International Journal of Engineering & Technology, *7 (3.2) (2018) 1-5*

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Experimental Study on Light Concrete Properties Using Bottom Ash of Thermal Power Stations

Oksana Demchenko[1]*, Volodymyr Shulgin[2], Ruslan Petrash[3]

[1]Poltava National Technical Yuri Kondratyuk University, Ukraine
[2]Poltava National Technical Yuri Kondratyuk University, Ukraine
[3]Poltava National Technical Yuri Kondratyuk University, Ukraine
**Corresponding Author E-Mail: Homenko_81@Ukr.Net*

Abstract

This paper presents the most optimal compositions of light concrete utilizing bottom ash for manufacturing the energy efficient wall products. Bottom ash usage as a filler instead of quartz sand acts as utilization of wastes which has a positive impact on ecology. It's been experimentally investigated the influence of the amount of cement and water on strength, density, water consumption, and thermal conductivity of light concrete manufactured using the bottom ash from thermal electrical stations as a filler. Using the STATISTICA 12 software there were obtained the precise values of coefficients that allow achieving the maximum strength. It's been manufactured the energy efficient wall blocks based on bottom ash with the concrete compression strength class of
LC 20/22. The conclusions quantify the results of these studies.

Keywords: *concrete, bottom ash, compressive strength. water consumption*

1. Introduction

The use of bottom ash in the production of structural and structural heat-insulating lightweight concretes can significantly improve the efficiency of light concrete and reduce its cost by reducing the cost of fillers and the amount of cement needed. In addition, the replacement of such expensive and scarce artificial porous fillers as keramzite gravel, agloporit, keramzite sand can reduce fuel and energy and material costs associated with the production of lightweight concrete. For example, ashes and ash-slag mixtures of TPPs can be used as a substitute for fine aggregates in light concrete in both natural form and in combination with artificial small porous filler, for example, keramzite sand. [3].

2. Overview of the Latest Research Sources and Publications

Wide opportunities are available when using ash-slag as a porous filler in lightweight concrete, as well as as a component that replaces quartz sand in heat-insulating concrete constructions. Using ash from TPS as a fine filler it is possible to get light concrete of LC 8/9 ... LC 20/22 classes while saving up to 10 ... 25% of cement [1].

The use of ash slag as a light porous filler instead of quartz sand allows not only to lower the average density of concrete, but also to reduce its thermal conductivity, which ensures an increase in the insulation properties of products and fuel economy during the buildings exploitation [2].

The introduction of ash in light concrete mixtures increases their static viscosity, but does not affect the conditions of thixotropic dilution during the vibration. Ash mixtures are easy to lay, fill in the form well and compacted under the vibration action. Molded products made of light concrete containing ash, have high structural strength, which allows quick applying and smoothing the top of the texture layer during the formation of enclosing structures. They also facilitate the conditions for the partial or immediate removal of the products formwork [3-7].

3. Main body

At the Ukrainian thermal power plants there are 15-16 million tons of generated ash-slag wastes, and the total amount of ash-slag in the waste is not less than 220 million tons. The share of ash processing in Ukraine is 10-14%, while in the USA this indicator reached 20%, in Great Britain - 60%, France - 72%, Finland - 84% [6]. Analysis of the experience of using ash shows that when it is introduced into the concrete mixture of ash it performs several functions. The amount of ash can be increased not only due to the use of different types of activation but also due to its polyfunctionality. At the same time, when using an excessive amount of ash in ash containing materials, there may be some increase in porosity and a decrease in the velocity curing, which compromises performance, including frost and corrosion resistance. To prevent these phenomena in the concrete mixture, complex supplements of polyfunctional action are introduced which determine not only the kinetics of curing but also the formation of the corresponding pore structure of the material, which has a significant effect on the properties and durability of the obtained artificial stone [4]. On the other hand, the problem of the increased use of ash in the composition of concrete is not so simple, since due to the lack of information on the long-term use of ash, along with the latest organic additives, there is always a threat to the negative impact of the latter on the processes of the artificial stone solidification, especially in the complex conditions of concrete use [8-12]. In addition, the great advantage of using ashes for the light concrete is low cost and huge reserves in Ukraine. Fillers from waste thermal power plants are universal because they can be used both without additional processing and with subsequent activation. The use of fillers from waste thermal power stations in the wall blocks serves as a waste disposal, which will have a positive effect on the environment. [7].

