https://doi.org/10.47456/bjpe.v10i3.44839

ARTIGO ORIGINAL | OPEN ACCESS

INDUCTIVE METHODOLOGY AND CASE STUDY FOR SELECTION OF CUTTING PARAMETERS IN MICROMILLING OF INCONEL 718

METODOLOGIA INDUTIVA E ESTUDO DE CASO PARA SELEÇÃO DE PARÂMETROS DE CORTE EM MICROFRESAMENTO DO INCONEL 718

METODOLOGÍA INDUCTIVA Y CASO DE ESTUDIO PARA SELECCIÓN DE PARÁMETROS DE CORTE EN MICROFRESADO DE INCONEL 718

Henrique Hansen Barros [1], **Gabriel de Paiva Silva** [2], **Lucival Malcher** [3], & **Déborah de Oliveira** [4]

[1 2 3 4] Universidade de Brasília, Faculdade de Tecnologia, Departamento de Engenharia Mecânica

[1] henriquehhb@gmail.com [2] dpaivagabriel@gmail.com [3] malcher@unb.br [4] oliveira.deborah@unb.br

ARTICLE INFO.

Received: 07.06.2024
Approved: 16.07.2024
Available: 25.07.2024

KEYWORDS: *Miniaturization; Micromilling; Size Effect; Cutting parameters; Inconel 718.*

PALAVRAS-CHAVE: Miniaturização; Microfresagem; Efeito de tamanho; Parâmetros de corte; Inconel 718.

PALABRAS CLAVE: *Miniaturización; Microfresado; Efecto De Tamaño; Parámetros de corte; Inconel 718.*

***Corresponding Author: Silva, G. de P.**

ABSTRACT

Manufacturing processes have been increasingly innovated to allow the fabrication of miniaturized parts with high levels of dimensional precision. When micromilling the tool tip radius has similar dimension to the uncut chip thickness, therefore the tool cannot be considered perfectly sharp. When the minimum chip thickness is not applied on the cut, there will be more deformation than the proper shearing of the material, leading to high specific energy, characteristic of the size effect. Thus, in micromachining processes, the adequate choice of cutting parameters is fundamental to enable chip formation. This necessity is highlighted for hard to cut materials, as the Inconel 718, which is nickel-based superalloy that is often used in harsh environments because of its high strength and corrosion resistance. In this sense, this work aims to contribute to cutting parameters selection for the Inconel 718 microcutting. By means of inductive methodology, case studies and bibliographic review, this work aims to determine the most efficient cutting parameters, tool materials and lubrication conditions in micromilling of Inconel 718. After the analysis some parameters and conditions stood out as being the more suitable. Therefore, for microcutting Inconel 718 it is suggested the use of cutting fluid with the MQL technique, TiAlN coated microtools, a feed per tooth of 5.0 µm/tooth and the axial depth of cut of 100 µm.

RESUMO

Os processos de fabricação têm sido cada vez mais inovadores para permitir a fabricação de peças miniaturizadas com altos níveis de precisão dimensional. No microfresamento o raio de ponta da ferramenta tem dimensão semelhante à da espessura de corte, portanto a ferramenta não pode ser considerada perfeitamente afiada. Quando a espessura mínima de cavaco não é aplicada, haverá mais deformação plástica do que o cisalhamento adequado do material, levando a uma alta energia específica, característica do efeito escala. Assim, nos processos de microusinagem, a escolha adequada dos parâmetros de corte é fundamental para possibilitar a formação de cavacos. Essa necessidade é destacada para materiais de difícil corte, como o Inconel 718, que é uma superliga à base de níquel frequentemente utilizada em ambientes agressivos devido à sua alta resistência mecânica e resistência à corrosão. Neste sentido, este trabalho visa contribuir na seleção de parâmetros de corte para o microcorte do Inconel 718. Por meio de metodologia indutiva, estudo de caso e revisão bibliográfica, este trabalho tem como objetivo determinar os parâmetros de corte, materiais de ferramenta e condições de lubrificação mais eficientes no microfresamento do Inconel 718. Após a análise alguns parâmetros e condições se destacaram como sendo os mais adequados. Assim, para o microcorte Inconel 718 sugere-se a utilização de fluido de corte com técnica MQL, microferramentas revestidas com TiAlN, avanço por dente de 5,0 µm/dente e profundidade de corte de 100 µm.

