INFLUENCE OF THE LUBRI-COOLING SYSTEM ON THE LIFE OF TiAlN COATED HSS TWIST DRILLS WHEN MACHINING BLIND AND THROUG HOLES

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Abstract. *The objective of this work is to evaluate the life of TiAlN coated HSS twist drills after machining HSLA- High Strength Low Alloy steels (DIN 38MnS6) when different lubri-cooling systems were used for drilling blind and through holes. The number of holes machined until the end of the tool lives was considered as the machinability parameter for comparison. The variables considered in the investigation were: type of hole (blind and through holes with L/D = 3), cutting speed (45 and 60 m/min) and the lubi-cooling system (dry; MQL – minimum quantity of lubricant, with vegetable and mineral oil base with a flow rate of 30 ml/h; and flood cooling of mineral neat oil and of semi-synthetic fluid). The results showed that through instead of blind holes decreased tool lives in an average of 30%. Dry cutting produced the lowest tool lives and MQL systems (both with vegetable and mineral oil base) and flood cooling of mineral neat oil produced practically the same average tool lives. These lubri-cooling systems produced intermediate tool lives in relation to dry cutting and flood of semi-synthetic fluids. The latter system produced the highest tool lives of the drills. When this system was used instead of dry cutting the average augment in tool lives was of 52%, and in comparison to the MQL and flood cooling of mineral neat oil systems the average increase of the tool life was of 25%. Raising the cutting speed from 45 to 60 m/min reduced the tool life in an average of 71%.*

Keywords: *MQL system; Blind and through holes; Coated HSS twist drills; Cutting fluids.*

1. Introduction

After Frederick W. Taylor at the beginning of last century demonstrated that a rich flow of water directed to the cutting region could allow the cutting speed to be raised up to two to threefold the cutting fluids are helping to achieve high production in machining (Drozda, 1993 and Degarmo et al, 1997). Since then they have been applied and their use until recently have not been questioned. However, several recent publications have called the attention for the need of restricting at the maximum the use of cutting fluids at the production lines (Heisel et al, 1998; Kalhöfer, 1997 and Klocke and Eisenblätte, 1997). Important facts that justify this procedure include the high operational costs, ecological concern, legal issues related to environmental preservation and to human health.

The MQL technique can be a promised alternative when the dry condition, coined by researchers of the area by ecological machining, is economically unviable or technically limited for some applications such as in drilling operations where the absence of a coolant and of the chip carrier could bring about a premature damage of the tool (Dörr and Sahm, 2000 and Machado and Diniz, 2000). Drilling differs from other popular machining processes because the cut happens internally in the work material, impairing heat dissipation and hindering the transportation of the swarf out from the cutting region. For these reasons the application of a cutting fluid is vital (De Castro, 2001).

The MQL is a system where the lubricant is sprayed in minimum quantities in a compressed air flow (Machado and Diniz, 2000). According to Sahm and Schneider (1996) the flow rate of the MQL varies, generally, from 10 to 100 ml/h and the air pressure from 4 to 6 Kgf/cm^2. These minimum quantities of fluids are enough to substantially reduce the friction between the chip and the tool and to avoid adherence of work material onto the tool surfaces, since the chip-tool contact area is pretty small what suggests that the necessary quantity of fluid to promote lubrication is very small. Machado and Wallbank (1997) studied and theoretically calculated this necessary flow rate to allow lubrication on the contact zone. Even considering only 1% of efficiency the figure encountered by these authors is only 0.1 mm/h. With this technique lubrication is attained by the oil and the cooling by the air flow (Heisel, et al, 1998).

Dry machining is more and more possible due to emerging new technologies such as: increasing use of improved machinability materials and mainly the massive development of material, coating and geometry of the tools that enhanced wear resistance and allow such tools to be used at elevated temperatures, compensating the absence of a lubri-cooling medium in the process (Miranda et al, 2001; Kubel, 1998 and Teeter, 1999).

The present work compares the machining performance of external application of MQL systems in drilling operation relative to flood application of a cutting fluid and dry cutting. The tool life, quantified by the number of holes machined until the total collapse of the twist drills was the evaluating parameter of the performance.

