Evaluation of Factors Affecting Ripping Productivity in Open Pit Mining Excavation

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ABSTRACT

Excavation of overburden material in open pit mine is usually done by digging, ripping or blasting method depending on the characteristics of materials to be removed. Ripping is usually preferred because it is more economical than the other methods. A common problem related to the ripping is wearing of the ripper tips which resulted in the decline of production. This paper presents the study on factors affecting the ripping productivity at an open pit mining at Bangko Barat, South Sumatra, Indonesia. Four types of common overburden material were selected for this study i.e. sandstone, tuffaceous sandstone, silty claystone, and silty sandstone. The rocks were characterized based on their compressive strength, cohesiveness, and hardness which were identified based on quartz content. The characterization of rock materials was performed methods suggested by ISRM. The wearing of the ripper tip was measured by measuring the length of the tip while the productivity was measured by the amount of material excavated in an hourly basis. Results show that the quartz content is the most influential factor on the wear rate of the ripper blades and therefore the productivity level. A chart was developed as guideline to determine the ripping production of Caterpillat D9R on the four types of overburden rocks found in Bangko Barat open pit mine.

KEYWORDS: *Open mine, soft rocks, quartz content, Ripper blades, ripping productivity*

INTRODUCTION

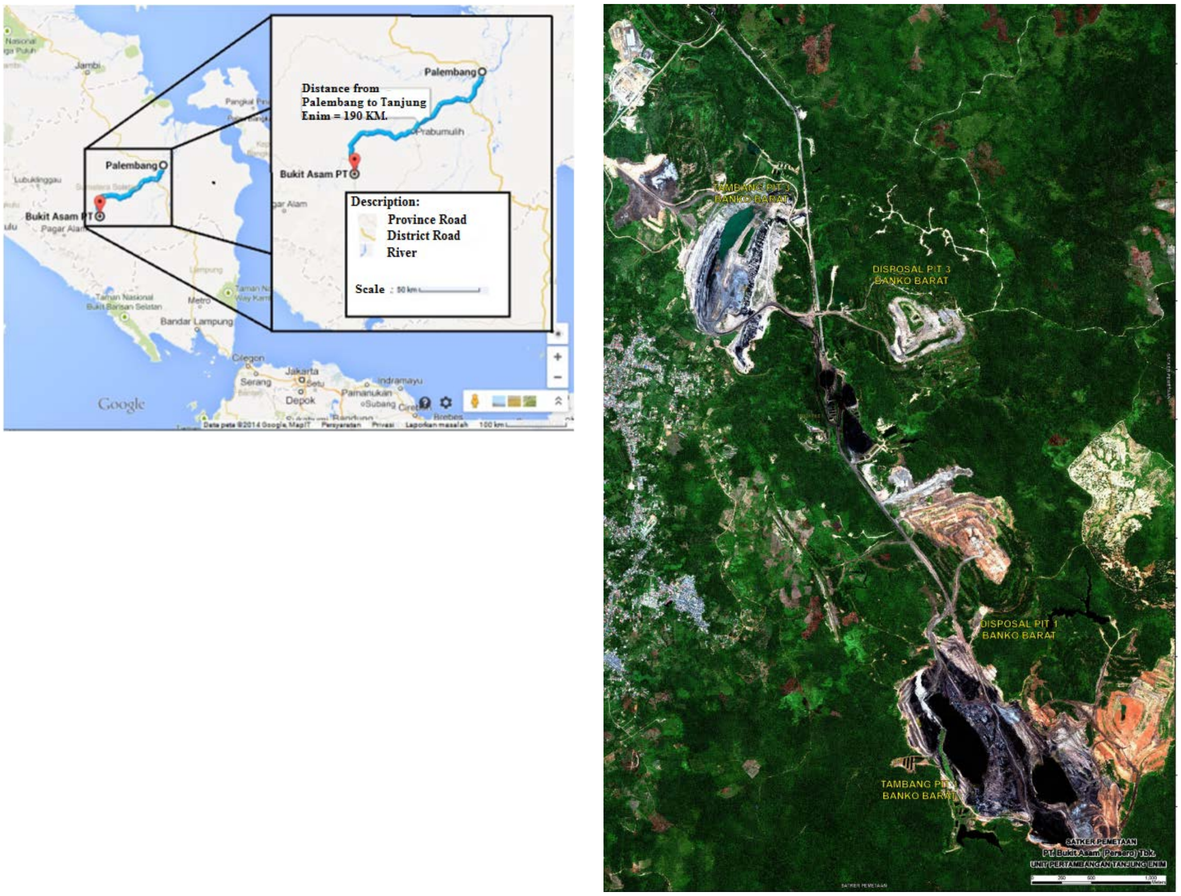
One important activity in open pit mining operation is the removal of overburden material. In general, the excavation is performed by three methods i.e. Digging, Ripping and Blasting (Tsiambaos and Saroglou, 2010). Detailed review of each excavation method is given in MacGregor et al. (1994) and Basarir and Karpuz (2000). Ripping method is usually preferred as compared to free digging because it is less time consuming. It is also more economical than blasting even though the effectiveness of ripping decreases as the ripper tips wearing out. Ripping allows the ground surface rock to be broken into small, easy to handle and transport rubble which can then be removed so that grading can take place. Evaluation of the material's rippability have been developed based on compressive strength (Weaver, 1975; Kirsten, 1982; Smith, 1986; Singh et al., 1987; Karpuz, 1980; Kramadibrata, 1998), weathering degree and spacing of discontinuities (Pettifer and Fookes, 1994) as well as seismic velocity (Catterpillar, 2008). Based on compressive strength, the ripping method is selected when the compressive strength of the material is between 10 and 25 MPa while blasting is used if the compressive strength is above 25 MPa (Bieniawski, 1989).