3.1. Aims and Objectives

The main objective of the research is the selection of the most optimal composition of light concrete with the use of ashes for the production of energy-efficient wall products and determination of the influence of water and cement on the strength, water absorption, density, thermal conductivity of concrete. Production of energy-efficient wall blocks based on ash-slag is also of the essence.

3.2. Results

The research was planned based on the two-factor matrix. The estimation of the weight of the linear regression was carried out on the basis of Fisher's criterion, where the variable factors were the flow of cement and water.

For this study, a mixture of the following materials was selected: cement CEM I 50.1 N, marked with high early strength, a high content in C3S clinker and low C3A content [8].

The ash-slag (bottom ash) from Starobeshivska TPS; true density 2,35 g/cm^3; final density 1,85 g/cm^3; coarseness module 2,58. As an additive, polycarboxylate superplasticizer GLENIUM 51 is used.

The calculation of concrete composition using ash-slag as a filler in the mixture is carried out in the following order. For the required strength of concrete Rb and activity (mark) of cement used Rc cement-water ratio C/W is determined by formula 1:

$$R = A_1A_2A_3A_4(0.63-0.4\frac{R_c}{1000})\frac{C}{W}R_c \qquad (1)$$

that goes down to:

$$\frac{C}{W} = \frac{R_{con}}{R_C}\times\frac{1}{A_1A_2A_3A_4(0,63-0,4\frac{R_c}{1000})}, \qquad (2)$$

where A_1 – a coefficient that takes into account the grain composition of the ash-slag mixture;

A_2 – a coefficient which takes into account the content of ash-slag mixtures of unburnt coal residues;

A_3 – a coefficient that takes into account the method of preparation of a concrete mixture;

A_4 – a coefficient that takes into account the conditions of curing and the age of concrete.

The amount of water (W) required for the preparation of the concrete mixture is determined depending on the desired ease of laying and the bulk density of the ash-slag mixture of optimal grain composition.

The consumption of cement in kg per 1 m3 of concrete is calculated by formula 3:

$$C = C/W\times W \qquad (3)$$

The consumption of ash-slag mixture in kg per 1 m^3 of concrete is calculated by formula 4:

$$\frac{C}{\rho_C} = \frac{ASH}{\rho_{ash}}\times W + AV = 1000 \qquad (4)$$

that transforms into formula 5:

$$AS = (1000-VA-W-\frac{C}{\rho_C}), \qquad (5)$$

where ρ_c – the density of cement used, kg/l;

ρ_{ash} – the density of the ash-slag mixture, kg/l.

AV – the volume of air drawn into the concrete mixture.

After calculating the composition of concrete, according to the mathematical planning matrix of the two-factor experiment, the cubic samples with 10 × 10 × 10 cm sizes that were to be tested for compressive strength were manufactured. As well as plates with 15 × 15 × 2 cm sizes, which were to be tested for thermal conductivity and blocks of 20 × 30 × 40 cm (with two voids of 10 × 10 × 20 cm in size).

Table 1. Working compositions of mixtures for 1 m^3 volume

№	Cement, kg	Water, l	Ash-slag, kg	Plasticizer, l
1	388,84	370	1115,24	5,83
2	388,84	310	1256.24	5,83
3	308,84	370	1175,88	4,63
4	308,84	310	1316,88	4,63
5	388,84	340	1185,74	5,83
6	308,84	340	1246,38	4,63
7	348,84	370	1145,56	5,23
8	348,84	310	1286,56	5,23
9	348,84	340	1216,06	5,23
10	348,84	340	1216,06	5,23
11	348,84	340	1216,06	5,23

The cubic shaped specimens were formed out of the fresh-manufactured mixture, its size was 100×100×100 mm. Then the samples were compacted on a laboratory vibroplate. For this process, a specially designed attachment for forms was used, that provided an additional compression of 40 g/cm^2 for all cases. Compaction time varied according to the experiment plan. The compaction quality of each samples series was controlled by determining the compaction coefficient.

In each set of samples, such parameters as the average density, compression strength limit at the age of 7, 14 and 28 days, water consumption, and thermal conductivity were determined.

