COBEM UBERLÂNDIA 2019

ABCM Associação Brasileira de Engenharia e Ciências Mecânicas

25th ABCM International Congress of Mechanical Engineering
October 20-25, 2019, Uberlândia, MG, Brazil

COB-2019-0575
THE INFLUENCE OF TEMPERATURE ON TOOL LIFE IN THREADING OF AISI 304L AUSTENITIC STAINLESS STEEL

Carlos Eduardo Costa
Milton Luiz Polli
Federal University of Technology – Paraná, PPGEM, Department of Mechanics, Rua Deputado Heitor Alencar Furtado, 5000 – Ecoville, CEP 81280-340, Curitiba – PR, Brazil
carlos.costa0121@gmail.com , polli@utfpr.edu.br

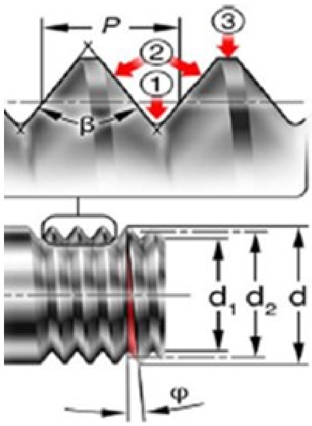
Abstract. *Usually the mechanical components are jointed by thread or welding. The thread is preferred in situations that require disassembly of the set. In pipes subjected to high temperature and pressure the stainless steel is typically used and connection per thread is employed. The objective of this work is to analyze the influence of the temperature on the tool life in turning of the external thread by the radial infeed method in the 304L austenitic stainless steel. The experiments were carried out in a CNC lathe and the temperature during the operation was measured by a thermographic camera. The tool wear was evaluated using a scanning electron microscope (MEV). The results showed that the maximum temperature measured increases linearly in function of the number of passes. The maximum temperature of the last pass was almost twice of the maximum temperature of the first one during the machining of the last workpiece due to tool wear. EDS analysis revealed that tool substrate was exposed and there was adhesion of the workpiece material on the worn tool.*

Keywords: *machining, threading, temperature, stainless steel.*

1. INTRODUCTION

There are several means used to join parts, two of which stand out: by means of the thread and welding. There are advantages and limitations to each case, which should be considered in function of the application. Threaded joints are the most common type of releasable connections.

NBR 5876 defines a thread as a helix formed by winding around a cylinder a triangle having the height equal to the pitch of the thread and the length of the circumference of the cylinder section as its basis. The two main threading systems are Metric and Whitworth. The design principles of ISO general-purpose metric screw threads ("M" series threads) are defined in international standard ISO 68-1 (ISO 68-1, 1998). Each thread is characterized by its diameters, angles and pitch (Fig. 1). ISO metric threads consist of a symmetric V-shaped thread. In the plane of the thread axis, the flanks of the V have an angle of 60° to each other.



P	Pitch
d	Major Diameter
d2	Effective Diameter
d1	Minor Diameter
β	Profile Angle
ϕ	Helix Angle
1	Root
2	Thread Angle
3	Crest

Figure 1. Design thread.

Manufacturing by machining is used especially in the materials with difficult plastic deformation and special dimensions (Manera et al., 2009). There are three possible infeed methods (radial, flank and incremental) for threading by machining, as shown in Fig. 2. The first case is the radial method, where the cutting depth is executed perpendicularly to the workpiece centerline until reaching the final height of the fillet. This method is widely used in the industry (Nalbant, et al. 2008).

