The Eurasia Proceedings of Science, Technology,
Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2023

Volume 24, Pages 211-218

IConTech 2023: International Conference on Technology

Quenching: An Improvement Factor of HSS Twist Drill Tool-Life When Machining C22 Steel

Nacer Mokas
Badji Mokhtar Annaba University

Sabiha Tekili
Badji Mokhtar Annaba University

Youcef Khadri
Badji Mokhtar Annaba University

Abstract: The present work is a contribution in understanding the effect of quenching and tempering of C22 steel on the tool life of twist high speed steel (HSS) grade drill bits. Experimental investigation has been conducted on annealed and tempered steel according to the planning methodology (L8). The input parameters are cutting regime elements (cutting speed, feed rate and drill diameter) and the output parameter is the tool wear related to tool life. Beyond, the common behavior that suggests that when the feed rate on tool life increases the tool life increases, the most interesting phenomenon is the controversial effect of the cutting speed when drilling the steel in tempered condition. The objective of this contribution then to in make in evidence the benefit effect of quench hardening on drill tool life through exploratory chip microstructure observations.

Keywords: HSS drill beet, Cutting speed, Machinability, Toole live, Hardening.

Introduction

In the machining industry, a great interest is given to tool life despite the high technological efforts that have been spent in developing the cutting systems. For instance, drilling which remains a complex operation represents almost 30% of the machining processes that needs much attention in order to increase the drill bit life and improve the surface quality of the produced hole.

During the last decade, there have been a large number of investigations in understanding the drilling machinability and the behavior of drilling tools and hole surface (Biermann et al., 2011; Desargues et al., 2013; Lin, 2002; Khashaba et al., 2010; Bryukhanova, 1978) according to factors controlling the drilling cutting conditions such as the cutting drill material, the geometry of the drill, the workpiece material, the cutting speed, the feed rate, the depth of cut, the lubricating conditions, the rise of temperature in the cutting zone and so on. Most of the investigations relied on tool wear behavior and surface roughness through experimental studies including different design experiment methods. Results are usually expressed in terms of wear behavior and surface roughness as a function of the cutting conditions. The interpretation of these results are difficult to follow and usually complex to adapt in real industrial applications. Moreover, some very interesting results such as the benefit effect of increasing the cutting speed on drilling machinability and on wear behavior of drill bits have been reported without convincing evidences.

In soft or annealed materials, the common observations reveal that when increasing the cutting speed, the drill bit tool life decreases (Okay et al., 2013; Kayhan & Budak, 2009). This is supported by the recent contribution of Kaplan et al. (2016) on the effects of process parameters on acceleration amplitude in the drilling of cold

- Selection and peer-review under responsibility of the Organizing Committee of the Conference

work tool steels. They have reported that when drilling annealed AISI D2 and AISI D3 steels with respective hardness of 20HRC and 28 HRC, increasing the cutting speed from 5 m/min to 15 m/min resulted in a decrease of tool life of 50% to 80% because tool wear increases up to cause the increase of the cutting forces, chatter, and vibration. SEM images of tool wear patterns when drilling AISI D3 steel at different cutting speeds and at a feed rate of 0.06 mm/rev, showed flank wear, chisel edge wear, outer corner wear, and BUE in the cutting tool that result excessive wear progression.

