International Journal of Modern Manufacturing Technologies
ISSN 2067–3604, Vol. V, No. 1 / 2013

SOLID CARBIDE TOOL WEAR MONITORING AND EVALUATION IN DRILLING PROCESSES

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Abstract: This paper aims to establish the wear mechanisms of Solid Carbide (SC) drills when drilling 42CrMo4 Material. Purpose of this is to evaluate and monitor the exact fazes of the solid carbide drill tool life in drilling operations so that production planning and workpiece quality receive a high process safety and repeatability, these factors will eventually determine a high profitable and efficient tool. The success of continuous improved drill performance in cutting applications has to date largely been based on significant advances in tool surface coatings and modifications of drill point geometry, and optimization of the rake angle distributions along the drill lips and the chisel edge.

Key words: drilling with solid carbide, adhesion, cutting application, surface coating

1. INTRODUCTION

The need of high performance cutting tools is driven by continuously improved mechanical properties of new work piece materials, which often results in a difficult machinability. Cutting tools represent the interface between machine tool and work piece. Therefore cutting tools must perform a reliable and stable cutting process with high productivity and maximum tool life. Cutting edge micro geometries influence the tool wear behavior and therefore the tool life significantly (Rech et al., 2005, Denkena et al., 2005). The chip formation mechanism is also influenced by changes of the ratio between undeformed chip thickness and the radius of the honed cutting edge (Jivishov 2008). The thermal load on cutting tools is one of the most important factors influencing the tool life.

Flank wear is one of the most important aspects that affect tool life and product quality in machining. However, only few works were published to identify the mechanism behind flank wear mainly due to the complexity in metal cutting process. At the present time, the most dominant flank wear mechanism is believed to be the abrasion by the hard inclusions in a work material, which results in the scoring marks on the flank surface (Ramalingam and Wreight1981).

Another important wear mechanism for flank wear is adhesion. This type of wear can take place when one solid material is sliding over the counteracting surface. The interaction between two surfaces can be represented by the metallurgical weld or adhesion joint. Adhesive wear takes place when discrete pieces are pulled out from the tool surfaces during sliding (Rabinowicz, 1964). Excessive localized wear at the depth of cut line on the flank surface is called notch wear. The main concern is that the notch wear often leads to catastrophic tool failure. Chandrasekaran and Johansson (Chandrasekaran and Johansson, 1994) investigated the mechanisms for notch wear in machining of various austenitic stainless steels with cemented carbide tools. They concluded that the sequence of the severe shear deformation and lateral extension of the chip leads to excessive abrasion or adhesion wear between the deformed chip and the tool surface at the notch region.

To identify the wear mechanisms that can be verified through the experiments, accurate measurement techniques are needed. In addition, the micro features on the tool surface such as the scoring marks by abrasion can be extracted and isolated using the wavelets (Raja et al., 2002), which enable us to analyze wear mechanisms. The effectiveness of the multilayer comes from the changes in interface conditions as each layer is exposed. As each layer is exposed, the maximum wear location changes instead of concentrating on one location. This extends the tool life substantially.

TiCN coating shows excellent wear resistance against the abrasion while the carbide has the least abrasive resistance. After carbide was exposed, the work material adhered to the carbide substrate and the cutting tools were fractured due to the crater degradation on the carbide surface. Because of the grain pullout in carbide, the wear mechanism can be quite different in the carbide substrate.

The measured groove size indicated that the softer coating is damaged much more. As soon as the hard TiCN coating is exposed, the abrasive cementite cannot affectively abrade the hard surface.

