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Water Vapour as Eco-friendly Cutting Fluid – Parametric Explorations in HSM of Inconel 718

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ABSTRACT

Considering the present need of green, cleaner and sustainable machining techniques along with higher productivity at reduced costs, this paper investigates the surface quality in high speed machining (HSM) of Inconel 718 by PVD coated carbide cutting tools using the limitedly explored water vapour as an eco-friendly cutting fluid. In this the effect of cutting fluid parameters like nozzle diameter, stand-off distance, pressure and flow rate, as well as main machining parameters like cutting speed, feed rate and depth of cut on the resultant surface quality generated by turning has been assessed in terms of surface roughness. It is observed that stand-off distance along with cutting speed, feed rate and depth of cut are the most significant factors influencing surface finish. Thus by proper selection of optimal parameters, usage of water vapour as a cutting fluid in machining can be promising effort towards green manufacturing in near future.

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Introduction

Inconel 718, a nickel-based superalloy is widely employed in the aerospace industry, particularly in the hot sections of gas turbine engines due to their superior high-temperature strength even upto 700 °C, corrosion resistance and low thermal conductivity [1]. It also finds applications in marine equipment, nuclear reactors, petrochemical plants and food processing equipments [2]. However, Inconel 718 is known to be among the most difficult-to-cut material due to the properties that are responsible for poor machinability like [1]: rapid work hardening causing tool wear and poor thermal conductivity leading to high cutting temperatures. It has been reported that the energy consumed in turning is largely converted into heat [3]. Many problems caused during machining are due to the heat generation and the subsequent high temperatures associated with it. The control over temperature in order to enhance machining performance can be thus exercised by proper selection and application of cutting fluids. However, use of cutting fluids cause problems such as high cost, pollution, and hazards to operator's health and thus have urged researchers to search for some suitable alternatives like MQL (minimum quantity lubrication), HPC (high pressure coolants), NDM (near dry machining), etc. Hence due attention needs to be directed towards exploring machining environment in terms of cutting fluids from eco-friendly nature point-of-view.

Attempts have been made in the past to improve surface quality in machining of Inconel 718 through assessment of surface roughness, a few of which focus specifically on the effect of cutting speed [4-8], feed [6-11] and depth of cut [4, 12] by using various cutting tools like coated and cemented carbides, CBN, PCBN, etc. Studies have been also reported on the effect of various machining environments like wet [4, 13], MQL [14-15], CAMQL (cooling air and minimum quantity lubrication) [16], Cryo-MQL [17], hybrid [18-19], high pressure assisted cooling [20] and liquid nitrogen cooling [3] on the surface finish in machining of Inconel 718. In an attempt of green machining, Podgorkov and Godlevski proposed a new and pollution-free cutting technique with water vapour as coolant and lubricant [23]. However, very few research investigations have subjected attention on water vapour as a coolant and lubricant as in machining of steels [24-25], titanium alloy [26] and Inconel 718 [27]. Liu et al. [24] in turning of steels observed lower surface roughness for water vapour as compared to dry, compressed air and oil water emulsion and they attributed this to the collective effect of reduced cutting force, minimal friction coefficient and lower cutting temperature due to water vapour application. Similarly Junyan et al. [25] in turning of steels observed a more regular surface texture and lower surface roughness by using water vapour as compared to oxygen and carbon dioxide gaseous lubricants which they attributed to the reduced cutting force, lower friction coefficient and chip deformation coefficient due to water vapour application. Kadam and Pawade [27] in high-speed turning of Inconel 718 reported lower surface roughness with water vapour machining environment as compared to dry and flood cooling, which was mainly attributed to the excellent penetration ability of water vapour and reduction in friction at tool-chip and tool-work interface.

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. Hence keeping this in view, the present paper discusses the experimental study to analyse the effect of machining process parameters as well as parameters related to water vapour on surface quality in high speed turning of Inconel 718.

