The evaluation of rock brittleness concept on rotary blast hole drills

by R. Altindag*

Synopsis

The rock brittleness is one of the most important rock properties that affect the drill-ability of rocks. It is supposed that the increase in rock brittleness causes the increase in penetration rate.

The drill-ability of rocks depends on many factors. These factors can be separated as two parts depending on a machine, bit type, rotational speed, thrust, blow frequency, flushing, and rock properties, brittleness, compressive strength, structure, hardness, etc. In this paper, the relationship between brittleness and drill-ability index, which is used in the prediction analysis of the penetration rate of rotary blast hole drills, were examined using regression analysis. It is also seen that significant correlations exist between brittleness and the drill-ability index.

Introduction

The prediction of penetration rate is very important in mine and in quarry planning.

The rotary blast hole drills are widely used in open pit mines and quarries all over the world. Therefore, to determine all the parameters affecting the penetration rate before drilling operation provide big opportunities to engineers.

The main objective of this study is to investigate especially, the relationships between brittleness and drill-ability index with the other rock properties.

Brittleness

The definition of brittleness, which is one of the mechanical properties of rock, has not been made for rock drilling studies. Unfortunately, there is not a universally accepted brittleness concept or measurement, which is to define or to measure the rock brittleness, nor has it been standardized. A wide brittleness measurement method is suggested or used in the literature by the various researchers (Evans and Pomeroy 1966; Reichmuth 1968; Selmer-Olsen and Blindheim 1970; Hucka and Das 1974; McFeat-Smith 1977; Becker *et. al.* 1984; Singh 1986; Göktan 1988; Göktan 1991; Göktan 1992; Inyang and Pitt 1991; Inyang 1991; Shimada and Matsui 1994).

- ➤ The determination of brittleness from the ratio of compressive strength to the tensile strength for the rock.

$$B1 = \frac{\sigma_C}{\sigma_T} \quad [1]$$

- ➤ The determination of brittleness from the area under the curve of relations (Figure 1).

$$B2 = \frac{\sigma_C \times \sigma_T}{2} \quad [2]$$

where $B1$ and $B2$ brittleness of rock,
σ_C: compressive strength,
σ_T: tensile strength.

The Equation [1] is widely used in the literature. The Equation [2] was suggested by the author (Altindag 2000).

In these evaluations, the brittleness values were taken as a unitless numerical value.

Drill-ability

The drillability concept could be defined in different ways. Many parameters, mainly, specific energy (Teale 1965, Miller 1972, Pathinkar and Misra 1976), the coefficient of rock strength,CRS, (Protodyakanov 1962, Poene *et al.* 1969, Tandanand and Unger 1975), rock impact hardness number,RIHN, (Rabia and Brook 1980), Vicker's microhardness (Miranda and Mello-Mendes 1983), rock texture (Howarth and Rowlands 1987) and drill-ability index (Bilgin *et al.* 1993, Kahraman *et al*. 2000) are widely used in drill-ability analysis.

The drill-ability index used in prediction of the penetration rate of rotary blast hole drills is

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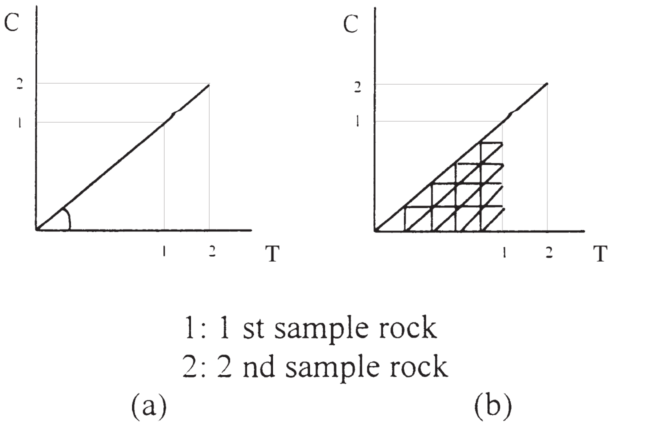

Figure 1—The graph for the relation between compressive strength and tensile strength of rock

one of the main parameters (Bilgin *et al.* 1993, Kahraman *et al.* 2000).