Sharp cutting edges are usually considered detrimental to cutting processes because of their low stability and low impact resistance (Karpat et al., 2008). Conversely, Yen et al. (Yen et al., 2004) postulate that round edges reduce the initiation of notch wear, since they have higher impact resistance. Thus, the earliest studies on cutting edge design are focused on the edge geometry, specifically on the edge radius. A critical relation between chip thickness and edge radius (the so-called relative tool sharpness) must be considered, since it characterizes the chip formation mechanism as pure shearing or ploughing (Childs et al., 2008). Özel (Ötzel et al., 2009) notes that the cutting efficiency decreases when the uncut chip thickness is two times smaller than the edge radius because of the predominating ploughing effect. The preparation of the cutting edges aims for the stabilization of the edge, the reduction of chipping and the improvement of the tool surface roughness, which improves the chip flow. This leads to increased tool life and process reliability, decreased cutting forces and a better work piece quality (Byme et al., 2003, Holsten, 2009). Guter's investigations (Guter, 2009) show that when utilizing a symmetric edge radius, a large edge radius is necessary in order to convert the bending and shear stresses acting on the wedge to compressive stresses. Should this not be the case, chip deformation remains localized at the tool tip and causes high pressure as well as significant thermal load leading to rapid tool wear. On the other hand, if the edge radius proves too big, higher forces are necessary to shear the material since the shear angle is small and the chip thickness is large (Yen et al., 2004). However, such high forces acting on the tool wedge can cause a sudden tool failure.

The influence of asymmetrical micro geometries on tool life is analyzed by Denkena et al. (Denkena et al., 2011). It is demonstrated that the slope of the edge towards the flank or rake face influences not only the wear mechanism, but also the mechanical and thermal loads. To achieve special micro geometries at the cutting edges, different manufacturing technologies can be applied depending on the productivity, precision and final micro geometry (Denkena, 2010). Sharp edges with cutting edge radius $r< 5m$ are generated by grinding the rake face. Grinding is also applied for the preparation of complex geometries, chamfers and for the removal of a larger material quantity at the cutting edge (Friemuth, 2002). Intermediary edge radii, $5m<r<20m$, can be prepared through abrasive blasting of the flank and rake faces. Brushing produces larger edge radii, with $r > 20m$.

In contrast to force-based processes, grinding parameters influence the edge quality, but not the dimensions of the micro geometry, and, as a result, the edge preparation process becomes more flexible. In addition, it permits grinding the flank face and preparing the edge when using only one work piece clamping, resulting into a decrease of the production time.

Kimura (Kimura, 1974) also demonstrates that increased edge chipping correlates with decreased tool life in cemented carbide tools. His investigations show that when grinding under identical conditions, a greater wear resistance of the cemented carbide tools with comparatively low Cobalt proportion correlates with a high degree of edge chipping, whereas cemented carbide tools with relatively high Cobalt proportion result into a small cutting edge roughness. He considers the different degree of bonding strength between the carbide and the binder as the main reason for this occurrence.

Coated tools have compound material structure, consisting of the substrate covered with a hard, anti-friction, chemically inert and thermal isolating layer, approximately one-two few micrometers thick. As such, coated tools compared to uncoated ones, offer better protection against mechanical and thermal loads, diminish friction and interactions between tool and chip and improve wear resistance in a wide cutting temperature range (Klocke and Krieg, 1999).

1.1 Definition of the cutting edge micro geometry

Different sizes and forms of cutting edge micro geometries can be produced by means of micro blasting, brushing, magnet- or drag-finishing or by laser ablation techniques (Aurich et al., 2010). The characterization of the cutting tool micro geometry is a fundamental requirement in order to investigate its specific influence on machining processes. The hone radius rb is not sufficient to characterize different cutting edge micro geometries precisely. This can be achieved by the definition of four fundamental parameters shown in Fig. 1. Applying this characterization of the honed cutting edge it is possible to distinguish three cases. A symmetrical cutting edge micro geometry is defined by a form factor $K = 1$, while $K > 1$ indicates a slope towards the rake face and $K < 1$ describes a slope towards the flank face. The size of the asymmetrical honed cutting edges is described by the parameters Sg, Sa and K. Symmetrical honed cutting edges will be described through their mean size ŻS.

