

H.J.R. Deketh

The Wear Sensitive Cutting Principle of a Cutter Suction Dredger

Abstract

The operating principle of a rock cutterhead such as used on cutter suction dredgers is an inefficient excavation process from a wear-point of view, because at each revolution of the cutterhead a pick-point has to enter the rock to make a new cut. Especially in the range of small feed, at the start of each cut, high rates of wear of the cutting tool are expected.

At least, this is shown by specially designed small scale rock cutting laboratory experiments. In these experiments high rates of wear were experienced at small penetration rates (feed) of a chisel cutting into rock. Mechanical properties and composition of the rock to be cut determine the range of feed where the high rates of wear are taking place and they affect the level of wear in the entire cut. The relevant mechanical properties are the unconfined compressive strength (UCS) and the Brazilian tensile strength (BTS). The compositional features affecting wear are the grain size and the volume percentage of the abrasive minerals in the rock; abrasive minerals are those minerals which are harder than the tool material under the conditions (stresses and temperature) of cutting.

Considering that wear occurs mainly at the start of a cut, some recommendations can be made to improve the cutting method or to optimise the cutterhead design or the cutting process, for example, by tuning operational parameters like haulage and rotation velocity of the cutterhead to the type of rock to be cut. Besides, a better understanding of the different wear processes and the effect of properties and composition of the rock on wear provides a better basis to estimate pick-point consumption in advance of a rock dredging project.

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In 1991 Jan Reinout Deketh received his MSc in Mining and Petroleum Engineering from Technical University Delft, The Netherlands, Engineering Geology Department. Since then he has been working as a research officer at the university, studying the wear of cutting tools on rock excavation machines in relation to the rock types being excavated. In March 1995 he obtained a PhD on this subject at TU Delft. At present he is observing the working performance of rock cutting trenchers at various construction sites throughout Europe.



Jan Reinout Deketh

Introduction

This article is based on the book *Wear of Rock Cutting Tools, Laboratory Experiments on the Abrasivity of Rock* (Deketh 1995). The book is the result of research which aimed at getting a better understanding of the wear processes acting in rock cutting operations and to determine which factors control these wear processes. An improved understanding of these processes finally allows for a better basis to predict expected rates of pick-point consumption in rock dredging practice. The insight in the wear processes can be useful to optimise the dredging method or dredger from a wear point-of-view.

In this paper the laboratory test set-up is described and some experimental results are shown. The relevancy and application of these experimental results to a rock cutter suction dredger is discussed and finally some recommendations regarding wear prediction and optimisation of the dredging process are made.

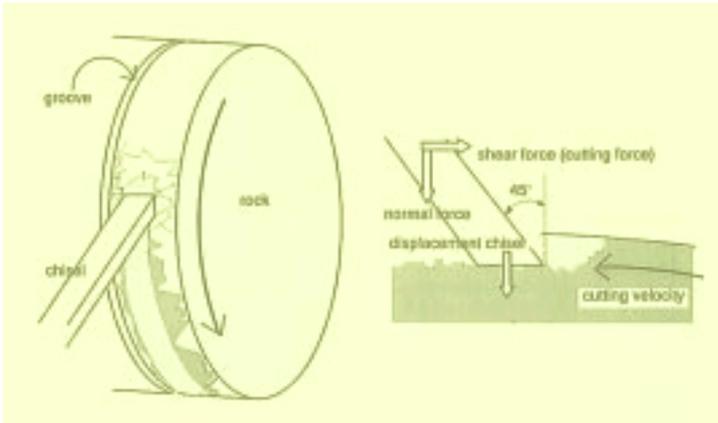


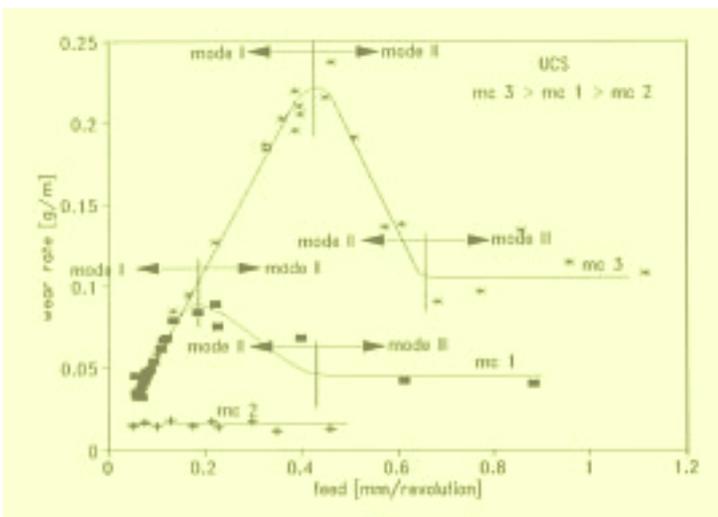
Figure 1. Scraping test.

