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Abstract

The main objective of proposed work is to determine the influence of controllable parameters on machining characteristics of Inconel-718 and to achieve the optimum parameters for sustainable and efficient turning. Understanding the consequences of advanced tool materials together with higher cutting speeds on the formation of residual stresses and therefore the underlying mechanisms of small structural alteration within the subterranean layer thereby becomes terribly crucial for predicting product quality and more optimizing the machining conditions. Controllable cutting parameters such as cutting velocity, feed rate and depth of cut were selected at different level for experimentations in accordance with the Taguchi L9 array method using Minimum Quantity Lubrication (MQL) cutting condition and three different tools namely PVD TiAlN carbide, Cubic boron nitride and ceramic. Extensive study is done on the resulting surface roughness, surface subsurface hardness, tool wear and chip morphology. The results obtained from each of the tool were thoroughly analyzed and finally the optimized parameters are obtained for efficient machining of Inconel 718.

1. Introduction

Almost 70 % of alloys used in the aerospace engine are nickel-based alloys and others are titanium alloys. Super alloy Inconel 718 has large number of applications in different fields of manufacturing sector due to its unique properties like high thermal resistance, high creep and corrosion resistance and retains toughness and strength at elevated temperatures [1]. It is very important that Inconel 718 has excellent yield strength (550 MPa) even at elevated temperature (700-800°C). Almost about 70% by weight in the case of aerospace applications and 50% by weight in the case of aero-engines components are made of Inconel 718 [2]. Further Inconel 718 applications are not limited to aerospace industry but it includes ship engines, nuclear power plants and petro-chemical plants. The use of Inconel 718 alloy in such destructive environments ensures that it upholds high corrosion resistance , high fatigue resistance, withstand them at high mechanical and thermal shock, creeps, and erosion at elevated temperature [3]. In aero engines, Inconel-718 is normally used for manufacturing of gas turbine blades, which operates at very high temperature and pressure. Inconel 718 retains high toughness and strength over a wide temperature range, striking for high temperature applications where other aluminum and steel alloys would get soften. But on other hand Inconel 718 offers serious challenge as a work material during turning/machining due to their exceptional combined properties such as high temperature strength and toughness, hardness and chemical wear and creep resistance. Although these properties are attractive for design requirements, they creates a bigger challenge to manufacturing engineers due to high temperatures and stresses generation during machining [4]. There are two main problems in machining of super alloy Inconel 718 a. less tool life due to the work hardening and abrasion properties of the Inconel718, b. metallurgical and surface damages to the workpiece due to very high cutting pressure and temperature, which also contributes towards work hardening, surface tearing, and deformation.[5]

Many researchers have investigated the machining characteristics of Inconel 718 by considering the general machining / cutting conditions and ordinary tool materials. Hence, there is still a scope and challenge to study and understand the nature, degree, and actual reasons behind the problems of machining. Extensive past researches have been concerned with surface integrity and chip formation during machining. Cutting pressure and temperature decrease with increase in cutting speed in high-speed machining. Therefore it is important to understand how the change of cutting speed affects on the surface integrity in inconel718 alloy machining[6]. According to literatures, it is found that the assessment for high speed turning of inconel718 with three different tool materials with MQL cutting condition has not been done completely. In the present study, the effects of controllable cutting parameters (cutting speed, feed rate and depth of cut) on the surface roughness and cutting force during turning Inconel 718 with Ceramic, cBN and Carbide cutting tools have been investigated. The design of experiments was selected from Taguchi's L9 orthogonal array. Subsequent to the experiments, the effect of turning parameters on surface quality, tool wear, hardness and chip morphology have been analyzed.

2. Experimental Setup

The experimentations were carried out to examine the effects of cutting parameters on surface integrity during machining Inconel 718 with the selected cutting tool materials and cutting condition. The experiments were conducted on Simple Turn 5075-SPM CNC lathe machine tool, equipped with variable spindle speed ranging from 20 to 4000 rpm and a 14 KVA motor capacity drive rating. The feed direction was taken parallel to the length axis of the specimen. The tool holder used for machining was PCLNR 2525M12 type. The major input parameter on which experiment was carried out was cutting parameters and tool materials. Table 2.1 shows the work material properties, tool geometry considered for all the cutting inserts and tool holder nomenclature. Table 2.2 shows the chemical composition of Inconel 718 which indicates the percentage value of all the elements. Table 3 shows the cutting inserts and the quantitative values of the cutting parameters considered for the experimental trial as per L9 orthogonal array.