2. Experimental Procedure

The drilling tests were carried out in the descending vertical position without pre-hole and with a constant feed rate of 0.25 mm/rev.. The parameters that have been varied with their respective values are illustrated in Tab. 1. Total collapse of the drill as recommended by the standard Nord Tech – NT MECH 038, (1997) was used as the end of tool life criterion. The number of holes machined quantified the tool life. Table 2 presents details of all tests.

Table 1. Variables of the cutting tests.

VARIABLES		VALUE
Lubri-Cooling System	DRY	-
	MQL-Veg. (vegetable oil)	30 ml/h
	MQL-Min. (mineral neat oil)	
	FLOOD COOLING (F.C)-Min. (mineral neat oil)	750 l/h
	FLOOD COOLING (F.C)-S.Synt. (semi-synthetic oil)	1230 l/h
Type of Hole (L/D=3,0)		Blind and through
Cutting Speed		45 e 60 m/min

Table 2. Test numbers and their respective cutting condition.

Test N°	Type of Hole (L/D=3,0)	Lubri-Cooling System	Cutting Speed (m/min)
01	Blind	F.C-Min.	45
02	Blind	F.C-Min.	60
03	Blind	F.C-S.Synt.	45
04	Blind	F.C-S.Synt.	60
05	Blind	DRY	45
06	Blind	DRY	60
07	Blind	MQL Veg.	45
08	Blind	MQL Veg.	60
09	Blind	MQL-Min.	45
10	Blind	MQL-Min.	60
11	Through	F.C-Min.	45
12	Through	F.C-Min.	60
13	Through	F.C-S.Synt.	45
14	Through	F.C-S.Synt.	60
15	Through	DRY	45
16	Through	DRY	60
17	Through	MQL Veg.	45
18	Through	MQL Veg.	60
19	Through	MQL-Min.	45
20	Through	MQL-Min.	60

Each test was performed (batch A) and repeated (batch B) and when the difference between these two tests exceed 20% a new test was conducted (batch C). The average of the tool lives from these two or three tests was the result considered for the test. During the tests, in an average of 22 holes, tool wear was measured photographed with an industrial microscope and a digital camera.

Tests were carried out in a vertical machine centre, Discovery 760 manufactured by Romi, with 9 kW of power and maximum spindle speed of 10,000 rpm. Blind and through holes were drilled with 30 mm of length given a L/D ratio of 3.

The work material was the DIN 38MnS6 HSLA steel with an average hardness of 252 HV. The chemical composition given by the manufacturer is presented in Tab. 3. This material was in a square cross section of 100 x 100

mm^2 delivered in 6 m bars. Blanks of 65 mm long were prepared after sawing and facing. This allowed blind holes to be drilled on both sides of the samples, leaving a distance of 5 mm between the bottoms of the holes. When through holes were tested blanks of 30 mm long were prepared. In order to optimise the number of holes in the workpiece a CNC program allowed a total of 67 holes per face alternating rows of 7 and 8 holes. This resulted in a minimum distance of the holes' wall of 2.11 mm.

Table 3 – Chemical composition of the work material.

C	Mn	P	S	Si	Ni	Cr	Mo	V	Al
0,3960	1,4400	0,0180	0,0650	0,5900	0,0500	0,1300	0,0200	0,0040	0,0040
Cu	**Pb**	**Ti**	**Nb**	**B**	**Sn**	**Ca**	**H2**	**N2**	**Te**
0,1000	0,0030	0,0021	0,0050	0,0008	0,0050	0,0006	0,0002	0,0171	0,0001

M42 (8% Co) HSS coated with TiAlN (10HSS-Co FUTURA®) twist drills with 10 mm of diameter, 30^o of helical angle and 130^o of point angle were used. According to the tool manufacturer the coating has 3300 HV of hardness and a friction coefficient against the steel of 0.25. These drills have the flank faces divided in three stages.

The cutting fluids used in this investigation were a vegetable base neat oil, a mineral base neat oil and a semi-synthetic fluid in 5% concentration. Tab. 4 presents details of these cutting fluids.

Table 4 – Typical characteristics and external application modes of the cutting fluids used in the tests.

