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Sandstone Rippability Assessment Based on Specific Energy Relationship with Tensile Strength and Surface Hardness

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ABSTRACT

Rock with moderate strengths (20 to 70 MPa) effectively excavated by ripping method which is considered as shallow excavation or surface striping method. Disputed between client and contractor often occur due to the lack of proper assessment to determine the rippabality of hard material. Practically, rippability of in situ rock is assessed based on field ripping test that being conducted using actual ripper dozer which is time-consuming and expensive. Therefore the assessment of rippability of rock based on specific laboratory tests able to resolve the conflict that occurs on ripping method. The correlation between specific energy with surface hardness and tensile strength is chose as the material properties to assess in order to determine the rippability of rock in this study. Few samples of Sandstone undergone several laboratory tests such as laboratory ripping test, Brazilian's test and Schmitt hammer test in order to obtain the required parameters in this study. The average tensile strength (σT) obtained was 4.62MPa with a range of value from 3.19 to 7.50 MPa whilst the average rebound number (R) obtained for Sandstone was 26.6 with a range between 19.0 and 34.0. The specific energy (SE) obtained indicates an average value of 3.95 MJ/m^3 with a range value between 1.73MJ/m^3 and 6.45 MJ/m^3. The correlation of R and σT with SE shows a relatively good relationship. Parameters of R and σT are acceptable and reliable for assessing rippability of Sandstone based on the value of regression coefficient (R2) which is consistence above 0.8 for both correlation between SE, R and σT.

Keywords:
Ripping, specific energy, tensile strength, hardness, sandstone

1. Introduction

Moderate strong rock is classified as a hard material that lies between soils (strength of less than 1 MPa) and rock (strength greater than 70 MPa) and in the fresh state it includes some of the sedimentary rocks, metamorphic rocks, and cemented sediments. The main problem is the rock is too hard to excavate by conventional method but too weak to excavate using blasting. The disputes often occur between the contractor and the client in selecting the best method of excavation

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especially when involve with moderate strong rock. The contractor tends to use blasting because it is more expensive and faster to conduct while the client want the most economical method such as ripping. To avoid this situation, rippability assessment of moderate-strong rocks must be implemented to ensure the best method of excavation can be selected and satisfied by both parties. Generally, the rippability of the rock depends on their characteristic and properties and can be evaluated using specific laboratory and field test. In this study only laboratory test will be conducted as the assessment of rock rippability. Samples of sedimentary rock will be tested to obtain their relevant material properties. The laboratory ripping equipment is designed with the aim of reducing the scale of the sample under the control condition to assess the ease of rock rippability. This test can be used as the alternative method if the direct ripping test cannot be conducted. The laboratory ripping test evaluates the rock rippability based on the specific energy. The equipment is designed with the specially shaped cutting shank and appropriate devices to measure the amount of power required to rip a specific unit of volume. In this study the special fabricated equipment used to simulates ripping of the single shank ripper dozer with the cutting speed of 150 mm/s and engine rating 1850 rpm. This laboratory equipment will be used as the indirect method for evaluating the ease of rock rippability under the laboratory condition [7]. The result of this test will be analyzed to assess the excavatibility of the sample. Generally, this study focus on the several objectives which are:-

• To understand the material properties (including specific energy) of Sandstone that is related to its rippability.
• To obtain relevant data on material properties of Sandstone using selected laboratory tests.
• To verify any correlation between the material properties of Sandstone and its rippability.

2. Background of the Study

2.1 Sandstone

Natural compaction of sandy sediment is development process of sandstone. The sandy sediment converted to the relatively hard rock through the cementation process. The common main elements that composed in sandstone are Feldspar, Lithic Fragments and Quartz. The diagenetic process that occurs on unconsolidated material transforms it to become sedimentary rock. This digenetic process happens when the sand has been deposited and buried by more sediment [1]. In this process, the sediment experiences the compaction stage by the pressure of overlying deposit and followed by cementation stage which involves with the cementing material that fills the pore space of the sand grains. Calcium carbonate and silica are the common cementing materials that are derived from dissolution or alteration of the buried sand. Sand stone is the clastic sedimentary rock that typically has compressive strength ranging between 12.5 to 100 MPa and it considers as a group of rock that rippable [2].

