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Study on the Mechanism of Chip Formation Employing Material Properties Consideration While Machining Inconel 718

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Abstract—*Nickel based super alloys such as Inconel 718 is the most difficult material to be machined. These nickel based super alloys have many advantages in different industries like aerospace industry, automotive industry etc. These alloys are very hard and corrosion resistant, so performing machining on these alloys is the most difficult task for most of the industries. Because of their large number of advantages over other materials, these alloys are widely used and are being popular in these days. To check the machinability of these alloys, some experimental work was carried out in which Inconel 718 was machined under different cutting conditions with the carbide tip tool. Different cutting speeds were chosen for the experimental purpose under the constant feed and depth of cut. Machining was performed without using the coolant, and thus, the problem of storage, handling, and disposal of cutting fluid was eliminated, and results were evaluated. Results were evaluated by considering the material properties and different response parameters were evaluated by using relations between material properties and these parameters were plotted. Chip thickness, total work done and Von mises stress were plotted for the different cutting conditions and found to have the decreasing trend at higher cutting speeds. Values of shear angle however increased with increase of cutting speeds. Chips were collected and micrographs were seen by using SEM and optical microscope and came to the fact that on machining Inconel 718, saw tooth and wavy form of chips were formed and also it was further revealed that on increasing the cutting velocity, the layering of saw tooth form increased tremendously.*

Keywords: *Inconel 718; SEM; Optical microscope; Saw tooth.*

1. INTRODUCTION

Inconel 718 is a most important alloy of nickel because of its different properties and its high corrosion resistance and also due to its high strength retaining property at higher temperature conditions that's why it is used in gas turbines and also in the aviation industry. This alloy is very difficult to machine as it has high affinity for the tool materials, low thermal conductivity and also due to its tendency of work hardening. Turning is the very vast field in machining area as many of the cutting processes are started with the turning operations. Different parameters which effect the turning process are the cutting conditions, holding devices used and also the speeds at which the operations are performed. All these conditions effect the final result of the turning operation. Tool geometry also capable of bringing the changes in the turning process. The types of chips formed directly influences the cutting forces. As Inconel 718 is the most versatile super alloy used in high temperature areas so many people studied about the different machining aspects of this material as, L.Li et al. [1] studied the effect of high speed machining of Inconel 718 super alloy with coated carbide and ceramic inserts and found that coated carbides are more suitable than ceramic inserts for high speed turning of Inconel 718. R.S.Pawade et al. [2] investigated the effect of various processes and tool dependent parameters on cutting forces in high speed machining of Inconel 718 , and found that magnitude of cutting forces are two to three times higher than that of other forces and also at higher speeds the smooth cutting action can be seen. M.Rahman et al. [3] experimentally studied the effect of cutting conditions on the machinability of Inconel 718 and found that tool life is increased by increasing side cutting edge angle of the tool and also the tool life decreased when the speed or feed is increased. Muammar Nalbant et al.[4] studied the effect of cutting tool coating material and cutting speed on cutting forces and surface roughness on machinability of Inconel 718 and concluded that minimum cutting force is obtained by alluminium oxide carbide tools while the maximum main cutting force is obtained by using titanium based carbide tools but they found that cemented carbide inserts have no effect on main cutting force and also surface roughness increased as the cutting velocity increased. S.Amini et al. [5] experimentally studied about the high speed turning of Inconel 718 by using ceramic and carbide tools and found that ceramic tools produced less effects on surface roughness and force as compared to the carbide tool. So in this study, an effort has been made to know the effect of various cutting parameters on the cutting forces and stresses and also on the chip surface morphology which was checked by using SEM testing and also by optical microscopy.

2. EXPERIMENTAL PROCEDURE

Experiments were performed using the Centre lathe with all gears drive and having maximum spindle speed as 1000rpm and minimum spindle speed as 48rpm and feed range as 0.028mm/rev-1.596mm/rev. Detail composition of Inconel 718 is shown in table1. The cutting conditions and tool specifications are shown in table 2. Different cutting speeds are used for the experimental purpose at same feed and depth of cut.

