2020

# Application of continuous mechanical cutting to coal overburden removal

Isaac Dzakpata
*Mining3*, Idzakpata@mining3.com

Dihon Tadic
*Mining3*, dtadic@mining3.com

Joji Quidim
*Mining3*, jquidim@mining3.com

# APPLICATION OF CONTINUOUS MECHANICAL CUTTING TO COAL OVERBURDEN REMOVAL

**Isaac Dzakpata[1], Dihon Tadic[2], Joji Quidim[3]**

ABSTRACT: Conventional overburden removal in coal mining is typically achieved using drill and blast. However, drill and blast is a cyclical (or batch) process that has inherent inefficiencies and offers limited opportunities for enabling automation technologies. Existing mechanical rock cutting systems such as surface miners, continuous miners, roadheaders, impact hammers and tunnel boring style machines are commonly applied in underground excavation environments and also in some mining operations. Most of these technologies are based on pick-based machines, mechanical indentation and hammer impact. A review of industry literature and OEM data indicates that beyond rock strengths of about 40MPa UCS, the cutting cost for pick-based systems escalates exponentially due to high pick consumption rates and low machine productivity. However, with the emergence of undercutting with oscillating discs (developed by Joy Global as DynaCut™), potential exists for economic mechanical excavation spanning the broad range of typical coal overburden materials - even those well beyond 40 MPa UCS.

This paper presents key findings from investigating the application of continuous cutting systems for surface coal mine overburden removal. Komatsu's DynaCut rock cutting machine was used for cutting trials at a sandstone quarry, to quantify performance in representative rock domains typical of overburden material found in Australian coal operations: (a) low-strength (<30 MPa UCS); (b) medium-strength (~30-50 MPa UCS); and (c) higher-strength (+50/60 MPa UCS). In total, approximately 500 m$^3$ of in-situ rock (overburden) was cut along a 40m bench section, with a 3m high x 5m wide working face.

The quarry cutting trial successfully demonstrated the performance of the DynaCut technology in representative overburden material domains. A general trend of increasing *specific energy of cutting* (SE) with increasing material strength was reported. The SE ranged from about 1.0 MJ/m$^3$ to 6.9 MJ/m$^3$, averaging between about 3.5 MJ/m$^3$ and 3.8 MJ/m$^3$ across the three rock domains. The instantaneous cutting rate (ICR) ranged from about 35 m$^3$/hr to 120 m$^3$/hr. This field experiment has shown the potential for a DynaCut system (using undercutting technology) to provide a competitive solution for mechanical overburden cutting, particularly for materials beyond 40MPa UCS, where traditional cutting systems become rapidly ineffective and inefficient. Early field results indicate that an up-scaled DynaCut system could average around $2.00/BCM for a mine with a broad material spread up to >100 MPa UCS.

## INTRODUCTION

Coal overburden removal is a critical bottleneck in the production of surface coal. Conventionally, surface coal overburden removal, handling and disposal in surface coal mining operations is typically achieved by means of drilling, blasting and haulage (Oggeri et al., 2019; Scott et al., 2010; Hustrulid et al., 2013). Figure 1(a) shows the typical overburden removal methods in Australia (Scott et al., 2010; Westcott, 2004) and Figure 1(b) shows a typical cost

[1] *Work Area Leader, Mining3,* *Email:* Idzakpata@mining3.com *Tel: +61 7 3346 5618*
[2] *Principal Research Engineer,* *Email:* dtadic@mining3.com *Tel: +61 7 3346 5602*
[3] *Technical Specialist, Mining3,* *Email:* jquidim@mining3.com *Tel: +61 7 3365 5677*

breakdown of strip coal mining (Thompson, 2005) . This illustrates that overburden removal is the single most expensive unit activity in surface coal mining (approximately one-third of total costs), with more than 60% of the material moved by truck and shovel. It also shows that approximately 95% of the mining methods would require some level of drilling and blasting to enhance the productivity of the primary loading equipment (draglines and shovels).

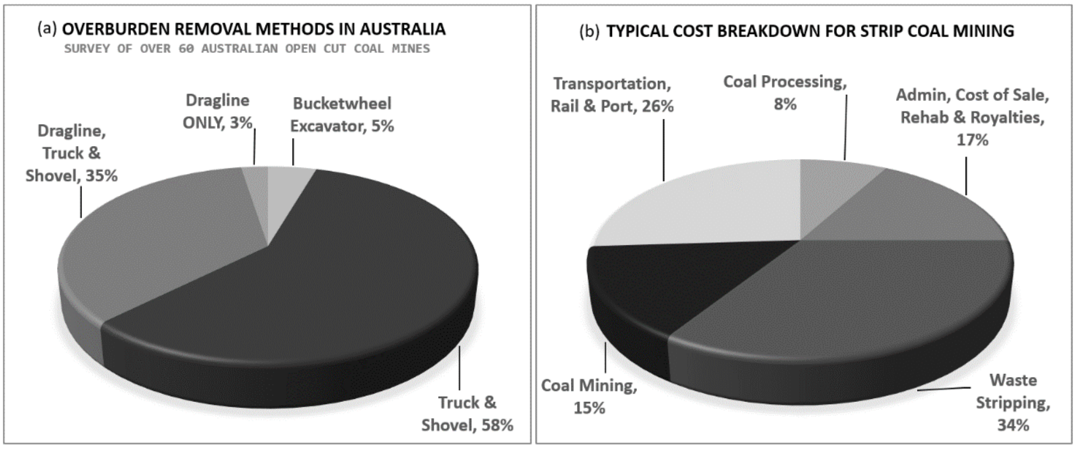


**Figure 41: (a) Typical overburden removal methods (b) cost profile of surface coal mining**

Mechanical rock cutting has been the subject of research interest over many decades for hard rocks (Kovalyshen, 2015; Pickering and Ebner, 2002; Erarslan and Ghamgosar, 2016; Karekal, 2013) and soft-medium rocks (Tiryaki and Dikmen, 2006; Abu Bakar et al., 2014; Cheng et al., 2018; Snowdon et al., 1982). Some of the identified benefits include the reduced need for explosives, consistency of fragmentation (with potential to sort ore from waste), opportunity for precision mining, improved stability of pit walls and amenability of mining to high levels of automation (Darling, 2011; Hood et al., 2005). The fundamental study and advances of the Oscillating Disc Cutting (ODC) technology have been discussed extensively by Hood et al. (2005); Hood and Alehossein (2000); Erarslan and Ghamgosar (2016); Karekal (2013); Grashof et al. (2019), with the cutting performance being a function of rock mass properties (including abrasivity and fracturing), and machine operating parameters including cutting force, amplitude of oscillation and frequency of oscillation.