Evaluation of experimental data

Tables I and II represent the experimental variables of Kahraman *et al.* 2000 and Bilgin *et al.* 1993, respectively. Using data from these Tables, the relationships between the brittleness concepts and rock properties were investigated using regression analysis (Figures 2–5). As can be seen from Figures 2–5, no meaningful correlation between the *B*1 brittleness and rock properties can be established.

On the other hand, reliable relationships between the *B*2 brittleness concept and rock properties were carried out using regression analysis. In these evaluations, high *B*2 brittleness show the decreasing brittleness of rock.

Figures 2b, 2c, and 4d show a plot *B*2 brittleness vs. drill-ability index. The equations are:

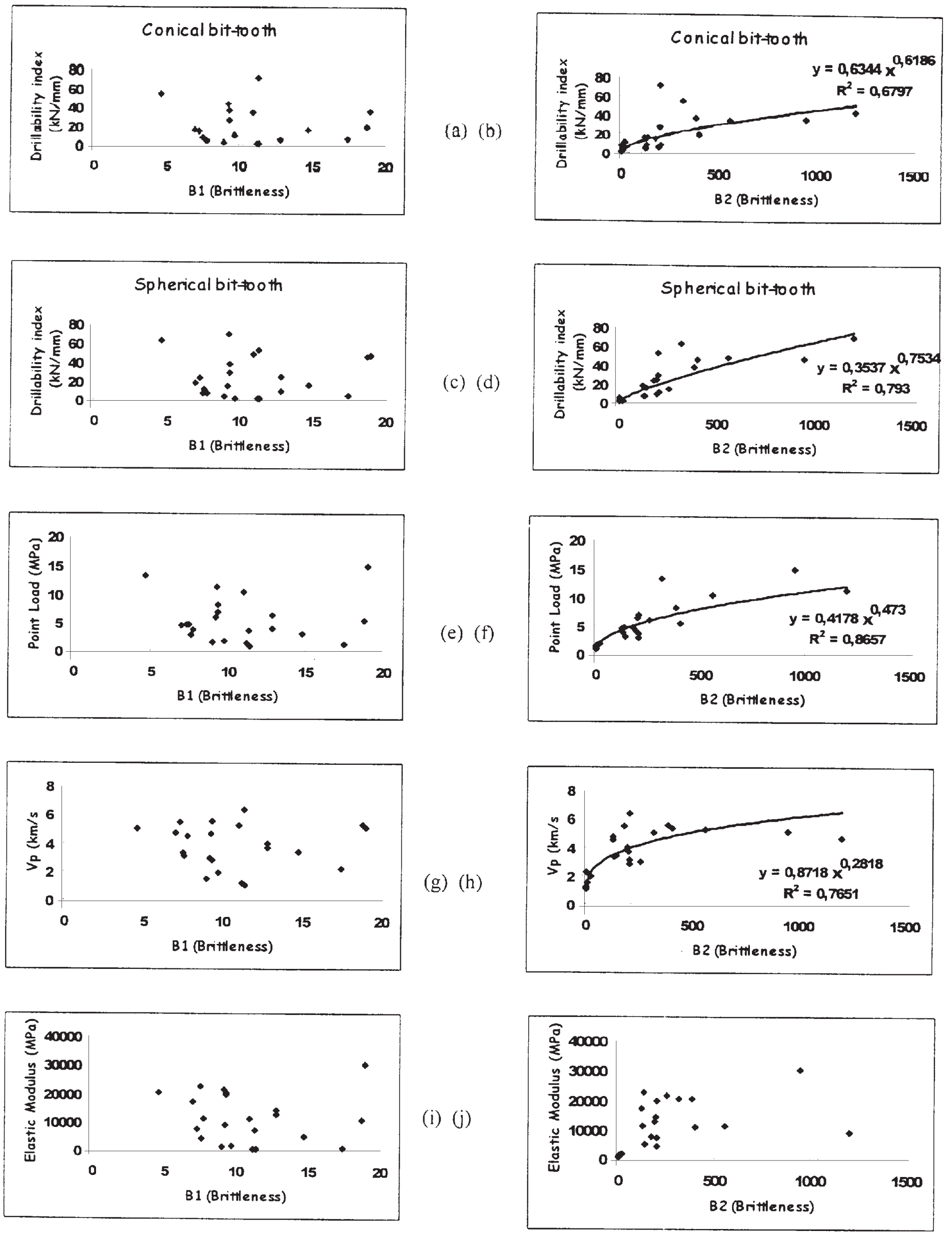

Figure 2—The relationships between brittleness and some rock properties

$$DI = 0.6344(B2)^{0.6186} \text{ for conical bit – tooth} \quad [3]$$

$$DI = 0.3537(B2)^{0.7534} \text{ for spherical bit – tooth (from Table I)} \quad [4]$$

$$DI = 0.086(B2)^{0.9096} \text{ for spherical bit – tooth (from Table II)} \quad [5]$$

where *DI* is the drill-ability index (kN/mm) and *B*2 brittleness. The correlation coefficient are 0.82, 0.89 and 0.97, respectively.

A plot of *B*2 brittleness and point load index with seismic velocity (*Vp*) are shown in Figures 2f, 2h, respectively. The equations are:

$$PL = 0.4178(B2)^{0.473} \text{ (from Table I)} \quad [6]$$

$$PL = 0.9526(B2)^{0.4835} \text{ (from Table II)} \quad [7]$$

$$Vp = 0.8718(B2)^{0.2818} \quad [8]$$

where *PL* is point load index (MPa), *Vp* is seismic velocity (km/s) and *B*2 brittleness. The correlation coefficients are 0.93, 0.98 and 0.87, respectively.

In Figure 3b, a power relationship between *B*2 brittleness and density of rock is shown. The equation of this relation is:

$$\rho = 1{,}572(B2)^{0.0978} \quad [9]$$

where ρ is density of rock (gr/cm3) and *B*2 brittleness. The correlation coefficient is 0.86.