The open pit mining of coal in Bangko Barat, South Sumatra, Indonesia involves an excavation of the so called ‘soft rock’ with an average compressive strength of less than 7 MPa by Bukit Asam Mining Company (PTBA). Theoretically the material with compressive strength less than 10 MPa can be excavated by free digging process; however, it is not the case in Bangko Barat. Thus, other characteristics should be considered for excavatibity assessment of the overburden material in this area and the application of ripping method is considered in this study. Mc.Gregor (1994) proposed that the rippability of a material can be categorized by the initial ripping productivity in m^3/h; this criterion can be used when considering if ripping is preferable at any situation.

The study focuses on the ripping production considering the effect of wearing of ripper tips during operation. The wear level of the ripper blades may be affected by rock characteristics. The mechanical characteristic of rocks is usually defined by several properties i.e. compressive strength, hardness, fracture mechanism, and durability. As indicated above, the compressive strength is the main parameter to consider in the rippability assessment of rock material. The hardness of rock is usually governed by mineral composition, especially quartz. Since quartz is classified as hard mineral (level 7 in Moh’s hardness scale), material containing high percentage of quartz indicates that the rock is hard and more difficult to dissemble, thus ripping is useful (Singh et al., 1986; Smart et al., 1982). In addition to strength and hardness, Karpuz (1990) and Kirsten (1982) also indicated that cohesiveness should be considered as a factor to determine the rippability of a rock mass. Therefore compressive strength, quartz content and cohesion are used in this study as factors that may affect ripping productivity.

RESEARCH METHODOLOGY

The study was performed in open pit coal mining area of Bangko Barat, South Sumatra, Indonesia (Figure1). The excavation of overburden material is performed by ripping using Caterpillar D9R bulldozer with long penetration tip as shown in Figure 2. The research focuses mainly on two approaches, i.e. laboratory characterization of rock mass i.e. the compressive strength of soil, the cohesiveness, and quartz content following ISRM Suggested Method (SM) for Determining the Uniaxial Compressive Strength and Deformability of Rock Materials – 1979; SM for Laboratory determination of Direct Shear Strength, and SM for Determining Hardness and Abrasiveness of Rocks - 1978, and field observation on the wearing level of ripper tip and ripping productivity. Four types of common overburden material were selected for this study i.e. sandstone, tuffaceous sandstone, silty claystone, and silty sandstone.



