REUSE OF TBM-MUCK
versus CUTTER SPACING

by

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Summary

The Robbins Company has performed a study about rock-boreability related to different cutter spacings. The tests took place in a hard solid granite - UCS 250 MPa - at the Äspö-Project in southern Sweden, using the TBM type Robbins Jarva MK 15-1680 with 5.0 m boring diameter. The authors had the opportunity for a detailed study of the TBM-muck, produced at the three different spacings of the face cutters of 86, 129 and 172 mm. The goal was to analyse the chip dimensions of the muck - produced at the different spacings - to evaluate the options reusing the muck for aggregates for shotcrete and concrete. The results have shown that the chip thickness (c-axis) - the critical dimension of chips considering the coarse-sized gravel for concrete - correlates directly to the cutter spacing. One can conclude that, for granitic rocks the cutter spacing of 107 mm would result in chips which are thick enough to produce the adequate coarse gravel for concrete aggregates 0 / 32 m, an obvious lack in muck produced by todays cutter spacing of 70 to 85 mm. Therefore the increase of cutter spacing will affect directly the potential to reuse the material for concrete aggregate followed by meaningful consequences for the economic and environmental aspects of a tunnelling project.

Introduction

Tunnel excavation by a tunnel boring machine (TBM) is a common method becoming more and more competitive to the drill and blast method even for large diameter tunnels in hard and good quality rocks. According to the design of the project engineer, temporary rock support and the final lining of the tunnel will include shotcrete and concrete. Today natural resources for well rounded river sand and gravel are becoming more and more rare - or due to environmental aspects an exploitation is restricted. In some areas they are just not available in a sufficient quantity. Therefore rock quarries will have to produce the necessary aggregates by crushing the suitable rocks.

TBM tunnelling however, can also be considered as a continuous crushing plant crossing through the mountain producing both a tunnel and crushed rock material (muck). The consequent question is raised whether the muck can be reused as aggregate to produce the necessary shotcrete and concrete, or as pea-gravel for backfilling concrete segmental linings.

In general 25 to 45% of the muck consists of sand ≤ 4 mm. The coarser material, up to the large chips, is mainly composed of flat rock debris with a maximum thickness of 15 / 25 mm. The maximum width of the chips is directly related to cutter spacing of the TBM - the radial distance of two cutting grooves. The chip-length is in general a consequence of the rock type and its properties such as brittleness and anisotropy.

Recent testing in Switzerland (Ref. 1) has confirmed that shotcrete of high strength can be produced from muck using the fraction 0/8 mm which is obtained by simple sieving out of the muck but without any further processing. Even very optimistic results have been obtained from a first test producing frost-resistant pump-concrete 0 / 32 mm, without any further adjustment of the sieve curve.

The remaining coarser material, however, can be processed - washing, crushing, sieving - to produce adequate quality aggregates with an approx. cubic shape. It is obvious that the maximung thickness of the chips (c-axis) determines the maximum possible grain size of the crushed "cubic" material. Consequently based on "today's muck characteristics" there results a lack of coarse grained material to produce standard concrete of 0/32 mm.

The processing costs and the lack of coarse aggregate are considered as the main reasons for not recycling the muck to concrete aggregate. Therefore only thicker chips and cheaper processing costs of the muck will result in an economic benefit when reusing the muck.

Of course the reuse of muck implies various benefits such as:

- lower costs:
  - for transport to dump the muck material
  - for transport to get the needed aggregate from a quarry
  - smaller dumping areas
- benefits to the environment:
  - less transportation needed
  - smaller dumping areas
  - careful management of natrual resources

The Robbins Company has tested in a research program the rock boreability as a function of different cutter spacings. The systematic tests with cutter spacings of 86 mm (standard), 129 mm and 172 mm were conducted on the Äspö-Project in Southern Sweden in August 1994. The authors had the opportunity for a detailed study of the muck as produced by boring with the three different cutter spacings. The findings are summarized in this paper.

