Tribological Investigation of Self-Sharpening Effect

How to use wear for Self-Sharpening of tools

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Abstract
During cutting process blades are in contact with abrasive materials and particles. Therefore, wear is observed, especially on cutting edge. The consequence, blades get dull. Dull blades need maintenance and replacement or time consuming re-sharpening. Scope of these work is to **use unavoidable wear for self-sharpening**. Unavoidable wear is used to keep a sharp cutting edge and therefore keep constant cut-quality over lifetime, to reduce maintenance, to lower required load and power and to conserve energy.

First a comparable **bionic** tribo-system is investigated and described. Wear regimes for hardness ratio from cutting material to abrasive are discussed. Different failure mechanisms of design are experimental tested on test bench and in field applications. Results are shown and discussed.

1. Introduction and motivation

Cutting processes are all-round in our daily life. Already during breakfast: we cut bread, use fine-cut cheese, divide our eggs. In industry there are many cutting processes e.g. in metal working, sawing, cut of sealings or papers, plastic granulation, forming, casting, post processing of 3D-printings. Also in garden and in agricultural applications there are many cutting processes e.g. lawn-mowing, harvesting and soil working. One common thing of all mentioned cutting processes is **wear**, especially wear on the cutting edge.

Even occasionally lawn mowers observe wear, however in agricultural application wear is higher and result in higher cutting forces and accordingly higher **energy consumption**. In addition, quality gets down and damage to plants increase until maintenance is required. Focus of these work is to use wear for self-sharpening of cutting blades, to get **consistent and good cut quality**, without maintenance/re-sharpening.

2. Scope

Typically, tribology minimizes wear. However, wear can not be avoided completely. Scope of this work is to **control wear**, to use unavoidable wear for self-sharpening. So, blade **keeps sharp** cutting edges or even **gets sharper during use**.
Traditionally, **cutting tool** and metal working address wear by using hard materials e.g. ceramics or hardened materials. Even hard coatings are used.
Drawback of hardness: material gets also brittle and therefore generates a potential risk of breakage. In addition, wear still limits lifetime, especially in cases, were high precision is required.

Described **self-sharpening** effect uses a different **wear strategy.** A structural base material and only one bottom layer tribological optimized coating. Cutting media wears base blade material in controlled way at a faster wear rate than the harder, more wear-resistant coating. So, design **controls wear and results in self-sharpening effect**.

3. Tribo-system based on bionic principal of a tooth

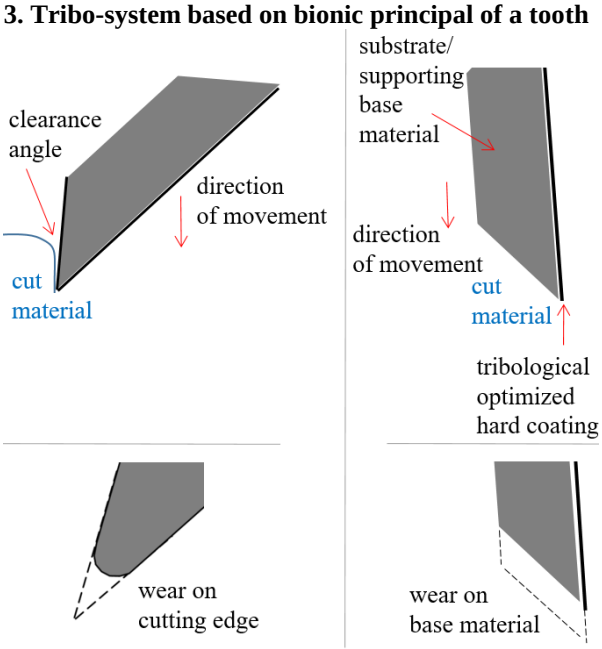

Figure 1: Comparison of traditional cutting process (left) and self-sharpening (right). Lower pictures show change of cutting edge due to wear. Left: cutting process with wear on cutting edge. Right: Schematic design of tribo-system based on bionic principals of a rodent-tooth. Because of tribological optimized hard coating wear is controlled. Wear on base material is higher compared to wear in tribological optimized coating. This results in a self-sharpening effect.

Durability enhancing options are locally graded steel structures, diffusion or laser hardening, cladding or coating e.g. thermal, plasma or laser. For cladding or coating high hardness is possible however also a potential risk of delamination or brittle breaking under shock load. To use wear effects for self-sharpening in next chapter required boundary conditions are investigated.

4. Wear regimes

In literature wear vs. hardness diagrams are found. Dependent on hardness there are low or high wear regimes.

