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THE INFLUENCE OF MACROGEOMETRY AND CARBIDE ON THE DURABILITY OF HSC DRILLS

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Abstract: *The main purpose of this paper is to determine how the geometry and the base material of the "high speed drills" influence their durability and also the way in which wear occurs during the drilling process. Four different types of high speed drills (A, B, C and D) were tested, their base material being tungsten carbide, and the coating, TiCN (Titanium Carboitride). After analyzing the wear in the case of the four tested HSC drills, the optimal variant was chosen, taking into account its geometry and material, but also its durability. This study was developed in collaboration with Gühring, because all the experiments and analyzes were done within this company.*
Key words: *macrogeometry, carbide, durability, HSC drills.*

1. INTRODUCTION

The development of new machining processes has a big importance nowadays, because these take a lot of time and resources, but have a big importance for the technological field. Increasing the number of researches in this field give major challenges for industries, which always pursue quality, productivity, flexibility and compatibility with the environment. High Speed Cutting (HSC) processes have been developed a lot in the last years, because of their high speeds, which also lead to a high productivity and other advantages. The most important ones are low cutting forces, good surface finish and low level of vibrations during the cutting.

High Speed Drilling is a "component" of HSC, but this process refers only to the drilling operation at higher speeds than the conventional ones.

The tools used during this process are called "HSC drills", as the name of the operation also suggests. These drills are known for their good properties, like the better cutting rates, improved surface finish of the workpiece and good dimensional accuracy. They have different geometries, depending on the material that will be machined, their base material, coatings and the coolant used during the process. There are made new studies and researches regarding the best geometry for HSC drills, but it is influenced by some factors, the most important one being the base material, which also influences their durability.

In this paper, there will be done experiments and measurements for determining the best geometries of the HSC drills. Also, it will be taken into consideration their base material, carbide, which has very good properties and provides a longer tool life and faster cutting rates during the drilling process.

The main purpose of this work is to find a balance between the geometry of the drills, their base material, the material tested and their durability, for improving the HSC drilling process and its productivity.

There will be tested four different types of HSC drills, each of them having some particularities in their geometry and differences in the composition of their base material, which is carbide. Also, the drills will be tested on two sitting faces, to determine exactly how they transform during the HSC process and how their wear evolves. It will be analyzed the influence of their macrogeometry and how the layer of coating applied on them influences the durability of the high speed cutting process.

2. HIGH SPEED DRILLING OPERATION

High Speed Drilling is a new type of drilling, where the spindle speeds are higher than the regular ones and they permit penetration rates of three to ten times the conventional rate, taking into consideration the workpiece material.

The high speeds that appear in this process are influenced by the spindle coolant, which goes directly to the tip of the tool and extends the drill life at almost any speed. Also, the coolant is responsible for the evacuation of chips and for removing the heat in excess. [15]

At cutting speeds 5-10 times higher than the regular ones, the cutting temperatures will begin to get lower. This hypothesis was confirmed experimentally and this can be seen in the figure 2.1.

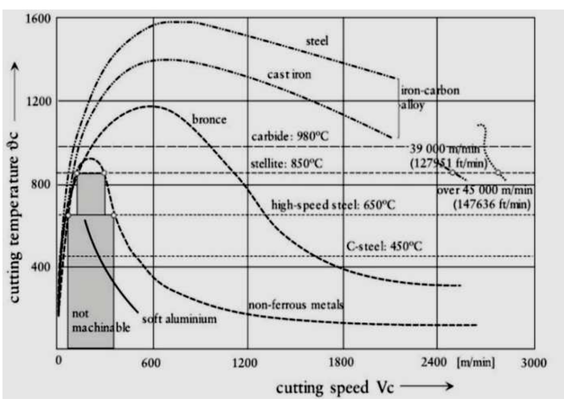

Fig. 2.1 Cutting temperature according to the cutting speed for different materials [3]

High speed cutting is performed if following requirements are generally met: small sections of chips, high speed of the main shaft, high linear work advances and small cutting depths. This process is a powerful processing method that combines high feed rates with the high cutting speeds, with special tools that obtain generation movements with specific features [3].

HSC drills are drilling tools which provide faster cutting rates, a good dimensional accuracy and improved surface finish. Because they have tight tolerances and short cycle times, they will also give a better quality to the manufactured part and optimum cost savings [17].

