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Stress-strain characteristics as a source of information on the destruction of rocks under the influence of load

Anna Bogusz[*], *Mirosława Bukowska*

Department of Rockburst and Rock Mechanics, Central Mining Institute, Katowice, Poland

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ABSTRACT

This paper presents the problems associated with the complete stress-strain characteristics of the destruction of rocks under load, in the full range of their strain. The most important factors influencing the course of a stress-strain curve are discussed, i.e.: the shape and size of samples and the conditions experienced when conducting the experiment in a testing machine. Presented mechanical and energy parameters were obtained in laboratory tests carried out by loading rock samples in a servo controlled testing machine as well as some indices devised on the basis of these parameters. The interpretation of complete stress-strain characteristics allow solve various issues connected with underground mining, especially assessing natural hazards which are common in underground mining for minerals, as well as designing and managing mining works within underground workings.

1. Introduction

In natural conditions a rock is subjected to load, resulting from the influence of the other rocks surrounding it. Due to load displacements and strains in their structure, the destruction of rocks takes place. Using modern research methodology and appropriate equipment, it is possible to create a model showing the destruction of rocks in laboratory conditions and therefore conduct tests on the destruction of rocks whilst experiencing a range of different forms of stress, i.e. compressive, tensile, bending, and shear stress. Using a testing machine and destroying rocks in different load systems provides insight into the processes that lead to their destruction. When testing under compressive stress states, the system of 'plates of a testing machine – compressed rock sample' is the simplest model of rock mass, where the sample is a model of a pillar, for example, and the plates of the testing machine represent layers of rocks above (roof) and below (floor). By inputting a rock sample in to a testing machine we get a representation of its destruction in the form of a stress-strain curve. The shape of the curve depends on the petrography of the rock and for samples of the same type of rock it depends on a range of factors. The most important of these being: the size and shape of samples, the method used to control the stiff testing machine, the strain rate applied during tests and the moisture content of the rock tested. Using the stress-strain curve values of mechanical parameters, including those of stress-strain and energy, are determined. The information, obtained from analysing the course of destruction samples of rocks in different loading conditions, is

* *Corresponding author*. Tel.: +48 32 259 21 14; fax: +48 32 259 23 61.
E-mail address: abogusz@gig.eu (A. Bogusz).

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used to solve problems associated with geoengineering and mining. The example presented in this paper is: the use of a stress-strain curve interpretation in mining practices to determine rock and rock mass susceptibility to rock bursts.

2. Stress-strain characteristics of rocks – selected problems

We obtain the stress-strain curves of rocks in tests conducted with testing machines. Until the 1970s research was conducted in so-called 'soft' testing machines. The tests represented the increasing of stress-strain characteristics, eventually reaching the value of maximal stress (where the destruction of rocks takes place) (Wawersik & Fairhurst, 1970).

Bieniawski's research (1970) enabled the stress-strain characteristics of a compressed rock sample in the full course of its strain to be obtained. The full characteristics were obtained through testing rock samples in servo controlled testing machines. To obtain the full course of destruction of a sample in a testing machine a number of conditions must be met. The machine has to be sufficiently stiff in relation to the rock sample, and the hydraulic system supplying the machine has to be sufficiently efficient.

Stress-strain characteristics obtained during tests on a rock sample in a servo controlled testing machine have a non-linear course and consist of an increasing and decreasing part. The rising part of the stress-strain characteristics reflects the pre-critical phase, when there is an increase both in stress and strain until the compressed sample reaches the value of maximal stress. In the decreasing part of stress-strain characteristics, which we call the post-critical phase, there is a decrease in stress until it reaches the value of residual stress. A decrease in stress in the post-critical part is accompanied with an increase in strain until the value of residual strain is reached.

Stress-strain characteristics of rocks are not linear, as rocks are not linearly deformable. To determine the values of some of the mechanical parameters of the stress-strain curve, in its pre-critical phase (Ulusay & Hudson, 2007) and post-critical phase (Bukowska, 2013), are represented by straight lines.

