Machinability of Stainless Steel Dentistry Drills

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Abstract. *The aim of this work is to compare the machinability of dentistry drills for dental implantology. Tool life tests were carried out in a CNC machine center varying the cutting parameters following an experimental design 2^3. During the tests the thrust force and the workpiece temperature were monitored and the tool lives were expressed by the number of drilled holes considering a workpiece temperature limit criterion of 47ºC. Two types of uncoated tool materials were used, a martensitic stainless steel (M340/Böhler) and an austenitic stainless steel (AISI 316L). The thrust force was measured with a Kistler rotating dynamometer and the temperature with three thermocouples of the type T (cupper-constantan) positioned close to the drill wall. A data acquisition board and a computer were used for automation of the measurement system. Bovine tibia was used as the workpiece. A mixture of 20% of car radiator fluid and water was applied as coolant (irrigation) with a flow of 160 ml/min. The results showed that the martensitic stainless steel outperformed the austenitic stainless steel and lowest temperatures and a conformity state at the clinic standard for thrust force values were obtained with the highest cutting parameters (45 mm/min and 2500 rpm). The feed velocity has a main influence on the temperature drop, while the higher spindle speed decrease the thrust force.*

***Keywords**: dental implantology, machinability, dentistry drills, machining temperature, thrust force.*

1. INTRODUCTION

The dental implants became an important therapeutic modality in the last decade, after works developed by Brånemark, (Bezerra e Lenharo, 2002). These dentistry elements are artificial dental roots implanted in mandibular or maxillary bone, which by substitution of original dental roots allows the fixation of prostheses about them, giving rises to aesthetics and functional rehabilitation, a decrease of the load in remnants teeth, the break of bone absorption, besides the social life return at toothless individual (Lenharo, 2007).

The implants are manufactured of commercially pure titanium, which is a biocompatible material with the mammiferous tissues (Lazzara, 1996). This metal has the capability of osseointegrate, constituting a unity to support forces, which is used as base for prostheses (Brånemark et al., 1987).

For Brånemark et al. (1987) the microvasculature around the implant insert in the bone is the great responsible by success of osseointegration. Thus, the maintenance of integrity of this tissue during drilling is the essence of surgical process. Eriksson and Abrektsson (1983), studying rabbit femur, showed histologically that the development of temperature superior to 47ºC in the drilling of the dental site can inhibit the bone regeneration. If these values of temperature are maintained for one minute, it could be sufficient to cause the necrosis of the dental wall, injuring the osteosynthesis (Eriksson and Adell, 1986).

Watanabe et al. (1992) conclude that the heat generation during the preparation of implant site depends on the drill cutting efficiency and the density of bone and Comar (2006) observed that the irrigation and the intermittent cutting motion have a fundamental play in the control of the temperature.

Bachus et al. (2000) evaluated experimentally the behavior of the temperature in the cortical bone, in the neighborhoods of the hole wall, varying the force applied during machining. They conclude that the increase of the force applied during the drilling process decreases significantly the temperatures. The main reason for this behavior is the reduction of the time for drilling and consequently less time to have dissipation of the heat between the drill and the wall bone.

The magnitude of the damage at a dental site depend basically on four factors regardless the surgical technique employed: the power of the cutting drill, the bone density, the continuous irrigation by the cutting fluid during drilling and the cutting parameters used.

Since the dental implants are unquestionable alternatives to support prosthesis, the objective of this work is to compare the machinability of uncoated austenitic stainless steel (AISI 316L) and martensitic stainless steel (M340 by Böhler) dentistry drills when machining workpieces of bovine tibia. The output variables analyzed were the thrust force and the number of drilled holes considering a limit of the workpiece temperature of 47ºC as the end of tool life criterion.

2. MATERIAL AND METHODS

In this investigation two different tool materials were compared. One was the AISI 316L austenitic stainless steel and the other the M340 by Böhler martensitic stainless steel, see Tab. 1. The drills of both materials were manufactured by SIN.

Table 1. Mechanical properties of tool materials.

Material	Tensile Strength	Modulus of Elasticity	Brinell Hardness
	MPa	GPa	HB
AISI 316L	567	147	143
M340	897	223	260

The tests followed an experimental design 2^3, and the inputs variables were: cutting tool material, feed velocity and spindle speed. They were varied in two levels given in Tab. 2.

Table 2. Experimental design 2^3.