Type of Cutting Fluid	Composition/Density	Application Mode (External)	Flow rate
Vegetable (Accu-Lube- LB-2000®)	Biodegradable, non toxic and insoluble in water Composition of the vegetable oil (soya, sweet corn and canola oils) and anti-corrosion additives **Density** (20 to - 3° C): 0,900-0,940	MQL	30 ml/h
Mineral neat oil (DMI 410®)	Composed by mineral oils distillated from crude oil derived from the paraffinic petroleum, sulfur, lard, EP, anit-corrosion and anti foam additives **Density** (20 to 4° C): 0,9032	MQL	30 ml/h
		FLOOD COOLING (F.C)	750 l/h
Semi-synthetic (DMS 250 EP ®)	Composed by mineral lubricant oil, anti-corrosion and anti-foam agents, bio stable emulsifiers and EP additives. They form semi-translucent micro-emulsion and used at 5% concentration. **Density:** (20 to 4° C): 0,9850	FLOOD COOLING (F.C)	1230 l/h

The MQL was applied using a sprayer apparatus, model O2AO-STD manufactured by ITW Fluid Products Group. The air pressure used was adjusted to 4.3 bars and the fluid was delivered intermittently in a rate of 1 pulse per second. A special pipe hose caring simultaneously the air (in a smaller inner hose) and the cutting fluid (in a larger outer hose) allowed the air-fluid mixture to be delivered externally to the cutting zone by two nozzles positioned on both sides of the drill.

Application of flood coolant was done by the machine-tool system that uses three nozzles equally distributed around the drill.

3. Results and Discussion

Tool life test results are presented in Tab. 5 and Fig. 1 illustrates them graphically. They show that, generally, the flood cooling of semi-synthetic lubri-cooling system gave longer and the dry cut shorter tool lives regardless the cutting condition used. The MQL systems (vegetable and mineral base oils) and flood cooling of mineral neat oil always gave close tool lives among them and intermediate relative to the two formers lubri-cooling systems.

Figure 1 also shows that for the cutting speed of 45 m/min the flood cooling of mineral neat oil has given tool life slightly superior than the MQL system, however, for the higher cutting speed of 60 m/min the inverse is true.

It is also clear that through holes reduced tool lives in relation to blind holes under all cutting conditions investigated.

Tests with the cutting speed of 60 m/min and through holes have given tool lives very similar with all lubri-cooling system used but with dry cut. At this condition the MQL with vegetable base oil has given exactly the same tool life (134 holes) as the flood cooling of semi-synthetic fluid.

Table 5. Tool life results (number of holes machined) obtained in the tests.

Test Number	Batch / Number of Holes		Difference (%)	Batch C (Difference > 20%)	Average Tool Life (Number of Holes)
	A	B			
01	361	313	13,3	-	337
02	101	159	36,5	118	126
03	407	501	18,8	-	454
04	216	175	19,0	-	196
05	213	259	17,8	-	236
06	130	92	29,2	103	108
07	264	345	23,5	299	303
08	152	160	5,0	-	156
09	355	252	29,0	342	316
10	109	192	43,2	153	151
11	253	238	5,9	-	246
12	147	81	44,9	108	112
13	256	290	11,7	-	273
14	120	148	18,9	-	134
15	164	196	16,3	-	180
16	120	90	25,0	78	96
17	234	226	3,4	-	230
18	99	165	40,0	138	134
19	244	209	14,3	-	227
20	83	154	46,1	134	124

