Experimental investigations of pick-rock interface temperature in drag-pick cutting

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Temperature developed during drag-pick cutting has been measured in laboratory, on a single pick orthogonal cutting tool. Other cutting responses such as cutting force, wear rate of picks, and depth of cut were also measured. All these measurements were carried out for different machining parameters such as thrust and cutting speed on five rock types viz., sandstone, two varieties of granites and two varieties of limestones. For softer rocks (limestones), the maximum temperature ranged between 236 and 566°C whereas in harder rocks (granites), temperatures as high as 920°C were also recorded. This rise in temperature may be due to the frictional heat produced by the rubbing of the rake and flank faces of the drag cutter against the rock surface. The deleterious effect of high temperature, indicated by wear rate, has also been studied.

The rock breakage for excavation and construction purposes is achieved either by drilling and blasting technique or by continuous mechanical cutting tools like tunnel borers and longwall shearsers. In these cutting and drilling machines, the cutters are rigidly fixed to a cutterhead, which rotates at a designed speed. The fracturing in rock is induced under the influence of the applied thrust and the cutting force. It is clear from the earlier studies that current mechanical fragmentation methods are inefficient because of excessive crushing and frictional heat losses. It is also reported that approximately 8 per cent of the total energy supplied to the pick is useful and that the remainder of the energy (more than 90 per cent) goes into producing frictional heat. As a consequence of this, excessive pick wearing and fracturing of the cutting tool is observed in the field operations. One reason for the fracturing of the cutting tool can be the excessive temperature developed at the pick-rock interface.

As observed, the hardness of tungsten carbide reduces drastically at higher temperatures. A critical temperature of about 500°C has been noted above which tungsten carbide becomes softer than quartz (Fig. 1).

The present investigation studies the effect of various parameters, which includes machine operating parameters as well as rock properties, on the temperature regimes at the pick-rock interface and also to study the effect of higher temperature of cutting on the wear rate of the cutting picks.

Experimental Procedure

The laboratory drag-cutting experiments were conducted on a heavy duty, 5 H.P., vertical drill machine of type BN-40, manufactured by Hillewerke, Dresden, Germany. To simplify the analysis, a single orthogonal cutting pick arrangement has been made. Picks have tungsten carbide inserts as the cutting edge. The dimensions of the inserts are 12 mm in length, 10 mm in width and 3.5 mm in thickness and is designed to have wedge angle of 80° and rake angle of 10°. For temperature developed during cutting, copper-constantan thermocouple was introduced into a 1 mm diameter hole drilled at a distance of 2 mm from the cutting edge, within the tungsten carbide insert and further it is blazed with silver to secure a good holding (Fig. 2).

Fig. 1—Variation in the hardness of tungsten carbide and quartz with respect to temperature
Table 1—Physico-mechanical properties of rocks considered

<table>
<thead>
<tr>
<th>Rock type</th>
<th>Compressive strength, MPa</th>
<th>Shore hardness index</th>
<th>PDI</th>
<th>Silica, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grey granite</td>
<td>209.4</td>
<td>117.0</td>
<td>20.8</td>
<td>37.3</td>
</tr>
<tr>
<td>Black granite</td>
<td>189.6</td>
<td>86.0</td>
<td>18.0</td>
<td>34.2</td>
</tr>
<tr>
<td>Sandstone</td>
<td>92.3</td>
<td>33.4</td>
<td>42.6</td>
<td>42.5</td>
</tr>
<tr>
<td>Limestone Gr-I</td>
<td>56.7</td>
<td>28.0</td>
<td>8.44</td>
<td>10.0</td>
</tr>
<tr>
<td>Limestone Gr-II</td>
<td>64.3</td>
<td>37.0</td>
<td>16.3</td>
<td>17.6</td>
</tr>
</tbody>
</table>

A precalibrated milli-voltmeter of the range 0.1 mV–1000 mV was used to record the difference in voltage across the thermocouple. Torque generated at the pick-rock interface is measured using a spoked wheel dynamometer in line with a recorder. In all these experiments, the drag pick cutter was held stationary between the plates of the dynamometer, and the rock core samples were held in a holder. The rock sample holder is designed to hold samples at one end, while the other end is provided with a taper, which fits into the drill shank. Thus with this arrangement, rock core sample rotates against the stationary drag-pick during the cutting process (Fig. 3). Fig. 4 shows the complete set-up used in the present investigation. The pick wear measurements were based on the decrease in the weight of the cutting pick after a specific duration of drilling.

The experiments were carried out in dry (no flushing) on the 5 rock types, for thrust levels, 230, 375, 510 and 650 N; and cutting speeds, 28.5, 45.0 and 70.8 m/min. The cutting responses measured were penetration rate, wear rate of cutter, cutting force and pick-rock interface temperature. The physico-mechanical properties of the rocks considered are given in Table 1.