Mechanical rock cutting systems typically include pick-based and indenter-based machines (e.g. surface miners, continuous miners, tunnel boring style machines). A baseline assessment was performed by Mining3 researchers, considering cost and productivity competitiveness of mechanical cutting with current mining systems. This was part of a study to understand the potential to replace drill-blast-load with mechanical cutting, at a reasonably large scale – i.e. using the nominal capacity of a large mining shovel (~40 Mtpa) as an indicative target for a cutting system. The assessment indicated that mechanical cutting machines for high-capacity overburden removal were more productive and cost-effective in lower-strength overburden materials (<40 MPa UCS), however, traditional machines rapidly become ineffective and inefficient as the material strength increases above 40-50 MPa UCS.

The chart in Figure 2 indicates that the costs for cutting of materials below ~30 MPa UCS typically ranges between $1.00-$2.00/BCM. The results also showed that the Dynacut undercutting disc technology may be competitive with drill-blast-load (averaging around $2.00/BCM) and, critically, that this technology would be far more capable in higher strength (>40 MPa UCS) materials than traditional pick-based cutting systems.

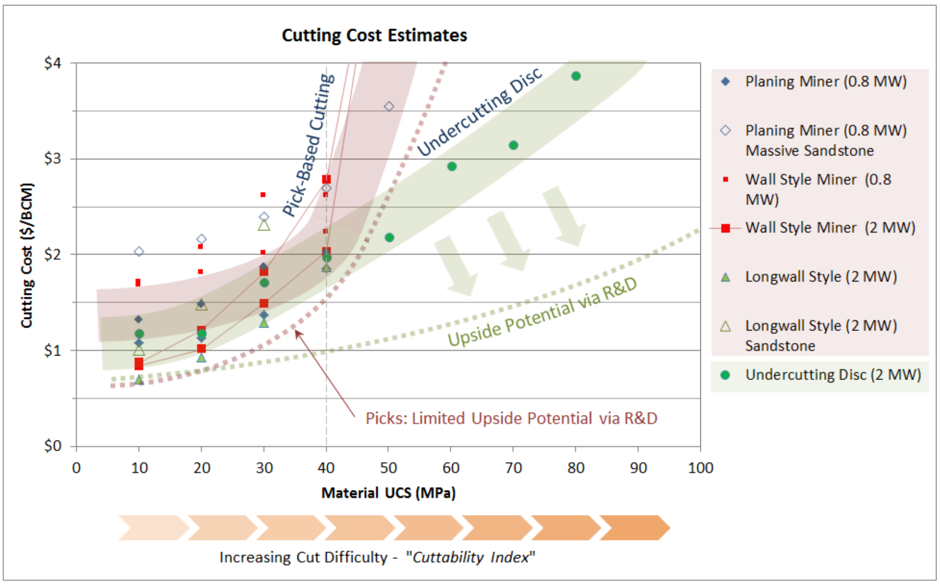


**Figure 2: Estimated cutting cost trends of current and emerging rock cutting technologies**

In fact, the Dynacut technology has proven effective even in materials far stronger than 100 MPa UCS, and would therefore handle essentially any coal overburden material likely to be encountered. Key findings of this initial work aligned well with those presented in the cost and productivity survey of 71 surface coal operations in Australia by Scott et al. (2010).

This paper presents the initial results of field trials aimed at investigating the cutting performance of Komastu's Dynacut rock cutting technology in multiple overburden domains. The cutting test was conducted in representative rock domains typical of overburden material found in Australian coal operations; (a) low-strength (<30 MPa UCS); (b) medium-strength (~30-50 MPa UCS); and (c) higher-strength (+50/60 MPa UCS).

## TEST EQUIPMENT AND SUPPORT EQUIPMENT

### Main test equipment

The DynaCut test machine is a modified roadheader carrier with a customised boom, designed for basic testing in a controlled experimental environment. The extendable boom and cutting head carries a single cutting disc, with reach that allows for cutting a face approximately 5m wide x 4.5m high without moving the carrier. The test machine has basic material handling capability, incorporating two backhoe attachments to clear material from the floor at the face between cuts as required (not used in this field testing). To minimise potential rotational movement of the carrier during cutting, the test machine was attached to a steel rail bolted to the floor alongside the machine. The boom can cut in any direction and can be operated in manual or semi-autonomous modes (with pre-defined cutting profiles and sequence). Figure 3 shows front and side views of the test machine.

The cutting process involves the disc attacking the surface in an undercutting mode (using the oscillating motion of the cutting head), excavating a relatively thin slice of the face as the boom slews. The cut path is typically the width of the cutting disc and about 40-140 mm deep (depending on the rock type and disc design). Optimum cutting performance is generally achieved when the cut depth is adjusted to deliver the maximum Instantaneous Cutting Rate (ICR); a product of the cutting velocity, cutting width and depth of cut.