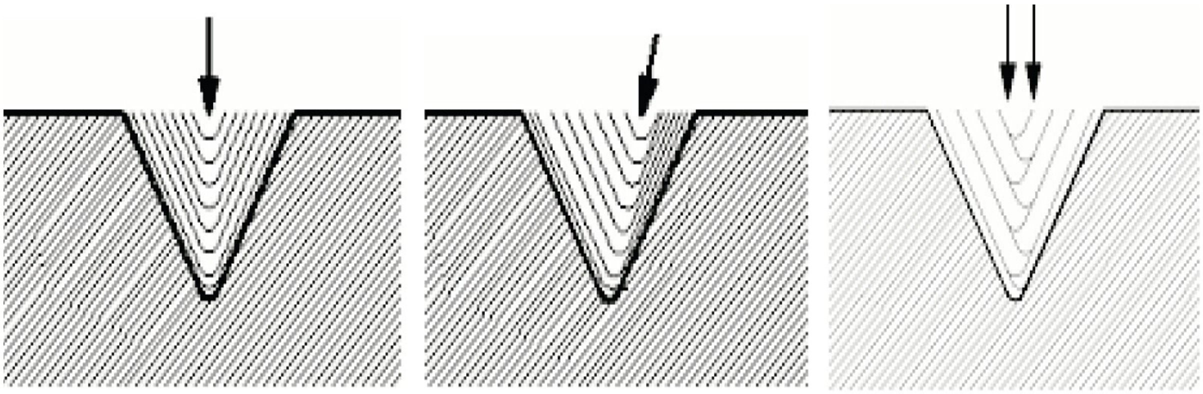


Figure 2. Infeed methods: radial, flank and incremental. (Nalbant, et al. 2008)

Threading is an operation that requires special attention due to the value added in the product as well as the future reliability, especially when applied as a fastening element in industries of oil, gas, and other that operate at high pressure and temperature. The case is even more critical in the machining of austenitic stainless steel 304, due to their characteristics. Among these, it is noteworthy its low thermal conductivity, which hinders the removal of heat in the cutting zone, increasing considerably the temperature on the tool (Shaw, 2005; Diniz, 2016). Moreover, high degree of cold-hardening causes the mechanical modification and heterogeneous behavior of the generated surfaces and instabilities in the chip formation (Akasawa, 2003). In addition, its high coefficient of thermal expansion hinders tight tolerances, and its high coefficient of friction increases machining forces and heat generated (DINIZ, *et al.,* 2001). These phenomena affect the surface finish, and in most of the time reduces tool life (Machado et al, 2003). In this context, this work aims to analyze the influence of the temperature on the tool life in turning of external thread by the radial method in the austenitic stainless steel 304L.

2. MATERIALS AND METHODS

The machined material was the AISI 304L austenitic stainless steel. Table 1 shows its chemical composition, according to ASTM A276/16. The thread (M16 X 2.5 X 170) was machined with the radial infeed method. Go and no go ring gauges were used for checking the conformity of the threaded samples.

Table 1. Chemical composition of the material ASTM (%)

C	Cr	Mn	Mo	N	Ni	P	S	Si
0.024	18.25	1.570	0.500	0.085	8.040	0.037	0.028	0.280

A cemented carbide tool PVD coating the (RG-16VM01A002M 1125) was employed in the experiments. The parameters used are shown in Tab. 2.

Table 2. Machining parameters

Radial Method	Vc (m/min)	Fillet height (mm)	Depth of cut per pass	number of passes
	50	1.58	0.09	16

The machine used in the experiments was a lathe Diplomatic BTP – 63. The experiments were performed in two stages. The preliminary stage was carried out in order to identify the tool life. This stage was performed with four tools that were removed from the lathe after machining a determined number of workpieces in order verify the tool wear condition in a Olympus SZX10 optical microscope. The first tool was removed after machining two workpieces. The second tool was removed after machining four workpieces. The third tool was removed after machining six workpieces and the last one was removed after machining seven workpieces. The second stage was carried out with two tools in order to monitor the temperature during machining. The first one was removed from the lathe after machining three workpieces for further wear analysis and the other one after machining seven workpieces. In this case, there was repetition of the experiments only for first three workpieces.

A Flir SC 600 series thermal camera with sensor resolution of 620 x 480 pixels and temperature range from -40°C to 2000°C was used to measure the temperature during machining in the second stage. This equipment can aquire images and data at high rates up to 200 Hz. The thermal camera was positioned in front of the machine tool in a distance suitable for focusing the entire workpiece and protect the camera lens against damage. Thermal video images of each pass of the threading process were recorded and transferred to Flir's R&D image processing software to further analysis. The scanning area for the temperature measurements covered the whole workpiece. The maximum temperature registered at the scanning area during each pass was verified with the software and it was taken in consider for the analysis of the tool life. Infrared thermography (IRT) is a matured and widely accepted condition monitoring tool where the temperature is measured in real time in a non-contact manner (Bagavathiappan et al., 2013). However, errors can be attributed to focusing difficulties, emissivity variation, chip flow effects and data averaging over the field of measurement (Aspinwall et al., 2013). The temperature measurements using thermal cameras tend to present lower temperature values to the interface tool/chip/workpiece than those measured by punctual methods such as the tool/workpiece thermocouple (Da Silva et al, 2018; Zgórniak and Grdulska, 2012). Aspinwall et al. (2013) reported that infrared thermography results when milling the 45-2-2-0.8 alloy were in all cases lower compared to values obtained with the constantan-workpiece thermocouple technique by an average of 28%. On the other hand, Prasad et al. (2017) proposed a tool condition monitoring condition in turning of AISI 316L steel by using infrared thermography technique and Laser Doppler vibrometer. The results indicated the feasibility of using temperatures gradient and vibration signals for the monitoring of high speed turning operations. According to Da Silva et al. (2018), the thermal images are effective to show how the regions surrounding the cutting zone heat up. The excessive heating of these zones can be a good indicator of the tool wear condition, therefore this method was used in the present work.

