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FLUID MECHANICS AND MINING

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ABSTRACT

Fluid Mechanics is an integral component of every aspect of engineering. Included in the large area of applied fluid mechanics knowledge is that of mining, particularly with the machinery used for extracting rock.

Mining (and tunnelling) relies on machines that are subjected to extremely adverse operating conditions. The majority of these mining machines are powered by hydraulic motors, and are heavily reliant on lubrication of bearings and tracks, all involving knowledge of lubrication theories.

Fluid Mechanics is also a part of the extraction process itself, at the tool/rock interface, where it can be combined with different tool assemblies to maximise the rock extraction and minimise the tool wear.

The paper discusses some of these and the benefits, disadvantages and necessities of using fluids in rock extraction are presented and discussed.

INTRODUCTION

There are a number of methods that can and have been used to extract rock, either to obtain the ore, as in mining, or to remove the rock to gain access as in tunnelling. The most common methods are blasting the rock into fragments, using explosives, or using a mechanical tool to fragment the rock. Both of these methods are more effective if fluids are used.

With blasting, the extraction process is cyclical, commencing with the drilling of a hole, then loading the explosive, firing the explosive and finally collecting the fragmented rock.

As with any drilling process, the use of a fluid, in practice water, to remove fragments and cool the tool can increase the tool life and the speed of drilling. Holes can also be drilled using high pressure jets.

Mechanical tools are of two forms:

1. a chisel shape, known as a drag pick or bit,
2. a free rolling, sharp edged disc.

Commercial machines use either in multiple tool arrangements on a rotating head.

Picks are single point tools that rip out the rock by exploiting the inherent fissures and cracks in the rock surface. The breaking of the rock is due to the penetration of the wedge shape of the tool. Sharp edge discs rely on a large force, applied locally, to generate microcracks, normal to the direction of the maximum tensile stress, that spread through the rock matrix causing fracture the force pattern shown in Fig.1.

At first, the cutter will produce a high point load on the rock surface, sufficient to cause localised crushing. Increased pressure will increase the penetration of the cutter into the rock, creating the stress pattern shown with a peak tensile stress occurring at about 2a below the surface. More pressure will force the cutter tip into the cracked zone, the cracks will extend and rock fragments will break off.

Picks are theoretically more efficient than discs but they are more prone to excessive wear and failure in hard and abrasive rocks, the performance of rolling discs are less effected by wear and are more effective for hard rock extraction.

The success of any of the methods is very dependent on the specific energy of the rock being extracted and this energy value is very dependent on the type of rock, the structure of the rock, the conditions existing at the site of the rock and the method by which the energy is applied.

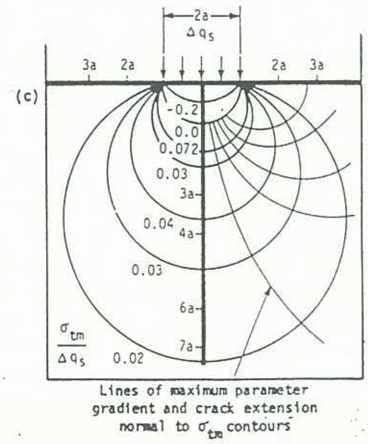

Fig.1. Force pattern produced by cutter. (Farmer and Glossop)

FRAGMENTATION

To remove rock, energy must be supplied to it by direct or indirect means to cause the rock to fragment. The amount of energy required is dependent on the properties of the rock, a soft rock with a large number of fissures providing a large free surface area will require less energy to fracture than a hard, solid rock with minimal fracturing. Unconfined tensile failure consumes the least energy. Increasing amounts of energy are required if the rock is more highly confined within a compressive stress field during fragmentation. A high rate of energy applied with a rock/tool interaction that produced only unconfined tensile failure would provide the most efficient fragmentation process and this is only possible with free standing rocks.

Most existing mining methods are in large ore bodies and the tools produce failure under conditions of high compressive confinement, high frictional energy requirements and high dispersive energy losses. The rock properties directly related to fragmentation are often poorly defined or unknown. Definition of rock type includes general factors of geological formation such as igneous, sedimentary and metamorphic as well as specific properties of texture, mineral composition, hardness, strength, etc. The definition can therefore be misleading, a hard quartzite for example may have a compressive strength of more than 210 MPa whereas a hard sandstone may only have a compressive strength of 120 MPa. 'Hard' is therefore a relative term.

