

# Surface Roughness and Tool Wear on Cryogenic Treated CBN Insert on Titanium and Inconel 718 Alloy Steel

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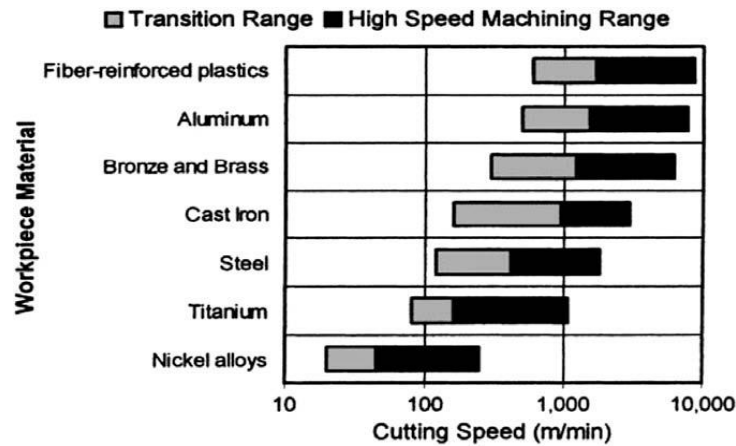
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**Abstract:** Machining of materials by super hard tools like cubic boron nitride (cbn) and poly cubic boron nitride (pcbn) is to reduce tool wear to obtain dimensional accuracy, smooth surface and more number of parts per cutting edge. wear of tools is inevitable due to rubbing action between work material and tool edge. however, the tool wear can be minimized by using super hard tools by enhancing the strength of the cutting inserts. one such process is cryogenic process. this process is used in all materials and cutting inserts which requires wear resistance. the cryogenic process is executed under subzero temperature -186° celsius for longer period of time in a closed chamber which contains liquid nitrogen. in this research, cbn inserts with cryogenically treated was used to turn difficult to cut metals like titanium, inconel 718 etc. the turning parameters used is different cutting speeds, feed rates and depth of cut. in this research, titanium and inconel 718 material were used. the results obtained are surface roughness, flank wear and crater wear. the surface roughness obtained on titanium was lower at high cutting speed compared with inconel 718. the flank wear was low while turning titanium than inconel 718. crater wear is less on inconel 718 than titanium alloy. all the two materials produced saw tooth chips.

## 1. Introduction

Machining of materials is recognized as removing unwanted materials by using different cutting inserts with variable cutting parameters. Cryogenic process is treating the work materials and cutting inserts at - 186° Celsius. CBN and PCBN cutting tools are used to machine difficult to cut materials like high strength alloy steels, stainless steel, Inconel 718, Titanium etc. Figure 1 shows generally accepted cutting speeds in high speed machining of various materials. High speed turning is recognized as a main manufacturing technology for higher productivity and throughput [1]. Barron [2] performed abrasive wear tests on a wide variety of steels and concluded that metals which can exhibit retained austenite at room temperature can have their wear resistance increased significantly, by subjecting them to cryogenic treatment. Seah et al. [3] studied and found that cryogenic treated tools improved wear resistance and overall tool lives of tungsten carbide tool inserts. Yong et al. [3] compared the performance of cryogenically treated and untreated tungsten inserts during high speed

milling of medium carbon steel. The cryogenically treated inserts exhibit better tool wear resistance than untreated.