The Äspö-Project

TBM-Tunnelling for the Äspö project forms part of the last step in the investigation program for the Äspö Hard Rock Laboratory (HRL) for SKB (Svensk Kärnbränslehantering AB) - the Swedish Nuclear Fuel and Waste Management Company. The Äspö HRL will provide an opportunity for research and technical development in a realistic setting.

The Äspö bedrock is a 1700 million years old granite (Smalands Granite) with typical rock strength of UCS = 250 MPa, Point Load Index I_{S50} = 7.5 MPa and a CHERCHAR Abrasivity Index of 5.3 (lab. results from representative rockcore samples).

After finishing the first spiral turn of 2.6 km to a depth of -345 m, SKB signed a contract with the Swedish Contractor SKANSKA that includes conventional drill and blast tunnelling from depth - 345 m to - 430 m, followed by approx. 420 m of TBM boring with a diameter of 5 m to a depth of approx. - 450 m below ground. During this TBM-tunnelling section the boreability tests were conducted in August 1994.

TBM in use - technical specifications

|		
Manufacturer, Type	:	ROBBINS JARVA MK 15 - 1680 / 5.0
boring diameter	:	5.00 m
cutter head drive	:	1680 kW
cutter head thrust	:	8330 kN
cutter head revolutions / min	:	0 - 12.7 rpm VSD
cutters, total number	:	34
cutter size	:	17"
rec. max. cutter load	:	245 kN per cutterring

Test procedure

Referring to the detailed study of muck, the test procedure was complementary to the boreability tests as performed at site, starting with standard spacing 100% = 86 mm for face cutters, followed by boring with 150% spacing = 129 mm, and 200% spacing = 172 mm respectively. For the tests only a limited number of cutters could be removed for wider spacing, allowing 60% of the total tunnel cross-section to be bored with an increased spacing. From all three test phases 40 to 90 kg of muck were collected for detailed analysis.
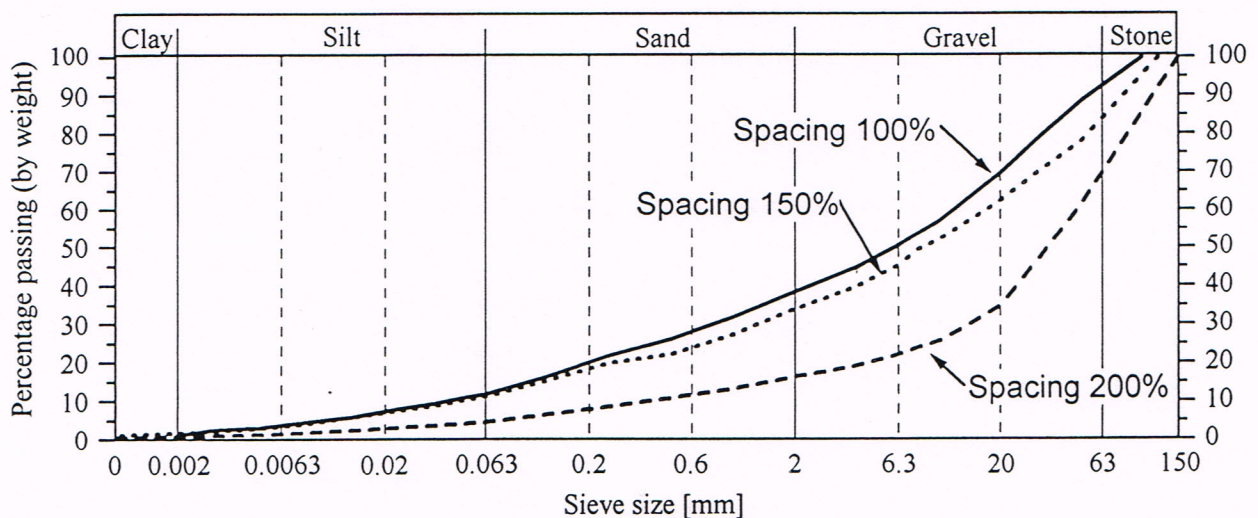
Muck Analysis