Tool wear analysis was performed by using a bench microscope and a Scanning Electron Microscopy coupled with Energy Dispersive X-ray Spectroscopy (Fig. 3).

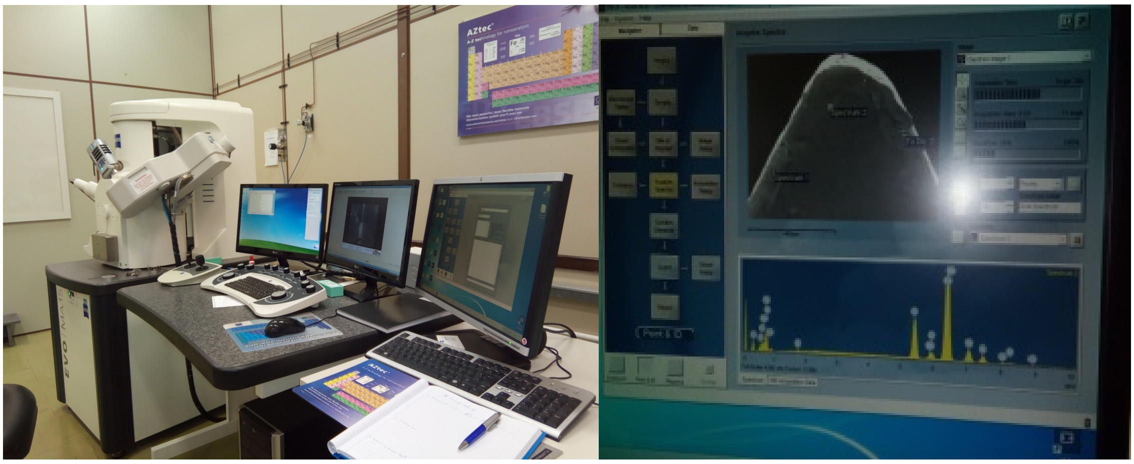


Figure 3. Scanning Electron Microscopy and EDS analysis.

3. RESULTS

Figure 4 presents one example of a thermal image where the red lines delimit the scanning area considered for the measurements. It also shows the maximum temperature measured during one pass at the scanning area. This maximum temperature measured was considered for the analysis of the tool wear. However, this is not the highest temperature that occurs during the cut, as discussed in the last section, the temperature measurements using thermal cameras tends to present lower values to the cutting zone than the actual ones. Chip obstruction also make it difficult to measure the temperature at tool-chip interface. The image also shows that continuous chip was formed during the threading process.

