Engineering Failure Analysis 54 (2015) 150–162

Contents lists available at ScienceDirect

Engineering Failure Analysis

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

Fracture failure analysis of hard–thick sandstone roof and its controlling effect on gas emission in underground ultra-thick coal extraction

Wei Wang, Yuan-ping Cheng *, Hai-feng Wang, Hong-yong Liu, Liang Wang, Wei Li, Jing-yu Jiang

Faculty of Safety Engineering, China University of Mining & Technology, Xuzhou, Jiangsu 221116, China
National Engineering Research Center of Coal Gas Control, China University of Mining & Technology, Xuzhou, Jiangsu 221116, China

ARTICLE INFO

Article history:
Received 3 December 2014
Received in revised form 17 April 2015
Accepted 23 April 2015
Available online 28 April 2015

Keywords:
Hard–thick sandstone roof (HTSR)
Fracture failure analysis
Super great mining height (SGMH)
Strata pressure behavior
Abnormal gas emission

ABSTRACT

In underground coal extraction of fully mechanized caving, the overlying hard–thick sandstone main roof could control the failure extent and the movement evolution of the entire overburden strata. The instantaneous failure of the hard–thick sandstone main roof possibly causes strata pressure behaviors, rock-bursts and abnormal gas emissions, which may result in equipment damages and casualties. Tashan coalmine was chosen as a field case study base because of its super great mining height (SGMH) and the overlying hard–thick sandstone roof (HTSR). This mine has experienced a great deal of damaging hydraulic support and abnormal gas emission accidents caused by strata pressure behavior. The fracture failure analysis was analyzed based on "Key Strata Theory" and numerical simulation results. The hard–thick sandstone main roof could perform as a very large double-sided embedded rock beam in the primary fracture and as a cantilever-articulated rock beam in periodic fracture, simultaneously generates a huge hanging space in the gob. The fracture failure of the hard–thick sandstone main roof causes a permeability enhancement in the adjacent rock-coal strata and near face coal seam. The substantial amounts of gas stored in the remaining coal, surrounding rock strata and adjacent coal seams rush out and aggregate in the caved and fissure zone of the gob, thereby forming a huge gas cloud. The disasters due to coupled strata pressure behavior and abnormal gas emissions, which primarily occurred after primary and periodic fracture failure, are predominantly caused by the instantly fracture of main roof. When the main roof reached the ultimate broken span and underwent, rotation and collapse, substantial amounts of gas accumulating in the gob escaped to the working face under the extrusion and impaction of the caving rock strata, which easily produced abnormal gas emissions, some of which exceeded the statutory limit. Shortening the length of the HTSR failure span using hydraulic presplitting and decreasing the gas content of the coal seam using gas drainage technology are recognized as two effective approaches to solve this issue.

* Corresponding author at: Faculty of Safety Engineering, China University of Mining & Technology, Xuzhou, Jiangsu 221116, China. Tel.: +86 516 83885948; fax: +86 516 83995097.

E-mail addresses: Chengypcumt@hotmail.com, cumtwangdavy@hotmail.com (Y.-p. Cheng).

http://dx.doi.org/10.1016/j.engfailanal.2015.04.016

1. Introduction

With the rapid development of mechanical mining equipment, the fully mechanized caving with super great mining height (SGMH) technique has been extensively used in China as an advanced underground coal extraction method with high recovery and efficiency [28]. Hard–thick roof is usually the main factor that causes excessive stress concentration and induces dynamic strata behaviors [12]. Dynamic stressing produced by key strata strenuous movement and fracture in roof caving zone can easily trigger the strong mining tremor (even rock-burst disaster) [16]. The mining-induced rock-bursts and earthquakes could indirectly trigger unusual gas emissions, and gas bursts could also trigger rock-bursts, which are referred to as gas outburst rock-bursts [15]. Due to the super great mining height and the hard–thick sandstone roof, the mining-induced strata deformation and failure area extended, the span and value of peak abutment stress enlarged, the height of caving and fissure zone increased. A series of health and safety hazards has been reported, such as hydraulic support damage, rock-burst and mine earthquake, coal and gas outburst, and abnormal gas emission. Under fully mechanized caving of the overlying hard–thick sandstone roof, the roof does not cave in a continuous manner respective to time and consequently forms a large overhang rock beam containing induced stress and concentrated energy. The accompanying dynamic load can cause rock burst or mine earthquakes. Furthermore, the roof rock debris falls at a high velocity due to the great height of the hanging space, and the temperature increase or spark which caused by the vibration and collision of roof rock debris may induce gas ignition even explosion [26,35,37]. Rock bursts easily lead to other mine disasters, the most serious of which is abnormal gas emissions. There have been numerous reports of such events. In Germany, Hauula Trask coalmine (1955) and Ruhr Coalfield (1981) were the sites of abnormal gas emission incidents accompanied by mine earthquakes [2,3]. In China, abnormal gas emissions following rock-burst occurred in the Huaibei coalfield and Fuxin coalfield [25]. Those accidents had the same characteristics of abnormal gas emission and rapid gas accumulation following rock-bursts, which were subsequently detonated by open lights or sparks from the mining.

