



24th COBEM - 2017



24th ABCM International Congress of Mechanical Engineering
December 3-8, 2017, Curitiba, PR, Brazil

COBEM-2017-5919

ANALYSIS OF THE INFLUENCE OF CUTTING EDGE PREPARATION IN GUN DRILL WEAR IN DEEP DRILLING OF AISI 4144M

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Abstract. *Methods of cutting edge preparation have been increasingly developed by the industry due to the provided benefits, like increasing tool life and consequently reducing costs. The technique of these methods is highly complex and there is relatively limited scientific data available about it. This paper evaluates the viability of using gun drills prepared through the automatic honing process of drag finishing, in which a machine is used for the cutting edge preparation, replacing the manual brushing process to prepare tools with rounded edges for deep drilling of SAE 4144M steel. Scanning electron microscope and EDS analysis were used to reveal the wear mechanisms. Local chemical composition of worn surfaces was detected by means of energy spectroscopy system (EDS). The results show that automatic honing process leads to a uniform cutting edge with a greater cutting edge radius when compared to the manual process. Gun drills prepared through the automatic honing process of drag finishing can achieve higher tool life due to the elimination of defects and irregularities of the cutting edge.*

Keywords: *drilling, gun drill, honing*

1. INTRODUCTION

Methods of cutting edge preparation have been increasingly developed by the industry due to the provided benefits, mainly expanding the tool's life and consequently reducing costs. The technique of these methods is highly complex and there is relatively limited scientific data available about it. Numerous experimental work and theoretical studies related to turning or milling have demonstrated that the cutting edge radius can influence several fundamental aspects of machining, such as shear forces, temperature, wear and tool life, chip formation and surface quality (Cheung *et al.*, 2008; Denkena *et al.*, 2011). However, experimental studies are very scarce in deep drilling.

Benefits related to the protection of the cutting edge achieved in different machining processes have been reported in previous works (Bierman *et al.*, 2008; Biermann *et al.*, 2012; Bouzakis *et al.*, 2000). Edge preparation has been made to avoid common defects from the sharpening process such as chipping, cracks and breakage in order mainly to improve the tool life by changing the micro-topography of cutting edge and also to adapt the surface of the cutting edge for a subsequent coating process of the tools (Cheung, 2008; Rech, 2006). The geometry of the edge preparation influences the thermomechanical aspects of the cutting process, such as shape of the deformation zone, temperature distribution in the cutting process, machining forces, chip formation and flow, superficial integrity of the workpiece and the tool's resistance to wear (Denkena *et al.*; 2011, Hosseni, 2012; Woon *et al.*, 2008; Heo, 2011). The influence of edge preparation on the machining surface quality, tool wear, cutting forces and temperatures has also been studied by other authors (Fang, 2005; Bouzakis *et al.*, 2003; Özel, 2005; Ranganath *et al.*, 2007).

SAE 4144M steel was specially developed for the automotive industry. One of its application is in the diesel fuel system components, especially for modern system generations that work with injection pressures up to 2,300 bar. Due to the high injection pressure, it is necessary to use a material with good high-pressure and wear resistance. In general, material used to manufacture injection holders are low alloy steels from the 41XX family. These steels are alloyed with Chrome (~1%) and Molybdenum (~0,2%) and achieve high resistance through heat treatment (Wosniak *et al.*, 2010).

This paper presents the results of investigations concerning the tool life of gun drills prepared through the automatic honing process of drag finishing, in which a machine is used for the cutting edge preparation, replacing the manual brushing process to prepare tools with rounded edges for deep drilling of SAE hardened steel 4144M.

2. MATERIALS AND METHODS

The workpieces used in this study were unit pump bodies designed to raise pressure in the diesel injection system. The material was a SAE 4144M forged, quenched and tempered (38HRc) steel, with a 100% martensitic structure. Table 1 presents its chemical composition measured by a spectrofotometer Spectrolab Analytical Instrument.

Table 1. Chemical composition (%) of SAE 4144M.

Steel	C	Si	Mn	Mo	Cu	Ni	Cr	P	S
AISI 4144M	0.44	0.24	0.95	0.25	0.22	0.17	1.26	0.02	0.02

Cemented carbide S20 grade gun drills, G-form with 2.5 mm diameter, 210 mm overall length were used to drill holes with 73.85 mm length (Fig. 1). Cutting edge preparation was made by using two different methods: manual brushing and automatic honing process. Diamond brushes assembled in a Kennametal equipment were used to perform manual honing. Automatic honing process was made in a drag finishing machine model DF-3 manufactured by OTEC. The cutting edge radius were measured by using a Jenoptik Hommel T8000 measuring instrument. The average cutting edge radius for the drills prepared by manual brushing and automatic honing process were respectively, 4.3 μm and 16.7 μm .

