Performance of Tool Wear Using Cryogenic Treated CBN Inserts

Sivaprakasam Thamizhmanii°, Sulaiman Hasan*and Elango Natarajan**

Abstract*—Machining of materials by super hard tools like CBN and 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 treatment. This process is used in all materials and cutting inserts which requires wear resistance. The cryogenic process is executed under subzero temperature -196° C for longer period of time for 30 hours in a closed chamber which contains liquid nitrogen. This treatment gives additional strength to cutting inserts to improve cutting ability and wear resistance. The cryogenic treated inserts produced low tool flank wear while turning Inconel 718 than Titanium and AISI 440 C Martensitic stainless steel. It needs to be justified for cost of the process. The research by cryogenic treated is not fully used in many of the industries due to cost and also non availability of the specialized equipment. The cutting edge deformed plastically at low cutting parameters especially in turning stainless steel than other two metals. All the three materials produced saw tooth chips and one reason for more crater wear formation while turning stainless steel. More abrasion occurred on the flank side in turning stainless than Inconel 718 and Titanium. The turning on stainless steel formed built up edge in all the parameters than other low metals. The formation of built up edge must have deteriorated the stainless steel surface. The depth of cut did not have affected the quality of machined surface. The formation of flank wear was less in turning Inconel 718 than AISI 440 C stainless steel and Titanium. Titanium alloy produced comparatively less flank wear than stainless steel. Flank wear occurred more in depth of cut 1 mm in all the three materials, but the intensity was less at less depth of cut of 0.50 and 0.75 mm. Even though all the three materials are difficult to cut (DTC) materials, stainless steel is more difficult than other two materials from this research. Crater wear formation was less in Inconel 718 than AISI 440 C stainless steel and Titanium alloy. AISI 440 C contains high carbon content which is responsible for more flank wear and crater wear. At depth of cut 1 mm, crater formation was high than at 0.75 and 0.50 mm.

Keywords:* *Machining, Electron microscope, Surface treatment, Tool material, Wear resistance.,

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I. Introduction

THE study of metal cutting focuses on the features of the behavior of tool and work materials that influences the efficiency and quality of cutting operations. The technology of cutting tools and cutting inserts has been rapidly developing. In recent years, instead of new tooling materials being introduced, secondary process to improve tool life is being explored, such as heat treatment of tool inserts and the employment of surface coatings on tool inserts [1]. Another process is the cryogenic treatment of tool inserts to improve the tool life. Cryogenic treatment is the treatment of cutting inserts at low temperature below −196◦ C. It is like superficial treatment and it is applied for all the materials subjected to this treatment and reaching the core of the materials. The important aspect of this process is changes in the mechanical properties and in the crystal structure of materials. For the past 30 years, there has been an increasing interest in the effects of cryogenic treatment on the properties of metals. Barron [2] performed abrasive wear tests on a wide variety of steels, and concluded that metals which can exhibit a retained austenite at room temperature can have their wear resistance significantly increased by subjecting them to cryogenic treatment. Quek [3] concluded that cryogenically treated tool inserts exhibited better wear characteristics than untreated ones at low turning speeds and feed rate. Trail was conducted trails using cryogenic treated tools and found that too life increased between 82-91 % after being treated at −196◦ C [4]. The hardness and wear resistance of tool steels can be improved simultaneously through cryogenic treatment [4-5]. In this research work, CBN tool which was used for turning Titanium, AISI 44 C martensitic stainless steel and Inconel 718 and this CBN inserts achieved maximum flank wear of 0.30 mm as per ISO 3685 of 1993.

II. EXPERIMENTAL WORK

A. *Experimental procedures*

The turning experiments were conducted using NC Harrison 400 Alpha Lathe with 7.5 kw capacity. Table I shows three parameters 30, 40 and 50 cutting speeds with three feed rate of 0.05, 0.05 and 0.10 mm/ rev. and also with three depth of cut 0.50, 0.75 and 1.00 mm. Table I shows the operating parameters. All the tests were performed under continuous turning conditions with dry turning. In every trial the flank wear, crater wear and BUE were measured by SEM. The CBN cutting tool was manufactured by Mitsubishi. The tool holder used was by MTJNR 2020 KL16N by Mitsubishi. Table I, II and III shows operating parameters, chemical and mechanical properties respectively. The rake angle is – 6°, side rake -6° and end clearance angle of 27° with nose radius of 0.80 mm for both tools. The used CBN inserts were treated with cryogenic process is explained in the section B.