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Table 1: Process Variables and Their Levels

Factor (units)	Levels		
	1	2	3
Nozzle Diameter, N_d (mm)	2	2.5	3
Stand-off Distance, S_d (mm)	20	30	40
Pressure, P (bar)	1	1.5	2
Valve Position, V_p (°)	60	120	180
Cutting Speed, V_c (m/min)	80	140	200
Feedrate, f (mm/rev)	0.1	0.15	0.20
Depth of Cut, a_p (mm)	0.25	0.50	0.75

Table 2: Experimental Test Matrix along with Observed Responses

Expt. No.	Water Vapour Parameters				Machining Parameters			Surface Roughness	
								Main expt.	*Replication expt.*
	N_d (mm)	S_d (mm)	P (bar)	V_p (°)	V_c (m/min)	f (mm/rev)	a_p (mm)	R_a (μm)	R_a' (μm)
1	2	20	1	60	80	0.1	0.25	2.23	2.15
2	2	20	1	60	140	0.15	0.5	2.10	1.89
3	2	20	1	60	200	0.2	0.75	4.09	4.12
4	2	30	1.5	120	80	0.1	0.25	2.42	2.35
5	2	30	1.5	120	140	0.15	0.5	1.27	1.35
6	2	30	1.5	120	200	0.2	0.75	4.19	4.09
7	2	40	2	180	80	0.1	0.25	2.74	2.45
8	2	40	2	180	140	0.15	0.5	1.53	1.51
9	2	40	2	180	200	0.2	0.75	2.75	2.86
10	2.5	20	1.5	180	80	0.15	0.75	1.91	1.97
11	2.5	20	1.5	180	140	0.2	0.25	4.06	3.89
12	2.5	20	1.5	180	200	0.1	0.5	3.07	2.97
13	2.5	30	2	60	80	0.15	0.75	1.95	2.38
14	2.5	30	2	60	140	0.2	0.25	2.16	2.92
15	2.5	30	2	60	200	0.1	0.5	1.00	1.09
16	2.5	40	1	120	80	0.15	0.75	1.85	1.61
17	2.5	40	1	120	140	0.2	0.25	2.33	2.39
18	2.5	40	1	120	200	0.1	0.5	2.55	2.39
19	3	20	2	120	80	0.2	0.5	1.45	1.75
20	3	20	2	120	140	0.1	0.75	2.74	2.58
21	3	20	2	120	200	0.15	0.25	2.57	2.65
22	3	30	1	180	80	0.2	0.5	2.78	2.49
23	3	30	1	180	140	0.1	0.75	1.80	1.92
24	3	30	1	180	200	0.15	0.25	2.07	2.14
25	3	40	1.5	60	80	0.2	0.5	0.84	0.76
26	3	40	1.5	60	140	0.1	0.75	2.94	2.85
27	3	40	1.5	60	200	0.15	0.25	2.97	2.65

Experimental

The experimental design based on Taguchi methodology was used for systematic planning, conduction and analysis of experiments [28]. In this work, high-speed turning experiments were carried out by incorporating standard L27 (3^7) Taguchi array under seven process variables viz., nozzle diameter, stand-off distance, pressure, valve position indicating relative flow rate, cutting speed, feedrate and depth of cut. Each process variable had three levels as shown in Table 1 and all the experiments were carried out using water vapour as cutting fluid. The machining parameters were selected on the basis of the knowledge available in the literature, past experience and from earlier experiments [29-30]. The response variable selected to assess the turning performance was surface roughness considering smaller-the-better quality characteristic. The experimental test matrix along with observed response variables is shown in Table 2 [30].

Inconel 718 cylindrical bar specimens having 25 mm diameter and 200 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 coated carbide double-sided trigon inserts (heliturn family) manufactured by Iscar, with a specification WNMX080708-M4MW and grade IC806 was used as cutting tool [29]. The tool holder used for clamping the insert was PWLNL 2525M-08X (make Iscar). The turning experiments were performed on CNC lathe (make Micromatic – Ace, model Jobber XL). For supplying water vapour as cutting fluid to the machining zone, assistance of steam generation device was taken (Fig.1a). Convergent type nozzles with various orifice diameters were used to eject the water vapour on the cutting zone. Provision was made such that the nozzle could be adjusted as per desired stand-off distance so that the jet is always oriented towards tool-work interface (Fig. 1b-c). Before every experiment the workpiece was prepared by removing its skin of 0.5 mm over the complete length to eliminate the effect of any workpiece inhomogeneity on the experimental results. Pressure and flow rate of the steam was maintained precisely during each experiment as per the experimental test matrix. The flow rate was controlled through fixing specific position of valve opening. Fresh cutting tip was used for every experiment. After the experiments surface roughness of the machined workpiece was measured using surface roughness tester MahrPerthometer M2. The cut-off and sampling length for each measurement were kept as 0.8 and 5.6 mm respectively. On each machined workpiece, surface roughness was measured at six different locations