Tests	Material	Feed Vel. [mm/min]	Spindle Speed [rpm]
1	316L	24	1000
2	M340	24	1000
3	316L	45	1000
4	M340	45	1000
5	316L	24	2500
6	M340	24	2500
7	316L	45	2500
8	M340	45	2500

The tests were carried out in a CNC machine center Discovery 760 Bridgeport – Romi with 12.5 cv of power, maximum feed velocity of 15,000 mm/min and maximum spindle speed of 10,000 rpm. As cutting fluid (coolant) a mixture the 20% of car radiator fluid and water was used, applied by an ampoule with a flow rate of 160 ml/min. This type of fluid was used to simulate the role of the physiological serum ordinarily used in dentist offices that would corrode the machine tool. This mixture has the same cooling property of the serum and efficiently avoids corrosion (Bertolete et al., 2007). Tibia bovine was used as work material for the drilling tests. The process of opening a site followed a sequence of four drilling operations using a drills' kit. The Figure 1 shows such a kit in the normal sequence experimentally used.

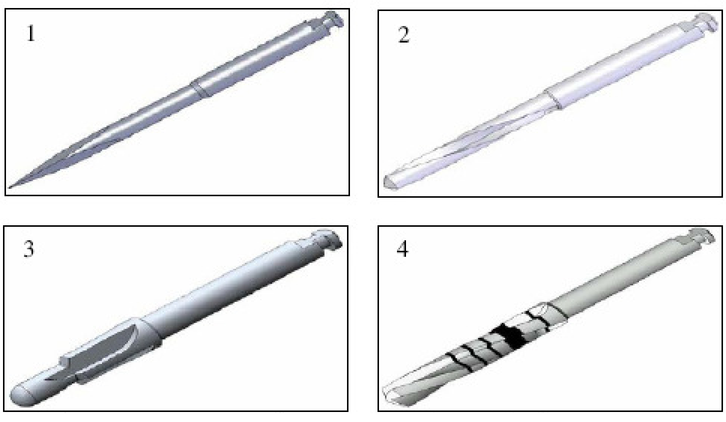

Figure 1. 1) Lance Ø 2 mm; 2) TD2 Ø 2 mm; 3) Pilot Ø 2 e 3 mm e 4) TD3 Ø 3 mm.

In the present investigation the lance drill was used in continuous curse of 5 mm, the 2 and 3 mm diameter twist drills (TD) in intermittent cutting motions with four steps for a total of feed length of 15 mm and the pilot drill was used with a continue curse of 7 mm. The Figure 1 shows the sequence of the drills used.

The output variables of the tests were the thrust force and the number of drilled holes. The thrust force was measured with a Kistler rotating dynamometer, model 9124B, fixed in the main spindle shaft of the machine tool, and the monitored by software Labview®. The measurements of thrust force were taken in the first hole, in the two ones following and in the same manner for each multiple of 10 holes, during all the time of drilling process. The tool lives were expressed by the number of drilled holes considering a limit of the workpiece temperature of 47ºC as the end of tool life criterion. The temperatures were monitored by using three thermocouples of the type T (cupper-constantan) inserted in the work material samples, positioned very close to the drill wall (0.5 mm when drilling with 3 mm diameter drills and 1.0 mm for the 2 mm diameter drills) at distances of 3, 7 and 13 mm from the top surface. A 34970A data acquisition board by Agilent, were used to manager the signal acquisition system. The measurements of temperature were taken in the first and every multiple of 10 holes machined, during three minutes. The Figure 2 shows the set-up of the experimental apparatus.