RESUMEN

Los procesos de fabricación se han vuelto cada vez más innovadores para permitir la fabricación de piezas miniaturizadas con altos niveles de precisión dimensional. En el microfresado, el radio del filo de la herramienta tiene una dimensión similar al espesor de la viruta sin cortar, por lo que la herramienta no puede considerarse perfectamente afilada. Cuando no se aplica el espesor mínimo de viruta en el corte, habrá más deformación que un corte adecuado del material, lo que conducirá a una alta energía específica, característica del efecto escala. Por tanto, en los procesos de micromecanizado, la elección adecuada de los parámetros de corte es fundamental para permitir la formación de viruta. Esta necesidad se destaca en el caso de materiales difíciles de cortar, como el Inconel 718, que es una superaleación a base de níquel que se utiliza a menudo en entornos agresivos debido a su alta resistencia y resistencia a la corrosión. En este sentido, este trabajo pretende contribuir a la selección de parámetros de corte para microcorte de Inconel 718. A través de metodología inductiva, estudio de casos y revisión de literatura, este trabajo tiene como objetivo determinar los parámetros de corte, materiales de herramienta y condiciones de lubricación más eficientes en el microfresado Inconel 718. Luego del análisis, se destacaron algunos parámetros y condiciones como los más adecuados, por lo tanto, para el microcorte con Inconel 718 se sugiere utilizar fluido de corte con técnica MQL, microherramientas recubiertas con TiAlN, avance por diente de 5,0 µm/diente y profundidad de corte de 100 µm.

1. INTRODUCTION

Micromachining is a mechanical manufacturing process allowing the fabrication of miniaturized components and details, with tight dimensional tolerances. Therefore, high levels of precision are required in such processes, which have been used in several industries “such as aerospace, biomedical, electronics, environmental, communications, and automotive” (Chae et al., 2006). Micromilling can be defined according to the dimensions of the cutting tool. A milling procedure can be characterized as micromilling if the diameter of the cutting tool is between 1 μm and 1000 μm (Camara et al., 2012).

A major challenge associated with micromachining is size effect, which hinders the process of chip formation. In micromilling, the radius of the cutting edge of the tool cannot be neglected, because its size is compared to the minimum uncut chip thickness. This opposes to conventional machining in macro scale, where the tool can be considered perfectly sharp. During micromilling, in the zone of interaction between the tool and the machined part, a relatively large amount of workpiece material is compressed and plastically deformed by the rounded tool edge, instead of being effectively sheard and removed in the form of chips. This phenomenon implies in a high specific cutting energy, because large quantities of energy are spent for removing relatively small volumes of chips. If the minimum uncut thickness is not sufficient, the tool may cause excessive plastic deformation with no chip formation, resulting in poor surface quality (Liu & Melkote, 2007).

Considering the tool size and material removal rate, the values of feed per tooth tend to be significantly smaller in micromachining than in conventional machining. In general, in micromachining, the size of the cutting-edge radius of the tool is comparable to the microstructure of the machined material. Therefore, in order to perform efficient cutting, the tool needs to shear individual grains or very few grains at each pass (Bissacco et al., 2005).

Most research works published in the field of micromachining tend to focus on materials of good machinability, such as steels, aluminum, and copper alloys. It is estimated that less than 6% of works on micromilling focus on other materials such as nickel alloys (Camara et al., 2012). Inconel 718 is a nickel superalloy often used in harsh applications, undergoing high cycles of stress and temperature, due to its high mechanical strength in elevated temperatures and excellent corrosion resistance. These characteristics make of Inconel 718 a low machinability material, especially in micromachining applications (Wang et al., 2017).

Therefore, considering the difficulties imposed by micromachining, as well as the scarcity of works on micromachining of Inconel 718, the present work objective it to discuss and identify the cutting parameters that can contribute to reducing cutting tool wear (tool diameter reduction) and burr formation in the micromilling of Inconel 718. As secondary objective this investigation aims to make recommendations and discuss the trends on the most efficient cutting parameters for micromachining of Inconel 718, considering previous experiences of other authors.

2. METHODOLOGY

The bibliographic data survey in the present work was performed according to the inductive method proposed by Zanella (2013). This method consists in three steps. The first step consists in identifying phenomena, in this case phenomena that happen in micromilling of Inconel 718, such as burr formation, tool wear and poor surface quality. In the second step, these phenomena are compared, and their causes are identified. Finally, in the third step, generalizations are made in order to propose the most efficient parameters for micromilling of Inconel 718.

Considering the scarcity of works on micromilling of Inconel 718, case studies were performed, using detailed analysis of representative works. The theoretic methodology proposed by Flynn et al. (1990). was used for the selection of bibliographic material, using key words such as: micromilling; micromachining; Inconel 718; cutting fluid; burr formation. For better visualization of the comparative results, as mentioned by Garza-Reys (2015) the systematic literature review should go through four phases (i.e. planning, sampling, analyzing and reporting). To present the data, the results are presented graphically. It is also important to remark that for the same reason no date limitation was applied to the results.

