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Aspects of Chip Deformation in Somewhat Eco-Friendly Inconel 718 HSM

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Abstract

Global manufacturers strive for increased productivity, which can be achieved through high-speed machining (HSM). Furthermore, strict government pollution control regulations have pushed for cleaner manufacturing methods. In light of the foregoing, this work analyses the characteristics of chip formation in high-speed turning of Inconel 718 utilising PVD coated carbide cutting tools at constant machining parameters under ideal environmentally friendly machining settings, namely dry, water vapour, and chilled air. The chip deformation coefficient, which assists in determining the lubrication state for the particular machining environments, has been used primarily to examine the chip formation features. Also, focus has been placed on comprehending the effectiveness of techniques for delivering environmentally friendly cutting fluids by external nozzle or via internal channel special tool holder. The findings demonstrate that using water vapour as a cutting fluid in machining results in a reduced chip deformation coefficient and is therefore an environmentally beneficial solution. Due to superior cutting fluid delivery and contact with the machining zone, the cutting fluid supply through internal channel unique tool holder is also discovered to be favourable over external nozzle supply. Water vapour as the cutting fluid and its delivery through a customised tool holder's internal channel together furthermore produce great results in terms of a decreased chip deformation coefficient. So, using the same can be a good strategy for green production.

Keywords: Inconel 718; high-speed turning; chip deformation coefficient; water vapour; eco-friendly

1. Introduction

The popular nickel-based superalloy, Inconel 718, finds wide usage primarily in aerospace industry particularly in the hot sections of gas turbine engines, as well as in marine equipments, nuclear reactors, petrochemical plants and food processing equipments due to its superior high-temperature strength, corrosion resistance and low thermal conductivity [1-3]. However it is also classified as one of the most difficult-to-cut material due to the properties like rapid work hardening causing tool wear and poor thermal conductivity leading to high cutting temperatures which leads to its poor machinability [1, 4]. The energy consumed in turning is largely converted into heat [5] and majority of the problems during machining are thus the result of the subsequent high temperatures associated with it. The control over this for enhancing machining performance can be best exercised through appropriate machining environment by proper selection and application of cutting fluids. However, use of conventional cutting fluids have caused problems like high cost, pollution, and hazards to operator's health and thus have challenged researchers to search for some suitable eco-friendly alternatives. Manufacturers are also under dual duress of higher production rate and reduced costs, the primer of which to some extent can be addressed through high-speed machining.

Apart from the vast surface integrity explorations, attempts have been also made in the past to understand the lubrication mechanics and chip formation aspects in machining of Inconel 718. Few of the same focussed particularly on chip formation aspects in turning of Inconel 718 wherein the effect of different cutting environments such as dry [6], wet [7], cooling air minimum quantity lubricant (CAMQL) [6], high pressure coolant jet [7, 8], and cryogenic cooling [5] on the chip formation mechanics have been studied by the researchers. In an attempt of green machining, a new and pollution-free cutting technique with water vapour as coolant and lubricant was proposed by Podgorkov and Godlevski [9]. However very few research investigations have subjected attention on water vapour as a coolant and lubricant as in machining of steels [10, 11], titanium alloy [12] and Inconel 718 [13, 14]. Primarily it has been revealed that minimum tool wear and maximum tool life can be obtained by water vapour as a coolant and lubricant in machining [9-11, 13].

It is thus learnt that most of the work on machining of Inconel 718 has been confined to machining environments like dry, wet, MQL, cryogenic cooling, etc. However use of water vapour as a cutting fluid especially in machining of Inconel 718 has received negligible attention. Further the focus on usage of completely eco-friendly cutting fluids on a comparative basis is again limited. Also the delivery method of cutting fluid from efficacy point of view is also not keenly explored. Hence keeping this in view, the present paper discusses the experimental study to analyse mainly the effect of completely eco-friendly machining environments of dry, water vapour and chilled air on the chip formation aspects so as to understand the lubrication/cooling mechanics in high speed turning of Inconel 718. The effectiveness of the method of delivering the cutting fluid to the machining zone especially in case of water vapour and chilled air machining environments is also investigated.