1.2 Coating deposition techniques for cutting tools

Fig. 1 presents the coating deposition technologies for cutting tools, classified according to pressure and temperature required for the process. Physical vapor deposition (PVD) covers a broad family of vacuum coating processes in which the employed material is physically removed from a source by evaporation or sputtering. Then, it is transported by the energy of the vapor particles, and condensed as a film on the surfaces of appropriately placed parts under vacuum. Chemical compounds are deposited by either using a similar source material, or by introducing reactive gases (nitrogen, oxygen, or simple hydrocarbons) containing the desired reactants, thus reacting with metal(s) from the PVD source. Most of the PVD processes are known by various phrases or acronyms and they are typically named for the physical vapor source; for example, diode or triode sputtering, planar or cylindrical magnetron sputtering, direct current (DC) or radio frequency (RF) sputtering, electron beam evaporation, activated reactive evaporation, and ARC evaporation (DC or alternate current (AC)). Chemical vapor deposition (CVD), unlike to PVD vacuum processes, is a heat-activated process based on the reaction of gaseous chemical compounds with suitably heated and prepared substrates. Primary reactive vapors can be either metal halides (chloride, bromide, iodide, or fluoride) or metal carbonyls, M (CO), as well as hydrides and organometallic compounds. To decompose or reduce the metal compound, a transfer of heat energy is involved, and the substrate is usually held at a substantially higher temperature than any other part of the system. For this reason, the reaction chamber may present more of a high-temperature problem than any other part of the system. Most reactions are also conducted in an anhydrous and anaerobic environment, and frequently at sub-atmospheric pressures. Typical deposition temperatures range from 800 to 1200 8C.

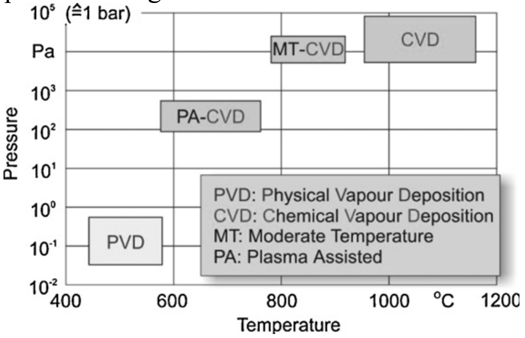


Fig. 1. Coating deposition technologies for cutting tools (Tönshoff et al., 1997)

The ability to provide uniformly thick coatings with refined grain is also influenced by the deposition temperature. In both cases, low-temperature processing is frequently desirable, although a compromise in the rate of deposition must often be made. Fewer CVD reactions are available for use at temperatures below 800 8C than above (moderate temperatures, MT-CVD). However, the temperature required for a given reaction can be lowered by exposing the substrate to an electrical plasma in the gas phase during deposition, referred to as plasma-assisted (PA-CVD). Metalorganic CVD (MO-CVD) has been reported for strengthening Al2O3-based ceramic tools (Konyashin, 1996).

CVD coatings were already commercialized for carbide inserts in the 1960s. PVD was developed almost 20 years later and today both CVD and PVD are sharing the coating market of cutting tools.PVD coatings for cutting tools can be deposited at temperatures lying in the range of (450–550)C, which allows the film deposition on high speed steel (HSS) tools. Moreover, the ability to control thicknesses on the edges, when PVD is employed, guarantees a sharp coated edge. High intrinsic hardness and compressive stresses inhibiting the crack growth in tool material are among the beneficial properties of PVD. The possibility to produce thick layers by CVD at increased deposition rates renders the CVD coated tools suitable for high material removal operations, whereas PVD ones are selected in medium finish and finish operations. PVD films can be produced without any chemical interaction with the substrate. CVD coatings easily interact with the substrates, occasionally producing brittle carbides at the interfaces. The ease of the coating and re-sharpening of PVD coated tools opened a large industrial market highly sensitive to cost reducing opportunities.

