International Journal of Rock Mechanics & Mining Sciences 76 (2015) 237–242

Contents lists available at ScienceDirect

International Journal of Rock Mechanics & Mining Sciences

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

Technical Note

# A study of hardness and fracture propagation in coal

Matthias Klawitter*, Joan Esterle, Sarah Collins

*School of Earth Sciences, University of Queensland, Steele Building, St Lucia, Brisbane QLD 4072, Australia*

ARTICLE INFO

*Article history:*
Received 14 February 2014
Received in revised form
1 September 2014
Accepted 24 February 2015
Available online 13 April 2015

*Keywords:*
Coal Properties
Surface Hardness
Shore Scleroscope Rebound Hardness
Breakage Behaviour
Fracture Propagation

ABSTRACT

The surface hardness of coal was estimated using a Shore Scleroscope Rebound Hardness (SSRH) tester. SSRH can be related to fracture toughness and strength, and was trialled as a quick field test to illustrate variability in these properties for coal seam gas reservoirs. Therefore, samples were selected to include different coal ranks and lithotypes from a suite of boreholes that intersect Permian coal seams within the Bowen Basin in Queensland, Australia. The tests were conducted unconfined on slabbed coal core and confined on epoxy encased coal blocks used for coal petrographic examination. The test results of the unconfined samples show that the hardness varies with lithotype. It increases with decreasing amount of bright bands, moreso than coal rank or thermal maturity. The test results of the confined samples show little variation with lithotype, but show a parabolic correlation of hardness with rank, similar to the behaviour found with Hardgrove Grindability tests. The resulting fractures of the SSRH test were analysed under the microscope to understand the fracture pattern, which can be scaled up to understand fracture propagation in natural systems and when induced in gas reservoirs.



## 1. Introduction

Coal is a heterogeneous material, which fractures naturally [1] and its properties are related to its lithotype (organic composition), rank (thermal maturity) and grade (mineral matter content) [2]. Therefore it is important to sample for these differences in any study of surface hardness to determine predictive relationships between these parameters. These relationships can also relate to fracture toughness and strength, which are useful factors for coal drillability, fracture stimulation, breakage and grindability.

Surface hardness is a physical property of rocks and can be tested using a Shore Scleroscope Rebound Hardness (SSRH) tester, a low budget method, which has been accepted as a non-destructive and convenient technique for rock hardness estimation [3]. The “Rebound Hardness Tester” from IMAI SIKENKI CO., LTD., Tokyo (Nov. 1970, No. 70756) has been employed in this study.

## 2. Geological setting of samples

Samples were collected from the Early Permian to Middle Triassic Bowen Basin that is located in eastern Queensland and northern New South Wales in eastern Australia. It is the northernmost basin of the Sydney – Gunnedah – Bowen basin system and developed over a period of approximately 70 Ma (from 300 to 230 Ma) [4,5]. The northern Bowen Basin comprises three coal measures (CM) of the Blackwater Group, which are termed Moranbah Coal Measures (MCM), Fort Cooper Coal Measures (FCCM) and Rangal Coal Measures (RCM) (from bottom to top). These Permian coal accumulations are known to contain large volumes of coal seam gas (CSG) and are main exploration targets for CSG production. Further most of the Gondwana coals are ranked as bituminous coals, although anthracites do occur [6]. A linear decrease of the coal rank was determined to the north and east of the studied area [7–9].

## 3. Testing

### 3.1. Methodology

Hardness is known as a function of the elastic resistance of a surface to local compression and can be measured by e.g. a scratch, rebound, impact or indentation hardness test [3,6]. The Vickers microhardness technique is commonly employed to quantify the surface hardness of coal and can be related to coal rank [6,10]. However, the goal of this study was to investigate an alternative field method to estimate the surface hardness on slabbed core, which could be employed during exploration on unconfined samples or samples prepared for other purposes, e.g. petrography. After attempts to measure the coal's hardness using a Schmitt Hammer and Point Load Tester failed due to coal's brittleness, the SSRH was selected. The tester consists of a diamond tipped hammer, which falls down freely from a predetermined height onto the sample's surface [11–13]. After

* Corresponding author. Tel.: +61 4 3553 8640.
*E-mail address:* m.klawitter@uq.edu.au (M. Klawitter).

http://dx.doi.org/10.1016/j.ijrmms.2015.02.006
1365-1609/

impacting the specimen's surface the hammer recoils and the maximum resulting distance of the rebound is measured. The calibrated scale gives a value of the hardness number in its own units between 0 and 140 [3]. The hardness is influenced by rock mineralogy (in this case coal lithotype), elasticity and competency [13], which could lead to a variation of the SSRH measurements even tested on the same sample's surface [3,14]. Therefore, for representative results and according to the International Society of Rock Mechanics (ISRM) suggested method, at least 20 measurements should be taken randomly on each sample's surface [3,12,13,15]. Moreover, measuring the exact location twice should be avoided since the specimen is damaged. The most reliable results are obtained when measurements are made on a flat, polished surface perpendicular to hammer trajectory, but this requires sample preparation. The position of the tester should be calibrated to the vertical by adjusting the level vial before using. The difference in surface strength determines the height of the resulting rebound.