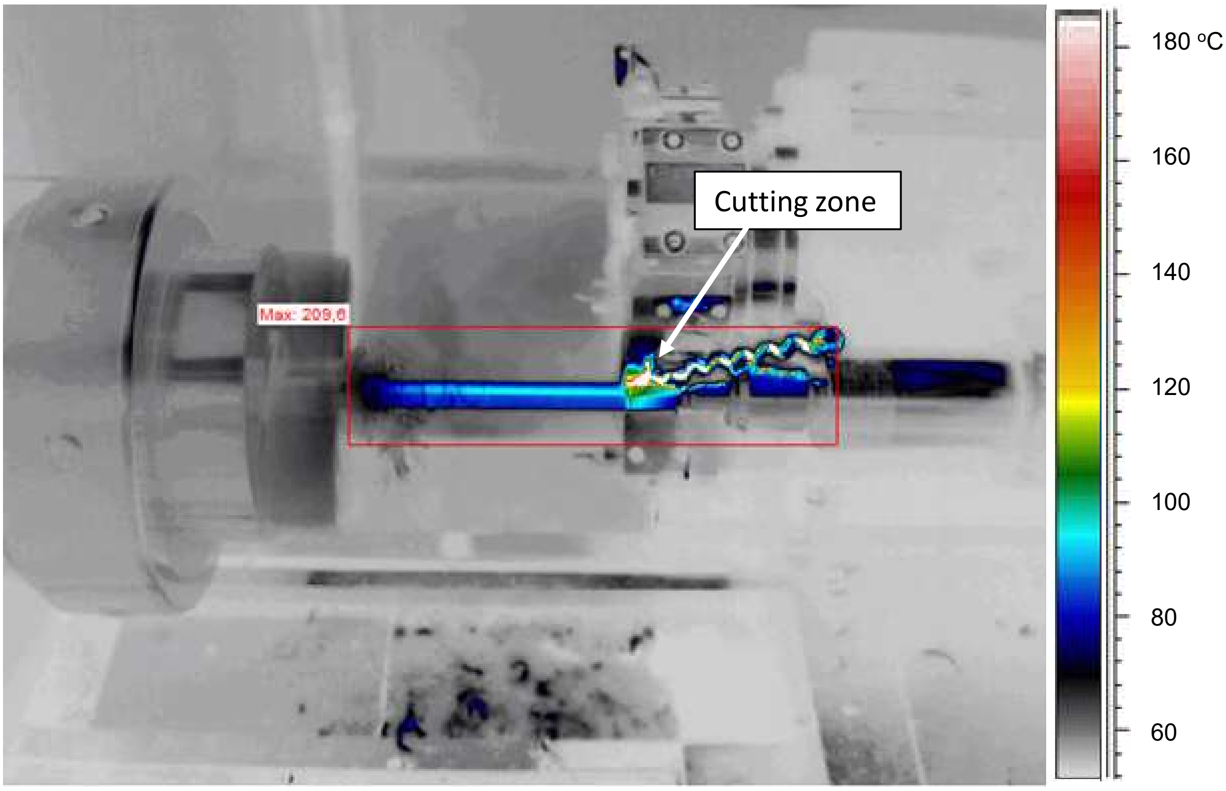


Figure 4. Thermal image of the threading process.

Figure 5 presents the evolution of the maximum temperature measured during the last pass of each machined workpiece. There is a tendency of the temperature to increase with the number of machined workpieces. For the first workpiece, the maximum temperature was close to 180 °C. There is an almost linear increase up to the sixth workpiece, when the maximum temperature was 370 °C. However, for the seventh workpiece the maximum temperature was considerably higher (670 °C), culminating in the end of the tool life.

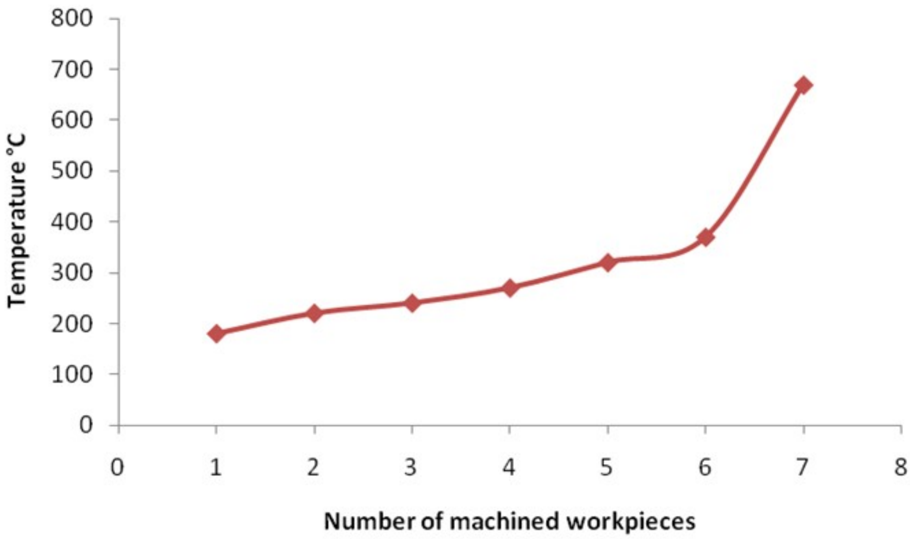


Figure 5. Maximum temperature measured during the last pass for each workpiece.