There is a decreasing linear relationship between *B*2 brittleness and penetration rate (Figure 4b). The penetration rate decrease with an increase of the brittleness value of rocks. The equation is:

$$PR = -0.0057(B2) + 2.3053 \quad [10]$$

where *PR* is penetration rate (m/min) and *B*2 brittleness. The correlation coefficient is 0.79.

The relationships between *B*2 brittleness and cone indenter with Schmidt hammer are shown in Figures 4h, 4j. The equations are :

$$CI = 0.1495(B2)^{0.5406} \quad [11]$$

$$RN = 5.9528In(B2) + 20.933 \quad [12]$$

where *CI* is cone indenter, *RN* is Schmidt hammer and *B*2 brittleness. The correlation coefficients are 0.99 and 0.75, respectively.

In case of the evaluation of point load index and drill-ability index data of Table I and Table II with together, the reliable relationships between *B*2 brittleness and point load index with drill-ability index were obtained (Figures 5a, 5b). The equations are:

$$PL = 0.2365(B2)^{0.5229} \quad [13]$$

$$DI = 0.1376(B2)^{0.8792} \quad [14]$$

The correlation coefficients are similarly 0.92 and 0.92.

Results

No meaningful relationships between the *B*1 brittleness and the other rock properties could be established. However, reliable relationships between the *B*2 brittleness and the other rock properties were carried out.

In two tables, the drillability index values and *B*2 brittleness values are investigated together. So, the relationship between *B*2 brittleness and drillability index is obtained with correlation coefficient of 0.92.

It is shown that the *B*2 brittlenees is closely related to rock drillability index, point load index, density, cone indenter, N type Schmidt hammer and seismic velocity. These relationships may also show the affect of the *B*2 brittlenees with rock properties used on drillability analysis.

More reliable relationships between rock brittleness and rock properties can be seen using *B*2 brittleness concept instead of *B*1 brittleness concept.

