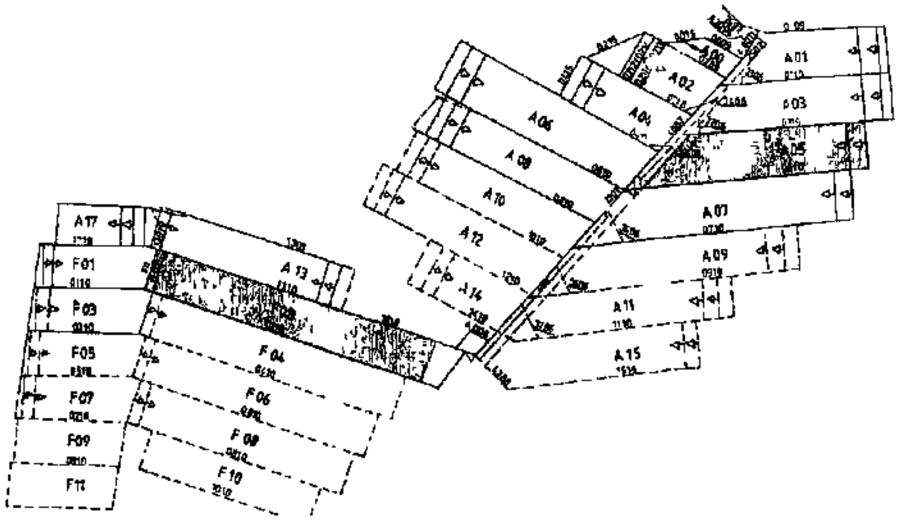

Figure 1. Panel layouts of A and F fields at Çayırhan Lignite Mine

3.4 *Schmidt hammer test*

The Schmidt hammer rebound test was developed to determine the compressive strength of concrete, and has been used to determine the hardness and compressive strength of rock material (ISRM 1978a). This equipment is portable, easy to use, and can be applied both in die laboratory and İn tihe field. It has also been reported that the Schmidt hammer has a possible use in the prediction of die performance of mechanical excavators considering the mechanical properties rock if proper testing, recording, and data processing methods are used (Göktan & Ayday, 1993).

Schmidt hammer rebound tests were carried out directly on the faces of the lower and upper coal beds at both the A-05 and F-02 panels by using a calibrated L-type hammer (Fig. 2). Face areas close to die main entries to four Iongwalls corresponding to die first 15 shield supports in these Iongwalls, each wim a width of 1.5 m, were adopted as die

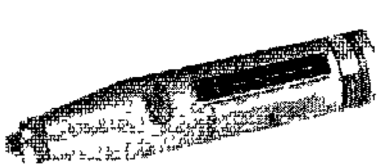

Figure 2. Schmidt hammer.

measurement areas. At least 20 individual tests were conducted on diese areas, separated by at least a plunger diameter, in which die longitudinal axis of the hammer was perpendicular to the face plane. Following die determination of individual Schmidt rebound hardness values for the longwall faces, corresponding uniaxial compressive strength values were calculated according to me calibration curves supplied by the hammer manufacturer (Table 1).

3.5 *Shore scleroscope test*

The Shore scleroscope rebound test was originally designed to determine the hardness of metals, and then a procedure was suggested by the ISRM with which to utilize this test for determining the hardness of rock materials (ISRM 1978a). Previous studies have revealed me potential of dûs test in the assessment of *the* plasticity and uniaxial compressive strength of rocks (McFeat-Smith 1977, Holrageirsdottir & Thomas 1998).

A senes of rebound tests were conducted on die flat surfaces of coal specimens from the lower and upper faces of the A-05 and F-02 panels using a Model C-2 Shore scleroscope (Fig. 3). At least 20 tests were conducted on each specimen, separated by at least 0.5 cm, in which the longitudinal axis of the glass tube was perpendicular to the bedding planes of me specimens. The Shore scleroscope hardness of each coal bed was determined by averaging die arimmetic mean values obtained from individual test specimens (see Table 1).

