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Review paper

INFLUENCE OF TYPE AND QUANTITY OF FILLER ON CHANGE OF DENSITY OF SULFUR CONCRETE

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Abstract: Concrete is a material that has been used for centuries and is often modified using polymers. In the last fifty years, synthetic polymers have been used for the modification of concrete, but also for the production of concrete. In recent decades, sulfur concrete has been an interesting product that can be used mainly in low-rise construction due to its characteristics. In this work, we used the starting mixture for the preparation of sulfur concrete (sand, elemental sulfur with the addition of modified sulfur and fillers) heated to a temperature of 120 ºC to 170 ºC and homogenized. The results of previous research on the production of sulfur concrete showed that the density of the obtained product changes depending on the type as well as the amount of filler added to the basic mixture based on raw materials. Talc, microsilicon, plate alumina and fly ash were used as fillers. The amounts of fillers were 0%, 1%, 3%, 5%, 7% and 10%.

Keywords: Filler, Density, Sulfur concrete

1 INTRODUCTION

Sulfur concrete is a relatively new material. In its final form, it is similar to cement concrete, but its production, use and testing are significantly different (ACI, 1998). It is a thermoplastic material obtained by mixing modified elemental sulfur and mineral aggregate at temperatures above the melting temperature of sulfur (120-130 ºC). By cooling below those temperatures, sulfur concrete hardens very quickly, acquiring the expected physical and mechanical characteristics (Blight et. al, 1978). As with other concrete materials, the characteristics of sulfur concrete depend significantly on the type and shape of the aggregate, the sulfur modifier and the applied proportions of mineral aggregate and binder (Jordan et. al, 1978; ACI, 2004, Vroom, 1977).

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The aim of all previous research (Vlahović et. al, 2006; Boljanac et. al, 2006; Vidojković et. al, 2006) in the field of development of the production and application of sulfur concrete was to make a simple and clear formulation, with high-quality physical, mechanical, chemical, and ecological characteristics of the obtained product. This product would enable the wide application of sulfur concrete, and thus significant consumption of elementary sulfur, which is a secondary product of oil production. For the widest possible application of sulfur concrete, it is necessary to ensure appropriate resistance to various mechanical and chemical influences (ACI, 2004).

The combination of sulfur with a mineral aggregate of the appropriate granulometric composition fast and quality connects the elements of the aggregate, resulting in a very strong and chemically resistant material. Over time, recrystallization of sulfur and changes in crystal modification occurs in such material, and the result of such a process is the weakening of the original characteristics of sulfur concrete (Vroom, 1977). This phenomenon significantly shortens the life of sulfur concrete, which results with limits its application, so later research required finding a solution that will suppress or completely prevent the change of crystalline modification of sulfur with time. It was largely successful, so today extremely effective combinations of sulfur and appropriate additives are known, which ensure a significantly longer service life of sulfur concrete (20-30%), in which it retains its original physical-mechanical and chemical characteristics (Vroom, 1981; Sodeberg et. al, 2001). Such combinations are commonly called modified sulfur or sulfur cement.

Numerous studies were conducted with the aim of defining the optimal combination of mineral aggregates which, together with modified sulfur, will provide the necessary, high-quality results. Ash and other waste materials were used as a binder in many researches, because the practical application of such technological solutions reduces the cost of binder materials to a minimum and at least partially solves two environmental problems (William & Liao, 1981; Vidojković et. al, 2006).

The main advantage of sulfur concrete is the possibility of its use as a highly resistant construction material in industrial plants and in other locations where an acidic environment or an environment saturated with various salts prevails. Cement concrete in such locations corrodes and deteriorates in a very short period, which leads to the conclusion that its application is practically impossible. In these places of application, the service life of sulfur concrete far exceeds the service life of all other known construction materials (McBee et. al, 1986). Another specific characteristic and advantage compared to cement concrete is the short setting time and the achievement of a high level of compressive strength. Since it achieves its maximum mechanical characteristics in less than 24 hours, the period until pouring sulfur concrete is put into operation is much shorter than in the case of cement concrete (ASTM C, 1997; ASTM C 2003).