In hard-to-machine materials, there is a great deal in comprehending the effect of cutting speed on the drill bit life. Xu et al. (2016), have shown in hard-to-cut materials as 1Cr18Ni9Ti stainless steel and ZGMn13 high-manganese steel that the flank wear can be reduced by appropriately increasing the cutting speed from 9.4 m/min to 23.5 m/min. Balaji et al. (2016) have contributed in optimizing the cutting parameters, cutting speed, feed rate, and helix angle when drilling AISI304 steel with carbide drill bits using design experiments according to L8 Tagushi orthogonal array with two levels. However, they should have pointed out that when increasing the cutting speed from 600 rpm to 800 rpm, the values of roughness decreased slightly resulting in a slight improvement of the tool life. Meena and El Mansori (2013) have proposed to assess the dry drilling machining of austempered ductile iron for different cutting parameters using physical vapour deposition-coated carbide tools in terms of specific cutting forces, tool wear mechanisms, chip morphology and machined surface roughness. They reported that there is a tendency towards the reduction in roughness values when the cutting speed increased from 30 to 60 m/min. Meanwhile the chip analysis revealed the segmentation of chips at higher cutting speed and the back surface analysis revealed the chip sticking and fold-type patterns at higher cutting speed suggesting that this can be explained by the increase of temperature in the cutting zone during drilling operation. Abouridouane et al. (2017) have conducted experimental and simulative investigations on the machinability of ferritic-pearlitic steels with different microstructures using twist drilling to predict four aspects of machinability thermomechanical, feed force, cutting torque and chip forming. Three graded steels 27MnCr5, C45 and C60 have shown different machinability and the best machinability is observed for the C45 grade steel. Adem et al. (2012) have evaluated the performance of cryogenically treated M35 high speed steel (HSS) twist drills in drilling of two stainless steels AISI 304 and 316 with respectively a hardness of 70 and 79 HRB, in terms of thrust force, surface roughness, tool wear, tool life, and chip formation. They have shown that treated drills expressed better tool life than untreated ones. Meanwhile it is important to note that regarding to the applied cutting speed, in both conditions of untreated and treated drill, the drill bit tool life was better when the cutting speed was 16 m/min, than that obtained at a cutting speed of 10m/min, suggesting that increasing the cutting speed resulted in increasing the drill bit life. Wang et al. (2013) have investigated the influence of the geometric structure of coated cemented carbide twist drills and various cutting parameters on the drill tool life when drilling ultrahigh-strength hardened steel42CrMo steel. When increasing the cutting speed from 80 m/s to 120 m/s, tool life decreased significantly in most drill bit geometry particularly at a feed rate of 0.14 mm/r; meanwhile when the feed rate increases to 0.18 mm/r the effect of cutting speed is greatly dependant on drill bit geometry. Zeilmann et al. (2012) have studied the Implications of the reduction of cutting fluid in drilling with carbide tools, AISI P20 steel AISI P20 steel hardened by heat treatment to obtain a final hardness of 36 to 39 HRC. They have reported that dry drilling presented better results comparing to those obtained by emulsion drilling tests. They have explained that the worst results for emulsion tests is attributed first to the presence of the cutting fluid that removed the positive effect of heat in the cutting zone, which facilitate the material shear and also to a high adhesion of material on the flank of the tools which led to microchipping and tool failure.

During the drilling process, a rapid plastic deformation of the workpiece and a friction along the drill-chip interface generates localized heat where temperature increases until sometimes reaching at the tool nose the fusion temperature at an instant time. The cutting temperature at the tool-chip interface is an important factor which directly affects workpiece surface integrity, tool wear, and hole diameter and cylindricity in the drilling process. However, the complex access to the cutting zone does not permit measurements of temperature. Meanwhile, temperature can be measured in regions close to the cutting zone. Bagci and Ozcelik (2006) have investigated the effects of sequential dry drilling operations on temperature changes in twist drill bit using two different workpiece materials, AISI 1040 steel and Al 7075-T651. Drill temperatures were measured by inserting standard thermocouples into the coolant and (oil) hole of TiN/TiAlN-coated carbide drills. They have reported that tool temperature increased with the number of drilled holes. Le Coz et al. (2017) have analyzed the local cutting edge geometry on temperature distribution and surface integrity when dry drilling of difficult to machine aeronautical alloys such as AA 7075 aluminum and Ti-6Al-4V titanium alloys. This has been achieved through experimental exploration of cutting temperature using a technique of dynamic thermocouple. They observed that the Temperature variation along the cutting edge depends on cutting speed, work material and local geometry and reported that temperature is much higher when drilling titanium Ti-6Al-4V than when drilling aluminum AA7075. Moreover, microstructural observations revealed that surface and subsurface are affected with grains elongation in cutting direction.

The present work is a contribution in improving steel drilling machinability and the drill bit lifetime through quench hardening of the workpiece. Drilling tests have been conducted on C 22 steel in annealed and tempered conditions using drill bits made of high speed steel (HSS). The input parameters are cutting regime elements (cutting speed, feed rate and drill diameter) and the output parameter is the tool wear related to tool life. Therefore, the objective of this contribution is to make in evidence of the benefit effect of quench hardening on drill tool life through exploratory chip microstructure observations.

Experimental Procedure

Workpiece Material and Preparation

C18 low carbon steel produced by the Algerian steel company of under the standard NF EN 10027-1 has been used. The chemical composition and mechanical properties are respectively given in Table 1 and Table 2.