Table 1. Measured index values and predicted uniaxial compressive strengths for A and F field coals.

Indices	Measured Index Values				Predicted Uniaxial Compressive Strengths (MPa)			
	A-05 Panel		F-02 Panel		A-05 Panel		F-02 Panel	
	Upper Bed	Lower Bed	Upper Bed	Lower Bed	Upper Bed	Lower Bed	Upper Bed	Lower Bed
Schmidt Hammer	47.43	52.98	40.42	52.19	53.00	63.00	43.00	61.00
NCB Cone Indenter	1.2123	1.2090	1.1785	1.1781	20.00	19.95	19.44	19.44
$I_{s(50)}$ Perpendicular	0.39 MPa	0.28 MPa	0.76 MPa	0.48 MPa	8.58	6.16	16.72	10.56
$I_{s(50)}$ Parallel	0.36 MPa	0.27 MPa	0.38 MPa	0.31 MPa	7.92	5.94	8.36	6.82
$I_{a(50)}$	1.08	1.04	2.0	1.55	–	–	–	–
Shore Scleroscope	43.34	47.85	40.18	46.03	–	–	–	–
Hardgrove	49.28	34.57	64.80	40.71	–	–	–	–

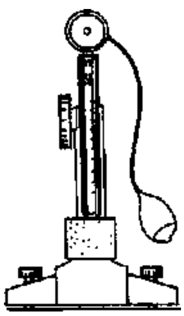

Figure 3. Shore scleroscope.

3.6 *NCB cone indenter test*

The NCB cone indenter test apparatus was developed at the NCB to determine the hardness and umaxial compressive strength of rock that may be cut by a mechanical excavator by measuring its resistance to indentation by a hardened tungsten carbide cone (Fig. 4). The basic principle of this apparatus is to measure the penetration depth of the cone into rock for a known applied force. Details of the testing, recording and data processing methodologies for the NCB the cone indenter test can be found elsewhere (NCB, 1977; Bilgin & Shahriar, 1986). It has been reported mat there is a high correlation between the NCB cone indenter hardness and the performance of mechanical excavators, especially for coal measures strata. In addition, the equation proposed by the NCB for predicting uniaxial compressive strength of rock in relation to the NCB the cone indenter hardness value gives satisfactory results in the extent of sedimentary rocks tested (NCB, 1977).

NCB cone indenter tests were conducted on the small pieces of coal 12 x 12 x 6 mm in size taken from the lower and upper coal beds of the A-05 and F-02 panels. An average of at least 10 measurements was considered to characterize the coal beds in terms of NCB cone indenter hardness. The average NCB cone indenter hardness values of each coal bed were then employed for the determination of the corresponding uniaxial compressive strength values using Equation 1 (see Table 1).

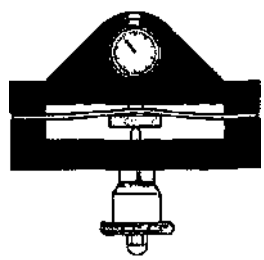

Figure 4. NCB cone indenter.

$$UCS = I_w \times 16.5 \quad (1)$$

where *UCS:* uniaxial compressive strength of coal and I_w*:* NCB the cone indenter hardness of coal.

3.7 *Point load test*

The Point load test has been widely used as a rock strength index for many years with great accuracy (Broch *&* Franklin 1972, Bieniawski 1975). The test apparatus is portable and can be applied either in the field or in the laboratory, on rock specimens that are in the form of a core, disc, or irregular lump (Fig. 5). The point load strength index (I450)) and the strength anisotropy index (b»<so)) values of rock specimens are determined by compressing the rock specimens between two standard conical platens. The strength index is calculated considering the load and the distance between the platens at failure (ISRM, 1985). Point load strength values are known to correlate well with the uniaxial compressive and tensile strengths of a wide range of rocks.