The course of stress-strain characteristics is different for different rocks and depends on numerous factors including the conditions in which the experiments were conducted and the size of the samples. Numerous researchers have described stress-strain characteristics of rocks by using a compression test in a stiff testing machine since the 1960s (Cook, 1965; Wawersik & Fairhurst, 1970; Peterson, 1978; Okubo & Nishimatsu, 1990; Bezat, 1987; Pells, 1993).

Many years of research into the strength and deformability of rocks under uniaxial compression and conventional triaxial compression shows that there are multiple stages of strain in rocks across their full stress-strain characteristics.

In the pre-critical part of a stress-strain curve we can distinguish three main stages of the destruction of a rock sample (Fig. 1):

- Stage I – the clamping and sealing phase. The plates of the stiff machine adjust to the surface of a sample, and the rock stiffens as pores and micro-cracks close.

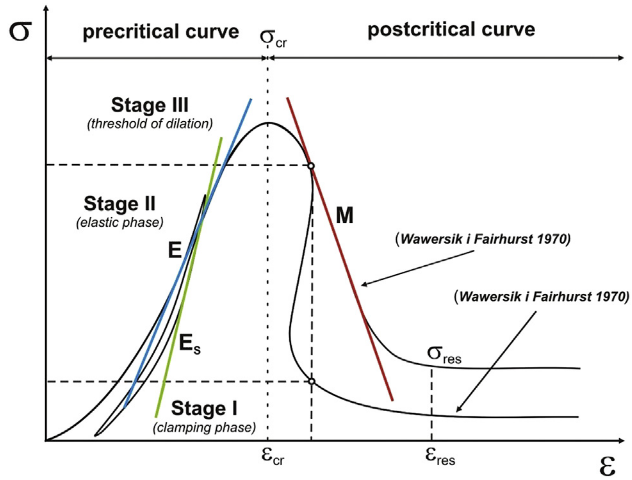

Fig. 1 – Ideal stress-strain characteristics obtained in a servo controlled testing machine during a uniaxial compression test: σ – stress; ε – strain; σ_{cr} – critical stress; σ_{res} – residual stress; ε_{cr} – critical strain; ε_{res} – residual strain; E – Young's modulus; E_s – elasticity modulus recovery; M – post-peak failure modulus.

- Stage II (elastic phase) – the course of the curve is linear.
- Stage III – starting with the threshold of dilation and finishing when the sample reaches its maximal strength. The course of a stress-strain curve in this phase is non-linear. The angle of inclination of the tangent to the stress-strain curve decreases, illustrating a more dynamic increase in strain in relation to stress. Additionally we can observe here a significant increase in transverse strain, and a rapid increase in volumetric strain. The phenomenon in Stage III is associated with an anomalous, in elastic increase in the volume of rocks resulting from compressive load. Moreover, Stage III is the beginning of the process of destruction the structure of the rock.

Based on tests conducted under axisymmetric compressive stress we devised a more complex description of strain in a sample in the pre-critical phase, and more stadia of the strain. The stadia of rock strain under axisymmetric compressive stress, including longitudinal strains, both transverse and volumetric are presented in Fig. 1.

- Stadium I – the non-linear strain of rock. The influence of differential strain causes the closing of micro-defects and micro-cracks. Initially, all the characteristics are non-linear. In later stadia of loading a rock sample there may be a linear dependence between stress and transverse strain.
- Stadium II – the linear strain of rock. Moduli of longitudinal strain and transverse strain have a constant value.
- Stadium III – linear longitudinal strain, non-linear transverse strain and volumetric strain. In the initial phase of the rock destruction process a propagation of primary micro-cracks, present in the rock, occurs. The relative dilation process begins. The threshold of relative dilation occurs at a value of between 0.3 and 0.6 of critical stress.