CUTTING EDGE OPTIMIZATION AND PERFORMANCE VALIDATION FOR SOLID CARBIDE TWISTED DRILLS

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ABSTRACT: This paper aims to establish the effects of the wet sand-blasting optimization process on twisted solid carbide drills and their assessment over other types of drills found on the open market for this type of machining. The abrasive effects of wet sand-blasting on the cutting edge and also upon the surface and micro-geometry of the tool body are to be taken into consideration. This process is one of the most common used in the solid carbide insert fabrication, being implemented in various ways, but the application in optimization processes for twisted drills is still undeveloped, due to the difficulties it brings when trying to provide a defined and reproducible optimized geometry for drill tips. The micro geometrical optimization of the cutting edge is concentrated on two important parameters, edge radius and K factor alignment, both of these having a critical role upon tool life and process cutting parameters. In the end the assessment of our optimization technique will be to verify by means of machining conditions the performance of our drills by comparing the to other drills found on the current tool market.
KEY WORDS: Drill, cutting edge, optimization, sand blasting, solid carbide.

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1 INTRODUCTION

In the past decades the machining conditions have evolved to a very high level, putting immense pressure on the tool designers to find new solutions for high performance cutting conditions. So it was obvious that the this process has to be attacked from two directions, one in designing new tool geometries for the cutting edge and the second is to optimize the once already available. This is why the studying of cutting edge micro-geometry and its optimization processes is still a very open field to studying. From this wide field the focus on rounded cutting edges is a very new and unstudied domain, only for the past decade the attention focused more in this direction. So in Figure 1 you can see the level of publications per year since 1968. From the beginnings until the year 2002 the studying of micro geometric modifications made to the cutting edge was very difficult due to a lack of performant and affordable microscopes, but in the past decade this things have changed allowing us to measure and confirm certain geometry's, making it this way reproducible.

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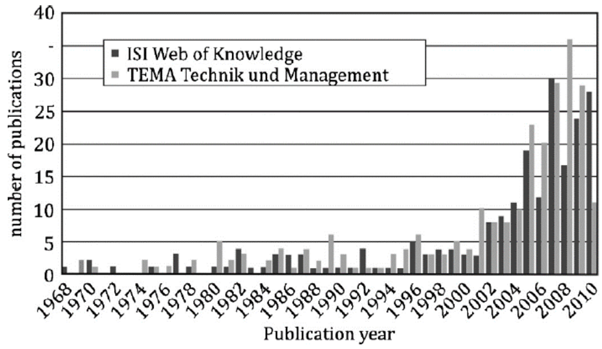

Figure 1 Publications related to rounded edge geometries [1]

The success of drill performance in cutting applications has to date largely been based on significant advances in reproducible and accurate tool production processes, modifications of drill point geometry, and optimization of the rake angle distributions along the drill lips and the chisel edge. The preparation of cutting edge radii was mainly done by manual processes at that early beginning and is still a production state in many companies, although the brushing and sand blasting applications have developed quite a lot in the past years. The development of new more accurate measurement has led to an increase in the application of prepared cutting edges [1].

In every cutting process the cutting edge suffers under the thermal and mechanical impact provided by the chip formation process, therefore the optimization of the chip flow over the cutting edge and into the flute. The more defined the cutting edge is the less damaging the effects of cutting are, and also the quality of the machined surface is drastically affected by the cutting edge geometry.

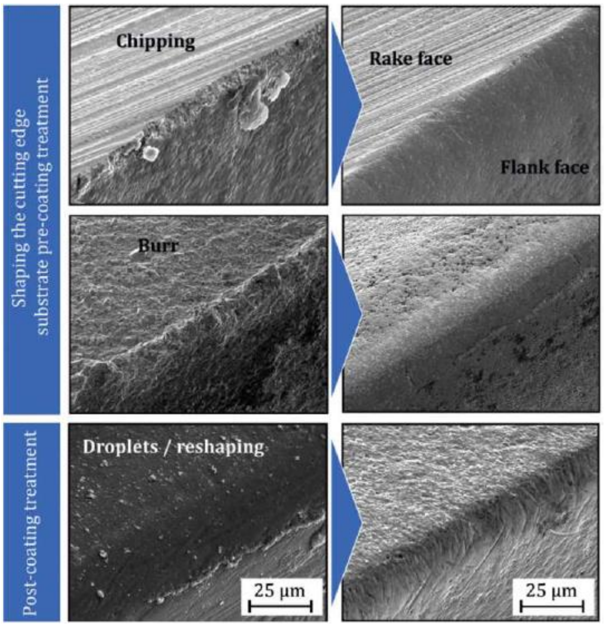

Figure 2 Main effects of the cutting edge preparation [1].