3. RESULTS AND DISCUSSION

3.1. ANALYSIS OF STUDIES ON MICROMILLING OF INCONEL 718

Ucun et al. (2015) performed an investigative study on tool wear during micromilling of Inconel 718. The authors used a micromill with diameter 768 µm and cutting-edge radius 2 µm, with the following coatings: TiAlN + AlCrN; DLC (diamond-like carbon); TiAlN + WC; and AlCrN. The cutting velocity used was 48 m/min and the machined length was 120 mm. After conducting the experiments varying the values of axial depth of cut and feed per tooth, the authors identified the presence of built-up edge, intense flank wear and fractures on the cutting edge due to fatigue. The coated tools presented considerably less wear and less diameter reduction compared to the uncoated tools. Higher values of tool wear were observed for smaller values of feed per tooth and axial depth of cut, which is uncommon in conventional machining. According to the authors, the use of cutting fluid in MQL (minimum quantity of lubrication), which was performed with the vegetable oil Coolube 2210 at 150 ml/h, decreased chip adhesion on the machined surface and promoted longer tool life.

Wang et al. (2017). performed a computational work on micromilling of Inconel 718. The authors highlight the existence of studies on conventional machining of Inconel 718, however there is still a deficit of studies on micromachining of this material, so that the comprehension of micro scale machining of this superalloy is partially limited. The authors used a tridimensional FEM (finite element method) model of a micromill with diameter 500 µm and edge radius 5 µm. According to the numerical results, the authors suggest that the cutting forces increase with greater values of feed per tooth. The authors also found a critical value of feed per tooth of 1.5 µm. Values below this threshold were not able to cause material removal, only plastic deformation. Thus, the authors recommend the use of feed per tooth greater than the threshold to reduce cutting forces in micromilling.

It is known that the application of cutting fluid can significantly improve the surface quality of surfaces obtained by micromilling Oliveira (2021). Oliveira (2019) analyzed micromilling of Inconel 718 using a micromill of diameter 400 µm, made of WC and coated with (Al,Ti)N. Machining experiments with cutting fluid and under dry condition were carried out, varying the cutting speed, the feed per tooth and the axial depth of cut, manufacturing micro slots of length 15 mm and a depth of 40 µm. In the dry machining experiments, the author observed a high level of tool wear and poor surface quality of the machined part. Other phenomena observed were elastic recovery of machined material, accumulation of workpiece material on the tool, diameter loss and decrease of coating adhesion. The burr size decreased with increase in cutting speed. It was observed that cutting forces are smaller for machining in dry condition than in lubricated condition. In the lubricated condition, the author also observed significant improvement on the surface quality of the machined slots in the zones with more lubrication.

An important aspect that highly affects the surface quality of surfaces produced by micromilling is the presence of large burrs. Burrs in micromilling are more significant than in conventional machining, because of size effect. Burrs resultant from micromilling of Inconel 718 are undesirable not only for the usage of the component, but also for microtool wear control (Kiswanto et al., 2014).

Kiswanto, Azmi and Ko (Kiswanto et al., 2019) conducted a study on surface quality of surfaces fabricated by micromilling of Inconel 718 under low cutting speeds, using microtools with diameter 1 mm coated with TiAlN, varying cutting parameters so that a total of nine sets of parameters were used. The authors obtained the highest values of surface roughness for the smallest cutting speed, which was 9.43 m/min, combined with the highest feed rate, 120 mm/min. The authors concluded that high values of feed result in high surface roughness and high cutting speeds lead to smaller roughness.

In another work, Aslantas and Çiçek (Aslantas & Çiçek, 2018) investigated the effects of the lubricating condition in micromilling of Inconel 718. The authors used the following lubrication conditions: ethanol; vegetable-based oil DuALL Al 2100 under conventional and MQL methods; and dry machining. The MQL method resulted in minimum tool wear, whereas lubrication with ethanol led to the highest wear and poorest surface quality. Ethanol proved to be a bad lubricant for micromilling of Inconel 718, since it led to abrupt reduction of tool diameter and the highest values of surface roughness.

Santos et al. (Santos et al., 2021) studied burr formation in micromilling of Inconel 718 and on stainless steel UNSS32205. The authors used a micromill of diameter 381 µm coated with TiN and edge radius 1 µm. Two different lubricants were used, both under flood condition, using a cutting speed of 36 m/min, feed of 1.5 µm per tooth and axial depth of cut of 30 µm. The authors observed that most burrs were generated on the up-milling side rather than the down milling side, for all lubrication conditions. The authors' main conclusion is that flooding is the most efficient lubrication condition, with less burr formation.

Sadiq et al. (2018) investigated micromilling of Inconel 718 fabricated by additive manufacturing, through SLM (selective laser melting), in order to analyze the effects of tool coatings and cutting parameters on surface roughness and tool wear. The performance of uncoated tools proved to be inefficient because expressive variations of surface roughness were detected.