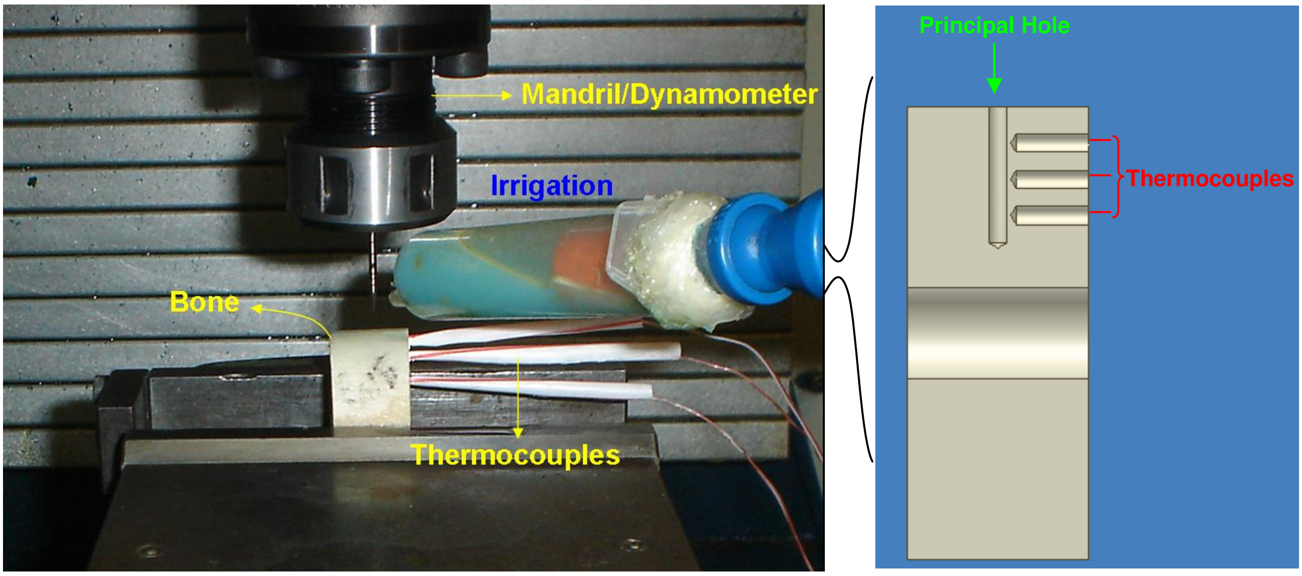

Figure 2. Experimental set-up of the apparatus and detail illustrating the thermocouple's positions.

3. RESULTS AND DISCUSSIONS

When opening a hole with the kit in the sequence showed in Fig.1 the 2 mm diameter twist drill is subjected to the higher load than any others because of the higher depth of cut (full diameter) experienced in these operations. Therefore, this twist drill is considered the most critical one when machining the sequence of holes, resulting in the highest thrust force and cutting temperature, consequently this tool was considered for data acquisition tests.

Table 3 shows the results of the thrust force when drilling with the twist drill of 2 mm of diameter (TD2). The media of maximum values of this force was considered for each test.

Table 3. Results of the maximum thrust force for different cutting conditions tested for the two tool materials.

Tests	Material	Feed Vel. [mm/min]	Spindle Speed [rpm]	Thrust Force Max. [N]
1	316L	24	1000	65.47
2	M340	24	1000	94.21
3	316L	45	1000	128.97
4	M340	45	1000	133.55
5	316L	24	2500	87.85
6	M340	24	2500	39.05
7	316L	45	2500	38.45
8	M340	45	2500	56.83

The results were analyzed using the software STATISTICA 6.0 by StatSoft. The analyses of significance were done with a confidence interval of the 95% and significance level of the 9% (or 0.09). Table 4 presents the result of the analysis for the feed velocity and spindle speed.

Table 4. Significance analyzes for the thrust force.

Factors	Effects	Std. Err.	p	CI -95%	CI +95%
Media	80.5489	7.46447	0.000418	59.8242	101.2736
Feed Velocity (fv)	17.8054	14.92893	0.298908	-23.6440	59.2548
Spindle speed (n)	-50.0043	14.92893	0.028582	-91.4536	-8.5549
fv x n	-33.6168	14.92893	0.087472	-75.0661	7.8326

It is observed that the spindle speed is the most significant input variable, although the effect of it cannot be analyzed in a single mode, because its interaction with the feed velocity had significant influence.

The Figure 3 illustrates this result for both tool material tested.

