THE STRUCTURAL CHANGES OF COAL UNDER PRESSURE

A. D. Alexeev, V. A. Sapunov, G. P. Starikov, L. V. Shevchenko

Donetsk Physico-Technical Institute, Ukrainian Academy of Sciences, 340114 Donetsk, Ukraine

The experience gained when performing face cleaning at the outburst-hazardous seams, has shown that more than 80% of sudden outburst of coal and gase occurs in zones of geological disturbance. As a rule, these are low-amplitude plication and disjunction (of the overlap type)disturbances characterized by different degree of coal preparation with which gas - and - hydrodynamic characteristics of coal seams are related. It is natural that, when the disturbances enter the zone of limiting equilibrium, the seam portions with the preparated coal will be under a low rock pressure, at the same time, sections of unfailured and overcompacted coal will go to the limiting state with the accumulation of substantional elastic energy and fail in the presence of enough saturation with methane. So, the methods avoiding coal and gas outbursts in zones of geologic disturbances should be realized beforehand, i.e. until the near-face zone approach, and should provide decrease of elastic and increase of deformation properties of coal. One of the most perspective methods satisfying the above conditions is the preliminary treatment of the mentioned zones by water solutions of surface-active substances (SAS) and solutions of binders which have changed their phase state.

Since zones of geologic disturbance of different degree of coal preparation are under conditions of bulk non-uniform loading, the influence of the above types of treatment on elastic and deformation properties of coals has been evaluated using a three-axial compression. Coal samples in the form of cubes with the dimension of face $6.5 \cdot 10^{-2}$ m have been investigated making it possible to simulate the stress-strain state and gas-dynamic properties of coal in the rock mass.The loading programme simulated the state of near-face zone of coal seam, i.e., the sample was first compressed evenly in three axes $\sigma_1 = \sigma_2 = \sigma_3$ up to 2.5–3 MPa, then σ_1 was increased up to stabilization level, the intermediate stress σ_2 formed spontaneously due to the deformation of sample; magnitude of σ_3 corresponded to the value of residual strength of partially destructed sample and was kept at the level of 2.5–3 MPa up to sample destruction. After small (3–5 MPa) decrease of σ_1 speaking of the onest of sample destruction, the smallest stress σ_3 was decreased down to zero, and σ_1 was kept constant.

The main parameters, which completely enough describe the stress-strain state of coal of different preparation degree and the contents of fluids there,are strength σ_1 , relative deformation *e*, bulk modulus, Joung's modulus *E*, shear modulus *G*, Poisson's ratio *g*, Nadan-Lode parameter characterizing the deformation mechanism in the process of destruction.

The Figure shows the results of the investigation of coal samples: those saturated with gas, wetted, partially destructed (at $\varepsilon_3 = 3 \cdot 10^{-2}$), bound with polymer composition. All the parameters referring to saturation with fluids are the ones for a given rank of coal. On the given dependences $\sigma_1 = [f](\varepsilon_1)$ there are four typical sections of different intensity of stress and strain growth. In the first *OA* section of curve *1* (see the Figure) the modulus of deformation, the Young's modulus, the shear modulus and the Poissou's ratio are of stable character, the Nadan–Lode

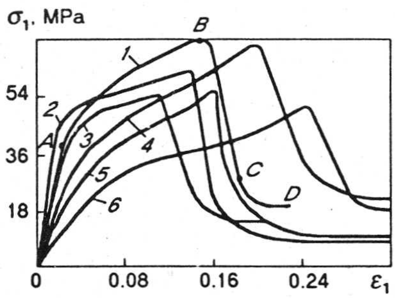

Fig. Influence of different fluids on deformation and destraction of different coals under the uniform compression: *1, 2, 3* — coal with natural jointing: without fluid, saturated with gas and wetted, respectively; *4, 5* — partially disturbed coal (ε_3 = 3 %), bound by polymer [KM] and non-bound one, respectively; *6* — coal with 36 % content of binder [KM]

parameter characterizes the generalized compression. All the factors correspond to the elastic deformation of coal. In the second section (*AB*), which is of nonlinear character, the more inverse increase of compressive strain, 3–5 times decrease of the shear modulus and 5–7 times decrease of the Young's modulus, as well as 2–3 times increase of cubic strain modulus and Poisson's ratio increase for 15–35% are observed. This evidences the transition of the sample to be limiting state and onset of coal destruction. The third section of curves (*BC*), corresponding to the beyond-critical state, characterizes behavior of samples when *s* decreases down to zero, i.e. coal mass extends to the near-face zone. In this case, cubic strain modulus is 2.5–3 times decreased, the Young's modulus is 2–4 times decreased,the shear modulus is 2.5–times decreased, the Poisson's ratio v increases and reaches values 0.48–0.5. The Nadan-Lode parameter shows that the gas–saturated and partially destructed samples are in the state of generalized tension.