Nomenclature

V_c	cutting speed
f	feedrate
a_p	depth of cut
ζ	chip deformation coefficient
t_c	chip thickness after cut
t_u	uncut chip thickness
K_r	principal cutting edge angle
V_f	chip flow velocity

2. Experimental work

Considering the present trend of manufacturers' drift towards sustainable manufacturing due to governmental pollution control norms, consumer awareness and corporate social responsibility, it was decided to primarily focus on machining environments which are completely eco-friendly. Thus completely eco-friendly machining environments chosen were dry, water vapour and chilled air. These machining environments are eco-friendly from the product cum process perspectives. From product point-of-view, these machining environments do not leave any residue on machined components thus eliminating additional cleaning requirement and further the scrap in the form of chips is also residue free thus permitting for direct recycling without any prior treatment as in case of conventional flood cooling machining. From process point-of-view, these machining environments do not contaminate the workspace envelope of the shop floor and thus provide safe healthy working conditions to operator. Also the machining regime was chosen as the finish-turning of Inconel 718. Considering this all above, the turning of Inconel 718 was carried out at constant optimal machining parameters, viz. cutting speed (V_c) of 140 m/min, feedrate (f) of 0.13 mm/rev, and depth of cut (a_p) of 0.5 mm, under the specific eco-friendly machining environments [15]. Further the method of cutting fluid delivery for the machining environments of water vapour and chilled air was through external nozzle and through internal channel of special tool holder. The experimental test matrix is shown in Table 1. The response variable selected to assess the machining performance in terms of chip formation aspects as well as lubrication/cooling aspects was chip deformation coefficient.

Table 1. Experimental test matrix.

Expt. No.	Machining Parameters (V_c, f, a_p)	Machining Environments (Cutting Fluid)
1		Dry (No cutting fluid)
2		Water Vapour -1 (Supplied through external nozzle)
3		Water Vapour-2 (Supplied through tool holder)
4	140 m/min, 0.13 mm/rev, 0.5 mm	Chilled Air-1 (Supplied through external nozzle from low pressure vortex Tube)
5		Chilled Air-2 (Supplied through external nozzle from high pressure vortex tube)
6		Chilled Air-3 (Supplied through internal tool holder from high pressure vortex tube)

Fully annealed Inconel 718 cylindrical bar specimens having 25 mm diameter and 100 mm length were used as work material. The chemical composition of Inconel 718 was Ni 54.95, Cr 17.90, Fe 16.54, Nb 4.85, Ti 0.92, Co 0.92, Al 0.52, Si 0.08 and C 0.03. PVD-TiAlN coated carbide inserts with specification CNMG120408MS and grade KCU10 manufactured by Kennametal were used as cutting tools. The tool holder used for clamping the insert was PCLNL2525M12 (make Widax) for dry machining and when cutting fluid was supplied through external nozzle. However when supplying cutting fluid internally through channel of tool holder, special PCLNL2525M12HP (make Sandvik) was utilized.

The turning experiments were performed on precision CNC lathe (make Micromatic Ace, model Jobber XL). For machining environment of water vapour, supply of water vapour as cutting fluid to the machining zone was with the help of an external steam generation device. Provision for supply of water vapour was through hose and further through external nozzle or special tool holder, depending on the adopted method. The chilled air was supplied through low pressure and high pressure vortex tubes, the latter one being through external nozzle and special tool holder. All the experiments were performed with a prior skin cut of 1 mm and fresh cutting tip. Post experimentation the chips were carefully collected and the chip thicknesses (t_c) of the same were measured using tool maker's microscope (make Mitutoyo, model TM505). Then the chip deformation coefficient was found out using below [16],

$$Ç = \frac{t_c}{t_\mathrm{u}} \tag{1}$$

where, ζ = chip deformation coefficient, t_c = chip thickness after cut and t_u = uncut chip thickness.
The uncut chip thickness can be calculated from [17],

$$t_u = \mathrm{f} \cdot \sin K_r \tag{2}$$

where, f = feedrate and $\sin K_r$ = 95° (principal cutting edge angle).
All the experiments were replicated and re-measurements were done to validate the data.

3. Results and Discussion

Chip deformation coefficient (ζ) is one of the most important parameter to describe the lubrication status in machining [10, 11]. The effect of various machining environments as well as cutting fluid supply method on chip deformation coefficient is shown in Fig. 1. It can be seen that the machining environment plays a crucial role as the cutting fluid seems to notably affect the chip deformation coefficient.

