Improved Technology of the Preliminary Cementation of Water-bearing Rocks

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ABSTRACT

Theoretical and experimental studies into cement grout filtration process allowed the development of technology associated with the precementation of water bearing strata encountered around vertical underground excavations. The technology entails cementation procedures by boreholes of variable length and pilot chemical grouting of the treated fractured-porous rock strata.

The length of a cementation borehole depends on the output of a grouting pump, injection pressure, grout density, hydraulic properties of aquifers and the required cementation radius.

Injection pressure is generally increased with regard to the reduction in rock permeability required through the holes of the first series.

The application of pilot chemical treatment is determined by the intensity of filtration of the liquid phase into porous rock blocks which form cracks. Depending on the intensity of filtration various measures are proposed to reduce it. They include a decrease of grout density, introduction of various additives or preliminary chemical treatment of the grouted strata.

Hydrogeological environments during shaft sinking in the Kuzbass Coal Basin area and the results achieved in applying the improved cementation technology are described.

INTRODUCTION

One of the essential factors influencing the time and the cost of sinking shafts is the flooding of the rock mass, which demands the application of special sinking methods. In the CIS (Commonwealth of Independent States Republics) according to the operating sinking standards and rules the residual water inflow to the sunk shaft of the coal or ore mine 800m deep must not exceed 5 m^3 per hour. Application of special methods of shaft sinking in the form of preliminary grouting in the mines of Donbass, Kuzbass and other CIS coal basins has reduced normal flows to these levels instead of 30 - 250 m^3/hr. In operating shafts which were sunk by ordinary methods water inflows exceed the normal standards. For example, in 88 per cent of the shafts in Krivorovsk ore mining basin and in 60 per cent of the shafts in Donbass the inflows exceed the standards, and 7 per cent of the shafts in Donbass contain the inflows reaching 30-70 m^3 per hour. In Kuzbass one third of shafts prepared for sinking need to be sunk with the help of special methods because of anticipated considerable inflows. Expected average hydrogeological conditions for the shaft sinking in Kuzbass for different coal regions are shown in Table 1.

coal region / mine / sinking conditions	Anzhersky, mine "Sudzhenskaya"	Kemerovo, mines "Beryosovskaya" "Pervomaiskaya"	Leninsk, mines "Kirov", "Oktyabnskaya"	Belovo, mine "Tchertinskaya"	Prokopievsk-Kiselovs mines "Zenkovskaya", "Karagalinskaya"	Yerunakovsky, mine "Iljinskaya"	Baidayevskaya, mine "Jubileinaya"	Tomusinsk, mine "Raspadskaya"
water inflow to the shaft. m3 per hour	up to 50	up to 200	194-250	50-250	37-82	50-60	up to 80	up to 208

Table 1

Besides the improved sinking conditions and the reduction of the time of sinking, counter infiltration curtains around the shaft excludes the drainage of underground waters and provides protection and conservation of water reserves. The environmental contamination is also reduced due to the decrease of mine spillway into the open water basins.

The main special methods of sinking are based on the alteration of the physical state of the rock mass by grouting of the rocks, chemical strengthening of the rock mass and freezing of the ground [1].

The analysis of the past research results and experience has shown that the simplest and cheapest special method is the grouting, but the sphere of its application is limited only to fissured rocks with cracks over $0.1 - 0.2 \times 10\ m^3$ or gravel rocks without filler with the grain size over $2 - 3 \times 10\ m^3$. In the fissured rock mass with thinner partings (fissure state) or in a porous medium the effect of injection may be received only by the application of highly penetratable chemical grouts. In saturated (floating) earth it is advisable to use freezing or electro-chemical packing (compression). Besides simplicity and considerably lower cost the application of grouting is desirable due to a sufficient number of fissured rocks being receptive to grouting. For example in Kuzbass the average thickness of drifts unreceptive to grouting is only 20 m. The main fundamental rocks which are present like sandstones, siltstones, argillits are fissured enough for grouting.

At present a complex grouting method of fissured rocks by clay-cemented non sedimented solutions is widely used. It was worked out in Spetstamponazhgeologia manufacture [2]. Together with the development of this method a traditional technology of preliminary grouting by cement solutions is being applied in Kuzbass. This work is devoted to the results of the research into improvement of this technology.

