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Sava centar, Beograd, 15. i 16. oktobar 2015.

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Tel. +381 (0) 11 3230-041, +381 (0) 11 3031-696,
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MOGUĆNOSTI KORIŠĆENJA OTPADNOG SUMPORA U BETONIMA I NJIHOVA PRIMENA

POSSIBILITIES OF USING SULFUR FOR CONCRETE PRODUCTION AND ITS APPLICATION

Milica VLAHOVIĆ,
Univerzitet u Beogradu, IHTM,
m.vlahovic@ihtm.bg.ac.rs,
Aleksandar SAVIĆ,
Univerzitet u Beogradu, Građevinski fakultet,
sasha@imk.grf.bg.ac.rs,
Sanja MARTINOVIĆ,
Univerzitet u Beogradu, IHTM,
s.martinovic@ihtm.bg.ac.rs,
Tatjana VOLKOV-HUSOVIĆ,
Univerzitet u Beogradu, Tehnološko-metalurški fakultet,
tatjana@tmf.bg.ac.rs

U okviru ovog rada biće predstavljene dve vrste betona dobijene korišćenjem otpadnog sumpora. Prvi beton je klasični, gde je Portland cement zamenjen sumporom. Drugi beton spada u grupu samozbijajućih betona, gde je sumpor korišćen kao zamena za deo filera u različitim procentima. Analiza utroška sumpora u ovim betonima, kao i uticaj na dobijen kvalitet i potencijalnu primenu za gradnju objekata u vezi sa obnovljivim izvorima energije, biće takođe dati u radu.

Ključne reči: *otpadni sumpor, beton, samozbijajući beton, primena*

Two types of concrete will be shown in this paper. First type of concrete is sulfur concrete, where part of Portland cement was replaced with sulfur. Second type of concrete is self-compacting concrete, where sulfur replaced part of the filler, with different contents. Analysis of the required amount of sulfur for these types of concretes, as well as the influence on the quality achieved and potential application in objects for Renewable energy, will be discussed.

Key words: *sulfur, concrete, self-compacting concrete, application*

I. Introduction

The aim of our study was to investigate the application of secondary sulfur as a binder or filler for the production of different qualities and types of sulfur concrete. Sulfur concrete is a thermoplastic composite, made of mineral aggregates and fillers. In this composite, sulfur was used as a binder (instead of Portland cement and water as in conventional concrete) at a temperature above the solidification of sulfur. It turned out that this relatively new building material can replace Portland cement concrete in many applications.

Noting that the global production of sulfur in 2013 and 2014 amounted to about 60 million tons per year, and predicts that by 2019 will reach 70 million tons, we believe that this trend will result in an annual excess of five million tons. Therefore, it is obvious that in recent decades the availability of sulfur from oil refining and processing of natural gas will increase significantly, mainly due to stricter environmental regulations. Technological process of obtaining sulfur concrete using the sulfur from Pancevo Oil Refinery, sand as aggregates and various fillers (talc, alumina, silica fume and fly ash) is presented in this paper. Modification of sulfur was performed by cyclic hydrocarbons (dicyclopentadiene) [1-6].

Advantages of sulfur concrete (SB) compared to the Portland cement concrete (PCB) are:

- Resistance to many acids and salts, the use in aggressive conditions;
- Low permeability, sealing materials;
- Fast curing and achieving min. 70-80% of the properties during first 24h;
- High strength;
- Application at temperatures below 0°C;
- Higher tensile, compressive and flexural strength, as well as a greater resistance to fatigue;
- The possibility of recycling.

Disadvantages of SB:

- The price of a modified sulfur binder is 2-3x higher than PCBs;
- The temperature of the mixture and separation of CO_2 and H_2S;
- long after the production and installation odor remains.

Self-compacting concrete (SCC) can be defined as concrete that will, without any mechanical means of placing, fill in all corners of the formwork and narrow gaps between densely spaced reinforcement bars, entirely under the influence of its own weight; so that at the end, compact concrete of better durability is achieved. Self-compacting concrete typically contains very fine mineral additives, of which the most widely used are limestone and dolomite flour and fly ash.

Slika 1 - Sprašivanje sumpora u laboratorijskim uslovima
Figure 1 - Grinding sulfur in laboratory conditions

Application of the principle of sustainable development in construction was the main motive for the adopted concept of research in this paper. The use of industrial by-products as a mineral additive (filler) was critically evaluated, in terms of their influence on the properties of SCC concrete, in fresh and hardened state. Therefore, ground (powdered) sulfur (obtained as a by-product of the oil industry, in the Pancevo Oil Refinery) was used in addition to the limestone filler in SCC.

II. Results

A. Sulfur concrete

Materials used as filler in this process were: talc (technical quality, China), alumina (Almatis, Germany), silica fume (Sika, Switzerland) and fly ash (thermal power plant "Nikola Tesla A", Obrenovac).