(a) (b)

Figure 1: Location of field study (a) Map (b) Satellite image

(a) (b)

Figure 2: (a) Caterpillar D9R bulldozer and (b) ripper tips used in the study.

Field observation was conducted on the performance of bulldozer caterpillar D9R utilized in the excavation of overburden material at open pit coal mine Bangko Barat. As shown in Figure 3, the ripper consists of four components i.e. power assembly, tool bar, shank and tips. Tip is the peg that penetrates into the rock formation. This part is vulnerable to wearing. Initial penetration of the tip determines the rippability of the rock. There are six types of tip, the one utilized by type D9R Caterpillar bulldozer in Bangko Barat is the long penetration tip which is connected to single shank; both are suitable for excavation on compacted rock with relatively low compressive strength (Caterpillar, 2008). The length of tip is 60 cm (Figure 3A). The wearing rate of the ripper tip is measured by the length of the ripper with the interval of one hour. Specification of the ripper tip indicates that the ripper tip should be replaced when the extent of the damage in ripping tips reach 40 cm. If the residual length of the tip reaches 20 cm, the tip should be replace with a new one (Figure 3B). The productivity data was obtained at the same time of the measurement of ripper tip by measuring the volume of material moved by the excavator in m^3/h. Three measurements of tip length and ripping productivity were made on each type of rock until the limit stated in Figure 3b is achieved or 10 h. of operation.

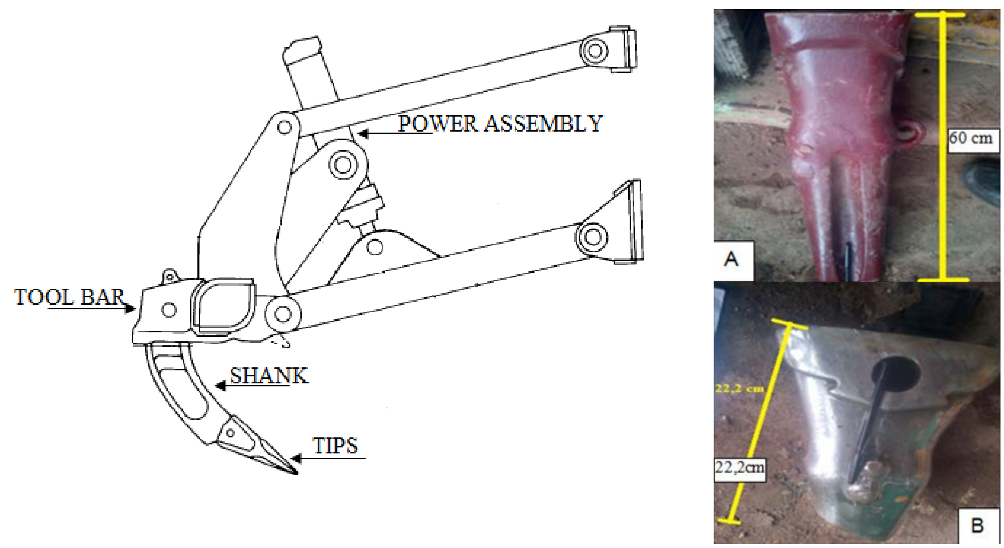


Figure 3: Schematic diagram of ripper components (A) New tip (B) Worn out tip

RESULTS AND DISCUSSION

The characteristics of overburden materials used in this study are summarized in Table 1. It can be seen that all rocks have a compressive strength of less than 7 kPa and they can be classified as soft rock (Figure 4); therefore theoretically, the rocks can be excavated by free digging. Laboratory test also indicates that the materials have quartz contents between 58 and 68% which indicated that the materials are hard to break and abrasive.

