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STABILITY CRITERIA FOR CUTTING INSERT AND GRAINS OF SUPER-HARD TOOLS

Failure of cutting tools may be the result of the continual wear, although their productivity can also be loosen due to hack, fracture, shelling or other causes, so generally because of breakage. The embedding of the grain to the binding material is also similar to the fixation (brazing etc.) of a super-hard inseRt tool with definite edge-geometry (diamond, cubic boron nitride). The productivity of the honing, grinding tools and other tools with bound grains (band grinders etc.) depends significantly on the cutting productivity of the active grains. The cutting productivity – beside other factors – depends also on the clamping stability of the grains into the binding material. The quantity and direction of the force that is necessary for the individual grains to break out of the binding material should be examined. The calculated values correlate well with the test results.

1. FAILURE OF CUTTING TOOLS WITH DEFINITE AND INDEFINITE EDGE-GEOMETRY

Tools of turning

For super-hard (diamond and cubic boron nitride) cutting tools with definite or standard edge-geometry, the cutting edge (possibly several edges) is found on the operating part of super-hard material [4]. The super-hard materialinsets are fixed, brazed or glued into the corner of the hard metal tips or in the peak of the structural steel bit. The technology of brazing is so-called hard-brazing (Fig. 1.).

Frequent deterioration of super-hard tools is caused beside the tear-and-wear by hack, fracture, notch of the super-hard material, or by its break out from the brazing or gluing seat. The worn tools can be renewed only in a limited extent. The fractured, ragged super-hard inserts and those which broke out of the seat cannot be renewed anymore.

According to the long-term industrial statistic data, the cutting capacity of the tools in 60 to 75% is loosen due to normal abrasive wear. Conversely, fracture, hack and break out ensued the outwear at 25 to 34% of the tools.

Some of the ultra precision turning tools are made of high quality, natural diamond. Their price is at least 450 … 600 USD. Clamping of these diamond inserts is also made by brazing, or some times by gluing or in a mechanic way. To avoid the break out of the diamond insert is therefore even more important than that in other cases. Thus the resolution of mechanical preconditions and strength criteria is essential.

Regulating, grinding- and honing tools

Super-hard tools that regulate the grinding wheels (diamond one-grain regulators, multi-grain regulating pencils, regulating rolls etc.) may be generally out of the following three types (Fig. 2.):

- one-grain regulators with diamond or cubic boron nitride particles,

- multi-grain regulating pencils, rolls,
- multi-grain regulating rollers.

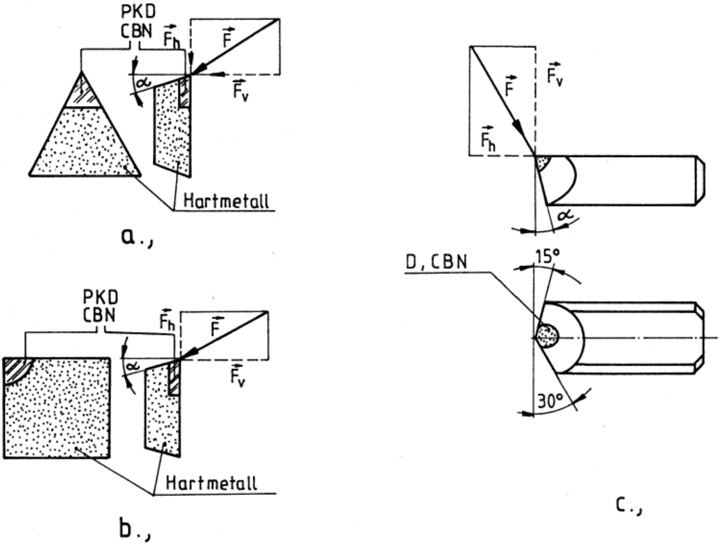

Figure 1 – Super-hard tools (insert) with definite edge-geometry: a, and b, polycrystalline artificial diamond (PAD) or cubic boron nitride (CBN) changing tips; c, natural diamond (D) or turning tool made of cubic boron nitride (CBN).

