International Journal of Mining Science and Technology 24 (2014) 747–754

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

In situ strength of coal bed based on the size effect study on the uniaxial compressive strength

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ARTICLE INFO

Article history:
Received 18 January 2014
Received in revised form 10 March 2014
Accepted 22 May 2014
Available online 14 November 2014

Keywords:
Size effect
In situ strength
Coal seam
Irapua

ABSTRACT

In the early 1990s, the Foundation for Science and Technology of Rio Grande do Sul State (CIENTEC) developed a pioneering study in Brazil, related to the simultaneous mining of multiple coal seams. One of the activities included detailed studies on the geomechanical characterization of materials present in the Irapua coal seam, under exploitation in the A-Sangao Mine, located near the city of Criciuma-SC, within the South-Catarinense coalfield. The goal of the laboratory tests was to define the behavior of the uniaxial compressive strength of the Irapua coal seam and establish a first approximation for the in situ strength value of this coal seam, since existing knowledge is solely based on practical mining experience over the years. Large samples of the coal seam were collected, using special techniques to maintain the integrity of the material, and a set of 56 uniaxial compression tests in cubic specimens, with side length ranging from 4.5 to 31 cm, were conducted in laboratory. This paper describes the experimental techniques used in the assays, and also presents the uniaxial compression strength results obtained. Moreover, important aspects of this type of study are considered, highlighting the size effect for the carbonaceous bed and the estimation of in situ strength values for the Irapua coal seam.

1. Introduction

Almost all of the scientific production on what is still considered the art of scaling pillars in coal mines, originated in the U.S. and South Africa countries, where underground coal mining, by the chamber and pillar method, surpassed 90% of the total amount produced until the early 1990s.

Considering the two necessary parameters for the analysis of the safety level of a pillar-strength and load-the first is the one that has deserved the most attention from many researchers who have dedicated themselves to this subject, and the latter, for practical purposes, is basically restricted to the application of tributary area theory.

Pillar resistance, defined by the maximum load supported by unit of area, depends on at least three basic elements:

– The size effect;
– The shape effect;
– The properties of the rock that forms the pillar and the host rocks.

In summary, the size effect implies higher strength values for samples tested in laboratory, when compared to that of real pillars. This increase in strength is attributed to the lower presence of surfaces of weakness in the samples used in laboratory tests, since the small dimensions used do not entirely represent the mass that originated them.

In the case of carbonaceous rocks, the definition of the characteristic strength of the coal seam is of paramount importance, since it is the very rock that composes the support structures (pillars) of the excavations from where the ore is extracted. In this type of rock, this is a complex task, since the size effect seems to be even more pronounced that in other materials, due to the formation characteristics of the coal, as reflected by the presence of small to large geological structures, such as cleats, bedding planes, fractures, faults and inclusions of material other than coal.

Different techniques for the estimation the in situ strength of the coal seam can be used. The technique of laboratory tests with small samples is among the less costly ones from the economical point of view; however, it is limited due to the low representation of the lithological variations and structural characteristics of the rock mass. When there is access to the coal seam, using larger samples than those obtained from borings is more desirable and tends to substantially help in the understanding of the mechanical

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http://dx.doi.org/10.1016/j.ijmst.2014.10.003
2095-2686/

behavior of the rock in order to estimate the in situ resistance with reasonable accuracy.

The use of laboratory testing technique, with variable sample sizes, has been done by many researchers worldwide for over 100 years of research. Studies on mineral coal have been conducted since approximately 1875 [1]. Steart, based on laboratory testing in small samples and underground observations, and Gaddy, individually studying several layers of American coal, concluded that the strength behavior is inversely proportional to the size of the sample [2,3]. They suggested the following generic function to explain this behavior:

$$\sigma_c \propto \frac{k}{D^{\alpha}}$$

where σ_c = uniaxial compressive strength of a cubic test specimen; k = constant dependent on the physical characteristics of each coal seam; D = size of the tested cubic test specimen; α = coefficient corresponding to the size effect for the studied coal seam, with a values of 0.5 representing the mean for the different studied layers.

Regarding British coals, Evans & Pomeroy conducted a large amount of uniaxial compression tests, using cubic test specimens, with base sides ranging from 0.3 to 5.4 cm and prismatic ones, with base sides ranging from 1.3 and 5 cm and height between 1.3 and 5.4 cm [4]. Bieniawski in turn, reports an extensive study conducted in South Africa, with samples from the Witbank coal seam [5]. This author was one of the first to study the size effect to uniaxial compressive strength in coal based on tests on cubic test specimens, with sizes comprised within a wide range-from 2 to 2 m-and all tests were conducted with underground infrastructure. For him, the decrease in strength as a function of the increase of the sizes of the test specimens is associated to the greater probability of more discontinuities in larger test specimens than in smaller ones. The approach by Protodiakonov & Koifman suggests some explanations for the decrease in rock strength with the increase in volume of the tested sample, shown in Fig. 1a: the "volume effect" and the "surface effect" [6].