2.2 Material Properties Relevant to Ripping

The rippability of hard material depends on several factors such as unconfined compression strength, hardness, and tensile strength. The fracture mechanism generated in the ripping process of hard material has a strong relation with these properties. During the ripping process the tensile strength has more significant influence than compressive strength. The Brazilian's Test is used to obtain the tensile strength of the rock sample. The tensile strength of the rock is regularly much lower than compressive strength; therefore rocks are most likely to fail under tension well before they would fail under compression. Thus, it is very important to know the stress regime a rock will be subjected to when used in an engineering project. Generally, most of the hard material have less or never subjected to the condition where tension is the primary force [3]. Density and mineral composition give a major influence to the hardness of the rock. The hardness of the hard material is described as degree of resistancy of hard material against permanent deformation

Schmidt hammer test is one of the effective methods used in order to determine the rock hardness. The parameter obtained by this test is the rock hardness on the surface only, therefore the hardness index obtained is considered as an indicator of the rock strength. Physically, hardness encompasses elasticity, plasticity, strength, ductility as well as the toughness of the surface of the rock. The compressive strength is defined as maximum load that the rock sample can receive without failure. The compressive strength is the maximum force that can be applied to a rock sample without breaking. The rippability of hard material generally directly proportional to the value of compressive strength [4].

2.3 Specific Energy

Specific energy is the main parameter that commonly determines during the assessment of machinery performance when rock excavation is conducted as it relates cutting force to the amount of rock excavated. This parameter is defined as amount of work done per unit volume of rock excavated. The specific energy generally recognized as an assessment of cutting efficiency meanwhile provides a practical and a significant measure of rock excavatibility. Basarir and Karpuz [5] established the relationship between the rock properties and the specific energy. They used specific energy as a unique parameter to assess the rippability of rock as indirect classification and found that it has a good relationship with the rock properties that frequently used in the other rippability classification system.

2.4 Ripping

Ripping is the process of breaking the rock by held down and drawn the steel tyne that being attaches to a bulldozer to the rock mass. It being used for of shallow rock excavation and inexpensive. The ease of material to being break using the ripperdozer to smaller pieces or boulder is defined as rippability of the hard material. This rippability also influence by type and size of ripperdozer being used and method of working. According to the Bell the tractive force to advance the tyne on the rock which determine the degree of tyne penetration control by weight and engine power of the ripperdozer [6].

According to Tatiya, they are several factors that determine the effectiveness and efficiency of ripping operation such as [3]:

- Tooth penetration into rock, particularly the homogenous rock such as mudstone, clay stone and fine-grained calices. The same logic is applicable for tightly cemented formation such as conglomerates, glacial tills and calices containing rock fragments.

- The degree of seismic of the material is one of the indicators of ripability but is not the sole parameter. The low seismic velocity of the sedimentary strata is an indication of the ripability but much depend on the presence of fracture and bedding planes. The presence of such discontinuities may not allow effective tooth penetration and, hence, ripping.

The most common type of rock that used ripping as excavated method is clastic sedimentary rock and some metamorphic rock that subjected to discontinuities' such as bedding and joint. However this method unsuitable being used for excavation of Intrusive igneous rock that has strength more than 70 MPa unless it greatly weakened by the weathering process and has closely joint structure. Ripping has been identified as the effective method for breaking the discontinuities of some weak rock masses compare to the blasting. Some of the rock is difficult to blast due to its physical properties. For example, weaker sedimentary rock that has a compressive strength less than 15 MPa such as mud stone cannot be blast because it easily pulverized when the blasting waves have dissipated [7].