Preliminary cementation is characterized by a number of essential characteristics by the alteration of the injection pressure along the length of the hole due to the solution gravity; by the necessity of correspondence of the absorbing abiliity of the hole to productivity of injection facilities; by the necessity of supporting a definite speed of the solution flow at the face with the aim to exclude its sealing (ramming in); by providing of baring and qualitative grouting of cracks in the area of grouting curtains. Theoretical basis of the preliminary cementation taking into consideration the physical characteristics of formulation of grouting curtains applying unstable cement solutions are introduced in this work [3].

According to the first characteristic of the preliminary cementation the length of the cemented hole (the length of the permeable part of the hole) must be co-ordinated with the productivity of the injection facilities, injection pressure, solution concentration, filtration characteristics of water bearing level and the demanded cementation radius.

The introduced scheme of cementation is carried out by means of worked out inter-supplemented methods, which include technicial decisions on cementation by the holes of variable length, control of injection conditions taking into account the changeable state of the cemented mass at each following hole, and taking into account the physical peculiarities of the cementation of fissured-porous rocks.

The method of cementation by the holes of variable length on the base of established dependence [3] of the hole length on the absorptivity of the rock massif is conducted by the drilling of holes with intervals, during which the water absorbtion of the hole is determined. The drilling interval up to the first stop is approximately determined beforehand on the base of available information about fissure state and hydrodynamic characteristics of the rock massif to be cemented with the application of pointed out dependence. If the absorptivity of cracks exposed by a hole is not enough for a complete application of the productivity of injection facilities, the hole is deepened.

The water absorptivity of the hole which is co-ordinated with the injection facilities productivity under the pressure, necessary for solution injection is reached, the drilling of the hole is stopped, specific water absorptivity is calculated, parameters of injection and solution concentration are determined, then the solution is prepared for injection.

The injection is stopped after the cracks have been filled on the demanded direction from the hole and up to the necessary density. After injection the hole is sealed (beared) hermetically till the solution is set. After that the hole is deepened on the next necessary length. During this process the drilling is stopped periodically and trial injections of water are made to determine the water absorptivity of the hole. Then the cycle of operation is repeated in the succession as it took place while drilling the previous hole.

After the cementation of the previous hole up to the final depth is finished the next cemented hole may be drilled.

To increase the density of the counter filtration curtain cemented holes are divided into holes of the first, second etc. turns of injection. On each following turn (stage) the injection must be stopped when the pressure increases because the permeability of the mass is decreased due to cementation through the holes of the previous turn.

According to the suggested method the mass is cemented firstly through the holes, which zones of solution extention do not contact with each other or contact slightly. For this purpose the holes are drilled, their water absorptivity is determined and their specific water absorptivity q_1 is calculated. The injection of the solution is conducted. The injection is stopped at the final pressure P_1 determined with the account [3] by a rated (designed) way according to the hydrodynamic characteristics of uncemented rock mass and demanded cementation radius.

After the cementation of the rock mass through the holes of the first turn, intermediate holes of the second turn are drilled, their water absorption is determined, specific water absorption of partly cemented rock mass q is calculated. Injection of solution into the holes of the second turn is stopped when the final pressure of injection exceeds the final injection pressure at the holes of the first turn ΔP, at the value ΔP_1 determined according to the formula

$$\Delta P = P_1 \left[\left(\frac{q_1}{q} \right)^K - 1 \right]$$

where k = 0, 275-0,550 is a coefficient, adopted according to cement-water ratio of the solution (C:W) equal K = 0,275 for unstable solutions with C:W ≤ 1:1 and equal to K = 0,550 for stable solutions with C:W ≥ 1:0,5 applied for all the rest of intermediate concentrations by interpolation. While cementation of strained rock mass the injection of the solution is stopped when the final pressure is decreased.

As the rise of the density of cement curtains in the rock mass with nonuniform fissure state before solution injection into the holes of the second turn extention of such holes is conducted by the admission of water into them under the pressure of 1,8 - 2,5 MPa, and the cement solution is injected into the extended fissures just after the admission of water under the same pressure.