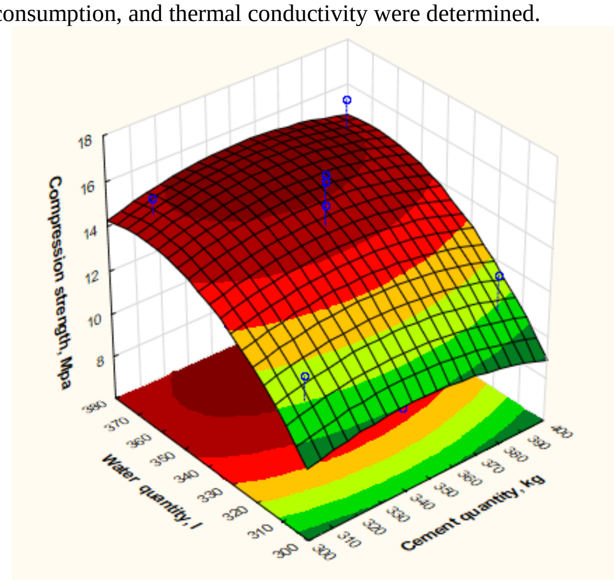

Fig. 1: Approximation surface of the samples strength depending on the variable factors of the experiment at the age of 7 days.

To process the results STATISTICA 12 software was used.

Figure 1 shows the approximating surface of the specimen strength changes at the age of 7 days depending on the variables of the experimental factors. It shows that the samples scored the greatest strength at the maximum water consumption, and the impact of cement consumption is not significant. The maximum strength of the sample is 16.40 MPa, and the minimum is 10.93 MPa.

The visual analysis of surfaces gives only approximate values of optimal component ratios. However, STATISTICA software allows determining the values of the factors at which the researched parameters reach the maximum rate (Table 2.), which is reflected by the isolines of the response function surface (Fig. 2).

Visual analysis of the surfaces reveals only approximate values of optimal relations of components. However, STATISTICA software allows the factors determination at which the investigated value reaches its maximum magnitude (Table 2).

Table 2. Critical values of variables

Factor	Observed minimum	Critical values	Observed maximum
Cement quantity, kg	308,84	352,53	388,84
Water quantity, l	310,00	367,44	370,00

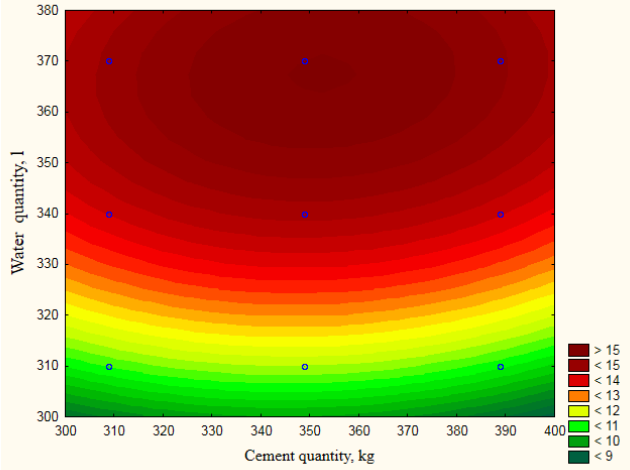

Fig. 2. Isolines of the response function surface of the samples' strength from the amount of water and cement used at the age of 7 days

Figure 3 shows the approximating surface of the specimen strength changes at the age of 14 days depending on the variables of the experiment.

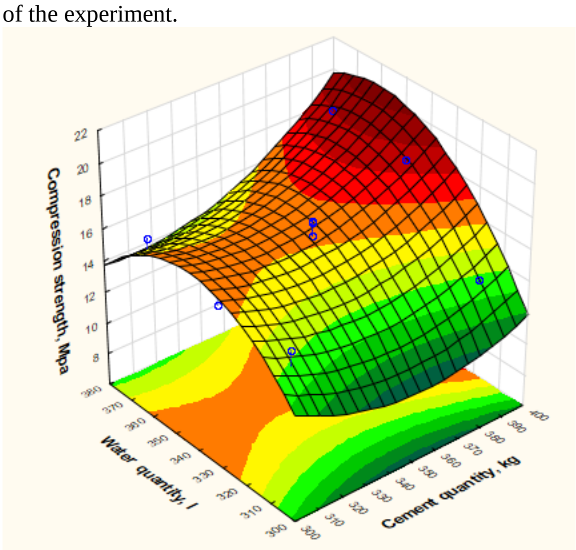

Fig. 3 Approximation surface of the samples strength depending on the variable factors of the experiment at the age of 14 days.