1.3 Coating thickness distribution on the cutting edge

For investigating cutting edge roundness changes as for example induced by micro-blasting on coated tools, confocal measurements along the tool edge of variously micro-blasted coated cutting inserts can be employed (Bouzakis, et al., 2011). In this way, successive cross sections of the cutting edges can be monitored and the corresponding tool wedge radii as well as the average value and the fluctuations of the cutting edge roundness, before and after micro-blasting at various pressures can be estimated. A characteristic example, for an as deposited TiAlN coating case is demonstrated in Fig. 2a. The course of cutting edge radius versus the micro-blasting pressure is shown at the right of Fig. 2a. These results reveal that by increasing the micro blasting pressure, an enlargement of the cutting edge radius develops. This growth is more visible at micro-blasting pressures over 0.2MPa. Taking into account the previous results, the coating thickness distributions along the cutting edge, after micro-blasting at various pressures, can be analytically determined. The calculated coated cutting edge cross section geometries at pressures of 0.2 and 0.4MPa are shown in Fig. 2b. The coating thickness tr-min may diminish to zero at 0.4MPa. Thus, substrate revelations may develop, as it is also indicated in the diagram of Fig. 2c. A coating thickness tr-min diminution leads to substrate thermal and mechanical loads growth and thus, the coated tool cutting performance may be deteriorated, although the augmentation of the cutting edge radius in general within a certain range improves the wear behavior (Bouzakis, et al., 2011, Rech, 2006). A characteristic case of the cutting performance of variously rounded by grinding coated cutting edges of cemented carbide inserts are presented in Fig. 2d (Bouzakis et al., 2011). Taking into account the determined film thicknesses on the flank.

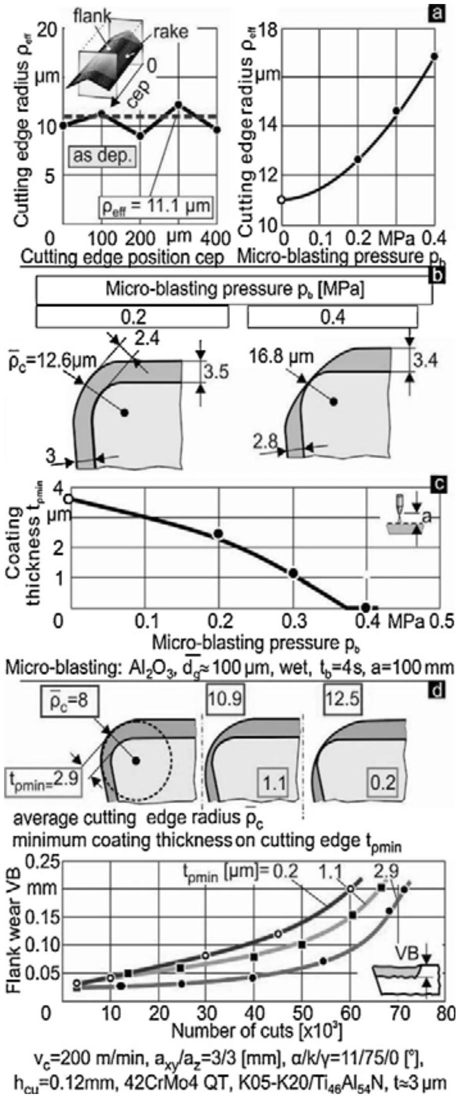


Fig. 2. (a) Cutting edge radius reff, (b) cutting edge geometries, (c) minimum coating thickness trmin of wet micro-blasted coated inserts at various conditions, (d) Flank wear development versus the number of cuts in milling with variously ground cutting edges, (Rech, 2006)

2. EXPERIMENTAL SETUP

For this experiment solid carbide drills have been used, with a RT100U cutting-edge geometry. This geometry is characterized by a four-facet drill point, with a straight cutting edge, clearance angle of 8°/20° and a drill core of 0,3xD. This geometry also possesses a corner chamfer and is exclusively used for steel boring applications.

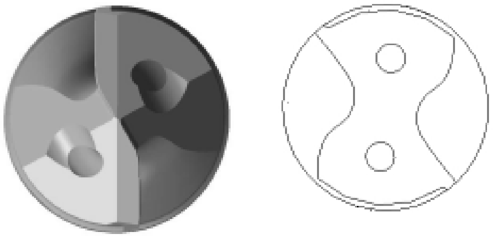


Fig.1 RT100U Solid Carbide drill overview (Gühring, 2012)

The cutting material used as a reference is a very common steel 42CrMo4, with very diverse applications in the automotive industry and not only. Cutting parameters in this case have been selected to reach the top performance of the drill and its geometry and can be seen in the Table 1.