**Figure 3: Main test equipment- modified roadheader with DynaCut cutting systems**

Several cutting discs were used for this quarry trial, including new purpose-built designs that were more aggressive than previous discs made for hard rock material. The cutting discs ranged from 650 mm to 700 mm in diameter, with each incorporating a ring of inserts bits around the perimeter, at the primary rock engagement edge. Various insert designs and cutter profiles were tested; however, the specific details of these cutters are excluded from this paper in compliance with non-disclosure agreements.

Ancillary and services equipment for the trial included those to supply power, air and water to the DynaCut test machine, and equipment for rock sample extraction and materials handling. In order to maximise the cutting machine utilisation during the limited trial duration, a 13-tonne excavator was utilised to remove cut material from the base of the advancing face. This was much quicker than using the on-board backhoe arms, which do not reflect the type of system that would be incorporated in a production system.

## TEST METHODOLOGY

The trial was designed to evaluate performance of the DynaCut test machine across several key domains and therefore some preliminary assessment was required to confirm that suitable zones would be available and accessible. The field cutting trial was therefore carried out at a quarry located on Seventeen Mile Road in Helidon and operated by Rock Trade Industries. The quarry extracts Helidon Sandstone, which it produces in several forms including rough-cut blocks, cut slabs, boulders, sand and gravel. The general deposit is relatively massive with a reported range of material strength from <10 MPa to >100 MPa (UCS). Investigations of suitable trial locations at the site were conducted, identifying areas aligning with the three target domains (<30 MPa, 30-50 MPa, > 50/60 MPa UCS). Whilst the quarry did not have accessible material representing the full range of rock strengths in Australia's coal overburden (e.g. including 100+ MPa UCS), the available material at the quarry (up to about 80 MPa) still allowed the project to achieve its core objectives. Initial core samples were extracted from the areas identified as target test sites and sent for UCS laboratory testing. Upon material domain/strength confirmation, final test blocks were selected that provided vertical cutting faces approximately 5 m wide x 3 m high, with block lengths of approximately 12 m. This would suit the boom reach of the DynaCut test machine and provide a sufficient block for cutting about 150 $m^3$ in each domain, time permitting, during the trial period.

### Coring and Sample Extraction

Core samples were periodically taken from upper and lower portions of the cut face during the cutting trial, from which multiple specimens were prepared for UCS testing. The Core samples were 54 mm in diameter, with UCS testing specimens typically prepared to 150 mm in length. The UCS results in Table 1 support the observation of lower-strength material (<40 MPa UCS) in the earlier bench faces (1-4) and higher-strength material (up to 85 MPa UCS) in the latter bench faces (5-9). Although there was minimal material substantially below 30 MPa UCS, the weakest sample measured was 11 MPa UCS and there was significant material around 30 MPa UCS to provide data for the low-strength domain.

**Table 1: Summary UCS test results from sampling faces (87 specimens tested)**

| | Face 1 | | Face 2 | | Face 3 | | Face 4 | | Face 5 | | Face 6 | | Face 7 | | Face 8 | | Face 9 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Bench position:** | 2.5m | | 5.5m | | 9.0m | | 17.5m | | 20.5m | | 23.5m | | 31.5m | | 34.5m | | 39.0m | |
| **Date:** | 16 Aug | | 17 Aug | | 21 Aug | | 29 Aug | | 30 Aug | | 30 Aug | | 7 Sep | | 13 Sep | | 21 Sep | |
| ***UCS Mpa*** | ID# | UCS (MPa) | ID# | UCS (MPa) | ID# | UCS (MPa) | ID# | UCS (MPa) | ID# | UCS (MPa) | ID# | UCS (MPa) | ID# | UCS (MPa) | ID# | UCS (MPa) | ID# | UCS (MPa) |
| 90 | 1.1.1 | 36.8 | 2.1.1 | 38.7 | 3.1 | 54.8 | 4.2.2 | 40.5 | 5.1.1 | 60.7 | 6.2 | 61.6 | 7.4.1 | 19.1 | 8.2 | 52.8 | 9.2 | 64.3 |
| 80 | 1.1.2 | 44.1 | 2.2.1 | 38.4 | 3.2.1 | 41.7 | 4.4 | 55.7 | 5.1.2 | 58.5 | 6.3 | 64.9 | 7.4.2 | 69.8 | 8.5 | 62.6 | 9.3 | 61.5 |
| 70 | 1.3.1 | 36.9 | 2.2.2 | 48.5 | 3.2.2 | 40.5 | 4.6.1 | 55.0 | 5.2.2 | 53.5 | 6.4 | 51.3 | 7.5 | 51.8 | 8.6.1 | 63.3 | 9.4 | 66.7 |
| 60 | 1.3.2 | 28.5 | 2.4 | 41.0 | 3.3.1 | 37.5 | 4.7.2 | 43.5 | 5.4.1 | 28.8 | 6.5 | 51.0 | 7.6.1 | 68.1 | 8.6.2 | 72.7 | 9.5.1 | 69.3 |
| 50 | 1.6 | 34.1 | 2.6.1 | 34.3 | 3.3.2 | 41.7 | 4.8 | 28.3 | 5.4.2 | 43.7 | 6.6.1 | 62.0 | 7.6.2 | 29.3 | 8.7 | 59.4 | 9.5.2 | 52.8 |
| 40 | 1.8.1 | 40.6 | 2.6.2 | 34.6 | 3.4.1 | 46.2 | | | 5.7.1 | 60.1 | 6.6.2 | 59.6 | 7.7.1 | 68.5 | 8.8.1 | 64.7 | 9.6 | 71.7 |
| 30 | 1.8.2 | 48.4 | 2.7 | 29.2 | 3.4.2 | 45.0 | | | 5.7.2 | 61.9 | 6.7.1 | 62.8 | 7.7.2 | 70.5 | 8.8.2 | 46.7 | 9.7.1 | 60.9 |
| 20 | | | 2.8 | 11.0 | 3.6 | 46.8 | | | 5.9.1 | 63.8 | 6.7.2 | 63.5 | 7.8.1 | 64.6 | 8.9.1 | 62.5 | 9.7.2 | 71.8 |
| 10 | | | 2.9.1 | 34.0 | | | | | 5.92 | 60.2 | 6.8 | 59.1 | 7.8.2 | 67.4 | 8.9.2 | 66.0 | 9.8 | 59.4 |
| | | | 2.9.2 | 33.2 | | | | | 5.10 | 60.3 | 6.9.1 | 61.3 | 7.9.1 | 69.6 | 8.11.1 | 81.5 | 9.9.1 | 65.9 |
| | | | 2.10.1 | 30.3 | | | | | | | 6.9.2 | 56.7 | 7.9.2 | 70.6 | 8.11.2 | 77.6 | 9.9.2 | 57.3 |
| | | | 2.10.2 | 25.1 | | | | | | | 6.10.1 | 59.5 | 7.10.1 | 68.0 | 8.12 | 84.5 | | |
| | | | 2.11.1 | 26.8 | | | | | | | 6.10.2 | 56.2 | 7.10.2 | 70.4 | 8.14 | 74.8 | | |
| | | | 2.11.2 | 31.0 | | | | | | | 6.11 | 60.9 | 7.11 | 67.3 | | | | |
| | | | | | | | | | | | 6.12 | 62.5 | 7.12 | 14.2 | | | | |

