Composite systems using ash from burning production waste

S Y Efremova, N I Zubrev, M I Panfilova and T V Matveyeva

1Department of biotechnology and tehnosfernaja safety, Penza State Technological University, Penza, 1A/11 proyezd Baydukova/Gagarina street, Penza 440039 Russia
2Department of Technosphere Safety, Russian University of Transport, Russian Open Academy of Transport, 22/2 Chasovaya St., 125190, Moscow, Russia
3Department of Physics and Construction Aerodynamics, National Research Moscow State University of Civil Engineering, Moscow, Yaroslavskoe highway, 26

* Corresponding author: efremova_s15@mail.ru

Abstract. This article proposes a method of obtaining composite solutions using ash from industrial wastes as a structuring additive. Their introduction into the technology of composite solutions not only as modifiers of the structure and properties of composite binders, but also as fine additives, can significantly reduce the cement consumption and prevent waste placement, as well as, improve the performance properties of the latter and obtain new promising types of materials.

During this study, the chemical and mineral composition of the ash was determined and the hazard class was calculated. Structure formation in composite solutions was studied when cement was replaced with different amounts of ash. The possibility of replacing 10% of cement with ash without loss of the technological parameters of the system has been established.

1. Introduction

The environmental strategy is considering the involvement of wastes as sources of raw materials in the field of circular economic. One of the promising streams in this regard is the creation of new technologies for composite solutions used to strengthen the soil in the construction and repair of tunnels. Introducing effective structure modifiers and composite binders to the technology of composite solutions, and more concretely, fine additives can significantly reduce the cement consumption and prevent the disposal of waste on already crowded rubbish dumps and authorized landfills. Such wastes may include ashes from fuel combustion and wastes, which can improve performance properties and produce new promising types of materials.

At present, it has been proven that replacing of 25–30% of Portland cement with fly ash in concrete is effective. Such a replacement presents no significant differences of concrete strength if compared with the concrete without the ash addition [1–4]. This was confirmed during the construction of the dam of the Bratsk hydroelectric station and the Dnieper hydroelectric complex [5]. In Germany, about 4 million tons of fly ash are used annually in the production of building mortars, concrete products and other materials containing cement [6, 7]. However, their use is limited due to the different origins of the initial fuel [8–13] and the variable chemical composition of the ashes obtained from combustion invarious thermal installations.

There are other known examples of the use of cement slurries with partial replacement of cement with ash resulting from coal burning for the storage and annular space of collector tunnels, as well as ash from the burning of railway sleepers [14–17].
At the enterprises of railway transport, the Forsazh-2 installation is often used for the incineration of oily waste. After temporary storage, the resulting ash is placed in the landfill. This waste can be used combined with ashes of a different origin to obtain composite systems for the transport construction industry.

Composite solutions, as a rule, consist of cement, bentonite and liquid glass. However, the main component in the formulation of composite solutions is cement. The ashes from the combustion of fuel oil and oily waste can be used as an additive in composite solutions, allowing to reduce the consumption of cement, due to its partial replacement.

The purpose of this study is to experimentally confirm the possibility of using ash obtained from the incineration of oily waste as a structuring additive to composite solutions. This will solve environmental problems and help saving cement during the building process without the deterioration the strength characteristics of the material.

2. Material and method
Composite solutions, including bentonite, cement-ashes in different ratios and liquid glass, were studied in this work [5]. The purpose of this work was to study the effect of ash addition on the structure and properties of cement stone. The composition of the ash resulting from the combustion of oily waste includes, mass. %: silicon dioxide - 57.36; aluminum oxide - 23.59; magnesium oxide - 0.93; calcium oxide - 4.07; sodium oxide - 0.51; manganese oxide - 0.035; potassium oxide - 1.07; phosphorus pentoxide - 1.13; titanium dioxide - 1.28; iron oxide - 4.33; sulfur oxide - 2.92; chlorine - 0.08; total - 97,305. Heavy metals - 2.695%. The total amount is 100%. The concentration of heavy metals was, respectively, in ppm: As - 35; Ni — 96; Cu - 161; Sn - 15; Cr - 122; Co - 30; Mo - 11; V - 152; Ni — 96; Zn — 192; Rb - 23; Sr - 1697; Zr - 313; Ba - 2125; U - 5; Th - 30; F - 668; Y - 63; Nb - 30; Pb - 73; La - 122; Ce - 231; Nd - 101; Sc - 25; Ga - 35.

According to the chemical composition of the ash, the environment and health hazard classes have been calculated. It turned out that it belongs to the third class of human health hazard and fourth of the environment hazard class [18].

Based on the X-ray powder diffraction obtained by using the X-ray diffractometer X-Pert PRO MPD (PANalytical, Netherlands), the ash powder was found to contain: coesite, graphite agidride, sulfur plagioclase, jarosite and cristobalite.

During the study, soda-modified bentonite clay of the P2T2A brand, cement of the brand M500 and liquid glass (density - 1.46 g / cm³, silicate module - 2.7-3.4%) were used.

Bentonite clay was added to the composite solution to increase its plasticity and viscosity and to retain its resistance to delamination. It consists of oxides of silicon, aluminum and calcium, which are the basis for hydraulic binders and have chemical affinity with cement.