Table 1: Characteristics of overburden rock at open pit mine Bangko Barat

Type of rock	Compressive strength (MPa)	Cohesion (MPa)	Quartz content (%)
Silty Claystone	3.69	0.028	58.5
Silty Sandstone	4.71	0.057	60.2
Tuffaceous Sandstone	5.65	0.099	62.4
Sandstone	6.31	0.190	67.6

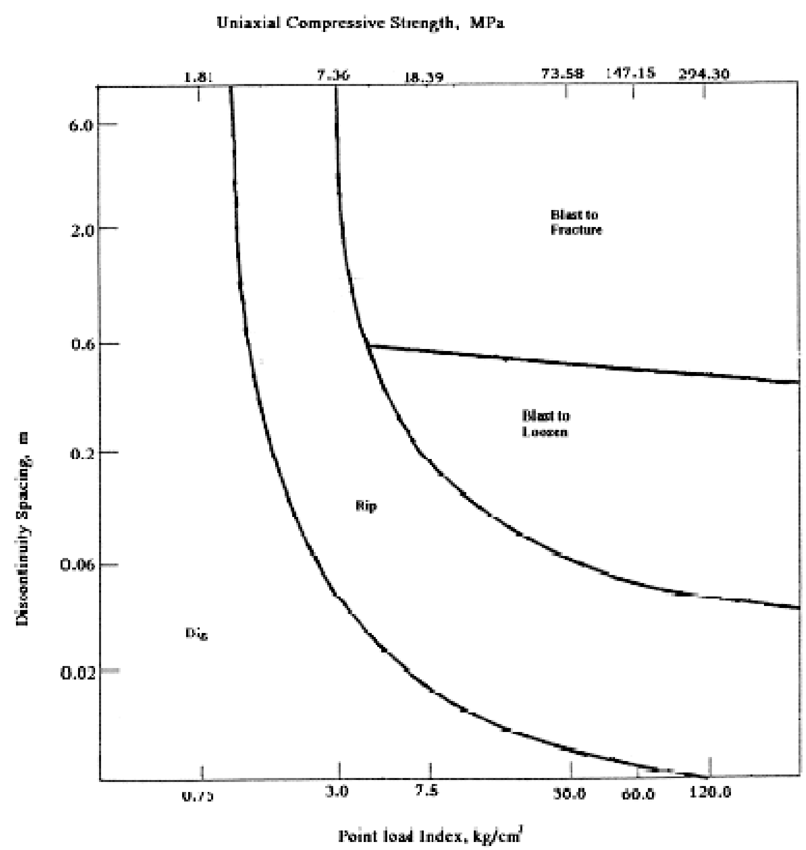
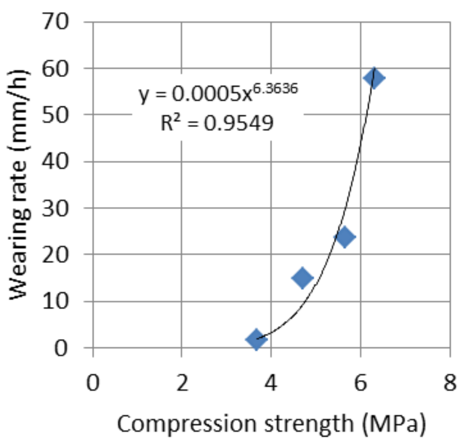


Figure 4: Rock Characteristics and rippability (Franklin et al., 1971)

