EFFECT OF MINE WATER ON ROCK DEFORMATION IN COAL MINES

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ABSTRACT

The paper presents results obtained for the effects of mine water on rocks of Russian coal-bearing sequences. The effects are correlated with a rock-type grouping according to the degree of secondary alteration which the rocks have undergone. Regression analyses performed on the results have enabled a stability factor to be evaluated which permits predictions to be made regarding the stability of rocks in-situ.

INTRODUCTION AND GROUPING OF ROCKS

The following effects of water on rock have been established from studies in the coal mines of the USSR :

(a) The disintegration and swelling of clayey rocks.

(b) Further deformation of broken rocks.

(c) Initiation of sliding on joints and partings.

(d) General weakening of rocks.

(e) The initiation of metabolic physico-chemical processes in rock.

(f) Physical effects due to hydrostatic and hydrodynamic pressures.

The character and the intensity of the above effects of water have been found to depend on the degree of secondary variations of rocks. The rocks in the coal-bearing sequences can be divided into four groups according to the degree of secondary rock variations. (See Table 1). The first group incorporates slightly changed loose and poorly cemented rocks including lignites and partly cannel coal; the second one consists of dense, cemented and slightly changed rocks with layers and sheds of cannel - and, to a smaller degree, gas coals; the third groups embraces the predominant quantity of highly cemented and considerably changed rocks and caking coals: gas, fat, coking and partly lean-caking; the fourth group covers rocks which according to their composition and properties are almost metamorphic anthracite coals.

Table 1

No. of Class	Character of Coal	% Carbon	Calorific Value cal/g
I	Dry, long flame, non-caking	75 - 80	8000 - 8500
II	Fat, long flame	80 - 85	8500 - 8800
III	Fat,	84 - 89	8800 - 9300
IV	Fat, short flame	88 - 91	9300 - 9600
V	Lean coals - semi anthracites	90 - 93	9200 - 9600
VI	Anthracites	93 - 95	9110 - 9200

Coal classification system used is based on that by Grüner-Bousquet, 1911.

EFFECTS OF WATER ON THE FIRST GROUP OF ROCKS

General "looseness" of the rock mass (porosity up to 43%) and extremely weak structural bonds of mineral components are the main peculiarities of the first group.

The rocks of this group are mainly composed of clays, siltstones and sandstones with a subordinate content of argillites, sandstones and limestones. The peculiarities mentioned above account for a wide occurrence (87%) of disintegration of these rocks. A part of the rocks can swell when saturated with water.

Experimental works in Donetzk basin showed that clayey rocks were the most susceptible to disintegration (in 98 cases of 100) against silt- and sandy rocks (in 83) and 48 cases of 100 adequately) which were less affected by water. The disintegration of carbonaceous rocks were observed in 12 cases of 100. In all the cases disintegration was observed in rocks containing no less than 10% of clayey material.

The following four types of disintegration have been qualitatively established according to the intensity of its manifestation in various rocks: full, moderate, slight and extremely slight.

A full disintegration is usually characteristic of clays, clayey silts and sands with the porosity of 26-40% forming a fluid mass when saturated with water. Such rocks amount to 36% of the coal-bearing sequences examined.

Dense clays and clayey silts with the porosity of 12-25% are distinguished by a moderate disintegration. These rocks form a plastic mass when saturated with water. They account for 37% of the section.

Slight disintegration is typical of poorly cemented silts and sandstones and to a lesser extent of clayey rocks enriched with a carbonaceous material as well as of certain varieties of clayey limestones. These rocks become semisolid in water. Their quantity in the section of coal-bearing sequences of the analysed group equals to 6%.

Certain varieties of clayey limestones and a number of rocks containing a considerable amount of carbonates (10-25%) are characterised by an extremely slight disintegration. These rocks remain solid when saturated with water. However, the following phenomena were observed : (1) an abundant suspension was created while slightly rubbing the rocks (with fingers) in water and (2) a "soapy" feel was generated on fracture surfaces. The content of such rocks in coal-bearing sequences is less than 6%.

Swelling of water saturated rocks in the first group is less marked than disintegration. It was observed in clayey rocks (in 63 cases of 100), siltstones (in 27 cases of 100), clayey sandstones (in 11 cases of 100) and limestones (in 3 cases of 100). The values observed fell in the following ranges in clayey rocks - from 36 to 57%, siltstones - from 15 to 32%, sandstones - from 3 to 14% and in limestones - from 1 to 3%.

The most intensive disintegration and swelling are characteristic of the rocks proximate to coal seams and rarely of underlying limestones. The effect of water on these rocks leads to considerable deformations which disturb tunnel linings.

