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Deformation properties of sedimentary rocks in the process of underground coal gasification

Mirosława Bukowska [a], *Anna Sygała* [b,*]

[a] *Central Mining Institute, Department of Rockburst and Rock Mechanics, Poland*

[b] *Central Mining Institute, Interdisciplinary Doctoral Studies, Clean Coal Technologies Centre, Poland*

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ABSTRACT

The article presents results of research into changes in deformation properties of rocks, under influence of temperature, during the process of underground coal gasification. Samples of carboniferous sedimentary rocks (claystones and sandstones), collected in different areas of Upper Silesian Coal Basin (GZW), were heated at the temperature of between 100 and 1000–1200 °C, and then subjected to uniaxial compression tests to obtain a full stress-strain curves of the samples and determine values of residual strain and Poisson's ratio. To compare the obtained values of deformation parameters of rocks, tested in dry-air state and after heating in a given range of temperature, normalised values of residual strain and Poisson's ratio were determined. Based on them, coefficient of influence of temperature on tested deformation parameters was determined. The obtained values of the coefficient can be applied in mining practice to forecast deformability of gangue during underground coal gasification, when in the direct surrounding of a georeactor there are claystones or sandstones. The obtained results were analysed based on classification of uniaxial compression strength of GZW gangue, which formed the basis for dividing claystones and sandstones into very low, low, medium and high uniaxial compression strength rocks. Based on the conducted tests it was concluded that the influence of uniaxial compression strength on the value of residual strain, unlike the influence of grain size of sandstones, is unambiguous within the range of changes in the parameter. Among claystones changes in the value of Poisson's ratio depending on their initial strength were observed. Sandstones of different grain size either increased or decreased the value of Poisson's ratio in comparison with the value determined at room temperature in dry-air conditions.

1. Introduction

Underground gasification is one of the promising methods of exploiting hard coal deposits especially where using traditional mining methods is impossible or uneconomic. Benefits of implementing the technology seem to be promising, however, there are still difficult safety issues to solve, before it can be commonly used. One of the issues is influence of high temperature of 1000–1200 °C, on the rocks in the

* *Corresponding author*. Zielonogórska 33/45, 41-218 Sosnowiec, Poland.
E-mail address: asygala@interia.pl (A. Sygała).

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immediate roof of a coal seam. Due to thermal transformation of the surrounding rocks and changes in their geomechanical properties, a mine working may lose its stability. It, in turn, leads to changes in stress and strain in the rock mass, which may result in displacing the surface, contaminating underground waters and even threatening the whole process (Białecka, 2008; Burton, Friedmann, & Upadhye, 2007; Younger, 2011). As the interest in underground gasification technology is growing and there have already been attempts to implement it, as well as other technologies where temperature affects the rock mass, researchers more and more often analyse changes in geomechanical properties of rocks caused by high temperature (Chen, Ni, Shao, & Azzam, 2012; Keshavarz, Pellet, & Loret, 2010; Korzeniowski & Skrzypkowski, 2012; Luo & Wang, 2011; Małkowski, Kamiński, & Skrzypkowski, 2012; Mao, Zhang, Li, & Liu, 2009; Pinińska, 2007; Zhang, Mao, Liu, Guo, & Ma, 2013; Zhang, Mao, & Lu, 2009). Among the tested parameters, literature often mentions influence of temperature on the value of uniaxial compression strength, Young's modulus, stress-strain curve, critical strain and Poisson's ratio. Influence of temperature on the last of the parameters is not so often tested due to difficulties in conducting the test to determine its value and then in interpreting the obtained results. Nevertheless, due to the geomechanical aspect of the process, determining changes in deformation parameters (critical strain and Poisson's ratio) under influence of temperature, is very important. Research into changes in parameters obtained from the post-critical part of stress-strain curve, including values of residual strain, is also very important. There has been no research conducted into the issue so far. Due to insufficient knowledge of changes in deformation parameters under influence of high temperature, the article focuses on changes in the value of residual axial strain and transverse strain expressed with Poisson's ratio.