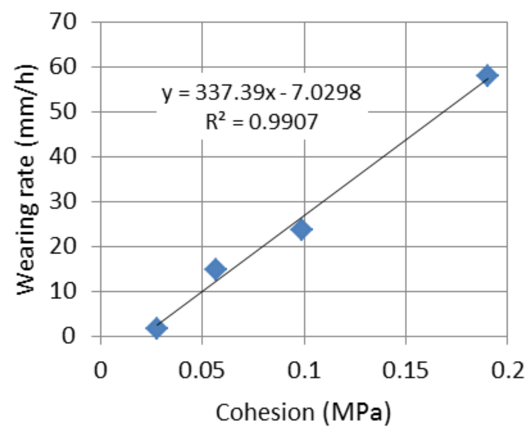
Table 2 shows the average wearing level and initial production of excavator on different types of rock. The field observation indicated that wearing level is increasing with increasing compressive strength, cohesion and quartz content, however; as shown in Figure 5 the effect of each parameter is not the same. On the other hand, the initial productivity of ripping is increasing as the compressive strength, cohesion and quartz content decreases. Table 2 indicates the initial production of ripping on sandstone, tuffaceous sandstone, silty sandstone, and silty claystone is 240.8 to 490 m^3/h while the average production for ten hour operation is approximately between 250.4 and 470.0 m^3/h. Thus all rocks can be categorized as medium to hard ripping according to McGregor (1994), thus free digging is not possible.

Table 2: Wearing of ripper tip and production of excavator

Type of rock	Wearing rate of ripper tip (mm/hr)	Initial Production of excavator (m^3/hr)	Average Production of excavator (m^3/hr) for 10 h.
Silty Claystone	1.60	490.0	470.7
SiltySandstone	14.90	358.7	349.1
Tuffaceous Sandstone	23.70	350.0	325.7
Sandstone	57.90	240.8	217.4



(a)



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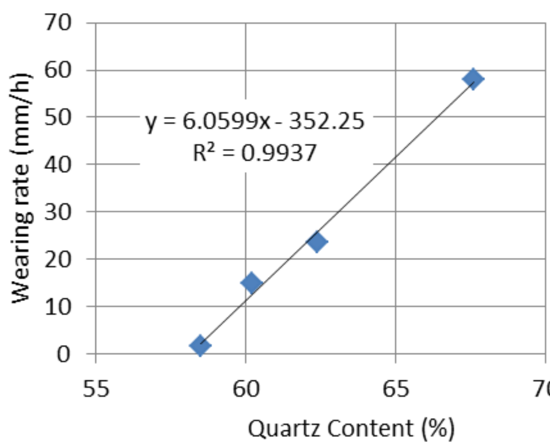

(c)

Figure 5: Effects of (a) compressive strength; (b) cohesion and (c) quartz content on the wearing rate of ripping tip

Observation on Figure 5 indicate that the effect of cohesion and quartz content on wearing rate can be approximated by a linear line while the correlation between the wearing rate and the compressive strength is nonlinear and can be approximated by power equation. Figure 5a indicated that the effect of compression strength is initially less significant but becomes more significant when the wearing rate exceeds 30%. Comparing the slope of the lines in Figure 5b and 5c, it can be seen that the cohesion has negligible effect on wearing rate and thus ripping production.

Figure 6 shows the wearing rate of the ripping tip for different types of rock. Red line in Figure 6 indicated the wearing level for which the ripper tip should be replaced with the new one. It is clear from Figure 6 that the sandstone has the highest level of abrasiveness, that ripper tips should be replaced with a new one within less than 7 h. of operation. Projection of the lines in Figure 6 indicates that the replacement of ripping tip should be made every 15, 26 and 250 h. for tuffaceous sandstone, silty sandstone, and clay sandstone. Thus the highest wear rate of ripping tip is 57.9 mm/h for sandstone, followed by tuffaceous sandstone with wear rate of 23.7 mm/h, silty sandstone with wear rate of 14.9 mm/h. The lowest wear rate was 1.6 mm/h for clay sandstone.