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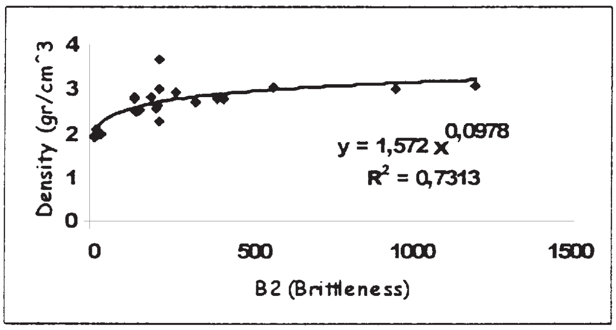
(a)



(b)

Figure 3—The relationships between brittleness and density

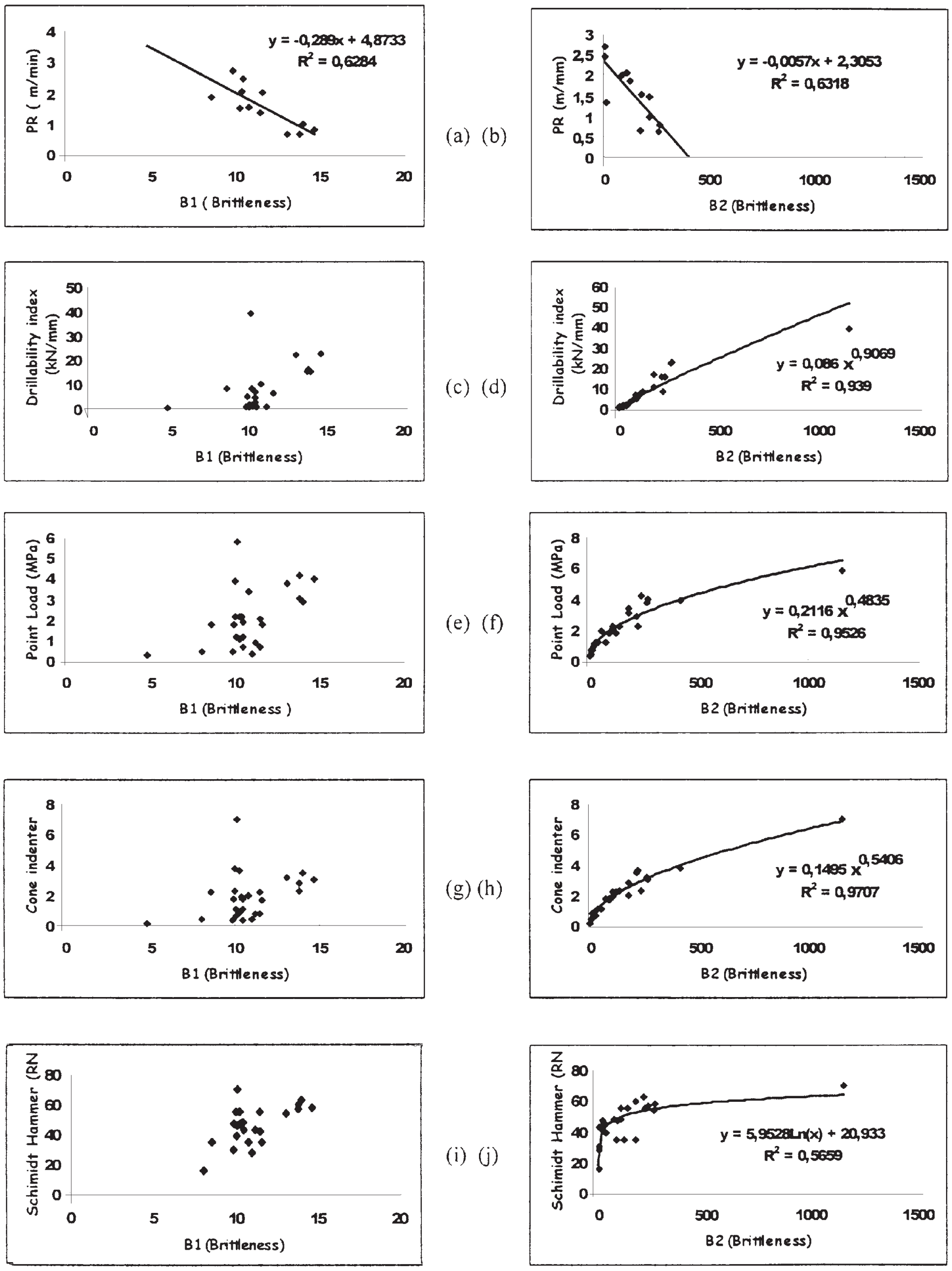


Figure 4—The relationships between brittleness and other properties

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Table I

Mechanical and physical properties of rocks (Kahraman *et al*. 2000)