2.1 Researches in High Speed Drilling

During the years, were made a lot of studies regarding the High Speed Drilling using HSC drills and how this type of process influences the machinability and the productivity. For example, in Bauman Moscow State Technical University from Russia were made investigations for the limiting state of high speed drills. They discovered that the life of the drills is directly influenced by their state during machining, which must be related to the standards regarding precision and quality, machining costs and productivity. Also, the life of the drill is influenced by the wear of the active surfaces. When wear appears on the surface of the drill, it leads to exhaustion of the tool's competence. [2]

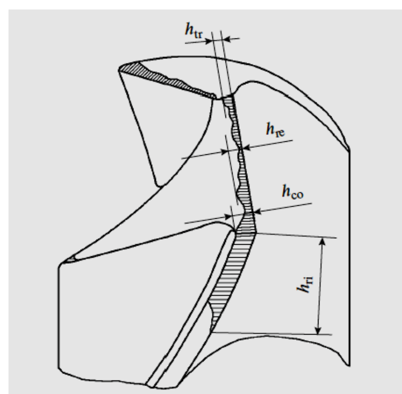

Fig. 2.2 Typical wear of a spiral bit [2]

In the figure 2.2 is represented the typical wear of the drill's cutting section. When holes are drilled in steel, all the parts of the drill's cutting section are worn:

- The primary surfaces, appearing the wear h_{re}
- The ribbon, affected by the wear h_{ri}
- The corner section, affected by the wear h_{co}
- The transverse edge, affected by the wear h_{tr}

The drill failure appears because of the wear of the rear surfaces and the tests show that the drilling tools keep their performance until failure, as a result of wear of the working elements. [2]

In this study is also investigated the quality of the holes obtained through drilling and what are the parameters that influence it, like feed rate or spindle rotational speed. It was discovered that the quality of the hole and the performance of the drill are better at lower feed rates and rotational speed. When higher cutting speeds appear, the tool wear appears also. [1]

Drilling experiments were done using drills made from different types of materials: high speed steel, tungsten carbide and tungsten carbide with physical vapor deposition and TiN coating. All the experiments have been done on a high speed CNC drilling machine, having three axis and it was programmed with Win CUT software, which uses standard G/M codes. Also, the spindle motor of the machine is 3,5 KW, having a spindle rotation speed up to 18000 rpm. [1]

2.2 The materials

The used materials during the experiments are **42CrMo4**, which is an alloyed steel, this being the tested material of the semi-finished parts and also **Carbide**, the material from which the drills are made.

The tested material – 42CrMo4 is used after it is quenched and tempered, this way obtaining a high intensity and hardenability

The base material of the tested drills – carbide is a material in which carbon is combined with a metallic or semimetallic element. Silicon or tungsten carbides are valued for their physical hardness, resistance to chemical attack at high temperatures and for their strength. The HSC drills are made from carbide, which is chosen for its good properties and because it provides faster cutting rates, longer tool life, better dimensional accuracy and also improves the surface finish. [20]

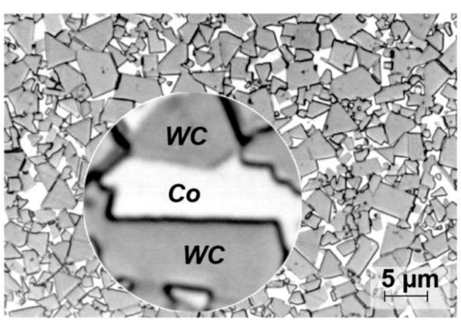

Fig. 2.3 The microstructure of a carbide [20]

In the figure 2.3 it can be seen that the tungsten carbide (WC), is surrounded by particles of Cobalt (Co) which have the role of binder for the hard metal grains.

Metal coatings are used in order to improve the physical properties of the top layers of tools, having a direct effect on tool durability and minimizing wear in the required areas.

3. THE EQUIPMENT

3.1 PG-2000 device

During this work, the device was used to track the wear evolution, by capturing images of the drills tested at different cutting intervals (Li), according to the Gühring protocol. Based on the catches, certain dimensions have been taken, to analyze the level of wear resulted from the drilling process (fig. 3.1).

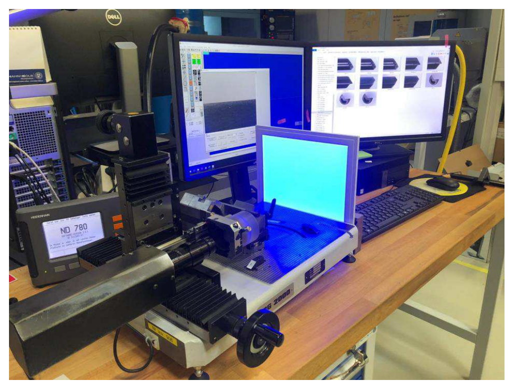
Fig. 3.1 PG-2000 measuring and checking device

3.2. Zeiss SEM (Scanning Electron Microscope) Sigma 300

The microgeometry of the drills was measured using the electrons emission microscope (fig. 3.2). The drills were checked and analyzed before and after the blasting process. After the polishing process, the drills were measured again and then subjected to the coating process. After this procedure, the microgeometry of the drills was again measured using the microscope.