2.5 Rippability Assessment Methods

There are many methods to determine the rippability classification but the main method is a direct method and indirect method. In situ field excavation which involved with direct ripping by the ripperdozer is considered as direct method. This method produces an excellent result but time-consuming and very expensive. The indirect method is the other way of rippability assessment which involved with the assessment of material and mass properties of the rock. The excavatibility of the rock on the site will be predicted based on these rock properties. The indirect method more faster to conduct and economical even though it doesn't produce exactly the same results as a direct method [5]. This study is based on material properties, therefore, it will focus on the indirect method only in order to determine the rippability of sandstone.

2.6 Indirect Assessment Methods

Geophysical techniques are one of the method that being used as rippability assessment for an indirect method which apply the principle of measurement of rock physical property changes. It is fast and relatively straight forward using the application of seismic velocity which considered as a non-destructive test. If the laboratory test data or seismic data are not available, graphical method and grading method is very practical for determine the rippability of hard material [5]. All types of indirect method considered more economical and produce fast result compared to the direct method.

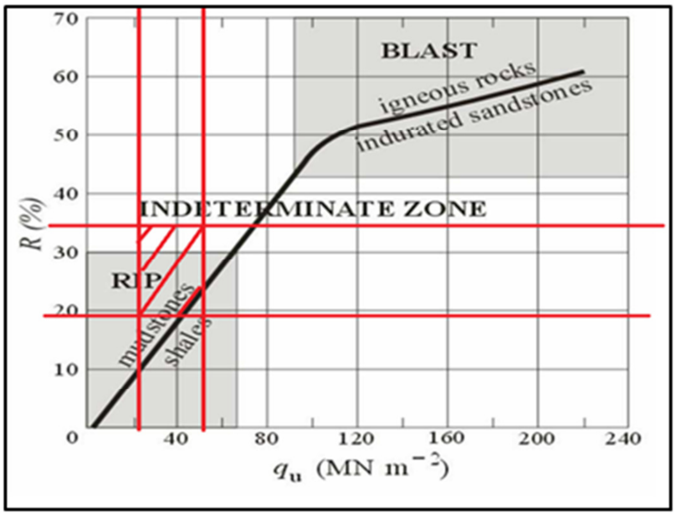

Fig. 1. Rebound number (R) plotted unconfined compression strength (qu) [4]

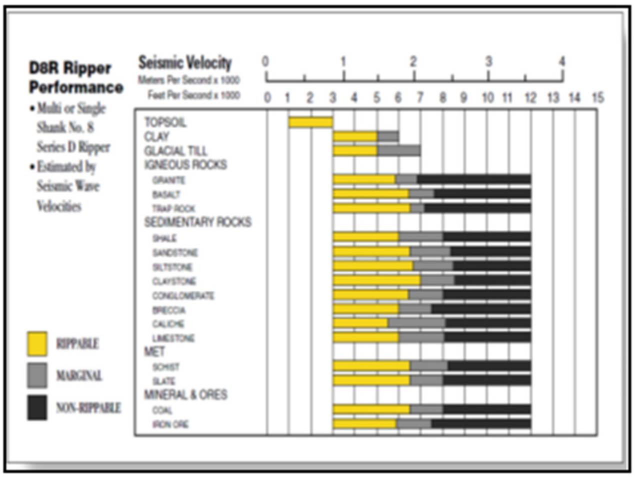

Fig. 2. Chart of ripper performance for D8 [9]

3. Methodology

The main interest of this study is to assess the correlation of specific energy and the rock material properties obtained from the laboratory test. Fifteen (15) numbers of samples from site at Dengkil Selangor were obtained for specific laboratory test. The assessment began with the identification of lithologic and geologic classification of physical properties of rock sample by visual inspection or physical observation in order to determine the type of the rock sample.

