Requirements and potential for high performance cutting tools based on superhard phases in new applications

Ståhl, Jan-Eric

2016

Extended Abstract for keynote lecture at
De Beers Diamond Conference 2016 hosted by Warwick University, UK

Requirements and potential for high performance cutting tools based on superhard phases in new applications

J-E. Ståhl[1]
[1]Division of Production and Materials Engineering, Lund University
Ole Römers väg 1, Lund, 22100, Sweden

This work covers qualitative and quantitative requirements with regard to material properties for cutting tools to be able to resist and balance the various interactive mechanisms that cause the wear of the cutting edge and put limits its tool life. In metal cutting, tool life T combined with the cutting data (cutting speed, feed and depth of cut) controls largely the manufacturing cost and related competitiveness. Selected cutting data determine the required tool engagement time t_i in a particular application, and thus have a direct influence on the manufacturing cost. The selected cutting data in a specific application result in a certain tool life with a statistic distribution. For example, Colding equation can be used to determine the link between tool life T and selected cutting data. The tool-cost and its influence on the final cost of manufacturing of a component is determined mainly by the tool performance, i.e. how high are the cutting data (Metal Removal Rate) that can be used for a given tool life T.

The tool deterioration during machining can be regarded as a balance and interaction between four different types of loads, which can be recognized as mechanical, thermal, tribological and chemical effects according to Fig. 1.

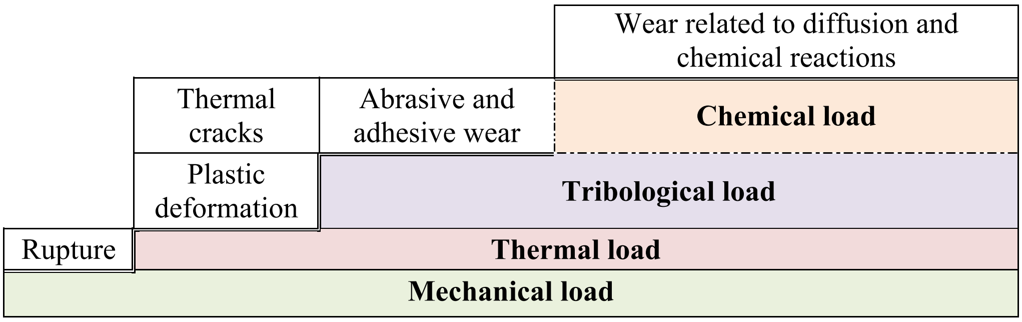


Fig. 1: *Interaction between different loads acting on a cutting tool and contribute to the tool deterioration.*

The deterioration of the cutting tools has a multifaceted behavior and is determined mainly by the relationship between the workpiece material and the tool material. High cutting data and difficult-to-cut materials provide both high mechanical and thermal load, which increase the influences of particular chemical load in the form of diffusion and chemical reactions. High-performance cutting materials such as ceramic whisker reinforced Al_2O_3, cBN and PCD are dominated by chemical degradation even if all the other known types of deterioration are also occurring. Both cBN and PCD and the elements they consist of are chemically reactive with several types of workpiece materials. The elements B, N and C also exhibit high solubility in various metallic phases which makes the use and utilization of its high potential (Fig. 2) with respect to abrasive resistance and thermal conductivity more difficult. For example, the PCD is sensitive for all carbide forming elements and BN-systems are sensitive to all boride and nitride forming elements. Under certain favorable circumstances, reaction products between the workpiece material, tool material, coatings and surrounding atmosphere contribute to a Tool Protection Layer (TPL). TPL forming in the contact zone between the tool material and the workpiece material could slow down chemical related deterioration, see Fig. 4. Successful development and use of high-performance tooling material is based largely on creation of a well-functioning TPL that can be built up by elements of the tool material, coating and the workpiece material or from surrounding atmosphere (cutting fluids included).