Apart from disintegration and swelling, water saturated rocks of coal-bearing masses of the given group are distinguished by the clearly defined exfoliation and softening. These phenomena are typical of limestones, sandstones and siltstones as well as of certain varieties of argillites with a high carbonaceous content (25% and more); all of these do not disintegrate in water.

Exfoliation occurs most frequently in thin - laminated siltstones and sandstones. The softening is more characteristic of argillites and is less prevalent in siltstones, sandstones and limestones. The decrease in compressive strength in water saturated argillites amounts to 65%, siltstones - 48%, sandstones - 32% and limestones - 18%.

EFFECTS OF WATER ON THE SECOND GROUP OF ROCKS

Rocks of the second group essentially differ from those of the first group according to the rock composition consisting mainly of dense clays, argillites, siltstones, dense cemented sandstones and limestones.

The main peculiarities of the rocks of this group of masses are the following : (a) occurrence of textures and structures accounting for a higher rock consolidation; (b) decrease in the quantity of a clayey material (clayey minerals with expanding crystalline lattices, in particular).

These peculiarities greatly change the nature of the effects of water on the rocks of this group, viz :- disintegration affects 60-72% of the rocks of the group while swelling effects 12-26%. 28-40% of the rocks in this section do not disintegrate.

Disintegration was observed in the following rocks : (1) clayey rocks - in 82 cases of 100; (2) siltstones - in 46 cases of 100; (3) sandy rocks - in 23 cases of 100; (4) carbonaceous rocks - in 3 cases of 100. It should be emphasised that in these cases disintegration occurred only in the rock varieties containing,a relatively large amount of clayey material (25% and more).

Like the rocks of the first group, the rocks most liable to disintegrate occur in the roof and the floor of coal seams. However correlation of the above data with corresponding values of the first group shows a distinct decrease (by a factor of 2) in the quantity of rocks liable to high disintegration and an increase in the amount of rocks characterised by a less intensive disintegration.

Practically, all the limestones (97%), an overwhelming majority of sandy rocks (77%) and siltstones (54%) as well as certain varieties of argillites (18%) did not disintegrate. In this group, the following rock quantities exhibited exfoliation: 60% of non-disintegrating argillites, 25% of siltstones, 12% of sandstones and 5% of limestones.

Like the rocks of the first group, argillites of the second group are characterised by the largest softening and limestones by the least. However, strength losses of water saturated rocks in this case are much less (by 15-20%) against those of the first group. The value of these losses varies depending on the types of rocks : argillites - 40-50%, siltstones - 25-35%, sandstones - 15-25%, limestones - 5-15%.

The data presented show that the occurrence of disintegration and swelling in rocks of the second group decreases considerably and there is a corresponding increase in the amount of the rock properties which are not greatly changed by saturation of the rock with water. Simultaneously, a decrease in softening and in the losses of rock strength related to it takes place. The quantity of the rocks liable to exfoliation increases however.

EFFECTS OF WATER ON THE THIRD GROUP OF ROCKS

The rocks of the third group are again characterised by a specific reaction to water.

These rock masses consist of argillites, dense cemented siltstones, sandstones and recrystallised limestones. At the sites of transition from gassy to fat coals the dense clays and clayey siltstones are sometimes preserved. The rock structures are characterised by an interadaptation of mineral components that accounts for a relatively low (1,6-7,0%) porosity and a high strength of rocks. Montmotillonite and consanguineous mixed-layered formations with an expanding crystalline lattice are practically absent; the content of hydromica with a mobile crystalline lattice decreases from 71% to 16% in the transition through fat to coking to lean coals.

All the above facts predetermine a relatively low degree of disintegration and an extremely limited swelling of rocks of this study showed that no more than 28-30% of rocks of this group disintegrated, while swelling occurred in 6% of the rocks.

It should be emphasised that in this case only clayey rocks exhibited swelling and disintegration.

The rocks of the masses of the third group are distinguished by the four types of disintegration, full, moderate, slight and extremely slight. However, in this case, only the latter three types can be considered as typical of the given group of rocks. Full rock disintegration was observed in 2 cases of 100, a moderate disintegration in 17 cases of 100; slight disintegration took place in 22 cases of 100 and an extremely slight disintegration in 35 cases of 200.

An estimation of rock swelling showed rather low values for an increase in volume, not exceeding 20%.

As in previous cases, rocks of this group which did not disintegrate were affected by exfoliation and softening. According to the data obtained, 40% of argillites, approximately 30% of siltstones, 15-20% of sandstones and 2% of limestones were affected by exfoliation.

In all the cases, softening of the enclosing rocks was followed by relatively small losses of strength: (a) argillites - 20-30%, (b) siltstones and sandstones - 10-20%, (c) limestones - 2-10%.

