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DISCUSSION

Reply to the Discussion by Yagiz on "Assessment of Some Brittleness Indexes in Rock-Drilling Efficiency" by Altindag, Rock Mechanics and Rock Engineering, DOI:10.1007/s00603-009-0057-x

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The author would like to express his thanks to the discusser Saffet Yagiz for his interest on the paper. In this reply, I present my explanations, hoping that they will help to clarify the points raised by the discusser.

First, the definition and better understanding of the brittleness concept are required. Brittle and ductile behaviors of materials are well described with stress–strain curves given in Fig. 1. Brittle rocks are not breakable quickly or excavable/drillable/ripperable easily with less energy. Brittleness is breaking event with little or non-deformation. In other words, it is the process by which sudden loss of strength occurs across a plane following little or no permanent (plastic) deformation. Ductile deformation occurs when the rock can sustain further permanent deformation without losing load-carrying capacity (Fig. 1 curve *d*). When a substance breaks easily under strain, it is said to be brittle. A general rule with regard to brittleness is that a brittle product breaks at very little deformation (Fig. 1 curve *a*). In Fig. 1, curve *a* is clearly more brittle than *b*, which is more brittle than *c*, which is more brittle than *d*. In the same time, curve *a* is stronger material than *b*, which is stronger material than *c*, which is stronger than *d*.

As seen from Fig. 2, the material having high mechanical strength is more brittle than the material having low mechanical strength (As seen from Fig. 2, the higher the strength of material, the more brittle the material is). In the Fig. 2a, rock *a* is clearly more brittle than *b*, which is more brittle than *c*, which is more brittle than *d*. In the Fig. 2b, the brittleness of rocks is equal. That means the ratio of UCS (σ_c) to TS (σ_t) ($tg\alpha = \sigma_c/\sigma_t = B_1$) is equal. Rock *a* is clearly harder the others. But, according to brittleness concepts [$B_3 = (\sigma_c\sigma_t)/2$ and $B_4 = \sqrt{B_3}$] used in this study (Altindag 2009), brittleness values for rocks *a*, *b*, *c*, and *d*, given in Fig. 2b are not equal. It is clear that rock *a* is more brittle and stronger than rocks *b*, *c*, and *d*, respectively.

Energy cost for cutting/drilling/ripping of high strength rocks (brittle rocks) is inevitably higher. Therefore, it is not a true expectation to arrive the aim of low specific energy (SE) values in the cutting/drilling/ripping of the highly brittle material. Glass is defined as high brittle material. Obsidian is a natural glass. The uniaxial compressive strength of Obsidian is over 200 MPa, and it is classified as a very high strength rock. At the same time, it is defined as a very brittle substance. Because the obsidian sample under compression test suddenly fails by breaking down into smaller pieces with no deformation in the post-failure region.

As can be seen from Tables 1 and 2, brittleness of rocks increases with increase in compressive strength.

Mellor (1972) discussed the importance of normalizing the specific energy with UCS. In this study (Altindag 2009), PR is normalized with UCS ($PR_n = PR/UCS$), based on the work done by Goktan and Yilmaz (2005). Generally, the purpose of these studies is to estimate energy consumption for unit material strength. This provides us a meaningful measure for understanding the PR value for unit rock strength. But normalizing the UCS with PR (UCS/PR), suggested by Yagiz (2009), is not meaningful, because targeted value is not UCS value. PR is depended value on UCS, but UCS is not depended value on PR. In this study, changes in penetration rate depending on UCS of rocks were investigated. Therefore, suggestion made by Yagiz is not appropriate for the concepts of this study.

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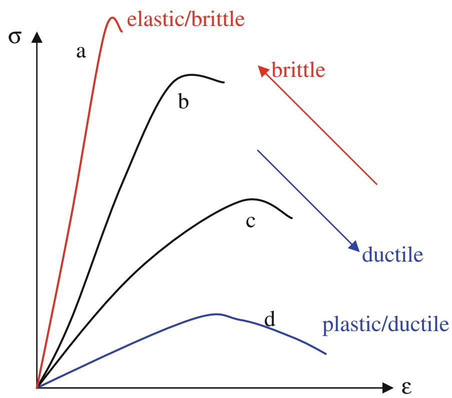

Fig. 1 Stress–strain curves of some rocks

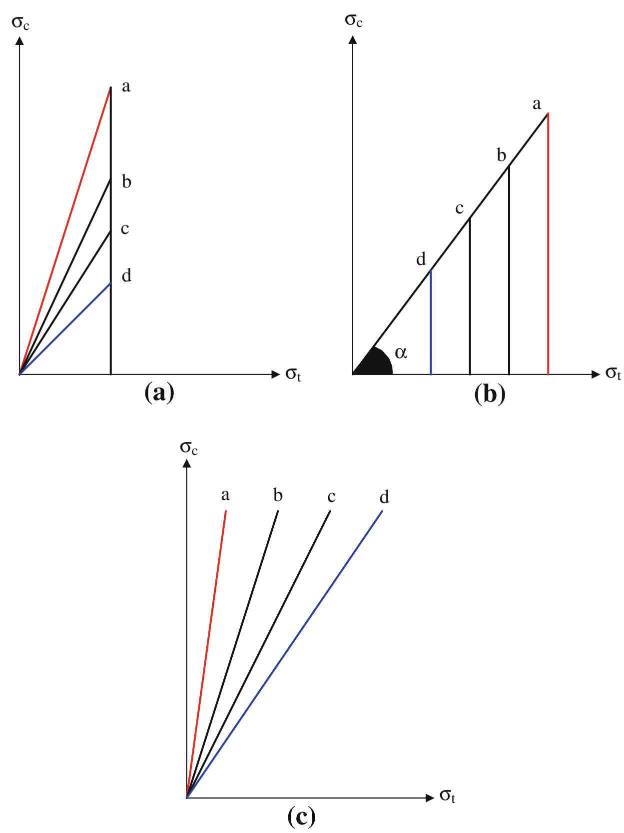

Fig. 2 Compression of compressive strength (σ_c) and tensile strength (σ_t) values of some rocks. **a** The curves of *a*, *b*, *c* and *d* have same tensile strengths and different compressive strengths, **b** the curves of *a*, *b*, *c* and *d* have different tensile and compressive strengths, **c** the curves of *a*, *b*, *c* and *d* have different tensile strengths and same compressive strengths

At the bottom of page 7 of the paper "*Normalized penetration rate values by uniaxial compressive strength increases exponentially as the brittleness increases.*" should be changed as "*Normalized penetration rate values by uniaxial compressive strength decreases exponentially as the brittleness increases*". It is mistakenly typed.

Table 1 Description of brittleness (Aftes 2003)

Class	σ_c/σ_t value	Description
1	>25	Very brittle
2	15–25	Brittle
3	10–15	Middle brittle
4	<10	Low brittle

Table 2 Description of brittleness (Gehring 1987)

σ_c/σ_t value	Description
<9	Ductile cutting behavior
9–15	Middle cutting behavior
>15	Brittle cutting behavior

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