Table 2.1 Work material (Inconel 718) properties, tool geometry and tool holder nomenclature

Work material		**Working Tool Geometry**	
Work specimens	Inconel 718	Inclination angle	−6°
Hardness	35 HRC	Orthogonal rake angle	−6°
Size	⌀ 40 × 60 mm	Orthogonal clearance angle	6°
Density	8.19 g/cm^3	Auxiliary cutting edge angle	80°
Young's modulus	206 GPa	Principal cutting edge angle	95°
Tool holder	PCLNR 2525M12	Nose radius	0.8 mm

Machine tool - CNC Simple Turn 5075SPM

Table 2.2 Chemical Composition of Inconel-718 (in percentages,%) [7]

Ni	Co	Cr	Mo	Fe	Si	Mn	C	Al	Ti	Cu	P	B	S
52.50	1.00	19.00	3.05	17.00	0.35	0.35	0.80	0.60	0.90	0.30	0.015	0.006	0.015

Table 2.3 Cutting inserts and the quantitative values of cutting parameters as per L9 orthogonal array

Test	Cutting Speed (m/min)	Tool Material	DOC (mm)	Feed Rate (mm/rev)
1	60	PVD Carbide	0.2	0.1
2	60	CBN	0.4	0.15
3	60	Ceramic	0.6	0.2
4	90	CBN	0.2	0.15
5	90	Ceramic	0.4	0.2
6	90	PVD Carbide	0.6	0.1
7	120	Ceramic	0.2	0.2
8	120	PVD Carbide	0.4	0.1
9	120	CBN	0.6	0.15

3. Results and Discussion

After conducting all experimentations, the surface quality of machined specimens was measured using surface roughness tester (Mitutoyo made), tool wear and chip morphology analysis were carried out with the help of Optical Microscope having 10 X to 1200 X magnification, equipped with Clemex Vision Professional Edition Image Analysis Software. Microhardness measurements were carried out using a Vickers microhardness tester at various locations on the cross section of machined samples.

3.1 Chip Morphology

The chip morphology is the one of the significant aspect which is commonly considered to evaluate the machining performance. The type and nature of chips depends on work material properties, tool geometry, cutting parameters and cutting conditions [8]. As per the observation they are divided into three categories, i.e., the washer type chip, the elemental chip and the ribbon chip. Further, to examine the effect of the cutting parameters and tool materials on the chip morphology, cross-sections of the saw tooth chips were made and the equivalent optical images are taken. Figure 1(a) to 1(i) shows the images of the chips collected following to machining of Inconel 718 under several machining conditions and various cutting tool inserts. Some fine and irregular saw teeth are witnessed at the chip cross-section at low cutting speed as shown in (figure. 1b). It is also seen that chips with the ceramic inserts were not continuous and also getting burnt as shown in (figure. 1c) due to low thermal conductivity of ceramic tool. TiAlN Carbide insert have the high thermal conductivity which leads to smooth and continuous chip as shown in (figure. 1f) however CBN insert gave the built up edges at the speed of 60m/min and 90 m/min.

3.2 Surface Roughness

The effects of cutting parameters (Speed, feed and depth of cut) and tool materials on surface roughness during machining of Inconel718 under minimum quantity lubrication (MQL) cutting condition can be understood from figure.2 (a, b & c). Quantitatively surface roughness depends upon ratio of square of feed rate and nose radius. In the existing set of experiments variation of surface roughness with cutting speed is observed .