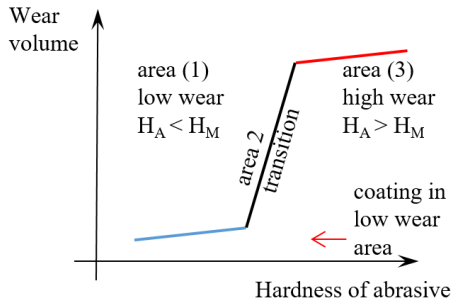

Figure 2: Influence of hardness of the abrasive H_A on the wear of a material with the hardness H_M, oriented on [1]. Three areas can be distinguished. Low wear regime (1) can be reached if the hardness of the abrasive H_A is smaller than that of the abrasive H_M. Scope of the tribo-system is to have a wear resistant coating in low end of area (1) which withstand all loads during lifetime.

Summarized, essential **requirements to enable self-sharpening** effect are

- selection of the materials used (hardness ratio base material : coating of 1 : 2)
- abrasive action of the cut material or of particles (e.g. soil, sand) and because of wear sensitive tribo-system constant tribological conditions over lifetime
- avoid damage of coating due to extreme stone impact, abuse and delamination of coating

5. Wear mechanisms and corresponding test setups

Depended on load profile in field experimental test setups are

- Bending flexural test and delamination of coating or hardend surface
- Impact test, stone impact
- Abrasive

6. Field testing and results

Because of plenty opportunities of cutting processes, focus of experimental testing was on field testing. Tested was a lawn mower blade. For investigations blade with wolfram-carbide coating is used.

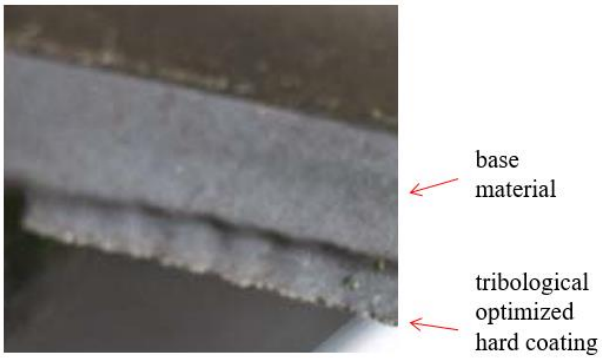

Figure 3: Wolfram carbide coated mower blade after 50 hours in field. The base material shows wear. Because of lower wear on carbide cutting edge, a new cutting edge is exposed. Cutting edge stays sharp.

In a second test row, on soil working tool a built-up welding is applied.

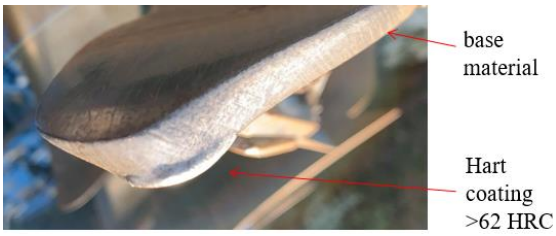

Figure 4: Soil working tool with hard coating on lower side. Picture shows part after testing. Shown is a typical wear/a typical equilibrium state because of combination of different materials with a hardness ratio base material : built-up welding 1 : 2.

7. Results and discussion

Tests showed that tribo-system worked as expected. Due to wear resistant coating on cutting blade wear is controlled and Self-Sharpening is observed. Because of sensitive and tribologically optimized system, the self-sharpening effect appears only under consistent field conditions. Therefore, only similar cutting medias regarding e.g. hardness, abrasive behavior are recommended [see requirements in chapter 4].

Because of coating additional costs are generated. However, on economical coat-able parts and because of reduced maintenance the amortization of costs is usually possible. Even without considering advantages like better cutting quality and reached energy consumption.

Contact ratio (Eingriffsverhältnis) has to be designed for wear of base material (figure 1). Consequently, wear particles are generated. Therefore, self-sharpening system should only be used in application where particles have no impact on quality.

Like in all cutting processes wear leads to a change of cutting edge (Figure 3). Quality of cut material and cutting edge need to be controlled and if required adjusted. Wear rate is similar or lower compared to traditional cutting systems without coating.

Advantages observed during tests are

- better and over lifetime consistent guidance of tools (no significant change of shape of tool cutting area)
- higher and consistent cutting quality over lifetime => healthier greener lawns
- lower cutting forces => lower energy consumption e.g. mowing with a dull blade can reduce fuel economy by as much as 22 percent, which increases operating costs and reduces productivity
- no maintenance and therefore no standstill times
- corrosion protection, coating or heat treatment offers a higher corrosion protection compared to blank steel

8. Conclusion

There are requirements and limitation for the design of the tribo-system. If requirements are considered, first results on tribometer and in field tests were successful and showed expected self-sharpening effects. Wear can be controlled and used for self-sharpening effect.

Reference [1] Czichos, Horst: Tribologie-Handb. 2015