Location	Formation	Compressive strength (MPa)	Tensile strength (MPa)	Brittleness (*B*1)	Brittleness (*B*2)	Drillability index (*) (kN/mm)	Drillability index (**) (kN/mm)	Point Load (MPa)	P-wave velocity (km/s)	Elastic Modulus (MPa)	Density (g/cm^3)
Soma Isiklar)	Marl	64.9	4.4	14.75	142.78	15.5	15.5	3.0	3.4	4758	2.45
Seyitömer	Marl	11.4	1.0	11.4	5.7	0.85	1.15	0.8	1.0	241	1.83
Tunçbilek (panel 36)	Marl	21.4	2.2	9.73	23.54	10.4	1.2	1.7	1.9	1595	1.91
Tunçbilek (Beke)	Marl	13.5	1.5	9.0	10.13	2.7	3.8	1.4	1.5	980	2.03
Pozanti	Limestone	123.8	6.6	18.76	405.9	18.8	46	5.3	5.3	10 682	2.73
Pozanti	Clayed limestone	45.1	6.0	7.52	135.3	8.0	6.5	4.6	3.3	22 419	2.42
Emet	Sandstone	70.5	5.5	12.82	198.88	5.5	9.0	6.3	3.7	13 855	2.56
Emet	Limestone	42.1	6.0	7.02	126.3	16	18.0	4.4	4.7	16 757	2.7
Orhaneli	Tuff	10.1	0.9	11.22	4.55	0.83	0.62	1.2	1.2	193	1.85
Bahçe	Sandstone-1	149.2	16.1	9.27	1201.06	43	69.0	11.2	4.6	8 746	3.0
Bahçe	Sandstone-2	45.2	5.8	7.79	131.08	4.5	6.5	3.6	4.5	11 092	2.77
Bahçe	Dolomite	68.0	6.0	11.33	204	71	51.7	3.5	6.3	6830	2.92
Erikli	Limestone	51.3	7.0	7.33	179.55	15	23.5	4.6	5.4	7193	2.74
Erikli	Serpantine	69.1	7.5	9.21	259.13	—	14.4	5.8	2.9	21 116	2.88
Erikli	Diabase	110.9	10.1	10.98	560.04	34.5	48.0	10.3	5.2	10 901	2.96
Erikli	Marl	39.5	5.2	7.6	205.4	8.2	11.0	2.7	3.1	4060	2.2
Konya	Serpantine	54.3	11.7	4.64	314.66	54.6	62.0	13.2	5.0	20 224	2.63
Yahyali	Hematite	61.8	6.6	9.36	203.94	26.5	29.0	6.7	2.8	19 566	3.61
Adana	Limestone	15.7	0.9	17.44	7.07	6.8	5.0	1.1	2.2	790	1.86
Misis	Limestone	85.2	9.1	9.36	387.66	37	38.0	8.0	5.5	20 253	2.71
Darica	Dolomite	189.8	10.0	18.98	949.0	36	46.5	14.9	5.1	30 163	2.92
Darica	Limestone	70.56	5.5	12.83	194.04	—	25.0	3.9	4.0	12 517	2.5

(*): For conical bit-tooth, (**): For spherical bit-tooth

Table II

Mechanical and physical properties of rocks (Bilgin *et al*. 1993)