As established in the CNC program, 16 passes were performed to the machine the threads. Figure 6 shows the maximum temperature measured for some of the passes during the threading of the seventh workpiece. The maximum temperature increases linearly in function of the number of passes. There is a significant increase in each pass reaching almost twice the start of the last pass. The maximum temperature measured during the last pass achieved almost twice of the maximum temperature of the first pass due to tool wear.

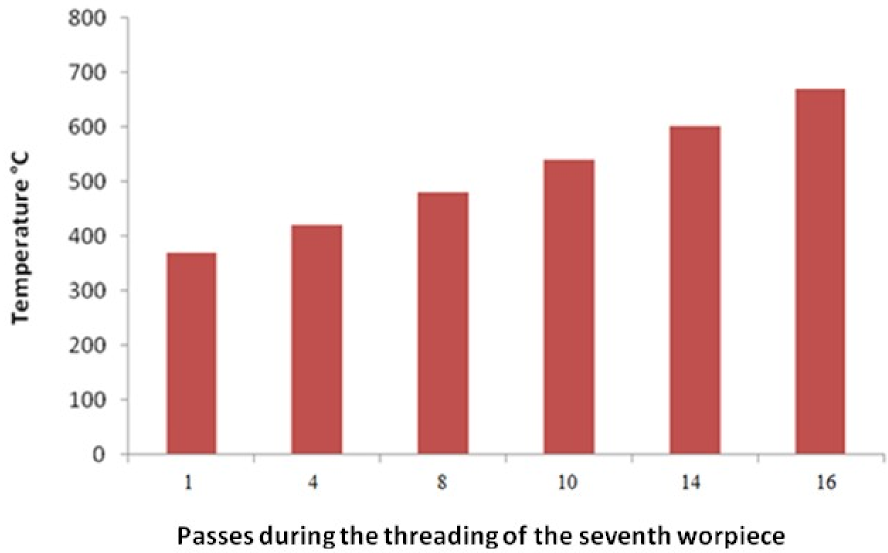


Figure 6. Temperature during machining of the last workpiece.

Figure 7 shows the evolution of flank wear as a function of the number of machined workpieces. Tool wear grew uniformly until the sixth machined workpiece, during the machining of the seventh workpiece tool wear developed rapidly. According to the thread gauge inspection, only the seventh workpiece was considered unacceptable. Severe adhesion was also responsible for the tool failure and alterations of the thread geometry.

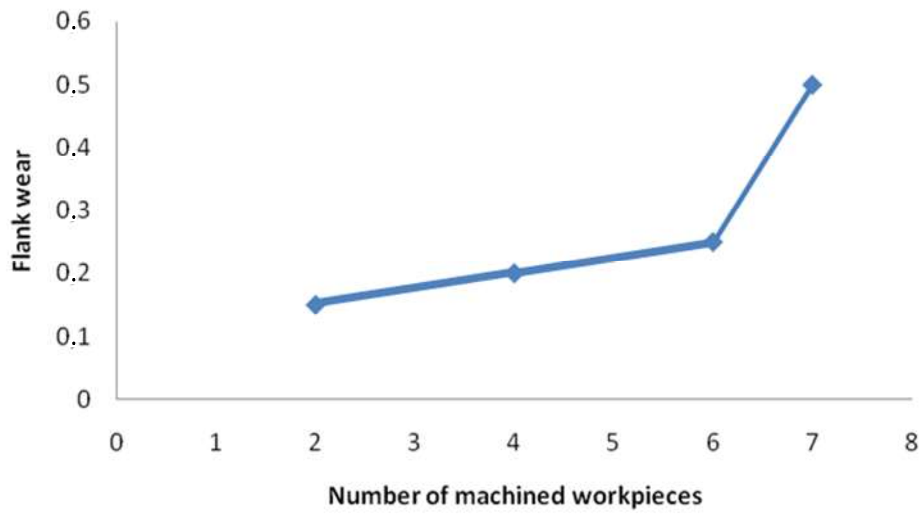


Figure 7. Flank wear in function of the number of machined workpieces.