Table 1. Cutting parameter

Cutting parameter		
Cutting speed (vc)	[m/min]	110
Feed per revolution (f)	[mm /U]	0,2
Number of revolutions (n)	[RPM]	5149
Feed rate (vf)	[mm/min]	1030
Cutting depth (ap)	[mm]	34
Cooling		WET/IC
Coolant		Emulsion ~ 8% Fat content
Pressure / Volume	[bar /l/min]	35 /~8 l/min

In order to forecast and determine the exact evolution of the tool life and drilling quality a number of systematic measuring procedures need to be followed. After these procedures we can establish a general model of the wearing mechanism in drilling operations for a whole family of drills and drilling geometry. To be able to provide the right measuring procedures we need to analyze the drill and its geometry with a number of four utensils. The first one is a digital microscope PG2000 with which we can measure the initial geometry state and further on the geometry after an established number of holes being drilled. The next step in progress is to measure the cutting edge radius and chisel edge corner near to the chisel edge in order to determine the effective production geometry. These two parameters are very important in order to obtain a constant chip formation and minimum drilling forces. The third step is to follow the wear of the cutting edge and cutting corner with the atomic microscope REM, also to determine the work piece material adhesion on the cutting edge. The fourth step for this experiment is to examine the coating material on the drill surface with the Kalomax spherical cap grinder. Due to the coating procedure the coating thickness is very uneven, this leading to higher wear in the thin coating areas. Also the coating binding between the layers is highly important for the chemical stability of the drill surface. If one of the chemical elements in the work piece material interacts with one from the drill surface it can lead to premature wear of a certain area of the drill.

2.1 Experimental results and analysis

The first step in the concept of predictive wear is the determination of the standard profile and geometry of the solid carbide drill. For this a digital microscope PG2000 had been used. With it all the geometry dimension and angels have been measured at the beginning of the experiment, dating the initial state and further on after 30 holes and from this point after every 150 holes. All the values have been put in the Tab.2 where all the important dimensions can be read.

Table 2. Initial dimensions

Cutting diameter	mm	6,808
Shank form	mm	HA/7,998
Number of blades	z	2
Overall length	mm	90,43
Flute length	mm	52,06
Mirror flank-front	mm	4,431/4,434
Mirror flank-back	mm	4,420/4,426
Coolant bore Ø	mm	1,20/1,21
Web thickness	mm	2,06
Point angle	°	141
Helix angle	°	26
Web thin **radial**	°	34
Web thin **axial**	°	32
Dimension " F "	µm	217
Web thin angle	°	104
Web thin radius	mm	0,24
Web thin rake angle	°	1
Radius HS	mm	0,28
Ground-honed cutting edge (1 / 2)	µm	36/34
ground-honed cutting edge angle	°	45
Angle 1 Chamfer 2 Chamfer	°	62/ 61
Round chamfer (**1** / 2)	µm	420/420
Clearance angle **primary**	°	11
Clearance angle length	mm	0,489
Clearance angle **secondary**	°	25
Clearance angle length	mm	2,883

After measuring all the initial values and dimensions the cutting edge and cutting corner are photographed in order to evaluate the progression of the wear, as seen in the Fig.2 underneath.

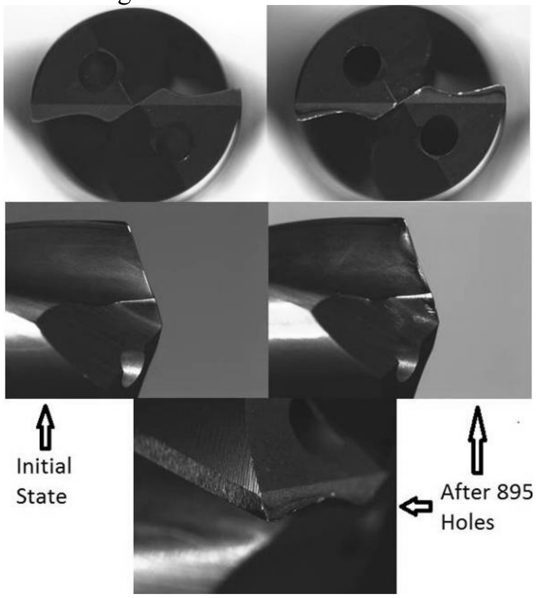


Fig.2. Evolution of wear

The next step in this experiment is to evaluate the cutting edge with the GFM MicroCAD microscope, with it we have been able to measure and compare the real life tool with the theoretical values written on the tool drawing. For this type of drills the production is very complex and with the many geometrical shapes at the tip of the drill it is even harder. This is why it is absolutely necessary to verify and know the exact geometry of the drilling tool. In our case the geometry and profile of the tool are within the tolerances of the drawing, seen also in the Fig.3 and Fig.4.