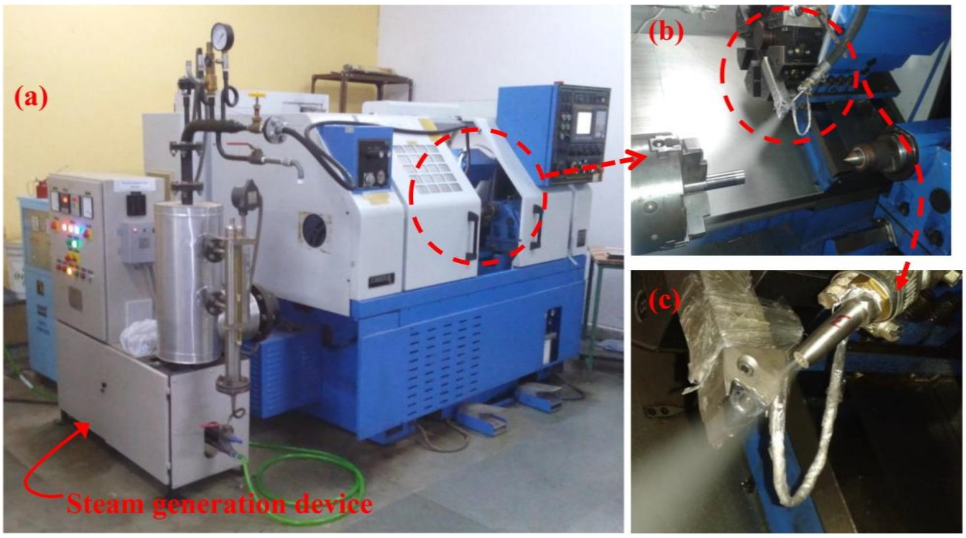

Figure 1: (a) Steam Generation Device and supply of water vapour to machining zone (CNC turning lathe) through hose; (b) Water vapour jet directed into machining zone through nozzle held in fixture, and (c) Water vapour jet flow visual close-up view

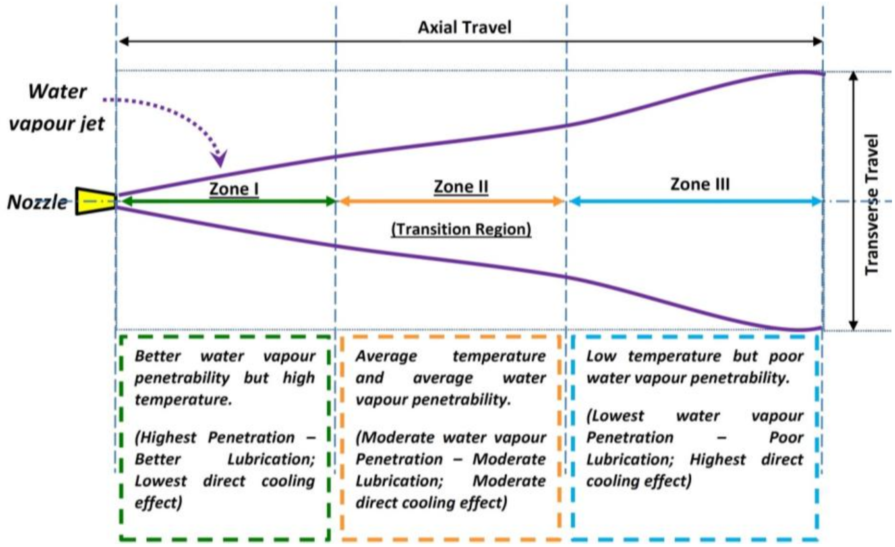

Figure 2: Basic characteristics of a water vapour jet flow [30]

and the average of them was taken as final roughness value. All the experiments were replicated and re-measurements were done to validate the data.

