About Principles of Chip Formation from Rock Treatment with Cutting Tools

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Machines with cutting tools, that means tools whose direction of attack is essential parallel to the free face of the material to be destructed are one of the main group of machines, which are used for rock desintegration by mechanical means. Fig. 1 shows the grooves remaining in the walls of a tunnel, which has been driven by a Habegger tunneling machine. Working in brittle rock, chips develope in form of seperate fragments. Principal relations of this process of chip formation should be discussed in this paper.

The result of the process of rock cutting, this means the intruding and moving of a tool in the rock on the one hand generates a track in the rock, which will here be called chip groove,on the other hand chip fragments are broken from the rock in an almost periodical sequence. (Fig2). Looking at the cross section of such a chip groove it can be shown that the process of chip formation surely is of complex nature. Evidently two areas can be defined in which different forms of fracture mechanism,respectively material destruction occur. This is on the one hand the area which is generated by the breakage of the big chip elements, the so called main chips, on the other hand a zone below, whose width is corresponding with the width of the cutting tool, while its depth is varying depending on the parameters of the cutting process. This zone below can be called shear groove. In this zone destruction results from a crushing process.

The phase between the breakage of two big chip elements can be named chip formation cycle, for - as mentioned above- chip formation is a periodical process.

Basing on research work done by the author the run down of a chip formation cycle occurs as follows: The starting point of which will here be considered to coincide with the termination of the breakage of a big chip element. In this moment the cutting force P_S (the force working parallel to the free face, which is the main force component in the rock cutting process) comes to a mininmum. During the forward movement of the tool an increasing depth of the shear groove caused by the free surface generated by the broken chip is effected (the shear groove has its minimum depth after the brakage of a big chip element).

In front of the tool now stresses are developed. At the same time a crushed zone is formed in the course of the forward movement of the cutting tool (this crushed zone is compareable with the built-up edge in metall cutting). In this crushed zone a state of three dimensional stress is produced, that means that stress components in every direction can appear. The effect of such forces is shown in Fig. 3. From this picture it is evident that rock destruction has occured in the bottom of the shear groove as well as on both walls. The only possible explanation for the phenomenon is the appearance of latterally and vertically directed forces. The destruction in the bottom of the chip groove is certainly mainly caused by the force acting in the tool perpendicularly to the cutting force. It can be considered, that this chrushed zone is also the initial zone for breaking the next chip element. For this fact the existence of a racting force component directed to the free face in this crushed zone is of great importance (Fig. 4).

The crushed zone is distinctly visible in this part of the

chips where the attack of the tool has taken place (Fig.5). The actual face of fracture begins, when the stress in the crushed zone reaches a level which enables crack propagation in that primary crack, which lies at the optimum place for the breakage of a big chip element.

The forward movement of the tool is accompanied by an increase of the cutting force. The cutting force reaches a maximum immedeatly before crack propagation and breakage of a big chip element begins and falls to a minimum suddenly after breakage has been completed. At the same time it could be found out that the instant before the big chip element is broken and the cutting force reaches its highest level also brings a maximum of extension of material destruction in the bottom and the walls of the shear groove. This can also be explained by the fact that the state of stress in the crushed zone is on its highest level when crack propagation begins. In Fig.6 (lower picture) a longitudinal section of a chip groove is shown. In the bottom of the shear groove the material which has been destructed by the attack of the tool has been removed. It can be seen that the maximum depth of material destruction corresponds to the point where breakage of a big chip element has begun.

In Fig.7 the run down of a whole chip formation cycle is shown. In this picture all phenomena described above can be seen. This diagram shows especially the function of cutting force versus time from which the conclusion can be derived, that only a portion of the whole cutting force is used for the separation of the big chips. Another portion must be expended to overcome several resisting forces as for example friction between cutting tool and rock caused by the normal forces which the cutting tool exerts on the surfaces of the rock and, most important, for the formation of the shear groove. For the following considerations the force required for the formation of the shear groove is regarded to be a force non contributing to chip formation. This way of consideration seems to be useful, since energy consumption which is related to the rock volume removed by this process and which occurs during crushing the material in the shear groove amounts at the minimum ten times the energy consumption necessary for the breakage of a unit volume of chips.