Table 1: Composition of Inconel 718

C=0.08	Mn=0.35	P=0.015	S=0.015
Si=0.35	Cr=21	Ni=55	Mo=3.30
Nb=5.50	Ti=1.15	Al=0.80	Co=1
B=0.006	Cu=0.30	Ta=0.05	Fe=11.084

Table 2: Specifications of the tool used

Tool	Rpm Used	Rake angle (˚)	Clearance angle (˚)	Principal Cutting edge angle (˚)
Carbide	421,646,1000	12	10	40

Inconel bar used for this analysis is of round shape having diameter as 30mm and length as 250mm (Fig. 1) and is prepared by solution treated and aged as follows:

Solution treatment: 1800˚F for 1 hour

Precipitation treatment: 1325˚F for 8 hours, then furnace cooled at 100˚F per hour to 1150˚F for 8 hours.

Fig. 1: Work piece

2.1 Mechanical Testing

Mechanical testing was performed on the specimen for finding out the different properties of the specimen which were further utilized for evaluating the different process responses. Brinnel hardness test was performed on the machined sample and hardness was found to be as 204 BHN and also the tensile test was performed on the specimen which showed ductile behaviour of the specimen, Graph of the testing is shown in Fig. 2.

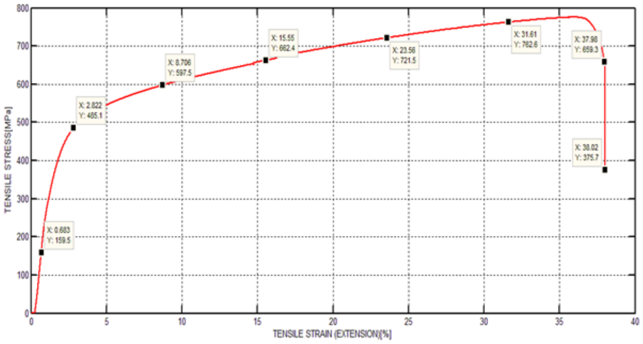


Fig. 2: Stress vs. Strain plot for Inconel 718

2.2 Theory used

1. Chip Thickness t_2, $t_2 = \dfrac{W}{\rho w l}$ (1)

Where,

t_2= Chip thickness

W=Weight of the chip in grams

ρ=Density of the work material in g/cm^3 (assumed to be unchanged during chip formation)

w=Width of the chip in mm

l=Length of the chip in mm

Weight of the chip is evaluated by using the weighing balance.

Width of the chip w, $w = \dfrac{d}{\cos(90-\phi)}$ (2)

Where,

d=Depth of cut in mm

ϕ=Principal cutting edge angle in degree

Length of chip is evaluated by thread bounding method.

2. Uncut chip thickness t_1, $t_1 = f * \sin\phi$ (3)

Where,

t_1=Uncut chip thickness in mm

f=Feed in mm/rev

3. Chip reduction coefficient ζ, $\zeta = \dfrac{t_2}{t_1}$ (4)

4. Shear angle β_0, $\tan\beta_0 = \dfrac{\cos\gamma_0}{\zeta - \sin\gamma_0}$ (5)

Where,

$\gamma_{0=}$ Rake angle in degree

5. Von Mises Stress σ_v, $\sigma_v = 1.74\,K(\ln\zeta)^n$ (6)

n and K were calculated by using tensile test results, True stress vs. true strain graph on log-log graph paper was obtained and from the true stress vs. true strain graph, values of n and K were determined. The graph is shown in Fig. 3. True stress and true strain are evaluated by using the relations as

True stress σ_t $\sigma_t = \sigma(1+\in)$ (7)

True strain= $\in_t$ $\in_t = \ln(1+\in)$ (8)

Where,
$\mathcal{E}$ =strain values obtained from the tensile testing graph.
σ=Stress values obtained from the tensile testing graph.

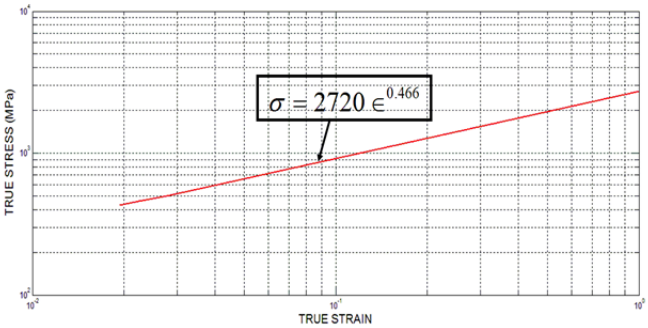


Fig. 3: True stress vs. true strain

From the graph, n value is obtained as 0.466 and K as 2720 and the power law equation was established as $\sigma = 2720 \in^{0.466}$. (9)

6. Total Work done T_w in Nm/rev
Elemental work done W_E,

$$W_E = \frac{K(1.15\ln\zeta)^{n+1}}{n+1} \quad (10)$$

Total Work done T_w, $T_w = W_E vfdt$ (11)

Where,

v=Velocity of particular experiment in m/min

f=Feed of particular experiment in mm/rev

d=Depth of cut for particular experiment in mm

t=Time of a particular experiment in minute

From the above equations, different response parameters were calculated which were further analysed to come to the conclusions. These relations are totally dependent on material properties and hence shows the most accurate results.