Table 1. Chemical composition of C18 steel (NF EN 10027-1 standard) in weight %

Elements	C	Mn	Si	P	S	Cr	Mo	Ni	V	Cu
Composition	0.22	0.492	0.307	0.09	0.033	0.032	0.021	0.078	-	0.195

Table 2. Mechanical properties of C22 steel (NF EN 10027-1 standard)

Property	Hardness	Yield Strength	Tensile Strength	Strain
Unit	HRB	MPa	MPa	%
Mean value	67.8	210	590	10

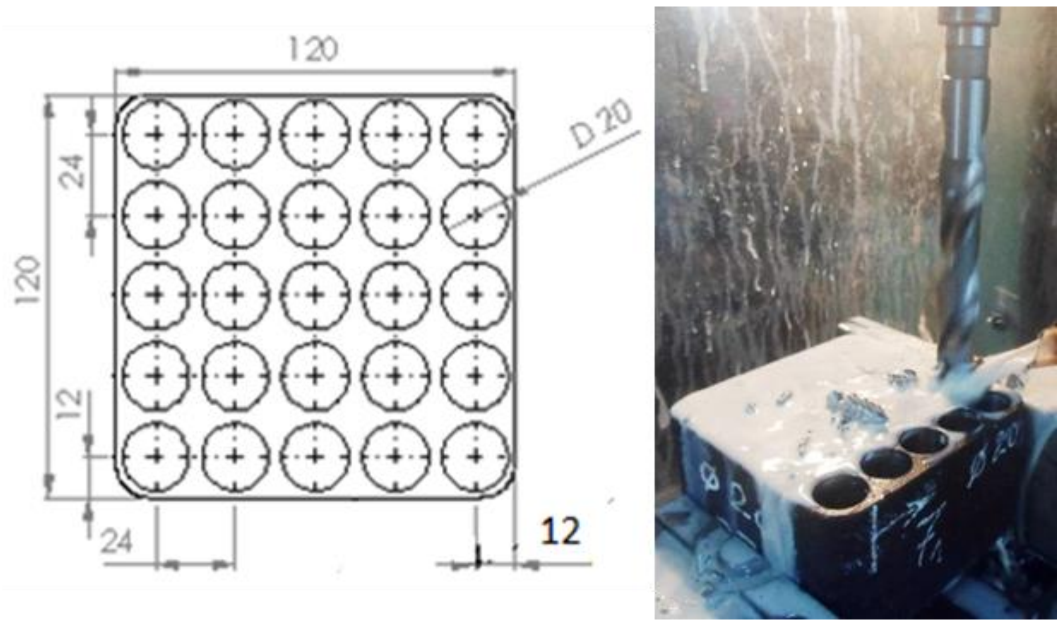


Figure 1. Specimen preparation hole repartition (25 holes for 20 mm diameter drill and 50 holes for 10 mm diameter drill) and photography of 20 mm hole blind drilling operation

Workpieces have been prepared from a square cross section parent bar of 120 x 120 mm² by cutting 60 mm length blanks on which intensive drilling operations will be carried out throughout the whole length. Figure 6 shows the cutting of the blanks and the repartition of the holes to be drilled on each blank.

Heat Treatment of the Blanks

Tool wear investigation has been conducted in two conditions: annealed and quenched states. The heat treatment has been achieved in a Nabertherm N 100 - N 2200/H furnace. Annealing has been conducted by heating the blanks at 900 °C for 1 hour and cooled them in the furnace. Austenisation of the blanks has been done at 850 °C for 35 min and water quench. Tempering at 240°C for 2 hours has followed the water quench. In addition, hardness tests have been carried out on a universal LEICA Wetzlar Vikers Indenter for both heat treatment conditions.