Figures 8 shows SEM image of the tool after machining three workpieces. It is possible to observe some adhesion of the workpiece material on the tool. The adhesion of the material influences negatively the tool life, hindering the chips formation and flow. Under these conditions, microscopic particles of the tool may be pulled out and dragged away together with the material flow accelerating tool wear. Figure 9 depicts the image of a worn tool after machining seven workpieces, where it is possible to notice the detachment of the coating and adhesion of the workpiece material on the rake face.

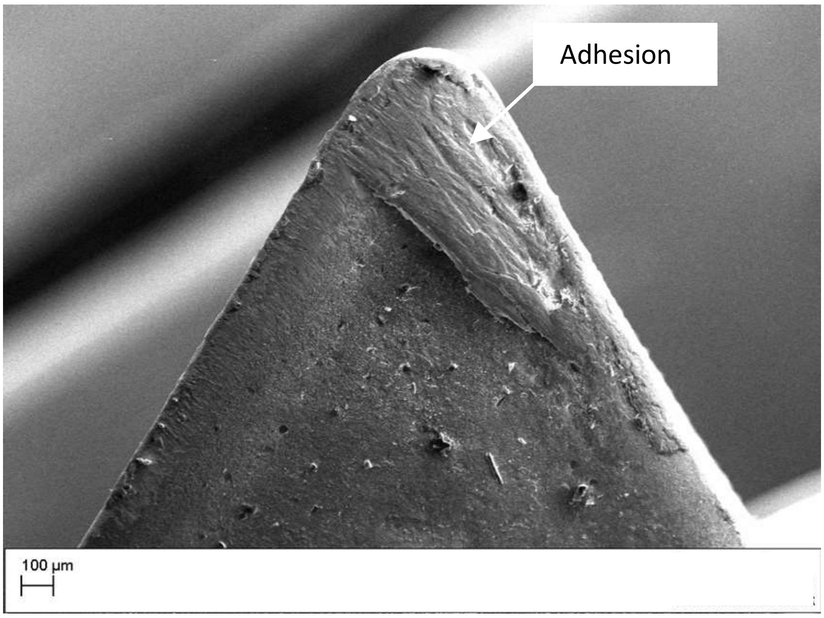


Figure 8. Tool after machining three workpieces.

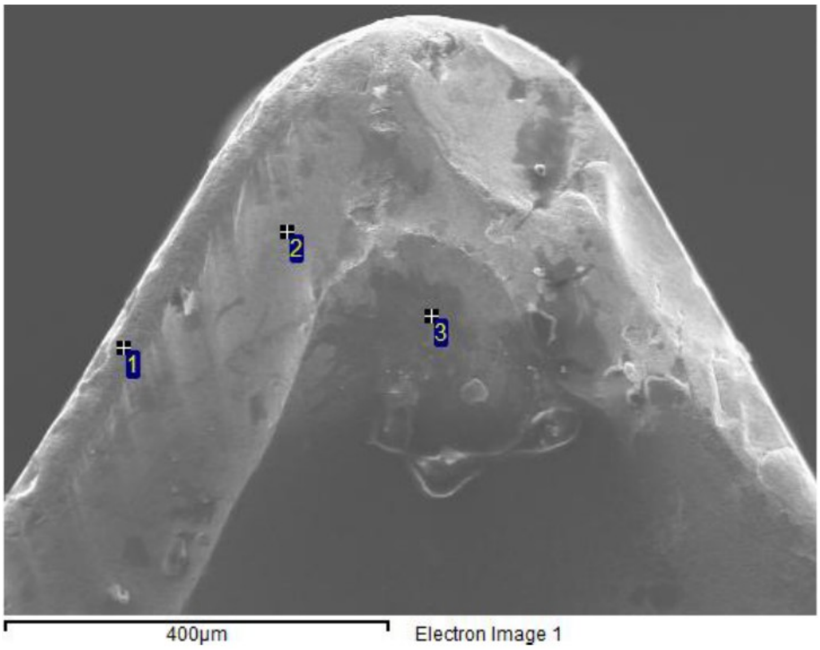


Figure 9. Tool after machining seven workpieces.

The SEM-EDS analysis (Tab. 3) reveals that at region 1, close to the cutting edge, coating is still preserved with a high concentration of Al and Ti and N. However, some adhesion of the workpiece material took place as indicated by the presence of Fe (6.24 wt%). Moreover, W and Co (72.95 and 7.71 wt%, respectively) elements from the substrate are found at region 2, what indicates that coating was peeled off at this region of the tool face and the substrate of the tool was exposed. After that adhesion easily took place on flank face where the presence of Fe (5.28 wt%) was detected. There was no significant adhesion of the workpiece material at region 3, which was more distant from the cutting edge.

