Correlation of specific energy with rock brittleness concepts on rock cutting

by R. Altindag*

Synopsis

In rock cutting mechanics, the effects of the rock and coal brittleness on the efficiency of cutting bits are examined by many researchers. There is no universally accepted brittleness concept as a measure of cutting efficiency. The effect of the brittleness on rock cutting has not been completely explained.

The aim of this study is to correlate the relationships between Specific Energy (SE) and brittleness concepts. The applicability of various brittleness measurement methods for rock cutting efficiency has been investigated.

In this study, the raw data derived from previous experimental studies were used, and the relationships between SE and brittleness concepts were investigated. The two previously used brittleness concepts, which are named as B_1 (the ratio of compressive strength to tensile strength) and B_2 (the ratio of compressive strength minus tensile strength to compressive strength plus tensile strength), and a new introduced brittleness concept named B_3 (the area under line in relation to compressive strength and tensile strength) were evaluated in this study. The relations among these brittleness concepts for rock cutting efficiency were established using regression analysis. There is no correlation found between the SE values and the brittleness of B_1 and B_2 values. But, the SE is strongly correlated with the brittleness of B_3. It was seen that the suggested brittleness of B_3 concept could be used as an indicator in rock cutting efficiency analysis.

Introduction

Rock brittleness is one of the most important mechanical properties of rocks. However, because of the lack of precise concept of brittleness and its measurement, its practical utility in the field of rock and coal excavation is hindered.

Specific energy is one of the parameters that describe the cutting efficiency in laboratory and in field. In mechanical excavation studies, some rock properties affecting the SE were investigated by different researchers (Paone *et al*., 1969; Schmidt, 1972; Dunn *et al*., 1993). But, the estimation of the cutting efficiency by using a single rock property is impossible. Since many rock properties affect the cuttability of rocks. In this study, beside two rock brittleness of B_1 and B_2 cited in literature, the brittleness of B_3 concept suggested by the author (Altindag, 2000a, 2000b, 2002) were evaluated.

Brittleness

There is no a standardized universally accepted brittleness concept or a measurement method defining or measuring the rock brittleness exactly.

An excessive number of different measures of rock brittleness in rock mechanics were developed and used up to date for different purposes (Morely, 1944; Baron *et al*., 1962; Coates, 1966; Evans and Pomeroy, 1966; Hetényi, 1966; Ramsey; 1967; Obert and Duvall, 1967; Reichmuth, 1968; Selmer-Olsen and Blindheim, 1970; Hucka and Das, 1974; McFeath-Smith, 1977; Smoltczyk and Gartung, 1979; Petoukhov and Linkov, 1983; Becker *et al*., 1984; Stavroguin and Protossenia, 1985; Singh, 1986; Goktan, 1988, 1991, 1992; Inyang and Pitt, 1990; Inyang, 1991; Shimada and Matsui, 1994; Tamrock, 1986; Altindag, 1997, 2000a, 2000b, 2002; Copur, 1999; Copur *et al*., 2001; Kahraman, 2002).

Morely (1944) defines brittleness as the lack of ductility. Hetényi (1966) defines brittleness as the lack of ductility or its inverse. Ramsey (1967) defines brittleness as follows: when the internal cohesion of rocks is broken, the rocks are said to be material varies from author to author. Obert and Duvall (1967) defined the brittleness as follow: materials such as cast iron and many rocks usually terminate by fracture at or only slightly beyond the yield stress.

Brittleness is defined as a property of materials that rupture or fracture with little or no plastic flow in the Glossary of Geology and Related Sciences (1960). However, it may be

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stated that with higher brittleness the following facts are observed (Hucka and Das, 1974):

- low values of elongation
- fracture failure
- formation of fines
- higher ratio of compressive to tensile strength
- higher resilience
- higher angle of internal friction
- formation of cracks in indentation.

The ratio H/K_C, where H is hardness (resistance to deformation) and K_C is toughness (resistance to fracture), is proposed as an index of brittleness (Lawn and Marshall, 1979).

The determination of brittleness is largely empirical. Usually, brittleness measures the relative susceptibility of a material to two competing mechanical responses, deformation and fracture; ductile–brittle transition.

The used brittleness concepts in this study are given below.

a—The determination of brittleness from the ratio of uniaxial compressive strength to the tensile strength for the rock (Figure 1a),

$$B_1 = \frac{\sigma_C}{\sigma_T} \qquad [1]$$

b—The determination of brittleness from tensile strength and uniaxial compressive strength,

$$B_2 = \frac{\sigma_C - \sigma_T}{\sigma_C + \sigma_T} \qquad [2]$$

c—The determination of brittleness from the area under the line of σ_C - σ_T graph (Figure 1b),

$$B_3 = \frac{\sigma_C \times \sigma_T}{2} \qquad [3]$$

where, B_1, B_2 and B_3 are brittleness, σ_C is the uniaxial compressive strength of rock (MPa), σ_T is the tensile strength of rock (Brazilian) (MPa).

In drilling process [percussive drilling (Altindag, 2000a (on 24 rock types)); Altindag, 2000b (on 38 rock types) and rotary drilling (Altindag, 2002 (on 49 rock types))], no meaningful relation could be found between the brittleness of B_1, B_2 and penetration rate. But, reliable relations between the brittleness of B_3 and the penetration rate were obtained.