Strength values can also vary for the same rock type. For example, if the confining pressure is increased, such as that occurring with increasing depth beneath the Earth's surface, or that produced as a result of the action of a fragmentation tool, there will be an increase in rock strength. Other rock qualities will affect the mining processes also. Hard rocks are more difficult to penetrate but may fragment into a suitable size for handling quite easily once broken. Softer rocks may choke the drills or cutters and have poor shattering characteristics. Other aspects of rock properties that can alter the fragmentation process are chemicals from pore fluids and pore fluid pressure that can decrease the rock strength, and increasing temperatures, although these effects are normally very small. Of more importance are joints and bedding planes that have a major influence on fragmentation at field scale.

The number of weakness planes such as joints, bedding planes and fissures will control the amount of energy required for excavation. The presence of a large number of such features provides a larger free surface of rock and this requires a lower energy input to fracture the rock. However, although this rock jointing does assist the extraction, McFeat (1987) has made the point that the joint frequency has to be about 100 millimetres to 200 millimetres, before the benefits are significant.

The extraction process of both picks and discs is directly dependent on the force applied normal to the rock face. Farmer and Glossop (1980) stated that although the penetration of a disc cutter, for example, is dependent on the disc diameter, the disc edge angle, the disc spacing and the rock strength it is primarily dependent on the applied force. Even here there are limits, however, as testing carried out by Ozdemir and Dollinger (1987) showed that the energy requirements to fracture a unit volume of rock are a minimum at a finite value of thrust called the critical thrust. This is minimum value is related to the changing from the crushing mechanism of the rock to fracturing, previously mentioned in Fig.1 and illustrated in Fig.2.There is, therefore, some relationship between the penetration depth of the cutter and the efficiency of extraction.

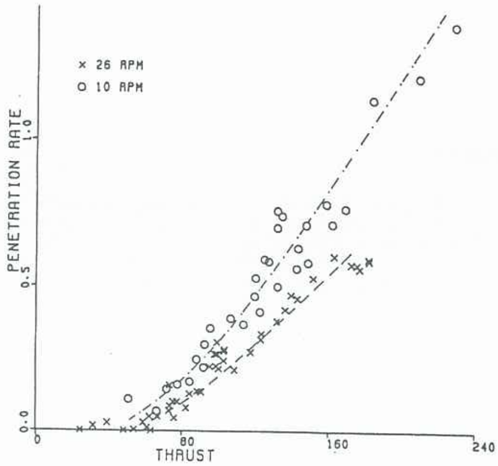

Fig.2. Penetration vs. thrust.
(Ozdemir and Dollinger)

WATER

Using the methods that have been briefly explained, it is possible to economically extract many types of rock, but more effective extraction can be achieved using a fluid, which in practice is nearly always water in the form of a jet.
These can be applied as:

1. Pure water jets.
2. Water jets with an added abrasive.
3. As a jet to enhance the cutting performance of picks or disc cutters.

Pure water jets have been used for many years to remove unconsolidated surface deposits of sand and silt. They were used as long ago as 1852 to remove gold bearing rock. Generally these devices rely on large volumes of water and low pressures and their use is limited. Adding an abrasive will greatly improve the cutting ability but their use requires a mixing chamber to combine the abrasive and the jet, and wear of the nozzles, the cost of abrasives and the reduction in velocity due to the mixing action limit the uses of this method for commercial rock extraction.

Applications of water jets have produced significant improvements in extraction rates when used to assist in the mechanical extraction of rock, the benefits resulting from;

1. Cooling the cutters. Picks are usually formed with a tungsten carbide tip. The cutting conditions can raise the temperature of the tip sufficiently to cause the carbide layer to soften and wear more easily (Barham and Buchanan 1987). Disc

cutters are normally made from steel, but again the use of water jets will reduce temperatures and wear rates.

2. Clearing debris from the crushed zone mentioned previously. Cutters crush the rock forming a plastic zone around the cutting edge. The effect is to dissipate the cutting force over a larger area, reducing its effectiveness. Greater forces are then needed to create sufficient pressure to fracture the rock. Removing the crushed rock, minimises the plastic zone either, allowing the cutter to maintain the original cutting rate, or alternatively allowing an increased penetration rate for the same force conditions. The removal of the debris allows the cutter to expend energy in fracturing the parent rock rather than further reducing the size of already fractured pieces.