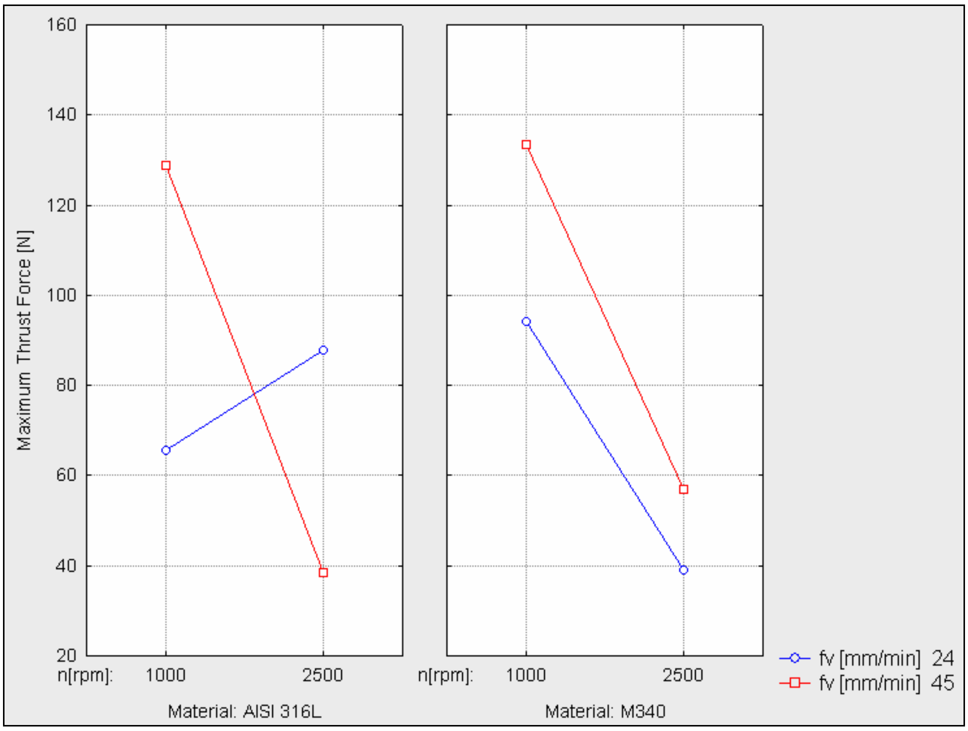

Figure 3. The influence of spindle speed on the thrust force.

In general, increasing the spindle speed the thrust force decreases. Exception of this behavior was when machining with the lowest feed velocity of 24 mm/min and the AISI 316L steel tool. When the cutting speed is raised normally the chip-tool contact length tends to decrease and this implies in reduction of the machining forces. However, when cutting with the AISI 316L steel tool with the low feed velocity plastic deformation occurred frequently. The cutting force in the lower spindle speed (test 1 of Tab. 2) caused excessive torsion (Fig. 4a). When using the higher spindle speed (test 5 of Tab. 2) the same fact occurred, the lower feed velocity combined with higher thrust force was enough to promote plastic damage on the tip of the drill (Fig. 4b). This result has proven that this tool material does not have enough strength to resist the higher forces undertaken during machining. On the other hand, when using the M340 – Böhler steel no plastic deformation was observed at any cutting condition tested. However flank wear was seen (Fig.4c).

It is interesting to point out that these results showed that for the patient in the dentist office the higher spindle speed will offer him more comfort due to reduction in the thrust force.