Location	Formation	Compressive strength (MPa)	Tensile strength (MPa)	Brittleness (*B*1)	Brittleness (*B*2)	Drillability index (*) (kN/mm)	Schmidt hammer	Point load (MPa)	Cone indenter	Penetration rate (m/min)
Isiklar	Marl	88.7	6.0	14.78	264	21.86	57	3.9	2.9	0.78
Isiklar	Limestone	77.3	5.5	14.05	213	14.71	62	2.8	3.4	0.97
Elmali	Marl	80.2	5.8	13.83	232.9	14.71	56	4.1	2.2	–
Ksrakdere	Marl	82.4	6.3	13.08	259.6	21.61	53	3.7	3.1	0.61
Sar kaya	Marl	69.2	5.0	13.84	173	15.69	59	3.0	2.7	0.63
T naz-B.Yaka	Marl	52.1	5.2	10.02	135.5	–	54	2.1	2.2	–
T naz-B.Yaka	Marl	66.6	6.5	10.25	216.5	7.84	54	2.1	3.5	1.47
Eskihisar	Marl	17.9	1.6	11.19	14.3	0.59	42	0.8	0.7	–
Eskihisar	Weath.M1	8.0	0.8	11.10	3.31	–	27	0.3	0.4	–
Milas-Sekköy	Marl	21.6	2.1	10.29	22.7	0.94	46	1.0	0.8	–
Milas-Sekköy	Marl	22.0	2.2	10.0	24.5	0.65	45	1.1	0.6	–
Beke	Marl	16.1	1.4	11.5	11.3	–	41	0.6	0.7	1.33
Panel 12 A	Marl	49.3	4.3	11.47	105.5	–	54	2.0	2.1	–
Panel 12 B	Silex	152.7	15.1	10.11	1152.9	38.54	69	5.7	6.9	–
Ömerler 4CD	Marl	41.8	4.2	9.95	87.4	4.57	46	1.7	1.7	–
Panel 37	Marl	38.7	3.7	10.46	71.6	3.92	47	1.1	1.7	–
Panel 36	Marl	46.9	4.5	10.42	105.5	6.54	47	2.1	1.8	2.03
Panel 37/Sh.	Marl	33.4	3.2	10.44	53.5	2.48	–	1.8	1.0	–
Orhaneli	Marl	45.5	5.3	8.58	120.6	7.60	34	1.7	2.1	1.85
Orhaneli	Tuff	26.2	2.8	9.36	36.7	1.23	38	1.1	1.0	–
Orhaneli	Tuff	43.4	4.0	10.85	86.8	5.88	34	1.7	1.6	1.98
Keles	Clay-Marl	10.5	1.3	8.08	6.8	–	15	0.4	0.4	–
Keles	Marl-Limestn.	61.5	5.7	10.79	175.3	9.80	34	3.3	1.9	1.52
Keles	Limestone	91.2	9.1	10.02	414.9	–	–	3.8	3.7	–
Seyitömer	Silex-Marl	2.4	0.5	4.8	0.6	0.10	–	0.2	0.1	–
Seyitömer	Marl	7.9	0.8	9.88	3.2	0.26	29	0.4	0.3	2.68
Seyitömer	Marl	10.5	1.0	10.5	5.3	0.54	42	0.6	0.3	2.43

(*) : For spherical bit-tooth

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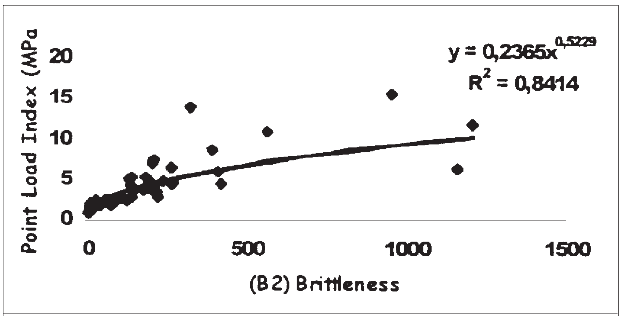

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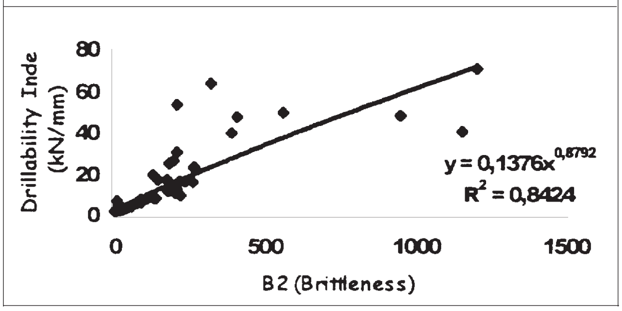

(b)

Figure 5—The relationship between brittleness (*B*2) with point load index and drill-ability index

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