**Figure 1.** High-speed cutting ranges in machining of various materials [1]

## 2. Experimental Setup

### 2.1. Principle of deep cryogenic treatment

In this research, CBN inserts were cryogenically treated and the process is explained briefly. Cryogenic expresses study and use of materials at very low temperature, below  $-186^{\circ}$  Celsius. Liquid Nitrogen (LN) is the most commonly used element in cryogenics. Nitrogen melts at  $-201.01^{\circ}$  Celsius and boils at  $-198.79^{\circ}$  Celsius, it is the most abundant gas, composing about four fifths (78.03 %) by volume of the atmosphere. It is colorless, odorless, tasteless and non-toxic gas. Deep cryogenic treatment comprises of cooling the material over a period for few hours to the sub-zero range, holding at this temperature for a long time and then returning to room temperature. The process is based on the predetermined thermal cycle that involves cooling of the engineering components/materials in a completely controlled cryogenic chamber. The material is slowly cooled to  $-196^{\circ}$  Celsius and soaked at deep cryogenic temperature for 20 hours. The material is then allowed to return slowly to ambient temperature. The complete cryogenic cycle would take up to 25-30 hours. Thermal control is achieved by continuously monitoring inputs and regulating the flow of LN into the chamber and alternating the heat. Precise program control takes the cycle through its three phases of descend, soak and ascend. It is imperative that a slow descend is followed by soaking period for at least 24 hours at  $-186^{\circ}$  Celsius and raised to room temperature with a slow ascend. In this process, no dimensional change and thermal crack occur. Strict computer control and precise processing profiles assure that optimum results are achieved with no dimensional change or thermal shock. The system is relatively simple and does not require large capital outlay.

### 2.2. Titanium (Ti-6Al-4V) alloy

Titanium alloy is an attractive material in many industries due to its unique and excellent combination of strength to weight ratio and their resistance to corrosion. However, because of its low thermal conductivity and high chemical reactivity, Ti-6Al-4V alloy is generally classified as a difficult to cut material that can be characterized by low productivity and rapid tool wear rate even at conventional cutting speeds. Table 1 and 2 show the mechanical and chemical properties of Titanium alloy and Inconel 718 alloy respectively. The chemical and mechanical properties details were given along with test certificates by the supplier.

### 2.3. Inconel 718

Inconel 718 is categorized as a nickel-based super alloy, which is extensively used in aerospace and energy industry, specifically in the high temperature area of engine, because of their excellent mechanical resistance to high temperature and corrosion. Many previous investigations have reported that nickel-based super alloys are difficult to machine [4-5] due to the following reasons: (1) high hot hardness and strength causing deformation of the cutting tool; (2) the rapid work hardening causing severe notch wear; (3) presence of primary carbide particles encouraging abrasion tool wear; (4) low thermal diffusivity leading to extremely high local temperature on cutting edge; (5) welding of the work piece to the tool cutting edge forming unstable built-up edge (BUE) which deteriorate machined surface; and (6) possible chemical reactions accelerating tool wear. One of major issues in machining of nickel-based super alloys is short tool life and thereby low productivity. Welding and adhesion of work piece material onto the cutting tool frequently occur during machining causing severe notching as well as alterations of the tool rake face due to the consequent pull-out tool material [6-7]. Surface quality is another important issue in the machining of nickel-based super alloys since critical components, such as discs for jet engine, are often made of this material. The main problems reported from previous investigations are surface tearing, cavities, cracking, metallurgical changes, plastic deformation and formation of residual stresses in the case of machining with carbide cutting tools [5, 8]. Sadat and Reddy [9] found that an increase in cutting speed reduced surface damages by reducing the cutting force due to an increase in cutting temperature and corresponding drop in work piece strength. Ezugwu [5] reported that the change of microstructure in subsurface when cutting tool changed from a new tool to worn tool.

**Table 1.** Mechanical properties

<b>Grades</b>	<b>Tensile strength</b>	<b>Yield strength</b>	<b>% elongation</b>
Inconel 718	1240 MPa	1036 MPa	12
Titanium	147.8 KSI	138.5 KSI	19.2

**Table 2.** Chemical properties

<b>Alloying elements</b>	<b>Titanium alloy</b>	<b>Inconel 718</b>
Carbon	0.030-0.031	0.08 max.
Manganese	< 0.01	0.35 max.
Chromium,	--	17-21
Molybdenum	< 0.01	2.80-3.30
Titanium alloy	Balance	0.65-1.15
Nickel	50-55	--
Aluminum	6.51-6.57	0.20-0.80
Vanadium	4 - 4.07	--
Fe	0.17- 0.21	Balance
Silicon	< 0.01	0.35 max.
Copper	< 0.01	0.30 max.
Cobalt	--	1.00 max.
Phosphorus	--	0.015 max
Sulfur	--	0.015 max.
Boron	--	0.006 max.

