Available online at www.sciencedirect.com
ScienceDirect
International Journal of Coal Geology 68 (2006) 196 – 204
International Journal of COAL GEOLOGY
www.elsevier.com/locate/ijcoalgeo

Uniaxial compression and tension tests of anthracite and loading rate dependence of peak strength

S. Okubo *, K. Fukui, Qi Qingxin

Department of Geosystem Engineering, The University of Tokyo, Bunkyo-ku, Hongo, Tokyo 113-8656, Japan

Received 7 December 2005; received in revised form 13 February 2006; accepted 19 February 2006
Available online 17 April 2006

Abstract

The mechanical characteristics of coal under uniaxial compressive stress and uniaxial tensile stress are key factors in investigations of the stability of galleries and coal faces, and are vital considerations for the efficient design of coalmines, disaster prevention, and environmental preservation. These mechanical characteristics have long been a topic of research, but remain insufficiently understood. In this study we performed uniaxial compression tests and uniaxial tension tests on coal, with particular attention to two concerns. The first was to measure the loading rate dependence of the peak strength of coal. Coal shows high sample-to-sample scatter in strength; test methods that are successful in comparatively homogeneous rock types cannot be used for coal. We therefore used an alternative test method that was recently developed by the authors. Anthracite samples were subjected to alternating slow and fast strain rates. Measured variations in stress during this process were used to estimate the loading rate dependence of peak strength. The second objective was to obtain complete stress–strain curves for coal under uniaxial tensile stress. It is difficult to hold samples secure during a tensile test; consequently, such curves have yet to be obtained. This study presents a successful application of the authors' method to the analysis of coal samples, yielding a complete stress–strain curve under tensile stress. The two methods presented here hold promise for application not only to anthracite but also to a wide variety of coals. It is possible to derive the values of the constants used in constitutive equations from the obtained experimental results. Once these equations are determined, they can be incorporated into finite-element software to investigate various time-dependent behaviors of coal and aid in the efficient design of coalmines and the prevention of subsidence and mine disasters.

Keywords: Anthracite; Loading rate; Strain rate; Tensile strength; Complete stress–strain curve

1. Introduction

Research has long been conducted on the uniaxial compressive strength of coal (Evans et al., 1961), and particularly interesting results have been obtained concerning the effect of sample dimensions on measured strength (Bieniawski, 1968; Mark and Barton, 1996). The tensile strength of coal has mainly been determined (Evans, 1961) using the indirect tension test (Bernbaum and Brodie, 1959) or the bending test (Pomeroy and Morgans, 1956). Few recent reports describe improved modern equipment or measurement methods, as research on coal strength peaked several decades ago. There remain many unexplained features of the long-term stability of galleries and of the close relationship between ground subsidence following

* Corresponding author. Tel./fax: +81 3 5841 7066.
E-mail address: ttokubo@geosys.t.u-tokyo.ac.jp (S. Okubo).

0166-5162/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.coal.2006.02.004

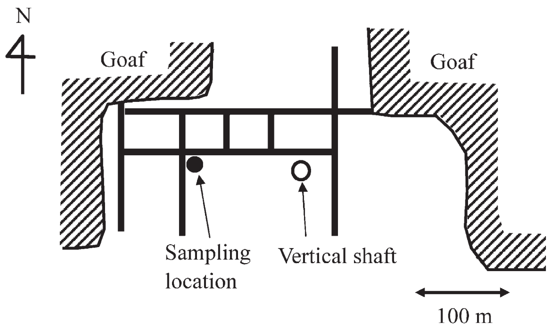

Fig. 1. Map view of mine layout in the area of the sampling location.

mining and the time-dependent behavior of coal, to name just two examples. As an example of outstanding problems in this field, there are almost no published reports concerning the behavior of coal under uniaxial tensile stresses: a key parameter in roof fall. Even such fundamental data as the complete stress–strain curves of coals remain poorly understood, let alone the load rate dependence of peak coal strength.

In the present research we used a servo-controlled testing machine to conduct uniaxial compression and uniaxial tension tests. We used the method developed by Okubo and Fukui (1996) for the uniaxial tension test, and subsequently obtained a complete stress–strain curve. The strain rate was varied during both the compressive and tensile strength tests, and the resulting increase or decrease in stress was monitored to estimate the loading rate dependence of peak strength. This method was recently developed by Hashiba et al. (2006), and enables the calculation of the complete stress–strain curve from a single specimen. As reported previously (Shin et al., 2005), the experience of these authors in measuring rock strength indicates a close relationship between the dependence of peak strength on loading rate and the stress dependence of creep lifetime, as well as other time-dependent properties of rock.

2. Sample preparation

The Jurassic anthracite used in the current tests was obtained by a subsidiary of Beijing Coal Group Company from a mine located approximately 26-km west of Beijing, China. Development of this mine began in 1921 and it reached a peak annual production of approximately 1.2 Mt during the 1970s (Okubo et al., 2002a).

The sample blocks were taken from near the center of the mine, approximately 350 m below ground level and 130 m below sea level. The coal seam dips at approximately 15° and is approximately 2.2 m in thickness. The sampling location, as shown in Fig. 1, had been mined using the room and pillar method. Five sample blocks were taken from a pillar using a coal pick and finished by hand so as to achieve a smooth condition as possible. Of the five collected samples, block #2 was used in this study.

The sample blocks are rectangular prisms of 15–25 cm length on each side. The blocks contain a bedding plane, a major cleat, and a minor cleat, as shown in Fig. 2. The major cleats occur at intervals of 2–10 mm, and the minor cleats at a large interval of 3–30 mm.

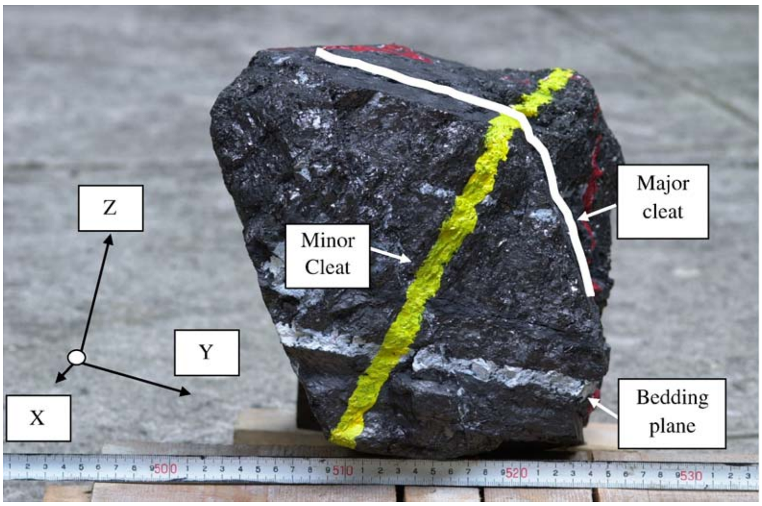

Fig. 2. Photograph of coal block #2. Lines upon the sample indicate the bedding plane (perpendicular to the *Z*-axis), the major cleat (perpendicular to the *X*-axis) and the minor cleat.