LABORATORY ROCK CUTTING WEAR EXPERIMENTS

Experiments have been designed to investigate wear processes resulting from sliding of the wear-flat of a test chisel over the surface of different rock types with the variation of the feed of a chisel into the rock, in such a way that the transition from scraping to cutting of rock by the test chisels could be investigated.

In Figure 1 the rock cutting wear test (named the scraping test to stress the feed range at which the experiments are carried out) is illustrated. The test is displacement controlled. A lathe is used to carry the test arrangement. Rotating rock cores are penetrated by steel chisels (steel type Fe60 K, relatively soft steel (Vickers hardness \pm 3000 MPa) or steel type SRO 57N, hardened steel from dredger teeth (Vickers hardness \pm 6000 MPa)) with a continuous feed. When the chisel moves to the centre of the disc of rock, the angular

Figure 2. The influence of the unconfined compressive strength on the rate and type of wear for mortars mc1, mc2 and mc3 for various feeds.



velocity is automatically increased to keep the cutting velocity constant. Most experiments are executed at a cutting velocity of 0.4 m/s.

Cutting forces, feed (displacement of the chisel into the rock per revolution of the rock disc) and cutting velocity are automatically recorded and stored by a data acquisition software package on a personal computer. Loss of mass of the chisel and amount of cut rock material are measured manually and fed into the computer. Finally wear phenomena of the chisel are described and photographed.

About 1000 different tests were carried out. Natural and artificial rocks were used. Artificial rocks (mortar) allowed for a controllable variation of one rock property at a time. The rock strength, the grain size, the volume percentage and the shape of the abrasive minerals (mostly quartz) have been varied. Experiments on natural rocks (sandstones and limestones) showed to which rock types the results of the experiments on artificial rocks could be applied.

Next to the rock properties also the feed, and in some experiments the cutting velocity, of the test chisel into the rock has been varied.

The loss of mass of the chisel in one test run per metre sliding length is taken as a measure for the rate of wear. The loss of mass of a chisel in one test run per cubic metre of cut rock material, the specific wear (SPW) is taken as a measure of the efficiency of the cutting process with respect to wear specific for this test.

EXPERIMENTAL RESULTS

The following factors showed to affect the wear process of the experiments on the mortars and the sandstones:

- the tensile and compressive strength of the rock.
- the grain size and volume percentage of abrasive minerals in the rock.
- the feed of the chisel into the rock.

Above a certain value of feed, which was determined by the properties of the rock to be cut, the type of wear changed and the rate of wear decreased rapidly.

In Figure 2 the effect of the feed on the rate of wear can be seen for three mortars, which differ in unconfined compressive strength (UCS), other properties were approximately the same (the mortars contained \pm 60 % of rounded quartz grains with an average grain size of 1.5 mm). The unconfined compressive strength of the mortars mc1, mc2 and mc3 was respectively 30, 18 and 64 MPa. In the graph each dot represents one test run in which all parameters were kept constant.

At low values of feed, the rock production was relatively low (scraping process) and the level of wear high; high temperatures and plastic deformation of the steel at the wear-flat of the chisel occurred, two-body abrasive wear dominated: *wear mode I*.

At higher levels of feed the rock production was relatively high (cutting process) and the level of wear low; lower temperatures and less plastic deformation took place, three body abrasive wear dominated: *wear mode III*. The feed at which a transition from the first type of wear during the scraping process to the latter type of wear during the cutting process takes place, was also dependant on rock strength (UCS and BTS), grain size and volume percentage of abrasive minerals (quartz) in the rock. The transition from wear mode I to wear mode III is called *wear mode II*. In Figures 4 and 5 photographs of chisel wear-flats in wear mode I and in wear mode III are shown.