Table 3. Results of EDS analysis (%).

Region	C	N	O	Al	Si	Ca	Ti	Fe	Co	W
1	9.46	27.59	3.02	10.29	0.31		41.87	6.24	0.23	1.00
2	1.02							5.28	7.74	72.95
3	57.74		6.37	5.23	0.42	0.17	26.08		0.18	3.80

4. CONCLUSIONS

The results showed that the maximum temperature increases with the number of machined workpieces. There was an almost linear increase of the maximum temperature up to the sixth workpiece. However, for the seventh workpiece the maximum temperature was considerably higher, culminating in the end of the tool life.

The maximum temperature increases linearly in function of the number of passes. The maximum temperature of the last pass was almost twice of the maximum temperature of the first one during the machining of the seventh workpiece due to tool wear. The EDS analysis revealed that tool substrate was exposed and there was severe adhesion of the workpiece material on the worn tool, which contributed to the tool failure and alterations of the thread geometry.

5. ACKNOWLEDGMENTS

The authors would like to thank the Centro Multiusuário de Caracterização de Materiais – CMCM of UTFPR-CT and the metallurgical company USIFIX-IANCO.

6. REFERENCES

Akasawa, T., Sakurai, H., Nakamura, M., Tanaka, T. and Takano, K., 2003. "Effect of free-cutting additives on the machinability of austenitic stainless steel". *Journal of Materials Processing Technology*, Vol. 143, pp. 143–144.

Aspinwall, D.K., Mantle, A.L., Chan, W.K., Hood, R. and Soo, S.L., 2013. "Cutting Temperatures when Ball Nose End Milling γ-TiAl Intermetallic Alloys". *CIRP Annals - Manufacturing Technology*, Vol. 62 (1) , pp. 75-78.

Bagavathiappan, S., Lahiri, B.B., Saravanan, T., Philip, J. and Jayakumar, T., 2013. "Infrared thermography for condition monitoring – a review". *Infrared Physics & Technology*, Vol. 60, pp. 35–55.

Da Silva L.R.R., Filho, A.F., Costa, E.S., Pico D.F.M., Sales, W.F., Guesser, W.L. and Machado A.R., 2013. "Cutting Temperatures in End Milling of Compacted Graphite Irons". *CIRP Annals - Manufacturing Technology*, Vol 26, pp. 474–484.

Diniz, A.E., Machado, A.R. and Corrêa, J.G., 2016. "Tool Wear Mechanisms in the Machining of Steels and Stainless Steels". *International Journal of Advanced Manufacturing Technology*, Vol. 87, pp. 3157–3168.

ISO 68-1:1998 *ISO general purpose screw threads – Basic profile – Part 1: Metric screw threads.* International Organization for Standardization.

Machado, A.R., Abrão, A.M., Coelho, R.T. and Da Silva, M.B., 2015. *Teoria da Usinagem dos Materiais.* Ed. Edgard Blucher, São Paulo, 3rd edition.

Manera, R.S., Rodrigues, A.R., Matsumoto, H. and Gallego, J. "Influence the External Threading Processa t High Speed Cutting on Turning of Dental Implants". In *Proceedings of the 20th International Congress of Mechanical Engineering-COBEM 2009*. Gramado, Brazil.

Nalbant, M., Gunay, M. and Yildiz, Y., 2008. "Modelling of the Effect of Different Infeed Angles and Cutting Areas on the Cutting Forces in External Threading". *Turkish Journal of Engineering and Environmental Sciences*, Vol. 32, pp. 153–161.

Prasad, B. S., Prabha, K.A. and Kumar, P.V.S.G., 2017. "Condition monitoring of turning process using infrared thermography technique – An experimental approach". *Infrared Physics & Technology,* Vol. 81, pp. 137–147.

Shaw, M.C., 2005. *Metal cutting principles*. Oxford University Press, New York, 2nd edition.

Zgórniak, P. and Grdulska, A., 2012. "Investigation of temperature distribution during milling process of AZ91HP magnesium alloys". *Mechanics and Mechanical Engineering*, Vol. 16, pp. 33-40.

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.