The muck was analysed at site by sieving. An additional shipment of approx. 280 kg has been sent to the Geotest Laboratory in Switzerland for further studies:

- standard sieve curves (b-axis)
- rod-sieve curves (c-axis)
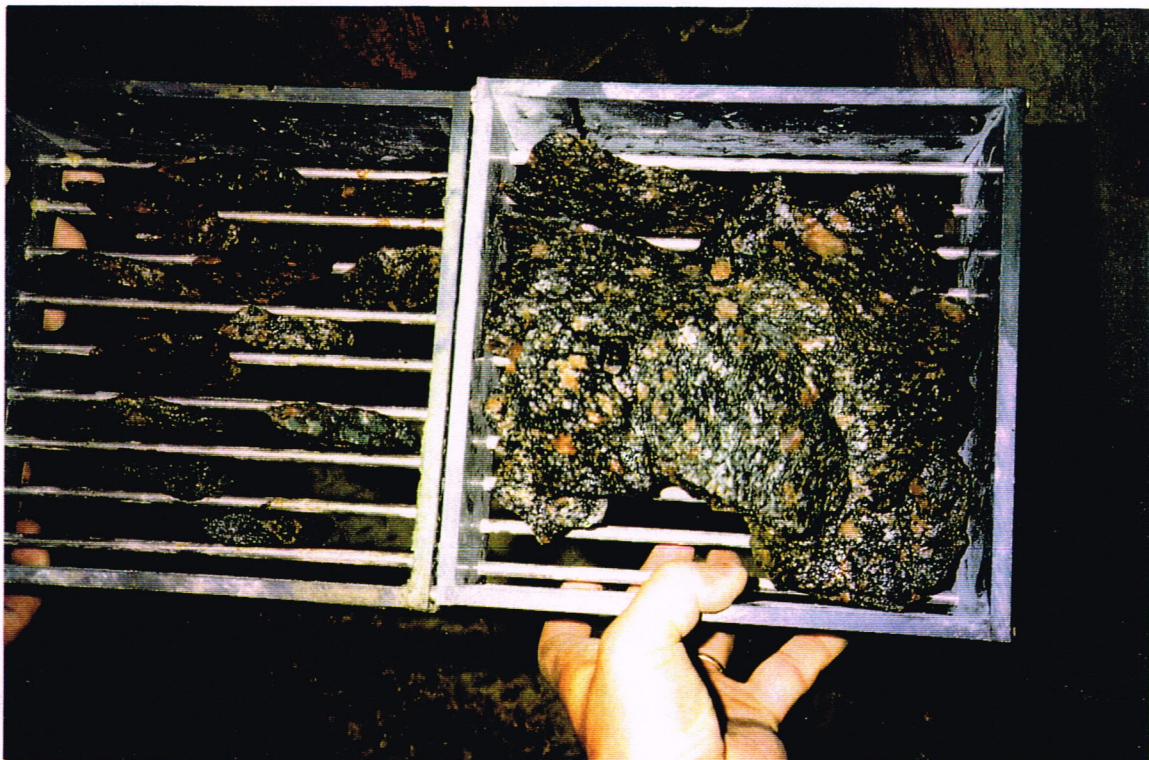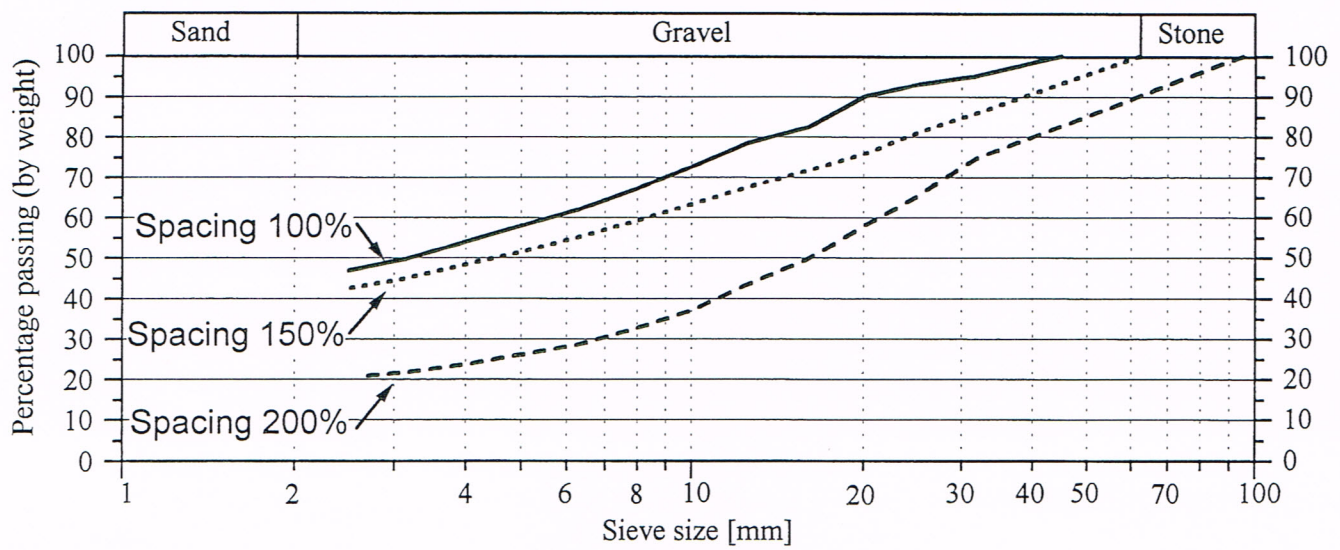- chip dimensions (a, b, c-axis)
- chip shape (cubic, flat, elongated)
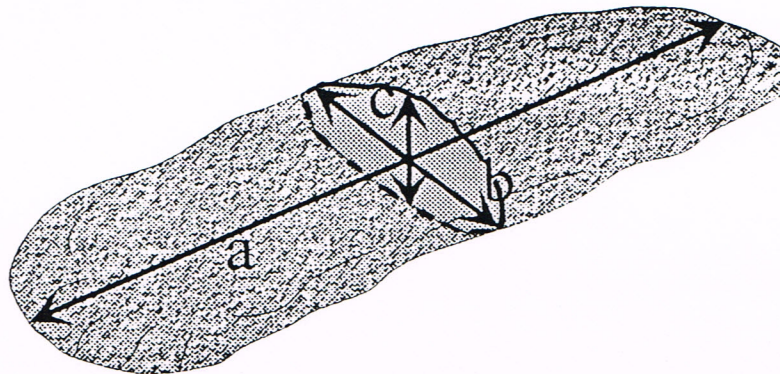
Results:

Sieve Curves (b-axis; standard sieves):

Sieve Curves (c-axis, rod-sieves, ≥ 2.5 mm):

Rod-sieves: measuring the chip thickness = c-axis

Large chip-dimensions

Meanvalues, based on approx. 50 chips per spacing

Spacing	[%]	100 Standard	150	200
greatest (a) axis (average)		142	257	426
middle (b) axis (average)	[mm]	72	113	154
smallest (c) axis (average)		22	35	58

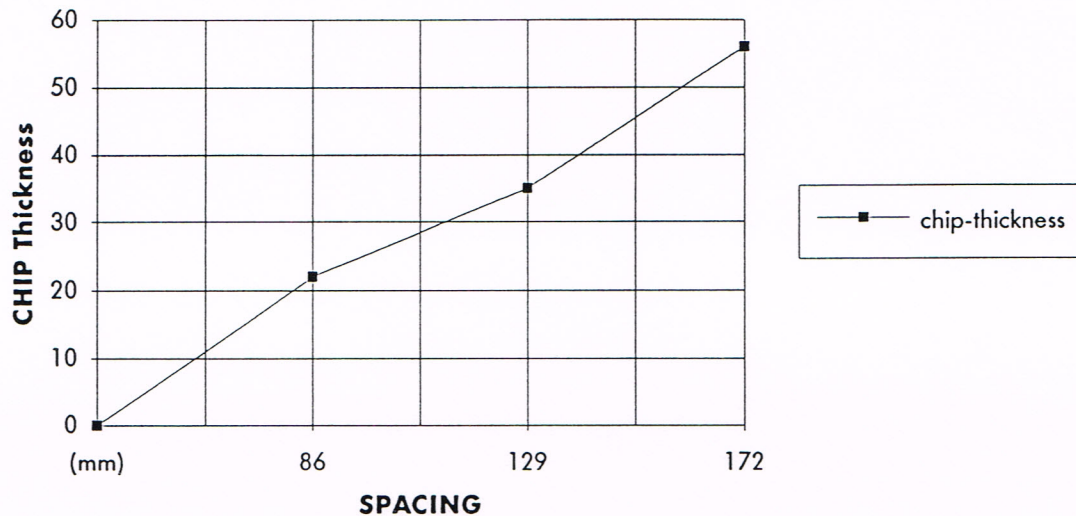**Average results of large chip shape measurements**
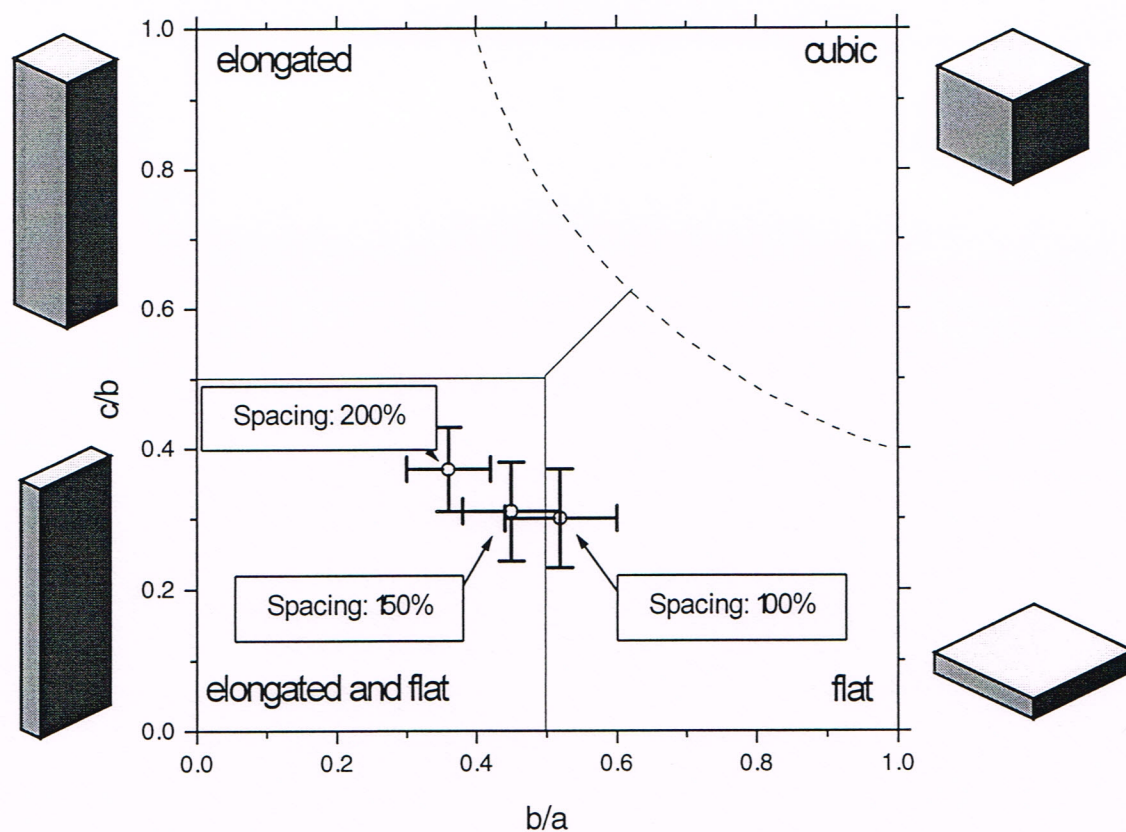
a = greatest; b = middle; c = smallest grain axis
Ō = mean value; + = standard deviation
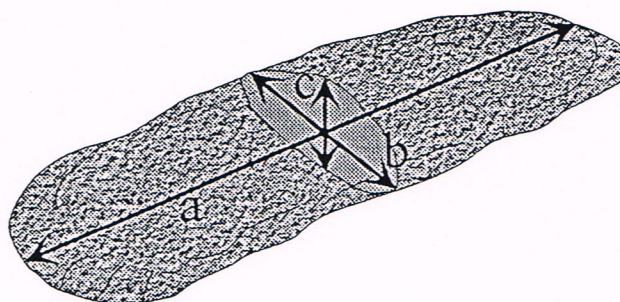
Conclusions