In recent years, an increasing number of studies of mining-induced stress redistribution, overlying rock strata failure and gas emission have been performed with consistent results [34,24,33]. Nie et al. [19] developed a computerized tomography (CT) scanning experimental system to observe the meso-structure and fracturing in coal. Cai et al. [5] reported that the large quantities of gas emitted after weighting are the result of the joint action of abutment stress redistribution and main roof fracturing. Li et al. (2008) concluded that the large quantities of gas emission after weighting are caused by a flow increase effect induced by pressure relief. Weng et al. [27] concluded that the predominant destruction of the coal-rock mass occurs slightly earlier than the period of weighting, whereas the peak gas emissions occurs slightly later than the period of weighting. However, there has been little investigation of the interactional influence of coal-rock strata movement, strata pressure behavior and gas emissions in fully mechanized caving with SGMH.

Most naturally occurring underground rock masses associated with coal measure strata consist of intact rock with discontinuities that include fissures, fractures, joints, faults, bedding planes and shear zones (Wang et al., 2013). The distinct element method [8] and discontinuous deformation analysis have the capability of simulating large displacements and rotations and are suited to discontinuum analysis of underground fully mechanized caving coal extraction. In this paper, a three-dimensional numerical model developed by 3DEC was used to investigate the fracture failure process of the hard–thick sandstone roof and its controlling effect on the adjacent coal seams and rock strata. In the middle of 1990s, Qian et al. [21] proposed the "Key Strata Theory" in strata control, the stratum which controls the movement of the whole or partial overburden strata is defined as the key stratum (KS), when the KS breaks, the whole or part of overburden strata above KS will subside simultaneously. Based on "Key Strata Theory" and numerical simulation results, the structural characteristics of the very large double-sided embedded rock beam performed in primary fracture and the cantilever-articulated rock beam performed in periodic fracture are analyzed. This paper studies the abutment stress field distribution, the large scale disturbance and permeability increase in the adjacent rock-coal strata and ahead self-coal induced by the instantaneous fracture failure of the hard–thick sandstone main roof. Then, the formation mechanism of the huge hanging space and gas warehouse stored in the gob, the coupling disaster-causing mechanisms of the instantaneous fracture failure of HTSR and concomitant abnormal gas emission are described. Finally, two effective approaches are proposed to mitigate and eliminate disasters associated with these process.

2. Geological setting and mining conditions

Datong coalfield, is situated in a northeast-trending syncline in the northern of the North China Block and the Shanxi Platform. Many thick coal seams in the Datong coalfield are of hardness higher than 2.5, and their roofs are of a hardness higher than 7.0, i.e., a configuration referred to as "double hard coal seam" [28]. Tashan Coalmine (TSCM) is a typical example, the hard–thick sandstone main roof produces an extremely large space and has a strong impact on the gas migration field. There have been many hydraulic support damage incidents and abnormal gas emission accidents (shown in Fig. 1) caused by the fracture failure of main roof. For example, the main roof of the 8210 working face ruptured and fell on November 30, 2012, and three gas over-limit accidents occurred over the subsequent three days.

Tashan coalmine (TSCM), is one of the largest underground coalmines in the world. It is located on the mid-east edge region of the Datong coalfield and was constructed by the Datong Coal Mine Group Co. Ltd. Its length (east–west) and width (north–south) are 24.3 km and 11.7 km, respectively. The mine produced more than 24 Mt of coal in 2013. The 8212 working