The composition of bentonite is established by the method of semi-quantitative X-ray phase analysis (wt.%): 75-80 montmorillonite, 15-17 quartz, 1-2 kaolinite and muscovite type hydromica 1-2. The sorption capacity of bentonite is 113.3 mg · eq / 100g.

3. Results and discussion
The choice of formulation of the composite solutions in relation to engineering and geological conditions is based on the assessment of their rheological and technological properties. Among the most important technological properties of injection solutions is the time of sedimentation or setting, since the solution in a more or less homogeneous state must be delivered (injected) at the right time interval. Equally important is the ultimate strength and durability of the hardened mortar. Therefore, when developing the technology of production of composite solutions containing ashes, two time intervals are to be considered. The first one is the necessary time of curing the solutions, that is, before its transition to a solid state. The second time interval corresponds to the study of the increase in strength during long-term storage.

The effect of the addition of ash on the change in the rheological properties of cement was determined using bentonite solutions during the curing process at a water / cement ratio of 2: 1 in the presence of
5% liquid glass. At the same time, cement was replaced with ash at an amount which varied from 5 to 20%. In this regard, ash was injected into the previously soaked 5% suspension of bentonite, after which the calculated amount of cement and liquid glass were introduced while stirring (Table 1).

**Table 1. Changes in plastic strength of the composite solution containing different ash content at different storage durations**

| Structure formation time, $\tau$, hours | The ash content in the mixture, % | Strength of the alumina-cement mixture $P_m$, $10^{-3}$ MPa |
|----------------------------------------|-----------------------------------|------------------------------------------------------------|
|                                         | 0                                 | 5              | 10             | 15             | 20             |
| 1                                      | 1,887                             | 1,351          | 1,211          | 0,801          | 0,543          |
| 2                                      | 3,654                             | 2,716          | 2,214          | 1,723          | 1,253          |
| 3                                      | 6,757                             | 6,245          | 5,284          | 5,011          | 4,352          |

Figure 1 shows that an increase in the ash concentration in the composite solution induces an initial strength of the composite solution that decreases with time.

A graphical method was used to determine the exact time of reaching loss of fluidity of the solution. For these purposes, in fig. 1, a straight line was drawn parallel to the abscissa axis, corresponding to the strength of an alumina-cement solution of $2.5 \times 10^{-3}$ MPa. Perpendiculars dropped from the intersection of the line with curves 1 - 5 indicate the curing time of the solution. The obtained data are presented in Figure 2 showing that with the increase of the cement replacement with ash, the curing time of the solution increases.
The strength of the hardened composite solutions was determined within 28 days on an IP-100 hydraulic press - at 7, 14 and 28 days. A non-linear change in the strength of composite systems with an increase in the ash content in the mixture was established. During storage, after 7, 14 and 28 days, different pattern of changes in the strength properties of composite mixtures prepared with different replacements of cement with ash can be observed (Figure 3).

![Figure 3. Structural formation of a composite solution with the introduction of ash, %: 1 – 0; 2 - 5; 3 - 10; 4 - 15, 5-20.](image)

Fig. 4 shows that increasing the ash content in the mixture induces a decrease in strength. Moreover, after 7 and 14 days, the strength decreases slightly with increasing ash content in the system. This fact can be explained by the low hydration rate of ash and cement. 28 days after the preparation, the pattern formation nature of the composite solutions changes. After 28 days, the strength of the solution with a 10% ash content in the cement is comparable with the control sample. The change in the structure formation of composite solutions with different ash additives can be explained by the ability of sulfur of ash to disproportionate, which occurs in concentrated solutions of alkalis with the formation of soluble sulfides and sulfites. In addition, the formation of homochains in concentrated solutions of basic sulphide is possible: \( \text{Na}_2\text{S} + (n-1) \text{S} = \text{Na}_2\text{Sn} \), in the presence of which the structure formation of the system apparently accelerates [19].

![Figure 4. Change in the strength of the composite solution at different ash concentrations in cement after 28 days of storage.](image)

It has been established that when bentonite and cement are mixed with water, an alkaline medium of \( \text{pH} = 12 \) is formed in the mixture. It turned out that during leaching, a change in the chemical composition of the ash occurs, with the sulfur content decreasing to its greatest extent [20, 21]. Thus, sulfur that has passed into the mixing water falls in the form of nanoparticles, which eventually increase in size to highly dispersed colloidal sizes and fill the cavities of crystallizing cement stone, forming a monolith.
The sample with a 10% replacement of cement with ashes achieved the strength of the control sample for 28 days shows that even such a composition can be recommended for practical application of these composite solutions in the construction and operation of transport infrastructure facilities.

The comparison of the strength analysis results obtained using the sample containing 10% ash and the control sample at day 28 shows that such this composite material composition can be recommended for practical applications in the construction of transport infrastructure facilities.

4. Conclusions.
The work investigated the possibility of neutralization and reuse of ash from the incineration of oily waste for the partial replacement of cement in injection solutions used in the construction of transport facilities.