B. Cryogenic process

Cryogenic expresses study and use of materials at very low temperatures, below – 196º C. Normal boiling point of permanent gases such as helium, hydrogen, neon, nitrogen, oxygen, normal air as cryogens lie below -180º C. Cryogenic gases have wide variety of applications in industry such as health, electronics, manufacturing, automotive and aerospace industry particularly for cooling purposes. Liquid nitrogen is the most commonly used element in cryogenics. Nitrogen melts at -201.01º C and boils at – 198.79º C, it is the most abundant gas, composes about four-fifths (78.03 %) by volume of the atmosphere. It is colorless, odorless, tasteless and non-toxic gas [6]. Cryogenic treatment comprises of cooling the material over a period of few hours to the temperature of 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 component/material in a completely controlled cryogenic chamber. The material is slowly cooled to -196◦C and soaked at the deep cryogenic temperature for 20 hours. The material is then allowed to slowly return to the ambient temperature. The complete cryogenic cycle would take up to 25-30 hours. The conventional cycle is shown below. The CBN inserts was treated for 30 hours. The materials are treated in the cryogenic chamber. The process involves raising and reducing the temperature. Thermal control is achieved by continuously monitoring inputs and regulating the flow of liquid nitrogen into the chamber and alternating the heat. Precise program control takes the cycle through its three phases of descend, soak and ascend. The entire cycle takes 48 to 72 hours depending on the weight and type of material. It is imperative that a slow descend is followed by a soak period of at least 24 hours at -196° C and raised to room temperature with slow ascend. Strict computer control and precise processing profiles assure that optimum results are achieved with no dimensional change or thermal shock. The cooling potential is obtained from bypass of a continuous nitrogen gas use. It also includes two solenoid valves tied in with a thermocouple and temperature controller allowing easy control of soak temperature. Long stem valves and an appropriate thermometer can be used for manual operation to provide economy. Either way, the system is relatively simple and does not require a large capital outlay to implement. By controlling the flow of liquid nitrogen into the cold box the temperature and cooling rate can be controlled.

A. Titanium

Titanium (Ti-6Al-4V) 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.

B. AISI Martensitic stainless steel

AISI 410, 420 and 440 A, B, C are all considered as martensitic stainless steel. In this research, AISI 440 C stainless was used under hard condition. AISI 440 C is widely used in aerospace industries for bearings, steam and water valves, pumps, turbines, compressor components, shafting, cutlery, surgical tools, plastic molds and nuclear applications which demand high strength and high resistance to wear and corrosion [4]. It has high viscosity, poor thermal conductivity, low corrosion, high work hardening rate and tendency to form built up edge (BUE) at tool edge. AISI 440 C has high chromium and high carbon content and possesses high mechanical strength in this group [5].Table II shows mechanical properties of Titanium and AISI 440 C stainless steel.

C. Inconel 718

Inconel 718, which is a nickel based super alloy and different from other alloys, has been widely used in the aircraft, in particular in the hot section of gas turbine, due to their high temperature strength and high corrosion resistance and nuclear industry due to its exceptional thermal resistance and the ability to retain its mechanical properties at elevated temperature over 700° C [6-7]. Inconel 718 also used in medical equipment, example dentistry use, prosthetic devices, space vehicles, heat treating equipment, nuclear power systems, chemical and petro-chemical industries, pollution control equipment and coal gasification and liquefaction systems [8]. Nickel based alloys are classified as difficult to cut material due to its their high strength, work hardening tendency, highly abrasive carbide particles in the micro-structure, strong tendency to weld and form built up edge (BUE) and low thermal conductivity [9-10]. They have a strong tendency to maintain their strength at the high temperature that is generated during machining [10].

TABLE I
OPERATING PARAMETERS

Cutting speeds m/ min	Feed rate mm/ rev	Depth of cut in mm
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

TABLE II
CHEMICAL PROPERTIES

Alloying elements	Titanium alloy	AISI 440 C	Inconel 718
Carbon	0.030-0.031	0.95-1.20	0.08 max.
Manganese	< 0.01	1.00	0.35 max.
Chromium,	--	16-18	17-21
Molybdenum	< 0.01	0.75	2.80-3.30
Titanium alloy	Balance	--	0.65-1.15
Aluminum	6.51-6.57	--	
Vanadium	4 - 4.07	--	--
Fe	0.17- 0.21	--	--
Silicon	< 0.01	--	0.35 max.