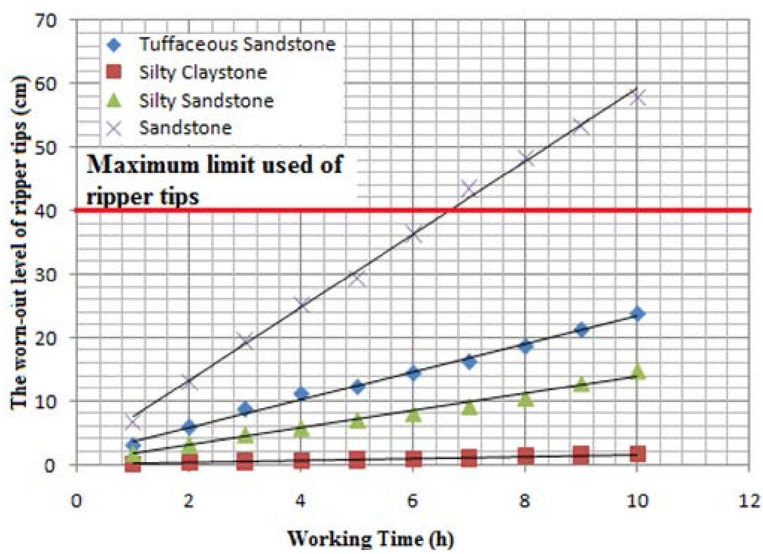

Figure 6: Relationship between wearing level of ripper tips with time of operation

The wearing of ripping tips results in the decrease in ripping production. A chart (Figure 7) was developed in this study to predict the productivity of bulldozer Caterpillar D9R in one cycle of ripping tip replacement.

Observation of Figure 7 indicates that the total productivity for one cycle of ripping tip replacement for sandstone is only about 1044 $m^{3,}$ much less than the predicted ripping production using the replacement time obtained previously from Figure 6 i.e 6.9 h. If the ripper tip is to be used for 6.9 h. before replacement, the ripping production is about 1500 m^3. The inconsistency might be due to the fact that the wear rate is actually increasing nonlinearly with time.