3. It can have some effect on the cracks. The pressure of the water entering the cracks can help to expand them, assisting the tool in the fracturing process. Coal is particularly suitable for this as it has a low tensile strength and contains many cracks and fissures. For most rocks, however, the fracturing can only be achieved by water jets of a sufficiently high pressure, that can force water between the interface at the edge of crystals, expanding the crack and removing the crystal.

4. Cutting a kerf, or slot. Kerf cutting is a method where a slot is cut parallel to the cutter path. This can enhance the fracturing of the rock and promote more effective cutting. The kerf is a feature that may be produced using water on its own. While assisting in the promotion crack formation it can also limit the extent of the fracture zone.

5. For many machines, particularly roadheaders with the cutters mounted on an extended boom, the addition of water jets reduces vibration of the cutters allowing a better tool to rock contact and a better cutting action.

The cutting efficiency of a water jet is due to the energy transfer across a very small contact face and small jet diameters with high pressures are the most efficient. Water jets with pressures up to 350 MPa have been used to directly cut coal but pressures of 70 MPa, used on smaller, lighter machines have given some benefits. Pressures as low as 20 Mpa will reduce pick wear and lower dust levels and most manufacturers now offer these low pressure systems. The reducing of the wear of the picks will also increase utilisation rates.

The performance of water jets is very dependent on the size of the jet, the pressure of the water, the stand off distance between the jet and the surface and the point of application. Early tests conducted by Fenn et al (1980) using a disc cutter, applied normal forces of 900 kN and rolling forces of 600 kN. Water jets were directed at the cutting edge of the cutter, and with a stand off distance of 35 millimetres and a flow rate of up to 82 litres per minute at 40 MPa there were reductions in the specific energy required to fracture rock of approximately 40%. Most of the benefit from the jets was in the pressure range of 0-5 MPa and it was concluded that there were no additional benefits to be gained form using pressures greater than 40 MPa.

Later tests with picks on a roadheader by Timko et al (1987), showed a doubling of the tool life at 69 MPa water pressure. Mort (1988) conducting similar tests on a long wall shearer using picks, obtained significant reductions in power consumption at the cutters using pressures of up to 65 MPa. For all tests however, the total energy required was in excess of that required for dry cutting, as the pumping requirements for the water jets were more than those for the cutting machines. High pressure equipment, using intensifiers or high pressure pumps, require very clean water and clean operating conditions. These systems are difficult, and can be potentially dangerous, to maintain and control under the harsh conditions of mining and tunnelling. This has led to developments directed to low pressure systems of less than 100 MPa, when ordinary piston pumps can be used, when the water jets are used with existing machines to enhance performance, and where there are some other benefits applicable to the mining environment of suppressing dust and minimising methane 'ignition'. The high pressure jets have generally been found to be unsuitable for rock extraction but they have been successfully applied to precision cutting of metals and other materials, particularly with abrasive additives (Hashish, 1989).

Other tests carried out by Baumann and Heneke (1981) used high pressure jets to cut parallel kerfs to the cutting tools.
This changed the fracture mechanism from a crushing action to a shearing action. The tests showed that pressures of 360 Mpa, with flow rates of 120 litres per minute, could reduce tool loads by 55% but with these flow rates there could be problems with water disposal.

Unfortunately, as previously mentioned, the benefits reduced as the tool feed rates and pressure were increased. To minimise the quantities of water required polymers added to the water have also been tried to increase the viscosity of the water and produce narrower water jets, less mist and lower flow rates. However the problems still exist.

SUMMARY

Any process to extract rock can be improved by using a fluid. In practice this fluid is water, used directly as a cutting medium, used with additives such as abrasives to enhance its cutting abilities, or as a low pressure enhancement to mechanical cutting methods. The most common application is to assist the cutting process of the mechanical cutters where the benefits can be achieved with low pressure systems. The cost of the equipment and its maintenance and the possible dangers of its use underground, have limited the applications of high pressure jets. When used as a low pressure system to enhance normal cutting tools, the benefits are longer cutter life with the added saving of maintenance time and replacement costs. There are also increased cutting rates as the jets allow deeper cuts and/or faster feed rates. In addition, the accompanying reduction in dust levels and the minimising of potential sparking provide a safer working environment.

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