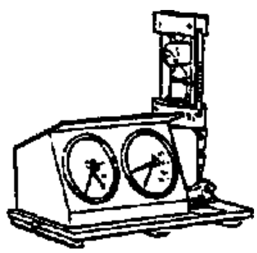

Figure 5. Point load test apparatus.

Point load strength tests were conducted on irregular coal lumps from the lower and upper coal beds of the A-05 and F-02 panels. Tests were carried out both in the perpendicular and parallel directions to the bedding planes of coal lumps. At least 10 tests were made in each loading direction for each coal bed. Anisotropy index values for each coal bed were calculated by dividing the average strength index values found during perpendicular loading by those found during parallel loading. The average $I_{s(50)}$ values found in both perpendicular and parallel loading directions, and average $I_{a(50)}$ values for each coal bed are given in Table 1. The average $I_{s(50)}$ values found during perpendicular loading were then employed for the prediction of the corresponding uniaxial compressive strength values using Equation 2 (see Table 1).

$$UCS = I_{s(50)} \times 22 \quad (2)$$

where *UCS:* uniaxial compressive strength of coal and $I_{s(50)}$- point load strength index found during perpendicular loading.

3.8 *Hardgrove grindability test*

With the development of pulverized coal-fired power stations, there was a need to evaluate the different coals in terms of resistance to grinding for use in pulverized fuel furnaces. The Hardgrove grindability test was developed to determine the relative grindability or ease of pulverization of different coals when compared to standard coals. A certain amount of coal is subjected to a grinding energy in a Hardgrove mill, and the change in the size of the coal particles is expressed as the Hardgrove grindability index by sieving. Lower index values correspond to a higher resistance to grinding (Hardgrove 1932, ASTM 1983, Szwilski 1985). Studies carried out at MTA on coals from different collieries in Turkey have shown that as the Vickers microhardness values of coals increase, corresponding Hardgrove grindability index values asymptotically decrease (Gencer 1986). Since the grindability of coal is mainly a function of mechanical properties of coal such as strength, hardness, elasticity and fracturing, it also has a close relationship with the cuttability of coal. It has been reported that the Hardgrove grindability method can also be adopted for determining the cuttability of coal (Evenden & Edwards 1985). Previous research by Roxborough et al. (1981) on the in-situ cutting performance of a continuous miner revealed that in all cases low Hardgrove grindability index values corresponded to high cuttability, i.e., high resistance to cutting action.

Hardgrove grindability tests were conducted on representative samples from the lower and upper coal beds of the A-05 and F-02 panels, İn the laboratories of the Mineral Analysis and Technology Division at MTA (see Table 1).

4 ANALYSIS OF TEST RESULTS

The data obtained from the laboratory and in-situ tests on the Çayırhan district coals were analysed in an effort to establish the correlation between the mechanical properties measured by rock index tests and the grindability of coal. These data were also analysed to investigate the reliability of some mechanical index tests in predicting the uniaxial compressive strength of coal, and to investigate the relationships between mechanical index tests. For these purposes, the test results were analysed statistically in series of pairs. In the analyses, the degree of the relationship between the variables investigated was explained in terms of the coefficient of regression.

Statistical analysis revealed that both the Schmidt hammer and Shore scleroscope hardness values were in very high correlation with Hardgrove grindability index values of four coal samples taken from different longwall panels of Çayırhan Lignite Mine. Figures 6 and 7 show the best-fit curves between the Hardgrove grindability index and Schmidt hammer and Shore scleroscope test results, respectively.

NCB cone İndenter tests showed that the coals of the A-05 panel were harder than those of the F-02 panel. According to the results of the Hardgrove grindability tests, coals of the A-05 panel are more difficult to grind than those of the F-02 panel. Since the Hardgrove grindability index is known to be indirectly proportional to the hardness of the material, NCB cone indenter tests can be considered to succeed in reflecting the differences found in the Hardgrove grindability values between the A-05 and F-02 panel coals (Fig. 8).