The demands of modern production are high productivity and high process reliability. One place these demands can be met is in cutting edge preparation [1].

In Fig.2 the main effects of a cutting edge preparation are summarized. In addition to the reduction of the chipping after grinding and burrs after sintering the preparation can be used as a post-coating treatment. Before the coating process, cutting edge preparation influences the surface topography and the residual stresses in the substrate. Regardless of the cutting procedure, the advantages of cutting edge preparation are scientifically proven by many investigations [1, 2, 3].

The conclusion of many researched papers shot that a good cutting edge optimization lead to a more secure process and therefore to better cutting performance, all this thanks to an enhanced cutting edge stability [1]. This stability is given by the geometrically defined cutting edge on with the cutting forces are equally distributed. But the positive effects of cutting edge optimization doesn't end here, there has been reported a raise in adhesion strength of the coating material on the tool surface, facilitated by the smoother surface of the cutting edge. The prefect cutting edge form and geometry is related to the machining process and workpiece material, also the process conditions are to be taken into consideration [1, 4].

Fig.3 shows the impact that the cutting edge optimization processes has on the drill tip, the images are taken after the grinding and wet sand-blasting processes. This is why our current study focuses on the wet sand-blasting procedure due to the more rounded and smooth edge, which translates into a more steady drilling process, the forces are being equally distributed onto the entire cutting edge.

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.

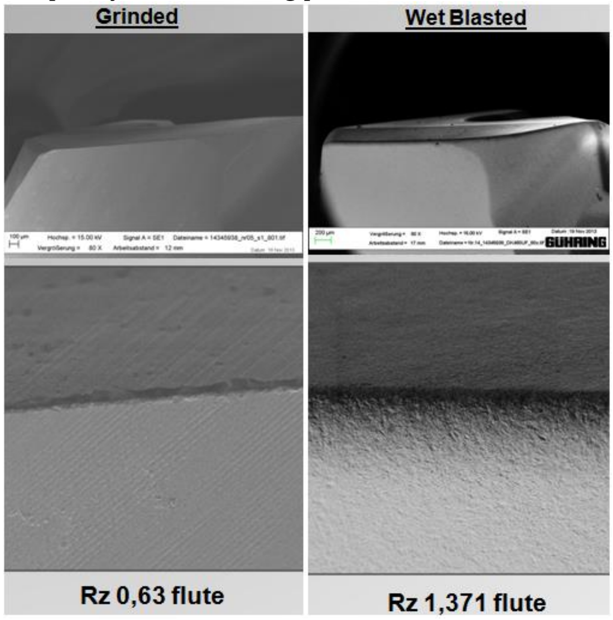

Figure 3 Cutting edge grinded and wet sand-blasted.

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. Sharp cutting edges are usually considered detrimental to cutting processes because of their low stability and low impact resistance [5] (Figure 4). Conversely, Yen et al. [6] 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.

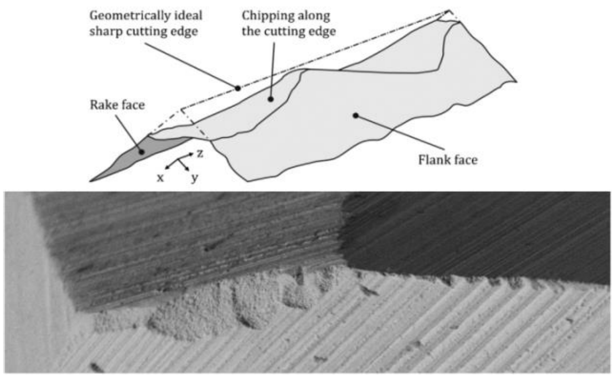

Figure 4 Cutting edge defects – after grinding.