The brittleness of B_1 concept is widely used in the literature (Walsh and Brace, 1964; Niwa and Kobayashi, 1974; Beron *et al.*, 1983; Chiu and Johnston, 1983; Kim and Lade, 1984; Vardoulakis, 1984; Koulikov, 1987; Inyang and Pitt, 1990; Goktan, 1991; Inyang, 1991; Kahraman, 2002). Hucka and Das (1974) stated that the brittleness of B_2 suitable even for friable substances like coal. The author (Altindag, 2000a, 2000b, 2002) proposes the Equation [3]. The B_3 values were taken as dimensionless numerical values in the evaluations.

The definition of brittleness, which is one of the mechanical properties of rocks, has not been made for rock excavations.

In rock cutting analysis, the same brittleness value by using B_1 concept could be obtained if slope at, σ_C - σ_T is same for different rock types. Because, in case of rocks have same *SE*, the brittleness of B_1 definition can not be seen to be reliable. So, it is difficult to evaluate the test results obtained same specific energy from the rocks that have very different tensile strength and compressive strength.

The brittleness of B_1 value of a rock equals the tangent of angle of the line in the related graph of compressive–tensile strength (Figure 1a). In this case, rocks also have same angle but have different strength can exhibit the same brittleness of B_1 value. So, the usage of the brittleness of B_1 concept could not be seen as a reliable parameter in cutting analysis. The similar results could be seen for the brittleness of B_2 concept. On the other hand, it was seen that considering the area under σ_C - σ_T relation line (Figure 1b) could be more useful than the slope of the σ_C - σ_T line (the ratio of compressive strength to tensile strength, B1) (Figure. 1a).

Evaluation of some experimental data

In order to investigate the relationships between the brittleness of rocks and coals with SE, the raw data derived from previous experimental studies were evaluated. The raw data are given in Tables I–VII. The relationships between brittleness concepts and SE were examined by using regression analysis (Figures 2–4).

The experimental conditions of the tests were very different. So, each test was examined individually in regression analysis.

The *SE* was correlated with the brittleness concepts using the method of least square regression. The equation of the best-fit line and the correlation coefficient (r) were determined for each regression analysis.

The *SE* values vs. the brittleness of B_1 and B_2 values are plotted in Figures. 2a–d, 2f–i. As can seen in Figure 2, there is no correlation found between *SE* and the brittleness of B_1 and B_2 as parallel to findings of Goktan (1991). However, the specific energy is strongly related with the brittleness of B_3 (Figure 4).

It was seen that the brittleness of B_1 and B_2 concepts evaluated in this study were not a good indicator for explaining the consumption of specific energy in rock cutting studies.

On the other hand, more meaningful relationships between the suggested brittleness of B_3 concept and *SE* were obtained in respect to the other brittleness concepts of B_1 and B_2 (Figure 4). The suggested brittleness of B_3 concept can be seen as a good indicator, defining the consumption of specific energy in rock excavation.

Despite different experimental conditions of the studies, all the *SE* values of Tables I–VII vs. the brittleness of B_1 and B_2 values are plotted, and it is seen that there is no correlation between *SE*s and the brittleness of B_1 and B_2 values (Figure 2e, 2j).

The specific energy values vs. the brittleness of B_3 values are plotted in Figure 4a-4h.

There is a strong linear relation, with high correlation coefficient, between the *SE* and the brittleness of B_3 using data of Table I. The equation is;

$$SE = 0.5816 + 0.0946\,(B_3), \qquad [4]$$

where, *SE* is specific energy (MJ/m^3), and B_3 is brittleness of

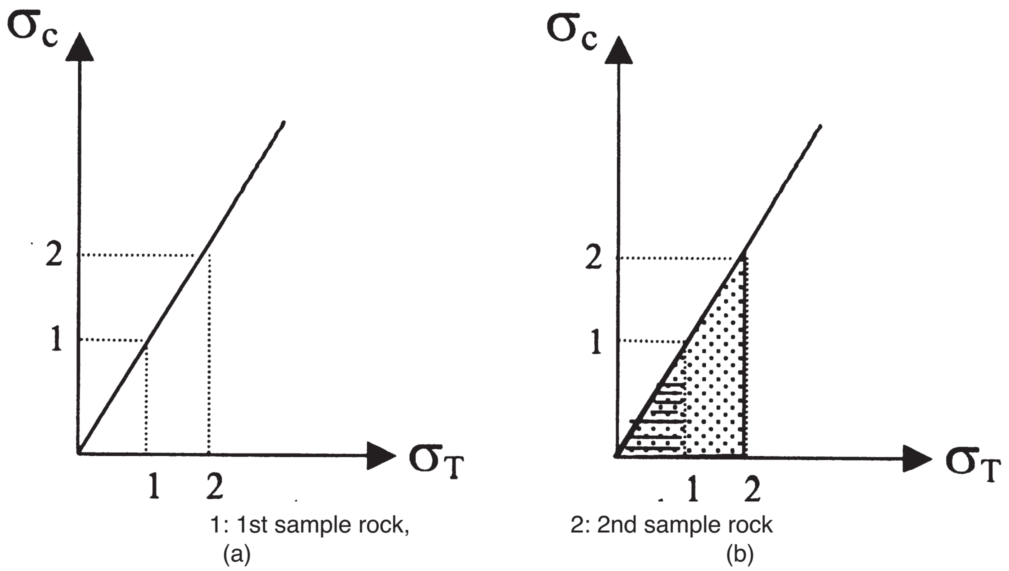

Figure 1—The graph for the relation between compressive strength and tensile strength of rock

