

# Development and Substantiation of Parameters of Environmentally Friendly Technology for Filling the Vertical Mine Workings with Autoclaved Slag-Concrete

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**Abstract.** The environmentally friendly technology for filling the vertical mine workings with autoclaved slag-concrete, prefabricated on the surface of the mine is presented in the article; the optimal parameters of filling technology are proposed. The developed technology for filling the abandoned vertical mine workings allows ensuring the environmental safety of the territories adjacent to the abandoned mine, utilizing slag dumps and providing the possibility of shaft recovery, if necessary, with minimal labor and material costs.

## 1 Introduction

According to the requirement of normative documents of the Russian Federation, vertical shafts and pits with unsatisfactory support, put down in unstable rocks, must be completely filled with waterproof non-shrink material up to the level of the earth's surface. The main requirements for the waterproof non-shrink filling mass: the filtration coefficient of the mass is less than 0.001 m/day; absence of the filling mass compression in the most loaded lower part of the opening.

The methods for filling the vertical mine workings with hardening mixtures in layers are developed in the Russian Federation. The expensive cement concretes or hardening mortar mixtures based on floured burnt rocks containing a large amount of cement-lime binder and special additives are used to create the filling waterproof and non-shrink mass in these methods. The proposed methods have not found practical application, due to the high cost of filling operations and the exhaustion of burned rock stocks in coal mines. In addition the filling of mine workings by hardening concrete mixtures completely eliminates the mine and excludes the possibility of its recovery and use in certain period of time after the termination of its operation.

## 2 Materials and methods

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The autoclave slag concrete, produced on the basis of ash and slag waste from fuel and energy enterprises [1-9], will be an effective filling material for the abandonment of vertical mine workings.

It is known that the autoclave curing of slag-lime mixture mix depending on the parameters of the mixture and its autoclave treatment allows producing the low water permeability and compression autoclave slag-concrete. Therefore, by autoclaving the slag-lime mixture it is possible to produce the water-proof and non-shrink autoclave slag-concrete to fill the abandoned vertical mine workings based at cheaper mortar mixes containing less binding and special additives,. The use of ash and slag wastes to fill the vertical mine workings will allow to utilize of these wastes, which will be beneficial for the environmental state of the territories.

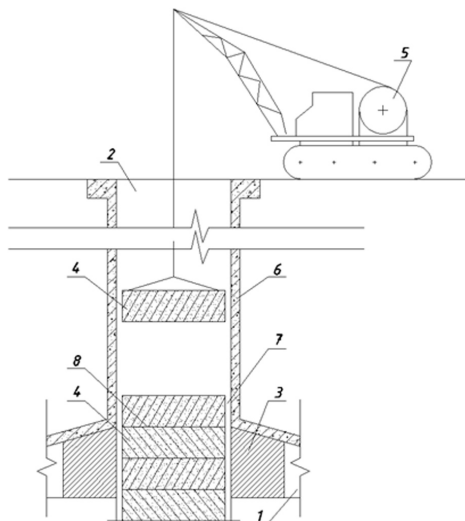
The experimental laboratory tests of compression and filtration properties of autoclave slag concrete, carried put in KuzSTU, showed that it is possible to use the autoclaved floured slag-lime mixtures for filling the vertical mine workings, but the production of waterproof and non-shrink filling mass is possible only with certain weight ratios of the components of the mixture, its chemical composition and autoclave curing modes [10, 11,12].

Table 1 shows the compositions of slag-lime mixtures and the parameters of their autoclave curing for producing the waterproof and non-shrink slag-concrete, laid down by the present research.

**Table 1.** Parameters slag-lime mixes and their autoclave curing, at which samples didn't contract and proved to be waterproof.