**Table 3.** Operating parameters

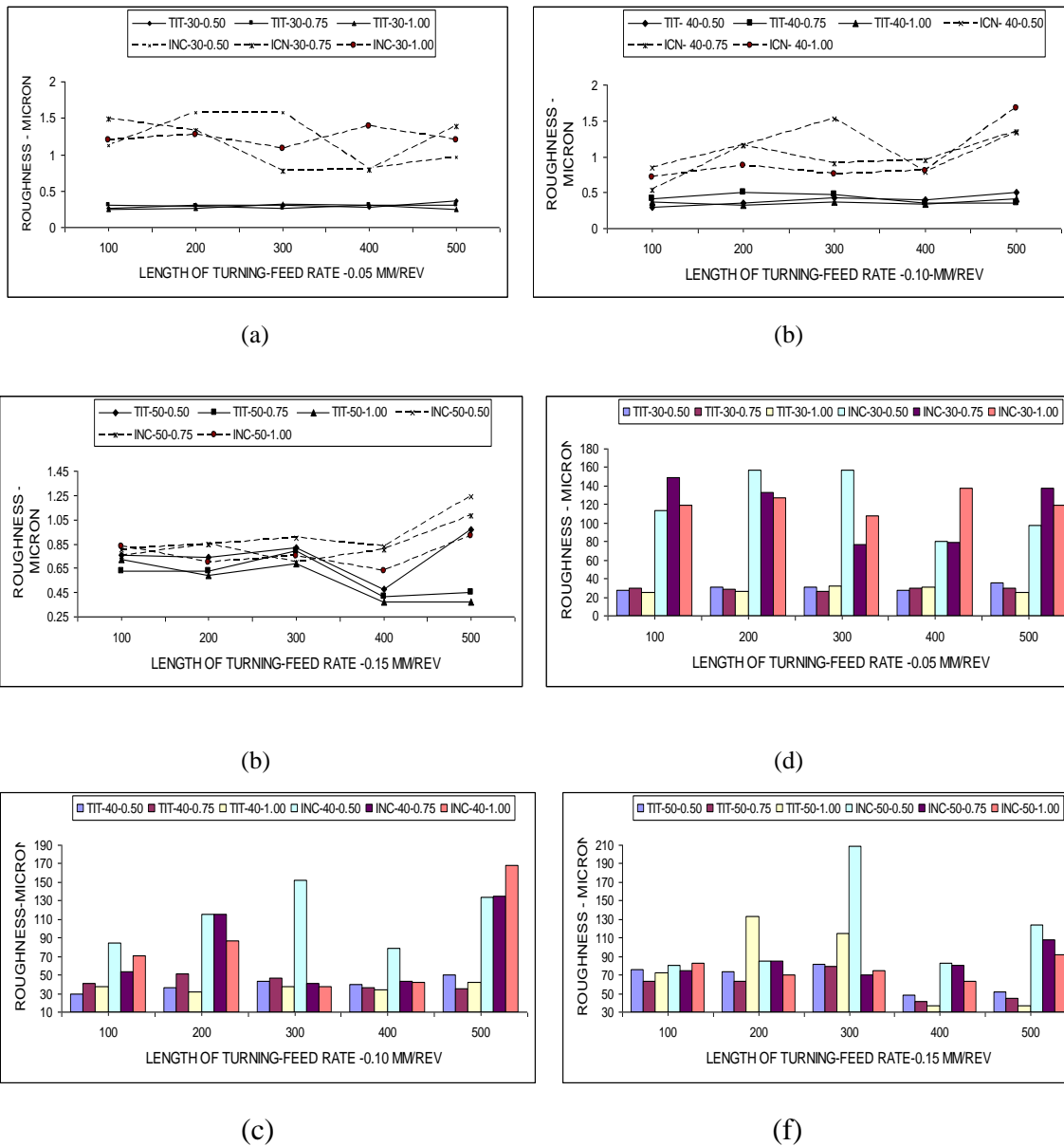
<b>Cutting speed m/min</b>	<b>Feed rate – mm/rev</b>	<b>Depth of cut –mm</b>
30	0.05	0.50, 0.75 & 1.00
40	0.10	0.50, 0.75 & 1.00
50	0.15	0.50, 0.75 & 1.00