## EXPERIMENTAL PROGRAM

The experimental program focused on assessing the performance of the DynaCut technology in several rock domains with the intent of investigating cutting rates, cutter wear performance and energy efficiency, to enable extrapolation of productivity for a larger-scale machine or system. The trial enabled the characterisation of cuttings (chip) properties and material handling requirements and other operational considerations such as noise, dust and vibration during cutting. There were two key operational variables for the cutting experiments; *Cutter Type/Design* and *Depth of Cut* (DOC). In all, four different cutters of various bit designs and body geometries were tested (650 mm and 700 mm in diameter). The DOC ranged from 30 mm to 160 mm, typically adjusted in 10 mm increments. The strategy was to initially test various cut depths to identify a typical depth that produced the highest Instantaneous Cutting Rate (ICR), and to use this optimum depth for most of the experiments to build a substantial data set. Figure 4 shows a grid-frame image of the cutting location ordered along the faces where the core samples were extracted.

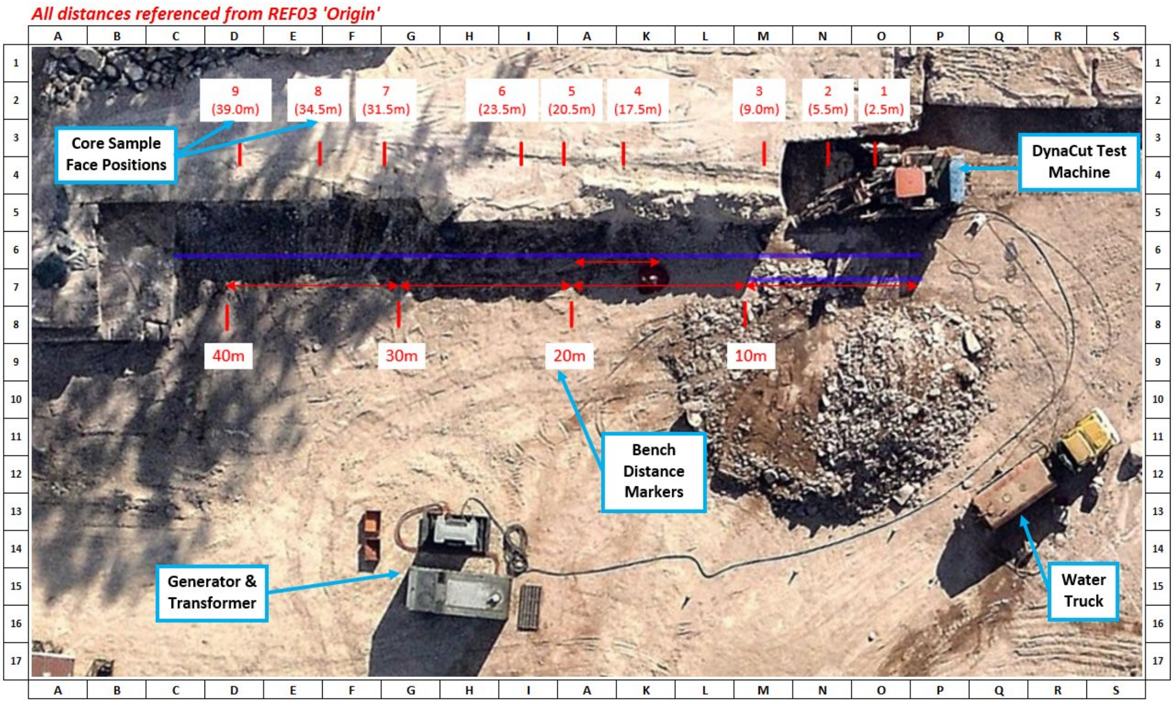


**Figure 4: Grid-frame aerial view of the cutting location and ordered faces**

## SUMMARY OF FIELD OBSERVATIONS

Overall, the performance of the purpose-built cutters indicated very low cutter wear rates. For example a single cutter was used for over 200 m$^3$ of rock (mostly 30-60 MPa UCS) with very little signs of wear. The machine readily adjusted to respect cutter force limit set points, contributing to the excellent cutter longevity. In all material domains, there was significant variation in ICR and SE. This was attributable to rock mass properties, which significantly affect the cuttability of material; in particular, accessible discontinuities, which enhance fracture propagation and chipping or block generation during cutting. To minimise the effect of these rock mass properties, and consequently build more comparable data sets for each domain, the test blocks were chosen to avoid structural variation where possible - at least as far as preliminary observation allowed.