The chisel worn in wear mode I shows clean parallel continuous grooves on the wear-flat, pointing to two-body abrasive wear. High temperatures at the wear-flat resulted in burs, tempering colours and plastic deformation of the steel, leading to adhesive wear, additional to the two-body abrasive wear. The chisel worn in wear mode III shows irregular, sometimes abruptly ending grooves, which are infilled by crushed rock material, pointing to three-body abrasive wear. The absence of burs, tempering colours and plastic deformation of the steel indicates lower temperatures at the wear-flat and therefore adhesive wear is not likely to occur.

These results hold for mortars as well as for the tested sandstones. Limestones behaved differently, probably due to the fact that the calcite in the limestone was not hard enough to be abrasive to the tested steel types.

In Figure 3 some scraping test results on a sandstone are shown. In the left graph both the influence of the feed and the cutting velocity on the rate of wear is shown. In the right graph the range of feed and cutting velocity at which the disadvantageous wear and cutting mode I is delineated.

RELATING THE EXPERIMENTAL RESULTS TO DREDGING PRACTICE

Before a comparison is made, first the relevancy of the laboratory experiments to dredging practice are put into perspective. Pick-point consumption in practice is due to damage, which is either failure (breakage) or wear of the pick-points. Whereas wear is a surface process, failure concerns the whole body of the cutting tool. In this research only wear has been considered.

The experiments in the laboratory are only remotely related to rock dredging in practice; in the experiments

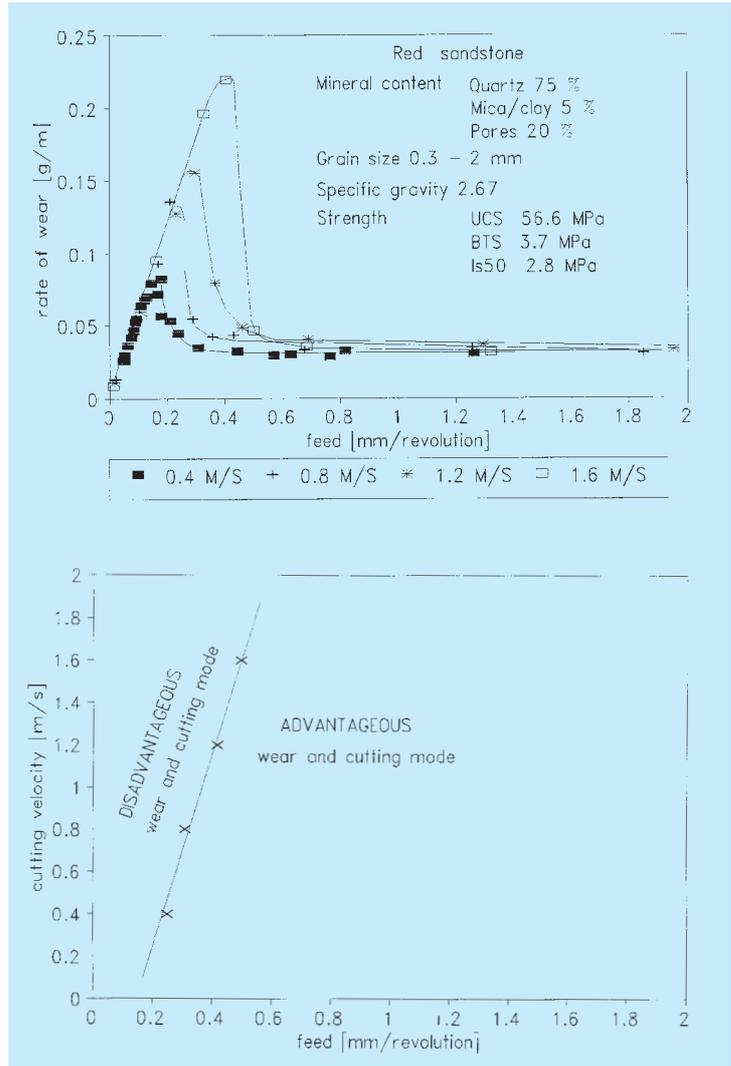


Figure 3. Rates of chisel wear in scraping tests on a sandstone as a function of the feed for different cutting velocities. At a higher cutting velocity a higher feed is needed for an advantageous mode of wear.

the chisel cuts continuously, but in practice only for about 25 % of each revolution of the cutterhead. In the experiments only wear due to sliding contact between tool and rock is studied. In dredging also wear due to impact may play a role. These and other differences between the experiments and wear in practice make a quantitative comparison questionable. Still major trends and wear phenomena observed in the laboratory experiments agree with those experienced in practice of rock cutting (Giezen 1993).