### 3. Results And Discussion

#### 3.1. Surface roughness

Formation of the machined surface is closely associated with the reaction of the edge of cutting tool and workpiece. Dhar et al. [10] reported that the surface roughness was low with cryogenic treated inserts in comparison with non-treated inserts at all cutting speeds. This has been more or less true for all the work – tool combinations undertaken in this research. Wuyi Chen [11] stated that the surface roughness would be low when the hardness of the material increased. Lateral plastic flow of the work material in front of the cutting edge increased roughness of the machined surfaces. Thakur et al. [12] turned Inconel 718 material by tungsten carbide tool and reported that the roughness value decreased at high cutting speed but increased as the feed rate increased. This was due to increased friction between work material and tool interface which eventually increases the temperature in the cutting zone. The surface roughness values are higher when lower feed rate was used, while the roughness values were smaller when higher feed rate was employed in the tests. This is presumably, is due to ploughing action caused by smaller uncut chip thickness [13, 14]. Rougher surface at small feed rate may associate with minimum chip thickness. Figure 2 (a to f) show graphical representation of surface roughness against operating parameters as given in the Table 3. The surface roughness obtained at cutting speed of 30, 40 and 50 m/min with at feed rate is low in turning Titanium than Inconel 718 alloy steel even after 500 mm length turning. Smooth roughness obtained at cutting speed of 50 m/min with feed rate 0.05 mm / rev. at 1 mm depth of cut. This was due to more tool plough effect and plastic deformation produced low surface roughness.

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**Figure 2.** Graphs showing length of turning vs surface roughness: (a) 30 m/min cutting and feed rate of -0.50 (b) 40 m/min cutting speed with 0.10 feed rate (c) 50 m/min cutting speed with 0.15 feed rate, (d) DOC of 0.50 mm, (e) DOC of 0.75 mm and (f) DOC of 1.00

### 3.2. Tool Flank Wear

Flank wear is formed on the flank side of the insert which is due to rubbing action of the insert and machining surface. Figure 3 shows the various tool wear that is likely to occur as per ISO 3685 of 1993 [15]. The tools often fail rapidly due to non-uniform flank wear, chipping, depth of cut notching, and plastic deformation of the cutting edge even at relatively low cutting. Low thermal conductivity (11.4 W/m K), leading to high cutting temperature in cutting and high strength under high temperature are responsible for its generally poor machinability [6]. In addition, the cutting forces generated are also very high around double that found when cutting medium carbon steels [7]. This, in combination with the relatively short chip contact length and high cutting temperature, induces very high stress concentration on the area of tool / work piece interaction and leads to highly plastics deformation in

cutting edge and work piece material. Manu Dogra et al. [15] found that during the turning of hardened AISI 4340 steel using CBN-TiN coated carbide and PCBN tools, result revealed that tool life of CBN –TiN coated carbide inserts was approximately 18-20 min per cutting edge, whereas PCBN tools produced a tool life of 32 min. Flank wear is primarily attributed to rubbing of the tool along the machined surfaces, causing abrasive diffusive and adhesive wear mechanisms and also high temperature, which affect the tool material properties as well as work piece surface.

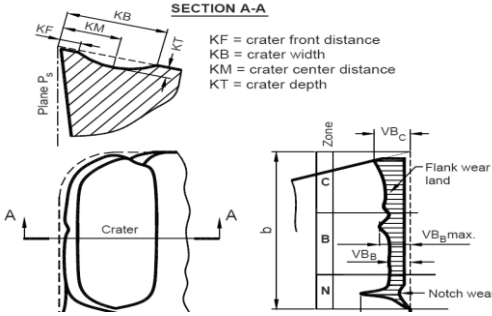


Figure 3. Various tool wear on a single point tool [15]