Cutting edge geometry is characterized by microgeometry and edge topography. The edge topography describes the surface structure of the cutting edge. It is highly impacted by microscopic damage like burrs or chipping [1]. The most common verification process for describing the cutting edge geometry without having to use an electron microscope is to determine the roughness of the surface, the bigger the roughness is the bigger the chipping effect and deviation from the geometrically ideal edge is. The schematic illustration of a chipped cutting edge after the grinding process is depicted in Fig.4. [1].

In order to define a geometrical shape of the cutting edge the different types of shape definitions have to be studied. In essence there are only two kinds of geometrical shapes that can be achieved without much effort, with cost efficient processes. The first shape is characterized by a chamfer between the flank surface and rake surface, having the option to add one or more chamfers with different angle to the final cutting geometry, Fig.5 [1].

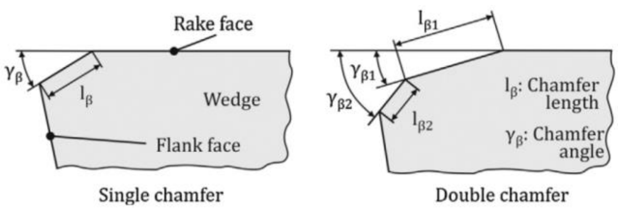

Figure 5 Cutting edge chamfer parameters.

Here the chamfer is the result of γβ, chamfer angle for each chamfer segment, and ιβ, chamfer length for each segment. Furthermore the chamfer is also categorized by the K-Factor, with describes the orientation of the chamfer on to the rake ore flank side, studies have shown that the ideal case is given when the orientation of the new edge is right in the middle K=1, so the cutting forces are equally distributed and there is an even wear. The second geometrical shape for the cutting edge is a round shape, a radius, which is a more complex shape which requires more parameters to be characterized [1].

To determine the cutting edge a constant circle is to be fitted into the intersection of the flank face and rake face, so several points need to be defined on the intersection by means of a measurement system. At least three of these measured points need to be determined in order to fit a circle on to the cutting edge, with the radius rβ.

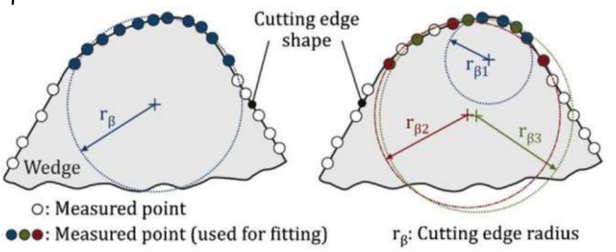

Figure 6 Inaccuracy when describing cutting edge geometry with one single radius [7].

In order to have an accurate result, it is advised to measure as many three-point combinations as possible and the arithmetic sum of all the rβ will be the final radius of the cutting edge, Fig.6. [7]. Due to the fact that measuring so many three-point combinations is very complicated, Denkena et al. [8] established another method, the form-factor method, also known as the K-Factor method.

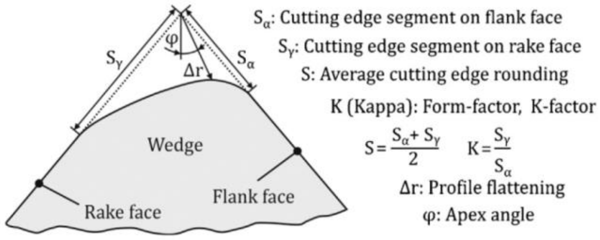

Figure 7 Form-factor methods for cutting edge characterization [8].

In Fig. 7 the form-factor method is described, Sα and Sγ are the cutting edge segments introduced to measure the distance between the separation point of the cutting edge rounding and the tool tip of an ideal sharp cutting edge at flank face and rake face, respectively. Based on these values, the average cutting edge rounding S specifies the dimension and the form-factor K (Kappa) specifies the orientation of the rounding at the cutting edge. In addition, profile flattening Δr and apex angle φ are used to characterize the tools bluntness by measuring the shortest distance and the shift between ideal sharp tool tip and actual shape of rounding [8].

2 TARGET DEFINITION

For the process to be truly efficient it needs to be both secure, reproducible and perhaps most important with the lowest economic impact. Having studies many different types of optimization processes, the one with the most advantages would be the wet sandblasting process. This cutting edge preparation process brings a few challenges to the equation, so order to obtain a perfect optimization there have to be some criteria fulfilled. The first criteria that needs to be fulfilled is a consistent parallel cutting edge (Figure 8), which can divide the cutting forces between the two edges of the drill. If one edge is slightly deformed the cutting force is unequal and the immediate result is uneven wear that might lead to breakage.