In Brazil, the first studies with coal using scientific techniques come from the early 1980s, with emphasis on the laboratory and in situ work developed by the Institute of Technological Research of the State of Sao Paulo (IPT) in the coal from the I_1F layer, and by the Foundation for Science and Technology of Rio Grande do Sul State (Cientec) [7,8]. Cientec studies, in about 1300 test specimens, covered the most important coal seams under underground exploration at the time or with future potential. This work was pioneering for the definition of in situ strength of the I_1F layers (Charqueadas deposits, in Rio Grande do Sul state) and Barro Branco (South-Catarinense deposit, in Santa Catarina state), in

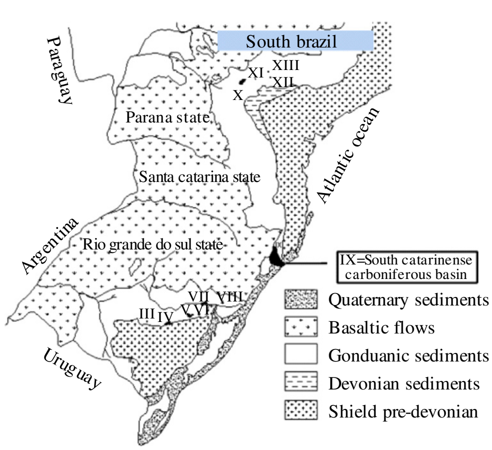

Fig. 1. Geological map of South Brazil (Numbers from I to XIII indicate known carboniferous Basin in Brazil) [11].

addition to serving as a base for the proposal of a methodology for pillar sizing applied to southern Brazil coal seam conditions [9]. Once the technique of laboratory tests was defined as the path chosen for estimating the in situ strength, the representativity of the samples regarding a particular rock mass is an important factor for the application of the results in the sizing of the underground structures. Generally, the ideal size (theoretical) runs into the limited operational capacity of the equipment available for the extraction as well as the performance of the laboratory tests.

The following topics show the results from studies conducted for the estimation of the in situ strength of the Irapua coal seam of the A-Sangao Mine, located in the South-Catarinense coalfield in southern Brazil, during the development of MULTICAMADAS project [10]. The work performed to prepare the specimens, equipments and the results are described. Finally, an estimation of the in situ strength of Irapua coal seam is suggested to use in the analytical models to pillar dimensioning.

2. Geology of study area

Geographically, A-Sangao Mine is located within the South-Catarinense coalfield, which is part of the Eastern Edge of the Parana Basin, as seen in Fig. 1. This basin, which in Brazil spans over several other states, is of Devonian age for its oldest sedimentary deposits and has the evolution characteristics of an intracratonic basin. Within the stratigraphic sequence, the carbonaceous lithologies are linked to the units called Itarare Group (more basal) and Guata, with ages between the Upper Carboniferous and Upper Permian. But it is in the Guata unit that the thicker coal seams are located, of better quality and under exploitation. Among the seven individual coal seams in the State of Santa Catarina, three have more expressive economical importance: Barro Branco, Irapua and Bonito seams.

The structural conditioning found throughout the Parana Basin is represented by normal faults, with subvertical planes. Thrust faults rarely occur, with little tailing. The presence of "slickensides" caused by differential sediment compaction is frequent. Fracture systems can follow faults, forming conjugated systems, filled or not by diabase dikes. The folds seen in some coal seams are associated to "drag fold" faults. However, folds caused by compressive stress fields are rarely found.

Stratigraphically, the Irapua layer is below the Barro Branco layer. The thickness of the cover ranges between 95 and 145 m, increasing to thicker coverage as the layer approaches the flows from the Serra Geral Formation. The sterile interlayer interval ranges between 12 and 16 m, with an average thickness of 13 m. Fig. 2 shows a typical profile of the Rio Bonito Formation and the Irapua coal seam in the study area.

The Irapua layer is of restricted occurrence and appears on plant view in the shape of a string, composed by isolated segments, with no apparent continuity. In profile, it shows a flat-bottomed trough shape, where the layer tapers towards one of the flanks. In some places of the mine, this shape is well defined by changes in the dipping of the floor or roof planes of the coal seam, reaching 10° of dipping, with thickness variations of more than 1 m. Its contacts with the floor and roof sandstones are sharp, forming well defined partition planes. This trough shape is associated to the possible tuff deposition in paleochannels. The mining area where this study was developed is located in one of these paleochannel segments. The average thickness in the mined section is 1.77 m, reaching 2.60 m in some localized points.

3. Sampling and preparation of cubic test specimens

The samples were collected during the mining of the Irapua seam. With the aid of a universal cutter, blocks of up to 0.4 m^3 of