In a cutting force versus time diagram two different zones clearly can be seen, one zone which corresponds to the breakage of big chip elements and one which corresponds to rock destruction by crushing. In this second zone also the other forces not contributing to chip formation are included (Fig.8).

As proof for this statement a clear relation between the magnitude ΔP_s, which means the decrease of cutting force after the breakage of a chip element and the volume of this chip element on the other hand could be found. Fig.9 shows this relation for three different rake angles. For the rake angles of -20° and 0° the diagram shows in fact the same result, it is an underproportional increase of ΔP_S with increasing chip volume V_s. For a rake angle of $+ 20^{\circ}$ principally the same behaviour appears, but the magnitude of ΔP_S is much lower.

The force P_{SR} remaining under the lowest point of the cutting force versus time diagram (Fig.8) shows a clear relation to the depth of the shear groove. It is evident, that the shear groove in particular its proportion to the total groove depth is decreasing with increasing rake angle.

Consequently a relation has been established between P_{SR} and $P_S max$ on the one hand and between the depth of the shear groove (s - s') and the total depth of the groove (s)

on the other hand. This two dimensionless ratios have been plotted in Fig.10 which shows an approximately linear relationship. Only for the lowest values the proportionality does not appear. That means that the mechanism of chip formation at very small cutting depth must be slightly different from the mechanism that is normal for the overall cutting process.

Because this results are gained from model work it is planned for the future to find a method for determining the characteristics of the process of rock cutting under field conditions as well as for the tools used for it.

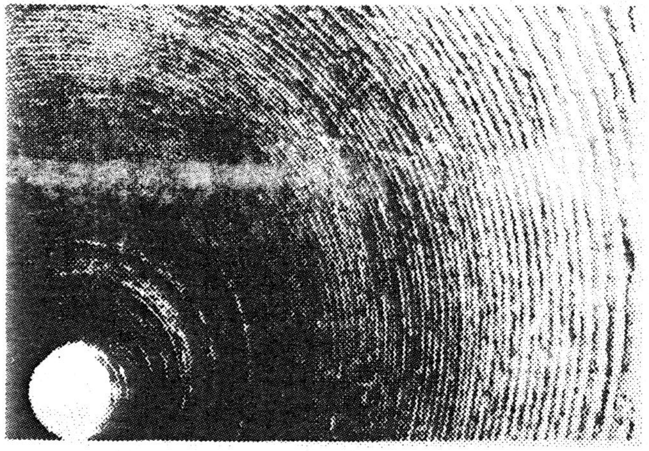
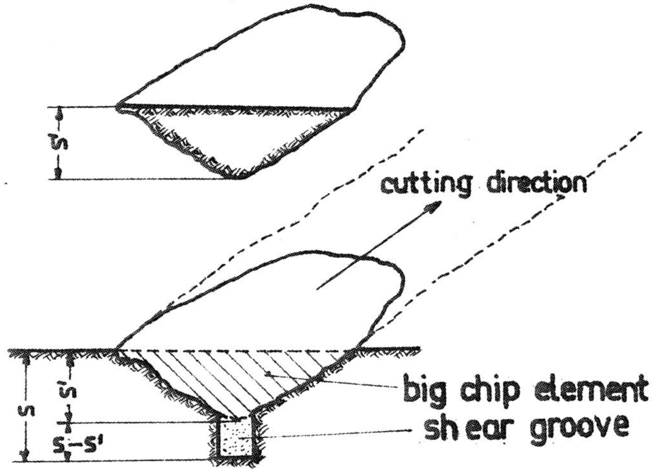


Fig.1 Walls of a tunnel driven by a tunneling-machine equipped with cutting tools.



s..........depth of tool intrusion

s'..........real thickness of chip

s-s'.....depth of shear groove

Fig.2 Scheme of a cross section of a chip groove.