At the cementation of fissured-porous rocks the quality of cementation is reduced due to intensive filtration of liquid state into rock pores and sealing (ramming in) of cracks near holesby solidified solution. The results of the investigations of the filtration of the liquid state of the solution has allowed engineers to work out the measures to decrease it (Table 2). The intensity of filtration out η is determined as a ratio of solution of a filtrating liquid state to expense of liquid state, injected into the hole together with the solution.

η / η*	Decrease of liquid state filtration from cement solutions
< 1	Is not demanded
1 - 1,4	Solutions with initial concentration are used, calculated with the help of the formula $C:W = C:W_0 - \frac{1}{1-\eta}$
> 1,4	Addition agents are used, which decrease the water yield (separation), or preliminary chemical processing of cemented mass is conducted

Table 2

While working out the measures it is admitted, that the solution looses its mobility at C:W = 1:0,4. The maximum admissible degree of filtrating out of liquid state η^* according to the conditions of preservation of solution mobility is determined by the formula

$$\eta^* = \left[1 - \frac{C_0 / W - 3}{5,5} \right]$$

where $C_0 : W_0$ is the initial concentration of cement solution (concentration of the solution injected into the hole).

In case of $\eta/\eta^* > 1,4$ when it is necessary to conduct preliminary chemical processing a new method is introduced to exclude the overexpense of the chemical solutions which checks the quantity of injected chemical solutions. Chemical solutions are injected in a quantity, determined from the correlation

$$0,25 < U_X / U_C < 1$$

where U_x, U_c are volumes of chemical solutions and cavities of cemented rock mass respectively.

The introduced method is carried out in a following way. A hole is drilled, its water absorption is determined and according to the calculated specific water absoption the initial concentration of cement solution $C_0 : W_0$ is determined. The value of criterium of the solution mobility η^* is determined with the help of above mentioned formula. Using the hydrogeological conclusions values δ, h_T, k_T (δ - is avarage opening of cracks, k_T - is average distance between the cracks; h_T - is coefficient of steam permeability of rock mass) are determined. With the radius of cementation R the degree of filtration is determined according to the formula

$$\eta = \frac{1}{1 + \frac{\delta^3 h R_{CK}}{(C_0 / W_0 + 3) k_T R^3}}$$

where R_{CK} - is radius of hole.

The necessity of conducting of chemical processing of mass is determined according to the formula $\eta/\eta^* > 1,4$. Chemical solutions are injected into the hole in a quantity which is determined by the correlation

$$U_X / U_C = 1 - \eta^* / \eta$$

To reduce labour expenses, the length of cementation at reduced cost, the number of injections, and volumes of injected liquids a method of cementation of fissured-porous rocks is suggested which proposes the injection of calcium chloride for preliminary chemical processing together with cement solution in a quantity of 0,7 - 2,2 from the quantity of cement above additional agents necessary to accelerate the setting of cement inside the rock mass, that is hydrogel of silicic acid is not formed before injection. It is formed due to soluble glass and the part of calcium chloride which is filtrated from the cement solution into poresand microcracks of rocks.

The results of implementation of the introduced technological scheme in the Kuznetsk coal field are shown in Table 3, cemented rocks are fissured sandstones, mudstone and siltstone. The capacity of cement pumps did not exceed 20 m. The number of injected holes located along the perimeter of the vertical shaft was 6, the diameter of the shaft was 6 - 8 m.

Mine	I Heading	The length of cemented area, m	Expected water inflow, m^3/h	Residual water inflow, m^3/h
"Raspadskaya"	5th block shaft	101	90	4
	ventilation shaft of the 4th block	118	208	5
"Beryosovskaya"	ventilation shaft	70	175	5
	air supply shaft	294	175	5
	skip shaft	124	175	3
Mine named after V.I. Lenin	cage shaft	246	127	10

Table 3

The residual water inflow more than the normal 5 m^3/h in the cage shaft at the mine named after V.I.Lenin is explained by the fact that the shaft crossed a pebble-sand parting which was not cemented.

As a whole the results of the carried out research shows that registration of physical characteristics of cementation allow to improve its quality using unstable cement solutions.

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