Using the electrons emission microscope, the two main faces of the drills were analyzed, along with the cutting edges, the corners of the drills and the tips. In case of a drill, were photographed 10 images, 5 images with the main sitting face I and 5 images with the main sitting face II. [6]

The main components are:

1. Frame;
2. Test chamber;
3. Electronic optical column;
4. Monitors;
5. SEM control computer;
6. On/Off/Standby buttons. [2]

Fig. 3.2 Zeiss SEM Sigma 300 microscope [6]

For the analysis of the samples, this microscope uses several detectors, which can be used both individually and together.

3.3. Coating measuring device – Kalomax

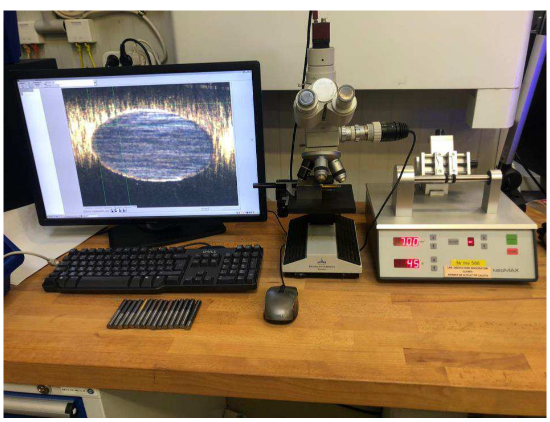
Fig. 3.3 Kalomax device

The Kalomax device (fig.3.3) is used together with an electronic microscope to measure the coating layer of the plastic deformation tap. The Kalomax apparatus is composed from a clamping device in which the tool is gripped at a certain angle and a shaft that rotates a sphere on which a diamond suspension is applied. During the rotational motion, the sphere contacts the tool surface for 60 seconds and the result is an elliptical trace left on the tool surface after grinding. This trace is analyzed with a normal electronic microscope, which is connected to a computer. [6]

3.4. Dimensional metrology and roughness measurement device

The InfiniteFocus device (fig. 3.4) is used for surface measurements and also for the measurement of surface roughness. Traceable measurement results can be achieved repeatedly with a vertical resolution of up to 10 nm. Its measurement principle is based on a vibration-isolating hardware which also allows the roughness measurement of heavy and large components. The axes of this device are equipped with accurate encoders which use precise stage movement. Also, InfiniteFocus is used for fully automatic measurement in production. [22]

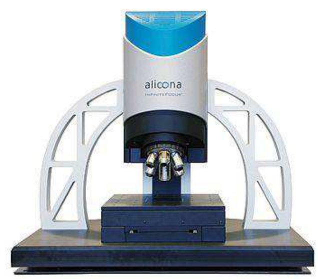

Fig. 3.4 InfiniteFocus device [22]

3.5. Fischerscope X-ray XDLM

This device is a benchtop X-ray fluorescence, which has a proportional counter, a programmable XY stage and adjustable measuring distance (fig. 3.5). It is used for automated measurements on a variety of coatings and components. [23]


Fig. 3.5 Fischerscope X-ray XDLM [23]

4. THE TESTED DRILLING TOOLS

4.1. Macrogeometry

At Gühring company were tested four different types of HSC drills, having a diameter of 6,8 mm, made of carbide and having different types of coatings, in order to determine their durability when machining 42CrMo4 material. They were also tested for determining the optimal geometry of the drills when using the High Speed Cutting process.

Due to confidentiality reasons, the name of the tested drills cannot be specified and during this paper, they were noted with A, B, C and D (fig. 4.1 – fig.4.4).

Fig. 4.1 Drill type A

Fig. 4.2 Drill type B

Fig. 4.3 Drill type C

Fig. 4.4 Drill type D

There appear also some differences between the HSC tested drills, mainly regarding their chip length, which has a smaller dimension at the drills C and D (51,31 and 51,49 mm) in comparison with the first ones, A and B (53,51 and 53,43 mm) and the diameter of the drilling channel, which is also smaller in the case of drills C and D (0,99 and 0,98 mm) in comparison with A and B (1,19 and 1,08 mm).

Also, the chisel edge angle is bigger in the case of drill B (59 mm) compared to the other ones, where it has a value of approximately 54 mm. The front and back core diameter is the biggest in case of the drill C, being followed by the drill D, A and B. Another important angle that appears at all the HSC drills is the point angle, which has the biggest value in the case of drill A (143, 57 mm), being followed by B (139,12 mm) and then C and D (around 137 mm).