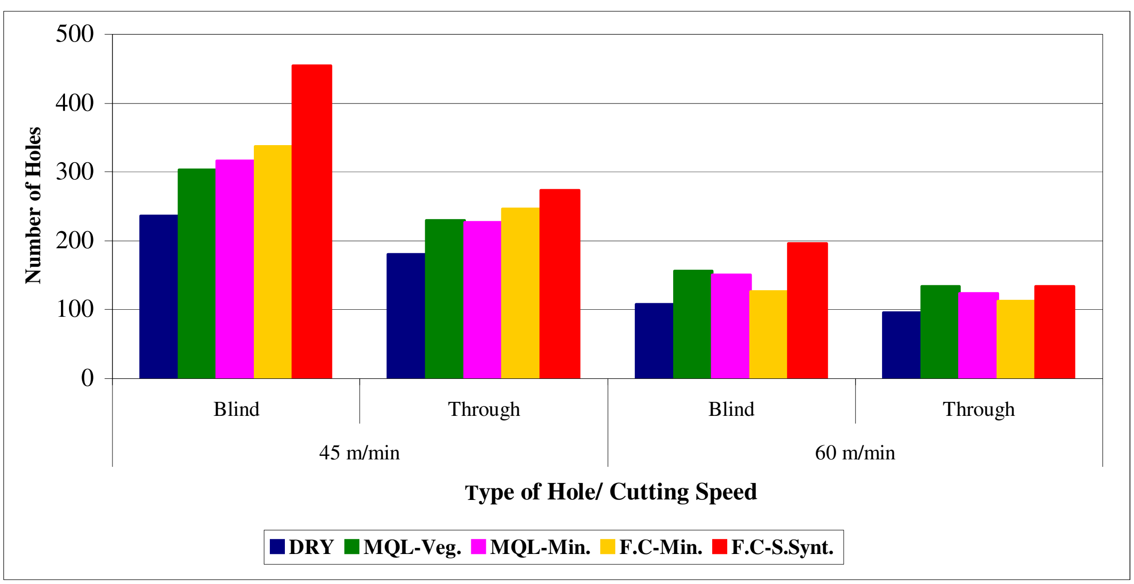


Figure 1. Diagram of tool life results for the different lubri-cooling systems

Table 6 present a statistic analysis for all tests. A 2^3 factorial planning was used considering the lubri-cooling system, the type of hole (blind or through) and the cutting speed. It shows the average effect on the tool life when changing from the inferior level to the superior level of the variables.

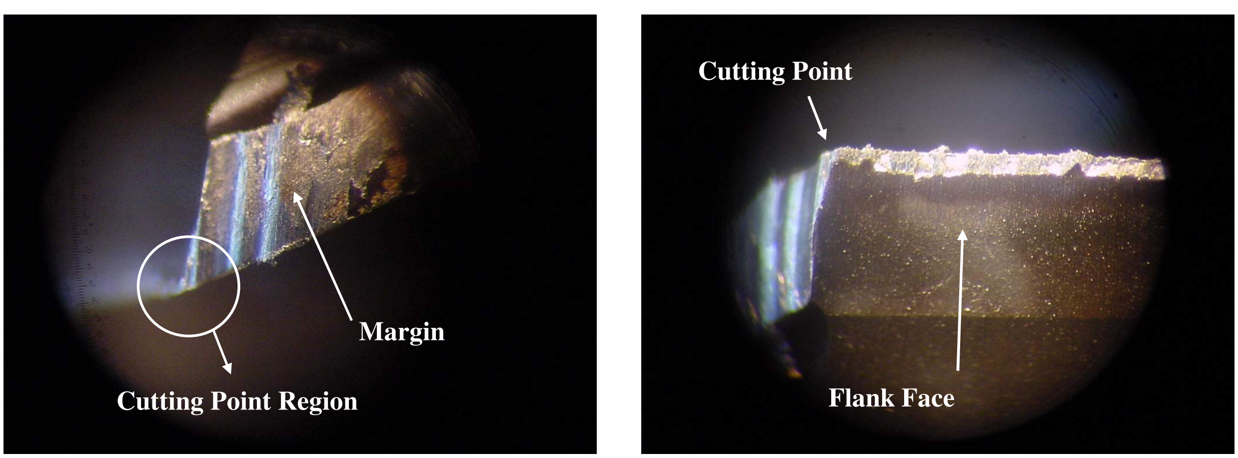
Table 6. Statistic analysis of the effect of the variables on the tool lives.

Lubri-Cooling System	Average Tool Life (number of Holes)	Average Effect on the Tool Life (Number of Holes)		
		Lub-Cool. Syst.	Type of Hole (Blind → Through)	Cutting Speed (45 → 60 m/min)
DRY → MQL Veg.	180	51 (↑ 28%)	-41 (↓ 23%)	-114 (↓ 63%)
DRY → MQL-Min.	180	50 (↑ 28%)	-46 (↓ 26%)	-120 (↓ 67%)
DRY → F.C*-Min.	180	50 (↑ 28%)	-43 (↓ 24%)	-139 (↓ 77%)
DRY → F.C-S.Synt.	210	109 (↑ 52%)	-78 (↓ 37%)	-152 (↓ 72%)
MQL Veg. → MQL-Min.	205	-1 (↓ 01%)	-53 (↓ 26%)	-128 (↓ 62%)
MQL Veg. → F.C-Min.	206	-1 (↓ 01%)	-50 (↓ 24%)	-147 (↓ 71%)
MQL Veg. → F.C-S.Synt.	235	59 (↑ 25%)	-85 (↓ 36%)	-160 (↓ 68%)
MQL-Min. → F.C-Min.	205	1 (↑ 01%)	-55 (↓ 27%)	-153 (↓ 75%)
MQL-Min. → F.C-S.Synt.	234	60 (↑ 26%)	-90 (↓ 38%)	-166 (↓ 71%)
F.C-Min.→ F.C-S.Synt.	235	59 (↑ 25%)	-87 (↓ 37%)	-186 (↓ 79%)