The pick-points mounted on the cutterhead of a cutter suction dredger make an arc-shaped cut through the rock at each revolution. The feed of each pick-point during a cut gradually increases from 0 at the start of the cut to a maximum feed at the end of the cut. The scraping test experiments showed that with an increase of feed the rate and type of wear changes. This can be applied to a pick-point making a cut in the rock.

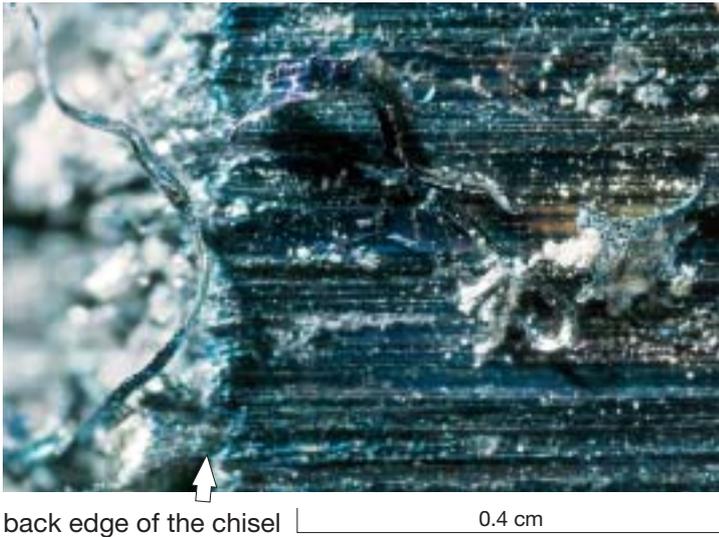


Figure 4. Part of a test chisel wear-flat worn in wear mode I.



Figure 5. Part of a test chisel wear-flat worn in wear mode III.

At the start of a cut a pick-point rather scrapes the rock than that it cuts the rock; there is relatively little production of excavated rock. Moreover, in this range the friction is high (two-body wear) causing high temperatures which in their turn weaken the tool material which then becomes vulnerable to abrasive wear. At a certain feed, the scraping action of the pick-points changes gradually into cutting with further increase of feed. At the same feed the mode of wear changes from mode I to mode III via mode II; two-body wear changes to three-body wear with lower temperatures at the wear-flat and lower rates of wear.

In Figure 6 a cut made by a pick-point mounted on a cutter head is shown for three different situations:

- Case A shows a pick-point which reaches at the end of the cut a maximum feed which is lower than the feed at which a transition from mode I to mode III

occurs (left graph). The rate of wear in this case is high in the entire cut.

- In case B, and more profoundly in case C, the maximum feed is larger than the feed at which a transition from mode I to III takes place (left graph). The greater the portion of the cut in mode III the lower the total rate of wear will be as can be seen in the right graph. The maximum feed value, at the end of a cut, depends on the resistance of the rock to cutting, the ability or power and design of the cutting machine (number of blades on the cutterhead) and the conditions of cutting (haulage and rotation velocity of the cutterhead).

RECOMMENDATIONS TO REDUCE WEAR OF THE PICK-POINTS

In general the amount of wear can be reduced by minimising or avoiding the time the cutting process is taking place in the disadvantageous wear mode, which is at small feed of the pick-points. This can be achieved by choosing a type of dredger with a cutting principle in which the pick-points do not cut at small feed (e.g. a trailing hopper dredger instead of a cutter suction dredger).

If we still are dealing with a cutter suction dredger a solution to decrease wear is to increase the maximum feed reached by a pick-point at the end of each cut by:

1. increasing the power of the dredger. An increase of power on the cutterhead and winches results in an increase of the penetration of the cutterhead (and therefore also of the pick-points) per revolution of the cutterhead.
2. increasing the ratio haulage velocity over rotation velocity of the cutterhead. This results in a higher maximum feed of the pick-points. An additional effect of a lower cutting velocity is that the temperatures at the tool-rock contact will remain lower, which ensures that the wear resistance of the cutting tool does not drop, by softening of the steel.
3. changing the cutterhead design such that the maximum feed of each pick-point increases. For example a reduction of the number of blades of a cutterhead would result in a higher maximum feed per blade (and therefore per pick-point).

A higher feed per pick-point can also be realised by positioning the pick-points in such a pattern on the cutterhead that the cutting paths of pick-points on different blades are not making a cut in the same groove made by a pick-point positioned on the previous blade. This can be achieved by situating the pick-points on the odd and even blades in staggered positions.

