Changes in Geomechanical Properties of Carboniferous Rocks Under the Influence of Water and Their Possible Consequences in the Areas of Abandoned Mines of the Upper Silesian Coal Basin (Poland)

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Abstract
In this paper, an analysis of the impact of changes in geomechanical properties of the rock environment, resulting from its secondary water saturation during the mine flooding processes, on the void volume assessment, and certain effects of the water-related changes in rock strength properties on the environment, are presented. The study attaches importance to the assessment of the void space stability in the Upper Silesian Coal Basin (USCB) mines in view of the long-term management of abandoned mines water, mainly as far as the surface and mine safety is concerned, and due to the economic assessment of the geothermal energy obtained from the water of void volumes of mines and due to the water discharge management on the surface.

Key words: geomechanical properties, minewater rebound, void spaces

Introduction

In the mine surroundings, in the eastern and western parts of the Upper Silesian Coal Basin (USCB), within the mineral deposit series being subject both to mining and now to flooding processes, there occur distinct variations in lithological, hydrogeological and geomechanical conditions (Bukowski, 2002; Bukowski, Bromek and Augustyniak, 2004; Rogoż, 2004; Różkowski et al., 2004). During the period of the last dozen or so of years, over the Upper Silesian Coal Basin area, almost half of the hard coal mines have been closed. This, in several cases, resulted in the total cessation of mine dewatering and, in several mines, a deep dewatering has been undertaken and the groundwater level was stabilised within the narrow fluctuation range (up to a dozen or so meters). In the abandoned mines, a secondary water saturation of rocks and the void volumes filling with inflowing water take place due to the partial, if not total, mine flooding. The water saturation process of rocks can undoubtedly influence the changes in geomechanical properties and the behaviour of void spaces. The water-related differentiation in behaviour of the Upper Silesian Coal Basin Carboniferous rocks has an impact not only on the correct assessment of the process but also, many a time, on the assessment of its effects.

The Mine Flooding Process Against a Background of Natural Conditions in the USCB

All the predictions of mine flooding time and the related hazards, such as carbon dioxide or methane gas explosion hazards (Bukowski and Grzybek, 2005; Hall, Glendinning and Younger, 2005), as well as the void volume assessments for the economic applications, as for example, geothermal water utilisation (Bukowski, Wagner and Witkowski, 2007), may prove entirely unsuccessful without taking into account the changes in geomechanical properties of the rock environment produced by water in course of time.

In addition to lithological conditions in the Upper Silesian Coal Basin Carboniferous rock masses composed of sandstones, claystones, mudstones and coal seams also come the conditions of feeding deposit formations with water associated with the confining beds occurring in the cover. The differentiation in geological and hydrogeological conditions can be manifested by the significant differentiation in water inflowing to the mines of the eastern and western parts of the Upper Silesian Coal Basin. In the eastern part, the amounts of water from a dozen or so to several dozen m^3/min are inflowing to individual mines, while to the mines of similar size in the rock mass lacking water storage capacity in the western part, the water inflows, in general, do not exceed 2-3 m^3/min (Bukowski, Bromek and Augustyniak, 2004).

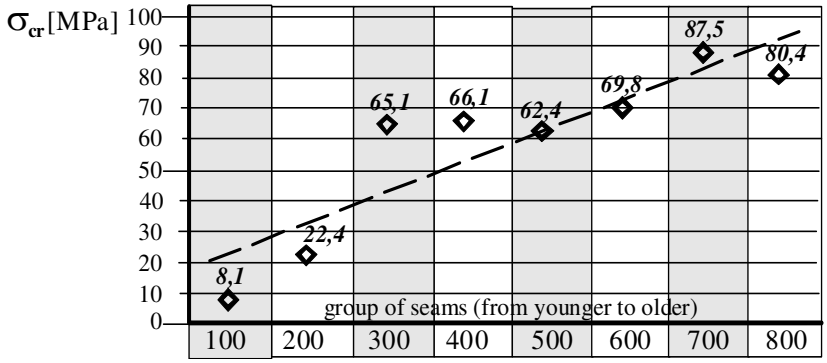
The inflow conditions in the western part render mine filling with inflowing water during the flooding process much slower than in mines of the eastern part of the Upper Silesian Coal Basin. However, the prevalence of water-storing rocks over the clayey rocks in the eastern part of the Basin make the void volumes theoretically much greater there than in the mines surrounded by non-water storing and