Kuram and Ozcelik (2015) conducted a study aiming at the optimization of machining parameters on materials used in aerospace industry through the Taguchi method. One of the materials studied by the authors was Inconel 718, with hardness 43 HRC. The tool used by the authors had 800 µm of diameter and cutting-edge radius of 3 µm. All the tests were conducted under dry condition, with cutting length 3000 mm and cutting width 100 µm. The authors detected predominant presence of tool wear, as well as burrs on the tool, which the authors justified with the high reactivity of the material combined with impacts and stress concentration.

Size effect in micromilling of Inconel 718 has been reported to drastically increase specific cutting energy. In the work of Oliveira et al. (2019), the authors observed that high rates of oxidation on small volumes of Inconel 718 can lead to the formation of spheroidal chips with dendritic microstructure. The presence of this type of chip can be an indicator of high specific energy and that cutting parameters should be optimized (Oliveira et al., 2021). It is possible to predict output parameters in machining processes using computational simulations, although the presence of non-linearities associated with size effect hinders simulation of micromilling (Silva et al., 2023).

3.2. COMPARISON OF CUTTING PARAMETERS

Considering eight different studies about micromachining of Inconel 718 from the bibliographic database, a comparative and statistical analysis was carried out. The works used for the case study are shown in Table 1. The eight works together provided 120 machined samples that were compared in the present study.

Table 1. Works analyzed for the case study

Study	Feed per tooth (µm)	Cutting speed (m/min)	Axial depth of cut (mm)	Cutting fluid	Tool diameter (µm)	Tool tip radius (µm)	Tool coating	Surface roughness (µm)	Down milling burr formation (µm)	Up milling burr formation (µm)	Tool diameter reduction (%)
Ucun, Aslantas and Bedir (2013)	1.25 2.50 3.75 5.00	48.00	0.11 0.15 0.20	Dry MQL	768	2.0	AlTiN DLC TiAlN+WC/C AlCrN Uncoated	-	-	-	✓
Oliveira (2019)	0.10 1.00 5.00	13.8 25.1 50.3 75.4	0.02 0.04	Dry MQL	400	1.1	TiAlN	✓	✓	✓	✓
Kiswanto, Azmi and Ko (2019)	1.50 2.10 3.00 4.30 5.00 6.00 8.60 10.00 20.00	9.43 22.00 31.43	0.01	Dry	1000	-	TiAlN	✓	-	-	-
Ucun, Aslantas and Bedir (2015)	1.25 2.50 3.75	47.75	0.10 0.15 0.20	Dry	760	2.0 3.0	Uncoated	✓	-	-	✓
Aslantas Çiçek (2018)	1.00	31.4	0.10	Dry MQL Flood	600	1.8	TiCN	✓	-	✓	✓
Santos et al. (2021)	1.50	36	0.03	Dry Flood	581	1.0	TiN	-	✓	✓	-
Sadiq et al. (2018)	0.80 1.20	14 19	0.02	MQL	508	3.18	AlTiN AlTiN/Si3N4 Uncoated	✓	-	-	-
Kuram and Ozcelik (2015)	2.50 3.40 4.20	25.13 27.65 30.16	0.05 0.08 0.10	Dry	800	3.0	-	✓	-	-	✓

In each one of the cases analyzed, the respective authors used a different value of tool diameter, so no predominance of specific diameters was observed. In nine of the 120 samples, the cutting-edge radius of the tool was not informed by the authors, and for the other samples, there is a predominance of the cutting-edge radius of 2 µm.

It is known that the coating of the microtool is an important parameter that affects its performance, considering that microtools need good wear resistance since they are subjected to high speeds. In 7.5% of the samples analyzed, the authors did not inform the coating of the tool. This omission only happened in one work with nine samples. It is possible to observe a tendency for the use of AlTiN, since it was the coating used in four out of eight of the studies.