3. RESULTS AND DISCUSSION

Machining was performed at 3 different rpm and chips were collected at these rpm for analysis. Images of the chips are shown in Fig. 4 (rpm 421, Weight 0.150gm, v=39.67m/min), Fig. 5 (rpm 646, weight 0.150gm, v=58.85m/min) and Fig. 6 (rpm 1000, weight 0.140gm, v=89.96m/min) and results on machining are shown in tabular form (table 3).

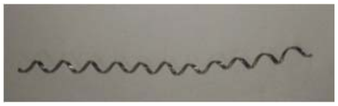


Fig. 4: Chip obtained by experiment no 1

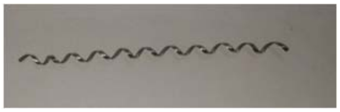


Fig. 5: Chip obtained by experiment no 2

Fig. 6: Chip obtained by experiment no 3

Table 3: Results obtained by analysis

S. no	RPM	V (m/min)	f (mm/rev)	d(mm)	t_1 (mm)	t_2 (mm)	ζ	β_0 (°)	σ_v (MPa)	T_w (Nm/rev)
1	421	39.67	0.138	1	0.088	0.0984	1.1092	47.33	1645.70	499.27
2	646	58.85	0.138	1	0.088	0.090	1.020	50.28	761.011	58.88
3	1000	87.96	0.138	1	0.088	0.0887	1.010	51	189.24	32.09

Recorded data are represented in graphical form (Fig. 7, figure8, figure9 and figure10) and subsequently explained.