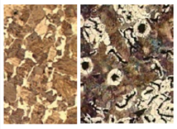
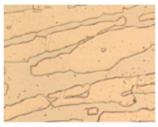
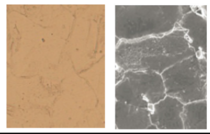
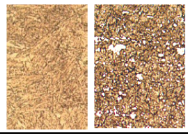
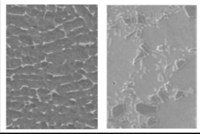
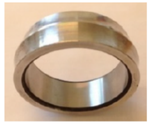
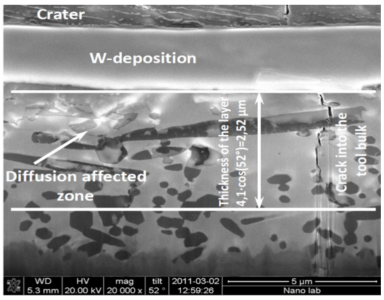
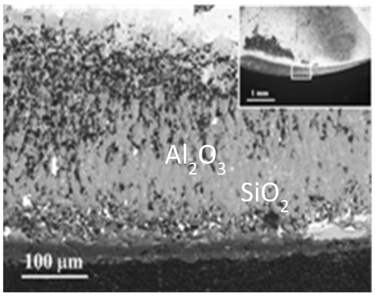
Ferritic and perlitic, **P**, **K**	Ferritic – austenitic, **M**	Austenitic and super alloys, **M, S**	Martensitic materials, **H**	Titanium alloys **S** and composites	Rock and minerals
					
Carbon steel (a), cast iron, ductile cast iron (b).	Duplex stain-less steels (c).	Stainless steel 316L (d) and Alloy 718 (e).	Toughened steels (f) and tool steel M2 (g).	Titanium alloy Ti6Al4V (h) and Al-based MMC (i).	Minerals (j) as Quartz, mica, feldspar, etc.
					
Automotive, home products, buildings, machinery, infra-structure, etc.	Off-shore, marine water distribution, home products.	Energy, med-tech, chemistry industry, off-shore and home products.	Automotive, tooling, and transmission parts.	Med-tech, energy, aviation, automotive components (break discs etc.)	Mining and construction, infrastructure and buildings.

Fig. 2: Potential application for use of high performance cutting tools based on superhard phases.

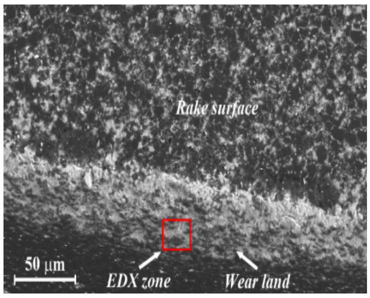
Fig. 3 illustrates various types of deterioration and TPL related to high-performance cutting materials such SiC-whisker-reinforced Al_2O_3 ceramic cutting tool, binderless cBN and PCD.



Diffusion of alloying elements from Alloy 718 into a SiC-whisker-reinforced Al_2O_3 ceramic cutting tool and a detected crack into the tool bulk.



Deposition of SiO_2 and Al_2O_3 on a bcBN tool during machining of high alloy white cast iron in hardened condition.



A reaction layer on PCD consisting of SiC formed between the chip and the tool serving as a platform for a built up edge in machining of Al-SiC_p MMC.

Fig. 3: *Formation of Tool Protection Layer (TPL) in machining with high performance cutting tools, Bushlya*[4].

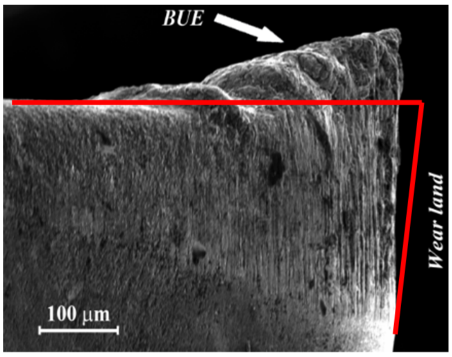
The tool lifetime T can be modelled in a variety of ways. The model most frequently employed in extension to the Taylor model is an Extended Taylor. It involves the use of 4 or 5 constants. Colding's equation[1] usually functions somewhat better than an Extended Taylor according to Hägglund[3], which in its most usual form also has 5 constants. It required also 5 individual tests to determine the constants in Colding equation in which the chosen wear criterion is reached. Colding´s equation describes, for an application having a predetermined tool life criterion, the relationship between the cutting speed v_c and both the equivalent chip thickness h_e and the tool life T. Coldings equation is presented below as Eq. 1