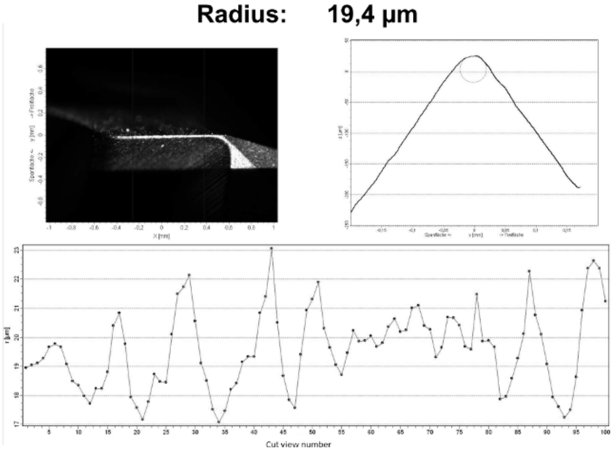


Fig.3. Chisel edge corner radius

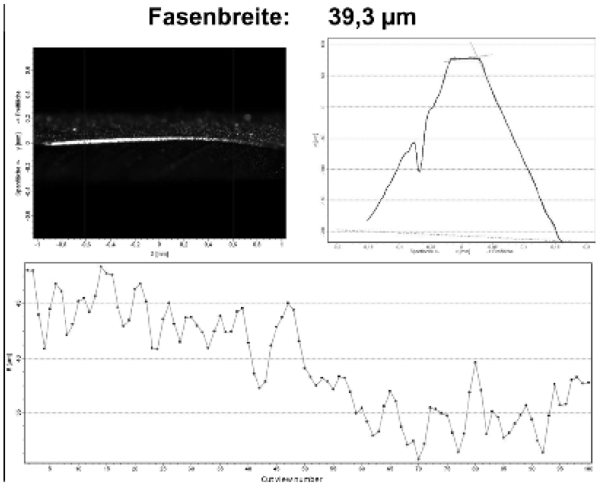


Fig.4. Cutting lip radius

After measuring the initial state of the cutting edge and cutting geometry the experiment begins with the first holes. The first set of 30 holes is considers to be the most critical of them all because any of the production defects, such as solid carbide defects or fissures in the tool body but also defects of tool geometry will conclude into a total tool break-off. Being thru with the critical step the tool is once again measured and photographed. From this point on the measurement will be done every 150 holes, taking into consideration also the adhesion of material on the cutting edge. The atomic REM-microscope comes in this step very handy, due to the very powerful zooming on the cutting edge.

In Fig.5 you can see the evolution of the cutting edge corner wear and also the material adhesion witch eventually concludes into a break-off of the cutting corner. With this analysis it is very easy to observe the linear evolution of the wear, and also where the most critical point of the drilling geometry is. It provides vital information about the material adhesion and also the state of the coating material witch is to be seen in the Fig.5 as very durable and with almost no chemical interaction with the cutting material. One of the biggest advantages in using a REM microscope is the detailed level of the pictures, offering a very early possibility to detect any fissures in the cutting zone.

The last test in this experiment is to determine the coating thickness and layer arrangement with the Kalomax spherical cap grinder.

A steel ball lies on a revolving shaft and also on the angular positioned sample. A small spherical cap is ground through the layer on the sample into the base material by means of the ball and a little abrasive slurry. On plane samples, the cap is circular.