Sulfur concrete has numerous useful characteristics that can give it an advantage over cement concrete (Khademi & Kala, 2015). Tensile, compressive and bending forces, as well as the fatigue life of the material, are better than cement concrete. Sulfur concrete has exceptional resistance to the influence of many acids and salts, even when they are in very high concentrations. It hardens very quickly and achieves a minimum of 70-80% of the required characteristics already within 24 hours. It can be produced and installed throughout the year in all weather conditions, even at temperatures below 0 °C. Due to the hydrophobicity of sulfur, it has very low water permeability and can be used as a waterproofing material.

It has been shown (ACI, 1998) that certain types of fillers with grain size below 100 μm have a positive effect on the physical and mechanical characteristics of sulfur concrete. By filling the free space between individual grains of larger aggregate, they reduce the porosity of the concrete, increase the overall density of the concrete mass, and thus the resistance of the concrete to mechanical influences increases. The aim of this work was to investigate the influence of several types of fillers on the density of sulfur concrete.

2 EXPERIMENTAL PROCEDURE

In all experiments, river sand (grain size up to 2mm), elemental sulfur (obtained as a by-product in the oil refining process of the Pančevo oil refinery) was used as an aggregate during the preparation of sulfur concrete, with the addition of modified sulfur, while talc, microsilica, sheet alumina and fly ash of the Nikola Tesla Power Plant "A" in Obrenovac. The amount of filler was 1%, 3%, 5%, 7% or 10%, while the amount of sand was successively reduced and amounted to 69%, 67%, 65%, 63% and 60% in relation to the total amount of the mixture. The sulfur content in all mixtures was constant and amounted to 30%. Sulfur concrete without fillers was prepared as a reference sample.

Sand with the addition of filler is placed in open reactors in laboratory conditions and heated to a temperature of 120 to 140°C. Melted sulfur in amounts of 30% was added to this mixture with intensive and continuous mixing. At the achieved temperatures, the sulfur in such a molten state coated the sand particles and the filler was homogenized. After homogenization, the obtained product was poured into special molds with intense vibration of the substrate for better settlement of the obtained mixture. The concrete in the molds cooled spontaneously to room temperature, after which the density of the samples was measured.

3 RESULTS

The test results showed that the amount of filler added to the mixture has a significant effect on the density of the obtained product. The density of the reference sample, which was prepared from sand and sulfur in a ratio of 70:30 without the addition of filler, was

2.155g/cm^3. Figure 1 shows a diagram of the dependence of the change in the density of sulfur concrete as a function of the type and amount of filler.

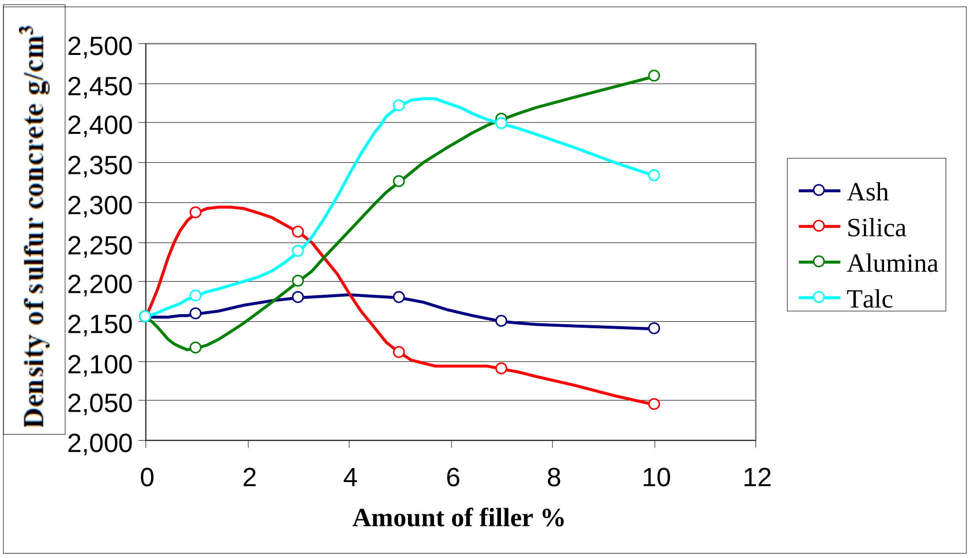

Figure 1 Changes in the density of sulfur concrete as a function of the type and amount of filler