The experiments were carried out on a Retco Maschinenbau V377 machine-center. Ecocut 610B neat mineral oil (manufactured by Fuchs) was applied under 150 bar. The cutting speed was 55 m/min and the feed-rate was 150 mm/min. Scanning electron microscope (Carl Zeiss - MA 15) was used to reveal the wear mechanisms. Local chemical composition of worn surfaces was detected by means of energy spectroscopy system (EDS).

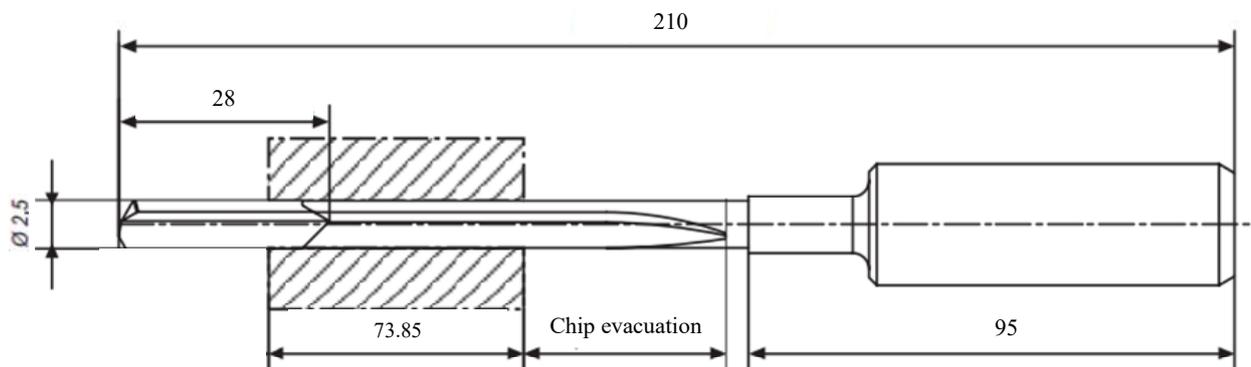


Figure 1. Gun drill dimensions.

3. RESULTS AND DISCUSSIONS

Figure 2 shows the sharp tool without any edge preparation, the drill prepared by manual brushing and the drill prepared by automatic honing process.

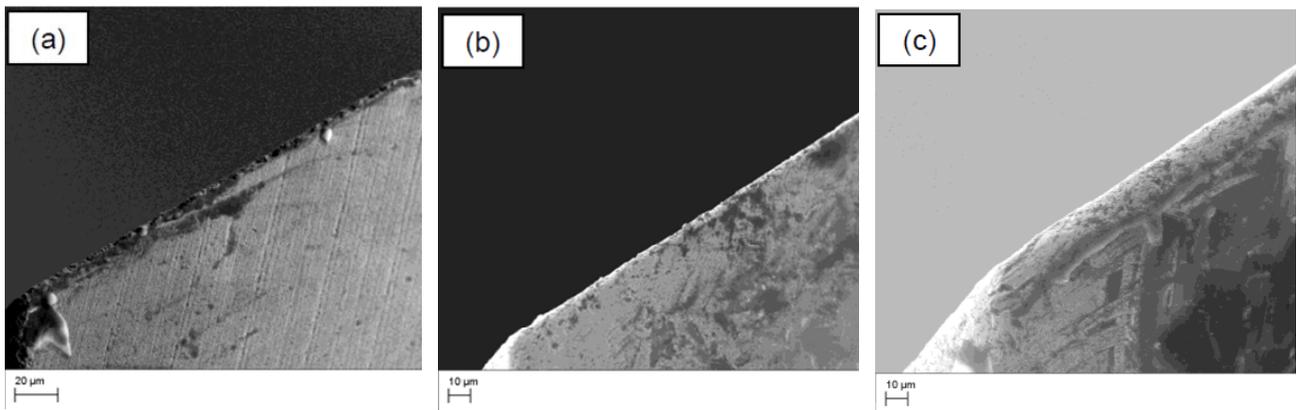


Figure 2. Sharp tool (a), Manual honed tool (b), Automatic honed tool (c).

