prepared samples were tested for their mechanical and physical properties. Flexural and compressive strengths were carried out in accordance with PN EN 196-1 in the strength press ADVANTEST 9 Controls (Fig. 5). The results are discussed below.

Abrasion resistance was tested on a Boehme abrasion testing machine (Fig. 6) according to the guidelines of PN-EN 14157:2005 standard. Cubic samples of sulphur concrete with the dimension of ±71mm were subjected to 16 rotary cycles (22 rotations each).

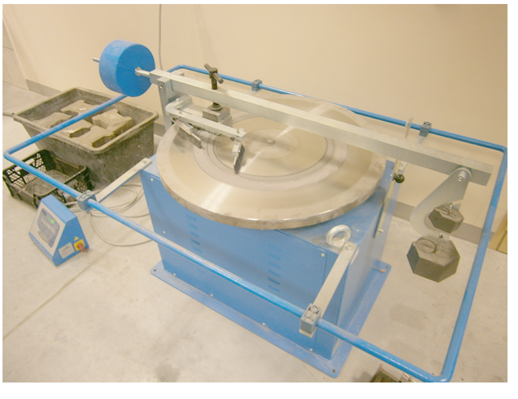

Fig. 6. Boehme abrasion testing machine
Source: Photograph taken by D. KOZŁOWSKI

Results

The analysis of strength tests after 28 days (Fig. 7) shows that the best results were achieved with samples, where fly ash (FA) was used as the microfiller. The use of microsilica and zeolite decreased the compressive and flexural strength. In case of flexural strength the decreases were about 45% (MS) and 30% (Z) and respectively 30% (MS) and 10% (Z) in the case of compressive strength, comparing them to the results achieved on the fly ash (FA) samples.

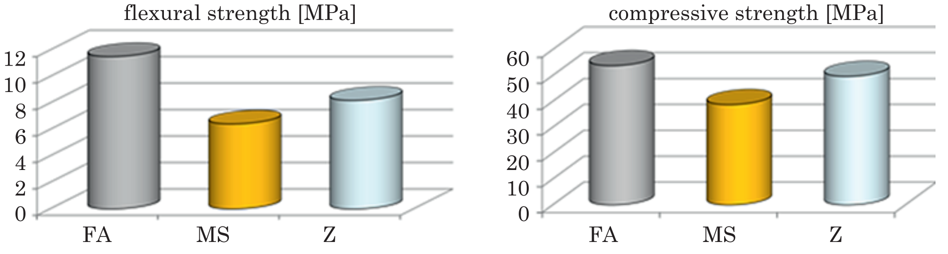

Fig 7. Tests results of the sulphur concrete samples with the micro fillers: fly ash (FA), microsilica (MS) and zeolite (Z)

In both compressive strength and the flexural strength tests results far exceeded the values obtained by standard concrete. It is especially noticeable in the flexural strength where the results can prove a different destruction mechanism. Concrete based on sulphur can be easily classified as fragile material as proved by the strength tests. Fragility which is described as a ratio of compressive strength to tensile strength in bending (Tab. 1), increases after the application of microsilica (MS) or zeolite (Z). It can evidence of decreased consistency of these fillers with the matrix – the sulphur binder.

Table 1

Average results of strength tests of the sulphur concrete samples

Type of a sample	Strength		Compressive strength /flexural strength
	compressive	flexural	
	MPa	MPa	
FA	53.78	11.51	4.67
MS	38.73	6.42	6.03
Z	49.64	8.20	6.05

As predicted, the apparent density (PN EN 12390-7) of the variations tested of sulphur concrete are quite similar (Tab. 2).

Table 2

Apparent density of the sulphur concrete

Concrete type	Apparent density [g/cm^3]
Sulphur concrete with fly ash	2.182
Sulphur concrete with microsilica	2.196
Sulphur concrete with zeolite	2.161

The summary of the Boehme abrasion tests results are presented in table 3. In this case, the mixture of fly ash still gave better results than microsilica (MS) and zeolite (Z).

Table 3

Abrasion resistance of the sulphur concrete after the Boehme test

Type and number of a sample		Mass before test m_i [g]	Mass after test m_f [g]	Loss of mass Δm [g]	Apparent density ρ_b [g/mm^3]	Change in the volume of a sample [mm^3]	Average change of the volume of a sample ΔV_{av} [mm^3]	Average loss of the height of a sample Δh_{av} [mm]
With fly ash	1	714.0	698.3	15.7	0.0021815	7,196.88	8,709.6	1.73
	2	715.8	692.3	23.5	0.0021815	10,772.4		
	3	730.0	712.8	17.8	0.0021815	81,59.52		
With microsilic	4	743.0	720.5	22.5	0.002196	10,245.90	10,898.6	2.16
	5	721.08	695.6	26.2	0.002196	11,930.78		
	6	729.07	706.6	23.1	0.002196	10,519.13		
With zeolite	7	718.8	701.6	17.2	0.0021609	7,959.65	8,530.4	1.69
	8	724.1	706.8	17.3	0.0021609	8,005.92		
	9	711.0	690.2	20.8	0.0021609	9,625.62		

Summary

The research proved the good strength performance of sulphur concrete. The results of 40÷50 MPa (compressive strength) and 6÷11 MPa (flexural strength) are comparable to the results of higher class concrete. What is more, low abrasion (1.6÷2.2 mm depending on used microfiller) shows that sulphur concrete and its products can easily compete with products made of standard or asphalt concrete. The additional advantage of sulphur concrete is the relatively simple technology of its production (similar to the asphalt concrete technology) and time span needed for the full maturity of the concrete. The tests also prove the effectiveness of fly ash application as microfillers. This article presents the results of the research, which are a part of a wider research program that aims at proving the necessity of a modification of sulphur concrete and of promoting its usage as a replacement for cement concrete and asphalt concrete.

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PN EN 196-1; Metody badania cementu. Oznaczanie wytrzymałości.

PN-84/B-04111; Badanie materiałów kamiennych – Ścieralność na tarczy Bohme'go.

PN-EN 1097-3; Badania mechanicznych i fizycznych właściwości kruszyw – Oznaczanie gęstości nasypowej i jamistości.

PN-EN 12390-1; Badania betonu. Kształt, wymiary i inne wymagania dotyczące próbek do badań i form.

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