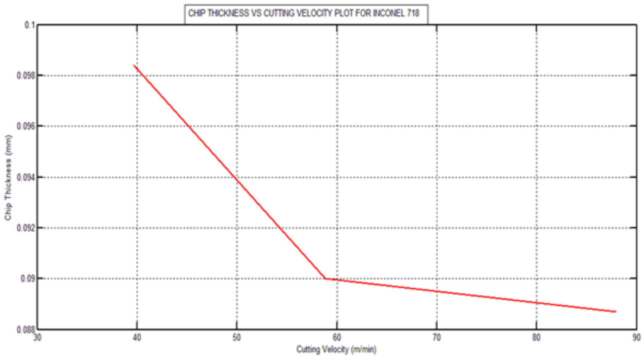


Fig. 7 : Variation of chipthickness vs. velocity

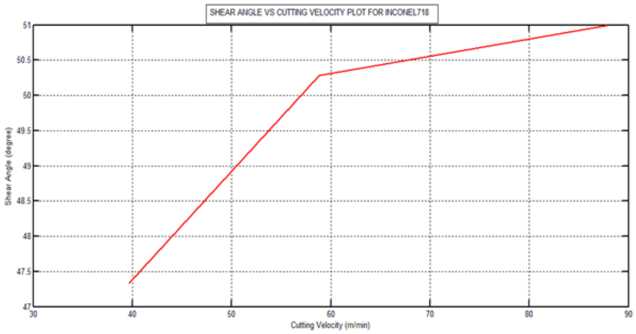


Fig. 8: Variation of Shear angle vs. Cutting velocity

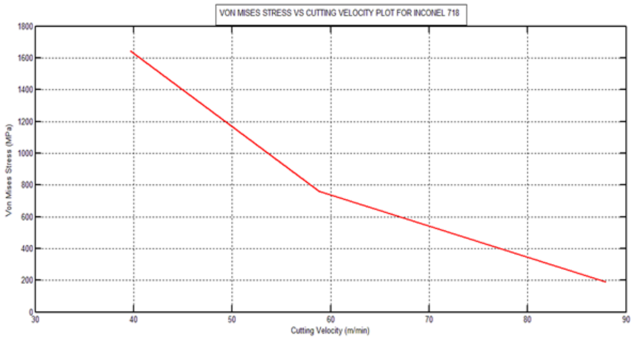


Fig. 9: Variation of Von mises stress vs. cutting velocity

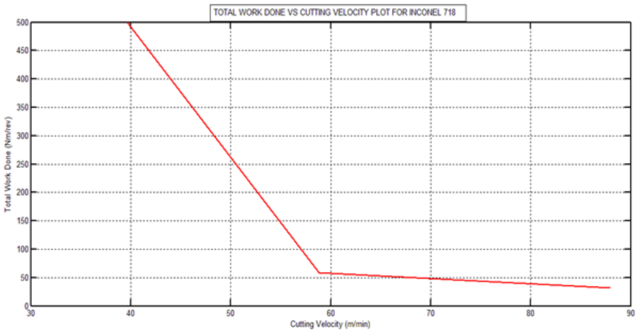


Fig. 10: Variation of total work done vs. cutting velocity

Different graphs are showing variation of the different parameters with respect to cutting velocity. In Fig. 7 it can be seen that chip thickness reduces when the cutting velocity increases, this indicates that the requirement of machining force decreases as the cutting velocity increases. This could be because of recrystallization of the chip material during machining at higher cutting speed. When the speed increases, there is rise in the temperature of work piece causing softening effect that leads to reduce the chip thickness resulting lesser values of machining force. Extent of recrystallization in the chip material seems to be extensive which can be easily predicted by lower chip thickness at higher cutting speed. As the temperature rises, plastic deformation of chip material promotes the recrystallization which reduces the force requirement during machining. On the other hand, it can also be seen that the shear angle value increases with increase in cutting speed (Fig. 8). This is in agreement with reduced chip thickness at higher cutting speed. Von Mises stress also reduces when the cutting velocity increases, (Fig. 9). This is due to reduced force at higher cutting velocity. Thus the cutting force decreases at higher cutting speeds which leads to the decrease in the total work done which can be seen in Fig. 10.

To validate the above results, SEM testing was performed on the collected chip samples and also the chip microstructures were obtained through optical microscopy and results are all seen in subsequent figures.

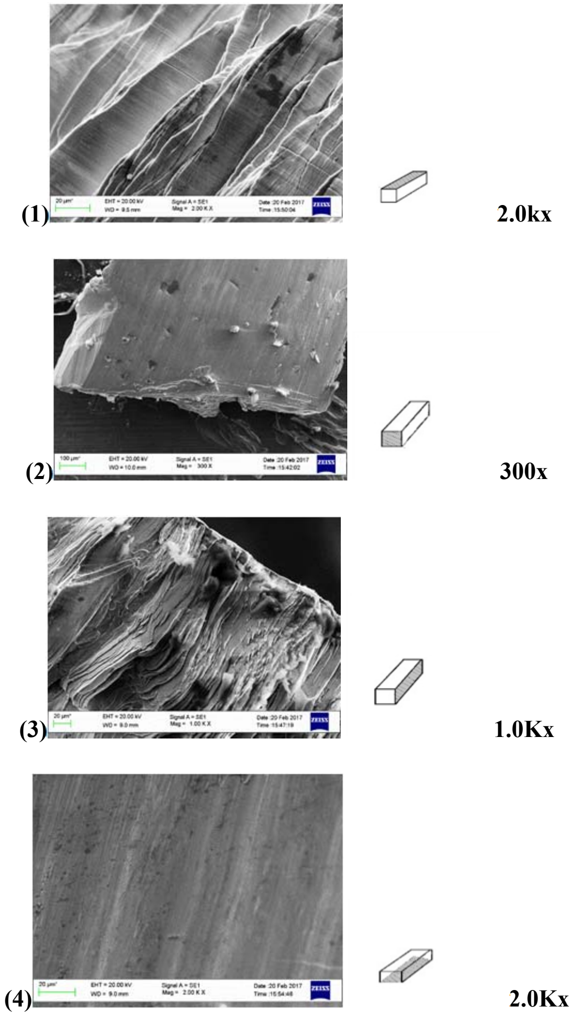


Fig. 11: SEM testing results showing different surfaces of the chip at 421 rpm.

From the SEM micrographs (Fig. 11), it can easily be seen that fracture of the chips took place by brittle mode and also it can be seen that chip formation takes place by saw tooth chip formation mechanism.