poorly fed with water rock masses in the western part. The flooding prognoses for the mines of both the eastern and western parts of the Basin depart from the real course. They usually show an underestimation of the flooding time for the western part of the Basin and a slight overestimation for the eastern part. Because the amount of water inflow and the feeding of the Carboniferous rock masses with water can be determined with a relatively great accuracy, the main reason why is that so can be considered the behaviour of void spaces under different geological and geomechanical conditions. The rock strength properties that are changing under the influence of water can, to a greater extent, decide on the behaviour of void spaces in conditions of mine flooding.

Characteristics of Strength Properties of the USCB Carboniferous Rocks

The many years' investigations of physical properties of the Upper Silesian Coal Basin rocks, including the Carboniferous sandstones, carried out at the Central Mining Institute, have mainly been focused on the assessment of the rock mass proneness to rockbursts and on the assessment of rockburst hazard (Bukowska, 2002, 2005, 2006). As a result, the compression strength variations for various types of Carboniferous rocks, among others, have been determined. The compression strength variations for the sandstones coming from various stratigraphic groups of the Upper Silesian Coal Basin ranging from the youngest formation (the Libiąskie beds), comprising coal seam group No. 100, to the oldest formation (the Gruszowskie beds), comprising coal seam group No. 800, are shown in Fig. 1.

Figure 1 *An example of the variations in average uniaxial compression strength, σ_{cr}. Coal seam group No. 100 – 800.*



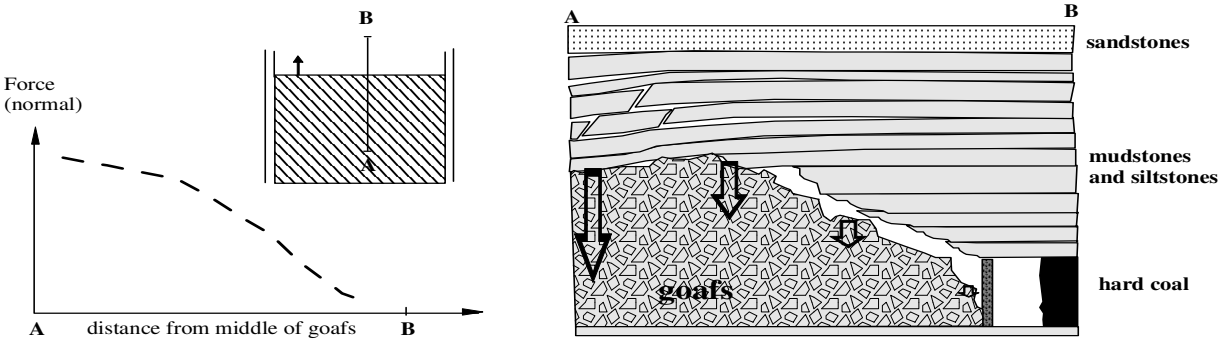
The geomechanical conditions prevailing in mines of the eastern and south-eastern parts of the Upper Silesian Coal Basin are less favourable, as far as the mining is concerned, than those elsewhere, despite smaller depths. The rock mass is composed of younger rocks (coal seam group Nos. ranging from 100 to 200) showing lower uniaxial compression strengths than those of other mining areas (Fig. 1). The roof rocks that occur here are, in general, weak (the strengths of sandstones are below 10 MPa). They easily undergo caving and the roof and floor claystone rocks can often swell under the influence of water. The coal seams frequently show higher strength values than those of country rocks. The rock mass geomechanical characteristics can vary in mines of the central and western parts of the Upper Silesian Coal Basin. The mining operations, here, are being conducted deeper, among the older rocks (coal seem group Nos. ranging from 300 to 800), where the participation of water-storing rocks can, in general, be lower. The rock mass, drained of free water, can be characterised by the lower values of the open porosity and gravity drainage capacity (of the water storing rocks) and, at the same time, by the higher values of the strength as compared with those of the rocks from the eastern part of the Basin.