The test results can be summarized as follows:

1. The dimensions of the chips are in a direct correlation to the spacing

2. The increase of the spacing by 50% leads to an increase of the chip thickness of approx. 60%

From the above diagram one can conclude that in granitic rocks a cutterspacing of approx. 107 mm would be large enough to produce chips with an average thickness of approx. 28 mm, thick enough to produce the coarse grained gravel for a 0 / 32 mm concrete. A rule of thumb says that a sieve curve of crushed aggregates 0 / 28 mm corresponds to natural rounded aggregates 0 / 32 mm.

3. The sieve curves of the b-axis clearly indicate that an increase of spacing reduces the production of fine material. The test showed that the sand-fraction 0 / 4 mm is reduced from 44% at 100% spacing to 39% and 19% at 150% and 200% spacing respectively.

    This demonstrates that, after crushing the coarser material, the overall grading of the muck would give a much better sand-gravel ratio for the production of concrete.

4. The sieve curves of the c-axis show that the increase of the c-axis due to larger spacing is not only valid for the large chips but also for the smaller rock debris, an important aspect for the grain-size distribution of the final processed material.

    The percentage of the aggregates thicker than 28 mm results to 6% for 100% spacing, 17% and 30% for 150% and 200% spacing respectively.

The results of this pilot study are considered as a basic input for a positive answer to the question whether TBM muck can be reused as shotcrete and concrete aggregates following to an increase of the cutter spacing.

In addition the boreability tests conducted by The Robbins Company have shown that TBM boring with significantly increased cutter spacing could well be realized in the near future. This can be considered as a new option, which is even valid for very hard and massive rocks like granite, still using 17" cutters with standard loads of 180 to 220 kN per cutterring.
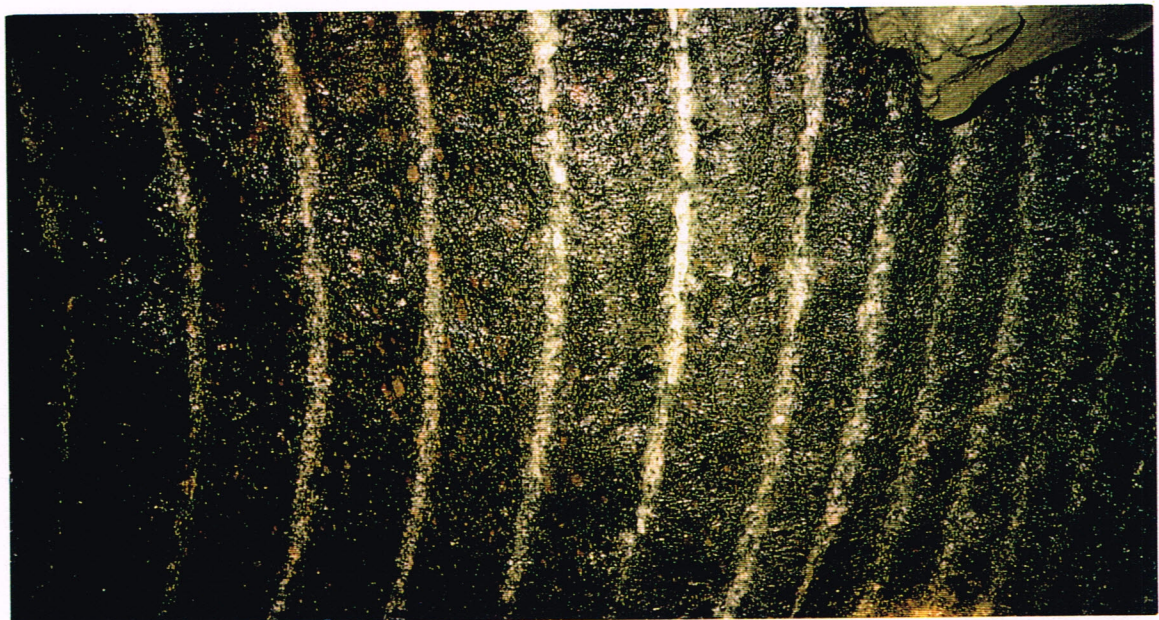
Acknowledgements