Results and Discussions

As expected the main observation is that when drilling annealed drill bits is generated rather than when drilling quenched and tempered workpiece. Regarding the cutting parameters, the best performance of wear resistance of twist drill bits giving a tool life Tmaxann of 456 min, corresponded to the combination of Vc = 11.15 m/min, f = 0.1 mm/rev and D = 20 mm when the workpiece is annealed. In the quenched and tempered condition of the workpiece, the performance dropped to a tool life Tmaxquen of 331 for a cutting speed of 22.30 mm/min, a feed rate of 0.1 mm/rev and a drill diameter of 20 mm. The respective rate of the beneficial heat treatment effect and cutting conditions is 1.38. The wear curves followed the conventional trend showing an initial wear zone, a steady wear zone and accelerated wear zone. The worst performance is observed for Vc = 22.30 m/min; f = 0.2 mm/rev and D= 10 mm, where the trend of the wear curve accelerated drastically and fast from the beginning of the curve. Table 3 illustrates the effect of the cutting parameters and workpiece heat treatment on the twist drill bit lifetime. The rate of heat treatment effect suggests that for lower value of the cutting speed (Vc = 11.15 m/min) the rate between the values of tool lifetime according to the allowable value of wear VB equals to 0.5 mm is less than 100% and in the case of higher value of cutting speed (Vc = 22.3 m/min) the rate is higher than 100%.

Table 3. Effect of cutting parameters and blank heat treatment on twist drill bit lifetime

N° essais	*Cutting parameters*			*C22 Steel Heat Treatment*		
				Annealing	Quench & Temper	*Heat treatment effect rate*
	Vc m/min	f mm/rev	D mm	T_{05a} (mm)	T_{05Q} (mm)	T_{05a}/T_{05Q} (%)
1	11.15	0.10	10	420	168	40,0
2	22.30			218	272	124,8
3	11.15	0.20		160	43	26,9
4	22.30			18	118	655,6
5	11.15	0.10	20	456	185	40,6
6	22.30			235	331	140,9
7	11.15	0.20		178	63	35,4
8	22.30			46	153	332,6