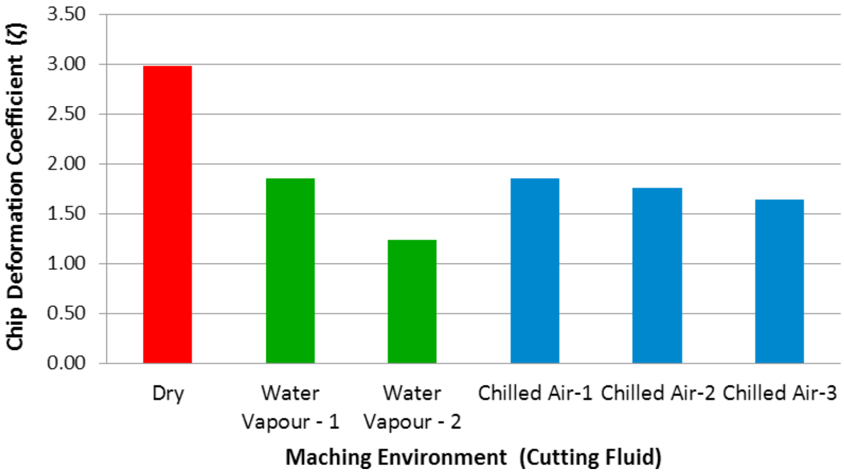

Fig. 1. Effect of machining environment cum cutting fluid delivery method on chip deformation coefficient.

The highest value of chip deformation coefficient was observed in the case of dry machining while the same was comparatively lower for the water vapour and chilled air machining environments. It is well known that chip deformation coefficient also depends on cutting velocity and chip velocity as per below [18],

$$Ç = \frac{V_c}{V_f} \tag{3}$$

where, V_c = cutting velocity or speed and V_f = chip velocity or chip flow velocity.

It is to be noted that in all cases the cutting speed (along with feedrate and depth of cut) is constant. Thus considering dry machining, for fixed cutting speed but lower chip velocity led to higher chip deformation coefficient. The lower chip velocity in dry machining can be attributed to the null lubrication due to the absence of cutting fluid. Thus the chips formed and moved slowly as they had to pass over the tool surface under heavy friction and as a result also became thick. As a result higher chip thickness and lower chip velocity led to higher chip deformation coefficient as can be inferred from equation (1) and (3).

Further considering the water vapour machining environment, lower chip deformation coefficient values are seen. This can be attributed to the better lubrication aspects of the water vapour which is also in well agreement with [9-11]. Water vapour has excellent penetrability and it forms a low shearing strength lubrication film which reduces the friction at tool-work and tool-chip interface thus leading to higher chip flow velocities as well as lower chip thickness. Considering the method of supply of cutting fluid, when water vapour was supplied through internal channel of special tool holder (Water Vapour-2) as against external nozzle (Water Vapour-1), the chip deformation coefficient appreciably reduced. The special tool holder permits supply of water vapour sufficiently close to the machining zone in a more efficient manner. Thus the water vapour has comparatively even better access to the tool-work and tool-chip interface providing necessary lubrication conditions. Also the focussed jet helps in driving away the chips from the machining zone and further reducing the friction at tool-chip interface.

Comparatively more or less intermediate values of chip deformation coefficient were evident for chilled air machining environment. This is because the primary function of using chilled air as cutting fluid is to provide desirable cooling characteristics at the machining zone. However, when considering chilled air supply from low pressure vortex tube (Chilled Air-1) with high pressure vortex tube (Chilled Air-2), the later led to slight reduction in chip deformation coefficient which can be again due to slight improvement in chip flow velocity. When chilled air is supplied from high pressure vortex tube, the high air pressure generates a partial film or cushion thus separating chip from tool surface and relatively increasing its flow velocity. Further, when the chilled air was supplied through internal channel of special tool holder (Chilled -3), the generated film or cushion due to air is slightly more effective due to the effective cutting fluid delivery characteristics of the tool holder as discussed earlier. Hence an additional marginal lowering of chip deformation coefficient is observed (Chilled -3).

4. Conclusions

The results of the experimental inquiry are as follows.

• The chip deformation coefficient is greatly influenced by the machining environment as well as the method used to distribute the cutting fluid.

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Due to lack of lubrication, dry machining results in a greater chip deformation coefficient.

• By taking into account the usual machining environments, it was discovered that the water vapour supplied as cutting fluid was generally effective since, due to its improved lubricating properties, it led to a comparatively lower chip deformation coefficient.

• Cooled air reduced chip deformation coefficient values when compared to dry machining, however despite being more environmentally friendly, it was less efficient than water vapour due to its inability to lubricate.However, supply of cutting fluid (water vapour or chilled air) through special tool holder was appreciably efficient in getting lower chip deformation coefficient on account of effective delivery of cutting fluid to the machining zone.