The fourth section (*CD*-residual strength) corresponds to the region in close proximity to the face end, it is characterized by stabilization of stresses σ_1. It shows more completely the change of coal properties depending on the degree of preliminary destruction of samples as well as on saturation of coal with methane, solutions of surface-active substances and binder.

Curves *1,2,3* characterizing the strain-strength properties of nondestructed coal have relatively high slope of linear portions *OA* which evidences the elastic energy to be mainly accumulated at the initial stage of three-dimensional compression of coal. The highest slope is typical of gas-saturated coal which acquires the increased brittlenes under the influence of gas accumulated in the pores. At the same time, humidity (curve *3*) increases coal plasticity resulting in lower slope of *OA* linear portion.

Somewhat lower slope of linear portions of curves *4, 5* evidences the accumulation of the elastic energy in partially destructed coals (preparated coal in the seam), but it requires much more deformation than in nondestructed coal.Therefore in the seam the more harder rock mass surrounding the zone of preparated coal will carry the main weight of rock pressure. The crushed coal further treated by the polymer binder [KM] (curve *6*) possesses pronounced plasticity. The linear (elastic) portion is small, whereas the transient one (*AB*) from the limit of elasticity to that of strength is lengthy and the most gentle one as compared to the similarenes at another curves. The *AB* portions of gas–saturated and wetted coal are of approximately the same shape which is evidently explained by slight interparticle friction. Since the similar character of *AB* portions has been obtained with different defects present in structure of the samples, it can be concluded that saturation of coal with solution of surface-active substances and with methane, with its slight (natural) jointing, is to the same extent as saturation of considerably crushed coal with the polymer solution. This result shows that solutions of surface-active substances possess higher penetrability as compared to that of polymer solutions.

Decrease in slopes of drooping *BC* portion reflects the character of coal destruction beyond the ultimate strength. Samples treated by polymer binders show high coal plasticity and high enough residual strength (σ_1 = 18–23 MPa). Approximately the same character of destruction is typical of samples wetted with SAS solution, however, their residual strength is lower (σ_1 = 15–17 MPa). In samples of nondisturbed and partially disturbed coal the shear modulus G at the onest of loading is of different value. Thus, in nondisturbed coal (wetted and gas-saturated) G = 750–842 MPa. The highest value refers to the gas–saturated and the lowest to the wetted coal. In partially destructed and then polymer-binded samples the value of the shear modulus is essentially lower (G = 430–450 MPa). Preparated samples with no polymer binding possess the lowest value of the shear modulus (σ = 305 MPa). Besides, it has been established that coals of high gas–saturation degree will possess the minimal values of shear modulus which decreases down to 5–7 MPa.

These data show that destruction of coal treated with water solution of SAS and binders occurs mainly in the result of shear strain (μ_σ = [0]). Stable rock mass surrounding the preparation zone and having high degree of saturation with gas will be carried to destruction mainly by separation and, to a less degree, by shear (μ_σ = 0.7–0.8).

So, treatment of zones of geologic disturbances should result in the levelling of elastic properties between nondisturbed and preparated coal and can be realized in two directions: decrease of elastic constants and improvement of deformation properties of nondisturbed coal adjucent to preparated regions of the seam. In the first case this is achieved by wetting with SAS solutions, in the second one- by strengthening of the rock mass preparated zone by polymer binders.

Now the organic coal mass is considered as heteropolycondensate of structural formations of variable composition interconnected primarily by associative (donor-acceptor) bonds.

To characterize a coal substance a notion about the statical average unit is used based on layers of aromatic carbon with non-aromatic fragments over the periphery. In coals of low metamorphism the aromatic nuclei are screened by the end, and first of all, oxygen-containing functional groups, whereas in coals of high metamorphism (C^{daf} > 87 %) the end groups are practically absent. So, interaction of coals of low metamorphism (up to the coke one) is by reactions with the oxygen functional groups. In water solutions the reactions are: the ionic exchange, esterification and others. Coals of high metamorphism interact with different reagents directly through the aromatic fragments. They are typical of reactions with the participation of π-electrons of the conjugate systems , i.e., formation of complexes of different types.

It has been shown by the multiple correlation analysis for coals (C^{daf} < 86 %) that correlation between the content of analytical moisture (W^a), elementary composition and another factors of technical analysis is not high. Nevertheless, the maximum values of correlation factors correspond to the $W^a - O^{daf}$ (0.47) and $W^a - C^{daf}$ (0.30) bonds.