$$v_c = \exp\left[K - \frac{(\ln(h_e) - H)^2}{4 \cdot M} - (N0 - L \cdot \ln(h_e)) \cdot \ln(T)\right] \tag{1}$$

where K, H, M, N0 and L are Colding's constants. The equivalent chip thickness h_e can be computed in terms of Woxén's approximation[2] using Eq. 2.

$$h_e = \frac{a_p \cdot f}{\frac{a_p - r_\varepsilon(1-\cos\kappa)}{\sin\kappa} + \kappa \cdot r_\varepsilon + \frac{f}{2}} \qquad (2)$$

Use of the equivalent chip thickness h_e is advantageous since it is combining 4 separate parameters to form a single one based on the cutting data parameters a_p (depth of cut) and f (feed) and respectively tool geometry r_ε (nose radius) and κ (major cutting angle).



Adhesion and formation of built-up edge (BUE) on a PCD/Co tool during machining of Al-SiC$_p$ MMC.

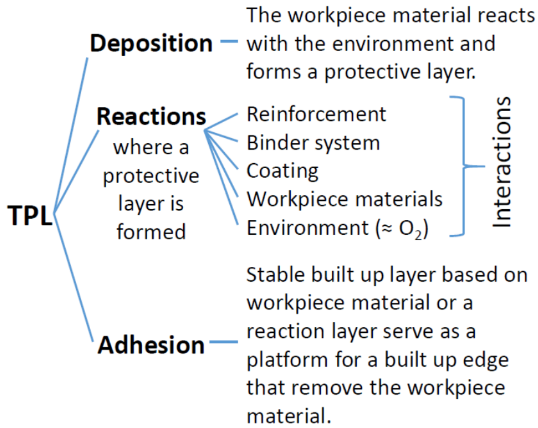


***Fig. 4:** A Tool Protection Layer in machining with high performance cutting tools.*

For the selected cutting data the equivalent chip thickness h_e is found for given cutting depth a_p and feed f according to Eq. 2. For the selected tool life T the cutting speed v_c can be calculated in accordance with Eq. 1. Tool engagement time t_i can, for a known application, be calculated according to $t_i = V/(f \cdot a_p \cdot v_c)$ where V is the volume of material to be removed from the workpiece. Engagement time t_i is in direct proportion to the manufacturing cost of a component. Through the development and use of high performance cutting tools based on superhard phases there is a high potential to machine advanced materials with high cutting data that can provide both cost and competitive advantages. A complete manufacturing economic model is published by the author[4], based on the engagement time, t_i.

Acknowledgements

The author wishes to thank the Sustainable Production Initiative - cooperation between Lund University and Chalmers University. This work was also co-funded from the European Union's Horizon 2020 Research and Innovation Programme under Flintstone2020 project (grant agreement No 689279).

Selected references

1. Colding B. The Machining Productivity Mountain and its Wall of Optimum Productivity 9th NAMRC p. 37, 1981.
2. Woxén R, Theory and an Equation for the Life of Lathe Tools, Ingenjörsvetenskaps-akademin, Handling 119, Stockholm 1932.
3. Hägglund, S. (2013). Methods and Models for Cutting Data Optimization, Doctoral Thesis, Chalmers University of Technology, Gothenburg, Sweden.
4. Ståhl J-E. An integrated cost model for metal cutting operations based on engagement time and a cost breakdown approach, Swedish Production Symposium (SPS16), Lund Sweden 2016.
5. Bushlya V., Zhou J., Avdovic P. and Ståhl J-E. Wear mechanisms of silicon carbide-whisker-reinforced alumina (Al_2O_3–SiC_w) cutting tools when high-speed machining aged Alloy 718, Int. J Adv. Manuf. Technol., DOI 10.1007/s00170-013-4899-8.