From amongst the explored totally ecofriendly machining environments, water vapour stands out to be the best eco-friendly cutting fluid thus making it a suitable approach towards green manufacturing.

References

[1] D. Dudzinski, A. Devillez, A. Moufki, D. Larrouquère, V. Zerrouki, J. Vigneau, A review of developments towards dry and high speed machining of Inconel 718 alloy, International Journal of Machine Tools & Manufacture 44, (2004) 439–456.

[2] D.G. Thakur, B. Ramamoorthy, L. Vijayaraghavan, Machinability investigation of Inconel 718 in high-speed turning, International Journal of Advanced Manufacturing Technology, 45 (2009) 421-429.

[3] R.S. Pawade, Suhas S. Joshi, P.K. Brahmankar, M. Rahman, An investigation of cutting forces and surface damage in high-speed turning of Inconel 718, Journal of Materials Processing Technology, 192-193 (2007) 139-146.

[4] R.S. Pawade, Suhas S. Joshi, P.K. Brahmankar, Effect of machining parameters and cutting edge geometry on surface integrity of high-speed turned Inconel 718, International Journal of Machine Tools & Manufacture, 48 (2008) 15–28.

[5] Z.Y. Wang, K.P. Rajurkar, Cryogenic machining of hard-to-cut materials, Wear, 239 (2000) 168–175.

[6] Y. Su, N. He, L. Li, A. Iqbal, M.H. Xiao, S. Xu, B.G. Qiu, Refrigerated cooling air cutting of difficult-to-cut materials, International Journal of Machine Tools & Manufacture, 47 (2007) 927–933.

[7] E.O. Ezugwu, J. Bonney, Finish machining of Nickel-base Inconel 718 alloy with coated carbide tool under conventional and high-pressure coolant supplies, Tribology Transactions, 48 (2005) 76-81.

[8] R. Polvorosa, A. Suarez, L.N. Lopez de Lacalle, I. Cerrillo, A. Wretland, F. Veiga, Tool wear on nickel alloys with different coolant pressures: Comparison of Alloy 718 and Waspaloy, Journal of Manufacturing Processes, 26 (2017) 44–56.

[9] Junyan Liu, Rongdi Han, Li Zhang, Hongbin Guo, Study on lubricating characteristic and tool wear with water vapor as coolant and lubricant in green cutting, Wear, 262 (2007) 442-452.

[10] Junyan Liu, Rongdi Han, Yongfeng Sun, Research on experiments and action mechanism with water vapor as coolant and lubricant in Green cutting, International Journal of Machine Tools & Manufacture, 45 (2005) 687-694.

[11] Liu Junyan, Liu Huanpeng, Han Rongdi, Wang Yang, The study on lubrication action with water vapor as coolant and lubricant in ANSI 304 stainless steel, International Journal of Machine Tools & Manufacture, 50 (2010) 260-269.

[12] Raju S. Pawade, D.S.N. Reddy, Ganesh S. Kadam, Chip segmentation behaviour and surface topography in high-speed turning of titanium alloy (Ti-6Al-4V) with eco-friendly water vapour, International Journal of Machining and Machinability of Materials, 13-2/3 (2013) 113-137.

[13] Yi Hang Fan, Zhao Peng Hao, Jie Qiong Lin, Zhi Xin Yu, New observations on tool wear mechanism in machining Inconel 718 under water vapour + air cooling lubrication cutting conditions, Journal of Cleaner Production, 90 (2015) 381-387.

[14] Ganesh S. Kadam, Raju S. Pawade, Surface integrity and sustainability assessment in high-speed machining of Inconel 718 – An eco-friendly green approach, Journal of Cleaner Production, 147 (2017) 273-283.

[15] Ganesh S. Kadam, Investigations on Surface Integrity in High-Speed Machining of Inconel 718 under different Machining Environments, Unpublished Thesis Report, DBATU, Lonere, Raigad, M.S., India, 2017.

[16] J. Paulo Davim, Machining - Fundamentals and Recent Advances, Springer-Verlag – London, 2008.

[17] Thomas Childs, Katsuhiro Maekawa, Toshiyuki Obikawa, Yasuo Yamane, Metal Machining: Theory and Applications, London, Arnold-Hodder Headline Group – London, 2000.

[18] R.S. Pawade, Suhas S. Joshi, Mechanism of chip formation in high-speed turning of Inconel 718, Machining Science and Technology, 15 (2011) 132-152.