Results and Discussion

The interaction of water vapour jet into the machining zone is very important. From the previous studies on the effect of water vapour jets' lubrication-cooling aspects [30], it is observed that the water vapour jet can be distinguished of having three zones as shown in Fig. 2. The first zone, zone I, corresponds to the jet's portion immediately at the exit of nozzle. In this zone, the water vapour has better penetrability due to high pressure regime, but at the same time the temperature is also high. However this zone can provide indirect cooling due to better lubrication as a result of water vapour penetrability and also due to chip divergence and evacuation. The extreme most distal zone from nozzle, zone III, has low temperature and thus can provide better direct cooling effect; however the penetrability is poor due to low pressure regime and thus the lubrication is poor. Further considering the intermediate or transition zone which lies between zone I and III, zone II, average effects of zone I and III are present and this can be also beneficial. Thus the water vapour jet has an axial and transverse travel length and its impact into the machining zone especially at tool-chip and tool-work interface can lie under any of the zones. Depending on the actual interaction of water vapour with machining zone, we may get better lubrication or better direct cooling or even both as can be inferred from above. But as the jet characteristics do vary with supply pressure, nozzle orifice diameter and flow rate, thus its actual effects on machined surface quality can be found only through experimental analysis.

Surface roughness is one of the most important parameter to describe machined surface quality. A statistical analysis of surface roughness was carried out and the results were analysed by Analysis of Variance (ANOVA). The resultant ANOVA is shown in Table 3. The main effects plots (Fig. 3 and 4) were plotted to see the effect of machining and water vapour related parameters on surface roughness (R_a). The ANOVA reveals that the stand-off distance, cutting

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speed, feed rate and depth of cut are the crucial parameters which significantly influence the surface roughness as their P-values are less than 0.05. The next subsections discuss the effect of each individual parameter on surface finish.

Table 3: ANOVA for Surface Roughness

Source	DF	Adj. SS	Adj. MS	F-value	P-value
N_d	2	1.0576	0.52881	1.73	0.190
S_d	2	2.3867	1.19334	3.91	0.028
P	2	1.5503	0.77515	2.54	0.092
V_p	2	0.4135	0.20676	0.68	0.514
V_c	2	5.5852	2.79261	9.15	0.001
f	2	5.1304	2.56520	8.41	0.001
a_p	2	8.4817	4.24084	13.90	0.000
Total	53	36.5027			

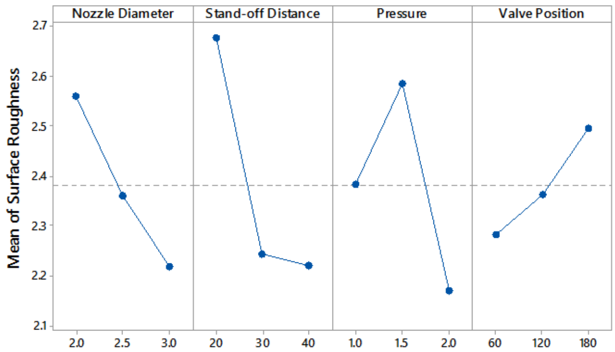

Figure 3: Main effect plots for surface roughness considering water vapour related parameters: Effect of nozzle diameter, stand-off distance, pressure and valve position

Effect of Nozzle Diameter (N_d)

From Fig. 3, it is observed that as the nozzle diameter increased from 2 mm to 2.5 mm and then further to 3 mm, the surface roughness continually goes on decreasing. This can be mainly attributed to the difference in interaction of water vapour jet into the machining zone. With increase in nozzle diameter, the amount of water vapour flowing through the cross-sectional area at nozzle tip also goes on increasing due to increase in jet's axial and transverse length. Thus as the water vapour quantity increases, the lubricating and cooling effect is also enhanced. This is because more the water vapour coming from nozzle, more chances of easy penetrability of the same into the tool-work and tool-chip interface which further assists in better lubrication and thus better surface finish. With better lubrication, the temperature in the machining zone is also reduced and thus the effect of cooling goes hand-in-hand with lubrication.