Among the tested parameters which determine changes in deformation properties of rocks under influence of temperature, the most often referred to ones are changes in the value of critical strain. The changes are determined with pre-critical part of stress-strain curve, obtained during uniaxial compression tests.

Zhang et al. (2013) determined changes in the value of critical strain for samples of mudstones at the temperature of up to 800 °C. Based on the obtained results, they observed an increase in the value of the tested parameter which followed an increase in the temperature. The biggest changes were observed for the range of temperature of 100–400 °C. In the range of temperature, changes were nearly linear, and the change in the value of critical strain reached 70% in comparison with the initial value, which was determined for samples in dry-air state. At the temperature of 600 °C there was a decrease in the value of critical strain, nevertheless, at the temperature of 800 °C its highest value was recorded. Luo and Wang (2011) also conducted research into changes in critical strain for mudstone samples. In their research they heated the samples to 750 °C. Like Zhang et al. (2013), they observed an increase in the value of critical strain. Up to the temperature of 400 °C it fluctuated a lot (decrease, increase or no significant change). Another research conducted by Zhang et al. (2009) on samples of sandstone, limestone and marble, heated up to the temperature of 800 °C, showed differences in behaviour of changes in the value of deformation following increases in temperature, depending on the type of rocks. Values of critical strain for samples of sandstone were higher in comparison with the ones recorded for limestone and marble. The lowest values were observed for the samples of marble. Nevertheless, in all of the three cases, for the temperature of over 600 °C, an increase in the tested parameter was observed, while at the temperature of 800 °C all the types of rocks reached the maximum value of critical strain. Chen et al. (2012), researching changes in critical strain for samples of granite, heated to the temperature of 1000 °C, did not observe any significant changes in its value up to the temperature of 400 °C. At higher temperatures, the value of deformation increased steadily, reaching the highest value after heating the samples at maximum temperature.

The hitherto research into changes in the value of critical strain under influence of temperature shows that, in general, there is an increase in the value following an increase in temperature, although reaching the maximum value, obtained after heating a sample to the highest temperature does not have to be smooth (Fig. 1). Zhang et al. (2013) attribute the phenomenon to mineral changes such as dehydration, recrystallisation or phase transitions, occurring under influence of high temperature, which lead to fluctuations in the value of critical strain. In turn, softening the structure of rocks at the temperature of over 500–600 °C leads to the rocks becoming less brittle and more plastic, which results in an increase in its deformability (Luo & Wang, 2011; Mao et al., 2009; Ranjith, Viete, Chen, Samintha, & Perera, 2012).

Research works into changes in the value of transverse strain, expressed with the value of Poisson's ratio, under influence of temperature are rare (Brotóns, Tomás, Ivorra, & Alarcón, 2013; Korzeniowski & Skrzypkowski, 2012; Wu, Wang, Swift, & Chen, 2013), in comparison with research into changes in critical strain. Due to insufficient data and major differences in the obtained results, drawing constructive conclusions, concerning influence of temperature on the value of Poisson's ratio, poses a significant problem and requires further studies of the issue.

2. Methodology

Samples of sedimentary rocks (rock core, 30 mm in diameter and 60 mm in high) represented claystones and sandstones of different grain size. The rocks included main lithologic types occurring in direct vicinity of coal seams deposited in Upper Silesian Coal Basin. The samples were collected in mine workings and bore holes, in all the currently mined coal-bearing stratigraphic groups of GZW carboniferous. In total, 31 series of rocks: 8 series of claystones, 4 series of coarse-grained sandstones, 10 series of medium-grained sandstones and 9 series of fine-grained sandstones, were collected.

The samples prior to the tests were heated at the temperature between 100 and 1000 °C for 8 h and 1200 °C for 24 h. In each of the series of rocks, samples were selected for tests in dry-air state, at room temperature, without prior heating. Within the series, for each of the temperature ranges (from room temperature to 1000 °C) up to 6 samples were tested.