Abstract

Underground coal gasification (UCG) is one of promising methods of using coal, which enables exploitation of deposits otherwise impossible or uneconomic to mine with traditional methods. Despite huge interest in the technology and its possibilities, a number of unsolved technological problems associated with safety of the process make it impossible to implement the technology on an industrial scale. One of them is the aspect of environmental safety, including geological safety and surface safety, as well as stability of the rock mass. High temperature, associated with the process of underground gasification, affects coal and the rocks surrounding the seam, which significantly influences changes in their physical properties, including geomechanical ones and hydrogeological ones. The changes, mainly in the distribution of stress in the rockmass, significantly influence occurrence of dynamic phenomena, e.g. caving zones over a gasified seam. As a consequence, it may endanger safety and efficiency of the process.

The scientific objective of the doctoral thesis was to assess influence of temperature on selected physical, hydrogeological and geomechanical properties of waste rock, which may occur in the direct vicinity of potential georeactors for underground coal gasification (UCG) in Upper Silesian Coal Basin (GZW). Realizing the scientific objective required realizing detailed objectives, e.g.:

- defining criteria of selecting research sites;
- devise research methodology;
- conducting laboratory tests on samples of the selected rocks;
- defining measures to assess influence of temperature on geomechanical parameters of waste rock;
- analysing parameters of selected properties, to determine forecast course of changes in values of particular geomechanical parameters of rocks of different uniaxial compression strength (air-dry state), determined according to M. Bukowska's classification (2012).

An important part of the doctoral thesis was, firstly, showing a potential of using the results of the research in mining practice, through developing a numerical model simulating a UCG process, to forecast stress distribution and displacement around a chamber of a potential georeactor; and, secondly, assessing possibility of determining the value of a coefficient of temperature influence on selected geomechanical parameters of sandstone from Barbara Experimental Mine heated in laboratory conditions and after a process of underground coal gasification.

Following the presented scientific objective, experimental studies were conducted on a few dozens of series of carboniferous rocks, occurring in direct surrounding of coal seams of currently mined stratigraphic groups – claystones and sandstones of different grain size, collected in different areas of Upper Silesian Coal Basin. It means that for the very first time such experimental studies have such a wide scope for the rocks of GZW. Moreover, a new issue raised in the thesis is also to research post-peak failure geomechanical parameters of rocks, obtained in the process of loading samples in a servo-controlled testing machine. Studies of changes in residual deformation and residual strength of the rocks subjected to the influence of temperature, concerning deformability and post-critical bearing capacity, are innovative and deserve special attention in a discussion on stability of carboniferous rock mass after underground coal gasification process.

Chapter 1 of the doctoral thesis describes introduction to the raised research issue, reasons for selecting it. It also characterizes the scientific objectives and the scope of works realised in the doctoral thesis. Chapter 2 presents the current state of the art in the raised issue, including characteristics of underground coal gasification, state of the art in distribution of temperature within the rock mass, as a result of UCG process and influence of temperature on physical properties, including mechanical properties of rocks. Chapter 3 discusses criteria of selecting the research sites, describes rocks collected for laboratory tests to assess changes in their properties under influence of temperature between 100 and 1000-1200°C. Chapter 4 describes methodology of conducting tests of physical properties of the rocks including mass loss and changes in bulk density. In the chapter there is also a description of macroscopic changes in the samples subjected to selected values of temperatures as well as results and an analysis of experimental studies. Influence of temperature on hydrogeological properties (porosity and filtration coefficient) of the tested carboniferous rocks is described in Chapter 5. Methodology of research is discussed there together with results of tests and an analysis of the changes. An important part of the thesis was to determine influence of temperature on geomechanical properties, obtained with a stress-strain curve which was, in turn, obtained in the process of loading rock samples in the full range of deformation in a stiff testing machine. It was the basis for determining forecast coefficient of the influence of temperature (Chapter 6) on stress, stress-deformation and deformation properties preceded with an analysis of influence of temperature on the parameters describing them (uniaxial compression strength, residual strength, Young's modulus, residual

deformation, and transverse deformation), which are described in w Chapters 7, 8 and 9 respectively. The obtained values of coefficient of temperature influence on particular geomechanical parameters may be used to prepare forecasts. Thus, they can be used in mining practice to realize tasks associated with stability of the rock mass resulting from changes in strength, elasticity and deformability of the rocks surrounding coal seams in GZW, which may be considered as potential site of underground coal gasification. The issue is described in Chapter 10. Chapter 11 presents summary of the doctoral thesis and conclusions made basing on the conducted experimental studies.

Results of tests of physical properties of rocks subjected to the influence of selected temperatures showed an increase in mass loss as the grain size of the tested rocks decreased, and in intensity of changes occurring in the temperature ranges specific for them. For the samples of clastic rocks and clayey rocks – sandstones of different grain size heated in the temperature of 600 and 1000°C, in general, a decrease in bulk density was observed when compared with the value of the parameter determined in air-dry state. For medium-grained sandstones, basing on the analysis of value of bulk density obtained after heating the samples to the temperature of 600°C, both increase in bulk density and decrease in the value, in comparison with air-dry state, were observed. It was explained to be associated with mineral transformations occurring at the temperature, particularly with recrystallization of quartz (573°C).

