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Use of Schmidt Hammer with special reference to strength reduction factor related to cleat presence in a coal mine

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1. Introduction

The Schmidt Hammer test has been widely used in civil engineering to define surface strength of concrete; however, its use in rock mechanics and mining applications have also been the subject of several research works in the past. Roxborough and Whittaker[1,2] and Kidybinski[3] were one of the first users of Schmidt Hammer to test the strength of coal and roof strata in coal mining. Carter and Snetton[4] compared Schmidt Hammer values with the point load and compressive strength of rocks. The research published by Young and Fowell[5] described the use of a Schmidt hammer with a grid on a tunnel face to determine the Schmidt Hammer value reduction index. The index was shown to be related to excavation rates of roadheaders, with increases in these rates being attributed to the fractured state of the rock mass. The authors considered that the relationships established for mudstone should also be applicable to most sedimentary rocks, though the values of intercepts and gradients would vary from site to site. Poole and Farmer[6,7] used Schmidt Hammer values in predicting performance of roadheaders. Shorey et al.[8] performed Schmidt Hammer tests to determine in-situ strength of coal seams. Haramy and DeMarco[9] found statistically reliable correlations between compressive strength and Schmidt Hammer values of coal. Ghose and Chakraborti[10] correlated Schmidt Hammer values with compressive strength, tensile strength, impact strength index and cone indenter values. Sachpazis[11] emphasized the importance of lithological classification of rock formations to find reliable statistical relations between rock properties and Schmidt Hammer values. Ayday and Goktan[12] and Goktan and Ayday[13] and Katz et al.[14] did comprehensive studies on Schmidt Hammer and correlated N- and L-type Schmidt Hammer test results. Other works on correlating rock properties with Schmidt Hammer values include.[15–32] Aydin's detailed works resulted on some recommendation for ISRM standards in using Schmidt Hammer tests.[33,34] Bilgin et al.[35] found a good correlation between Schmidt Hammer values and net breaking rate of impact hammers used in Istanbul Metro drivages. Ozkan and Bilim[36] and Bilim and Ozkan[37] investigated the change of Schmidt Hammer values with changing coal roof strata conditions related to mining activities. According to Vakili and Hebblewhite,[38] basic parameters affecting excavability/workability and cavability of a coal seam are thickness of coal seam, strength characteristics and elasticity modulus of coal, overburden, and spacing of face and butt cleats.

In thick coal seam mining where sublevel caving method is used, it is vital to know the changing strength characteristics of different levels of coal seams, which would determine the excavability/workability of the seam for planning of the mine. The Schmidt Hammer seems to be one of the best methods to be used for this purpose. However, according to the best knowledge of the authors of this study, there is not any information in the published literature on how the Schmidt Hammer value is affected by the existence and spacing of cleats.

The main objective of this research is to see whether it is possible to define a Schmidt Hammer strength reduction factor related to

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cleat occurrence and cleat spacing, and a methodology of using in-situ Schmidt Hammer values to correlate with laboratory coal strength values, and thus to develop a new excavability/workability classification system for coals. For this purpose, an underground coal mine having around 30 m of seam thickness located in Soma Coal Basin of Turkey was selected for sampling and field tests with an N-type Schmidt Hammer. 1357 Schmidt Hammer test readings corresponding to 134 different locations in the mine were carried out and coal samples were collected to determine some of their physical and mechanical properties to identify the variability of coal strength along the thickness of the coal seam. Cleat spacings were measured by examining visually the samples obtained from the field. A statistical analysis was carried out to see the effect of cleat spacing on the in-situ strength and workability of the coal. A strength reduction factor as defined by Young and Fowell[5] for rock discontinuities is used in this study to see the effect of cleats on Schmidt Hammer values. Some strength tests such as compressive strength, dynamic and static elasticity modulus were also carried out in the laboratory and the results are correlated with Schmidt Hammer values performed at different levels in the coal seam (mean value, the highest value, mean of the highest 2, 3, 4, and 5 values of the Schmidt Hammer readings) to develop a methodology for using Schmidt Hammer value in excavability classification of coal seams.