The sharp tool presents micro fractures, burrs and surface defects. The cutting edge of the drill prepared by manual process is more uniform along its entire length when compared to the sharp drill. The manual honing resulted in a slight increase in the cutting edge radius. The automatic honing process resulted in a uniform cutting edge with a greater cutting edge radius.

Figure 3 shows the sharp tool after drilling 50 holes (3.7 m). There are noticeable irregularities along the cutting edge due to workpiece material adhesion and oxidation during the machining.

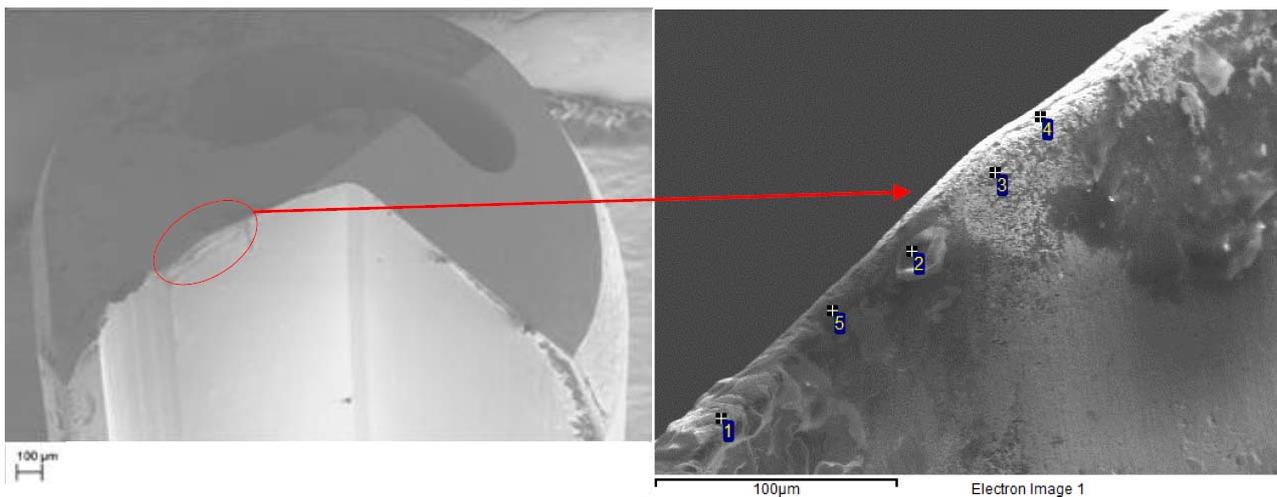


Figure 3. Sharp tool after drilling 50 holes (a), detailed view (b).

The analysis by EDS (Tab. 2) presents a high percentage of iron at region 1 close to the chip breaker, confirming that the workpiece material welded on the tool edge. The same occurs for region 4, but in smaller quantity. At region 2 there is a high percentage of carbon and oxygen, what can indicate oxidation or some type of contamination. At the other regions, there is presence of carbon and great concentration of tungsten what is expected for a cemented carbide tool.

Table 2. Local chemical analysis of regions indicated in Figure 3.

Element (mass %)	C	O	Co	W	Fe
Region 1	18.16	-	-	-	79.56
Region 2	61.22	31.63	-	2.88	0.28
Region 3	23.71	3.96	5.06	64.69	1.54
Region 4	16.82	3.04	4.89	64.11	10.25
Region 5	49.08	9.84	2.39	34.72	1.47

Figure 4 shows the manual honed tool after drilling 50 holes (3.7 m). There are some irregularities in the cutting edge, but with a better aspect when compared to the sharp tool.