Table I

Test data of New South Wales Coals (after Roxborough and Sen, 1986)

Rock no.	Coal seam	σ_C (MPa)	σ_T (MPa)	SE (MJ/m³)	Brittleness*		
					B_1	B_2	B_3
1	Bulli	22.3	1.85	2.3	12.05	0.846	20.63
2	Y.Wallsend	10.8	1.26	2.0	8.57	0.791	6.80
3	Whybrow	18.6	1.56	1.3	11.92	0.845	14.51
4	G. Northern	44.3	3.56	8.3	12.44	0.848	80.40

σ_C : Compressive strength, σ_T: Tensile strength, *SE*: Specific energy.
Experimental conditions:
Pick type: 13 mm wide chisel, rake angle: 0°, clearance angle: 10°, cutting depth: 5 mm.
* Calculated by the author.

Table II

Test data of Amasra Coalfield rock (after Bilgin and Shahriar, 1988)

Rock no.	Rock type	σ_C (MPa)	σ_T (MPa)	SE (MJ/m³)	Brittleness*		
					B_1	B_2	B_3
1	Marl	26.0	1.91	6.77	13.61	0.863	24.83
2	Marl	62.0	3.68	26.3	16.85	0.888	114.08
3	Tuff	27.9	2.52	16.2	11.07	0.834	35.14
4	Andesitic Tuff	44.7	2.83	16.8	15.80	0.881	63.25
5	Andesitic Tuff	35.0	2.64	19.2	13.26	0.859	46.20
6	Andesitic Tuff	38.4	2.22	16.0	17.30	0.890	42.60
7	Basaltic Andesite	49.6	3.14	29.9	15.80	0.881	77.87
8	Basaltic Andesite	53.0	6.20	22.4	8.55	0.790	164.30
9	Basaltic Andesite	53.0	2.30	19.8	23.04	0.916	60.95
10	Limestone	37.0	1.98	8.16	18.69	0.898	36.63
11	Sandst.-Conglomerate	17.1	0.77	7.40	22.21	0.913	6.58

σ_C : Compressive strength, σ_T: Tensile strength, *SE*: Specific energy.
Experimental conditions:
Pick type: 12.7 mm wide chisel, rake angle: - 5°, clearance angle: 5°, cutting depth: 5 mm.
* Calculated by the author.

rock. The correlation coefficient of the equation is $r = 0.982$.

According to the data of Table II, a power relationship between the specific energy and the brittleness of B_3 was found (Figure 3b). The relation is given in Equation [5].

$$SE = 2.4147\left(B_3\right)^{0.4826}, \qquad [5]$$

where, *SE* is specific energy (MJ/m³), and B_3 is brittleness of rock. The correlation coefficient of the equation is $r = 0.802$.

Table III

Test data of cutting experiments (after Bilgin, 1977 and Bilgin, 1982)

Rock no.	Rock type	σ_C (MPa)	σ_T (MPa)	SE (MJ/m³)	Brittleness*		
					B_1	B_2	B_3
1	Greywocke	183.9	16.45	42.5	11.20	0.836	1512.58
2	Gypsum	45.0	2.75	11.0	16.36	0.885	61.88
3	Sandstone	55.8	3.12	5.5	17.88	0.894	87.05
4	Anhydrite	112.9	5.47	22.0	20.64	0.907	308.78
5	Limestone	127.3	7.45	37.5	17.09	0.889	474.19
6	Granite	179.1	10.77	58.0	16.63	0.886	964.45

σ_C : Compressive strength, σ_T: Tensile strength, *SE*: Specific energy.
Experimental conditions:
Pick type: 30 mm wide chisel, rake angle: 10°, clearance angle: 10°, cutting depth: 5 mm.
* Calculated by the author.

Table IV

Test data of cutting experiments (after Rad and Olson, 1974)

Rock no.	Rock type	σ_C (MPa)	σ_T (MPa)	Shore hardness	SE (MJ/m³)	Brittleness*		
						B_1	B_2	B_3
1	Marble	71.4	5.59	49.5	59.60	12.77	0.855	199.56
2	Limestone	108.4	3.78	56.2	43.43	28.68	0.933	204.88
3	Granite	183.4	11.00	84.4	88.24	16.67	0.887	1006.50
4	Quartzite	559.2	8.91	89.1	103.09	62.76	0.969	2491.24

σ_C : Compressive strength, σ_T: Tensile strength, *SE*: Specific energy.
Experimental conditions:
Groove spacing: 58 mm, Disk cutter diameter: 17.78 cm, Disk thickness: 25.4 mm, Nornal force: 3171 kg
* Calculated by the author.

Table V

Test data of cutting experiments (after Demou *et al.*, 1983)

Rock no.	Rock type	σ_C (MPa)	σ_T (MPa)	SiO_2 (%)	Shore hardness	SE (MJ/m³)	Brittleness*		
							B_1	B_2	B_3
1	Trona	49.55	3.3	<1	23	1.83	15	0.875	81.76
2	Indiana limestone	68.82	3.92	<1	32	3.37	17.55	0.892	134.89
3	Tennessee marble	3.92	8.4	<1	55	5.62	13.77	0.865	485.52

σ_C : Compressive strength, σ_T: Tensile strength, *SE*: Specific energy.
Experimental conditions:
Pick type: CC-45-5 point attack, attack angle: 45°, cutting depth: 5.1 mm
* Calculated by the author.