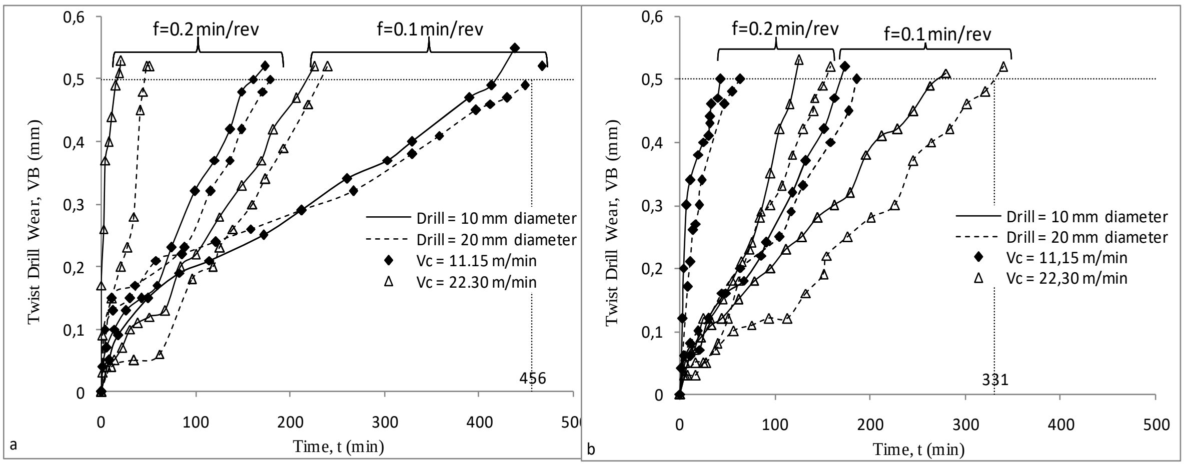
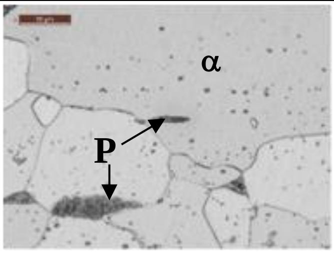
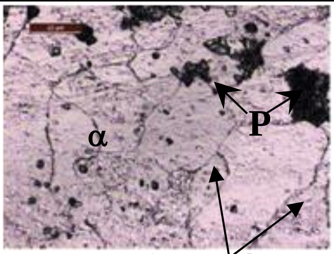
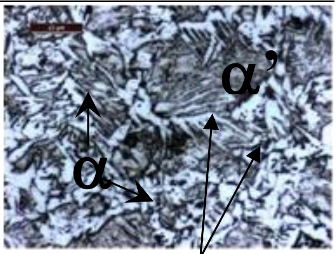
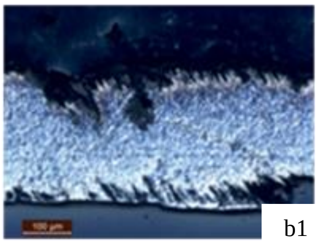
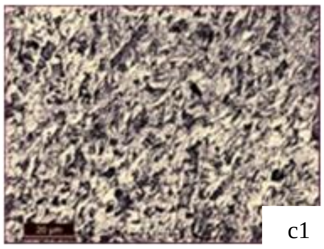
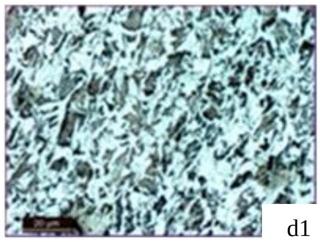
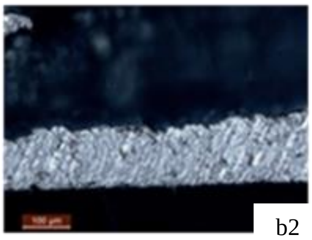
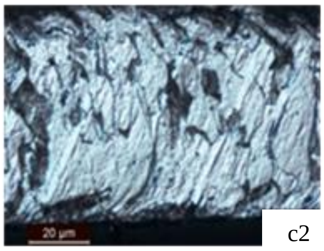
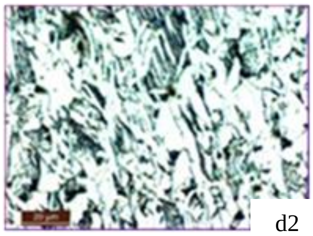
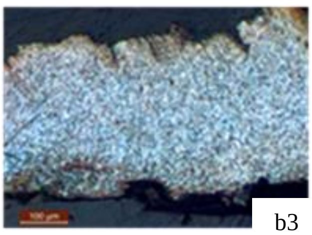
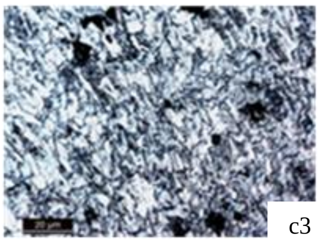
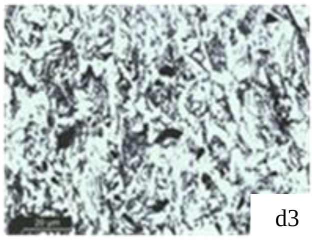
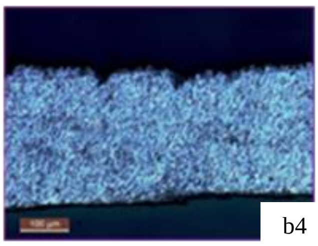
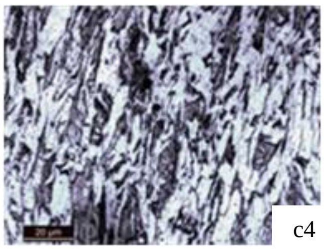
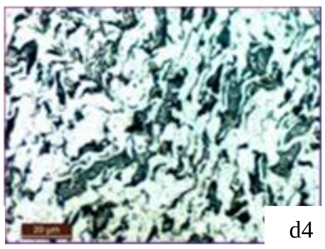


Figure 2. Evolution of flank wear in twist drill bits when drilling C22 steel:
a) annealed steel; b) quenched and tempered steel.

The most effective cutting parameter influencing flank wear is the feed rate. Effectively, in both heat treatment conditions, at lower value of feed rate of 0.1 mm/rev the tool lifetime is longer than that of 0.2 mm/rev. Then unexpected phenomena occurred when the heat treatment revealed that there has been a controversial effect of the cutting speed on twist drill resistance to flank wear between drilling annealed steel and drilling quenched and tempered steel. In fact, when drilling annealed steel, the common effect of cutting speed on tool wear is observed, Figure 2a: the lower the cutter speed the longer the lifetime of the twist drill bit. When drilling the quenched and tempered steel the effect of cutting speed is inversed, figure 2b: the higher the cutting speed, the longer the lifetime of the twist drill bit. The phenomena is observed for the 2 drill diameters as shown in Figure 4 suggesting the controversial effect of the cutting speed on flank wear in twist drill with respected to heat treatment condition of the workpiece.