It is established that with an increase in the concentration of ash in the composite solution, the increase in the strength of the solution decreases with time. It has been established that it is possible to replace 10% of cement with ash has since there is no decrease in the strength characteristics of concrete at after 28 days of storage which was comparable with the control sample. This makes it possible to save cement. It has been proven that using secondary raw materials such as ash to reduce the consumption of expensive materials, and improve the environment is possible.

According to the obtained results, it can be concluded that the use of such composite solutions is promising.

References
[1] Dvorkin L I and Dvorkin O L 2007 Stroitel'nye materialy iz othodov promyshlennosti: Uch.-sprav. Posobie (Rostov-na-Donu: Feniks)
[2] Ignatova O A, Berdov G I and Fomenko V V 2011 Osobennosti processov tverdeniya zolo – cementnyh vyazhushchih Sovremennye naukoemkie tehnologii 1 pp 80-2.
[3] Rubcov I V, Mitrokov V I and Rubcov O I 2007 Zakreplenie gruntov zemlyanogo polotna avtomobil'nych i zheleznych dorog (Moscow: ASV)
[4] Fursov L F and Yakovleva I I 1981 Ispol'zovanie zoly TEHS dlya in'ekcionnyh rabot Izv. VNIIG im. B.E. Venedeeva 150 pp 77-80.
[5] Nekrasov A S and Sinyuk Yu V 2007 Perspektivy razvitiya toplivno-energeticheskogo kompleksa Rossii na period do 2030 goda Problemy prognozirovaniya 4 pp 21-53.
[6] Vatin N I, Petrosov D V, Kalachev A I and Lahtinen P 2011 Use of ashes and ash-and-slad wastes in construction Magazine of Civil Engineering 4
[7] Putlin E I and Cvetkov V S 2003 Obzhornaya informaciya otechestvennogo i zarubezhnogo opyta primeneneniya othodov ot szhiganiya tverdogo topliva na TEHS (Moscow: Soyuzdonii).
[8] Kokubu I and Yamasada D 1976 Cementy s dobavkoj zoly unosa Shestoj mezhdunarodnyj kongress po himii cementa (Moskva. 1974) 3 pp 83-93
[9] CBNTI Minavtodor RSFSR 1977 Opyt ispol'zovaniya aktivnyh i neaktivnyh zol unosa TEHS Francii v dorozhnom stroitel'vte (po materialam zarubezhnogo opyta) EHkspress-informaciya Povyshenie efektivnosti proizvodstva i kachestva dorozhnyh rabot 18
[10] Elks A D and Redman G T R 1965 Site control and the construction of embankments using pulverson fuel ash from Lagoons The Surveyor and Municipal Engineer
[11] Shuster Dzh S and Hansen R L 1972 Zola unosa, kak stroiteľnyj material dlya nasypnych sooruzhenij. American Society of Civil Engineers Journal of Power Division
[12] Haga N, Okawa V, Kawamoto T, Konno M and Mizoguchi J 1981 Utilisation of blast furnace and steel slags in road construction NipponSteelTechn.Rept. 17.
[13] Sobaida N A and Solodkova A B 2015 Recycling Spent Activated Sludge Int. J. of Environmental Problems 1 (1) pp 64-74.
[14] Lyapidevskij B V, Nikitin A V, Rodina G P and Badamshin S O 2008 In'ekcionnye sostavy dlya zablochnogo i zarubnogo prostranstv kollektornyh tomeevl Nauka – moskovskomu stroitel'stvu. Sbornik teknicheskij informacii 2 pp 19-21.
[15] Zubrev N I and Ustinova M V 2013 Recikling zoly ot szhiganiya otrabotannyh derevyannyah shpal HKHI vek: itogi proshlogo i problemy nastoyashcheho plyus: Periodicheskoe nauchnoe izdanie 1 09(13) pp 140-4.
[16] Ustinova M V 2012 Razrabotka tehnologii kompozitnyh cementno-bentonitovyh sistem s dobavkoj zoly ot szhiganiya shpal i primenenie ih pri stroitel'стве i ekshploatacii ob'ektov infrastruktury zheleznodorozhnogo transporta. Dissertaciya na soiskanie uchenoj stepeni kandidata tekhnicheskih nauk. (Moskva)

[17] Sanitarnye pravila po opredeleniyu klassa opasnosti toksichnyh othodov proizvodstva i potrebleniya SP 2.1.7.1386-03 (zaregistrirovany v Minyuste 19 iyunya 2003 goda № 4755)

[18] Massalimov I A, Husainov A N, Abdakipova L F and Mustafin A G 2009 Vydelenie nano chastic sery iz rastvorov polisul'fidov kal'ciya i natriya Zhurnal prikladnoj himii 82 12 pp 1946-51.

[19] Zubrev N I, Matveeva T V, Ustinova M V et al Patent №2645691 «Sposob poluchenija tamponazhnogo rastvora»

[20] Matveeva T V, Zubrev N I and Ustinova M V 2015 Ispol'zovanie zoly ot szhiganiya mazuta v kompozitnyh rastvorah dlya stroitel'naja Mezhdunarodnij nauchno-issledovatel'skij zhurnal 9 (40) pp 61-3