In fact Tab. 6 confirms numerically the results presented and commented in Fig. 1. Interpretation of this table gives:

- Machining with MQL (vegetable or mineral base oils) and with flood cooling of mineral neat oil result in the same increase in tool life relative to dry cutting. When these lubri-cooling system were used instead of dry cut the tool lives increased 50 holes or 28% (yellow cells in the Tab. 6);
- Changing the lubri-cooling system from MQL (vegetable and mineral base oils) to flood cooling of mineral neat oil has the negligible effect on tool life of only 1% (blue cells in Tab. 6);
- The flood cooling of semi-synthetic fluid has given the highest tool lives. When machining with this system instead of dry cut the average tool life has increased 52%, and in relation to MQL and flood cooling of mineral neat oil the semi-synthetic fluid has raised the average tool lives in 25%;
- Through holes instead of blind holes reduced the tool lives in 30%, average;
- Increasing the cutting speed from 45 to 60 m/min unquestionably reduced the tool life in 71%, average.

Microscope observation of the tools indicates that the cutting point and the margin of the twist dills are the critical worn areas (see Fig. 2) and the lubri-cooling systems did not change this form of wear. However, the flood cooling of semi-synthetic fluid was able to retard, some times significantly, the development of these wear. With this fluid the tool first start loosing the coating at the cutting point and at the margin and then the wear were progressively developed at these regions as the number of holes increased and the drill, even showing severe wear lands, could still be used to continue to open holes until total collapse. Figure 2 shows a severe wear at the cutting point, at the flank face and at the margin of the drill after 402 holes were machined in test number 3, batch B. However, this represents only 80% of the total tool life of the drill since a further 99 holes were machined with this tool prior to collapse. For the other lubri-cooling systems, principally for the dry cut, the wear developed rapidly at these critical areas leading the tool to fail after a few number of holes later. Sales et al. (1998) when machining ABNT 8640 steel with HSS twist drills have also attested that the semi-synthetic fluid is able to retard the process of progressive increase of wear.



a) b)

Figure 2. Worn are of the tool used in test 03 batch B after machining 402 holes in a total of 501 for its tool life. Flood cooling of semi-synthetic fluid, v_c = 45 m/min and blind hole; a) Wear on the margin and on the cutting point region; b) Wear on the flank face.

Two fact seems to be pertinent to explain the superior performance of the semi-synthetic fluid relative to the other lubri-cooling systems. Firstly, this is a water base fluid (concentration of 5% of oil) which confer a cooling ability sensibly higher than its counterparts. Second and significantly is the flow rate at which this fluid was applied, 1230 l/h against 750 l/h for the mineral neat oil and only 30 ml/h for the MQL systems. The ability of the fluid to cool and to carry the swarf away from the cutting zone is proportional to the fluid viscosity and flow. In drilling these functions are extremely important to avoid obstructions and clog of the swarf in the drilling hole, and consequently damage to the tool (Machado e Da Silva, 2004).

4. Conclusions

The results obtained from the drilling tests, considering the variables' level used allow the following conclusion to be drawn.