Using ash as a filler, the density of product did not have significantly changes, with the fact that the density dependence curve on the amount of filler shows a slight maximum for the addition of 3% and 5% ash (2,180 g/cm^3). With the addition of 7% and 10% ash, the value concrete density decreased to slightly lower values than the initial sample (2,140 and 2,150 g/cm^3). During the homogenization of the initial mixture at temperatures above 130 ºC, it was observed that after the addition of molten sulfur, the sample was visually wet, and after a few minutes of mixing, it almost dried up, and the homogenization process itself was difficult. This phenomenon occurs due to the effect of wetting the ash particles with sulfur, whereby the sulfur coats the ash particles and binds to it with adhesive forces. This reduces the role of sulfur in the basic mixture for obtaining concrete, which at high temperatures has the function of enabling a homogeneous and dense binding of sand in a two-component system, thus achieving adequate conditions for obtaining concrete of higher strength. By visual analysis of the obtained sample of concrete with ash, with all individual compositions of ash, significant voids were observed, which can significantly affect the compactness and quality of sulfur concrete as a final product.

With the addition of plate alumina as a filler, it was shown that the density of the obtained concrete decreased to 2.116 g/cm^3 with the addition of 1% alumina, after which the density values increased sharply as a function of the increase in the added filler, and reached a value of 2.459 g/cm^3 for the sample with 10% filler, and these are practically the highest concrete density values obtained in these studies. This data points to the assumption that the addition of alumina enables uniform homogenization of the components that make up sulfur concrete, while the shape of the density dependence curve on the amount of filler shows that with further addition of filler, the maximum density of the sample would be reached (the curve tends to the asymptote), after which further addition fillers would not change the density value.

The results of the change in concrete density depending on the amount of added filler in the case of microsilica show slightly different results. The density compared to the reference sample without filler jumps sharply with the addition of 1% microsilica (2.286 g/cm^3), which achieves the maximum density of the final product with this type of filler. With the addition of 3% microsilica, the density of concrete is slightly lower (2.262 g/cm^3), but with the addition of 5% microsilica, the value of concrete density drops sharply to 2.111 g/cm^3. By further increasing the amount of this filler, the density of the concrete still tends to stagnate, so that with 10% microsilica, the value of the density of the obtained concrete finally drops to 2.045 g/cm^3. A photo of sulfur concrete samples with 5% filler is shown in Figure 2.

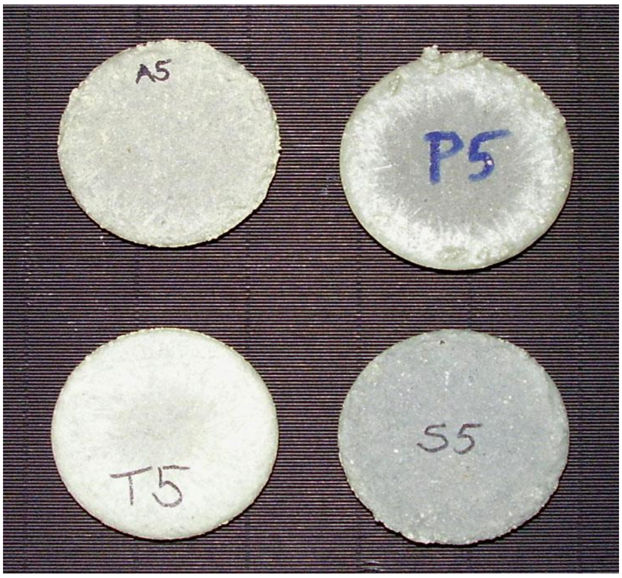

Figure 2 Photographs of samples of sulfur concrete with 5% filler (A5-alumina, S5-microsilica, P5-fly ash and T5-talc)

The increase in the amount of talc as a filler in the production of sulfur concrete shows an increase in the density of concrete with an increase in the amount of talc up to 5% (concrete density 2.421 g/cm^3), after which, with a further increase in the amount of talc, the density of concrete decreases to 2.333 g/cm^3 for 10% talc. When mixing the basic components, it was observed that increasing the amount of talc facilitates the homogenization of the sample and the pouring of the sample into the appropriate molds for cooling and the formation of sulfur concrete.