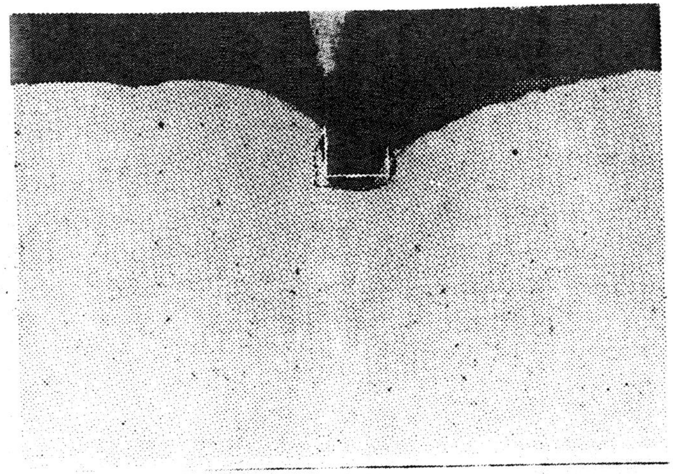
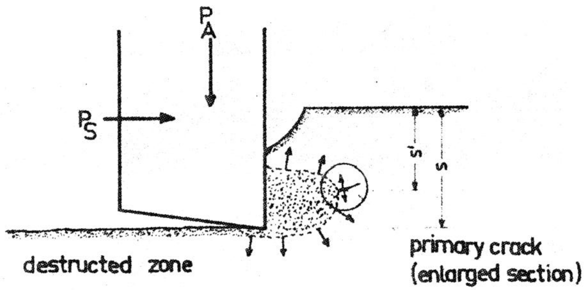


Fig.3 Cross section of a chip groove
black: real boundary of material destruction
white: boundary of the shear groove, visible after the passage of the tool.



P_S.....cutting force

P_A.....force acting rectangular to the free face

Fig.4 Longitudinal section of the area of tool attack with crushed zone in front of the tool.

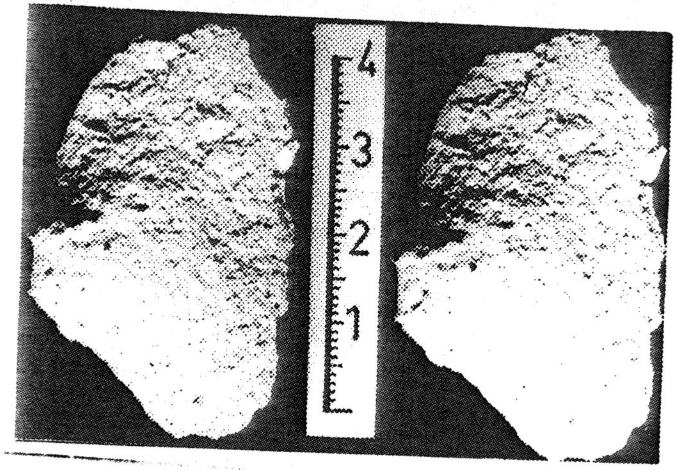


Fig.5 Big chip elements with point of tool attack showing the extent of crushed zone.

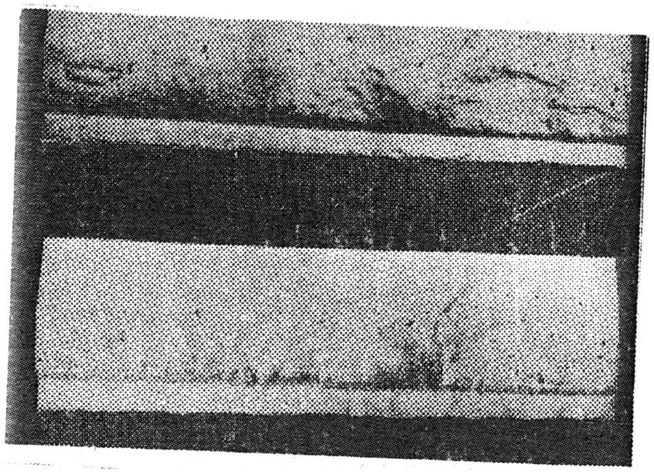


Fig.6 Longitudinal section of a chip groove showing material destruction in the bottom of the groove. (In the lower picture the destructed zone is removed as opposed to the upper picture)