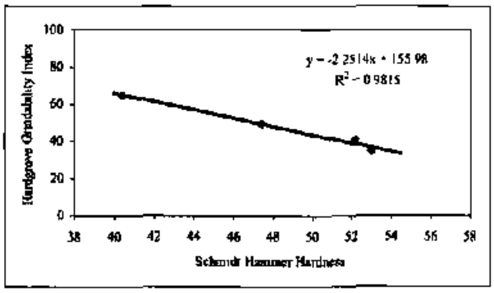

Figure 6. Relationship between Schmidt hammer hardness and Hardgrove gnndability index.

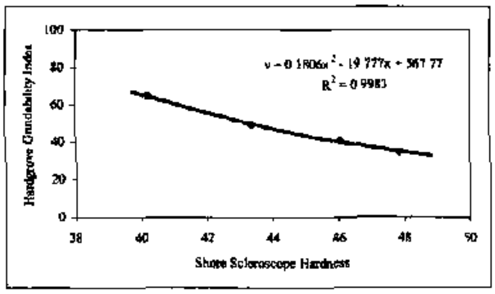

Figure 7. Relationship between Shore scleroscope hardness and Hardgrove gnndability index.

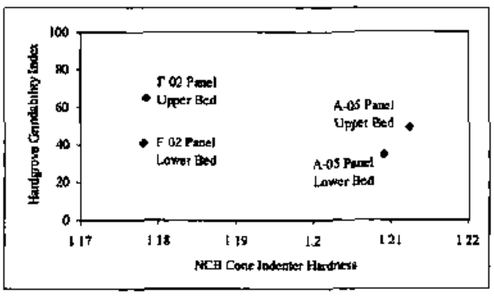

Figure 8. Relationship between NCB cone indenter hardness and Hardgrove grindability index.

However, NCB cone indenter tests did not reveal differences between the lower and upper coal beds for both the F-02 and A-05 panels in terms of NCB cone indenter hardness. This may be due to the lack of differences between the indentation hardness values of coals of the upper and lower coal beds for each longwall panel, which can be sensed by the NCB cone indenter test. According to the hardness scale for the standard NCB cone indenter test proposed by McFeat-Smith (1977), coals of the A-05 and F-02 panels can be considered moderately soft.

The Results of the point load strength tests for perpendicular and parallel loading directions showed that as point load strength index values for both loading directions increased, the Hardgrove grindability index values also increased (Fig. 9). This finding conflicts with the fact that, the Hardgrove grindability test suggests a decrease in grindability index values, i.e., increase in the power required to grind a certain coal, with increase in hardness and strength values.

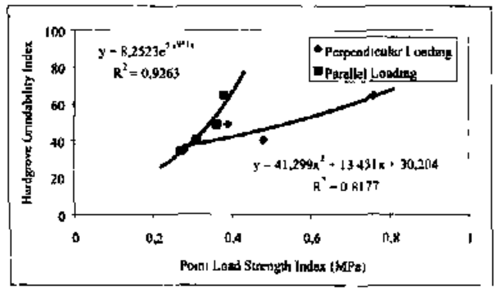

Figure 9 Relationship between point load strength and Hardgrove gnndability indices.

This situation may arise from the impracticability of point load strength test for characterization of rock materials with very low strengths with respect to their point load strength index values. Hoek (1977) pointed out that very soft materials, such as mudstones and claystones, with a compressive to tensile strength ratio of about 5 may not be tested accurately using the point load test.

Even if the correlation between the point load strength index values and Hardgrove grindability index values was regarded as unsatisfactory, the point load test seemed to be best as a prediction tool for the compressive strength of coal. For the strength classification of weak rocks by using point load test, it seems to be more realistic to use uniaxial compressive strength values rather than point load strength index values. However, for the strength classification of rock materials by using point load test, it is recommended to use point load strength index values rather than uniaxial compressive strength values (ISRM 1985). This is due to the fact that the correlations between the point load strength index and uniaxial compressive strength values are only approximate as seen in Equation 2. However, this approach is likely to be valid for the rocks with moderate and high strengths.