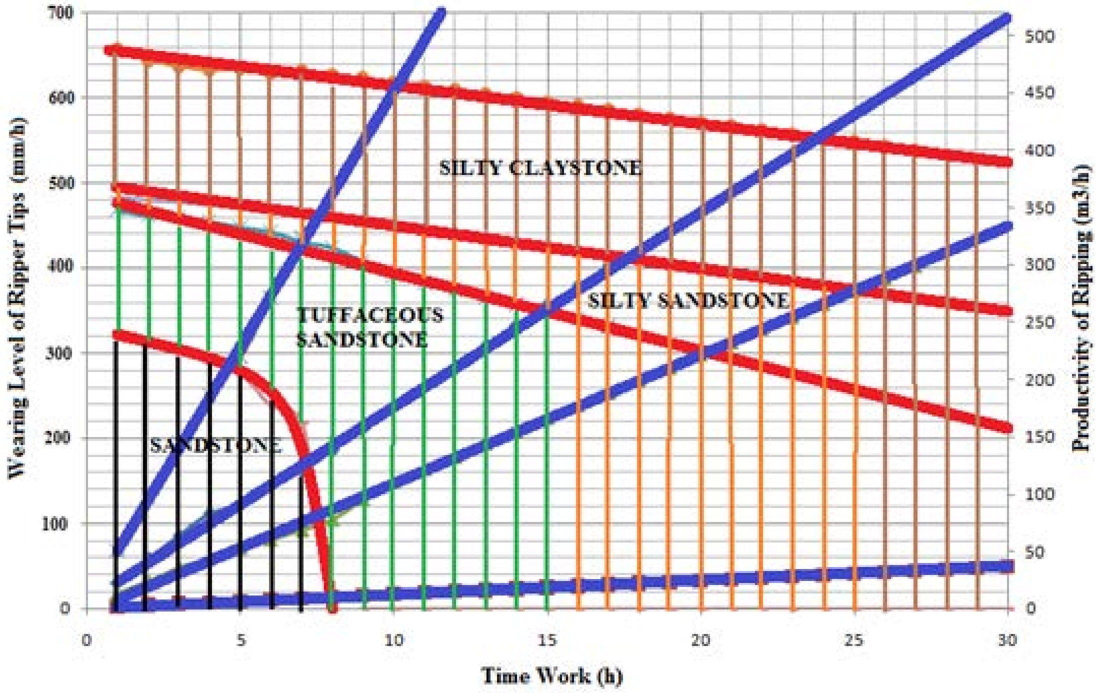

Figure 7: Prediction of wearing level of ripper tips and ripping productivity

Discrepancy was also observed on the ripping production of tuffaceous sandstone at 15 h. which is about 4885 m^3. This value is slightly less than the predicted ripping production of 5471 m^3 assuming that tip replacement could be made after 16.8 h. The initial ripping production is 500 m^3/h and it decreases steadily at a rate of 6m^3/h as the ripping tip wearing out. This outcome also confirms that the wear rate is actually increasing nonlinearly with time.

For silty sandstone, the initial production rate of ripping is 358.7 m^3/h. This study shows that the optimum service life of the ripping tip is 26 h., at which point the hourly production has decreased to 290 m^3/h. This shows that the ripping production on this type of rock is at the rate of 2 m^3/h. The total ripping productivity after 26 h. operation is about 9078 m^3. If the rate of wear 1.49 cm/h is applied, the service life of the ripper should be 26.8 h. Hence, the actual ripping production for 26.8 h. is 9357 m^3.

Different from the other rocks, the life time of the ripper tips in silty claystone is optimized because the production level can be maintained until 250 hours or more than 10 days of operation with ripping production of 117.500 m^3. The highest productivity achieved in the first hour is almost 500 m^3/h and decreases with time by 0.5 m^3/h.

In summary, the rate of decrease in ripping production is 10 m^3/h, 6 m^3/h, 2 m^3/h, and 0.5 m^3/h for sandstone, tuffaceous sandstone, silty sandstone, and silty claystone respectively. However, the wearing of ripper tip is actually not linear with time. Nevertheless, the curves in Figure 7 could be used as first estimation of wear rate of ripper tip and ripping productivity.

CONCLUSIONS

Characteristics of rock commonly found as overburden material at open coal mining area at Bangko Barat South Sumatra, Indonesia was studied. There are for group of material i.e. sandstone, tuffaceous sandstone, silty sandstone and silty claystone. Field observation was conducted on the performance of caterpillar D9R bulldozer with single shank. The following conclusions can be derived from the study:

1. All materials have low compressive strength of less than 7 MPa (3.69 – 6.31MPa) but ripping is required for excavation because based on initial productivity (240.8 and 490 m^3/h), the excavation could be classified as medium to hard digging.
2. The materials contain high percentage of quartz (58 – 68%), thus they can be classified as hard material.The quartz content is the most influential factor in the performance of ripper tip during excavation.
3. The highest wear rate of ripper tips occurred on the excavation of *sandstone* i.e. 57.9 mm/h. with optimum service life of 4.8 h. The wear rate of tuffaceous sandstone, silty sandstone, and silty claystone are 23.7 mm/h, 14.9 mm/h and 1.6 mm/h respectively. However study also shows that the actual wear rate is not constant.
4. The service life of ripper tip is determined when the extent of damage at the tip reached 400mm. Thus prediction of the optimum service life of ripper tip for excavation on sandstone, tuffaceous sandstone, silty sandstone, and silty claystone are 7h, 15 h, 26 h, and 250 h respectively.
5. Ripping productivity decreases as the wearing of ripper tip increases and the wearing rate of ripper tip increases as the rock material contains higher quartz content.

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