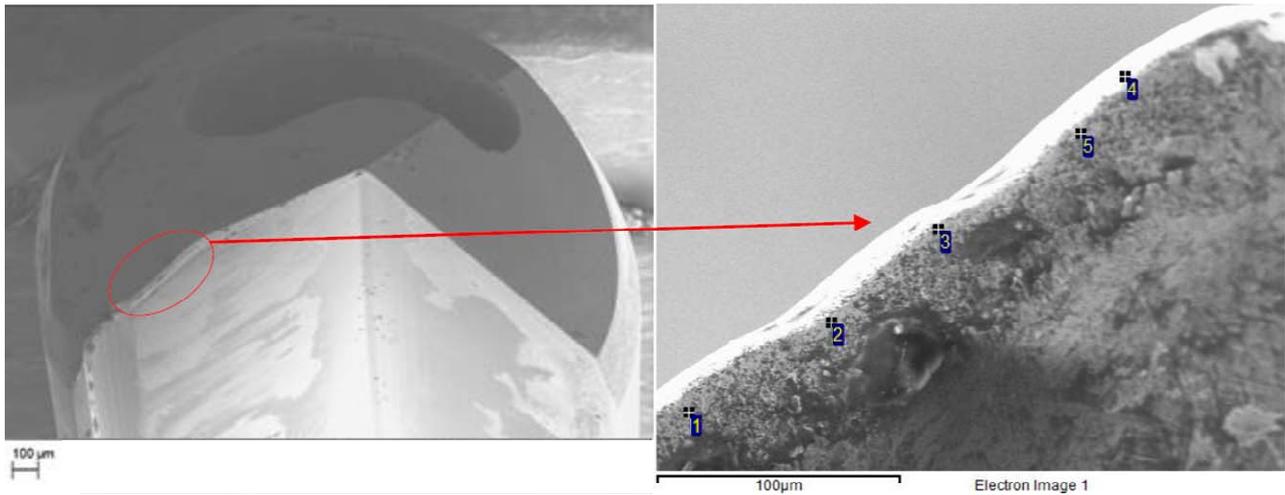


Figure 4. Manual honed tool after drilling 50 holes (a), detailed view (b).

The local chemical analysis (Tab. 3) shows the presence of iron in some regions, confirming that there was some adhesion of the workpiece material, but in smaller quantity compared to the sharp tool. It also shows a low percentage of oxygen, indicating that no significant oxidation occurred for this tool.

Table 3. Local chemical analysis of regions indicated in Figure 4.

Element (mass %)	C	O	Co	W	Fe
Region 1	9.38	1.23	25.11	53.55	9.06
Region 2	12.45	2.97	2.2	66.17	15.26
Region 3	10.03	1.14	7.59	80.4	0.85
Region 4	10.2	2.1	45.57	26.59	12.77
Region 5	56.85	2.17	13.85	72.78	3.79

Figure 5 shows the automatic honed tool after drilling 50 holes (3.7 m). There are no irregularities in the cutting edge and it still presents a uniform aspect along its entire length.

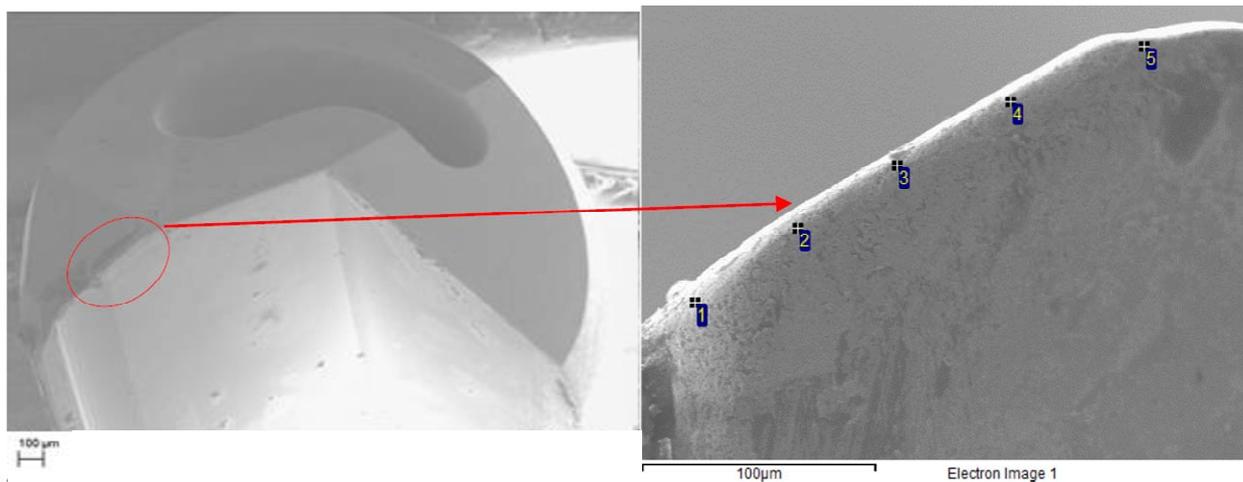


Figure 5. Automatic honed tool after drilling 50 holes (a), detailed view (b).

The analysis by EDS (Tab. 4) shows a higher percentage of iron in regions 1 and 5, which are close to the chip breaker and tool tip respectively. This confirms that there was a slight adhesion of the workpiece material on the tool edge, but in smaller amount when compared to the other tools. This tool presented no significant oxidation.

Table 4. Local chemical analysis of regions indicated in Figure 5.