4.2. The HSC drills analyzed on Infinite Focus Alicona device

The InfiniteFocus device was used for surface analysis of the HSC drills and also for the measurement of their surface roughness. The measurement results were achieved repeatedly with a vertical resolution of up to 10 nm.

From the results obtained and the captured images, it can be observed the margin of the drill and its type.

The single margin has only two guides, which have the role of giving to the drill a better stability and accuracy during the high speed process.

The double margin has four guides and these have the role of reducing bending and undulation and also to improve the stability and accuracy during the high speed process, but their disadvantage is the fact that they create more friction.

Fig. 4.5 Drill type A

Fig. 4.6 Drill type B – first view

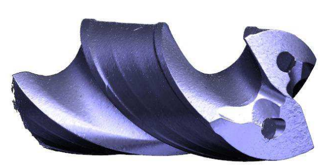

Fig. 4.7 Drill type C – first view

Fig. 4.8 Drill type D – first view

From all the measures, all the HSC tested drills (fig.4.5 – fig.4.8) have a diameter of approximately 6,8 mm, an overall length of approximately 92 mm and their shaft diameter has a dimension of 7,9 mm.

5. THE EXPERIMENTAL RESULTS

The parameters during high speed drilling operation are the following:

- cutting speed, vc= 200 [m/min];
- feed, f=0,2 [mm/rev];
- penetration rate, vf=1872 [mm/min];
- spindle speed, n=9362 [rpm];
- depth of cut, ap=34 [mm];
- pressure of the emulsion, p=40 bar.

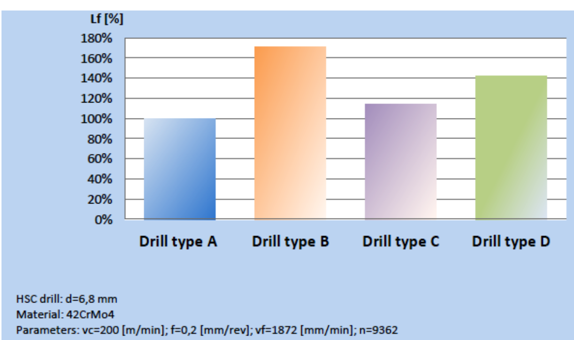

Fig. 5.1 The durability diagram

The durability diagram, presented in the figure 5.1, represents the durability of all the four tested HSC drills and what length (Lf), expressed in percentage, they can drill until the catastrophic wear occurs.

Firstly, it was tested just the drill type A, two drills of this type being analyzed and the average between their drilled length being 100%. The process of high speed drilling was stopped at a length of 100% because of the catastrophic wear. Then, it was tested the drill type B, four drills of this type being analyzed and the average between their drilled length being 171,4%. In the case of drill type C were analyzed two drills and the average length is 114,2% and in the case of drill type D the average is 142%.

After all the analysis done during this research, it can be observed that all the four HSC drills (A, B, C and D) have a high durability and they perform well during the high speed drilling process. The main purpose of this work was to determine how the macrogeometry and the base material (carbide) influence the durability of the HSC drills. It was achieved, because in all the four cases it can be observed how the wear appears on the drills based on their macrogeometry and also because of the material from which they are made.

All the analyzed HSC drill have a diameter of 6,8 mm and a length of 92 mm and their base material is carbide, which has different chemical and mechanical properties from case to case.

Also, the coating layer used for all the drills is TiCN (Titanium Carbonitride), this having the role of protecting the surface of the HSC drills and giving them a higher durability. The thickness of the coating layer used is also the biggest in the case of drill type B (3,3 μm), which leads to an improved drill life.

The tests were done using a cutting speed (v_c) of 200 [m/min] and the holes made have a length of 5xd, which is 34 [mm]. Also, the spindle speed was 9362 [rpm] and the pressure of the emulsion, 40 [bar]. All the drilling lengths obtained after the analyses, were related to the drill type A, which drilling length represents 100%. In all the cases, two main faces of each drill were analyzed, along with the cutting edges, the corners of the drills and the tips. To observe better how the wear evolves during the high speed process were captured images, using the microscope, with the new drill and then with the drill after a specific drilled length.

In the case of drill type A, the maximum drilled length is 100%, the tests being stopped because of the catastrophic wear that appears on the surface of the HSC drill. The wear appears, mostly, at the corner of the drill, and in this case, it breaks a little bit, the process being stopped because of this.