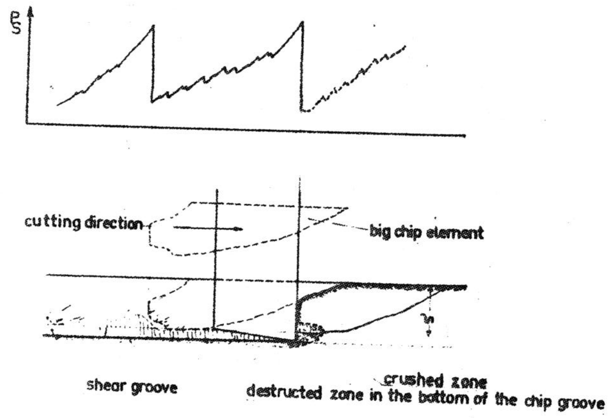


Fig.7 Total view of the configuration during chip formation.

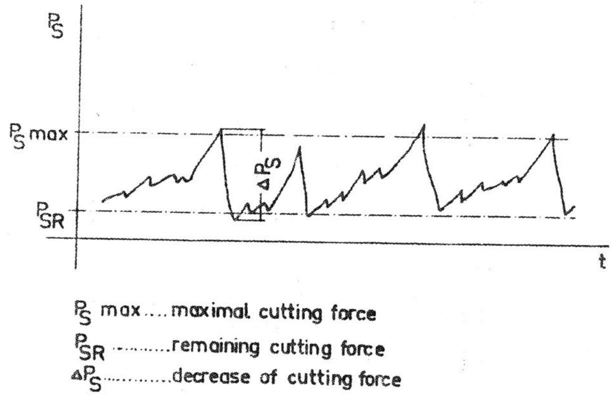


Fig.8 Example of a cutting force versus time diagram.

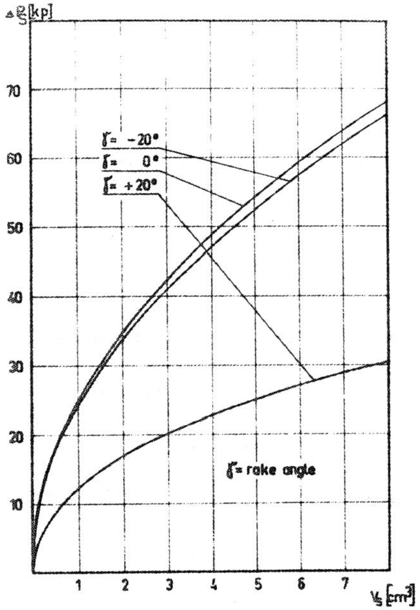


Fig.9 Diagram showing the relation between decrease of cutting force and chip volume for various rake angles.

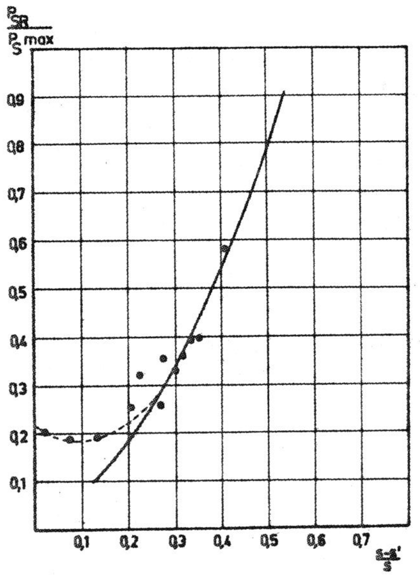


Fig.10 Relation between $\frac{P_{SR}}{P_{S}max}$ and $\frac{s - s'}{s}$.