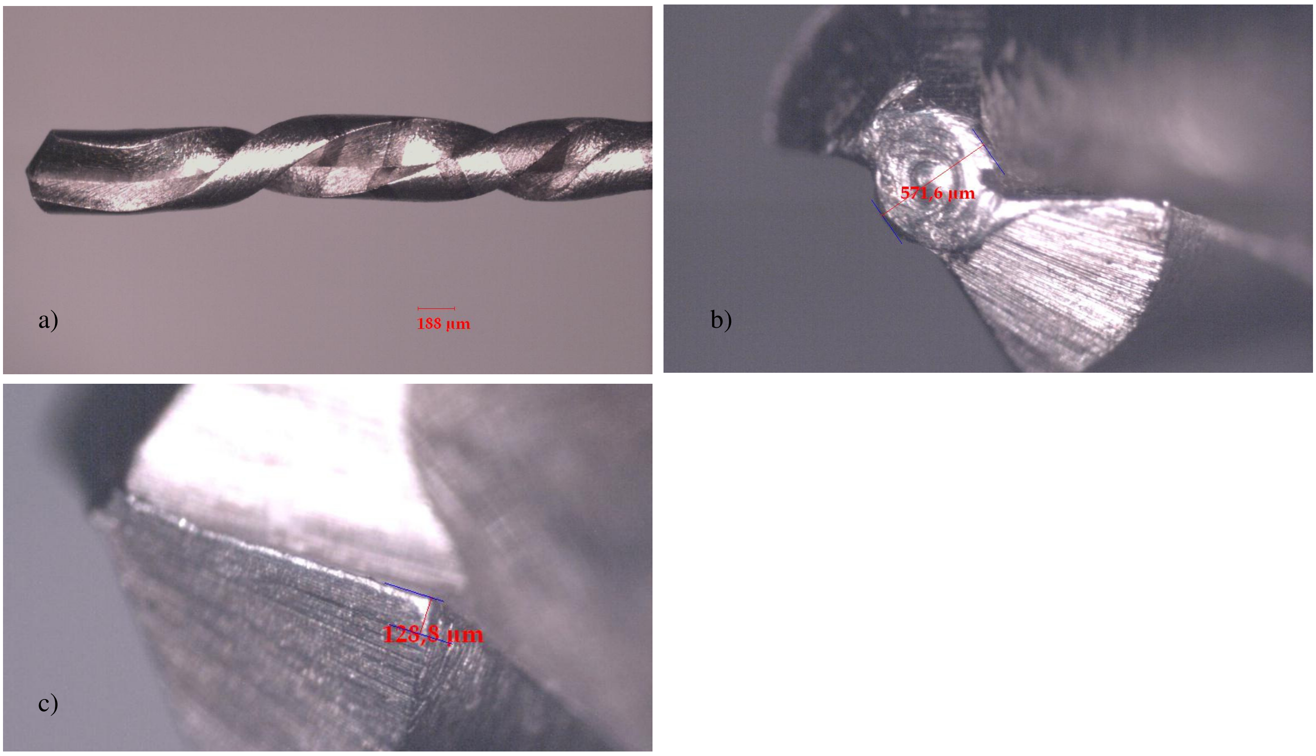

Figure 4. a) Test 1, twist drill Ø 2 mm, AISI 316L, (10x), b) Test 5, twist drill Ø 2 mm, AISI 316L, (45x) and c) Test 8, twist drill Ø 2 mm, M340 – Böhler, (45x).

Table 5 shows the results of the tool lives for all the tests, expressed by the number of drilled holes before the limit of 47°C in the hole wall was reached which was the criterion for the end of the tool life used.

Table 5. Tool life results.

Tests	Material	Feed Velocity [mm/min]	Spindle Speed [rpm]	Nº Holes
1	316L	24	1000	2
2	M340	24	1000	1
3	316L	45	1000	3
4	M340	45	1000	40
5	316L	24	2500	1
6	M340	24	2500	30
7	316L	45	2500	40
8	M340	45	2500	70

The results shown in Tab. 5 can be seen graphically in Fig. 5.

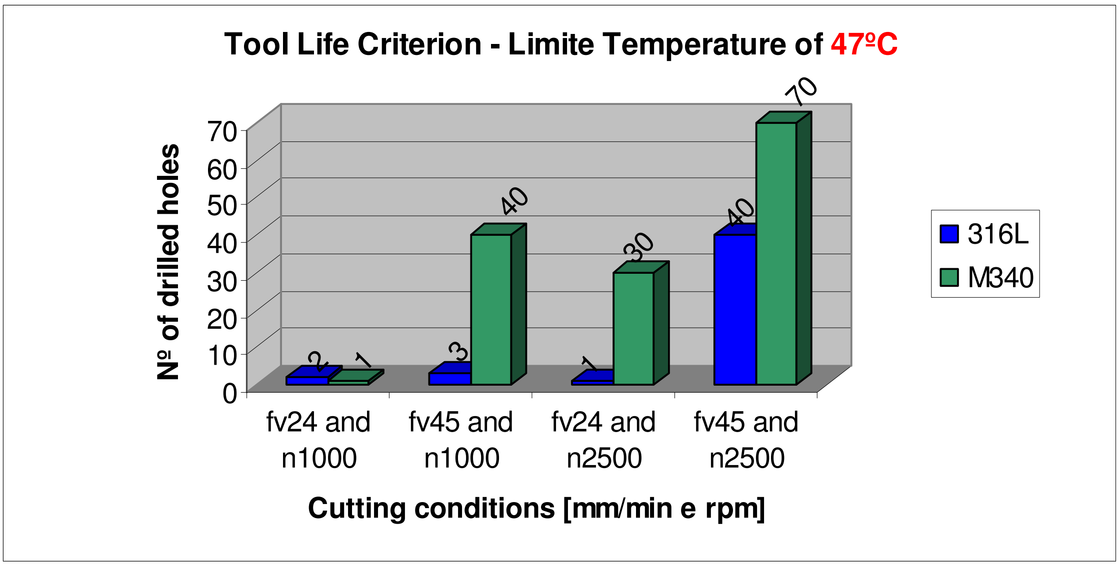

Figure 5. Number of drilled holes.