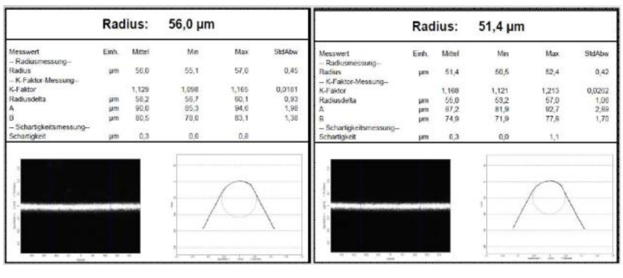

Figure 8 Geometry of both cutting edges.

The second criteria to be fulfilled are a good surface roughness on both cutting edges and on the surrounding surfaces. In this way the chip can easily glide over the edge into the flute without generating excessive frictions (Figure 9).

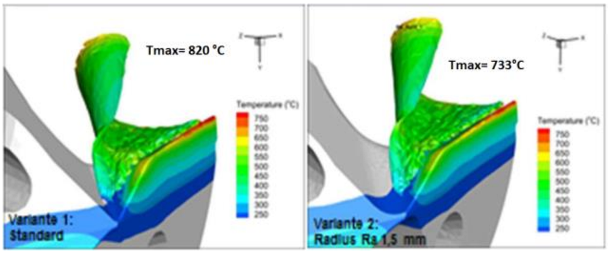

Figure 9 Heat generated by chip formation friction.

The third criteria to be taken into consideration are a good design and shape of the cutting edge (Figure 10). The meaning of this is that the geometry needs to be reproducible on a large scale, in production conditions, it is shore that under optimal labor conditions all the geometries and shaped of a cutting edge are easily reproducible but hate same is to be expected under normal mass production. So the design needs to be as simple as possible and also the parameters that are applied need to be as simple as possible.

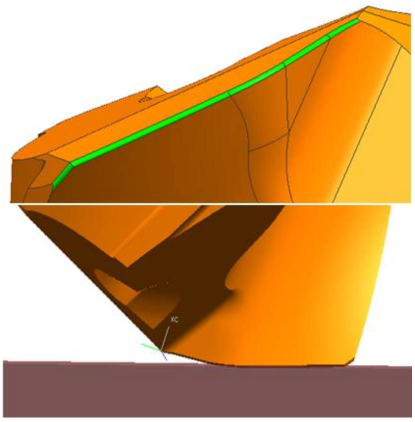

Figure 10 Design and shape of cutting edge

Beside the three criteria there are also another very important point to be focused on; this is to adapt the process parameters in such a way that the web thinning and flute geometry is not to be destroyed. When blasting with high pressure a mixture of abrasive particles and water the possibilities to focus the jet on to a small defined surface is very difficult, so it's almost impossible not to affect the geometry of the tool that isn't to be sanded. But through a combination of jet pressure, nozzle type and drill movement it is possible to minimize the impact upon this two geometries (Figure 11).

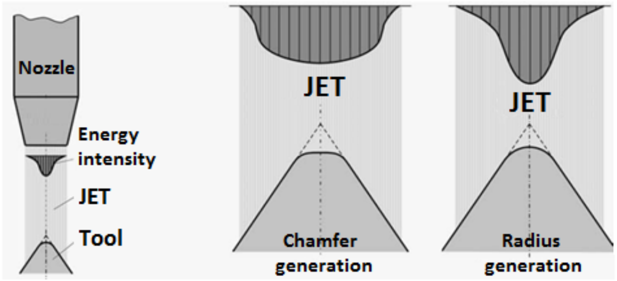

Figure 11 Influence of energy intensity of abrasive jet.