Impact of the Rock Mass Water Saturation Process on the Rock Strength and Void Space Stability

The changes in rock strength properties occurring under the influence of water are being investigated in almost every research centre having at its disposal a suitably equipped Laboratory. In Poland, such studies have been conducted since the 1970s of the twentieth century. The studies were, in principle,

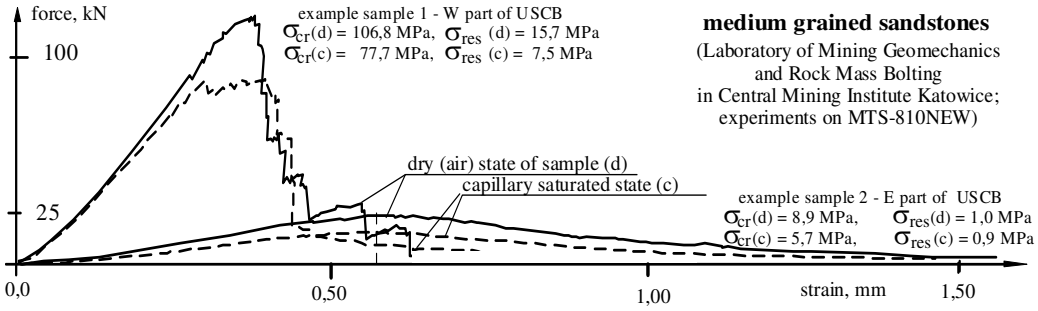
carried out on a rock medium saturated with water, in different manners, under uniaxial and/or, rarely, triaxial operating conditions. Although, the rock triaxial investigations relating to the mine flooding process have been conducted by some research centers (Li, Sheng and Reddish, 2005), the rock uniaxial investigations were considered as the most appropriate to the assessment of the impact of water on the void space stability in mining-disturbed rock masses of the Upper Silesian Coal Basin. This, especially, refers to the flooding of goaf and mine workings because the vertical pressure can be the main factor affecting the stresses in the failed rock mass structure.The lateral components of the pressure are not regarded as being of any significance (Fig. 2).
The way the rock is water saturated and its moisture content were also taken into account as an essential element of the studies.

Figure 2 *Scheme of dry goafs under normal stress*



The rocks have been brought to the state of capillary humidity using the method of competent rocks draining developed by Bukowski (2007). That state was regarded as being able to closely characterise the natural, average humidity conditions in drained rock masses. The comparative study was conducted to obtain full progress of the failure characteristics for the sandstone specimens taken from Carboniferous rock formations in the eastern and western parts of the Upper Silesian Coal Basin (Fig. 3).

Figure 3 *Uniaxial compression progress of the medium-grained sandstones of different geomechanical parameters coming from various parts of the Upper Silesian Coal Basin (after Bukowski, Bukowska and Haładus, 2006)*



It has been found that the surroundings of mine workings in the western part of the Upper Silesian Coal Basin are composed of competent rocks which do not change their properties under the influence of water just enough to affect the behaviour of void spaces. The void volumes can usually be greater than the predicted ones, which renders them possible to be characterized by a higher investment safety factor if they are considered as a topic from the economic potential point of view. They may be much more dangerous if they are regarded as the sources of water hazard. The values of volumes of the mine workings in the eastern part of the Upper Silesian Coal Basin may undergo considerable reduction as compared with the assessments made by the methods used since the 1970s of the twentieth century. If

so, then the volume of water-storing formations may decide on a possible assessment of the water hazard and the use of void spaces.