Analysis of significance with confidence interval of 95% and the significance level of 6% (or 0.06) of these results are shown in Tab.6.

Table 6. Analysis of significance for tool lives.

Factors	Effect	Std. Err.	p	CI -95%	CI +95%
Media	23.37500	4.392821	0.006001	11.17857	35.57143
Tool Material	23.37500	8.785642	0.053911	-0.64285	48.14285
Feed Velocity (fv)	29.75000	8.785642	0.027627	5.35715	54.14285
Spindle speed (n)	23.75000	8.785642	0.053911	-0.64285	48.14285

It is observed in this table that there is significant differences in the results, when change the main input variables from the lower level (-1) to the top level (+1) ($p < 0.06$). Changing the tool material from the AISI 316L steel to the M340 – Böhler steel an average increase of approximately 23 holes is expected. Moreover, increasing the feed velocity and the cutting speed from level (-1) to the level (+1) averages increase of approximately 30 and 24 holes is expected, respectively. The feed velocity is, therefore the most significant parameter influencing the hole wall temperature, within the range of cutting conditions tested. When increasing it from level (-1) to level (+1) this temperature is reduced, giving higher tool lives. Figure 6 illustrates the influence of this variable on the tool lives in the two levels of spindle speed and for both tool materials tested.

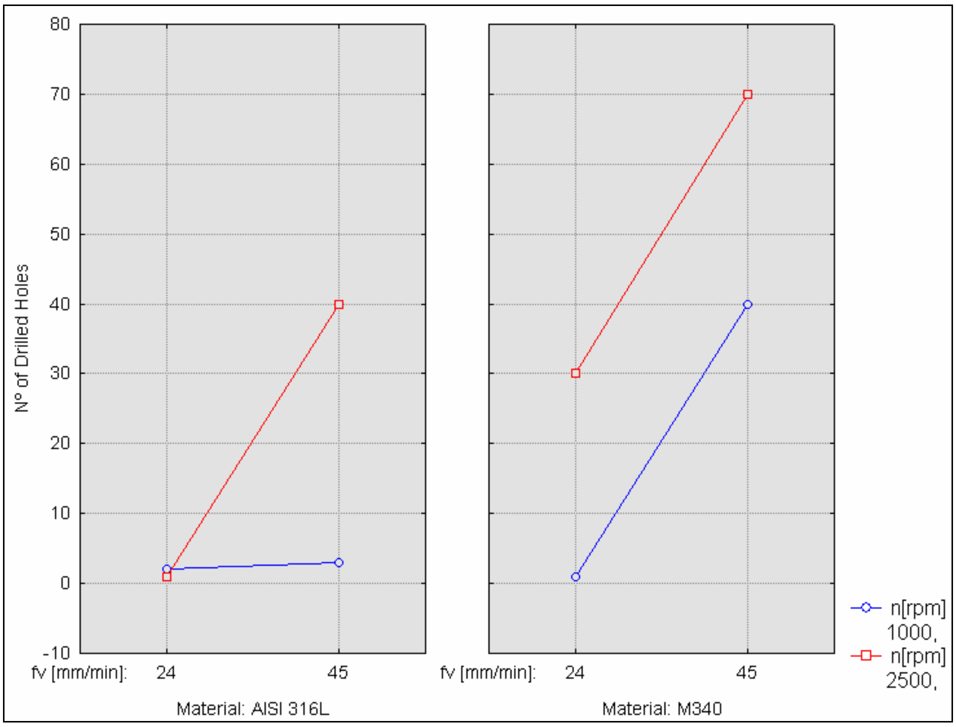

Figure 6. The influence of feed velocity on the tool lives.

When using the higher feed velocity of 45 mm/min the tool travels faster through the hole length consequently with less time to allow the heat from the tool and from the chip be dissipated into the hole wall (workpiece). In Figure 6 the superiority of M340 – Böhler steel is also evident.