References

1. Thalmann, C.: Beurteilung und Möglichkeiten der Weiterverwertung von Tunnelausbruchmaterialien aus dem maschinellen Tunnelvortrieb (Dissertation ETH Zürich, Ingenieurgeologie, in Vorbereitung)

2. SKB-Swedish Nuclear Fuel and Waste Management Company -
    Report: Activities 1993

SPACING: 150%

0 1 2 3 4 5 6 7 8 9 10 cm
0   1   2   3   4 in

SPACING: 200%

0 1 2 3 4 5 6 7 8 9 10 cm
0   1   2   3   4 in

SPACING: 100%

0 1 2 3 4 5 6 7 8 9 10 cm
0   1   2   3   4 in
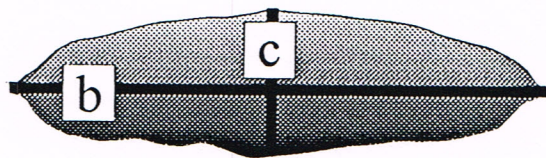
Chips from Äspö-Test:

-     86 mm :   100 %

-    129 mm :   150 %

-    172 mm :   200 %

Tunnel face with 150% cutter spacing (left side: face area), right side: inner gage area

Chip Dimensions-Results: Äspö

Standard-Spacing
100%

b = 72mm
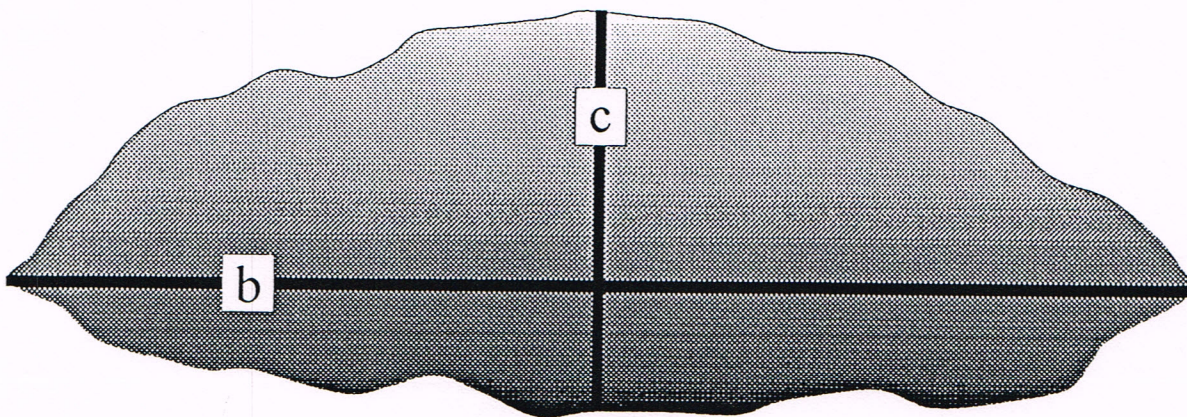c = 22mm

Spacing
150%

b = 113mm
c = 35mm

Spacing
200%

b = 154mm
c = 58mm

b   = chip width
c   = chip thickness   (Scale 1:1)