### 3.2. Sample preparation

The SSRH was tested on unconfined, slabbed core – (Fig. 1) and confined epoxy block (Fig. 2) samples selected from a suite of boreholes that intersect a range of coal seams with variable rank, grade and type that occur in the Permian coal seams of the MCM, FCCM and RCM.

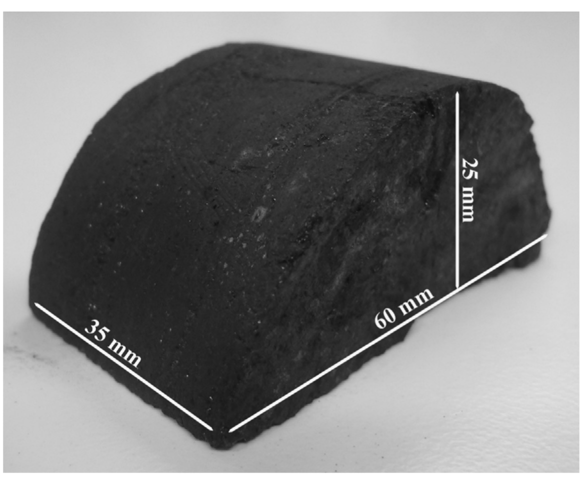


**Fig. 1.** Unconfined sample.

219 unconfined samples without any preparation were tested parallel and perpendicular to the banding. The samples were taken directly from the slabbed core and met the critical sample volume of $> 80\ cm^3$ according to ISRM (2006). Due to the uneven surface of the samples perpendicular to the banding the SSRH was often measured as zero (0) and therefore excluded as not reliable. Hence the SSRH results measured perpendicular to the banding were not further considered in this study.

Additionally, 70 samples were cut in order to fit $30 \times 50\ mm^2$ moulds, embedded into epoxy and dried for 24 h. Afterwards these samples were ground and final polished to 0.04 μm to obtain a flat mirror surface for petrographic analysis. This study opportunistically tested these blocks, but due to the preparation these confined samples were only tested parallel to the banding. Although the critical volume of the prepared samples did not meet the specifications according to ISRM (2006), all samples were prepared and tested equally. As the objective was to illustrate the effect of type and rank on hardness, these results were comparable and fit for purpose.

## 4. Results

### 4.1. Unconfined samples

20 measurements of each of the 219 unconfined samples were taken parallel to the banding and averaged to receive comparable

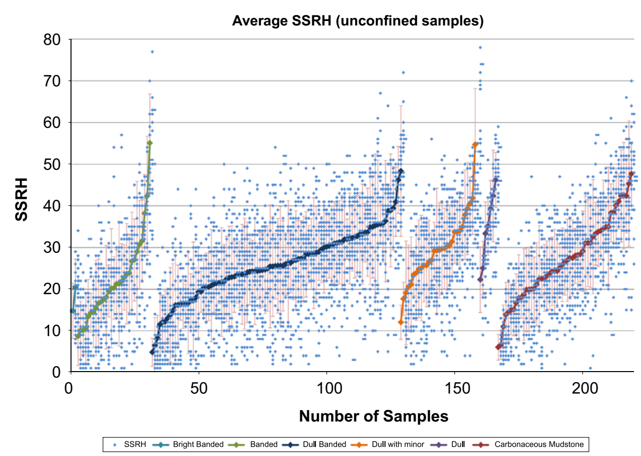


**Fig. 3.** Average SSRH values for each of the 219 individual unconfined samples. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

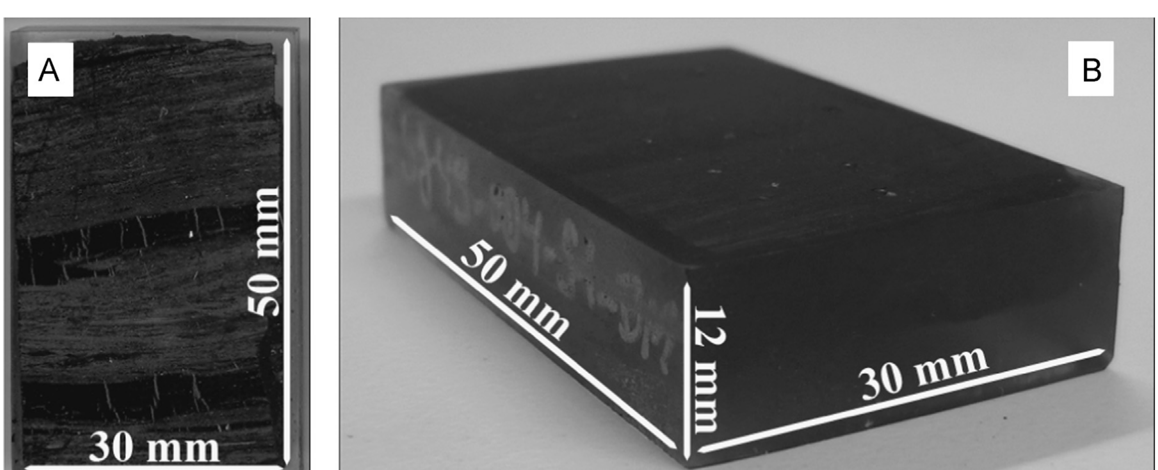


**Fig. 2.** Confined sample (A) surface; (B) edge of specimen.