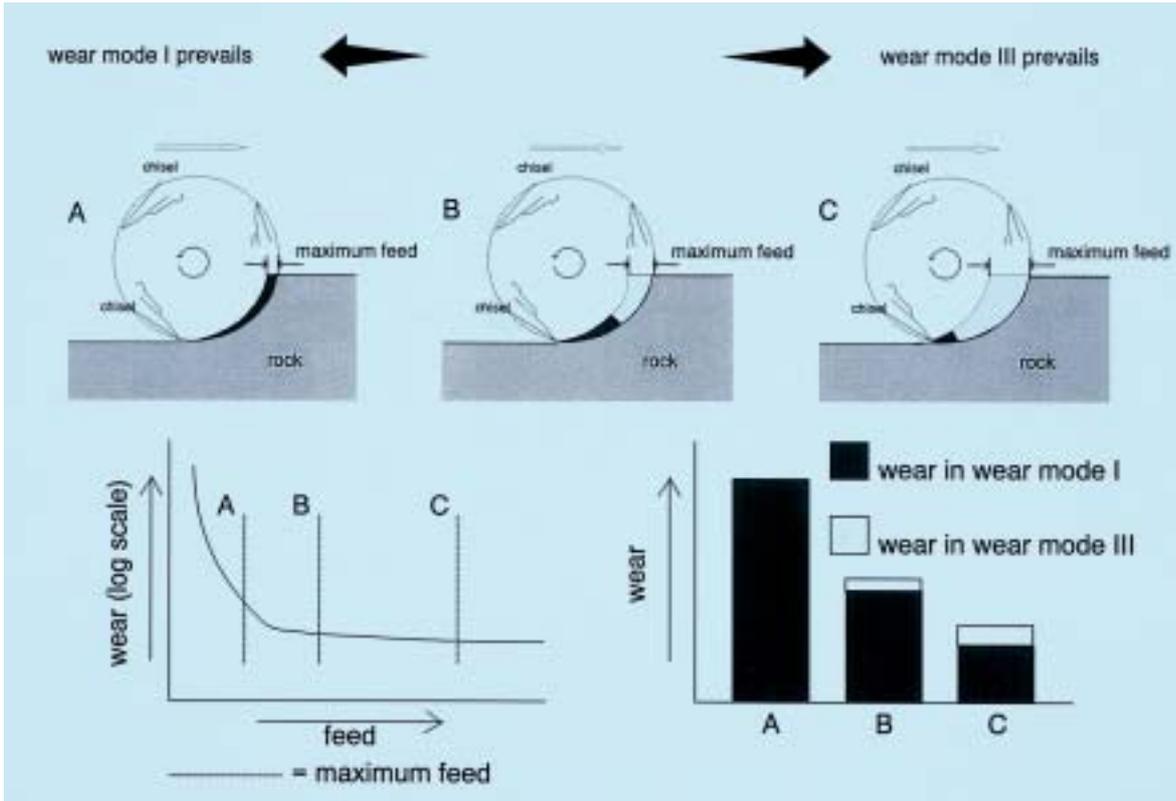


Figure 6. Wear at low feed (start of a cut) is higher than at higher feed (end of a cut). The wear during a cut is determined by the magnitude of the contribution of wear mode I.

Conclusions: Implementation of Research Results in Wear Prediction

The experiments showed that wear is mainly occurring at the start of a cut in wear mode I. To predict the rate or amount of wear for a specific dredger it is therefore very important to determine for what part of the total cut made by a pick-point this disadvantageous wear mode I will take place.

For that we have to calculate:

1. the maximum expected feed per pick-point of the chosen dredger in the rock to be dredged. This is a function of the advance (haulage) rate and rotation velocity of the cutterhead. These dredging parameters depend in their turn on the dredger characteristics like power on the cutterhead and the winches, cutterhead design etc. and the resistance of the rock to cutting.
2. the feed at which a transition (mode II) from wear mode I to III takes place. The transition is a function of the UCS, BTS, the content (vol.%) and the grain size of the abrasive minerals in the rock.

The total expected wear is approximated by:

- the percentage of the cut at which wear mode I takes place multiplied by the magnitude of wear in wear mode I.

- the magnitude of the wear in wear mode I is determined by the same rock properties and by the sensitivity of the tool material to wear.

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