Noise levels during cutting were not typical of general mining equipment, e.g. not similar to a large shovel or excavator. Dust generated was relatively very little compared to typical cutting machines and far less than the pick-based quarry rock saws operating nearby, even with the DynaCut dust suppression sprays off during some tests. No abnormal vibration was apparent, compared to typical mining equipment such as drills, shovels or excavators. Cuttings were typically plate-like, varying in size up to about the disc diameter. Occasional blocks dislodged from the face in zones with structural discontinuities. These occurred mostly in the upper section of the face due to the intersection of the discontinuities, the cut face and the upper bench surface. Material swell was determined by comparing loose cuttings pile volume to the excavated bench volume after 215 m$^3$ of cutting. The estimated swell was approximately 1.33 (33% volume increase).

## DISCUSSION OF RESULTS

In all, over 1500 individual slew cuts were performed during the trial, through approximately 40 m of bench section that transitioned between sandstone of varying properties, resulting in approximately 500 m$^3$ of in-situ material volume cut.

### Depth of cut

Approximately 50 slew cuts were initially performed at the start of the trial to investigate the depth of cut (DOC) which would produce the best cutting performance i.e. the highest ICR. This identified an optimum depth of ~120 mm. Similar, although fewer, tests were completed upon each cutter change to ensure this depth was still in the optimum range. Table 2 presents the summary results of this cutting data, comparing results from cut depths of ~140 mm, ~120 mm and ~90 mm with cutter #218. The minimum, maximum and average ICR peaked with the 120mm cut depth; the minimum, maximum and average SE all bottomed with the 120 mm cut depth also. In this case, reducing the cut depth from 120 mm to 90 mm saw a reduction in average ICR from ~84 $m^3$/hr to 54 $m^3$/hr, with a corresponding increase in average SE from ~ 3.4 MJ/$m^3$ to 5.2 MJ/$m^3$. These results highlight the importance of identifying the optimum cutting depth for a particular material, and potentially periodically re-testing to ensure optimum cutting rates are maintained.

### Rock strength and cutting performance

A summary of the data for the different domains appears support a general trend of increasing average SE with increasing material strength (low-strength: 3.47 MJ/$m^3$, medium-strength: 3.57 MJ/$m^3$, high-strength: 3.83 MJ/$m^3$). A wide range of SE and variability of average SE within each domain indicate that this trend may not be significant, or is being confounded by other controlling parameters such as rock mass structural properties. Table 2 provides a summary of different cutters in the three main testing domains. The results in Table 2 suggests that different cutters may be best suited to particular rock properties (intact properties including but not limited to rock strength; but also rock mass properties such as jointing, fractures and other discontinuities). This further suggests that a particular cutter simply performs better with decreasing rock strength or increasing general "rock mass cuttability". Regardless of the suitability of a specific cutter to a particularly range of material properties, this results shown in Table 2 general supports the trend of decreasing ICR with increasing SE and rock strength.

**Table 2: Summary of different cutters in the three main testing domains**

| Material Strength | Face Zone | Valid cuts | Cut Depth | ICR ($m^3$/hr) | | | Specific Energy (MJ/$m^3$) | | | Cutter ID |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | (mm) | Min. | Max. | Avg. | Min. | Max. | Avg. | |
| Low | 2 | 39 | 121-126 | 66.9 | 109.5 | 78.2 | 1.00 | 4.45 | 3.57 | #167; 650mm |
| Med | 1 | 11 | 102 - 122 | 63.7 | 80.9 | 73.0 | 3.30 | 4.89 | 4.03 | #166; 650mm |
| | 2 | 13 | 121 - 127 | 54.1 | 106.6 | 65.8 | 1.23 | 5.75 | 4.67 | #166; 650mm |
| | 3 | 26 | 102 - 122 | 59.0 | 95.0 | 72.8 | 3.25 | 5.27 | 4.19 | #166; 650mm |
| | 4 | 23 | 121 - 124 | 78.5 | 118.5 | 101.7 | 1.02 | 3.46 | 2.02 | #166; 650mm |
| | | 73 | 102 - 127 | 54.1 | 118.5 | 80.69 | 1.0 | 5.7 | 3.57 | |
| High | 5 | 24 | 121 - 124 | 79.4 | 111.7 | 94.0 | 1.75 | 3.30 | 2.78 | #167; 650mm |
| | 6 | 25 | 91 - 141 | 34.7 | 103.1 | 63.7 | 2.74 | 6.48 | 4.51 | #218; 700mm |
| | 7 | 24 | 102 - 122 | 69.0 | 110.7 | 87.5 | 1.47 | 4.20 | 3.03 | #218; 700mm |
| | 8 | 38 | 121 - 124 | 63.7 | 111.8 | 83.3 | 2.29 | 4.79 | 3.53 | #218; 700mm |
| | 9 | 27 | 81 - 122 | 42.1 | 67.4 | 56.0 | 4.24 | 6.88 | 5.27 | #218; 700mm |
| | | 138 | 81 - 141 | 34.7 | 111.8 | 77.01 | 1.47 | 6.88 | 3.83 | |

Results of the cutting performance for the various rock strength domains were as follows:

a) *Performance in low-strength material (Domain 1)***:** 39 valid data sets from the three bench horizons. The results showed a significant variation in SE from about 1 – 4.5 MJ/$m^3$. This variation is likely due to the structural features of the rock mass that appear to have been responsible for the SE increasing from horizon 1 (top of bench) to 3 (lower in bench), with the cutting in horizon 1 effectively assisted by these structural features compared to the more confined and massive nature of the lower material around horizon 3.

b) *Medium-strength material (Domain 2):* 73 valid data sets (from 73 valid cuts) at the selected horizons with cutters #166 and #167. These cutters were identical in design; however, #166 had very minor prior use (several $m^3$ of sandstone in a laboratory rock bunker test), whilst #167 was in as-new condition. The ICR with this cutter design averaged about 81 $m^3$/hr, with SE averaging about 3.6 MJ/$m^3$. As with the results from the low-strength material, there was also significant variation in both the ICR and SE.

c) *Performance in higher-strength material (Domain 3):* 138 valid data sets (from 138 valid cuts) at the selected horizons using a variety of cutters and cut depths. The average ICR varied with cutter type and cut depth from about 56 $m^3$/ hr to 94 $m^3$/ hr, with the average SE of cutting varying from about 2.8 MJ/ $m^3$ to 5.3 MJ/ $m^3$. As with the results from the low-strength and medium-strength materials, there was also significant variation in both the ICR and SE for each specific cutter and cut depth.