Table 4. Effect of heat treatment of C22 steel blanks and twist drill cutting speed on chip microstructure

Heat Treatment				As Received	Annealed	Quenched & Tempered
a) Blank Microstructure (X600)				 a_1	 Grain Boundary a_2	 Grain Boundary a_3
Cutting Regime			Tool life	b) Shape and Thickness of the chip (X120)	c) Chip Profile Microstructure (X600)	d) Chip Surface Microstructure (X600)
D	f	Vc	Te mpere			
Twist Drill Diameter, D=20 mm	0.1 mm/rev	11.15 mm/min	185 min	 b1	 c1	 d1
		22.30 mm/min	331 min	 b2	 c2	 d2
	0.2 mm/rev	11.15 mm/min	63 min	 b3	 c3	 d3
		22.30 mm/min	153 min	 b4	 c4	 d4

Meanwhile, there should be stated that drilling with a twist drill bit of 20 mm has contributed slightly in improving the tool lifetime than drilling with a drill of 10 mm. In drilling operations, the diameter of the drill represents the cut of depth, so unlike the other machining processes where tool life decreases when depth of cut increases, the effect of depth of cut is inversed. This is due to the rapid dissipation of heat from the cutting zone as larger diameters have more space to ensure good lubrication and chip evacuation.

As reported in the above literature review and in the present investigation, when machining hardened materials using high-speed steel twist drills, the increase of cutting speed could bring beneficial effect as the tool life increases, Figure 4b. Therefore, in order to explain the physical significance of this unusual behavior additional investigation throughout microstructure observations of the formed chips according to cutting speed has been conducted. table 4 shows exploratory microstructure observations on blank material and formed chips according to heat treatment condition of the blanks and the cutting parameters.

Optical microstructure observations of the blank in the conditions as received, annealed and then quenched and tempered, revealed the usual transformation of a carbon steel when ferrite and perlite (P) of soften C22 steel by annealing (tab 4.a2) changes into martensite and rediffusion of ferrite when C22 steel is hardened by austenising process at 850 °C during 30 min and water quenched, then tempered for 2 hours at 240°C. So the final structure is martensitic with well-defined grain boundaries (tab 4.a3). During twist drilling with HSS drill bit, the material removal causes changes in the original martensitic structure because of large amount of heat generated at the surface contact between the cutting tool and the workpiece. The removed chips have been subjected to microscopic observations that are discussed below.

The first apparent feature is that the thickness of the chip is affected by the feed rate and the cutting speed. Effectively, when drilling with the same drill bit diameter of 20 mm, as the feed rate increases from 0.1 mm/rev to 0.2 mm/rev, the chip thickness increased from a range 1.73 to 2.90 times depending on the cutting speed. Lower cutting speed (Vc = 11.15 m/min) resulted in higher irregular chip thickness for a given feed rate such as at 0.1 mm/rev, the chip thickness is 0.22 (Table 4.b1) and at 0.2 mm/rev the chip thickness is 0.38 mm (table 4.b3) (1.73 times higher). Higher cutting speed (Vc = 22.30) resulted in lower regular chip thickness of 0.11 mm (table 4.b2) when f is 0.1 mm/rev and 0.32 mm (table 4.b4) when f is 0.2 mm/rev.

