Coal Squeezing-Out, its Description and Conditions of Development

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Abstract. The article reviews the need to develop a normative document in Russia on sudden coal squeezing-out based on the analysis of scientific studies. Descriptions of geomechanical, mining, and geotechnical conditions for development of sudden coal squeezing-out are given including the indicators characteristic to sudden coal squeezing-out.

1 Introduction

Information about the first coal squeezing-out dates back to the end of the 40s of the XX century, when gas and dynamic events began to be recorded. In the beginning, these phenomena carried a variety of names: ‘coal movement’, ‘buckling of the coal face’, ‘face slip’. Later they received the term of ‘gas and dynamic events of the 3rd kind’, and at present their official term is ‘sudden coal squeezing-out (slip).

Seams prone to rock bumps and explosions are being developed in many coal fields of the world: in USA, Australia, India, Poland, China, and other countries.

The earliest studies of rock bumps abroad were carried out by Cook. The overview of current scientific achievements in studying gas and dynamic events was prepared by the Institution of Mining and Metallurgy (London, UK) [2]. In this work, it was noted that the most important thing in combatting, in particular, rock bumps was not the overall reduction of the released energy, but the restriction of stress concentration ahead of the working face. The study details the concept of the effect of coal and rock strata strength in the three-dimensional stress state on the nature of gas and dynamic events development.

2 Materials and methods

Geomechanical conditions of sudden coal squeezing-out development

Geomechanics impact takes place in coal seams grouped in formations when development of one of the seams leads to a change in the stress-strain state of other seams in the formation. This impact varies depending on the interaction of mining operations at adjacent seams.

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To determine the type of the geomechanics impact, it is good to review the general scheme of rock strata moving in and deformation during driving of a working (Fig. 1).

A part of the rock strata where the change of the stress state takes place is called the zone affected by the production face 1. Two large geomechanics zones are identified therein – abutment pressure zone 2 and pressure release zone 3. In the abutment pressure zone, normal stresses $K_\sigma \gamma H$ are 5 times higher than in the tight rock 6 (K_σ – stress concentration factor, its value reaches 5 and higher) due to the fact that a part of weight of undermined rock is transferred to the edges of the coal seam during mining.

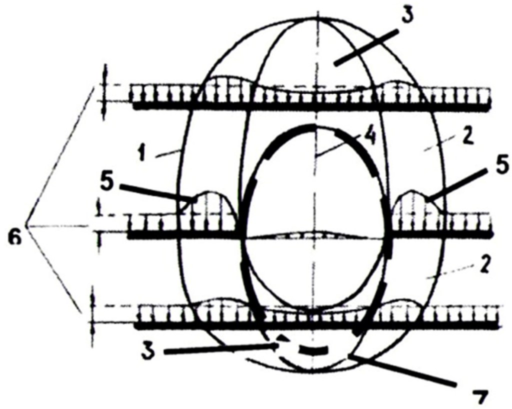

Fig. 1. Geomechanical zones affected by mining.

Zones at the level of over- or underworked seam (rock layer) are called the abutment pressure zones (APZ). Their dimensions decrease when moving away from the seam.

In the release zone, normal stresses are less than the stresses in the tight rock. Within this zone, protected zone 4 is identified, in which normal stresses and stresses along the formation are lower γH_0 (H_0 – critical depth from which gas and dynamic events start to develop) [5, 6].

In the release zone during overworking of the seam, one can distinguish the artificial protected zone 7 which has formed due to degassing of the overworked rock strata [7].

The sizes and parameters of the geomechanical zones depend on the geological and geotechnical mining conditions of development: the depth of work, the thickness of the protective layer, the dip angle of the rocks, the interbed thickness, the composition and properties of the interbed rock, the dimensions of the heading, the method of rock pressure management etc.

In the process of seam underworking (overworking), the coal seam undergoes three main stages of deformation: the contraction stage in the abutment pressure zone; the tensile stage in the release zone; the stage of repeated contraction in the zone of loads restoration.