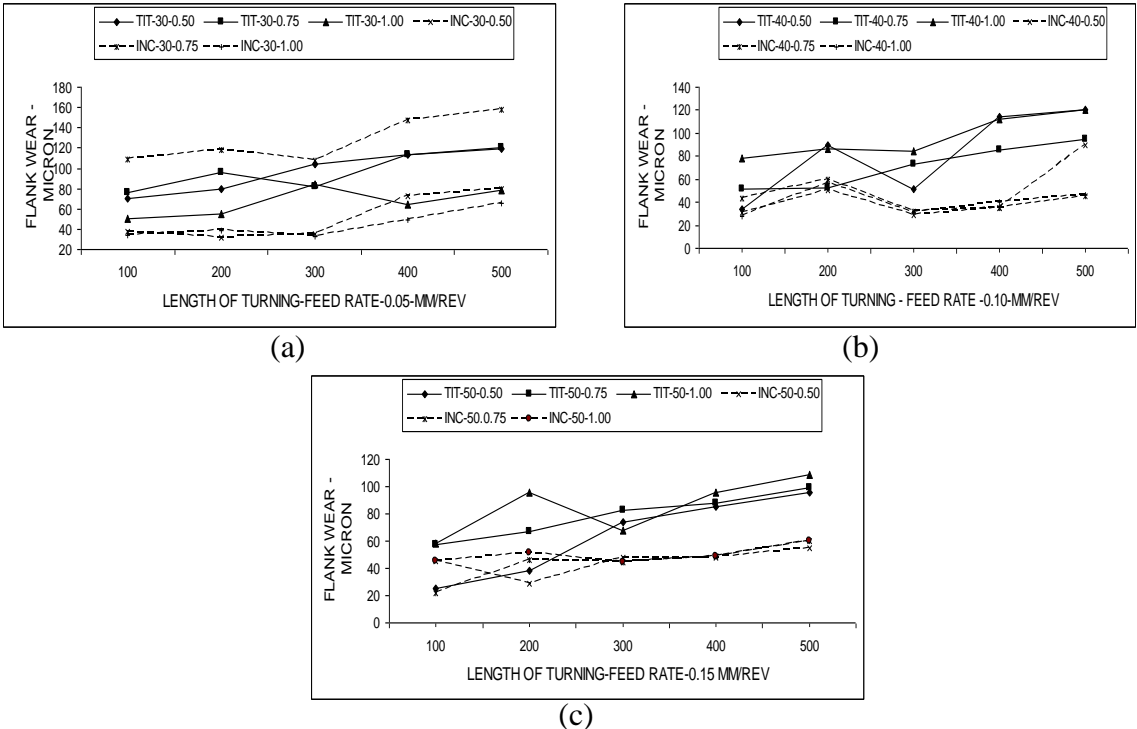
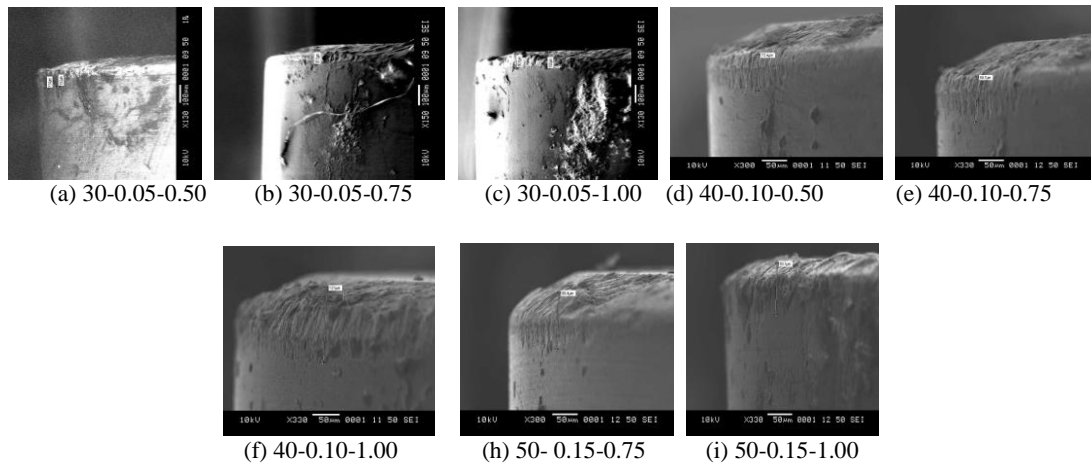
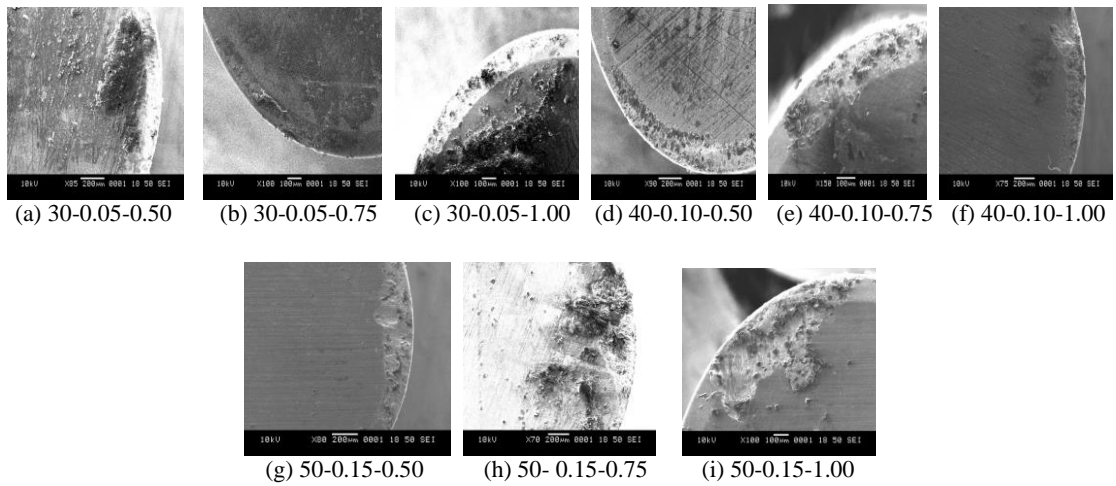