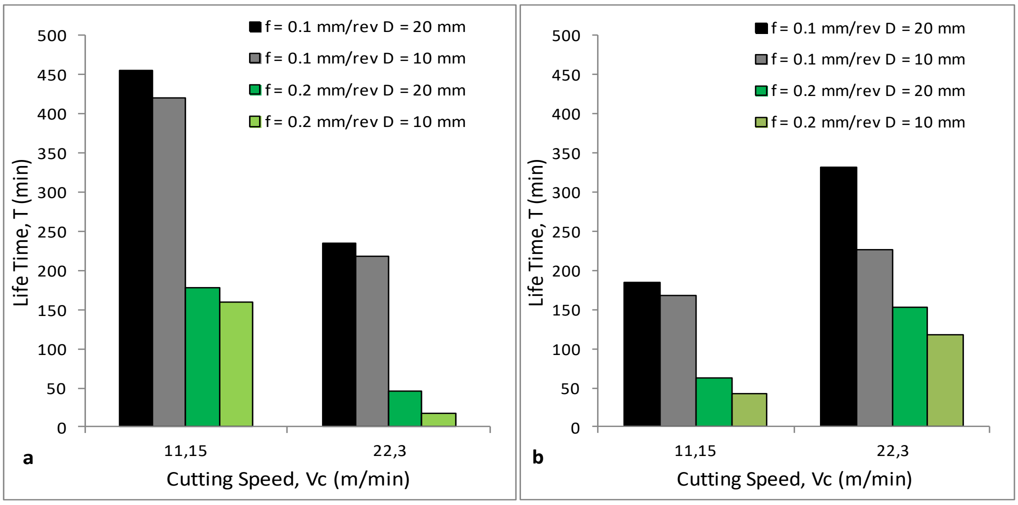


Figure 3. Effect of cutting speed on twist drill lifetime. a) When drilling annealed C18 steel. b) When drilling hardened C22 steel

The second feature is the change of microstructure due material removal as the drilling operation is complex. The original grain boundaries observed the microstructure of C22 steel after austenizing and quenched then tempering, table 4. a3 are no more apparent in the microstructure of the chips. table 4. c and d because, heat generated by the friction between the drill cutting nose and the surface blank is so high and could even reach the melting point instantly as the material is removed in the form of chip. Therefore, the initial repartition of grains the structural microstructure in the initially quenched and tempered, changes. However, at higher cutting speed Vc = 22.30 m/min, the grains elongate, revealing a tendency toward a return to a structure of an annealed material which means that the material softens. The phenomenon is well observed on the microstructure of the chip profile (table 4. c2 and c4). At lower cutting speed Vc = 11.15, the phenomenon is much more less important (table 4. c1 and c3) suggesting that the material still hard. Observing the chip surface, the microstructures obtained at Vc = 11.15 m/min (table 4. d1 and d3) are similar and approach the initial structure (table 4. a3) and at Vc = 22.30 m/min, the microstructures (table 4.d2 and d4) are also similar but move away from the initial microstructure suggesting that the steel microstructure is recrystallising. Hence, the increase of the tool life as the cutting speed increases is justified through microstructure observations.

Conclusion

The present work is a contribution in understanding the effect of quench hardening on machinability of C22 steel when executing drilling operations using twist HSS drill bit. Beyond, the common behavior suggesting that when the feed rate on tool life increases the tool life increases, the most interesting phenomenon is the controversial effect of the cutting speed when drilling the steel in tempered condition. Effectively, high cutting speeds generate large increase of temperature in the cutting zone permitting changes in microstructure. Chip microstructure observation revealed that the material is recrystallized as to get a consequent improvement in material machinability from 1.14 to 3.70. Moreover, more the thickness of the chip is small more the recrystallization is important. An engineering correlation between the thickness and tool life has been given in the form of third degree polynomial equation. At lower cutting speed, the phenomenon is not observed.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements

* This article was presented as an oral presentation at the International Conference on Technology (www.icontechno.net) held in Antalya/Turkey on November 16-19, 2023.

*This work is achieved in the LRTAPM, Laboratory of advanced technology in mechanical engineering of badji Mokhtar-Annaba University, in collaboration with the LEM3, material mechanics and microstructure studies of the University of Lorraine, Metz, France. Financial support are due to the delegated ministry of scientific research (MDRS) of the Algerian ministry of higher education and scientific research (MESRS) under the CNEPRU research projet-LRTAPM: A11N01UN230120140056 (Annaba).

References

Abouridouane, M., Klocke, F., & Dobbeler, B. (2017). Characterisation and modelling of the machinability of ferritic-pearlitic steels in drilling operations. *16th CIRP Conference on Modelling of Machining Operations. 58*, 79 – 84.

Bagci, E., & Ozcelik, B. (2006). Analysis of temperature changes on the twist drill under different drilling conditions based on Taguchi method during dry drilling of Al 7075-T651. *International Journal of Advanced Manufacturing Technology*, *29*, 629–636.

Balajia, M., Murthy, B. S. N., & Mohan Rao, N. (2016). Optimization of cutting parameters in drilling of AISI 304 stainless steel using Taguchi and ANOVA. *Procedia Technology*, *25*, 106 – 113.