Coefficient of mixture basicity $K_{осн}$	Slag and lime fractions	Water-binding ratio BBO	Pre-autoclave exposure duration, hour	Duration of pressure rise, hour.	Duration of autoclave curing under pressure 0,9 MPa, hour	Duration of pressure descent, hour
0,3	0,08	0,5	4	0,75	6	5
0,5	0,08	0,5	4	0,75	6	5
0,7	0,08	0,5	4	0,75	6	5
0,7	0,16	0,5	4	0,75	6	5

The method for filling the mine opening with cylindrical autoclave slag-concrete blocks, previously manufactured on the surface of the mine (RF patent No. 2449129, 2012) is developed in T.F. Gorbachev Kuzbass State Technical University (KuzGTU). Filling the vertical mine workings according to the developed method is carried out as follows (see Figure 1).



**Fig. 1.** Scheme of filling the vertical mine workings by the large-size cylindrical autoclave slag blocks.

The level openings 1 are filled in the areas of their junction with the vertical opening 2 by building the wall 3.

The cylindrical autoclave slag-concrete blocks 4 are manufactured using an autoclave mold on the surface and stored near the collar. The diameter of the cylindrical autoclave slag-concrete block 4 is taken less than the internal diameter of the concrete support of the shaft, taking into account the unevenness of its walls, from the condition that the cylindrical block does not jam when it is lowered into the shaft.

The shaft filling with cylindrical block is performed by pockets. The projected number of slag-concrete blocks is lowered down into the shaft within the limits of the pocket, and then the grouting container is lowered down into the shaft, from which the calculated amount of the grout is poured into the space 7 between the concrete support of the shaft 6 and the cylindrical autoclave slag-concrete blocks 4 and plugged. In this case, the solution also plugs the horizontal slits between the stacked cylindrical blocks 4. They pass to the laying by cylindrical cinder blocks of the overlying ridge. The blocks and a grouting container are lowered into the shaft using either jib (self-propelled or tower) or gantry cranes 5.

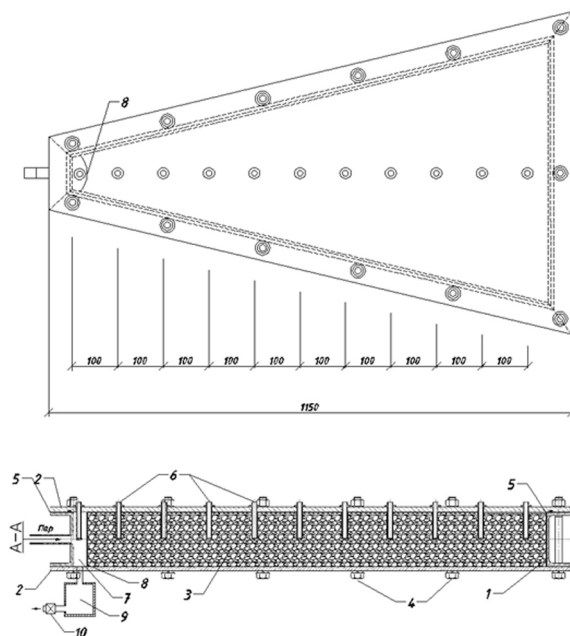
The method for the production of cylindrical large-sized autoclave slag-concrete blocks according to which the slag-concrete blocks are manufactured in a cylindrical autoclave form using steam wells (RF patent No. 2562307, 2015) is developed in KuzGTU. The autoclave curing of the concrete mixture in the autoclave form is carried out both through the open surface of the concrete mixture in the form and through the steam wells, which are located in a concrete mixture at a given distance from each other.

The distance between the steam wells in the mold is taken depending on the magnitude of the autoclave curing propagation radius from the steam well to the slag-lime mixture.

### 3 Experimental research methods

The experimental laboratory radial autoclave was developed to perform studies on establishing the relationship between the propagation radius of the autoclave curing of the slag-lime autoclave mixture from the steam well, the parameters of the slag-lime autoclave mixture and its autoclave curing.

Fig. 2 shows the design of the experimental laboratory radial autoclave.