Studies of changes in hydrogeological properties of rocks at selected temperatures (23, 600 and 1000°C) showed, in general, increase in porosity and permeability. Effect of the selected temperature on the tested samples of rocks caused, in general, an increase in open porosity, in comparison with the value determined in air-dry state. The biggest increases in porosity were observed in rocks of relatively low open porosity observed in air-dry state. For samples showing greater porosity in air-dry state, the observed changes, in general, were not big and for temperature of 1000°C they did not differ significantly from the ones determined at the temperature of 600°C. An increase in the values of filtration coefficient after heating to the temperature of 1000°C for claystones did not result in changes in their permeability (the samples remained impermeable). Among sandstones of different grain size it was possible to observe an increase in filtration coefficient up to the value attributing semi-permeable character to them, regardless of their permeability determined at room temperature.

The biggest differences of changes in physical and hydrogeological parameters were observed for sandstones of the youngest lithostratigraphic members.

The obtained results of geomechanical tests – values of stress parameters, stress-deformation parameters and deformation parameters – indicate, that one of the criteria, which have to be taken into account to show differences in behaviour of the tested rocks, as a result of influence of different values of temperature up to 1000-1200°C, is their uniaxial compression strength in so called air-dry state, at room temperature.

At the temperature of 100°C and higher, distinct changes in strength of claystones and sandstones were observed, as their strength determined in air-dry state, at room temperature, increased. Claystones and sandstones of very low and low compression strength strengthen their structure and their strength increases. Claystones of medium and high strength and sandstones of high strength get distinctly weaker in air-dry state and their strength decreases. Only sandstones of medium strength take a position in between them in air-dry state. It refers to sandstones of all three grain sizes. Claystones of high strength decreased their strength starting from the initial temperature of heating and for the temperature of 1000°C they showed distinct and significant decrease in strength when compared with low strength claystones of younger lithostratigraphic members. Sandstones of high strength, in general, show distinct weakening when compared with the strength determined in air-dry state, throughout the range of heating temperature. However, it is possible that single peaks of maximal strength, above the air-dry state strength, occur at higher temperature. The tendencies of changes in strength of carboniferous rocks, resulting from the influence of temperature of between 100 and 1000-1200°C, depend mainly on their initial strength determined at room temperature in so called air-dry state, and they do not depend on their grain size. The higher strength of rocks (claystones or sandstones) occurring in the direct vicinity of a seam is, the worse the conditions of the rock mass after the underground coal gasification process may be. However the conditions do not have to lead to the rockmass destruction around a georeactor. It has certain practical implications for stability assessments of rockmass and mine workings in the vicinity of a georeactor.

For claystones and sandstones of between very low and high strength (according to the classification determined for GZW) there is a forecast increase in the value of residual strength above the value determined at room temperature, in air-dry state conditions, up to the critical temperature specific for them, after exceeding which value of the parameter decreases, compared with the initial value.

Results of studies on Young's modulus for claystones indicate that the border of reducing elasticity of the rocks decreases below the value of elasticity, determined in air-dry state conditions, towards higher temperature as uniaxial compression strength, determined in tests conducted at room temperature, decreases. The type of changes in Young's modulus for the samples of sandstones of different grain size and compression strength, which were heated at the temperature of 1000 – 1200°C is similar to similar changes in uniaxial compression strength of the samples. Tests of very low, low and medium strength sandstones showed that after an initial increase in the value of Young's modulus, after reaching critical temperature, there is a distinct decrease in elasticity of the rocks. Sandstones of high uniaxial compression strength can reach the value of Young's modulus below the value determined at room temperature at the very beginning of heating the samples.

Basing on the tests and analyses of the results, it was concluded that the influence of uniaxial compression strength on the value of residual deformation, when compared with the influence of grain size of sandstones, is unambiguous as far as changes in the parameter, an increase or a decrease in the values, when compared with the results of tests conducted at room temperature, are concerned. An increase in residual deformation accompanying an increase in temperature of heating samples of claystones and sandstones results from, among others, a decrease in elasticity of the rocks in the range of temperature used in the tests.

Claystones of low and medium air-dry state compression strength, up to the value of critical temperature, showed an increase in the value of Poisson's ratio above the initial value. After exceeding critical temperature there was a decrease in the value of Poisson's ratio below the initial value unlike in claystones of high strength, which, throughout the range of temperature, reached values of the parameter below initial value. Sandstones of different grain size increased or decreased the value of Poisson's ratiocomparing to the value determined in air-dry state, at room temperature.

Laboratory tests of claystones and sandstones belonging to different lithostratigraphic members of Upper Carboniferous in GZW showed significant changes in geomechanical properties depending on the temperature forecast in their surroundings. That is why, in the rock mass where the UCG process can take place, thermal stresses resulting from it may affect rockmass stability as a result of unfavourable distribution of stress and the volume of deformation, as it was shown in the results of numerical modeling. Numerical modeling is an example of application of the obtained test results in mining practice, when use of unconventional methods of mining hard coal deposits is considered.