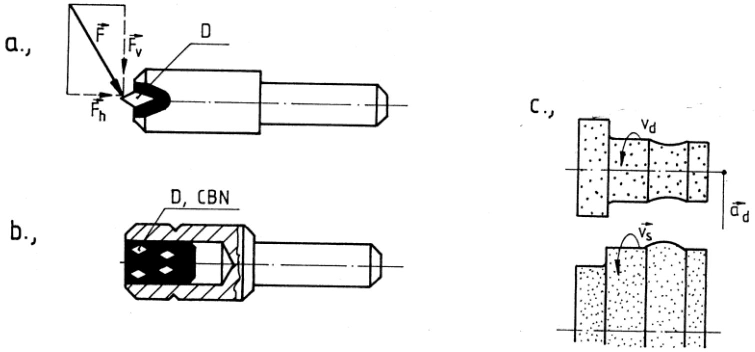

Figure 2 – Super-hard particles for grinding wheel's regulation: a, one-grain diamond; b, regulator pencil made of diamond or cubic boron nitride; c, diamond regulator roll (with grinding wheel).

The wear, fracture and break out of super-hard grains in the regulating tools caused by cutting pressure forces is similar to the wear out of the tools with normal edge-geometry.

The latter ones are the so-called multi-edge tools with indefinite or irregular edge-geometry. The grinding wheels, honing bars, band grinders belong to this group.

It can be concluded that the loading of a super-hard tool with definite edge-geometry or that of the individual cutting grains of a tool with indefinite edge-geometry is analogous respectively to the cutting force (main cutting force) and the force effecting to one grain (Figs. 1. and 2.). They could be discussed by a similar model. To impose generalisation, a tool with definite edge-geometry and one of its grain in cutting situation will be examined in the followings.

Thus the so-called one-grain cutting model can be obtained. It is not necessary to prove the adequacy of the one-grain model and the actual cutting grain. The one-grain case is analogous with the one-edge cutting tool with definite edge-geometry.

The binding material of the cutting grains functions as an elastic bedding. A similar situation occurs at the gluing or brazing of the super-hard cutting particle. Compared to the binding or gluing material, the cutting grains and the cutting inlet behave as an absolute rigid body.

2. STABILITY OF THE ACTIVE SUPER-HARD GRAINS OR INSERT

Frequent break out or fracture of the cutting grains from the binding material will cause rapid wear of the tool. The stability of the grains fixed in the binding material depends on the force effecting to the grains as well as on the mechanical and geometrical properties of the grain - binding material system.

To investigate the grain or cutting insert - binding material system, the Winkler-hypothesis was applied [1,2, 3,5].

According to the Winkler-hypothesis, a solid with six-degree of freedom may be considered as a system with three-degree of freedom in case of elastic embedding.

Investigating the load to a single grain at the start of cutting, it can be stated that the loading will increase approximately linearly from t=0 moment until the $t=t_1$ moment. Until this moment the grain will separate a chip with h_c width. It is supposed that the grain in question can be characterised by the average size and geometry of the grains (Fig. 3.).

The main average properties are as follows:

d – grain size,
h – protrusion height of the grain above the binding material level,
φ – rake angle of the grain,

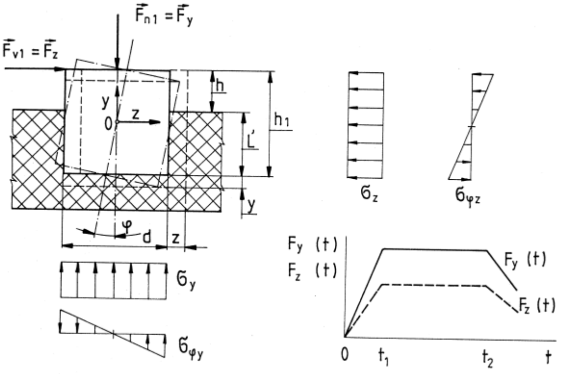

Figure 3 –Mechanical model of the grain - binding material system and the change of forces arising on the grain as a function of time

At a moment $t=t_1$, the cutting pressure forces on the grain are , (Fig. 3.). Furthermore, it can be supposed that until the grain is in cutting position, the force components remain constant, and at the end of cutting, after the moment $t=t_2$, the cutting pressure forces will decrease linearly to zero.

The investigated grain (modelling with a cube in the system of axes) influenced by forces – according to the three-degree of freedom – will be displaced by an y and z values and will turn off by φ angle. The possible displacements and turnings off will be small.