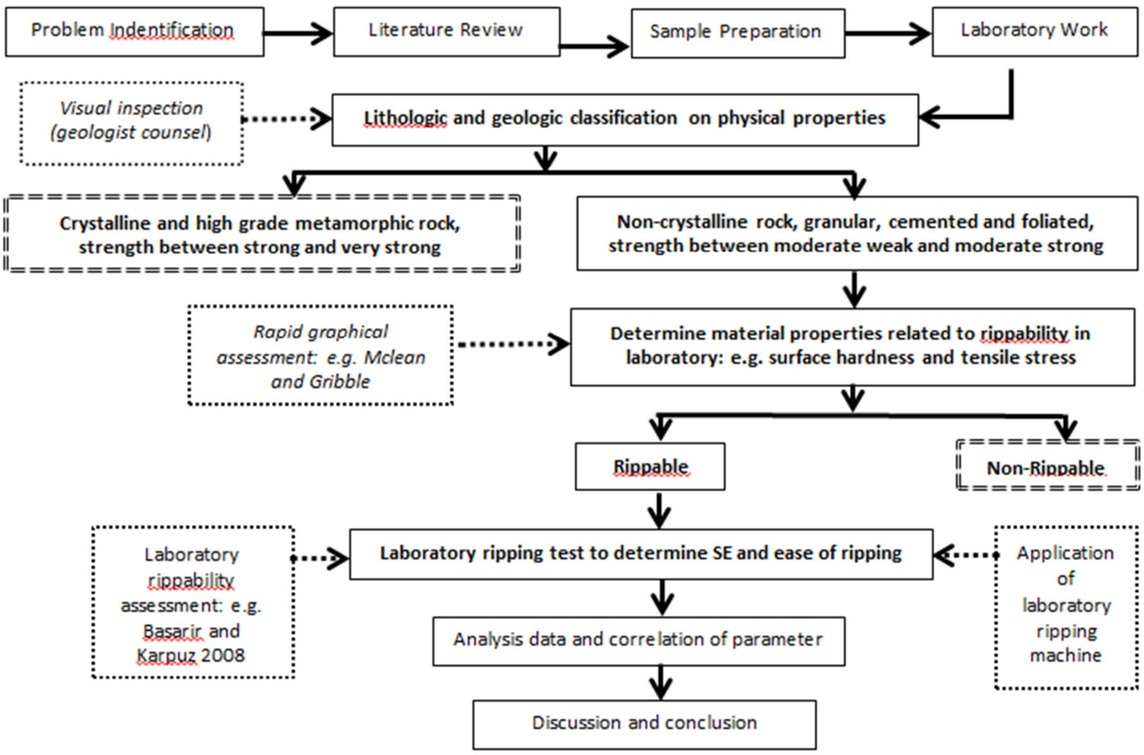

Fig. 3. Research Methodology

In this stage, good geology knowledge and advice from geological expert is necessary. Schmidt Hammer Test (Figure 5) and Brazilian's Test (Figure 6) were conducted to obtain material properties such as surface hardness and tensile strength. These material properties were correlated with the specific energy obtained from Laboratory Ripping Test. The Laboratory Ripping Test and Schmidt Hammer Test were conducted on prismatic-shape sample whereas the core sample was tested using Brazilian Test.