Biermann, D., Heilmann, M., & Kirschner, M. (2011). An analysis of the influence of tool geometry on surface integrity in single-lip deep hole drilling with small diameters. *First CIRP Conference on Surface Integrity (CSI)*,*19*, 16 – 21.

Bryukhanova, L. S., Miroshniehenko, U. M., Polukarova, Z. M., & Shehukin, E. D. (1978). Optimum conditions for using molten metals in cutting solids. Effect of molten-metal chemical composition and cutting tool material on drilling of steel 45. *Fiziko-Khimicheskaya Mekhanika Materialov*, *14*(6), 14-18.

Cicek, A., Kıvak, T., Uygur, I., Ekici, E., & Turgut, Y. (2012). Performance of cryogenically treated M35 HSS drills in drilling of austenitic stainless steels. *International Journal of Advanced Manufacturing Technology, 60*(1-4), 65–73.

Desargues, J. E., Lescalier, C., Bomont Arzur, A., & Bomont, O. (2013). High strength steel solutions for automotive parts: State of the art of machinability enhancement and further developments steel. Proceedings of the *Tenth International Conference on High Speed Machining - Progress in Productivity and Quality.* Germany.

Kaplan, Y., Motorcu, A. R., Nalbant, M., & Okay, S. (2016). The effects of process parameters on acceleration amplitude in the drilling of cold work tool steels. *International Journal of Advanced Manufacturing Technology, 80,* 1387–1401.

Kayhan, M., & Budak, E. (2009). An experimental investigation of chatter effects on tool life. *P I Mech Eng B-Journal of Engineering Manufacture, 223*(111),1455–1463.

Khashaba, U. A., El-Sonbaty, I. A., Selmy, A. I., & Megahed, A.A. (2010). Machinability analysis in drilling woven GFR/epoxy composites: Part II – effect of drill wear. *Composites: Part A, Applied Science and Manufacturing, 41*(9), 1130–1137.

Le Coz, G., Jrad, M., Laheurte, P., & Dudzinski, D. (2017). Analysis of local cutting edge geometry on temperature distribution and surface integrity when dry drilling of aeronautical alloys. *International Journal of Advanced Manufacturing Technology,93,* 2037-2044.

Lin, T. R. (2002). Experimental design and performance analysis of TiN-coated carbide tool in face milling stainless steel. *Journal of Materials Processing Technology, 127*(1), 1-7.

Meena, A., & El Mansori, M. (2013). Specific cutting force, tool wear and chip morphology characteristics during dry drilling of austempered ductile iron (ADI). *International Journal of Advanced Manufacturing Technology, 69,* 2833–2841.

Okay, S., Kaplan, Y., Motorcu, A. R., & Nalbant, M. (2013). Evaluation of cutting tool wear characteristics and removed chip volumes in drilling of AISI D2 and AISI D3 cold work tool steels. *7th International Advanced Technologies Symposium (IATS'13),7.* Istanbul, Turkey.

Wang, X., Huang, C., Bin Zou, B., Liu, H., & Wang, J. (2013). Effects of geometric structure of twist drill bits and cutting condition on tool life in drilling 42CrMo ultrahigh-strength steel. *International Journal of Advanced Manufacturing Technology, 64,* 41–47.

Xu, L., Wu, Q., Qin, M., &Yong Tang, Y. (2016). Flank wear of twist drills and surface quality of holes in hard-to-cut materials by electric hot drilling. *The International Journal of Advanced Manufacturing Technology, 84,* 513–522.

Zeilmann, R. P., Nicola, G. L., Vacaro, T., Teixeira, C. R., & Heiler, R. (2012). Implications of the reduction of cutting fluid in drilling AISI P20 steel with carbide tools. *International Journal of Advanced Manufacturing Technology, 58,*431–441.

Author Information

Nacer Mokas
Badji Mokhtar Annaba University,
P.O. Box. 12, 23000, Algeria
Contact e-mail*: nacer.mokas60@gmail.com*

Sabiha Tekili
Badji Mokhtar Annaba University,
P.O. Box. 12, 23000, Algeria.

Youcef Khadri
Badji Mokhtar Annaba University,
P.O. Box. 12, 23000, Algeria

To cite this article:

Mokas, N., Tekili, **S.,** & Khadri, Y. (2023). Quenching: An improvement factor of HSS twist drill tool-life when machining C22 steel. *The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 24,* 211-218.