Element (mass %)	C	O	Co	W	Fe
Region 1	13.48	1.55	14.41	52.09	17.23
Region 2	10.25	2.00	2.09	84.31	1.35
Region 3	24.05	4.29	13.74	51.04	3.78
Region 4	11.66	1.84	15.31	66.94	3.39
Region 5	18.67	3.17	7.87	35.93	24.74

Figure 6 shows the manual honed tool after drilling 250 holes (18.4 m). Wear occurs mainly on the rake face of the tool in the formation of a severe crater wear. The crater front distance (K_f) was approximately $8 \mu\text{m}$, indicating that the complete tool failure was imminent. Crater wear is usually related to diffusion or chemical wear mechanism. The tool also presented a relative small flank wear, as well as the formation of built-up-edge near the center of the drill.

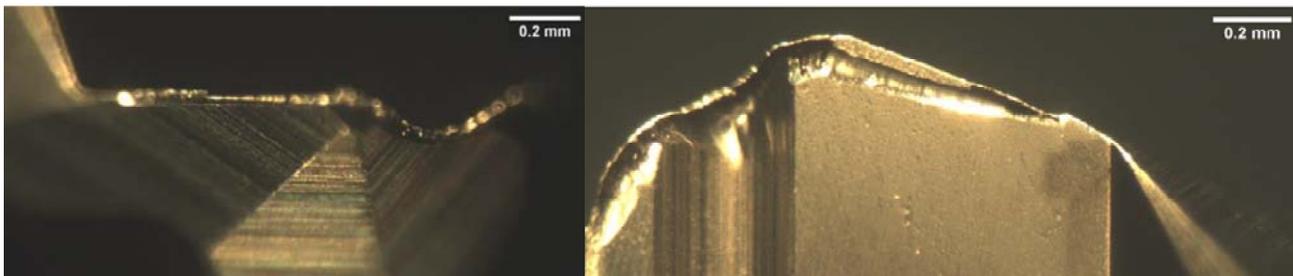


Figure 6. Manual honed tool after drilling 250 holes, flank (a), rake face (b).

Figure 7 shows the automatic honed tool after drilling 250 holes (18.4 m). The dominant wear was also crater wear. The crater front distance (K_f) was approximately $75 \mu\text{m}$, indicating that tool was not close to the end of its life. The tool presented only a slight flank wear and no built-up-edge formation. The honing process improves the surface roughness of the drill flank and face near to the cutting edge, and decreases the friction between tool and chip minimizing the adhesion mechanism.

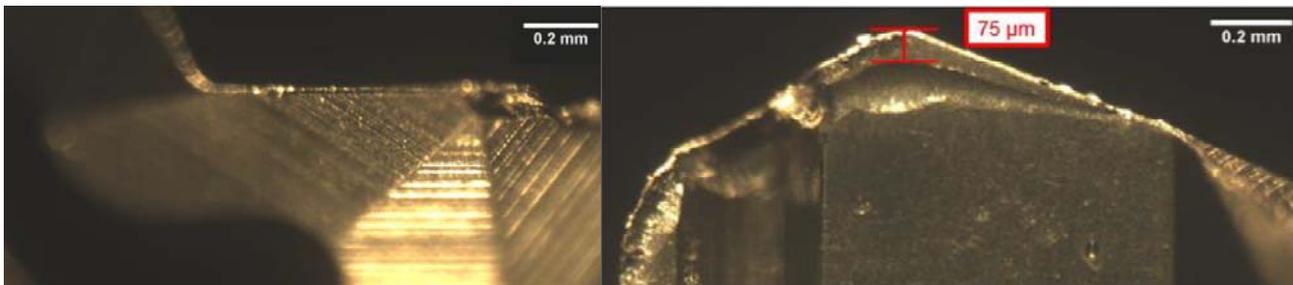


Figure 7. Automatic honed tool after drilling 250 holes, flank (a), rake face (b).

4. CONCLUSIONS

The sharp tool presents micro fractures, burrs and surface defects. The cutting edge of the drill prepared by manual process is more uniform along its entire length when compared to the sharp drill. The manual honing resulted in a slight increase in the cutting edge radius. The automatic honing process resulted in a uniform cutting edge with a greater cutting edge radius.

The worn tools presented adhesion of the workpiece material on the tool edge and wear occurred mainly on the rake face of the tool in the formation of crater wear. Gun drills prepared by the automatic honing process of drag finishing achieved higher tool life due to the elimination of defects and irregularities of the cutting edge.

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