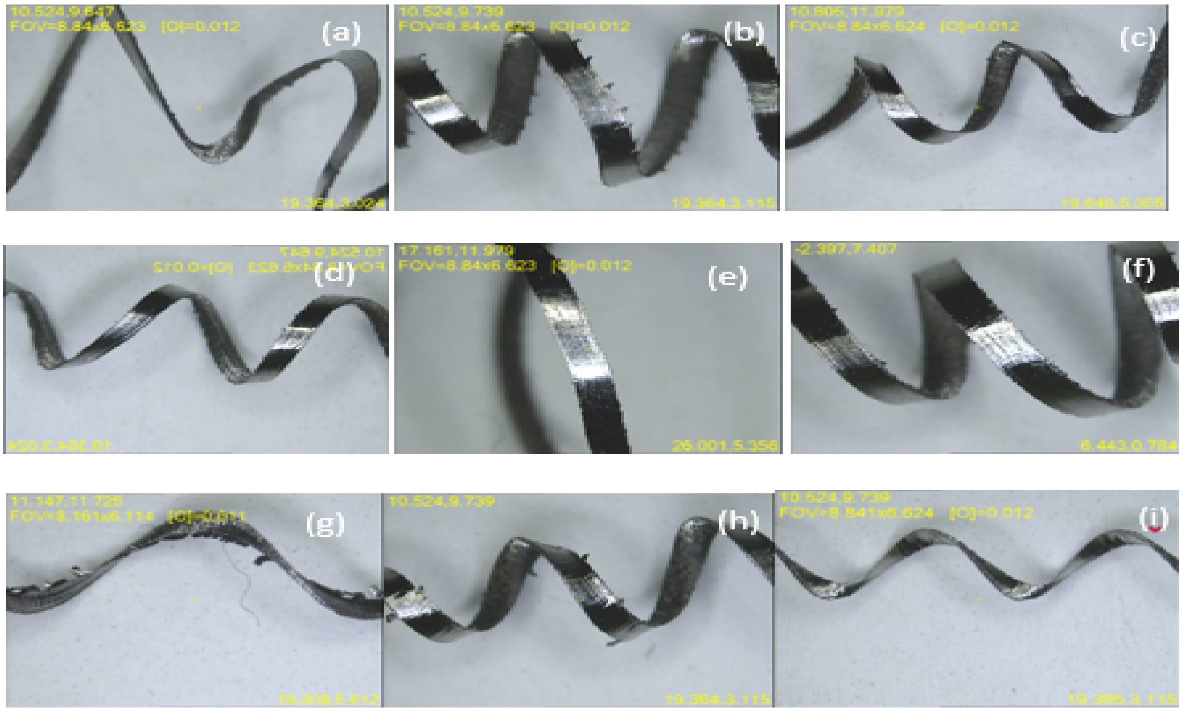

Figure 1 Chip morphology of INCONEL 718 machined using Ceramic Insert at speed of (a) 60 m/min, (b) 90 m/min and (c) 120 m/min, TiAlN Carbide insert at speed of (d) 60 m/min, (e) 90 m/min and (f) 120 m/min, CBN insert at speed of (g) 60 m/min,(h) 90 m/min and (i) 120 m/min,

It can be observed that in the case of CBN and PVD (figure 2a and 2c) surface roughness decreases with increasing cutting speed, whereas for carbide tool (figure. 2b) gives higher surface roughness with increasing speed. One of the noticeable reasons for this is that Carbide tool is getting more plastic deformation between tool and workpiece, which causes more work material plastic flow out from trailing edge to form side flow. Increase in temperature due to increasing speed can be the reason endorsed for increase in surface roughness while machining with carbide, whereas for cBN and ceramic development of built up edges increases surface roughness at low speed. In addition, cBN has higher thermal conductivity (100 W/m K), while ceramic has much lower thermal conductivity (28 W/mK). Therefore, in comparison with cutting using CBN cutting tool takes part in heat conduction during machining that means workpiece experiences less thermal loading effect as compare to ceramic tool.

3.3 Tool Wear

The cutting edge and tool faces after machining was observed with the help of the optical microscope. Flank and crater wear has been independently identified. It is observed that amount of wear decreases with increase in the cutting speed in ceramic and cBN tool (figure 3c, d, e and f) whereas there is decrease in the amount of wear at low cutting speed at Vc =60m/min for Carbide tool (figure 3 a & b). The dominant wear modes in the early stages of cutting are welding and adhesion of the workpiece on the cutting tool face forming built up edge which in turn increases the temperature which enhances the possibility of flank and crater wear on the tool. Whereas in case of carbide tool its inability to with stand high temperatures during high speed machining leads to the considerable wear. On the basis of the result obtained from the magnified image of the tool it is observed that minimum wear of tool occurs at the cutting speed of 120 m/min for CBN and for Ceramic tool on the other hand minimum amount of wear is obtained for carbide tool at low cutting speed (Vc =60m/min).