The abutment pressure zone is characterized by an intense manifestation of rock pressure (increased rock displacements at the contour of headings, loads on the supports, etc.), as well as an increased hazard of gas and dynamic events development. It is not advisable to locate mine workings (including production ones) in these zones. When abutment pressure zones form as a result of production (near the borders of protective pillars) or mining/geological reasons (near the borders of intransgressible geological faults), passing of these zones is accompanied by additional measures aimed at eliminating gas and dynamic events development.

The analysis of distribution of sudden squeezing-out in the abutment pressure zones formed by the junction areas of production faces shows the following:

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- The overwhelming majority of the events (99%) occurred when crossing the junctions of production faces in the direction under unmined coal;
- The most dangerous are the abutment pressure zones formed by the junctions of stopped production faces (93% of face slips occurred) as compared to the abutment pressure zones from junctions formed by the face entry;
- No significant distinctions were observed in development of squeezing-out in relation to location of the sources of the abutment pressure zones.

In the overworked zones of abutment pressure with interbed thickness up to 40 m no sudden coal squeezing-out was observed.

One of the main factors influencing the protective effect is thickness of interbed rock strata which is the distance from the protective to the protected seam along the normal. As it was established by the methods of correlation regression analysis, the dependence of the number of sudden coal squeezing-out N on the thickness of the interbed rock strata M during overworking operation has the following character.

$$N = a \cdot \exp(b \cdot M) \tag{1}$$

where *a, b* – regression coefficients which have been found by the least square method for the linearized form of equation are 0.0526 and 0.0897, respectively.The correlation coefficient of this equation in the linearized form is K = 0,947.

Mining and geological conditions for development of sudden coal squeezing-out

Let us analyze the dependence of the manifestation of sudden coal squeezing-out on the main mining and geological factors.

With an increase in the depth of development of coal seams, the number of sudden coal squeezing-out increases.

The mathematical model of the dependence of the number of sudden coal squeezing-out N on the depth H is as follows.

$$N = a \cdot \exp(b \cdot H) \tag{2}$$

where *a, b* – regression coefficients which have been found by the least squares method for the linearized form of equation are 1.2617 and 0.003736, respectively.

The correlation coefficient of this equation in the linearized form is K = 0,765.

The distribution of sudden coal squeezing-outs by the thickness of the protective seam is characterized by the following data: the range of value variation is 0.42-2.2 m; the average value of 1.25 m, and the standard of 0.37 m. These data were obtained for conditions without taking into account the dip angle, since the differences in this factor turned out to be insignificant.

The sudden coal squeezing-outs were happening within the entire range of dip angles of the coal seams being developed.

Analysis of the composition of the strength properties of the roof rock strata of 33 seams in the Central district of Donbass, the most dangerous by sudden coal squeezing-outs, showed that 70% of the roof rock strata were prone to periodic hang-ups in the mined-out space and to subsidence with dynamic impact on the supports and the face area of the seam.

The analysis of statistical data of the effect of geological disturbances on the occurrence of sudden coal squeezing-out showed that in the areas affected by geological faults there were 88.5% of sudden coal squeezing-outs in flat seams and 15.2% in steep seams.

The histogram of the distribution of the natural gas content of the seams prone to sudden coal squeezing-outs is governed by the lognormal law, which has the following form

$$f(x) = \frac{1}{x\sqrt{2\pi}\sigma} \exp\left(-\frac{(\ln x - \mu)^2}{2\sigma^2} \right) \quad (3)$$

where: μ – the mathematical expectation of the logarithm of a random variable is assumed equal to 2.87 m3 / ton dry ash-free mass; σ - RMS deviation is assumed equal to 0.26 m3 / t dry ash-free mass.

The histogram of the distribution of the relative gas make during sudden coal squeezing-outs is governed by the lognormal distribution law with the probability density (3) and parameters $\mu = 2.84$ and $\sigma = 0.77$.