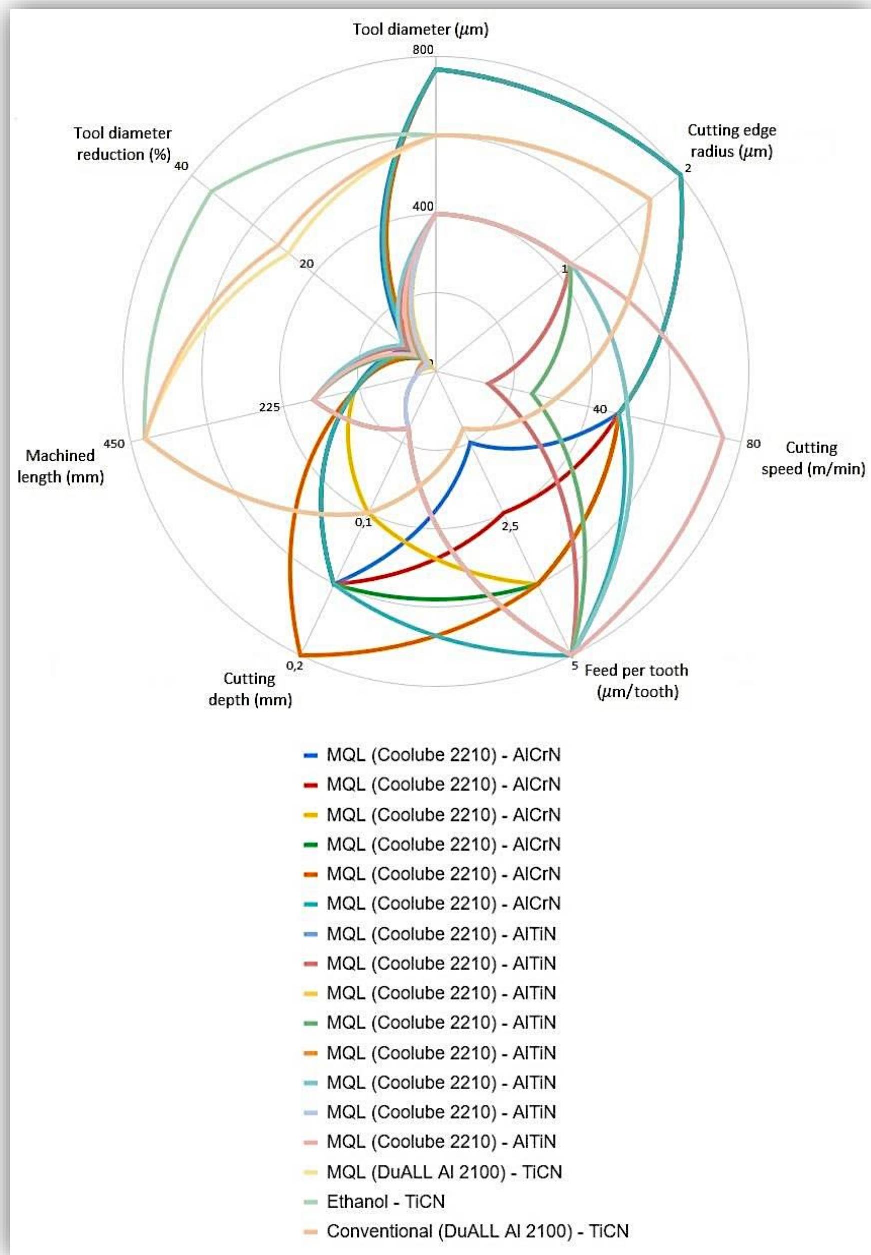
The cutting speed is one of the most important factors in determining cutting tool life (Saedon et al., 2012). The works in the bibliographic database presented considerable variation in cutting speed, so no standardization of this parameter was detected for micromilling of Inconel 718. As for the feed per tooth, all authors informed the values in their respective works. It is known that the higher feed per tooth the better surface finish in micromilling it gets, also with shorter machining time and less tool wear (Kiswanto et al., 2019). There was a significant range between the smallest and the highest values of feed per tooth in the studies analyzed (0.1 µm and 20 µm, respectively). Nevertheless, the feed of 5 µm per tooth occurred in 50% of the works.

The axial depth of cut of the samples analyzed varied within a wide range, from 0.01 mm to 0.2 mm. The value of 0.1 mm stands out as the most frequently used among all the authors. As for the length of cut, only one of the studies did not inform its value. The cutting length of 120 mm was used in 60% of the samples, however, this occurrence was limited to the two works with the biggest number of samples. The cutting length is directly associated to burr formation, since burrs tend to increase with the degradation of the cutting tool, which suffers higher wear rates with the machined length.

Another factor that is important in determining surface quality in micromilling of Inconel 718 is the lubrication condition. In seven out of eight works analyzed in the present review study, there were samples manufactured with dry machining, not using any lubrication, even though lubrication is expected to improve surface finish, decrease burr formation, and minimize tool wear (Oliveira, 2019; Oliveira et al., 2021). Considering that authors applied different cooling-lubrication methods in the same study, the lubrication was used in five out of the eight studies, one of which did not test dry machining, whereas four studies presented samples manufactured in both dry and lubricated conditions.

