Completely Neat Eco-friendly HSM of Inconel 718

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Abstract

Worldwide manufacturers always struggle for higher productivity and this can be well ascertained by incorporating high-speed machining (HSM). Further due to strict governmental pollution control norms as well as manufacturers' corporate social responsibilities, researchers worldwide are vigorously exploring various alternative cooling and lubrication approaches focusing towards usage of cleaner cutting fluids. Hence having a keen focus on this dual objectives of higher productivity and cleaner machining methodologies, this paper investigates the surface quality in high-speed turning of Inconel 718 by using PVD coated carbide cutting tools at optimal constant cutting speed, feed and depth of cut under completely eco-friendly machining environments viz. dry, water vapour and chilled air. Further emphasis has been also given on understanding the efficacy of methods of supplying the eco-friendly cutting fluids through external nozzle as well as through internal channel special tool holder. Results show that use of water vapour as a cutting fluid in machining comparatively gives better surface finish and hence proves to be an eco-friendly solution. Also cutting fluid supply through internal channel special tool holder is also found to be advantageous than external nozzle supply due to the better cutting fluid delivery and interaction with machining zone. Further combination of both, water vapour as cutting fluid and its supply through internal channel special tool holder, still further relatively gives excellent results in terms of better surface quality. Thus usage of the same can be a well suitable approach towards green manufacturing.

Keywords:Inconel 718, High-speed turning, Machining, Cutting fluid, Surface roughness, Water vapour, Chilled air, eco-friendly, Green manufacturing.

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. Manufactures 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.

Attempts have been made in the past to understand and 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 [3, 6-9], feed [3, 8-12] and depth of cut [3, 6] 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 [6, 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 [5] on the surface finish in machining of Inconel 718.

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 [21]. However very few research investigations have subjected attention on water vapour as a coolant and lubricant as in machining of steels [22, 23], titanium alloy [24] and Inconel 718 [25, 26], all of which in general have reported lower surface roughness with water vapour as compared to various other machining environments like dry, wet, compressed air, gas as lubricant (O_2 and CO_2), etc. 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 [21-23, 25].

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 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 surface finish 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.

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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 perspective. 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 [27]. 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 was surface roughness.

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	140 m/min, 0.13 mm/rev, 0.5 mm	Water Vapour-2 (Supplied through tool holder)
4		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.

(a) (b) (c)

Fig. 1. (a) Steam generation device and supply of water vapour to machining zone through hose, (b) Water vapour supply through external nozzle, and (c)Water vapour supply through special tool holder

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 steam generation device (Fig. 1a). Provision for supply of water vapour was through hose and further through external nozzle (Fig. 1b) or special tool holder (Fig. 1c), depending on the adopted method. The chilled air was supplied through low pressure (Fig. 2a) and high pressure vortex tubes, the latter one being through external nozzle (Fig. 2b) and special tool holder (Fig. 2c). All the experiments were performed with a prior skin cut of 1 mm and fresh cutting tip. 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. All the experiments were replicated and re-measurements were done to validate the data.

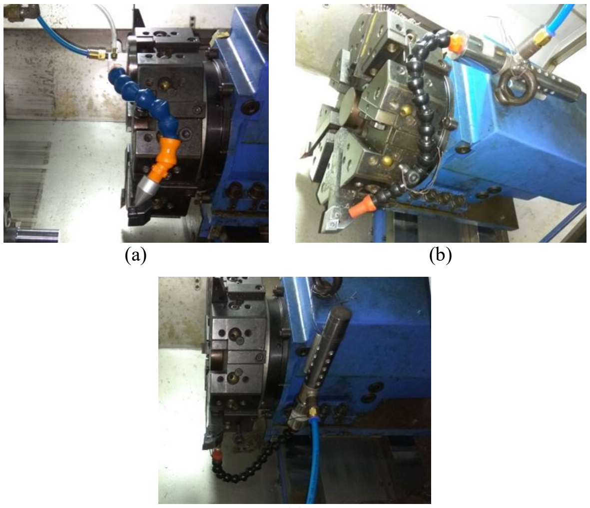

Fig. 2. (a) Chilled air supplied through external nozzle from low pressure vortex tube, (b) Chilled air supplied through external nozzle from high pressure vortex tube, and (c)Chilled air supplied through special tool holder from high pressure vortex tube