The point load test, being almost a simulation of a laboratory compression test intended for use in the field, is very useful for strength classification of intact rocks. Therefore, this test should be adapted for use in the strength classification of weak rocks with respect to point load strength index values, through intensive theoretical, laboratory, and field studies.

The prediction of rock strength using the NCB cone indenter test has been recommended to be accomplished considering the region and type of rocks (Bilgin & Shahriar, 1986). It has been reported that, in order to have similar uniaxial compressive strength values to those determined by compression tests, the equation coefficient proposed by NCB should be changed depending on the region and type of rock tested (Bilgin & Shahriar, 1986). Investigations into the reliability of the NCB cone indenter test for the strength classification of coals from different collieries are expected to improve our knowledge of the prediction of strength properties of coals.

The Schmidt hammer, one of the simplest and easiest- to -operate rock testing methods, overestimated the uniaxial compressive strength of the coals tested in this study. This may be due to the data processing method suggested by ISRM, in which only the top readings are considered for determination of Schmidt hammer hardness. However, it showed a very close agreement with the Hardgrove grindabİlity test indicating its potential for use in testing coal properties. Empirical equations correlating Schmidt hammer hardness with uniaxial compressive strength for coal with an acceptable accuracy may be established through consistent efforts carried out in this field.

Statistical evaluation of the test results indicated that, there was a very high correlation between the Schmidt hammer and Shore scleroscope hardness values (Fig. 10). There found to be no other statistically significant correlations between the mechanical index tests.

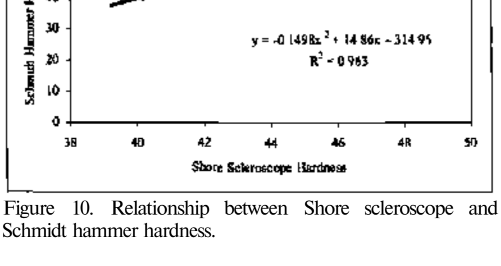

Figure 10. Relationship between Shore scleroscope and Schmidt hammer hardness.

Shore scleroscope and Schmidt hammer rebound tests seemed to be the most reliable means of hardness assessment for Çayırhan district coals.

5 CONCLUSIONS

Coal strength properties are known to affect the support capability of coal pillars and the cuttability and grindability of coal. However, these properties are difficult to determine, both in the field and in the laboratory, due to the brittle and visco-elastic nature of coal influenced by bedding planes and cleats. In this field, rock index tests can offer valuable data for strength characterization of coal in an economical and time-efficient manner.

Based on the results of comprehensive in-situ and laboratory rock and coal index tests described in this paper, the following conclusions can be drawn:

1. The Hardgrove grindability index, being an indicator of the ease of grinding or pulverization of coal, and being one of the significant parameters used in determining the capacity of a coal mill in a coal-fired power station, was found to be İn very high correlation with the results of Schmidt hammer and Shore scleroscope rebound tests for Çayırhan district coals. There is also a significant relationship between this index and NCB cone indenter hardness.

2. For the prediction of the uniaxial compressive strength of Çayırhan district coals, point load tests gave the most reliable results, similar to those determined by the compression tests conducted İn the laboratory. It seems to be more reliable to use point load strength test for weak rocks such like coal in order to predict their uniaxial compressive strength values, instead of characterizing these rocks with respect to their point load strength index values.

3. It was found to be possible, for the coals of Çayırhan Lignite Mine, to estimate the Schmidt hammer hardness from Shore scleroscope rebound tests, or vice versa, by using the regression equation given in Figure 10. However, if it is necessary to determine either of the two hardness properties, appropriate tests should be conducted.

The use of rock index tests for the classification of rock materials with respect to their strength properties largely depends on the statistical analysis carried out. Past experience and results of this study indicate that the equations proposed for the prediction of uniaxial compressive strength of rock are usually valid for specific site conditions and rock types. The rank, i.e., carbon content, ash content, density, and structural properties of coal should be taken into account when these tests are utilized for different coals.

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