It shows that the samples have gained the greatest strength with maximum cement consumption and average and maximum water consumption. The maximum strength of the sample is 18.87 MPa, and the minimum is 11.28 MPa.

The isolines analysis of the response function surface of the samples' strength (fig. 4.) is presented in table 3.

Table 3. Critical values of variables

Factor	Observed minimum	Critical values	Observed maximum
Cement quantity, kg	308,84	328,75	388,84
Water quantity, l	310,00	348,03	370,00

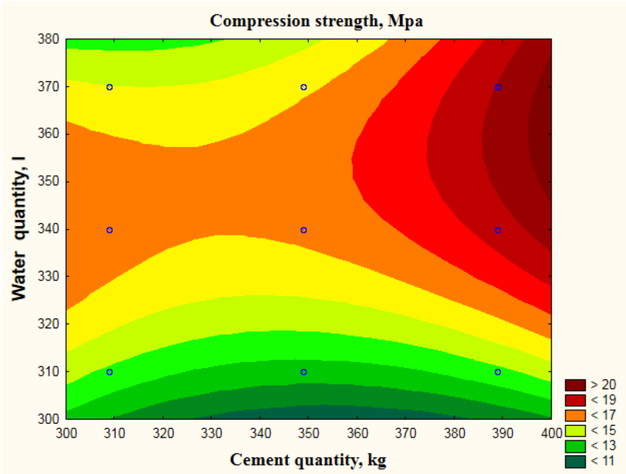

Fig. 4. The response function surface isolines of the samples' strength from the amount of used water and cement at the age of 14 days

Figure 5 shows an approximating surface change of specimen strength at the age of 28 days depending on the variables of the experiment. It shows that the specimens have gained the greatest strength at the maximum cost of cement and average water consumption. The maximum strength of the sample is 26.53 MPa, and the minimum is 15.67 MPa.

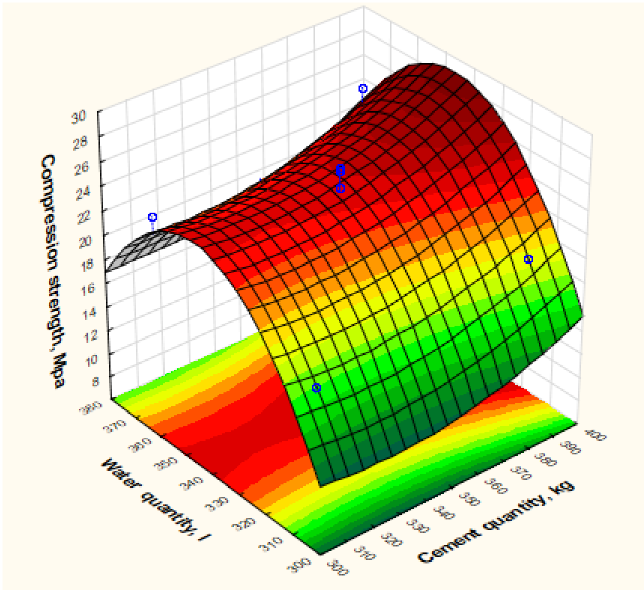

Fig. 5. Approximation surface of the samples strength depending on the variable factors of the experiment at the age of 28 days.

The isolines analysis of the response function surface of the samples' strength (fig. 6.) at the age of 28 days is presented in table 4.

Table 4. Critical values of variables

Factor	Observed minimum	Critical values	Observed maximum
Cement quantity, kg	308,84	319,26	388,84
Water quantity, l	310,00	345,57	370,00