To formulate the model of the interactions of the grain - binding material system, the following conditions were presumed:

- the (super-hard) grain is an absolute rigid body,
- the above mentioned, concentrated cutting pressure forces will take place,
- the effect of cutting temperature is not important, shall be neglected,
- because of the wear of the tool, the h1 size will decrease, however, the size-change of the grain (wear) is negligible,
- the binding material of the grain is homogenous and elastic, its rigidity can be characterised by a K value.
- the protrusion height of the grain above the binding material (at a given grain size) is h,
- the height distribution of the grains above the binding material follows the Gauss-distribution,
- the grain will turn around the centre of gravity by φ angle,
- the origo of the system of axes (0) and the centre of gravity of the grain are identical,
- the rigidity is determined as a force causing a unit displacement in the direction of the force.

The grain is considered as a mass that appears in the elastic bedding and for which the Winkler-hypothesis is relevant. According to the hypothesis, reaction force of the bedding (binding material) is proportional to the turns, and the dynamic equilibrium of the grain can be described in the most general way by means of the following equation system:

$$F_{n1} = F_y(t) = m\frac{\mathrm{d}^2 y}{\mathrm{d}t^2} + a_1 \cdot y \tag{1}$$

$$F_{v1} = F_z(t) = m\frac{\mathrm{d}^2 z}{\mathrm{d}t^2} + a_2 \cdot z + a_3 \cdot \varphi \tag{2}$$

$$F_{v1} = F_z(t) \cdot \left(h_1 - \frac{L}{2} \right) = \Theta \cdot \frac{\mathrm{d}^2 \varphi}{\mathrm{d}t^2} + a_4 \cdot z + a_5 \cdot \varphi \tag{3}$$

where y, z, and φ are the requested displacements and turning values; m – mass of the grain; Θ – moment of inertia to the 0 point (centre of gravity) of the grain; h_1, L' – sizes that can be obtained from figure; a_1, a_2, a_3, a_4, a_5 – constants that belong to the displacements and turning off.

Resolution of the system of equations should be examined in the following two time intervals:

$$0 \le t \le t_1 \tag{4}$$

$$t_1 \le t \le t_2 \tag{5}$$

The mathematical resolution yields the followings [1,2,5].

3. CONCLUSION

Considering the wear of the tool, a distinction should be made between the wear of the grain and the wear of the binding material. As the grain wears, dulls, the cutting pressure force will increase. Meanwhile the strain will also increase. The strain will reach the σ_{kr} value and then exceeding it the grain will break out of the binding material. If the wear of the binding material is quick, the clamping length of the grain into the binding material (L') decreases, however, the strain increases. If this strain overrides the critical value, the grain turns out of the binding material. At this moment the sharp or slightly worn grains will turn out of the binding material and the specific abrasive consumption and operation costs will increase.

The intensive wear of the binding material could be a consequence of such a technological setting in that the binding material continuously makes contact, rubs with the material separated from the workpiece or with the surface to be machined or with the worn parts arising from the grains. The wear of the binding material becomes faster due to such abrasive effects.

The rate of wear of grain and binding material should be approximately the same. This depends not only on the features of the tool (grain, binding material etc.), but also on the conditions of machining. Therefore the strength of binding material – hardness of binding – should be in accordance with the wear of the grain to ensure the self-sharpening of the tool.

The binding material with too great strength (hard binding) will not release the worn grains, despite the cutting pressure force on them will increase. In this case the

$$\sigma_{zB} < \sigma_{kr} \tag{6}$$

relation holds in each moment. If self-sharpening of the tool is not ensured, it only presses, rubs the surface to be machined. Separation of the material becomes slower and then terminates. On the active part of the tool, practically worn grains could only be observed, separation of which requires an extra regulating operation. Finally, decrease of productivity and deterioration of roughness will result, the operation cost increases.

In case of binding material with too little strength (soft binding), the not worn grains will turn out of the binding material, the specific abrasive consumption increases.

The criteria formulated above is also holds in case of super-hard tip with definite edge-geometry. The tip will be fixed e.g. by hard brazing, for which the same is relevant than that to the binding material and to its strength.

The calculated values correlate well with the test results (within 5% deviation).

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