When the specific energy values (in Table III) are correlated with the brittleness of B_3 values, a power relation was found (Figure 3c) with correlation coefficient (r) of 0.910. The relation is;

$$SE = 0.5481\left(B_3\right)^{0.6412}, \qquad [6]$$

where, *SE* is specific energy (MJ/m³), and B_3 is brittleness of rock.

The specific energy was correlated with the brittleness of B_3 using data of Table IV. A logarithmic relation was found between *SE* and the brittleness of B_3. The equation is;

$$SE = 59.239 + 20.957\,Ln\left(B_3\right), \qquad [7]$$

where, *SE* is specific energy (MJ/m³), and B_3 is brittleness of rock. The correlation coefficient of the equation is $r = 0.965$.

When the specific energy and the brittleness of B_3 are investigated in same graph using data of Tables I–IV, a power relation was obtained (Figure 4h). The equation of the relation is given in Equation [8].

$$SE = 1.0045\left(B_3\right)^{0.6079}, \qquad [8]$$

where, *SE* is specific energy (MJ/m³), and B_3 is brittleness of rock. The correlation coefficient of the equation is $r = 0.843$.

If it is omitted the circled value in Figure 4h, a more reliable relationship can be obtained between the specific

Table VI

Test data of cutting experiments (after Morrell *et al.*, 1970)

Rock no.	Rock type	σ_C (MPa)	σ_T (MPa)	SiO_2 (%)	Shore hardness	SE (MJ/m^3)	Brittleness*		
							B_1	B_2	B_3
1	Indiana limestone (Type 1)	68.76	3.45	<1	32	5.76	19.9	0.904	118.61
2	Indiana limestone (Type 2)	62.81	4.67	<1	27	4.46	13.44	0.862	146.66
3	Kasota stone	90.74	5.45	--	37	7.09	16.65	0.887	247.27
4	Tennessee marble	115.69	8.39	<1	55	9.69	13.79	0.865	485.32
5	Valders white rock	187.41	5.46	30	68	11.44	34.34	0.943	511.63

σ_C : Compressive strength, σ_T: Tensile strength, *SE*: Specific energy.
Experimental conditions:
Disk edge angle: 90°, disk diameter: 17.78 cm, disk thickness: 2.54 cm
* Calculated by the author.

Table VII

Test data of cutting experiments (after Snowdon *et al.*, 1982)

Rock no.	Rock type	σ_C (MPa)	σ_T (MPa)	SE (MJ/m^3)	Brittleness*		
					B_1	B_2	B_3
1	Gregory sandstone	50	3.53	10.7	14.16	0.868	88.25
2	Merrivale granite	174.2	9.96	36	17.49	0.892	867.52
3	Dolerite	339.8	27.53	46.1	12.34	0.850	4677.3
4	Plas Gwilym limestone	155	13.72	22.6	11.3	0.837	1063.3

σ_C : Compressive strength, σ_T: Tensile strength, *SE*: Specific energy.
Experimental conditions:
Disk diameter: 200 mm, Disk edge angle: 80°, Penetration: 6 mm, Groove spacing: 60 mm
* Calculated by the author.

energy and the brittleness of B_3 with correlation coefficient of $r = 0.862$ (Equation [9]).

$$SE = -42.083 + 15.337\ Ln\left(B_3\right), \qquad [9]$$

where, *SE* is specific energy (MJ/m^3), and B_3 is brittleness of rock.

The reliable relationships between the brittleness B_3 and *SE* were obtained using data of Tables V–VII. The equations are, respectively:

$$SE = 2.0544\ Ln\left(B_3\right) - 7.0031 \qquad [10]$$

$$SE = 0.0148\left(B_3\right) + 3.2323 \qquad [11]$$

$$SE = 8.5904\ Ln\left(B_3\right) - 28.416 \qquad [12]$$

Where, *SE* is specific energy (MJ/m^3) and B_3 is brittleness of rock. The correlation coefficients of the equations are $r = 0.99$, $r = 0.96$, $r = 0.91$, respectively.

The brittleness B_3 was correlated with the Shore hardness of rocks using data of Tables IV–VI. Linear relations were found between B_3 and Shore hardness. The equations are:

$$SH = 15.402\ LN\left(B_3\right) - 28.392 \qquad [13]$$

$$SH = 0.0743\left(B_3\right) + 19.271 \qquad [14]$$

$$SH = 0.0887\left(B_3\right) + 17.013 \qquad [15]$$

Where, *SH* is Shore hardness and B_3 is brittleness of rock. The correlation coefficients are $r = 0.97$, $r = 0.99$, $r = 0.96$, respectively.

Conclusions

Brittleness, defined differently from author to author, is an important mechanical property of rocks, but there is no universally accepted brittleness concept or measurement method in mechanical excavation. Many studies can be seen of the relationships between brittleness and the other performance parameters of machines and rock properties in literature.

The relationships between three different brittleness concepts and specific energy were statistically examined using the raw data obtained from the experimental studies of different researchers.