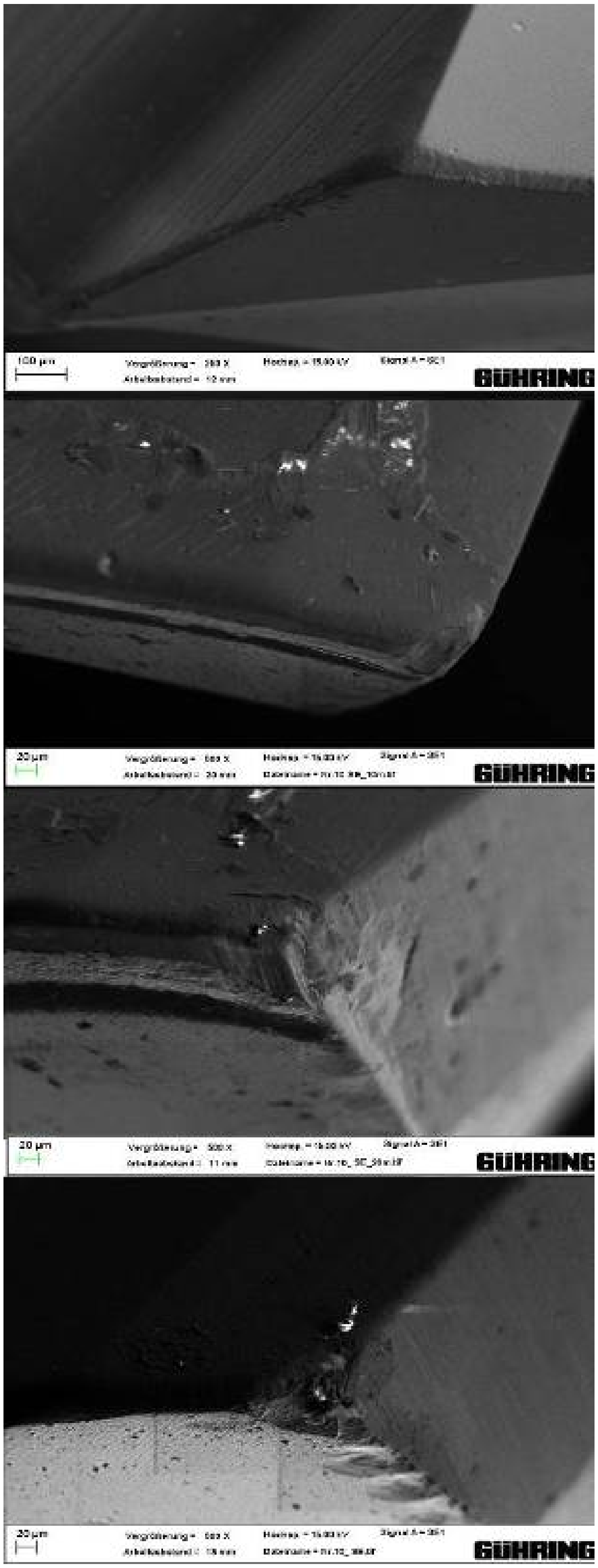
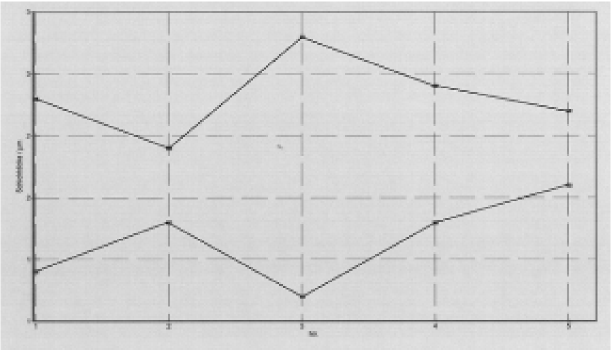


Fig. 5. REM-Cutting corner wear

The layer thickness can be calculated from the difference of the cap diameter at the surface of the sample and the diameter of the boundary between layer and base material. These diameters can be measured with a microscope. The diameter of the grinding ball, which goes into the calculation, is known. This purely geometrical method for determination of layer thickness can be extended to layer systems, Fig.6 and Fig.7.