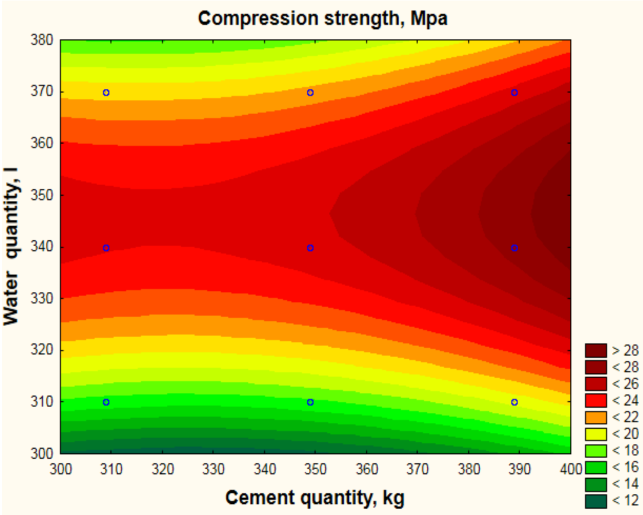

Fig. 6. The response function's surface isolines of the samples' strength from the amount of used water and cement at the age of 28 days

Figure 7 shows the approximating surface of the density changes of samples, depending on the variables of the experimental factors. With average water consumption and maximum cement consumption, the density of samples is the highest. The maximum sample density is 1540 kg/m^3, and the minimum is 1396 kg/m^3.

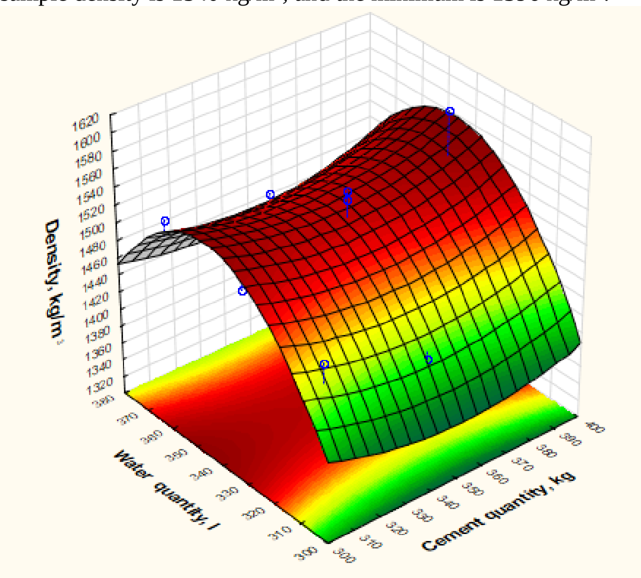

Fig. 7. Approximation surface of the samples density depending on the variable factors of the experiment.

The value of the optimal ratios of components in the study of their effect on the average density (Fig. 8) is given in Table 5.

Table 5. Critical values of variables

Factor	Observed minimum	Critical values	Observed maximum
Cement quantity, kg	308,84	343,82	388,84
Water quantity, l	310,00	346,14	370,00

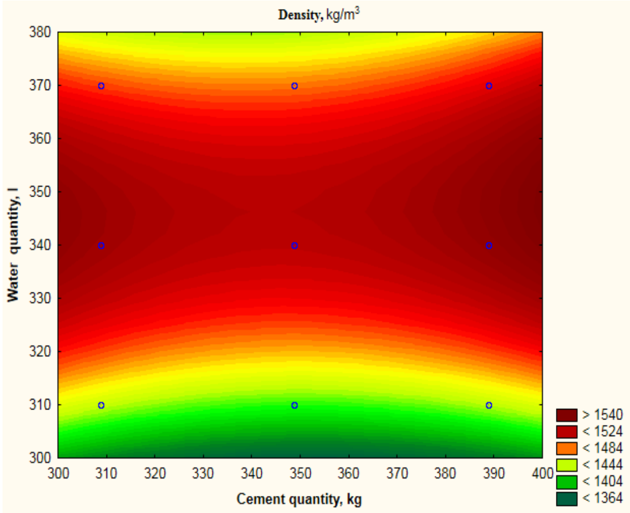

Fig. 8. The response function surface isolines of the samples' density from the amount of used water and cement at the age of 28 days

Figure 9 shows the approximating surface of the change in water consumption depending on the variables of the experimental factors. In samples researching of for water absorption, the cubes soaked for 4 days, after which they were dried and weighed. The dependence is obvious - the smaller the amount of water, the greater water consumption is. The maximum value of water consumption is 14.7% and the minimum value is 10%.