Correlating the data that characterise the exfoliation and the softening of rocks with the corresponding rock values of the previously analysed rocks, it can be seen that there is a significant increase in the prominence of these phenomena in the rocks of the third group, while the processes of disintegration and swelling of rocks are of reduced importance.

THE EFFECTS OF WATER ON THE FOURTH GROUP OF ROCKS

The composition of rocks of the fourth group is represented by quartzite-like sandstones and siltstones, shaly argillites and limestones with a high degree of recrystallisation. The porosity of rocks amounts to 1-4%.

A widespread occurrence of the structures characterised by the processes of dissolution under pressure, directed erosion and crystallisation followed by the formation of stable contacts between mineral components is typical of the rocks of this group. The quantity of minerals with an expanding crystalline lattice is practically negligible in these rocks. In this connection, the rocks of this group don't swell when saturated with water, while slight disintegration takes place in 32 cases out of 100.

The rocks which do not disintegrate in this group (amounting to 95%) are distinguished by a high degree of sheeting. According to the available data these rocks when saturated with water, are very prone to exfoliation in the following amounts : 60% of argillites, 45% of silt-stones, 18% of sandstones and no less than 3% of limestones.

The softening values of the rocks of this group is less significant than exfoliation. The losses of strength of the most saturated rocks now exceeding 28% and generally being within the range 5-10%.

The data presented shows that the effect of water on the given rock group mainly results in rock exfoliation.

IMPLICATIONS AND FURTHER ANALYSES OF RESULTS

Disintegration, swelling, softening and exfoliation of rocks in the process of their interaction with water are phenomena which cause problems in the extraction of coal.

Water saturation of a finely fragmented material can lead to further deformation in mines. This material when saturated with water is easily mobilised.

Rock mobilisation over the surfaces of fractures in the roof, floor and walls of mines occurs in a more intensive way provided that these surfaces are wet. It is associated with an increase in sliding friction on the wet surface and the formation of a specific plastic clay gouge. The analysis of the cases of water interaction with the rocks located in the zone of mines shows that sometimes a negligible water quantity or moistening of a weak rock can cause an increase in the deformations.

An impact of the chemical composition of ground- and mine waters on the metabolic physico-chemical processes occurring in the rocks is characterised by the following peculiarities. Water containing sodium ions usually accounts for the metabolic phisico-chemical processes in clayey rocks causing swelling and disintegration. Acidic water has a destructive influence on the rocks enclosing a carbonaceous cement as well as on the carbonaceous rocks as a whole.

An impact of hydrostatic and hydrodynamic head on the rock deformations in mines is manifested itself combined with the other geological factors.

As a result of a study of the effects of mine water on the engineering properties of rocks and their stability in mines, a stochastic model of the predicted environment has been constructed with the use of correlation- and regression analyses and the programs specially developed on a computer.

The ability of the moistened rocks to resist the manifestations of various deformations in mines is expressed by a stability factor.

To obtain this factor, a correlation matrix has been studied and analysed :

$$X_i = \sum_{z=i}^{k} \ell_{i2} f_2 + \varepsilon \; ; \quad \ell_i = 1,2 \ldots p$$

where p - number of the factors observed;

X_i $(i = 1,2 \ldots p)$ - factors observed;

$f_1 \ldots f_2 + \ldots + f_3$ - hypothetic simple factors;

k - number of simple factors;

ε_i - remainders being the sources of deviations which affect the factors observed (X_i);

ℓ_{ir} - coefficient (load, weight); r - a simple factor which is included into i - factor observed.

Processing of the data has established that the stability factor depends, first of all, on the lithological composition (X_1^e), jointing (X_2^T), strength of water saturated rocks (X_3^{σ}), depth of location (X_4^{H}) and porosity (X_5^{n}),

A correlation matrix composed of double correlation coefficients with the level (r) = 0,20 is characterised by the following values :

$$X_k = 0.64\ X_1^{e} + 0,68\ X_2^{T} - 0,56\ X_3^{\sigma} - 0,31\ X_4^{H} + 0,17\ X_5^{n}$$

The following typification of rocks according to their stability has been worked out as a result of analysing the in situ effects of mine water :-

Table 2

No.	Stability factor	Type of rocks according to their stability
1	0,0 - 0,5	Highly unstable
2	0,5 - 1,0	Unstable
3	1,0 - 1,5	Medium-stable
4	1,5 - 2,0	Rather stable
5	2,0 - 2,5	Stable
6	More than 2,5	Highly stable

CONCLUSIONS

Analysis of numerous results for the effects of mine water on rocks of Russian coal-bearing sequences has enabled stability factors to be evaluated, making it possible to estimate the boundary conditions of rock behaviour depending on the degree of rock saturation, chemical composition and other natural factors at various stages of geological prospecting.

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