Effect of Stand-off Distance (S_d)

The stand-off distance is basically the distance between the nozzle tip and the tool-work interface. It is observed that increase in stand-off distance from 20 to 30 mm, improves the surface finish as shown in Fig. 3. At low stand-off distance of 20 mm, the water vapour has better penetrability. However the direct cooling is very less due to the jet characteristics as discussed earlier. But at a stand-off distance of 30 mm, sufficient distance exists between nozzle tip and tool-work interface. This distance not only provides ideal conditions for water vapour jet to penetrate into the chip-tool interface thus providing better lubrication effect, but also provides dominant direct cooling effect and thus lower surface roughness is observed. With further increase in stand-off distance from 30 to 40 mm, there is a marginal reduction in surface roughness. This is again due to the dominant cooling effect prevalent at a stand-off distance of 40 mm.

Effect of Pressure (P)

The effect of water vapour pressure on the surface roughness shows (Fig. 3) initially an increasing and then a decreasing trend. At the lowest pressure of 1 bar, the water vapour has just sufficient penetrability so as to provide sufficient lubrication conditions and cooling effect at the tool-work and tool-chip interface. But as the pressure is increased from 1 bar to 1.5 bar, the surface roughness increases. In the current case, increase in pressure leads to increase in penetrability; but it simultaneously also has reduced direct cooling effect deteriorating the surface finish due to higher machining temperatures generation. With further increase in pressure from 1.5 bar to 2 bar, the surface roughness drastically reduces. This can be attributed to the better penetration ability and lubrication performance as well as cooling effect of the water vapour at such higher pressure of 2 bar. The jet of water vapour at a pressure of 2 bar has better access to the tool-work and tool-chip interface as the jet's momentum is sufficiently higher to have a direct access to the cutting zone. The jet also drives away the generated chips away from the machining zone leading to better surface finish. This is in well agreement with the finding of [24-25] wherein it was reported that surface finish improved with increasing pressure for turning of steels.

Effect of Valve Position (V_p)

The valve position basically corresponds to the flow rate. Larger the valve opening in terms of degrees, more will be the amount of water vapour flowing resulting in increase in flow rate and vice-versa. It is observed that increase in valve position from 60° to 120° and then further to 180° leads to increase in the surface roughness as shown in Fig. 3. At a valve position of 60°, the flow rate is such that the penetration and lubrication effect as well as cooling effect is sufficient enough to provide better surface finish. However at the higher valve positions of 120° and 180°, the flow rate is so high that at any given confined volume space, the amount of water vapour is comparatively much higher. Thus more water vapour per unit volume and its forced contact into machining zone leads to higher cutting temperatures thus proving detrimental to surface finish.

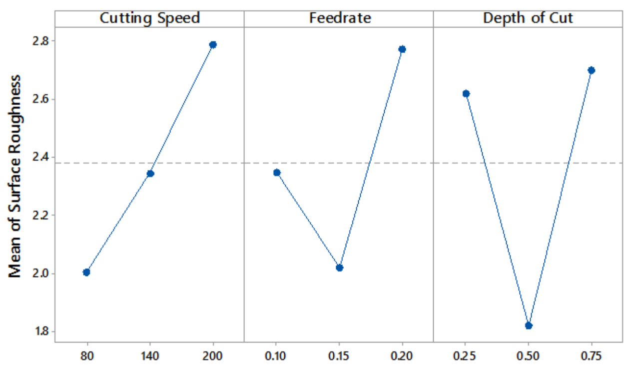

Figure 4: Main effect plots for surface roughness considering main machining parameters: Effect of cutting speed, feedrate and depth of cut

Effect of Cutting Speed (V_c)

The effect of cutting speed goes hand-in-hand with valve position. It is observed that as the cutting speed is increased from 80 m/min to 140 m/min and then further to 200 m/min, the surface roughness goes on continually increasing as shown in Fig. 4. This is mainly because, as the cutting speed increases, larger cutting temperatures are generated. Also Inconel 718 is sticky in nature. Thus due to such higher cutting temperatures the chips generated tend to stick to the tool edge because of sticky nature leading to tool erosion. Thus tool wear results from it and the surface finish gets deteriorated. Also the effect of water vapour as a coolant and lubricant in lowering the surface roughness goes on diminishing with increase in cutting speed [27].