3 EXPERIMANTAL SETUP AND TESTING RESULTS

3.1 Sand-blasting setup and results

In the tool manufacturing industry, there is a large variety of applications for wet sand blasting, although very few for micro geometric cutting edge optimization, due to the low focalization possibilities of the abrasive jet. For the process to be truly efficient it needs to be both secure, reproducible and perhaps most important with the lowest economic impact. The wet sandblasting process is from the first point of view the most undefined, due to the excessive spreading of blasting mix, but after a more careful look the blasting jet can be very precise when combining the right parameters:

· Orientation
· Blasting speed
· Fluidity
· Focusing
· Pressure
· Nozzle diameter
· Blasting method (combination of rotation speed and modulation speed)

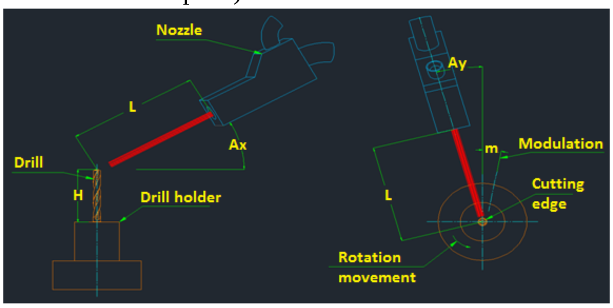

Figure 12. Geometric calibration of the nozzle.

Depending on the values of the nozzle calibration, different types of radius can be obtained for all sorts of drill diameters. From the calibration test we took for different drill diameters we found a connection between drill geometry and the adjusting values for the nozzle.

For example:

- L= 2xH – where L is the distance from the nozzle to the drill tip and H is the height from the holder to the drill tip.
- Ax= ¼ of the drill tip angle - ax being the angle between the cutting edge and nozzle axis
- Ay= ½ of Ax – where Ay is the angle between the nozzle axis and Z axis of the drill
- m= Ay – where m is the alternative revolving motion of the drill around its axis

After identifying all the nozzle adjustment parameters there remains to be demined the nozzle diameter and pressure of the blasting mixture. We've made tests with three different kinds of nozzles identifying the attributes for each diameter at two different pressures recommended by the manufacturer of the wet sand-blasting machine (Figure 13).

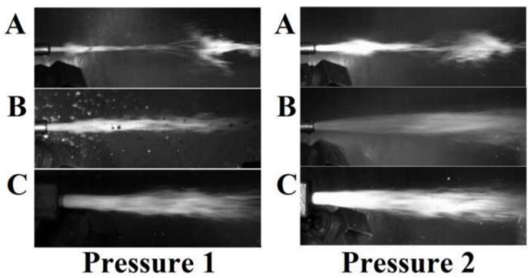

Figure 13 Nozzle – blasting mix pressure combination.

As mentioned before the blasting parameters need to be correlated between each other, in Fig. 8 is shown the different nozzle and pressure combinations, for example the combination between nozzle A and pressure 1 is very misfortunate, the jet is very erratic, having a very discontinuous pattern. This type of combination is to be avoided, due to the discontinuous jet the abrasive effect would be drastically influenced. The best results were obtained with the combination C-1 and C-2 where the dismantling effect over the solid carbide cutting edge is the most linear and focused.

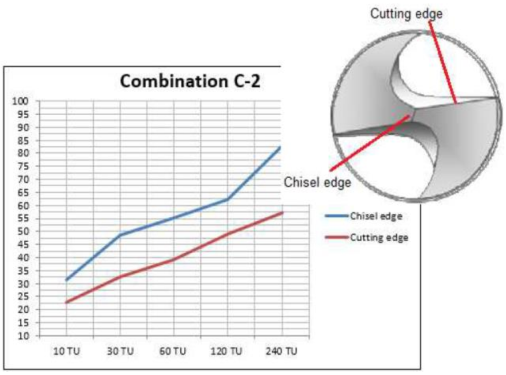

Figure 14 Time – Roundness chart.

The other 3 combinations of nozzle type and pressure obtained less satisfying results, so their use was not recommended.

Here we can trace the process in time units, each unit results in certain edge roundness, this way the cutting edge radius is easily predicted and measured.

Fig. 14 exemplifies exactly the predictability of the sand blasting process once all the parameters are established and known. But in order for this chart to be accurate all the parameters need to be constant, this is why any change the tool body material or different sand

/water combination will have a very big influence on the optimization process itself.

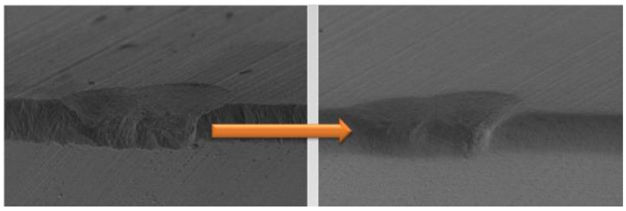

Figure 15 Benefits of wet sand-blasting.