Tool No.	1	2	3	4	5
d/µm	2,3	1,9	2,8	2,4	2,2
d/µm	0,9	1,3	0,7	1,3	1,6
Total	3,2	3,2	3,5	3,7	3,8

Fig .6 Coating thickens

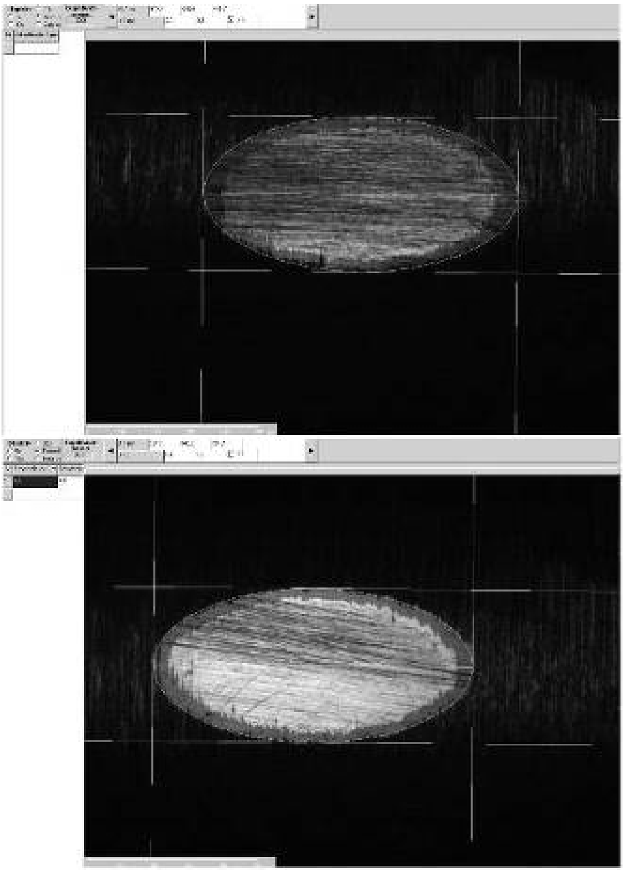


Fig.7 Coating layer system

3. CONCLUSIONS

In the production planning the most important feature and property for a boring tool is the predictivity of the wear machanism. Knowing at each given hole the state of the cutting edge and other geometrical feature gives the tool the posibility to have a stable and linear tool weare. This is possible after performin the steps taken in this experiment. Each tool dimension and tool geometry has its own wear mechanism, seen also in the Fig.8, where the different edge radius, coating thickness and cutting corner radius puts the tool on a different wear curve.

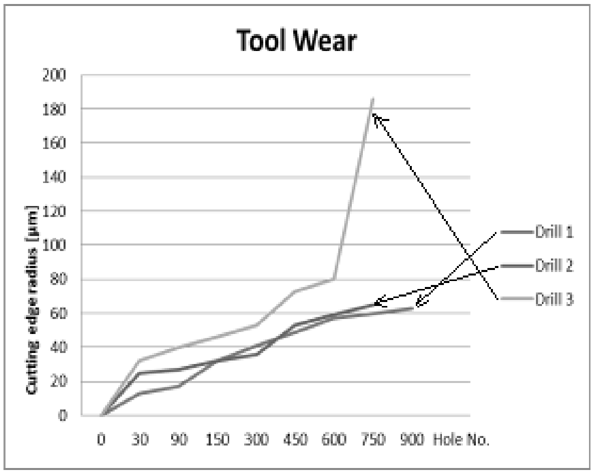


Fig. 8. Tool wear curve

Having these results for each tool diameter/femily we can assute a minimum number of holes with one tool without having the risk of a unsecure process. It is easy to forsee the hole quality and tool wear with just a few number of tests performed on a lot of 3-5 tools. The cutting psrsmeters can be ajusted on the process requirements, and the cutting quality is also determined to be within a known interval. Ofcourse ther is also the other aspect of material problem in the tool core, but in taking these measures, tests, the process becomes more secure.

Acknowledgments

This paper was supported by the Research and Development Center at the Gühring oHG Tool Company, Albstadt Germany.

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Received: April 30, 2013 / Accepted: June 5, 2013 / Paper available online: June 10, 2013 © International Journal of Modern Manufacturing Technologies.