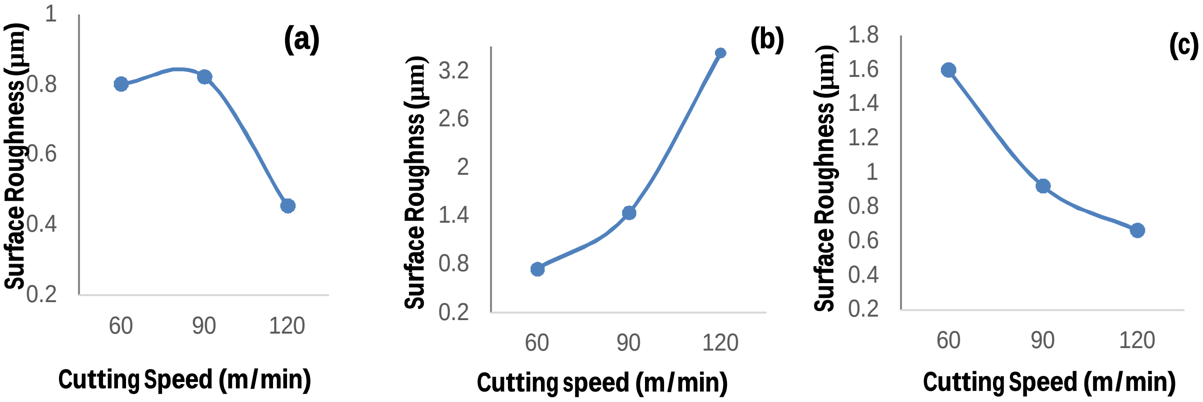

Figure 2 Variation of surface roughness with cutting speed (a) CBN Tool (b) Carbide Tool (c) Ceramic tool**.**

3.4 Micro-hardness Variation

Machining generally makes a severe plastic deformation in the material. The changes in micro hardness of the machined workpiece from surface to subsurface beneath were measured using a Vicker's micro hardness tester. Equal spacing between each indents were maintained. Higher microhardness values were found near the machined surface layer and decreases consistently as the depth increases. There was a sharp hardness gradient observed from the machined surface to the bulk material, this is due to high heat generation and higher cutting forces. The fact that the region confined to the machined surface is subjected to high plastic deformation, this can be ascribed to the increase in the dislocation density within work material. The plastic deformation and heat generation on machined surface plays a major role in work hardening during machining of Inconel 718 [9]. It is obvious that variation in the degree and depth of work hardening is a function of process parameters. Up to approximate depth of 1.5mm there was correlation between cutting parameters and tool materials in relate with microhardness were observed, after this depth material again acquires its bulk hardness value. The microhardness near the machined surface was found approximately about 1.6 to 1.7 times the bulk material microhardness (i.e 450 HV). It was observed that microhardness decreases with increase in cutting speed for carbide, ceramic and cBN tools, microhardness values were minimum at high cutting speed (Vc =120m/min) and higher microhardness values were observed at low cutting speed (vc = 60/min) as shown in (figure 4 a,b &c).