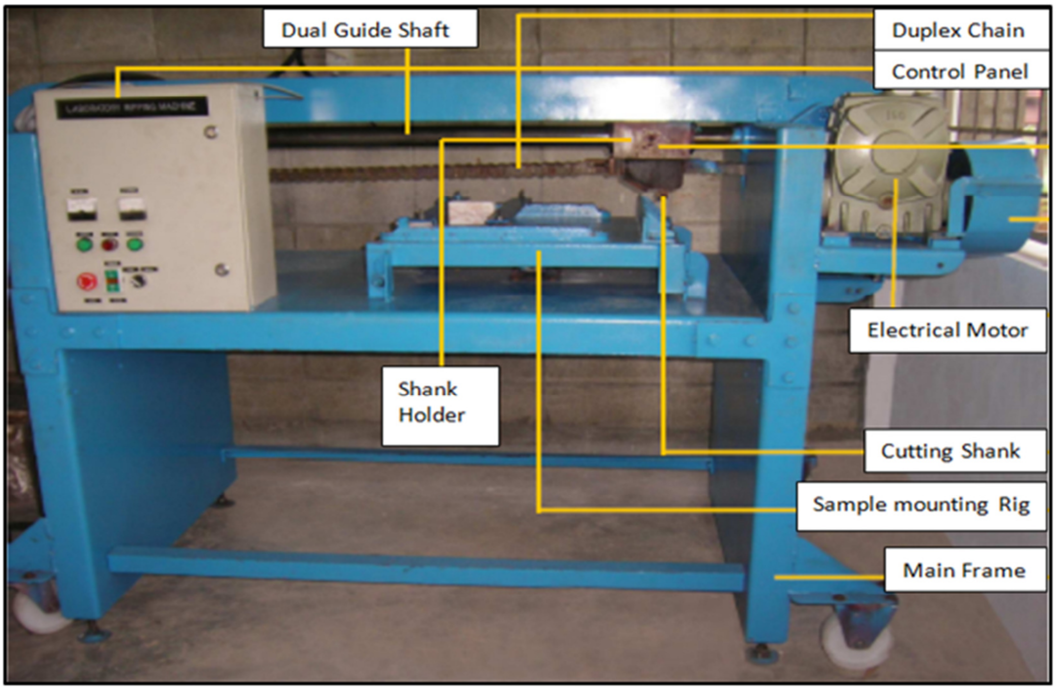

Fig. 4. Laboratory ripping test

Fig. 5. Schmidt

Fig. 6. Brazilian test

The laboratory ripping test (Figure 4) was conducted with the main objective to determine the specific energy required to rip the known volume of the rock. The performance of surface excavation machinery such as ripper dozer can also be estimated by using specific energy principle. The fabricated laboratory machine has the characteristic that represents D6 caterpillar ripper with horse power 125. The ripping test was conducted using the block specimen with the dimension of 150 mm x 100 mm x 75mm (L × W × H). The sample was held in position by sample holder and the machine started to rip. V-shaped groove of 5 mm deep and 12-13mm wide was produced when the cutting shank horizontally dragged in the test sample. The data of the ripping process was automatically recorded for further calculation and analysis. The datum of the test should be established first to represent the data on fluctuations of power to drive the shank freely without cutting samples. Then the amount of additional power required to overcome the resistance imposed by the block sample were calculated to determine the difference in the fluctuate power between cutting test and the datum. The variety of power (Watt) during the ripping test was measured in 0.1 second intervals. Data analysis was done to compute the amount of Specific Energy required to rip the block sample.

All the test procedures were complied with the procedures suggested by International Society for Rock Mechanics for rock characterization testing and monitoring [9]. The analysis of the correlation between properties of the rock obtained from rippability assessment was executed including verifications of the results with the chart and figure established by other researchers.

3. Results and Discussions

The rippability generally reduces with the increasing of surface hardness (R). Based on the results obtained, the classification of excavitibility of the rock sample is referred to Figure 1 and the result showed that the rock sample is classified in the zone of indeterminate and rippable. The indeterminate zone is the transition zone from ripping to blasting and the material that lay within this area was indicated as difficult to be ripped. Generally, the rippability will reduce with the increasing of surface hardness (R) but some cases the degree of rippability of the samples varies according to the hardness.