**Results and Discussion**

The results obtained during the rock cutting experiments, for brevity are represented in graphical form, from Figs 5-10.

In the drag-pick cutting process, rock cutting is achieved under the influence of both the vertical thrust and the horizontal cutting force. The cutting force is calculated by taking a ratio of measured torque during cutting to the average radial distance of the cutting slot from the central axis of rotation. It is observed that the magnitude of cutting force is increasing linearly with the increase of applied thrust (Fig. 5). However, the magnitude of the cutting force is different for different cutting speeds and rock types. For all the rock types tested, linear relationships have been observed between the cutting force and the maximum temperature attained while cutting. This may be due to the fact that at higher force of cutting, the quantity of heat generated at the pick-rock in-
Fig. 5—Thrust versus cutting force developed at the pick-rock interface (Rock: Sandstone)

Fig. 6—Effect of cutting force on the maximum temperature attained while cutting

Fig. 7—Temperature built-up (for different rock types)

Fig. 8—Effect of temperature on the wear rate of cutter

Fig. 9—Effect of compressive strength on the maximum temperature attained while cutting

Fig. 10—Effect of silica percentage on the maximum temperature attained while cutting

The interface is satisfying the equation:

\[ Q_f = \mu N_f V_{int} \]

where, \( Q_f \) is the quantity of frictional heat generated per second (W), \( \mu \) is the coefficient of friction between pick and rock surfaces, \( N_f \) is the normal force (N), and \( V_{int} \) is the interface velocity (m/min).

A maximum temperature of 920°C was recorded in grey granite, followed by black granite (820°C) and sandstone (780°C), while the maximum temperature regimes are lower in limestones at 566°C.

In the present investigation, the time-temperature curves are found varying for different combinations of machine parameters. The time period when the temperature reaching its maximum value and, thereafter, stabilizing is also observed to be different for different rock types. Fig. 7 gives the nature of the temperature curve against the pick
Table 2—Maximum temperatures recorded in various rock types and approximate time to reach the maximum

<table>
<thead>
<tr>
<th>Rock type</th>
<th>Thrust, N</th>
<th>Cutting speed, m/min</th>
<th>Maximum temperature, °C</th>
<th>Time, min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grey granite</td>
<td>230</td>
<td>70.8</td>
<td>920</td>
<td>2</td>
</tr>
<tr>
<td>Black granite</td>
<td>650</td>
<td>70.8</td>
<td>820</td>
<td>4</td>
</tr>
<tr>
<td>Sandstone</td>
<td>650</td>
<td>70.8</td>
<td>780</td>
<td>4</td>
</tr>
<tr>
<td>Limestone Gr-I</td>
<td>510</td>
<td>70.8</td>
<td>566</td>
<td>4</td>
</tr>
<tr>
<td>Limestone Gr-II</td>
<td>510</td>
<td>70.8</td>
<td>562</td>
<td>2</td>
</tr>
</tbody>
</table>

The present investigation reveals that in dry cutting operations, temperatures of 700°C and above are reached in less than 2 min contact time of the pick with the rock, while cutting the rocks which are hard and abrasive, with a compressive strength of 100 MPa and also containing 25 per cent or more of silica. Further, it is observed that cutting temperatures above the critical temperature (500°C) will result in very high wear rates. It is, therefore, advantageous to design cutting machines so that the effective cutting time is reduced to the extent that the pick-rock interfacial temperature is less than the critical temperature of the hard metal picks.

**Conclusion**

The wear rate is quantified as the amount of weight-loss of tungsten carbide per unit volume of rock removed by cutting. The wear rate studies have indicated that the rate of wearing increases exponentially with increase in temperature of the cutting process, particularly above 500°C onwards (Fig. 8). Similar findings were also reported from the rock cutting investigations using tungsten carbide-tipped picks.\(^6,7\) It is further reported that at temperatures beyond the critical temperature the hard metal pick is worn-out at a rate up to 5 times exceeding the wear at the critical temperature of 500°C. The highest temperature recorded in this investigation is 920°C in granite at 230 N thrust and 70.8 m/min cutting speed. The temperature rose to the highest within 2 min of cutting and the cutting process could not be continued beyond 2 min as the silver blazing started melting at this temperature resulting in an improper contact of the thermocouple. However, the temperature recorded in the other rock types remained within 900°C for any combination of thrust up to 650 N and cutting speed not exceeding 70.8 m/min. Though it is imperative that rock properties influence the temperature values, no significant relation could be established on the effect of rock properties such as compressive strength, Protodyakov strength index and Shore hardness index. Fig. 9 illustrates a non-linear relation between compressive strength and the maximum temperature recorded. However, a near-linear relationship is found to exist between silica per cent and the maximum temperatures (Fig. 10).

**References**