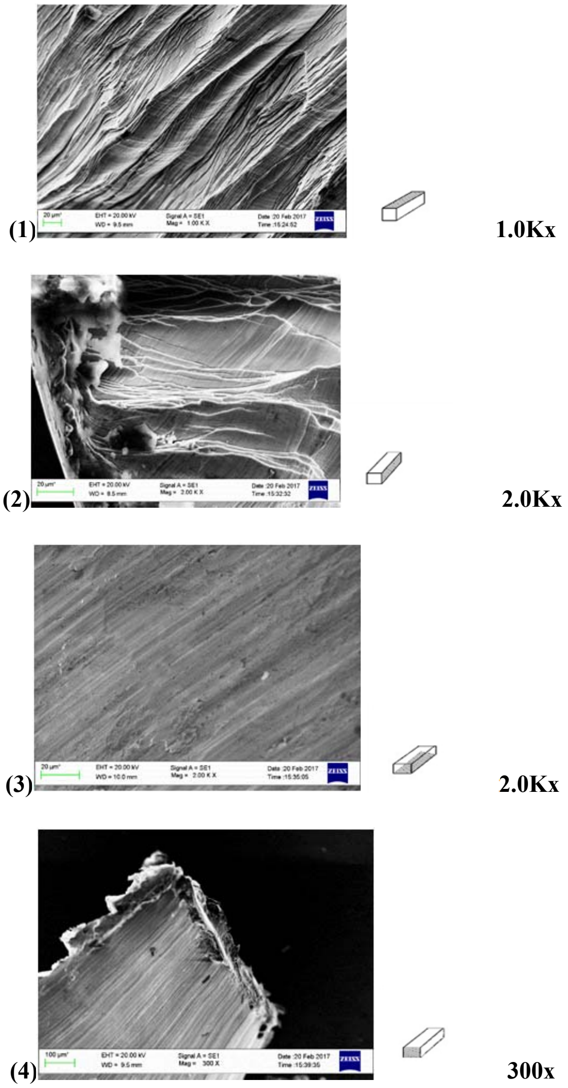
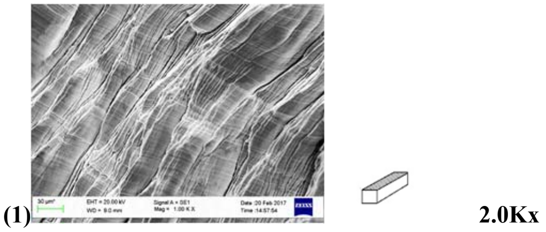


Fig. 12: SEM testing results showing different surfaces of the chip at 646 rpm.

SEM micrographs (Fig. 12) revealed that frequency of saw tooth formation increases with increasing cutting velocity and also the cutting action takes place in a better manner than the lower rpm.



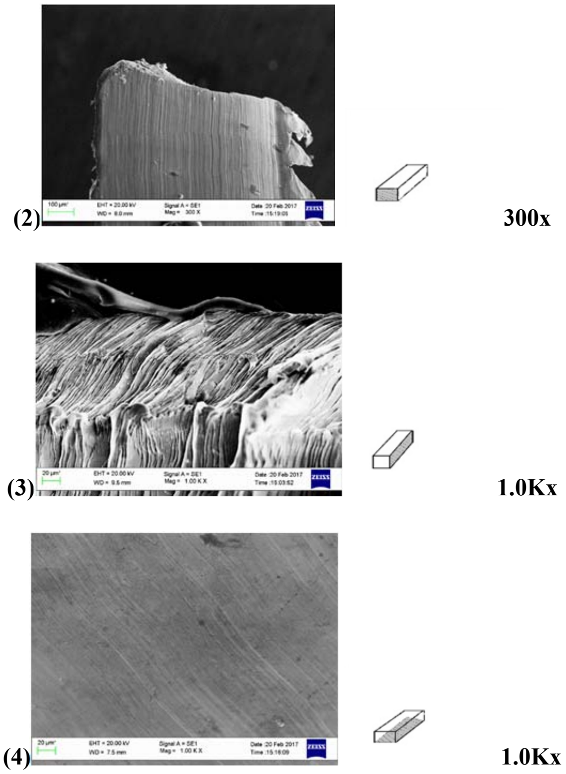


Fig. 13: SEM testing results showing different surfaces of the chip at 1000 rpm.

It can be seen in the above micrographs (Fig. 13) that on increasing the cutting velocity better cutting action is revealed and also the frequency of saw tooth formation increases in comparison to the previous cases and fracture of chips takes place by ductile mode.