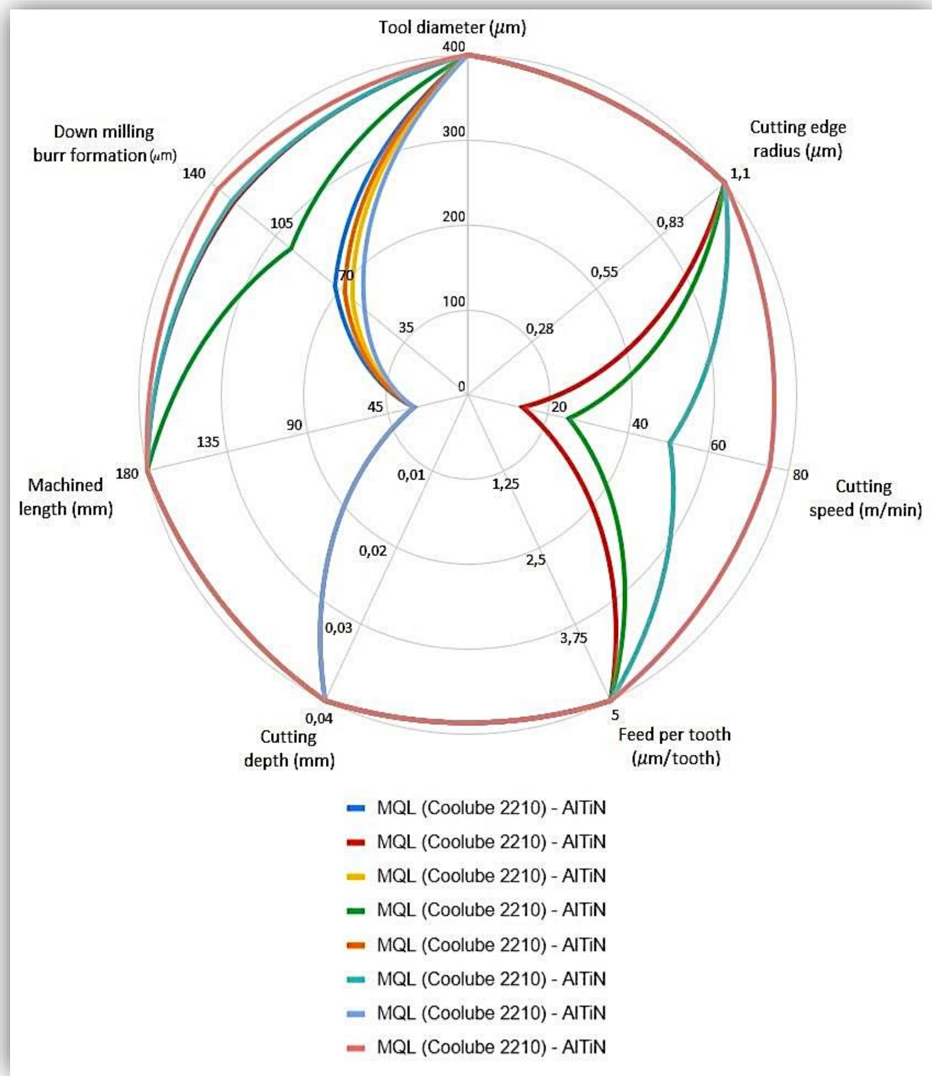
Fig. 1 shows the percentage of tool diameter reduction according to the cutting parameters used in each experiment conducted under lubricated condition. Seventeen samples were used in Fig. 1, which were the experiments whose authors informed the tool conditions, as well as lubricating and machining parameters. Three samples are remarkable for generating significative more tool wear in comparison to the others, which were samples produced in the work of Aslantas and Çiçek (Aslantas & Çiçek, 2018). The third greatest value of diameter loss, which was 24.16%, is roughly five times greater than the fourth value, of 4.75%. These same samples also had superior machining lengths. Therefore, it can be observed that length of cut is a relevant factor in determining tool wear in micromilling of Inconel 718.