**Fig. 2.** Experimental laboratory radial autoclave.

The experimental laboratory radial autoclave is a prefabricated metal structure made in the form of a sector with an angle at the apex of  $30^\circ$  (see Figure 2) consisting of a frame 1, two 8 mm thick sheet metal covers 2. In the whole, the frame 1 and its two covers 2 form a radial autoclave chamber, which is filled with the slag-lime autoclave mixture 3. The lower cover is fixed and connected to the frame by the welded joint along the inner contour. The top cover is removable for the direct filling of the radial autoclave chamber with filling material. To ensure the integrity of the autoclave chamber in working condition, the top cover is connected to the frame by bolted connections 4. The paronit cushion is laid on the high-temperature sealant 5 between the frame and the cover. There are eleven wells 6 for placing thermometers in the top lid. The distance between the thermometers is 100 mm. The alcohol thermometers were filled with the glycerin before the installation.

The 76 mm diameter steam well 7 is made in the form of a sector with an angle at the apex of  $30^\circ$ . The radial wall of the steam well is made of a steel mesh 8. During the autoclaving process, the steam condensate (water) is removed by gravity from the steam well 7 to the of steam condensate collection tank 9 equipped with a drain cock 10.

The essence of the experimental research method was to establish the effective propagation radius of the autoclave curing from the steam well, within which the non-shrink and water-proof autoclave slag-concrete was being produced in radial autoclave. The autoclave curing radius was determined from the temperature change of the slag-lime mixture in an autoclave form as it moved away from the steam well. The maximum water vapor pressure in the steam well was taken as  $P_{\text{CKB}} = 1,2 \text{ MPa}$ , which corresponded to the vapor temperature in the well  $\approx 187.0^\circ\text{C}$ . The radius at which the temperature in the autoclave form was  $\approx 174.5^\circ\text{C}$ , which corresponds to a pressure of 0.9 MPa, was taken as the limit of the radius of propagation of effective autoclave curing from the steam well. The thermometer readings were recorded at the end of the autoclave curing - "duration of autoclaving at maximum pressure". The parameters of the slag-lime mixture and its autoclave curing were assigned from Table 1. In addition, in order to study the effect of the composition of slag-lime mixtures on the radius of propagation of autoclave curing from the steam well, the

experiments with slag and lime fraction «-0,16» and  $K_{och} = 0,3$  и  $0,5$  were additionally performed.

4 Results and discussion

The results of the experimental studies are presented in Table 2 (the experiments, in which the waterproof and non-shrink autoclave slag-concrete for filling the laying of vertical mine workings was formed with the specified compositions of the slag-lime mixture and its autoclave curing, are presented in bold).

As a result of the performed studies, the ratios of the propagation radius of the effective autoclave curing of the filling mixture from the steam well are established depending on the parameters of the slag-lime mixture and its autoclave curing. As follows from Table 2, the maximum radius of autoclave curing of the slag-lime mixture equal to  $R = 0.53$  m, at which water-proof and non-shrink autoclave slag-concrete for filling the vertical mine workings is produced, is attained at  $K_{och} = 0,3$ , slag and lime fractions "-0.08" the water-binding ratio of the mixture  $BBO = 0.5$  and the "medium" autoclaving mode.

**Table 2.** Radiuses of autoclave curing propagation from the steam hole depending on mix compositions and autoclave curing parameters.

Radius of autoclave curing, м	$K_{och}$	Slag and lime fractions	Water-binding ratio BBO	"Medium" autoclaving mode, hour
0,61	0,3	(-0,16)	0,5	4+0,75+6+5
0,53	0,3	(-0,08)	0,5	4+0,75+6+5
0,49	0,5	(-0,16)	0,5	4+0,75+6+5
0,34	0,5	(-0,08)	0,5	4+0,75+6+5
0,42	0,7	(-0,16)	0,5	4+0,75+6+5
0,21	0,7	(-0,08)	0,5	4+0,75+6+5

5 Conclusion

The developed technology for filling the abandoned vertical mine workings with waterproof and non-shrink autoclave slag-concrete allows ensuring the environmental safety of the territories adjacent to the abandoned mine, utilizing slag dumps and providing the possibility, if necessary, of shaft recovery with minimal labor and material costs.

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