Table 1
Result obtained from laboratory test

Material Properties	Rebound Number, R	Tensile Stress, σ_t (MPa)	Specific energy (MJ/m^3)
Ranges	19.0-34.0	3.19-7.50	1.73-6.45
Average	26.58	4.62	3.95

Table 2 shows the summary of correlation between specific energy and rippability for D8 ripper [5]. Based on the correlation, the data represent the ease of rippabilty by the D8 ripper dozer (more horsepower) while the laboratory test conducted was representing the D6 ripper dozer. Therefore if the rock samples indicated easy and moderate to be ripped by the ripper D6 (laboratory ripping machine) it can be more easily ripped with higher production rate when using D8 ripper dozer. In conclusion, the ranges of SE obtained show that the rock sample can be categorized as very easy to moderate to rip with the most of the sample fall in the moderate ranges.

Table 2
Correlation between specific energy and rippability for D8 ripper [5]

Specific Energy (MJ/m^3)	Ease of Ripping	Production Rate (m^3/h)
<3.75	Very easy	>1300
3.75-5.25	Easy	900-1300
5.25-7.00	Moderate	400-900
7.00-9.00	Difficult	250-400

The data of Specific Energy, Rebound number, and Tensile Stress are used to obtain the relationship of linear regression line analysis. In graphical method, the surface hardness data is an indicator of rippability of hard material but it cannot determine ease of excavation. Therefore an integration of those properties with specific energy was important to clearly estimate the ease of rippability of hard material. Figure 7, 8 and 9 showed the correlation between Specific Energy, Rebound number and Tensile Stress and its regression coefficient (R2) for reliability with all correlations displaying R2 > 0.8. Generally, the correlation showed that resistance to ripping was increase with the increase of surface hardness and tensile strength. The best correlation was obtained from the relationship between the Surface Hardness and Specific Energy (Figure 8) which have Regression Coefficient R2=0.8568.