Figure 1. Tool diameter reduction according to lubrication condition



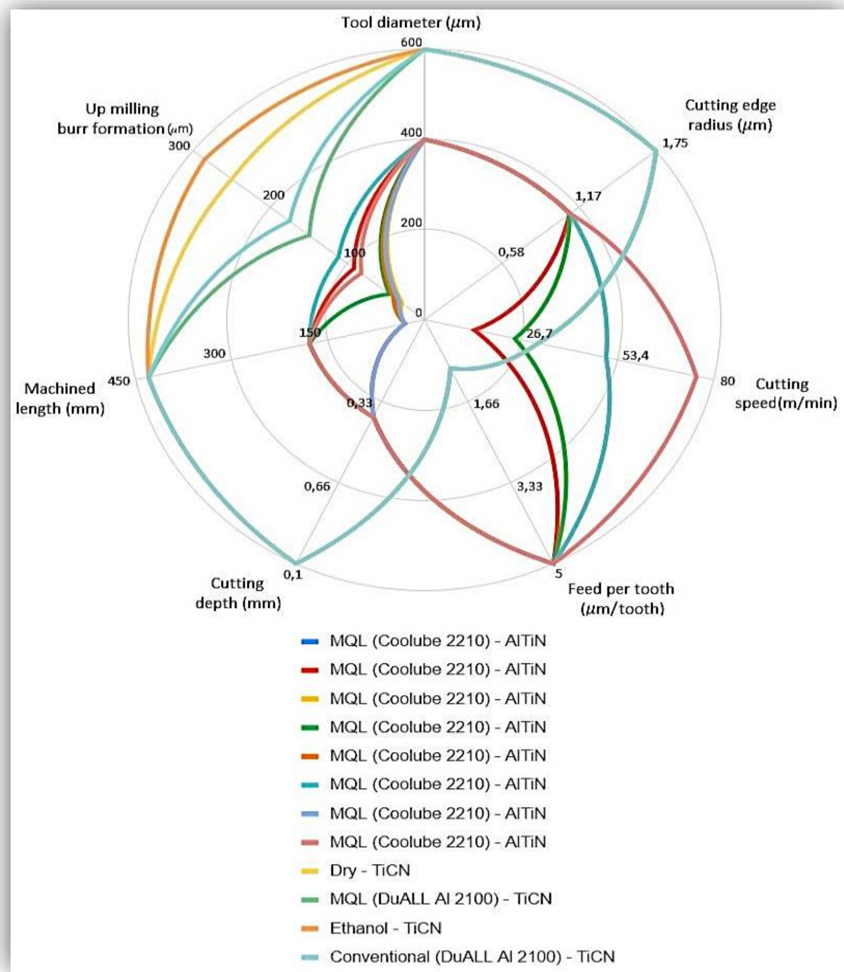
The burrs in micromilling can be divided in up milling burrs or down milling burrs, according to their position in respect to the direction of rotation of the tool. Considering only down milling burrs, eight samples presented in the work of Oliveira (Oliveira, 2019) were analyzed, because only in this study supplied information on the burr's conditions, as well as tool wear, lubrication and cutting parameters. These samples are shown in Fig. 2. It is possible to observe in Fig. 2 that four samples, 50% of the total, presented burrs with more than 96.4 µm, measuring the burr height, which is a high value considering that it is more than double the axial depth of cut (40 µm). As observed in Fig. 2, these samples stand out for their superior machining length, thus, it can be concluded that greater machining length tends to formation of higher burrs, especially on the down milling side, in micromilling of Inconel 718. It is important to highlight that the machining length possess a great correlation with the microtool wear, and it is reported that the tool condition is one of the main factors to the burr formation.

Figure 2. Down milling burr formation according to cutting parameters



Considering up milling burrs, a total of 12 samples were evaluated, from the works of De Oliveira (2019) and Aslantas and Çiçek (2018), these samples are shown in Fig. 3. It can be noticed from Fig. 3 that micromilling processes performed under lubrication with ethanol and under dry condition generated the most burrs, even compared with other samples manufactured under the same machining parameters. Dry machining resulted in burrs 30% higher than conventional lubrication with the fluid DuALL 1l2100. It can also be noted that the experiments performed by Aslantas and Çiçek (2018) presented more burrs than in the work of Oliveira (2019), because of the greater machined length, of 430 mm. Finally, it can be inferred from Fig. 3 that burrs tend to be higher in experiments with smaller values of feed and greater values of cutting-edge radius, because of the plowing effect.

Figure 3. Up milling burr formation according to cutting parameters



3.3. Cutting conditions recommendations

Micromachining is a relevant manufacturing process in modern industry due to the increasing trends towards miniaturization of mechanical components, however, this process differs from conventional machining because of size effect. Micromachining of Inconel 718 is challenging because of the plowing effect, that hinders chip formation and causes bad surface quality and high tool wear rates. To avoid some of these defects, some parameters stood out after the data and literature analysis.

i. Prefer machining with use of cutting fluid applied with the MQL technique,
ii. Apply TiAlN coated microtools,
iii. The feed per tooth of 5.0 μm/tooth and
iv. The axial depth of cut of 100 μm.

4. CONCLUSIONS

According to the literature review and the comparison of different samples from works about micromilling of Inconel 718, the following conclusions can be drawn:

i. There is great variation in the values for cutting tool diameter or cutting-edge radius used in micromilling experiments of Inconel 718. No trends were observed for the values of cutting speed and machined length, either.

ii. The coating of AlTiN is recurrent for microtools. Its use is therefore recommended considering the conservation provided to the tool.

iii. The value of feed per tooth of 5 µm and axial depth of cut if 0.1 mm can be recommended since these values were identified as the most common in the studies analyzed, providing better surface quality to the machined samples.

iv. Despite the better surface finish and the shorter burrs provided by lubrication during machining, dry machining was the most recurrent in the studies analyzed. Lubrication with ethanol proved to be inefficient compared to other lubricants.

v. The machined length significative influences burr formation and tool wear, with higher lengths generating shorter tool life and more burrs, which tend to be higher in the down milling side than in the up-milling side.