There is no correlation found between the specific energy values and the brittleness of B_1 and B_2 values. But, meaningful relationships, with high correlation coefficients, between the specific energy values and the brittleness of B_3 were found. According to these results, the usability of B_1 and B_2 brittleness concepts in cutting efficiency could not be seen as a reliable parameter. But, the suggested brittleness of B_3 concept can be seen as an indicator to define the cutting efficiency.

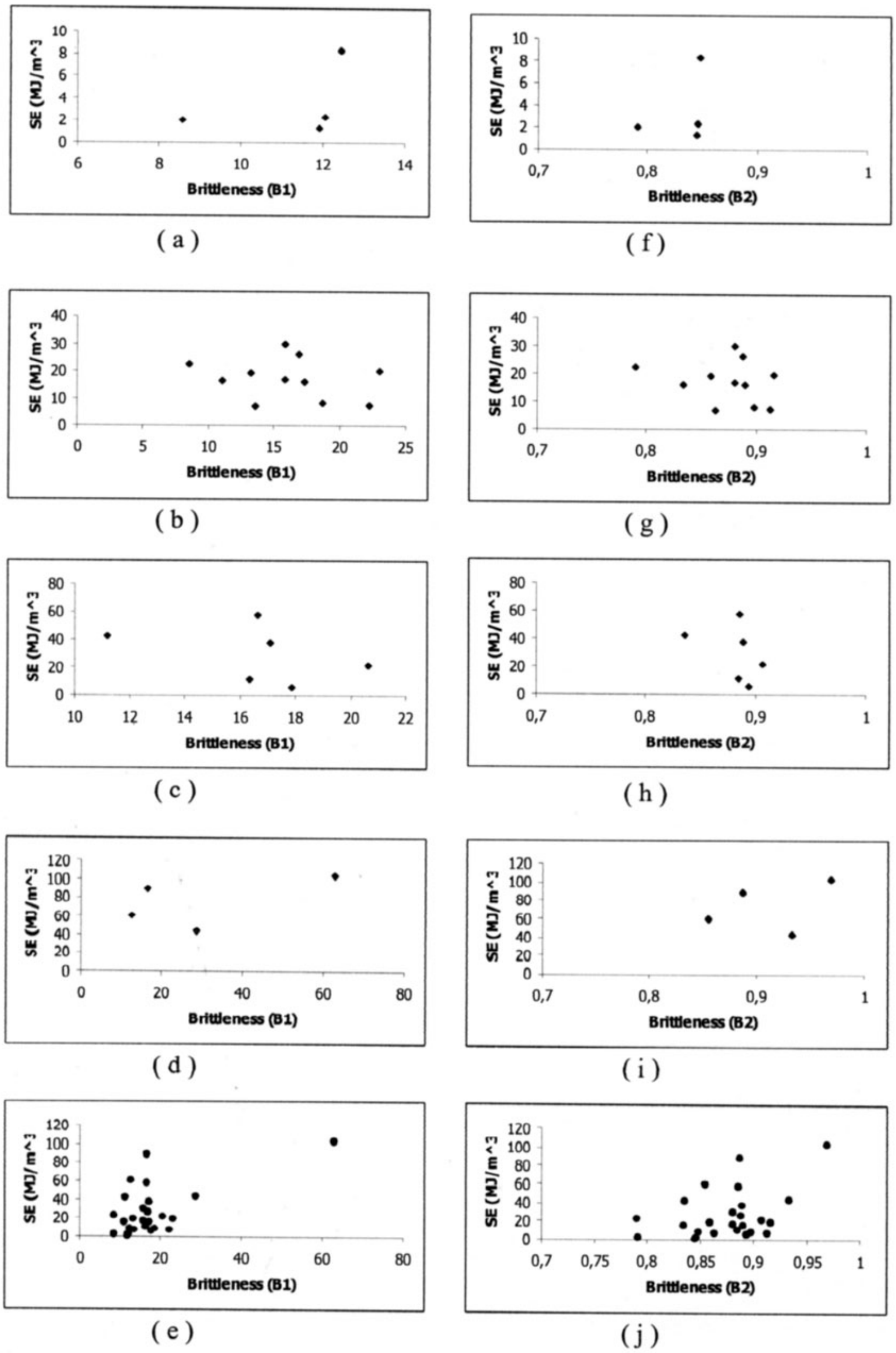

Figure 2—The relationships between the brittleness of B_1, B_2 and the specific energy values (Figures a–e were plotted from Tables I–IV, and Figures. f–j were plotted from Tables I–IV, respectively)

Although the experimental conditions at the provided data given in tables are different, a power relationship between the specific energy and the brittleness of B_3 was obtained when all data were evaluated in the same graph.

The high brittleness of B_3 value shows the high specific energy in a rock cutting efficiency.