The wet sandblasting process offers under carefully selected process parameters a series of advantages, direct advantage that concern the cutting edge and indirect advantages that focus on the process itself:

a) Edge benefits:
   - smooth round shape of the edge;
   - defect decrease (Figure 15), if defect appear during the grinding process, they are diminished through blasting;
   - surface receives a sanded, uniform appearance on which the coating material has a better adhesion;
   - all edges can be blasted in one step;
   - Linear evolution of edge radius over process execution time.

b) Process benefits:
   - cheap sanding equipment
   - quick process timing
   - simple grip of tool shaft in holder
   - very productive and economic due to cheap materials, long lasting as well
   - Easy programming due to just a few parameters that can be influenced at the machine, for

- example pressure, mixture, time, nozzle diameter, rotation speed of the drill.

After carefully setting up the wet sand-blasting machine, a number of 5 drills were sanded to identify the system behavior. A edge radius was to be created between 0,25-0,35 from the tool diameter, this value was selected due to the fact the this is the current standard for this type of drill.

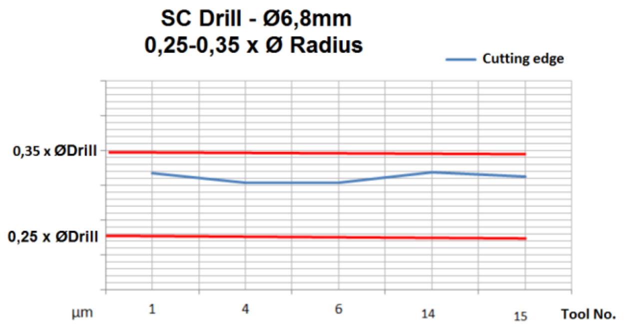

Figure 16 Edge radius for testing tools.

As you can see from Figure 16, the evolution of the radius for all five tools is very linear, having just a small deviation step one to another. This means that the sanding process is predictable and secure. The five drill ware sanded under production condition one after another, this way any unforeseen changes in the machine parameters are bypassed.

In the Fig. 17 the K-factor resemblance the same process stability, having a very linear character. The slightly higher value than the optimal one is due to the drill rotation movement during the blasting process. The drill movement represents the number of rotations that a drill must take during the blasting process, for example a large radius requires more rotations in order for the blasting jet to grind the equal amount on each cutting edge.

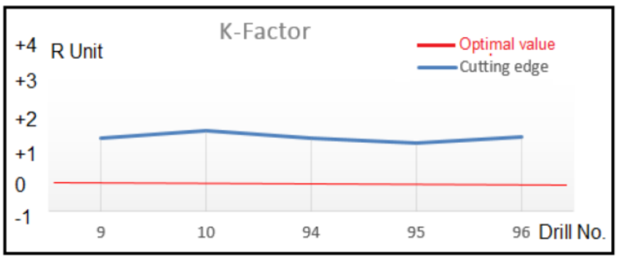

Figure 17 K-Factor measured values.

3.2 Testing procedure and results

After developing a secure manufacturing process and adjusting the whole parameters, the optimized and the market drills were put to the test in comparison with a reference drill from the production, the work piece material was manufacturing steel 42CrMo4. It can be seen that the tool lifetime of a drill with an optimized cutting edge is more than doubled while using identical machining parameters and conditions.

Table 1 Cutting parameters used for all testing procedures

Parameter	Unit	Value
Cutting speed (vc)	[m/min]	110
Feed (f)	[mm /rot]	0,2
RPM	[rot/min]	5149
Feed speed (vf)	[mm/min]	1030
Cutting depth (ap)	[mm]	34
Cooling system (internal / external / MQL)		Internal coolant
Pressure / Volume	[bar /l/min]	35 /~8 l/min

Before testing all the drills they were measures with an electronic microscope to identify the cutting edge geometry, in order to understand the behavior of each drill and the reasons why it's winning or failing.