BIBLIOGRAPHY

Aslantas, K. & Çiçek, A. (2018). The effects of cooling/lubrication techniques on cutting performance in micro-milling of Inconel 718 superalloy. *Science Direct,* 77, 70-73. https://doi.org/10.1016/j.procir.2018.08.219

Bissacco, G., Hansen, H. N., & Chiffre, L. D. (2005). Micromilling of hardened tool steel for mould making applications. *International Journal of Materials Processing Technology*, 201-207. https://doi.org/10.1016/j.jmatprotec.2005.05.029

Camara, M., Rubio, J. C., Abraao, A., & Davim, J. (2012). State of the art on micromilling of materials, a review. *Journal of Materials Science & Technology,* 28(8), 673-685. https://doi.org/10.1016/S1005-0302(12)60115-7

Chae, J., Park, S. S., & Freiheit, T. (2006). Investigation of micro-cutting operations. International *Journal of Machine Tools and Manufacture,* 6(3), 313-332. https://doi.org/10.1016/j.ijmachtools.2005.05.015

Flynn, B. B., et al (1990). Empirical research methods in operations management. *Journal of operations management*, 9, 250-284. https://doi.org/10.1016/0272-6963(90)90098-X

Garza-Reys, J. A. (2015). Green lean and the need for six sigma. *International Journal of Lean Six Sigma*, 226-248.

Kiswanto, G. Zariatin, D. L., & Ko, T. J. (2014). The effect of spindle speed, feed-rate and machining time to the surface roughness and burr formation of aluminum alloy 1100 in micro-milling operation. *Journal of Manufacturing Processes,* (16), 435-450. https://doi.org/10.1016/j.jmapro.2014.05.003

Kiswanto, G. Zariatin, D. L., & Ko, T. J. (2019). The Effect of Machining Parameters to the Surface Roughness in Low Speed Machining Micro-milling Inconel 718. *International Conference on Materials and Intelligent Manufacturing*, 654 (1).

Kuram, E. & Ozcelik, B. (2015). Optimization of machining parameters during micro-milling of Ti6Al4V titanium alloy and inconel 718 materials using Taguchi method. *Journal of Engineering Manufacture*. http://dx.doi.org/10.1177/0954405415572662

Liu, K. & Melkote, S. N. (2007). Finite element analysis of the influence of tool edge radius on size effect in orthogonal micro-cutting process. *International Journal of Mechanical Sciences,* 49, 650-660. https://doi.org/10.1016/j.ijmecsci.2006.09.012

Oliveira, D. de. (2019). *Efeito escala e integridade superficial no microfresamento da liga de níquel inconel 718*. (PhD thesis) - Federal University of Uberlândia, Uberlândia, MG, Brasil.

Oliveira, D. de., et al. (2021). Experimental and Computational Contribution to Chip Geometry Evaluation When Micromilling Inconel 718. *Wear,* 47,(203658). https://doi.org/10.1016/j.wear.2021.203658

Oliveira, D. de., Gomes, M. C., Santos, A. G. dos., & Silva, M. B. da. (2021). Influence of Cutting Fluid Application Frequency in Micromilling Cutting Forces. *International Journal of Engineering Materials and Manufacture,* 6(3), 195-201. https://doi.org/10.26776/ijemm.06.03.2021.11

Oliveira, D de., Gomes, M. C., & Silva, M. B. da. (2019). Spheroidal chip in micromilling. *Wear*. 426-427, 1672-1682.

Sadiq, M. A. et al. (2018) Experimental study of micromilling selective laser melted inconel 718 superalloy. *Procedia Manufacturing,* 26, 983–992. https://doi.org/10.1016/j.promfg.2018.07.129

Saedon, J. B., et al. (2012). Prediction and optimization of tool life in micromilling aisi d2 (62 hrc) hardened steel. *Procedia Engineering,* (41), 1674-1683. https://doi.org/10.1016/j.proeng.2012.07.367

Santos, A. G. dos., et al. (2021). Evaluation of the cutting fluid influence in the burr formation when micro milling inconel 718 and uns s32205 duplex stainless steel. *Brazilian Journal of Development,* 7(6), 56931-5694. http://dx.doi.org/10.1016/j.promfg.2020.05.082

Silva, G. P., Silva, M. B., & Oliveira, D. de. (2023). Influence of Abrasive Deburring in Indirect Tool Wear Measurement in Micromilling of Inconel 718. *Journal of Brazilian Society of Mechanical Sciences and Engineering*, 45(262).

Ucun, I., Aslantas, K., & Bedir, F. (2015). The performance of dlc-coated and uncoated ultra-fine carbide tools in micromilling of inconel 718. *Precision Engineering*, 41, 135-144. https://doi.org/10.1016/j.precisioneng.2015.01.002

Wang, F., et al. (2017). Micromilling simulations for the hard-to-cut material, 13th global congress on manufacturing and management, gcmm 2016. *Procedia Engineering*, 174, 693-699. http://dx.doi.org/10.1016/j.proeng.2017.01.209

Zanella, L. C. H. (2013). *Metodologia de Pesquisa*. 2. ed. [S.l.]: Universidade Federal de Santa Catarina / Sistema UAB.