3. RESULTS AND DISCUSSION

The effect of various machining environments as well as cutting fluid supply method on surface roughness is shown in Fig. 3. It can be seen that the machining environment plays a crucial role as the cutting fluid seems to affect the surface finish. The lowest surface roughness is observed in general for water vapour environment (Water Vapour - 1 and 2). This is mainly due to the better lubrication cum cooling aspects of the water vapour which is also in well agreement with [22, 23, 26]. 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 lower surface roughness.

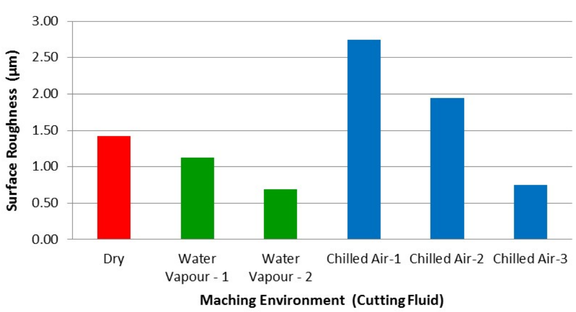

Fig. 3. Effect of machining environment cum cutting fluid delivery method on surface roughness

Further an intermediate value of surface roughness is evident for dry machining. Since in dry machining, there is absence of cutting fluid, friction generates stress on the tool. However thermal softening also plays some role in the surface generation. Thus prevalent frictional conditions and thermal softening are crucial factors granting surface roughness for the case of dry machining. Considering the supply of cutting fluid as chilled air (except the case of Chilled Air-3), the surface roughness was found to be on a comparatively higher side. For chilled air-1, the surface roughness was highest which is mainly due to the supply of air from low pressure vortex tube. Since the supplied chilled air is at low pressure, it is not effective in providing necessary cooling at machining zone; also its chip evacuation capability is poor thus leading to highest surface roughness. However, when the chilled air was supplied from high pressure vortex tube (Chilled Air-2) lowering of surface roughness compared to prior was noticed. This can be attributed to the better cooling characteristics of the chilled air on account of it lower temperature as well as effective evacuation capability for driving chips away from the machining zone.

Considering the delivery method of cutting fluid, it is observed that whenever the cutting fluid was delivered through internal channel of special tool holder as against external nozzle, the surface finish was always better. The special tool holder permits supply of cutting fluid close to the machining zone in a more efficient manner. Thus the cutting fluid has better access to the tool-work and tool-chip interface providing necessary cooling/lubrication conditions. Also the focussed jet helps in driving away the chips from the machining zone, which otherwise may have hampered the freshly generated turned surface. Thus lower surface roughness is seen for Water Vapour-2 and Chilled Air-3. The prior is seen to be effective than later, as water vapour has the dual advantage of lubrication and cooling as against only cooling for the case of chilled air. Thus water vapour seems to be a better cutting fluid for having lower surface roughness.

4. CONCLUSIONS

The experimental investigation leads to the following conclusions.

- Both, machining environment as well as method of delivering the cutting fluid, play a crucial role on the resultant surface finish.
- Considering the machining environments, in general, the water vapour supplied as cutting fluid was found to be effective as it lead to better surface finish.
- Cutting fluid supplied as chilled air through external nozzles lead to higher values of surface roughness and is thus not efficient even though eco-friendly.
- However, supply of cutting fluid (water vapour or chilled air) through special tool holder was appreciably efficient in getting better surface finish on account of effective delivery of cutting fluid to the machining zone.
- From amongst the explored completely neat ecofriendly machining environments, water vapour stands out to be the best eco-friendly cutting fluid thus making it a suitable approach towards green manufacturing.

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