2. General information on the coal mine studied

The studied coal mine is located in Eynez province of Soma district in the city Manisa and operated by Imbat Coal Mining AS under license from Turkish Coal Enterprises (TKI). Soma Coal Basin is one of the largest economic lignite-bearing alluvial basins in the western Turkey, with around 600 million tonnes of coal reserves dispersed in 11 different areas.[39] The studies on cuttability, excavability/workability and cavability of coal seams are gaining importance in the area for replacing classical mining methods with mechanized systems normally using shearers.[42] The coal seam in Imbat Mine has a thickness of around 30 m and a total coal reserve of 60 million tonnes which is planned to be mined in the near future. The coal is hard and difficult to excavate, explosives with a specific charge of between 0.30 and 0.55 kg/m^3 is used to ease excavation of the coal. The mean overburden is around 600 m and a total 5300 miners are currently working in the mine. Access to the mine is via four inclined drifts.[41]

The sublevel caving method is used with three consecutive longwalls following each other by 20–25 m in general. Drilling and blasting are used for coal extraction and roof caving. Transportation of the extracted coal is by chain conveyors of 1700 m within the longwalls and with belt conveyor of 7700 m in the roadways. The mean panel length is around 1000 m with total mine openings of 12 km. The mean daily coal production is around 20,000 *t*.[41]

The coal is highly prone to spontaneous combustion in the mine. The fly ash obtained from a thermal power plant is mixed with water and pumped behind the longwall to prevent spontaneous combustion of coal. Gas emissions are recorded with a Senturion Remote Control Gas Monitoring System established in August 2009. All the electrical systems automatically cut off if the methane emissions reach a level of 0.5% in the mine air. Output coal is transported directly to the coal preparation plant having a washing capacity of 600 *t*/*h*.

3. General information on Schmidt Hammer and standards used

Schmidt Hammer is a portable device developed in 1948 to measure the surface hardness of concrete and it has been later used extensively to test in-situ strength of rock formations and coal. The main working principle is realized by transforming potential energy to kinetic energy by means of a spring and hammer within the testing device. Mainly two standards are used for Schmidt Hammer tests.[34,42]

The standard suggested in the "ISRM suggested methods for rock characterization, testing and monitoring (2007–2014),[34]" is based on detailed work carried out by Basu and Aydin[21] and Aydin and Basu.[22] In their studies, the influence of hammer type, direction of hammer impact, specimen requirements, weathering, moisture content and testing, data gathering/reduction and analysis procedures were considered in detail. In this standard, it was pointed out that L- and N-type hammers, with respective impact energies of 0.735 and 2.207 Nm, should be used with caution when the uniaxial compressive strength of the rock material is outside the range between 20 and 150 MPa, where sensitivity decreases and data scatter increases. The N-type hammer is less sensitive to surface irregularities and should be preferred in field applications, while the L-type hammer has greater sensitivity in the lower range and gives better results when testing weak, porous, and weathered rocks in the laboratory.[29] For data gathering, 20 rebound values should be recorded from single impacts separated by at least a plunger diameter (to be adjusted according to the extent of impact crater and radial cracks). On the other hand, the test may be stopped when any ten subsequent readings differ only by four (corresponding to Schmidt Hammer repeatability range of ± 2). In rocks such as coal, shale, and slate, testing over lamination walls may produce a narrow range of rebound values due to their uniform and smooth nature, but also significantly low values due to these interfaces.

ASTM standard for Schmidt Hammer[42] points out that the test is best suited for rock material with uniaxial compressive strengths ranging between approximately 1 and 100 MPa and the rebound hardness value can serve in a variety of engineering applications that require characterization of rock material. These applications include, for example, prediction of penetration rates for tunnel boring machines, determination of rock quality for construction purposes, grouping of test specimens, and prediction of hydraulic erodibility of rock. Rock at 0 °C or less may exhibit very high rebound values. Temperature of the rebound hammer itself may affect the rebound value. The hammer and materials to be tested should be at the same temperature. For readings to be compared, the direction of impact must be the same. Different instruments of the same nominal design may give rebound values differing from one to three units and therefore, tests should be performed with the same instrument to obtain comparable results. If more than one instrument is to be used, a sufficient number of tests must be performed on typical rock surfaces to determine the magnitude of differences to be expected in the readings of different instruments. Samples can be drill cores having a size of NX or larger, rock blocks, or in situ rock surfaces, such as tunnel or gallery walls. The test surface of all specimens, either in the laboratory or in the field, should be smooth to the touch or free of joints, fractures, or other obvious localized discontinuities to a depth of at least 6 cm. In-situ rock surface should be flat and free of surface grit over the area covered by the plunger. If the surface of the test area is heavily textured, it should be ground with an abrasive stone to smooth the surface. According to ASTM, 10 representative locations on the specimens should be selected. Test locations should be separated by at least the diameter of the plunger and only one test may be taken at any one point. The average of the ten readings should be obtained for each specimen to the nearest whole number.

4. Schmidt Hammer (SH) tests carried out and methodology of the investigation

In-situ N-type Schmidt Hammer tests were carried out perpendicular to fresh coal surfaces in 134 different areas along the