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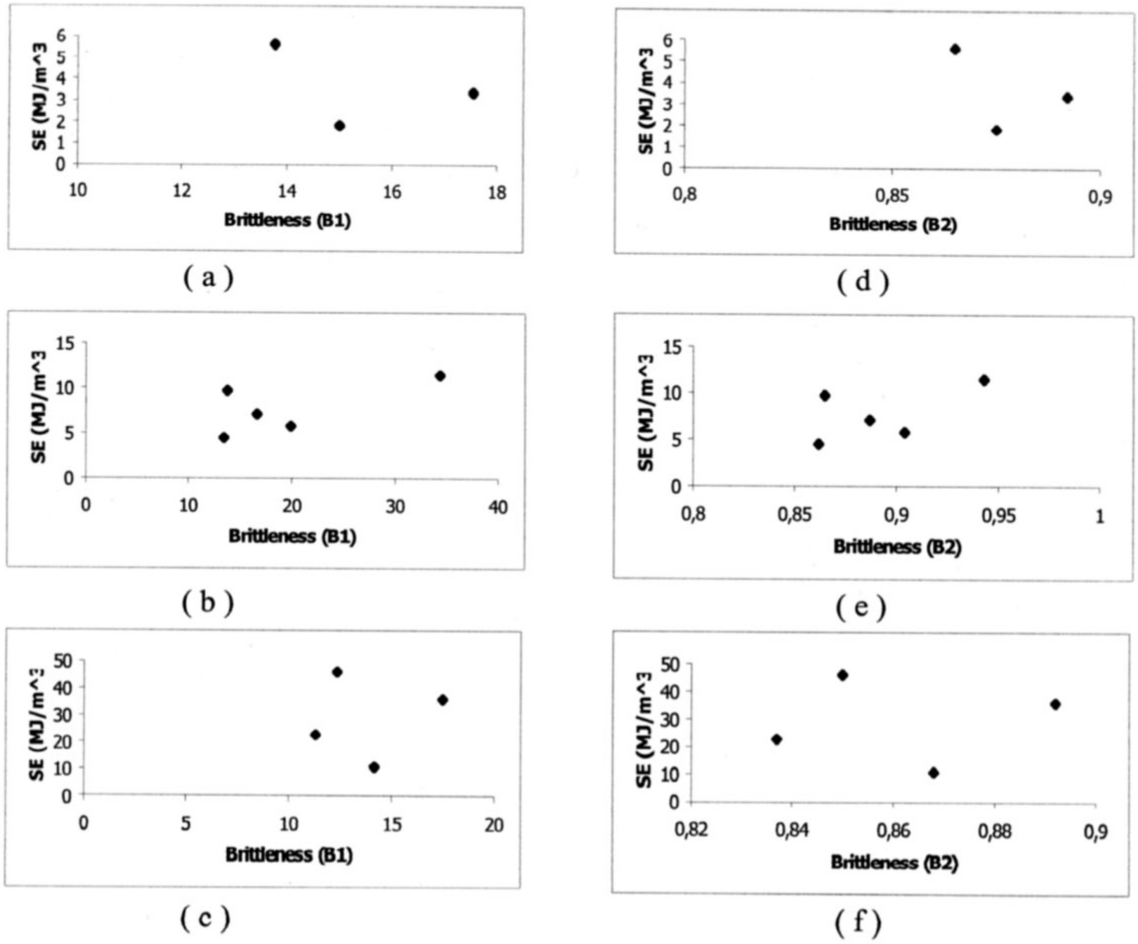

Figure 3—The relationships between the brittleness of B_1, B_2 and the specific energy values (Figures a–c were plotted from Tables V–VII, and Figures. d–f were plotted from Tables V–VII, respectively)

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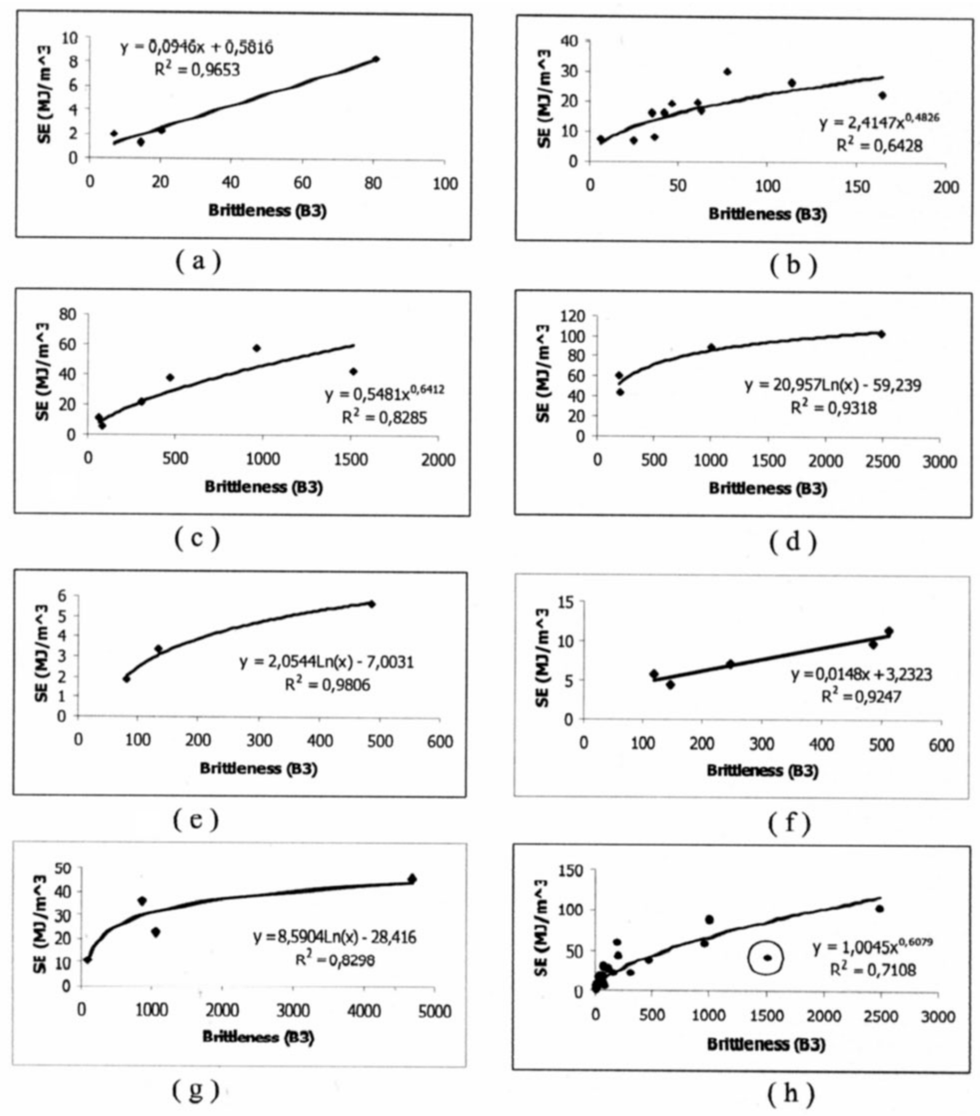