- The flood cooling of semi-synthetic fluid gave the highest drill lives. In comparison to dry cut an average increase of 52% was achieved;
- Machining with MQL (Vegetable and mineral base oils) and flood cooling of mineral neat oil generally gave equal tool lives and 28% (average) superior to dry cut;
- Although generally the MQL systems and flood cooling of mineral neat oil have presented the same performance in terms of tool life, a more detailed analysis shows that the MQL with vegetable base oil gave marginally higher tool lives than the MQL with mineral base oil and flood cooling of mineral neat oil. With the cutting speed of 60 m/min and through hole condition the MQL (vegetable base oil), together with the flood cooling of semi-synthetic fluid, gave the highest tool life of 134 holes;
- Through holes instead of blind holes reduced the tool lives by an average of 30%;
- The increase in cutting speed from 45 to 60 m/min reduced the tool lives significantly by an average of 71%;
- The lubri-cooling systems tested did not change the form of the tool wear, but the cutting fluids are able to retard the development of this wear in relation to the dry condition, principally the flood cooling of semi-synthetic fluid.

5. Acknowledgements

The authors would like to thank FAPEMIG, CAPES, CNPq and IFM for financial support and Aços Villares S.A., Shell do Brasil S.A. and OSG Ferraments de Precisão Ltda for providing the work material, the cutting fluids and the twist drills, respectively.

6. References

De Castro, P. R. A., 2001, "Aspectos Tecnológicos da Usinagem a Seco e com Mínima Quantidade de Fluido de Corte na Furação com Broca Helicoidal", 178 f. Dissertação (Mestrado em Eng. Mecânica) - UFSC, Florianópolis-SC, julho.

Degarmo, E. P., Black, J. T. and Kohser, R. A., 1997, "Materials and Processes in Manufacturing", 8 ed. Upper Saddle River, NJ, Prentice Hall.

Dörr, J., e Sahm, A., 2000, "A Mínima Quantidade de Lubrificantes Avaliada pelos Usuários", Máquinas e Metais, Ed. Aranda, novembro, pp. 20-39.

Drozda, T.J. and Wick, C., 1993, "Cutting Fluids and industrial lubricants", Tool and Manufacturing Engineers Handbook, Vol. 1 , 4ª Ed., pp. 4.1-4.60.

Heisel, U., Lutz, M., Spath, D., Wassmer, R. e Walter, U., 1998, "A Técnica da Quantidade Mínima de Fluidos e sua Aplicação nos Processos de Corte", Máquinas e Metais, Ed. Aranda, fevereiro, pp. 22-38.

Kalhöfer, E., 1997, "Dry machining – Principles and Applications", 2° Seminário Internacional de Alta Tecnologia, UNIMEP, Santa Bárbara D'Oeste-SP, julho.

Kloche, F. and Eisenblätter, G., 1997, "Presented at the Opening Session Dry Cutting", Annals of the Cirp, v. 46 (2), pp. 519-526.

Kubel, E., 1998, "Cooatings Crank up Tool Performance", Manufacturing Engineering, jan., pp. 40-46.

Machado, A. R. and Wallbank, J., 1997, "The Effect of Extremely Low Lubricant Volumes In Machining", Wear, 210, pp. 76-82.

Machado, A. R. e Silva M. B., 2004, "Usinagem dos Metais", Laboratório de Ensino e Pesquisa em Usinagem, Universidade Federal de Uberlândia, 8° versão, abril.

Machado, A. R. e Diniz A. D., 2000, "Corte a Seco, com Mínima Quantidade de Fluido e com Fluido em Abundância: Usos, Aplicações, Vantagens e Desvantagens", In: Congresso Usinagem 2000, São Paulo-SP.

Miranda, G. W. A, Coppini, N. L., Diniz, A. E. e Braga, D. U., 2001, "Quando as Brocas de Metal Duro Revestidas Dispensam os Fluidos de Corte", O Mundo da Usinagem, ISSN 1518-6091, RG.BN 217.147, março, pp 20-25.

NT MECH 038, 1997, "Cutting Fluids for Drilling: Evaluation by Drill Life Test. Published by NORDTEST.

Sales, W. F., Machado, A. R. e De Mello, J. D., 1998, "Influência do Fluido de Corte no Desgaste de brocas de Aço-Rápido", Contribuição Técnica ao IV Seminário de Desgaste, São Paulo-SP, julho.

Sahm, D. and Schneider, 1996, “A Produção sem Refrigeração é Interessante e Deve ser mais Conhecida”, Máquinas e Metais, Ed. Aranda, agosto, pp 38-55.
Teeter, F. J., 1999, “Cooating Takes Place of Coolant”, American Machinist, pp. 50-52.