Effect of Feedrate (f)

It is observed that as the feedrate is increased from 0.10 mm/rev to 0.15 mm/rev, the surface roughness goes on decreasing as shown in Fig. 4. This can be attributed to the fact that the cutting inserts used had additional radius due to wiper geometry. At higher feedrate of 0.15 mm/rev, the tool edge experiences such severe stresses that the wiper geometry gets sufficiently worn out so that the effective tool nose radius increases as both, initial tool tip nose radius and wiper radius merged out into one. Hence widening of nose radius occurs and results in feedmarks getting wiped out due to which the surface roughness decreases. However, with further increase in feedrate from 0.15 mm/rev to 0.20 mm/rev, the surface roughness increases. This is in well agreement with the fundamentals of metal cutting as is evident from the equation (1) [31] below,

$$R_a = 0.0321 \cdot \frac{f^2}{r_\varepsilon} \qquad (1)$$

where, R_a = Surface roughness, f = feed rate, r_ε = nose radius of tool. Thus, for the given fixed nose radius of tool, the surface roughness further increases with an increase in feedrate.

Effect of Depth of Cut (a_p)

The effect of depth of cut goes hand-in-hand with feedrate. It is observed that, as the depth of cut is increased from 0.25 to 0.50 mm, the surface roughness decreases as shown in Fig. 4. This can be mainly because of the resulting effect of cutting edge getting blunt due to wear, as like in case of feedrate. However with further increase in depth of cut from 0.5 to 0.75 mm, it is noted that the surface roughness increases. This is also in well agreement with [4]; increase in depth of cut leads to higher values of cusp height and thus increase in surface roughness.

Conclusions

The experimental investigation leads to the following conclusions-

1. The machining parameters viz. cutting speed, feedrate and depth of cut, and the water vapour related parameter stand-off distance, are found to be highly statistically significant.
2. The effect of stand-off distance, feedrate and depth of cut on surface roughness goes hand-in-hand; whilst the trend is opposite for the effect of pressure on surface roughness.
3. Increase in nozzle diameter leads to improvement in surface finish as a result of better penetrability and thus better lubrication and cooling effect of water vapour.
4. The effect of cutting speed on surface roughness shows an increasing linear trend which mainly can be attributed to the corresponding rise in tool wear and erosion.
5. A lower surface roughness can be obtained through optimal combination of process parameters being cutting speed of 80 m/min, feedrate of 0.15 mm/rev, depth of cut 0.50 mm, nozzle diameter of 3 mm, stand-off distance of 30 mm, lower flow rate with valve opening of 60° and a pressure of 1 bar.
6. Thus it is possible to achieve better surface quality incorporating eco-friendly cutting fluid and thus machining using water vapour as a cutting fluid is a promising effort towards green manufacturing.

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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, 2004, 44, 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, 2009, 45, 421-429.
3. Z.Y. Wang, K.P. Rajurkar, Cryogenic machining of hard-to-cut materials, Wear, 2000, 239, 168–175.
4. R.M. Arunachalam, M.A. Mannan, A.C. Spowage, Residual stress and surface roughness when facing age hardened Inconel 718 with CBN and ceramic cutting tools, International Journal of Machine Tools & Manufacture, 2004, 44, 879-887.
5. B. Shi, H. Attia, R. Vargas, S. Tavakoli, Numerical and experimental investigation of laser-assisted machining of Inconel 718, Machining Science and Technology, 2008, 12, 498-513.
6. 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.
7. D.G. Thakur, B. Ramamoorthy, L. Vijayraghavan, Study on the machinability characteristics of superalloy Inconel 718 during high speed turning, Materials and Design, 2009, 30, 1718-1725.
8. Domenico Umbrello, Investigation of surface integrity in dry machining of Inconel 718, International Journal of Advanced Manufacturing Technology, 2013, 69, 2183-2190.
9. I.A. Choudhury, M.A. El-Baradie, Machinability assessment of Inconel 718 by factorial design of experiment coupled with response surface methodology, Journal of Materials Processing Technology, 1999, 95, 30-39.
10. J.S. Senthilkumaar, P. Selvarani, R.M. Arunachalam, Intelligent optimization and selection of machining