4 CONCLUSION

Examinations of changes in the density of sulfur concrete depending on the type and amount of filler showed that the density of concrete increases with the increase in the amount of added filler (except in the case of flat alumina, where with the addition of 1% alumina, the concrete density value decreased compared to the reference sample, so that with a further increase in the amount of filler, the concrete density increased). The highest concrete densities were achieved with 1% microsilica (2.286 g/cm^3), 5% talc (2.421 g/cm^3) and 10% plate alumina (2.459 g/cm^3), while with the addition of ash of 3% and 5% the value was achieved concrete density of 2,180 g/cm^3.

Since the density of concrete is an important factor affecting the physical characteristics of the product, these tests show that talc and microsilica as fillers showed better properties than plate alumina and fly ash.

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REFERENCES

ACI, Guide for mixing and placing sulfur concrete in construction, Report 548.2R-93 (American Concrete Institute), 1998.

BLIGHT L., et al. 1978 Preparation and properties of modified sulfur systems, New Uses of Sulfur – II, Advences in Chemistry Series 165, American Chemical Soc., 1978.

JORDAN I., et al. 1978 Improved ductility of sulfur concretes and its relation to strenght, Proceedings of the International Conference on Sulfur in Construction, Ottawa, 1978.

ACI MCP604 Manual of Concrete Practice Part 6, American Concrete Institute, 2004.

VROOM, A.H., 1977 Sulfur Cements, Process for Making Same and Sulfur Concretes Made Therefrom U.S. Patent No. 4,058,500, 1977.

VROOM, A.H.,1981 Sulfur Cements, Process for Making Same and Sulfur Concretes Made Therefrom U.S. Patent No. 4,293,463, 1981.

SODEBERG, A.F., TERNESS, P., THOMAS, D.L., 2001 Drop Forming Method and Sulphur Polymer Concrete Process U.S. Patent No. 6,228,905, 2001

WILLIAM J. HEAD, MIN-FU LIAO 1981 Fly Ash Sulfur Concrete, Transportation Engineering Journal, Vol. 107, No. 3, 1981.

VIDOJKOVIĆ V., et al 2006 Vezivanje letećeg pepela termoelektrana elementarnim sumporom dobijenim u procesu rafinacije nafte, Pat. prijava 2006/0513, 2006.

MCBEE, W.C., SULLIVAN, T.A., JONG, B.V., 1986 Corrosion-Resistant Sulfur Concretes» Corrosion and Chemical Resistant Masonary Materials Handbuk, Noyes Publications, Park Ridge, 1986.

ASTM C 1159 Standard Specification for Sulfur Polymer Cement and Sulfur Modifier for Use in Chemical-Resistant, Rigid Sulfur Concrete, 2003

ASTM C 1312 Standard Practice for Making and Conditioning Chemical-Resistant Sulfur Polymer Cement Concrete Test Specimens in the Laboratory, 1997.

VLAHOVIĆ, M., 2006 Application of hydro-isolating and anticorrosive coatings based on secondary sulfur, 4th Balkan Conference on Metallurgy, Zlatibor, Knjiga radova: 301-304, 2006.

BOLJANAC, T., et al 2006 Sulfur agglomeration of power-plant ashes and removing of sub-micro ash particles, 4th Balkan Conference on Metallurgy, Zlatibor, Knjiga radova: 305-309, 2006.

VIDOJKOVIĆ, V., et al. 2006 Ispitivanje mogućnosti vezivanja čestica letećeg pepela iz termoelektrana elementarnim sumporom, Hemijska industrija, 60 (5-6) 144-147 (2006.).

A.G.KHADEMI, H.I.KALA, 2015 Comparison of Sulfur Concrete, Cement Concrete and Cement-sulfur Concrete and their Properties and Application, Current World Environment Vol. 10(Special Issue 1), 201-207 (2015)