Figure 4. Graph showing length of turning Vs flank wear (a) 30 m/min cutting and feed rate of -0.50 (b) 40 m/min cutting speed with 0.10 feed rate and (c) 50 m/min cutting speed with 0.15 feed rate.

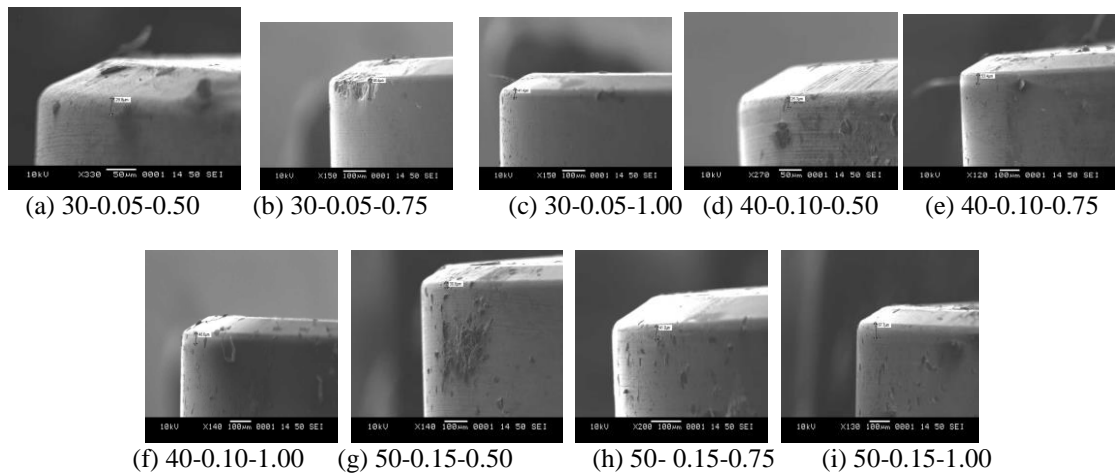
In all the cutting speeds, flank wear was formed more at low feed rate of 0.05 mm/rev. Titanium alloy steel. At 1 mm depth of cut in turning Inconel 718, the flank wear was low than 0.50 and 0.75 mm depth of cut. In this research, it was found that flank wear formation was high in Titanium than Inconel 718 and shows that Titanium alloy is difficult to cut metal. Figure 4 (a to c) show graphical representation of flank wear for all the three parameters. Figure 5 (a to i) shows SEM view on flank wear by titanium alloy and more abrasion occurred than Inconel 718. Figure 6 show SEM view on flank wear by Inconel 718 alloy steel which shows less flank wear.