In the case of drill type B were obtained the best results, the maximum drilled length being

171,4%, having a durability much bigger than the first tested drill. The corner of the drill is affected the most, this being broken, because of the high peripheral speed of the HSC drill. Also, because of the fact that this is the most resistant drill, its drilling length is also the longest, so the wear starts to appear more on the surface of the drill, this leading to a major corner break.

Also, the drills type C and D have some similar results, their drilling lengths being 114,2 % and 142%. All the analyses were done on the two main sitting faces and it was observed how the wear evolves during the process. For these two drills, the corner didn't break, but the wear was the biggest also in this area. Their durability was smaller than that of drill type B, but higher than the first tested drill, the drill type D being the second best variant of HSC drill.

For a better understanding of how the wear appears in the case of a high speed drill it was done a comparison with a conventional drill, which uses a cutting speed of 100 [m/min]. All the cutting parameters are the same as for the HSC drill, the only difference being the cutting speed.

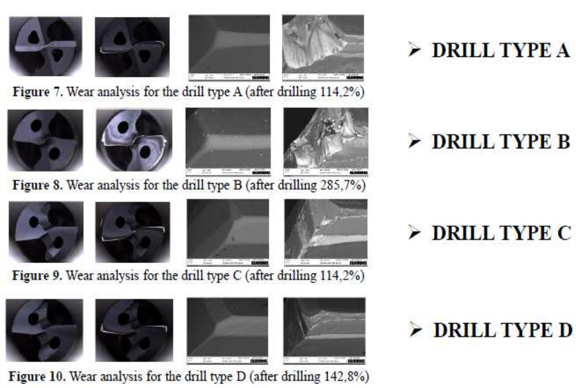

Fig. 5.2 Wear analysis

The cutting edges are more affected by the wear in the case of the conventional process and there exists a big difference between the drills geometry after a length of 171,4%, the best results being in the case of the HSC process. Because of the higher cutting speeds, the energy and power consumed during the process decrease, this leading also to a higher productivity and lower costs.

6. CONCLUSIONS AND PERSONAL CONTRIBUTIONS

There were realized analyses for 4 different types of HSC drills in order to determine their durability taking into consideration their geometry and base material;

The experiments and analyses were done on Zeiss SEM Sigma 300 microscope and PG-2000 device, to see how the wear evolves on the surface of the drills and using Kalomax device it was measured the thickness of the coating layer. Also, for measuring and analysis of the drills were used the devices Infinite Focus Alicona and Fischerscope X-ray XDLM;

It was analyzed the composition of the base material (carbide) and of the tested material (42CrMo4) and all the drills were measured, their diameter being 6,8 mm, which is the most common type of drill, used in a lot of applications;

The analyzed drills were compared, taking into account their geometry and material, and it was seen that the maximum durability was achieved in the case of drill type B, which has the biggest content of Cobalt, the thickest coating layer and a single margin, which has the role to improve the stability and accuracy during high speed drilling.

For a better understanding of how the wear appears in the case of a high speed drill it was done a comparison with a conventional drill, which uses a cutting speed of 100 [m/min]. All the cutting parameters are the same as for the HSC drill, the only difference being the cutting speed.

It was seen that the wear appears mostly at the corner of the HSC drills and as a future perspective is to improve the corner geometry in order to increase the durability.

In conclusion, after all the analysis done during this paper, it was determined how the macrogeometry and carbide influence the durability of the HSC drills. It is known that there are a lot of factors that influence the wear that appears during the process, but the most important one is the geometry of the tool. It was determined the best variant of drill (drill type B), which has a good balance between its base material and geometry and it was identified that the biggest problem, in all the cases, is the geometry at the corner. The most important future perspective after all the analysis done is to improve the geometry of the corner of the drills, because this way, it could be achieved a higher durability.

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INFLUENȚA MACROGEOMETRIEI ȘI A CARBURII ASUPRA DURABILITĂȚII BURGHIELOR HSC

Rezumat: Scopul principal al acestei lucrări este de a determina modul în care geometria și materialul de bază al „burghielor de mare viteză” influențează durabilitatea acestora și, de asemenea, modul în care se produce uzura în timpul procesului de burghiere. Au fost testate patru tipuri diferite de burghie de mare viteză (A, B, C și D), materialul lor de bază fiind carbură de wolfram, iar acoperirea, TiCN (carbonitrură de titan). După analiza uzurii în cazul celor patru burghie HSC testate, s-a ales varianta optimă, ținând cont de geometrie și material, dar și de durabilitatea sa. Acest studiu a fost dezvoltat în colaborare cu firma Gühring, deoarece toate experimentele și analizele au fost făcute în cadrul acestei companii.

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