Tabela 1 – Fizičko-mehanička svojstva uzoraka sumpornog betona posle 24 časa nege
Table 1 – Physical and mechanical properties of sulfur concrete samples after 24 hours care

Sample	Density (g/cm^3)	Liquid water (%)	Apparent porosity (%)	Mechanical strength (MPa)	
				compressive	flexural
SB-T	2,16	1,31	3,14	55,4	8,3
SB-G	2,20	0,56	1,38	49,2	8,4
SB-MS	2,03	1,48	3,21	50,3	7,2
SB-EP	2,01	2,38	4,93	48,9	7,8

SB-T = sulfur concrete with talc, SB-G = sulfur concrete with alumina, SB-MS = sulfur concrete with microsilica, SB-EP = sulfur concrete with fly ash.

By comparing the properties of the prepared samples of sulfur concrete with data from references [6], conclusion can be drawn that, in terms of mechanical strength, samples with different fillers fully satisfy the usual quality requirements (Table 1).

The differences in the values of mechanical strength and apparent porosity of sulfur concrete samples can be attributed to the physical and chemical properties of the used fillers, due to the fact that the other components of the sulfur concrete are the same.

B. Self-compacting concrete with sulfur

After analyzing the results of several pilot mixtures (prepared with the aim to record changes in the properties of fresh and hardened SCC, due to the variation of the components), final composition of SCC mixtures was established, and then these mixtures were thoroughly investigated. A total of five comparative SCC mixtures were investigated. All tested SCC mixtures had the same water content (183 kg/m^3), chemical admixture - superplasticizer (7.6 kg/m^3), cement (380 kg/m^3), the total amount of powder component (600 kg/m^3 - powder type SCC). Also, the weight ratio of fractions (2:1:1) and the total amount of all three fractions used (1700 kg/m^3) were the same in all of the SCC mixtures. The quantity of sulfur was different in these mixtures, as fallow:

1. SCC without the addition of sulfur, marked as E,
2. SCC with 2% of ground sulfur (of the total amount of powder component of concrete), marked as S2;
3. SCC with the addition of 5% of ground sulfur (of the total amount of powder component of concrete), marked as S5;
4. SCC with the addition of 10% of ground sulfur (of the total amount of powder component of concrete), marked as S10;
5. SCC with the addition of 20% of ground sulfur (of the total amount of powder component of concrete), marked as S20.

Slump flow values of these mixtures ranged from 77.5 cm to 82.0 cm. After 28 days, compressive strength of these SCC mixtures ranged from 54.6 MPa to 62.2 MPa (Table 2). The samples used for compressive strength tests were 10 cm cubes.

Tabela 2 – Čvrstoće pri pritisku SCC sa sprašenim sumporom, različite starosti [MPa]
Table 2 - Compressive strength of SCC with ground sulfur, at different ages [MPa]

Series	Time (days)			
	3	7	14	28
E	48.8	53.9	58.3	62.0
S2	48.3	53.0	58.0	61.5
S5	46.1	52.0	58.0	62.2
S10	46.1	49.2	53.4	54.8
S20	44.1	47.9	53.0	54.6

The positive effects that might arise from the present research are following:

- Increasing the amount of resources available for the preparation of SCC mixtures,
- Positive impact on the environment by reducing the amount of this material in landfills,
- Smaller amounts of the material to be exploited from nature (aggregate, filler),
- Use of recycled materials in systems for the production of electricity from renewable energy sources (Table 3).

Tabela 3 – Upotreba betona sa sprašenim sumporom u sklopu sistema za proizvodnju električne energije iz obnovljivih izvora

Table 3 - Use of concrete with powdered sulfur within the system for electricity production from renewable sources

Type of the concrete	Application fields
Sulfur concrete	- structural elements that use Portland cement concrete as a replacement of the same class, especially in terms where it is expected the acid, base or salt influence.
SCC with sulfur	- Structural concrete elements corresponding to the projected class (strength, frost resistance, water resistance) within the system of wind turbines, solar panels and/or small hydro power plants (Figure 2) - Anchor blocks for stabilization - The non-structural elements made of concrete - Access and internal roads and pavements.

Slika 2 –Konstruktivni i nekonstruktivni elementi od betona u sklopu sistema za proizvodnju električne energije iz obnovljivih izvora

Figure 2 - Construction and non-structural concrete elements within the system for the production of electricity from renewable sources

III. Conclusion

In this paper, the analysis of the use of waste sulfur from oil refineries, in order to obtain concrete with different characteristics was given. Based on obtained results we can conclude the following:

- The use of the waste sulfur from oil refineries will help solving problem of large amounts of secondary sulfur generation;
- Application of the secondary sulfur, as a substitute for cement for Portland cement concrete, showed that sulfur concretes posses good features, and have better resistance to chemicals;
- If secondary sulfur was used for self-compacting concrete, smaller amounts of sulfur are used, but better properties can be achieved in comparison to the sulfur concretes.

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