Geotechnical conditions for development of sudden coal squeezing-outs

The analysis of the mining technical conditions presented in [4] for the development of sudden coal squeezing-outs shows the following:

1. Sudden coal squeezing-outs occur in all types of mine workings, with all technological schemes for the development of coal seams, in all types of mechanization in coal production and development faces, with all the main methods of rock pressure control, however, the level of sudden coal squeezing-outs development in these conditions is different.
2. In flat seams, the vast majority of sudden coal squeezing-outs (90% of their total number) occurred during the implementation of the main production processes of coal mining: mining coal from longwalls and driving development headings. In steep dipping seams, the overwhelming majority of sudden coal squeezing-outs (about 90%) occurred in production faces, and in the shield faces the number of sudden coal squeezing-outs is 3.2 times greater than the number of sudden coal squeezing-outs in stepped faces.
3. By the type of coal mining, the majority of sudden coal squeezing-outs occurred during the most common methods of mining: low dip seams – when mining by shearers and ploughs; steep seams - when mining by conveyor-plough (shield faces) and by a jackhammer (stepped faces).
4. By the rock pressure control method, the majority of sudden coal squeezing-outs, both in low dip and steep seams, occurred at full roof caving; in steep seams, the level of coal slips is also significant when supporting the wall rock by cribs (21%).
5. In the long workings, the maximum number of sudden coal squeezing-outs in flat seams occurs during driving headings by road headers and extraction of coal by jackhammers; the level of sudden coal squeezing-outs is significant (21%) when driving by drill and blast method. In steep-dipping seams, the greatest quantity of sudden coal squeezing-outs (77%) is recorded when mining coal with jackhammers.
6. The analysis of operations preceding the development of sudden coal squeezing-outs allows us to state unambiguously that the majority of them (76% on low-dip and 94% on steep seams) occurred during extraction of coal. It is necessary to pay attention to the high level (12.2% on low-dip seams) of sudden coal squeezing-outs development during implementation of measures aimed at prevention of gas and dynamic events.

The most characteristic features of sudden coal squeezing-outs are as follows:

- the intensity of sudden coal squeezing-outs is much lower than the intensity of sudden coal and gas outbursts and coal falls; the intensity of the latter two types of gas and dynamic events can reach over several hundred tons;
- the average value of the relative gas emission at sudden coal squeezing-outs is 1.2 times higher than the average value of the natural gas content of the seam, while at sudden outbursts of coal and gas this ratio can be several times;
- the shape of the cavity during sudden coal squeezing-outs is mostly pocket-like or dome-shaped;
- in production faces the width of the cavity is, as a rule, bigger than its depth;

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- the average value of the slope angle of the squeezed-out coal is approximately equal to the value of its depositional angle;
- the minimum ratio of cavity depth at sudden coal squeezing-outs to the seam thickness *m* is 0.6, while the minimum ratio between the distance to the maximum of the abutment pressure to the thickness of the seam is 2; consequently, a part of these events occurs in the face area of the seam to the maximum of the abutment pressure.

3 Conclusions

In the development of coal seam formations, the zones of abutment pressure are hazardous in relation to sudden coal squeezing-outs. The most hazardous are the abutment pressure zones formed by the junction areas of production faces when they are crossed over towards the coal mass.

The following are the main mining and geological factors affecting the development of sudden coal squeezing-outs, including the depth of occurrence, seam thickness, its gas content, volatile matter yield, strength properties of the wall rock, presence and type of geological disturbances.

Sudden squeezing-out of coal occurs almost in all mining conditions of the development of seams prone to squeezing-out. The highest level of coal squeezing-out development has been recorded: on steep dip seams - when coal is mined by conveyor-ploughs in shield faces and by extraction of coal by jackhammers in stepped faces; on low dip seams - when coal is mined by narrow-web cutter-loader and by ploughs in longwall faces; in development headings - when cutting coal with jackhammers on steep seams and when driving roadways by roadheaders in flat seams; by the method of the rock pressure control - at complete caving of the roof strata.

The characteristic parameters of sudden coal squeezing-outs were analyzed.

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