**Figure 5.** SEM view on flank wear on Titanium alloy



**Figure 6.** SEM view on crater wear while turning Titanium



**Figure 7.** SEM view on flank wear on Inconel 718 alloy

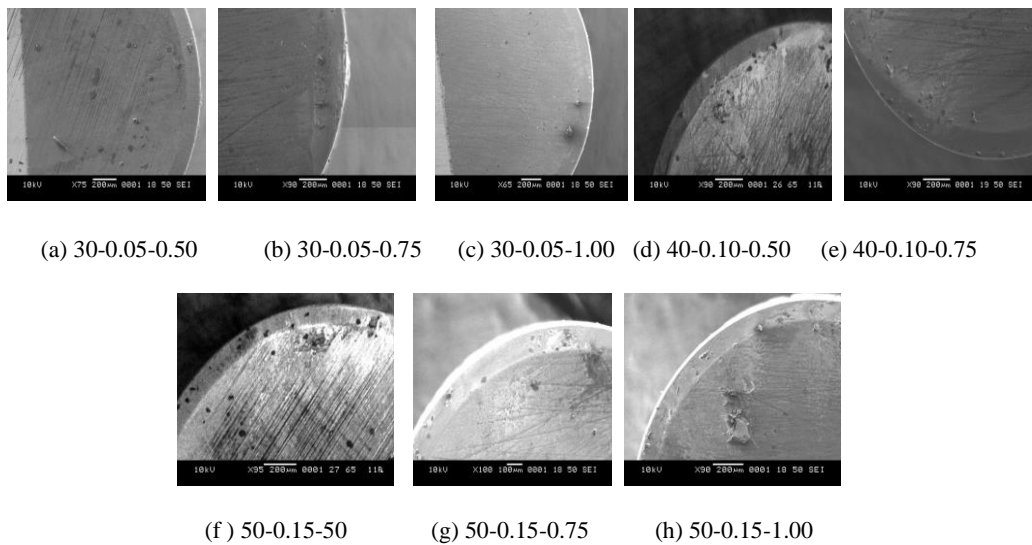
### 3.3. Crater wear

Crater wear is formed at rake face of the tool. Figure 3 shows the various crater wear formation which is represented by  $K_T$ . The ISO 3685 of 1993 recommends the criterion of tool life due to crater wear and can be calculated by using the formula as given below:

$$K_T = (0.06) + 0.3f \quad (1)$$

where  $f$  is the feed rate and  $K_T$  is the depth of crater.

Crater wear is dished out section which develops on the rake face of the tool. The formation of crater wear occur little away from the cutting edges. In fact at low cutting speed, crater wear is usually insignificant compared with flank wear in normal operations. There is no standard available for maximum depth of the crater specification like flank wear. Deeper crater will lead to failure of the cutting edge. When machining using CBN, PCBN inserts and other high strength inserts the formation of wear take longer time. At high cutting speeds crater wear formation would be more severe and depth of crater  $K_T$  will be deeper. While turning difficult to cut materials crater wear was more due to saw tooth chips. In turning Titanium alloy, the formation of crater wear was low than Inconel 718. The saw tooth chips rougher and deeper crater formed. Figure 6, 7 and 8 show the crater wear formed while turning Titanium and Inconel 718 respectively. More craters formed in turning Titanium than Inconel 718.



**Figure 8.** SEM view on crater wear on Inconel 718 alloy

### 4. Conclusions

The following conclusions were arrived in this research. They are:

- Surface roughness obtained in turning Titanium alloy was low at cutting speed 50 m/min than 30 and 40 m/min than Inconel 718.
- Surface roughness at depth of cut 1 mm is low than 0.50 and 0.75 mm in Titanium alloy than Inconel 718.
- Flank wear by Inconel 718 was low than Titanium. Flank wear at 1 mm depth of cut was low than 0.50 and 0.75 mm.
- Crater wear formed in turning Titanium alloy was un-uniform in wear. The crater wear by Inconel 718 was less deep and small in magnitude of  $K_T$ .



- Cryogenic treated inserts performed very well by producing smooth surface roughness in Titanium alloy than Inconel 718. On the other hand, flank wear was low in turning Inconel 718 than Titanium alloy.

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