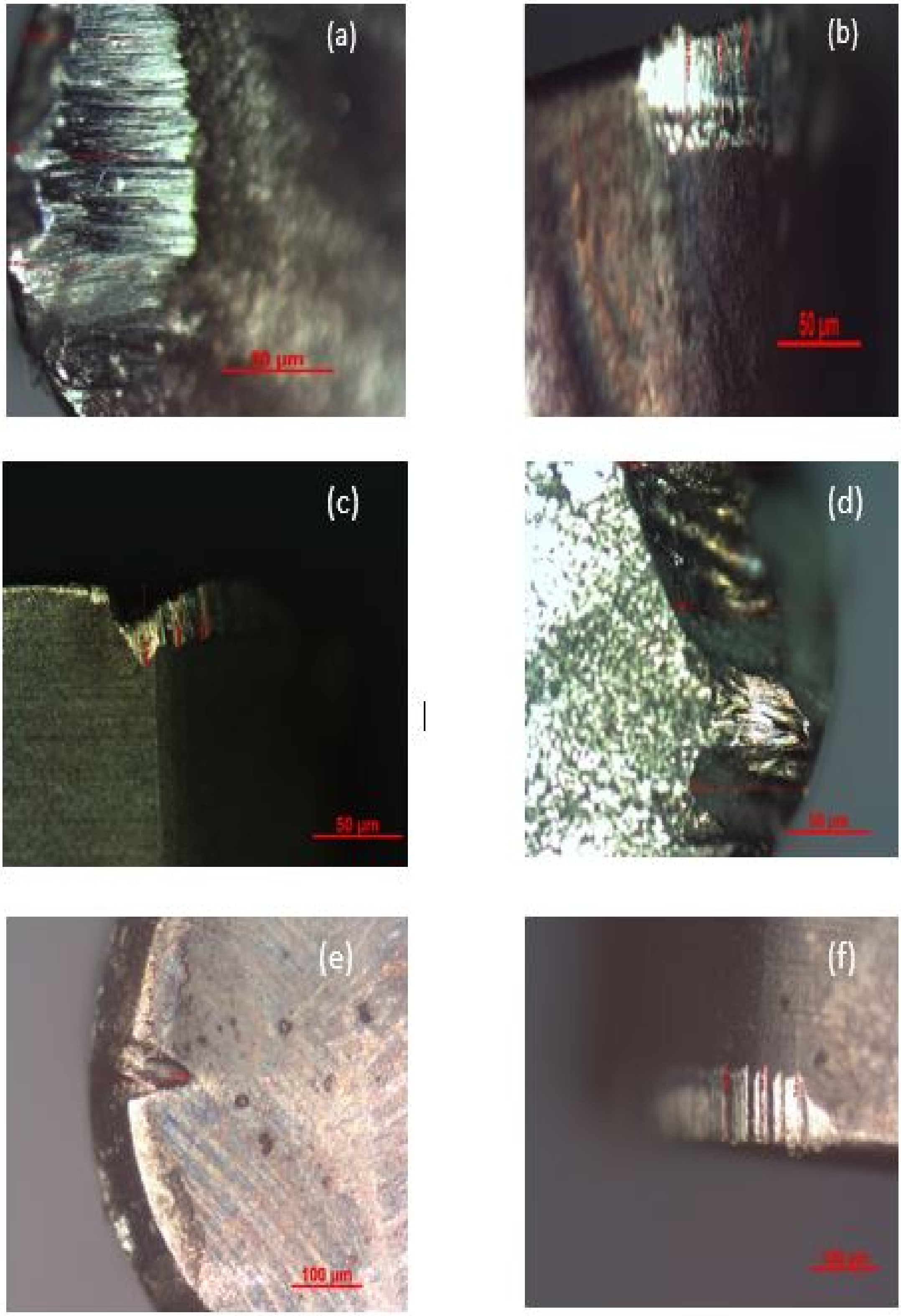

Figure 3 Carbide tool wear (a) Crater wear at Vc=60m/min is 84.31 µm (b) Flank wear at Vc = 60m/min is 33.36µm, Ceramic tool wear (c) Crater wear at Vc = 120m/min is 98.36 µm (d) Flank wear at Vc = 120m/min is 33.54µm, CBN tool (e) Crater wear Vc = 120m/min is 133.75 µm (f) Flank wear at Vc = 120m/min is 82.81µm.