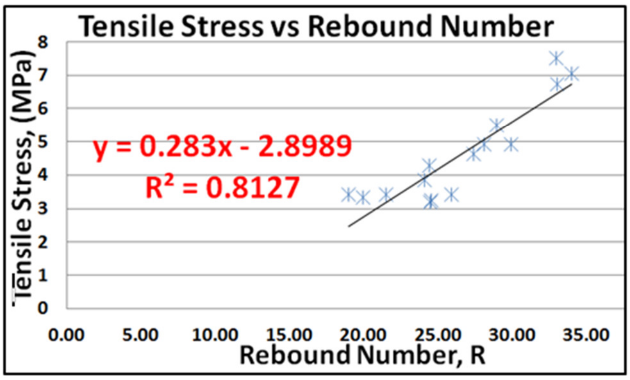

Fig. 7. Graph Tensile Stress vs Rebound Number

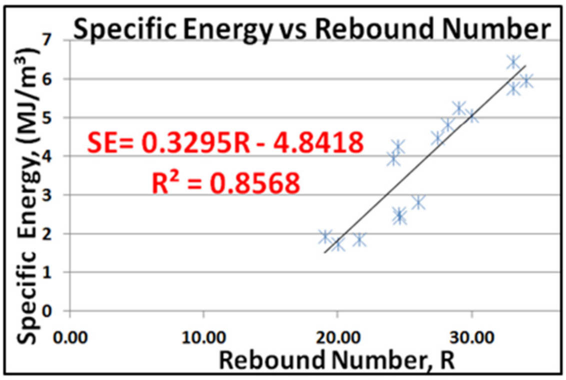

Fig. 8. Graph SE vs Rebound Number

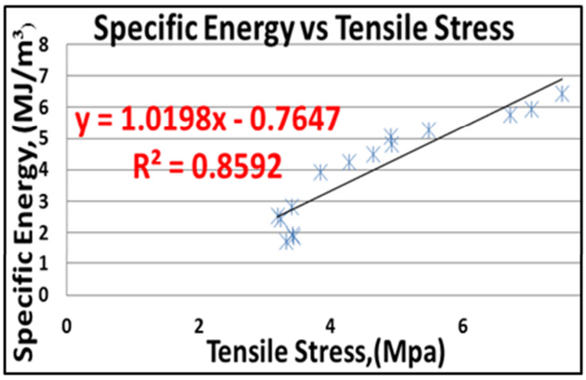

Fig. 9. Graph SE vs Tensile Stress

The tensile stress of hard material has major influence in ease of ripping since the ripping applied the tension force during the process of pull the riper dozer shank. Therefore the tensile strength is a crucial strength parameter in asses the rippability of hard material and its relationship with the specific energy give a good indicator of the degree of ripping process. Ripping process is commonly used for the shallow excavation, not a deep excavation. The surface hardness plays important role in determining the rippability of the hard material, and as an indicator of the rock strength and it correlation with specific energy give an estimated degree of rippability of hard material. Thus, the correlation between the properties involved in this study showed that the surface hardness was proportional to the tensile stress. Based on the correlation data, the specific energy was competence to be a good parameter in characterizing ease of rippability of hard material since the R^2 value is above 0.8 which implying a good and reliable correlation[10].

5. Conclusion

The condition of rock sample generally will affect the hardness value of rock. The condition where the intact sample that free from any defect such as fracture, joint, and weathering effect definitely makes the laboratory sample much stronger than in situ rock mass that has a variety of defects. Therefore the sample that can be ripped in the laboratory definitely can be ripped at the real field. Regarding to this study, the laboratory test is a reliable assessment with the systematic procedure to assess the rippability of material. The assessment gives some advantages which are more economical and faster to conduct.

Based on the laboratory ripping test and material properties obtained, the degree of rippabality can be predicted with the estimated production rate for the use of D6 ripperdozer or with the lower horse power than D6. The laboratory ripping test was conducted on the sample is important to correlate the specific energy with the material properties obtained and further verify the ease of rippability. Reffering to the finding, a good correlation between surface hardness, tensile stress and specific energy are found out. Thus, the outcomes of the study are listed out to fulfill the objectives of the study:

1. Surface hardness and tensile strength are the effective material properties that can be used in assessing the rippability of rock. The ripping test is also effectively conducted and produced an excellent and consistent results

2. Good correlations have been established between specific energy and material properties which are surface hardness and tensile strength. The regression coefficient that obtained is above 0.8

3. The correlation between specific energy with surface hardness and tensile strength is directly proportional and for that reason, Specific Energy become a reliable indicative parameter for assessment of hard material rippability

References

[1] Blyth, Francis George Henry, and Michael De Freitas. *A geology for engineers*. CRC Press, 2017.
[2] Boggs, J. R. Principles of sedimentology and stratigraphy. 3rd ed. Toronto: Merril Publishing Company, 2000.
[3] Tatiya R. Civil Excavation and Tunneling. London: Thomas Telford, 2005.
[4] Gribble, C., and A. McLean. *Geology for civil engineers*. CRC Press, 2003.
[5] Basarir, H., C. Karpuz, and L. Tutluoglu. "Specific energy based rippability classification system for coal measure rock." *Journal of Terramechanics* 45, no. 1 (2008): 51-62.
[6] Bell, Fred G. *Engineering geology and construction*. CRC Press, 2004.
[7] Mohd For Mohd Amin. Laboratory Ripping Machine-Invention Disclosure for INATEX 2008, Skudai,Johor: Research Management Centre,Universiti Teknologi Malaysia, 2008
[8] Brown, E. T. "Rock Characterization, Testing and Monitoring. ISRM Suggested Methods Pergamon press." (1981): 201.
[9] Caterpillar . Handbook of Ripping Edition . 12th ed. Illnois, USA: CAT publication, 2000.
[10] Amin, M. M., C. S. Huei, Z. A. Hamid, and M. K. Ghani. "Rippability assessment of rock based on specific energy and production rate." In *2nd Construction Industry Research Achievement International Conference (CIRAIC 2009)*, vol. 9. 2009.
[11] Nicieza, C. González, MA Rodríguez Díaz, MI Álvarez Fernández, and AE Álvarez Vigil. "Characterization of ground from the point of view of its excavatability." *Engineering geology* 126 (2012): 8-18.