To validate the above points on SEM micrographs microstructures of the chips were seen under optical microscope and results were interpretted (Fig. 15 and Fig. 16).

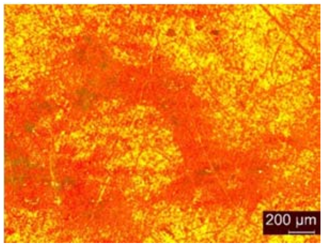


Fig. 14: Microstructures of parent metal

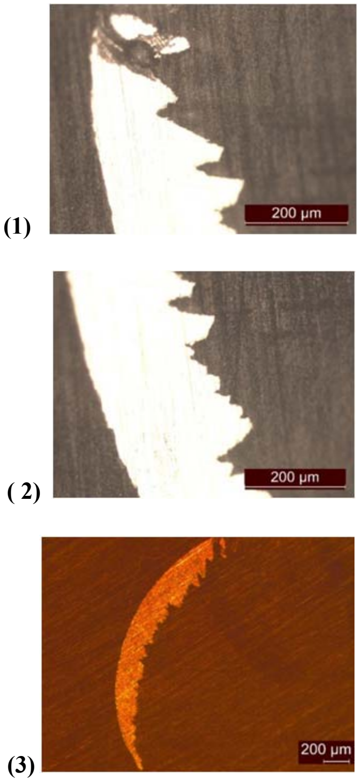


Fig. 15: Unetched and etched sample shows saw tooth chip formation when chips are kept in vertical position.

Same chips when kept in horizontal position saw tooth in the chip were distinctly appeared as shown in Fig. 16.

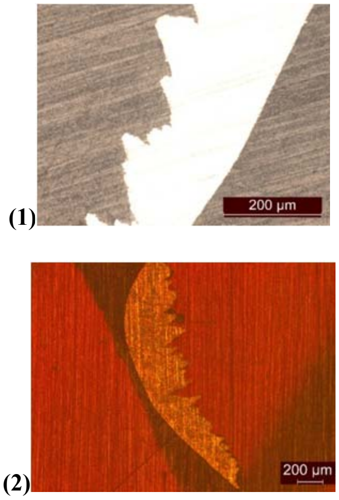


Fig. 16: Unetched and etched sample shows saw tooth chip formation when chips are kept in vertical position.

The saw tooth chip formation is actually taking place by generation of higher amount of heat in a localized shear band during the process of chip formation. Such developed heat however getting confined within the narrow shear band area without getting dissipated i.e. the heat is stored in a narrow region under adiabatic state. Actually, during the process of saw tooth chip formation, the developed heat gets accumulated in the narrow band without further heat dissipation and finally getting slided segmentally along the weakest narrow heat concentrated shear band successively forming the shape of a saw tooth.

4. CONCLUSIONS

1. Effect of cutting speed on machining responses (chip thickness, shear angle, Von mises stress, total work done) based on material properties has been identified i.e. chip thickness, Von mises stress and total work done decreases with increase in cutting velocity whereas shear angle increases with increase in cutting velocity.
2. Saw tooth chip formation is attributed to successive lamellae formation and propagation along the tool rake face during machining on Inconel 718.
3. Machining responses produced (through material property consideration) can be validated through microstructural study i.e. saw tooth and wavy form of chips are obtained. Mechanism of saw tooth chip formation occurred through shear sliding along heat concentrated shear band area without any heat dissipation.

REFERENCES

[1] L.Li ,N.He , M.Wang, Z.g Wang,"High Speed Cutting Of Inconel 718 with Coated Carbide and Ceramic Inserts", Journal of Materials Processing Technology, 129,2002,pp. 127-130.

[2] 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,pp. 139-146.

[3] M. Rahman W.K.H Seah and T.T. Teo, "The Machinability ofIncone1 718", Journal of Materials Processing Technology, 63, 1997, pp. 199-204.

[4] Muammer Nalbant, Abdullah Altın , Hasan Gokkaya,"The effect of cutting speed and cutting tool geometry on machinability properties of nickel-base Inconel 718 super alloys", Materials and Design, 28, 17 February 2006, pp. 1334-1338.

[5] S. Amini, M. H. Fatemi, R. Atefi,"High Speed Turning of Inconel 718 Using Ceramic and Carbide Cutting Tools", Arab J Sci Eng, 39, 2014, pp. 2323-2330.