Figure 4—The relationships between the brittleness of B_3 and the specific energy values (Figures a–g were plotted from Tables I–VII, Figure h was plotted from Tables I–IV, respectively)

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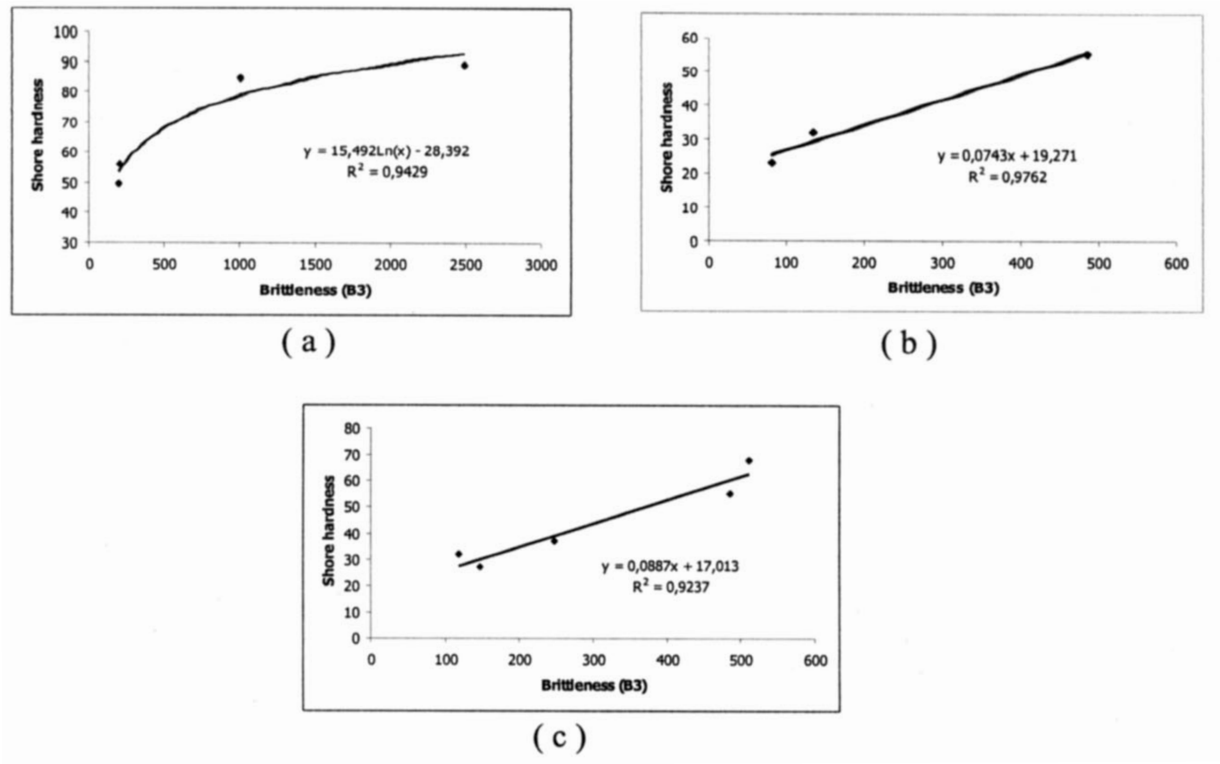

Figure 5—The relationships between the brittleness of B_3 and Shore hardness (Figures a–c were plotted from Tables IV–VI, respectively)

Roche Mining (MT) moves to Richards Bay*

Roche Mining (MT) previously known as MD mineral technologies is relocating its South African manufacturing facility and customer service base from Johannesburg to Richards Bay in April 2003.

Mr Glen Zille, General Manager of Roche Mining (MT) said the move meets with the long-term strategic goals of the company, however the company will continue to maintain a sales office in Johannesburg.

'The move to Richards Bay will provide benefits to us with its conveniently located port, and provide us with suitable support services,' said Mr Zille.

'Key staff will be relocating and we will also be taking the opportunity to upgrade some of our processes to achieve higher quality standards and provide for larger production volumes,' he said.