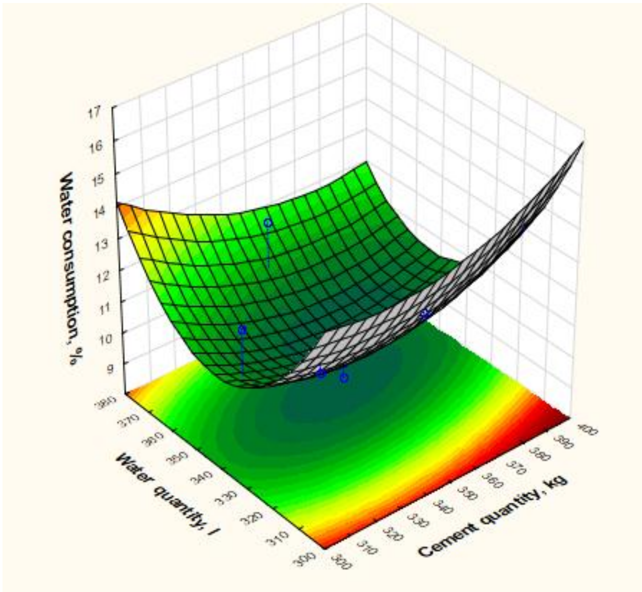

Fig 9: The approximate surface of the samples water consumption variation depending on the variables of the experimental factors.

The isolines analysis of the response functions surface of the samples' water consumption (fig 10.) is presented in Table 6.

Table 6. Critical values of variables

Factor	Observed minimum	Critical values	Observed maximum
Cement quantity, kg	308,84	357,26	388,840
Water quantity, l	310,00	348,39	370,0000

For the determination of thermal conductivity coefficient there were made specific plates (150x150x25 mm) that were tested by the TCM-1 device (thermal conductivity measurer). Actual obtained values were shown by the coefficient of thermal conductivity – 0,3 Vt/(m·K).

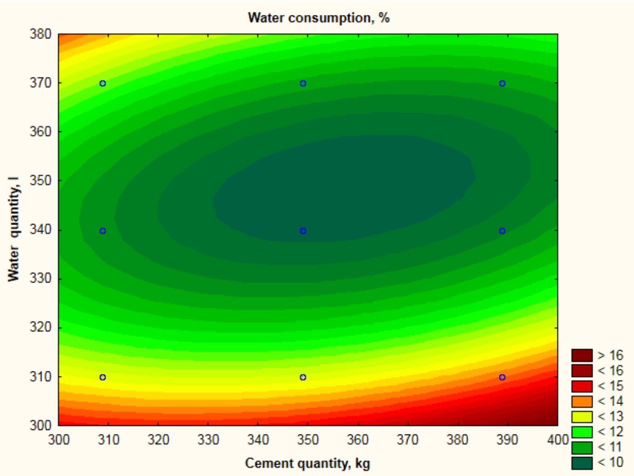

Fig. 10. The isolines of the response function's surface of water consumption against used amount of water and cement.

The wall units were made with the sizes of 20×30×40 cm (with 2 voids of 10×10×20 cm size).

Taking into account its density of 1200 kg/m^3 and the aforementioned strength and thermal conductivity it's possible to conclude that wall unit is a construction heat insulating product.

Fig. 11: A wall unit with the ash slag used as a filler.

The advantage of the ash-slag unit is that it does not need to be baked in contrast to ceramic blocks. And unlike blocks on porous fillers, it does not require a coarse-grained filler.

The advantage of the ash-slag unit over blocks of nitrogen-based concrete lies in the high technological efficiency of the above mentioned production.

The use of fillers from waste TPP in wall blocks serves as a waste disposal, which, in case of large-scale utilization, will reduce the number of contaminated waste areas.

The wall blocks with a bottom ash are characterized by a greater cohesion and a smaller segregation. Concrete at the same time has a greater strength, density, and smaller heat conductivity.

4. Conclusion

The bottom ash block is a polyfunctional product, therefore, it is not only energy-efficient but also a constructive product (it can be used in the construction of multi-story buildings). Block production is neither energy-intensive process nor does it require special equipment.

The influence of cement and water consumption in concrete with bottom ash slag on its strength has been investigated. After testing the samples, it was established (according to the mathematical planning) that they scored the greatest strength at the maximum level of cement and average water consumption. The maximum strength of the samples was 26.53 MPa. Concrete compression strength class LC 20/22 was obtained.

It has been determined the water consumption of cube-shaped specimens of ash slag concrete that was 11.37%. The thermal conductivity of ash slag concrete was 0.3 Vt/(m·K).

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