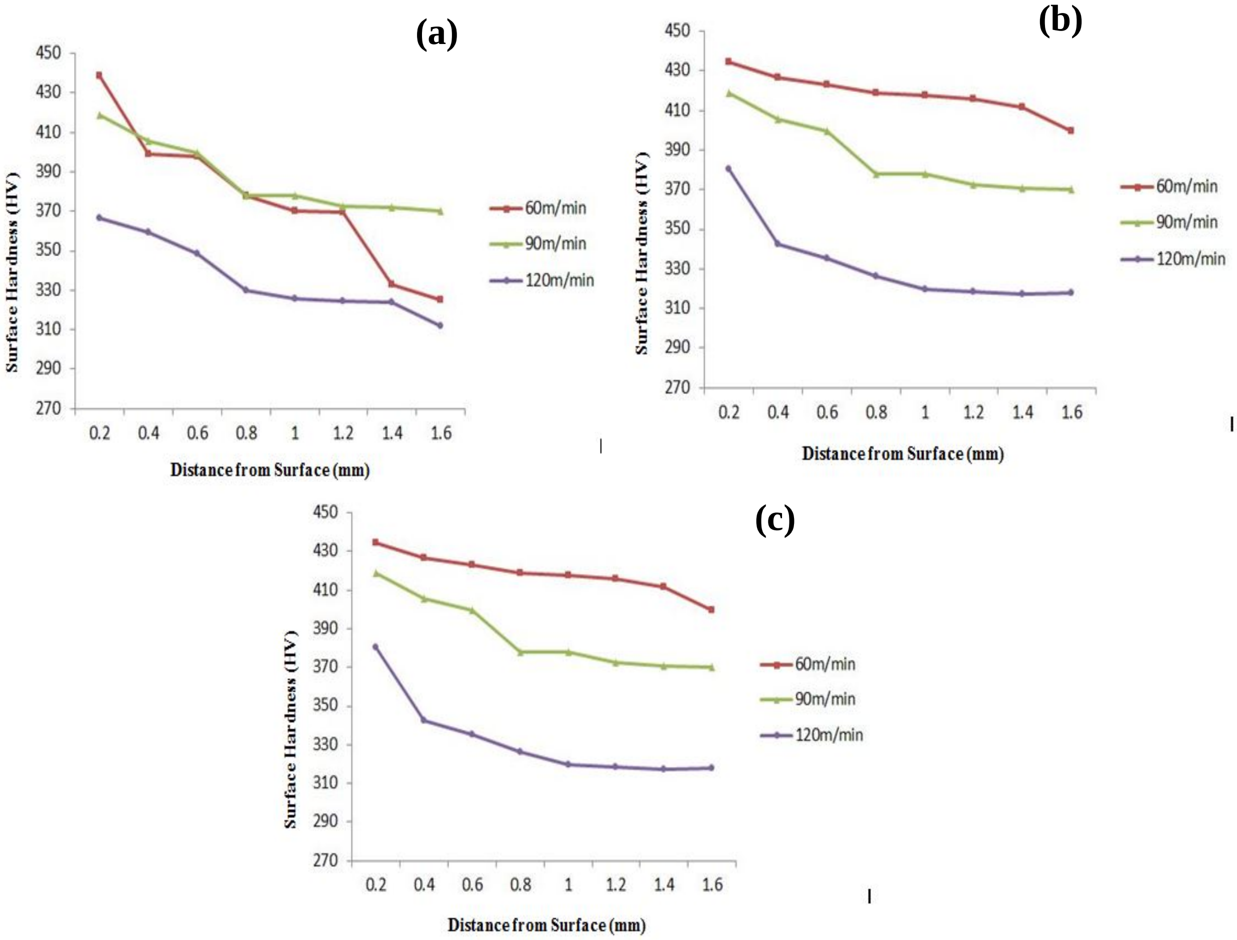

Figure 4 Variation of surface hardness (HV) with distance from machined surface (mm) (a) Ceramic tool (b) Carbide tool (c) CBN tool

4. Conclusion

From the experimental results, it is being inferred that surface roughness on the work specimen machined using carbide tools increases at higher speeds on the other hand carbide tools show relatively high microhardness with increase in the cutting velocity. Tool wear is also found to be maximum for carbide tool at highest cutting speed of 120m/min therefore it can be concluded that carbide tools cannot be used at higher speed ie speeds above 60m/min. The best machining results with the help of carbide tool is observed at the speed of 60m/min. On the other hand ceramic and CBN tools show more favorable results whenever they are used at high speed. When comparing between ceramic and CBN tools CBN tools provide better results in terms of tool wear, surface roughness and s hardness. Therefore it can be concluded that best machining parameters of Inconel 718 is observed while machining with a cutting speed (Vc = 120m/min), depth of cut (DoC = 0.6mm) and feed rate (fd = 0.15m/rev) using CBN tool.

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