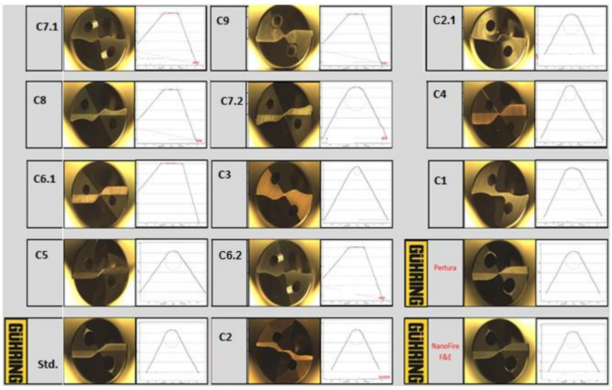

Figure 18 Edge type and measurement.

Figure 18 shows a very different approach when drilling 42CrMo4 from all the producers, each has an independent geometry, some of them are counting on an edge chamfer to do a good job, others have gone the same way as we did, with an edge radius. Due to confidentiality reasons an fair play we didn't divulge the value of the edge radius or chamfer, what we can say is that each drill is design for this particular material, having the same cutting parameters as do ours.

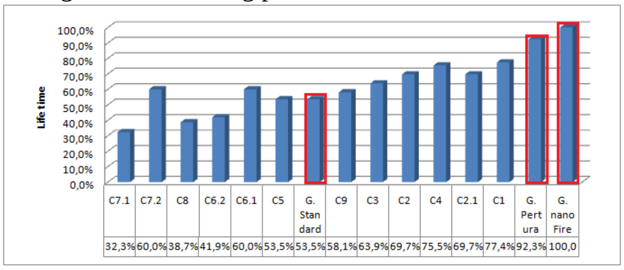

Figure 19 Drill testing – Life time in [%].

The values in the Fig. 19 were obtained by subjecting each of the 15 drills to a cutting process in which alloy steel 42CrMo4 was machined with standard cutting parameters Table 1.

As it can be seen in Figure 18, each of the competitors have different type of edge contour, but the best result in cutting performance were obtained by drill with a rounded edge, the value of the radius was making the difference between the best life time values. The Standard drill that came out of the production line have a brushed cutting edge, compared to this one's the optimized drills have almost the double lifetime. The final conclusion which can be drawn is, that by combining the necessary parameters for wet sand-blasting and in the right order, the result consists in an optimized micro geometrical cutting edge optimization witch shows a higher tool life and a more stable and secures cutting processes.

4 CONCLUSIONS

This paper has established the abrasive effects of wet sand-blasting on the cutting edge and also upon the surface and micro-geometry of the tool body. The optimum edge radius and K-Factor values have been determined and tested, resulting an increase in tool life of up to 30% compared to the current production standard. Also the cutting edge defects resulted from the production process have been reduced, thus having a direct consequence upon the higher tool life.

Acknowledgments

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5 REFERENCES

► [1]B. Denkena, D. Biermann, 2014, Manufacturing Technology 63: Cutting edge geometries, CIRP Annals 63, p.631–653

► [2] Bouzakis K-D, Michailidis N, Skordaris G, Bouzakis E, Biermann D, M'Saoubi R, 2012 - Cutting with Coated Tools: Coating Technologies, Characterization Methods and Performance Optimization, CIRP Annals 61, p.703–723

► [3] Denkena B, Breidenstein B, 2011 Cohesive Damage of PVD-coated Cutting Tools – A Result of the Residual Stress Distribution. 9th Int. Conf. ''THE A Coatings'', p.89–97, Thessaloniki, Greece

► [4]Bassett E, Köhler J, Denkena B., 2012 – On the Honed Cutting Edge and its Side Effects During Orthogonal Turning Operations of AISI1045 with Coated WC-CoInserts. CIRP Journal of Manufacturing Science and Technology 5, p.108–126

► [5] Karpat Y, Özel T., 2008 - Mechanics of high speed cutting with curvilinear edge tools. International Journal of Machine Tools and Manufacture, p.195–208

► [6] Yen Y-C, Jain A, Altan T. A, 2004, Finite element analysis of orthogonal machining using different Tool edge geometries. Journal of Materials Processing Technology, p.72–81

► [7] Wyen C-F, 2011 - Rounded Cutting Edges and Their Influence in Machining Titanium, (PhD-Thesis) ETH Zürich, Zürich

► [8] Denkena B, Reichstein M, Brodehl J, Leon Garcia L de, 2005 - Surface Preparation, Coating and Wear Performance of Geometrically Defined Cutting Edges. 8th CIRP Int. Workshop on Modeling of Machining Operations, May 10– 11, Chemnitz