**Cutter type and cutter designs**

Four different cutter rings (three different designs: #166/167, #218, #220) were tested during the trial, resulting in approximately 500 $m^3$ of excavated bench volume. All cutters except #218 were pre-tested before the field trials. Table 3 provides a summary of performance data of the three cutter designs with the lower half of the table filtered for only 120mm depth of cut. The results show that that cutter #167 performed relatively better (higher ICR and lower SE) than cutter #218 and #220, with cutter #220 being the least effective in these materials. The results also show a similar trend for the filtered results, given the spread is reduced across the three cutter types. This brief analysis highlights the significance of rock mass properties in cutting performance.

**Table 3: summary result of investigating the optimum Depth of Cut (DOC)**

| Face Zone | Valid cuts | Cut Depth | ICR ($m^3$/hr) | | | Specific Energy (MJ/$m^3$) | | | Cutter ID |
|---|---|---|---|---|---|---|---|---|---|
| | | (mm) | Min | Max | Avg. | Min | Max | Avg. | |
| 5 | 24 | ~120 | 79.4 | 111.7 | 94.02 | 1.75 | 3.30 | 2.78 | #167; 650mm |
| 6-9 | 99 | ~90 - 140 | 34.7 | 111.8 | 76.58 | 1.47 | 6.48 | 3.84 | #218; 700mm |
| 9 | 15 | ~80 - 120 | 42.1 | 65.1 | 52.62 | 4.24 | 6.88 | 5.48 | #220; 700mm |
| | | | | | | | | | |
| 5 | 24 | ~120 | 79.4 | 111.7 | 94.02 | 1.75 | 3.30 | 2.78 | #167; 650mm |
| 6-9 | 69 | ~120 | 62.3 | 111.8 | 83.88 | 1.47 | 4.84 | 3.41 | #218; 700mm |
| 9 | 2 | ~120 | 59.7 | 63.8 | 61.76 | 4.44 | 4.67 | 4.56 | #220; 700mm |

**Limitation of field trials**

Two key limitations are highlighted throughout the analysis of field trials results: (a) the limited data sets for each cutter were inadequate for thorough statistical evaluation and comparisons of cutters and cutting parameters over broad domain areas; (b) simply classifying rock domains using measures of uniaxial compressive strength (UCS) is insufficient for the cuttability of a rock mass when applying this type of cutting technology.

## KEY FINDINGS

Data collected from the quarry trial was compared to the initial baseline performance results (productivity and cost performance estimates for the DynaCut rock cutting system), to determine the existence of any aberrations and whether these deviations (if any) were reasonable both in relation to cutting rate and cost performance. This section presents these key findings from the field trail observations and analysis of the results.

### Cutting rate (productivity)

Concerning the low-strength material (<30 MPa), the quarry trial results showed a slightly lower performance (higher actual SE) for material averaging about 29 MPa UCS compared to the baseline estimates. For the medium-strength material (30-50 MPa), the quarry trial result appears to support the baseline cutting rate estimates, indicating similar performance (similar actual SE) for material averaging about 43 MPa UCS. Finally, for the high-strength material (>55 MPa), the quarry trial cutting rate appeared to be slightly higher compared to the baseline performance estimate, indicating better performance (lower actual SE) than anticipated for the ~63 MPa UCS material. Figure 5 shows the revised cutting rate and cost trends estimates for pick-based and undercutting disc systems, for various larger-scale machines (between 0.8 MW and 2 MW power).

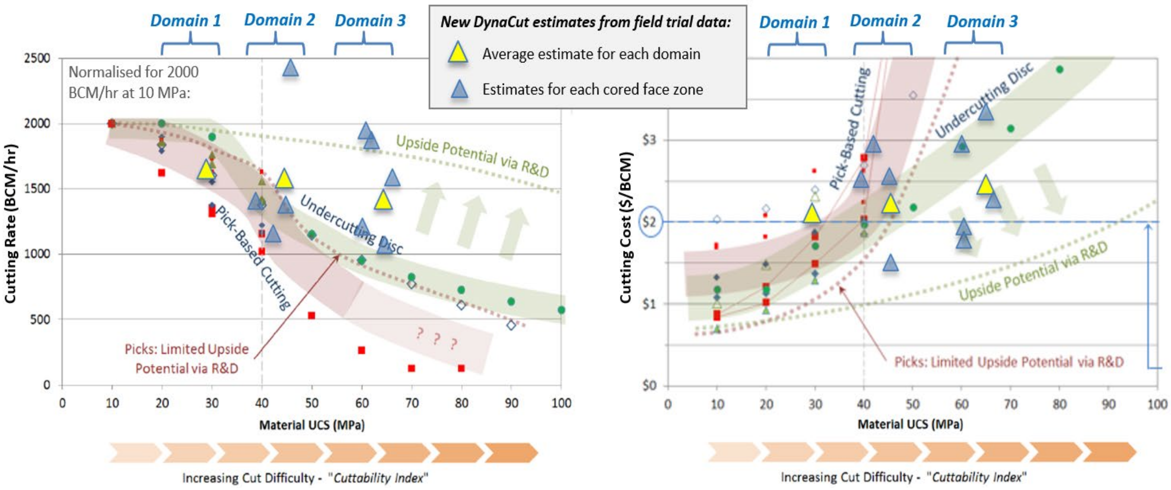


**Figure 5: Revised estimates of cutting rate (*left*) and cutting cost (*right*) for pick-based and undercutting disc technologies – based on new test results**
(Updated to include cost estimates based on quarry trial data points)

### Cost (estimate) performance

In generating the cutting cost chart in Figure 6, the DynaCut cost estimates (the green Undercutting Disc band) for an up-scaled 2 MW cutting system were derived using an extrapolation of minimal data from preliminary cutting tests in small test-bunker constructed with sandstone rock boulders in a concrete matrix. The average UCS of test samples extracted from these boulders was ~80 MPa.