parameters in finish turning and facing of Inconel 718, International Journal of Advanced Manufacturing Technology, 2012, 58, 885-894.
11. Jinming Zhou, Volodymyr Bushlya, Pajazit Avdovic, Jan Eric Stahl, Study of surface quality in high speed turning of Inconel 718 with uncoated and coated CBN tools, International Journal of Advanced Manufacturing Technology, 2012, 58, 141-151.
12. 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, 2007, 192-193, 139-146.
13. R.M. Arunachalam, M.A. Mannan, A.C. Spowage, Surface integrity when machining age hardened Inconel 718 with coated carbide cutting tools, International Journal of Machine Tools & Manufacture, 2004, 44, 1481-1491.
14. Y. Kamata, T. Obikawa, High speed MQL finish-turning of Inconel 718 with different coated tools, Journal of Materials Processing Technology, 2007, 192-193, 281-286.
15. Toshiyuki Obikawa, Yasuhiro Kamata, Yuki Asano, Kousuke Nakayama, Andrew W. Otieno, Micro-liter lubrication machining of Inconel 718, International Journal of Machine Tools & Manufacture, 2008, 48, 1605-1612.
16. 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, 2007, 47, 927-933.
17. F. Pusavec, H. Hamdi, J. Kopac, I.S. Jawahir, Surface integrity in cryogenic machining of nickel based alloy – Inconel 718, Journal of Materials Processing Technology, 2011, 211, 773-783.
18. Z.Y. Wang, K.P. Rajurkar, J. Fan, S. Lei, Y.C. Shin, G. Petrescu, Hybrid machining of Inconel 718, International Journal of Machine Tools & Manufacture, 2003, 43, 1391-1396.
19. Taghi Feyzi, S. Mohsen Safavi, Improving machinability of Inconel 718 with a new hybrid machining technique, International Journal of Advanced Manufacturing Technology, 2013, 66, 1025-1030.
20. Zydrunas Vagnorius, Knut Sorby, Effect of high-pressure cooling on life of SiAlON tools in machining of Inconel 718, International Journal of Advanced Manufacturing Technology, 2011, 54, 83-92.
21. Dong Lu, Qiang Wang, Yongbo Wu, Jianguo Cao, HuiruGuo, Fundamental turning characteristics of Inconel 718 by applying ultrasonic elliptical vibration on the base plane, Materials and Manufacturing Processes, 2015, 30, 1010-1017.
22. A.R.C. Sharman, J.I. Hughes, K. Ridgway, Workpiece surface integrity and tool life issues when turning Inconel 718™ Nickel based superalloy, Machining Science and Technology, 2004, 8 (3), 399-414.
23. Junyan Liu, Rongdi Han, Li Zhang, HongbinGuo, Study on lubricating characteristic and tool wear with water vapour as coolant and lubricant in green cutting, Wear, 2007, 262, 442-452.
24. Junyan Liu, Rongdi Han, Yongfeng Sun, Research on experiments and action mechanism with water vapour as coolant and lubricant in Green cutting, International Journal of Machine Tools & Manufacture, 2005, 45, 687-694.
25. Liu Junyan, Liu Huanpeng, Han Rongdi, Wang Yang, The study on lubrication action with water vapour as coolant and lubricant in ANSI 304 stainless steel, International Journal of Machine Tools & Manufacture, 2010, 50, 260-269.
26. 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, 2013, 13 (2/3), 113-137.
27. 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, 2017, 147, 273-283.
28. M.S. Phadke, Quality Engineering using Robust Design, Prentice Hall Publication - New Jersey, 1989, 30-112.
29. Turning & Threading Tools Metric Version Catalog 2012, Iscar – Israel, 2012.
30. 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.
31. Geoffrey Boothroyd, Winston A. Knight, Fundamentals of Machining and Machine Tools, CRC Press-Taylor & Francis Group - New York, Third edition, 2006.