'The move will also strengthen our ability to provide a high level of customer support, as we appoint additional staff in Richards Bay,' he said.

'Our customers in the coal, chrome and gold sectors of industry and in other parts of South Africa will also benefit, as they receive more focused attention as we introduce the latest technology in mineral processing solutions,' said Mr Zille.

Roche Mining (MT) is an Australian based group with over 60 years of history serving the Mineral Sands industry.

The company established itself in South Africa in 1977 as the principal engineering and technology supplier at the start up of the Richards Bay Minerals mining and mineral processing venture.

Roche Mining (MT) supplied all the spiral concentrators, WHIMS magnetic separators and HTR and Plate electrostatic separators together with commissioning and start-up services on the project.

Roche Mining (MT) develops, manufactures and markets its own technology under the brand names of MD (Gravity Separators), Kelsey (Jig Concentrators), Reading (Magnetic Separators) and Carrara (Electrostatic Separators).

The new location of Roche Mining (MT) is 14 Bauxite Bay Avenue, Alton.

Roche Mining is a division of the Downer EDI Limited (Downer EDI), Australia's second-largest listed engineering, infrastructure and resource services company with assets of A$1.7 billion, 11,000 employees and an annual turnover of over A$2.0 billion. ◆

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SPOTLIGHT ON
Sustainable SHEQ Management in the Mining Industry Symposium

The importance of the topic of this symposium was amply enforced by the status of the session chairman that the symposium organizer, Alastair Douglas, Managing Director, Cementation Mining Skanska had asked and who had readily agreed to take time off from busy schedules to take part. Namely, Bill Nairn, Group Technical Director, Anglo American plc, Rick Mohring, Deputy CEO, Eyesizwe Coal, Peter Kinver, Divisional Director Mining Operations, Anglo Platinum, Western Limb Bushveld Complex (His place was in the event taken by Dr Johnny Johnston, SHE Manager)and Dr James Motlatsi, Deputy Chairman, Anglogold, CEO TEBA and President Emeritus, 'The NUM'.

The Keynote address was given by Piet Botha, on behalf of Ms May Hermanus, Chief Inspector of Mines, Department of Minerals and Energy. He reviewed the trends in mining accidents in South Africa and the fact that a worker was three times more likely to be hurt in South Africa than the USA, UK or Australia. Although there had been the Leon Commission, MHSA Act and various codes of practice, there had been little or no improvements in safety statistics. He highlighted the following areas as the main concern; poor hangingwall conditions, substandard transport, lighting and low meaningful involvement of the work force. He went on to raise the continuing problem of airborne pollutants, noise, silicosis, radiation and flammable gasses. He concluded that the challenges to overcome were; the risks still exist, the reoccurrence of similar events, the gap between standards and practice, the need for higher standards and more precautions with ever-increasing mine depths, increased measurement and control, improved leadership and an overall comprehensive approach to safety.

The symposium was split into four sessions; Mine Qualification Authority (MQA), Certification, Integration, and Behaviour Based Safety.

Mine Qualification Authority (MQA)

Keith Charles, Education Training and Quality Assurance (ETQA) Manager of the MQA set the scene with a presentation on the MQA, giving policies, deliverables, new developments and the challenges for the next 3 years. Lou de Klerk, Technical Training Manager at Lonmin Platinum gave a practical approach of the implementation of the MQA requirements for 'Falls of Ground' and the lessons learnt. The Anglogold experience in implementing ISO 9001 was given by Peter Anderson, Engineering Development Manager. The successes and difficulties were presented and the IRCA developed Electronic Business Management System (EMBS) was described.

Certification

Vaughan Clarke of the British Standards Institute (BSI) presented a different approach to auditioning and the reasons for the new approach using the CAP™ Common Audit Process, which aims to integrate audits and assessment across a number of areas in a systematic manner. William Graham then gave the approach used by Global Conformity Services (GCS Pty Ltd, an affiliated company of SABS). He stressed the need, value and benefits of certification. With the growth world-wide and future trends in certification.

Integration

The NOSA view was given by Carl Marx, Business Development and Operations Manager. He explained how the integration of safety, health and environment risks are best managed as integrated units, although individual business units are important components of any management system. Jaque Oosthuizen, Environmental Coordinator for De Beers Consolidated Mines, Premier Mine gave good practical demonstration of their SHREQ system. Eugene Dabner, Risk Manager, Douglas Colliery presented their integrated approach and gave the benefits as they saw them.

Behaviour-based safety

This new field of interest was presented in two papers. One by Neil Franklin, Sasol Infrachem, who gave the background to their project, which included the four elements of behaviour-based safety; Identification of critical behaviours, gathering of data, provision of feed-back and using data to remove barriers. The second paper was by Dr Johnny Johnston of Anglo Platinum, who described the newly introduced system that aimed to provide visible felt leadership. He said that analysis of safety statistics show that 87% of injuries are behaviour related. The new system addressed culture and value systems, which highlighted activators, behaviour and consequences.

It is a pity that the trend for papers to be presented at symposia are provided to the SAIMM in PowerPoint format. This precludes these presentations from being published in the *Journal* as 'Journal' papers, so useful contributions as presented at this symposium are not available to a wider audience. It does mean that members of the industry must therefore attend our symposia to increase their knowledge and learn from their colleagues. ◆

Richard D. Beck