Based on the results obtained from the trials, for Domain 1 material (<30 MPa) earlier cutting cost estimates appear to be slightly low, with the quarry trial data indicating slightly higher costs (higher actual SE only partially offset by better cutter wear performance) for material averaging about 29 MPa UCS. for Domain 2 material (30-50 MPa), earlier cutting cost estimates appear to be well supported, with the quarry trial data indicating similar costs (slightly higher actual SE, offset by better cutter wear performance) for material averaging about 43 MPa UCS. for Domain 3 material (>55 MPa), earlier cutting cost estimates appear to be slightly high, with the quarry trial data indicating lower costs than anticipated (due to lower actual SE and better cutter wear performance) for material averaging about 63 MPa UCS.

### Energy performance (Specific Energy)

Based on the data analysed in this field trial, the average SE (one average value for each face zone per domain) ranged from about 2.0 to 5.3 MJ/m$^3$ with the lowest SE for individual cuts being ~1.0 MJ/m³ (low-strength domain, face 2; medium-strength domain, face 4) and the highest SE for individual cuts being ~6.9 MJ/m³ (high-strength domain, face 9). In the previous limited tests in sandstone blocks, the average SE was 5.0 MJ/m³, with a range from 2.2 to 8.4 MJ/m³. This correlates relatively well with the findings from the current quarry trial. Figure 6 shows a reproduced chart from a prior phase report (ACARP C24011 final report). This chart now includes a summary of the SE data from the recent quarry cutting tests, as well as a data point from previous preliminary sandstone tests in a constructed test bunker. The green and blue data points on the chart represent two SE models for pick-based rock cutting performance estimation.

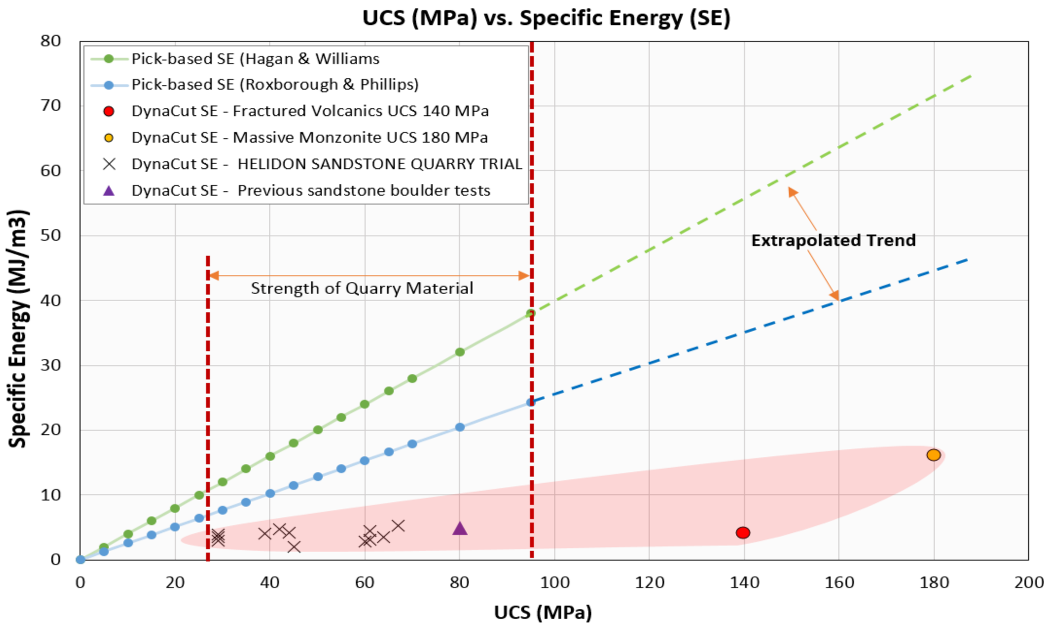


**Figure 6: Comparison of SE data of trials to cutting performance estimates by Roxborough and Phillips (1975) and Langham-Williams and Hagan (2014)**

The red and yellow data points represent DynaCut cutting tests by Komatsu on massive Monzonite (yellow data point) and fractured Volcanics (red data point). The new DynaCut quarry cutting data is shown as black crosses; it includes one data point (average SE value) for each face zone across the three material domains. The broken portions of the trend lines for pick-based SE are projected based on a linear extrapolation from the region below 100Mpa (UCS).

As shown in Figure 7, the new results obtained from the current field trials highlights the relatively low SE of the DynaCut technology, and supports the hypothesis that for material in the 20-80 MPa UCS range, the SE is consistently and significantly lower than that for traditional pick-based cutting systems.

## CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

The quarry cutting trial successfully demonstrated the performance of the DynaCut technology in representative overburden material domains. There was a general trend of increasing *specific energy of cutting* (SE) with increasing material strength. The SE ranged from about 1.0 MJ/m³ to 6.9 MJ/m³, averaging between about 3.5 MJ/m³ and 3.8 MJ/m³ across the three rock domains. The Instantaneous Cutting Rate (ICR) ranged from about 35 m³/hr to 120 m³/hr. The ICR and SE varied significantly within each rock domain, due mainly to rock mass properties controlling the cuttability; in particular, discontinuities that assisted fracture propagation and facilitated chip or block generation during cutting.