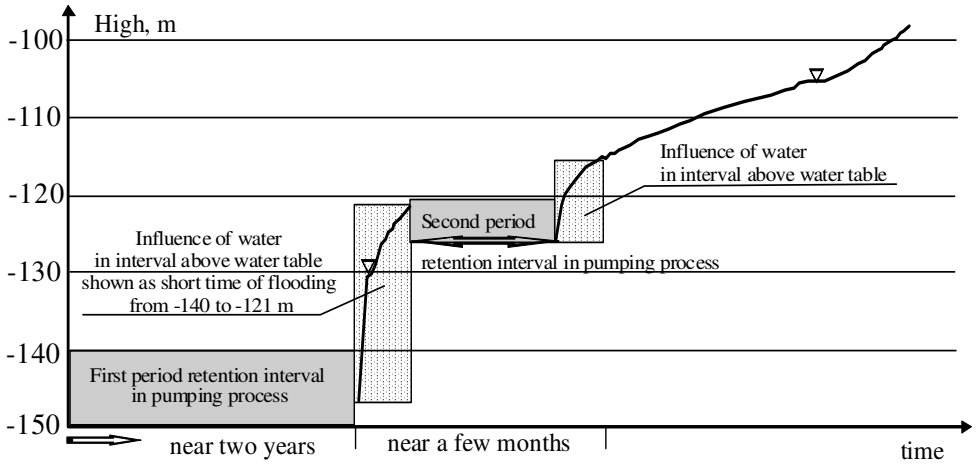
Concluding Remarks and Some Consequences of Changes in Rock Water Saturation and Void Volumes

The stability of void spaces in dewatered rock masses depends, in general, on time and strength properties of the rocks, including the post-failure rocks.

Changes in the stability of void spaces in conditions of a mine having been flooded or undergoing flooding depend on the susceptibility of the rocks, surrounding the mine workings and goaf, to the action of water. A decrease in strength of the competent rocks under the influence of water, even following their mining-induced failure (caving in goaf), allows preserving the high stability of the formed void spaces and their vertical pressure resistance. The behaviour of the goaf composed of weak rocks can be opposite. The closure of the void spaces proceeds more rapidly and on a larger scale. The flooding of this kind of goaf may proceed during a period shorter than anticipated and the volume of void spaces for the water of high freedom of movement, contrary to the original prognoses, may be as small as practically unprofitable, from the economic point of view, in such applications as geothermal potential utilisation, brine water storage and gas reservoir.

The course of the curves of mine flooding by stages (Fig. 3a) gives evidence of the unquestionable influence of water on the behaviour of rocks in the zone of saturation and water level fluctuation. The void space closures in the retention reservoirs of the mines being drained using the dewatering well technique may, during a long period of operation, result in making the broken down rock mass structure cyclically subject to saturation and loading during filling and depleting of the reservoir, respectively (Fig. 3b). As a result, this may cause the goaf and the old shaft backfills to be reactivated and may lead to the systematic drop in the storage capacity of the reservoir, and also, what is worse, of the emergency reservoir of deep pumping stations. This may also lead to the occurrence of subsidence and sink-holes at the surface of the abandoned mines (Fig. 4).

Figure 4 *Scheme shown the water influence of stability the void spaces expressed by the curve of flooding process within one example coal mine dewatered by well discharge system.*



In the extreme case, when the stability of void spaces is lost and the volume and water inflow parameters are lowered with time, especially as far as the mines interconnecting several aquifers are concerned, this process deprives one of the ability to fully control the levels of damming up of water and the water inflow between mines. These limitations may constitute the essential requirement to develop an efficient and controlled system of water inflow and retention and mine dewatering. The above mentioned statements are important from the view-point of the water discharge and dewatering costs and the selection of the surface drainage area. This area may constitute the receiving body of discharge water and, as such, may become the most advantageous as far as the water protection and the recommendations to improve the water environment quality within the framework of water directive are concerned.

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