	A^d	V^{daf}	C^{daf}	H^{daf}	N^{daf}	S_{com}	O^{daf}
w	0.05	0.27	0.30	0.05	0.05	0.01	0.47

Low values of correlation factors are due to nonequivalence (with respect to W^a) of atom (carbon, oxygen) which are the components of different structural fragments.

–COOH	–OH	$\equiv\!>\!=O$	$\underset{\mid O \mid}{C{-}C{-}C}$	C–O–C
0.87	0.75	0.63	0.59	0.25

The maximum value of correlation factor (0.87) corresponds to the C^{daf} – [COOH] bond, it decreases with decreasing of polarity of oxygen-functional groups. Basing on the above fucts it can be supposed that in coals of low metamorphism moisture is primarily represented by solvate shells of polar groups. The performed correlation analysis revealed the existence of binding not only with O^{daf} , but C^{daf} as well. The maximum carbon content corresponds to highly metamorphized coals in whose structure the polyconjugated, mainly polyarene structures, with practically no oxygen-containing groups, play a defining role.

The X-ray structural and thermogravimetric analyse done at samples of anthracites and semi-anthracites have shown that polyarenes of coals possessing movable π–electrons can easily become polarized which favours their subsequent solvation with water. Taking activation with the alkali as an example we can schematically represent the interaction of polyarenes of coals with water as follows:

$$DA + I\,KOH + p\,H_2O \rightleftarrows \quad (I)$$

$$\rightleftarrows (K^+ \ldots DA \ldots OH^-)I\ KOH\ p\,H_2O \rightleftarrows \quad (II)$$

$$\rightleftarrows (K^+ \cdot D)^- OH\ m\ KOH\ qH_2O + \quad (III)$$

$$+ (A^- OH)^+ K (1-m)\ KOH\ (p-q)H_2O \quad (IV)$$

according to which the primary donor-acceptor (DA) associate of coal (I) is transformed to solvated complex (II). Because of the weakening of the D ... A bond, further reassociation takes place with the formation of the structures (III) and (IV). The above scheme has been used to elaborate the principles of selection of the surface-active substances, used under the outburst-preventive measures, and based on different routes of structural reconstruction of coals.

Solutions of surface-active substances and polymer substances possess their own peculiarities from the hydrodynamic point of view. A specific feature of the solution to penetrate the rock lies in the fact that the additions of SAS not only decrease surface tension of water, but also change the internal surface of coal, thus making it hydrophilic, decrease water friction at the boundary layer [1]. This results in decreasing the pressure of water injected for 2–2.5 times and increasing the injected water volume for 1.5–2.1 times as compared to the same indices for water under the most effective mode of filtering [2]. Polymers added to water result in 5–10 time increase if its viscosity [3], require high injection pressure resulting in the formation of hydraulic loosening.

So, this technique is the most effective for strengthning coals and rocks possessing high jointing. The obtained laboratory results have made it possible to elaborate the method of preliminary treatment of geological disturbances which is based on drilling deep boreholes at workings and their filling with SAS solutions. The investigations performed at mines of Donbass Central region, at scans Bezymyanyi, Kutsyi, Pyata, Julievskyi suffering from geological disturbances have made it possible to elaborate the main principles and technological schemes of the treatment of geological disturbances. Low-amplitude plication disturbances containing the prepared coal of small amount and not disturbing the confirming of the seam are intersected by discharge boreholes and treated by SAS water solution together with the surrounding rock mass. In case of disjunctive disturbances containing large amount of broken reduced coal, the boreholes are drilled until they meet a geological disturbance or in parallel with its longitudinal ais at a preset distance from the side boundary of the disturbance.

Check of the effectiveness of treating the zones of geological disturbances is done by drilling check boreholes, sampling wetted coal and by analysis of the samples. The outburst-hazardous seams at zones of geological disturbances are considered to be enough wetted if the content of physically bound moisture in coal of rank [Г], [Ж], is 2.5%, [ОС], [Т]–2%, [А]–3%. The tests performed at mines in compliance with the decision of Central commission (dated 30.07.86) have acknowleadged the trustworthiness of main conclusions disclosed in this paper.

1. *Pykhachev G. V., Isaev R. G.* Underground hydraulics.— M.: Nedra,1973.—225 p.
2. *Alexeev A. D., Starikov G. P. et al.* Treatment of the outburst-hazardous seams with water solutions of SAS/ — Kiev, Tekhnika, 1988.— 86 p.
3. *Nakaznaya Z. G.* Filtering of Liquid and gas in jointy filters .— M.:Nedra , 1973.—184 p.