Cutting rate and cost estimates from the previous project phase were generally well supported by the new data. Refined estimates, based on the new data, indicate slightly flatter cost and rate curves than anticipated, with higher performance (higher cut rate and lower cost than expected) in the higher-strength material. Indicative average cutting costs for material across the three domains tested are around $2.00 to $2.50 per BCM for an up-scaled machine. Since the technology is still relatively new in comparison to conventional cutting systems, there is undoubtedly still upside in performance to be realised through continued RD and engineering aimed at improvement of overall system performance and operating costs.

The investigation of these key performance factors and parameters forms the basis of future research work, which aims to identify further design and operational improvements, validate these through additional testing, and use the results to inform (and de-risk) the design of an up-scaled test machine. Future research would also investigate and test key DynaCut parameters outside of the limits of the current test machine, and in particular rock types or rock mass conditions to ascertain if cutting performance may be enhanced by operating the cutter at an oscillation amplitude beyond the capability of the current machine

## ACKNOWLEDGMENTS

Key Individuals, teams and management personnel of the following organisations (named in the full report) are gratefully acknowledged for their assistance with this project:

- Komatsu Mining Corp: Research Partner and execution of the cutting trial:
- ACARP: Research sponsor and team of Industry Monitors
- University of Queensland: Preparation of rock testing specimens
- Rock Trade Industries: Team at Helidon Quarry – for hosting field trial
- Aggreko: discounted rental of power equipment for the trial

This ongoing research initiative is a joint collaboration between Mining3 and Komatsu Mining Corp, with funding support from ACARP. This project directly addresses the ACARP Research Priority "Investigate continuous cutting technology for overburden and coal removal e.g. no drill and blast (high volume surface longwalls, surface miners, etc.)".

## REFERENCES

Abu Bakar MZ, Gertsch LS and Rostami J. (2014). Evaluation of Fragments from Disc Cutting of Dry and Saturated Sandstone. *Rock Mechanics and Rock Engineering* 47: 1891-1903.

Cheng Z, Sheng M, Li G, et al. (2018). Imaging the formation process of cuttings: Characteristics of cuttings and mechanical specific energy in single PDC cutter tests. *Journal of Petroleum Science and Engineering* 171: 854-862.

Darling P. (2011) Chapter 7.1 Mechanical Rock Breakin. *SME Mining Engineering Handbook (3rd Edition)*. Society for Mining, Metallurgy, and Exploration (SME), 417.

Erarslan N and Ghamgosar M. (2016). An Innovative and Effective Approach to Hard Rock Cutting. *ISRM International Symposium - EUROCK 2016*. Ürgüp, Turkey: International Society for Rock Mechanics and Rock Engineering, 913-916.

Grashof B, Alvarez Grima M, Schott DL, et al. (2019). Oscillating disc technology for rock excavation. *Proceedings of the 8th International Conference on Discrete Element Methods*. pp 1-11.

Hood M and Alehossein H. (2000) A development in rock cutting technology. *International Journal of Rock Mechanics and Mining Sciences* 37: 297-305.

Hood M, Guan Z, Tiryaki N, et al. (2005). The benefits of oscillating disc cutting. *Australian Mining Technology Conference*: 'New Technologies to Produce More with Less'; 27 - 28 September 2005, Fremantle, W.A. Carlton, Vic.: AusIMM, 267-275.

Hustrulid WA, Kuchta M and Martin RK. (2013). *Open Pit Mine Planning and Design*, Two Volume Set CD-ROM Pack: V1: Fundamentals, V2: CSMine Software Package, CD-ROM: CS Mine Software: CRC Press.

Karekal S. (2013). Oscillating Disc Cutting Technique for Hard Rock Excavation. *Proceeding of 47th U.S. Rock Mechanics/Geomechanics Symposium*. San Francisco, California: American Rock Mechanics Association, 8 : 2395-2402.

Kovalyshen Y. (2015). Analytical model of oscillatory disc cutting. *International Journal of Rock Mechanics and Mining Sciences* 77: 378-383.

Langham-Williams J and Hagan P. (2014). An assessment of the correlation between the strength and cuttability of rock. *Proceedings of 14th Coal Operators' Conference*. Wollongong: University of Wollongong, pp 186-192. [https://ro.uow.edu.au/coal/512/]

Oggeri C, Fenoglio TM, Godio A, et al. (2019). Overburden management in open pits: options and limits in large limestone quarries. 29: 217-228.

Pickering R and Ebner B. (2002). Hard rock cutting and the development of a continuous mining machine for narrow platinum reefs. *Journal-South African Institute of Mining and Metallurgy* 102: 19-24.

Roxborough FF and Phillips HR. (1975). Rock excavation by disc cutter. International Journal of Rock Mechanics and Mining Sciences Geomechanics Abstracts. Elsevier, 361-366.

Scott B, Ranjith PG, Choi SK, et al. (2010). A review on existing opencast coal mining methods within Australia. *Journal of Mining Science* 46: 280-297.

Snowdon RA, Ryley MD and Temporal J. (1982). A study of disc cutting in selected British rocks. *International Journal of Rock Mechanics and Mining Sciences Geomechanics* Abstracts 19: 107-121.

Thompson R. (2005). Surface strip coal mining handbook. Surface strip coal mining handbook. Johannesburg: South African Colliery Managers Association (SACMA).

Tiryaki B and Dikmen AC. (2006). Effects of Rock Properties on Specific Cutting Energy in Linear Cutting of Sandstones by Picks. *Rock Mechanics and Rock Engineering* 39: 89-120.

Westcott P. (2004). Dragline vs truck/shovel. *Australian Journal of Mining* 17: 47-52.