Finally, Fig. 7 shows the influence of spindle speed on the tool lives in the two levels of feed velocity and for both tool materials tested. Generally, increasing the spindle speed the number of drilled holes also increases, indicating that the temperature around the site wall decreases. The explanation for these results can be given by considering the Salomon hypotheses (Longbottom e Lanham, 2006). He advocated that the temperatures due to heat generate during machining increase until a maximum point, then beginning to decrease as the cutting speed increases. Although, this theory is controversial, it can be true for the temperature changes in the workpiece in machining process. O'Sullivan e Cotterell (2001 e 2002) observed the decrease of temperature in machined surface for higher cutting and feed speeds. Dagiloke et al. (1995) said that the higher cutting speed, the lower is the time available for the heat generated to be dissipated for the workpiece. Thereby, higher spindle speed leads to increase the temperature in tool and in the chip, but not necessarily in the workpiece (in this case in the bone).

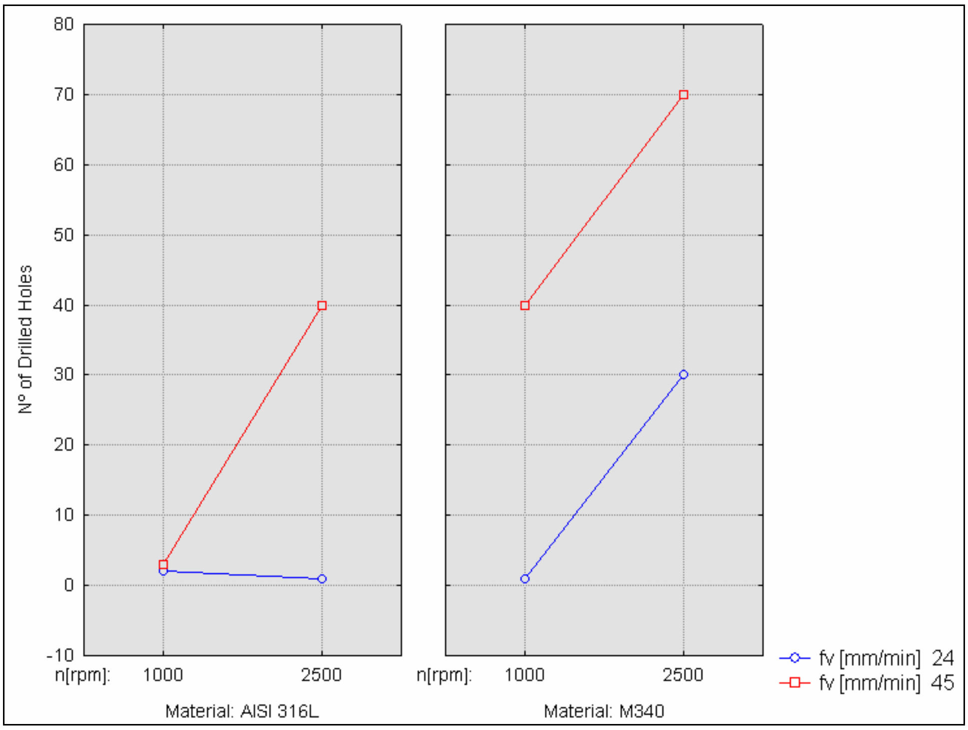

Figure 7. The influence of the spindle speed on the tool lives

3. CONCLUSIONS

The results presented allow the following conclusion to be drawn.

The martensitic stainless steel M340 by Böhler was the best tool material tested, drilling a higher number of holes than the austenitic stainless steel tool within the stipulated end of tool life criterion used (limit of 47°C on the hole walls).

The twist drills with 2 mm of diameter were subjected to the highest load and cutting temperature due to inherent higher depth of cut used.

In general, increasing the spindle speed the thrust force decreases. Exception of this behavior was when using the lowest feed velocity of 24 mm/min and the AISI 316L steel tool. Using this tool with the low feed velocity of 24 mm/min plastic deformation occurred frequently causing either excessive torsion or plastic damage of the drill tip.

It was also observed that the feed velocity is the most significant parameter influencing the hole wall temperature, within the range of cutting conditions tested. When increasing it from 24 to 45 mm/min this temperature is reduced, giving higher tool lives.

The lowest temperature and thrust force were obtained when machined with the highest cutting conditions (fv = 45 mm/min and n = 2500 rpm). This indicates that more comfort to the patient in the dentist office is achieved with this condition. This result suggests, that higher spindle speed and feed velocity may be used giving more comfort and security to the patient in the dentist office, breaking down a dentistry paradigm.

4. ACKNOWLEDGEMENTS

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