TABLE III
MECHANICAL PROPERTIES

Grades	Tensile strength	Yield strength	% elongation
AISI 440 C	1965 (MPa)	1900 (MPa)	2
Titanium alloy	147.8 (KSI)	138.5 (KSI)	19.2
Inconel 718	1240 MPa	1036 MPa	12

III. RESULTS AND DISCUSSION

A. *Flank wear*

Flank wear is primarily attributed to the rubbing of the tool along the mechanical surfaces, causing abrasive, diffusive and adhesive wear mechanisms and also high temperature, which effect the tool material as well as work piece surface. The cryogenic tool inserts formed low flank wear at high cutting speed with high feed rate compared to non-treated inserts. Long tool life is possible with cryogenic treated PVD inserts in machining Inconel 718. 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 significantly reduced by subjecting them to cryogenic treatment. The trails conducted using cryogenic treated HSS tools and found that tool life increased between 82-91 % after being treated at -196° C [4]. The hardness and wear resistance of tool steels can be improved simultaneously through cryogenic treatment [5]-[5]. The maximum flank wear was 0.03 mm. Fig. 1 shows the flank wear formed while turning three difficult to cut materials at various cutting speeds, feed rates and depth of cut. As the cutting increases, wear increases for two reasons: (i) the sliding distance of cutting tool increases with increase in cutting speed for a given time and (ii) increasing the cutting speed increases temperature, which leads to increase in wear and plastic deformation of the cutting edge. The relative wear resistance at different cutting speeds are presented in Fig. 1 (a) to (i) for three cutting speed with different feed rate and three depth of cut. flank wear formed in Inconel 718 less than stainless steel and Titanium alloy. In all the three materials, the flank wear was not formed uniformly and erratic which is common in turning these types of materials. Thamizhmanii, Mohd Nagib Derani and Sulaiman Hasan [12] conducted study in using cryogenically treated PVD coated and uncoated inserts in milling Inconel 718 material, found that untreated inserts performance was poor than treated inserts in terms of surface finish and wear.

B. *Crater wear*

Crater wear K_T is dished out formation which is occurring in the rake face of the tool little away from the cutting edge. The ISO 3685 of 1993 [11] 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.

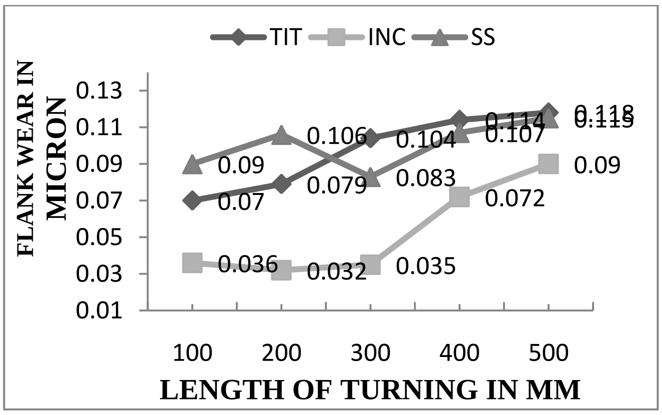
Even though there is formula available for measuring depth of cut theoretically, no standard is specified. Crater wear was due to high contact stress and high interface temperature. In fact at low cutting speed, crater wear is usually insignificant compared with flank wear in normal operations. There is no standard available for maximum depth of the crater specification like flank wear. Deeper crater will lead to failure of the cutting edge. At high cutting speeds crater wear formation would be more severe and the depth of crater is possible. While turning difficult to cut materials the formation of crater wear was more due to saw tooth chips. In turning Titanium alloy the formation of lower compared to Inconel 718 and stainless steel. The stainless steel contains hard carbides which were responsible for deep crater wear and also carbon present in stainless steel is more compared to other two materials. Fig 1 (a) to (i) show the graphical representation of flank wear obtained in machining AISI 440C, Titanium and Inconel 718 materials.

While turning stainless steel, chip produced was saw tooth and this produces a severe crater than the other two materials. In turning AISI 440 C stainless steel, more rupture occurred in the cutting zone. Fig.2 (a) to (i) shows the crater wear formed by all the three materials by the respective operating parameters.

IV. CONCLUSION

The summary of this research on flank and crater wear are:

01. The formation of flank wear was less in turning Inconel 718 than AISI 440 C stainless steel and Titanium.
02. Titanium alloy produced less flank wear than AISI 440 C stainless steel and Inconel 718.
03. Flank wear occurred more in high depth of cut 1 mm in all the three materials, but the intensity was less at less depth of cut of 0.50 and 0.75 mm.
04. Even though all the three materials are difficult to cut (DTC) materials, stainless steel is more difficult than other two materials from this research.
05. Crater wear formation was less in Inconel 718 than AISI 440 C stainless steel and Titanium alloy. AISI 440 C contains high carbon content which was responsible for more flank wear and crater wear. At high depth of cut 1 mm, crater formation was high than at 0.75 and 0.50 mm. A conclusion section is not compulsory. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.



(a) 30-0.05-0.50

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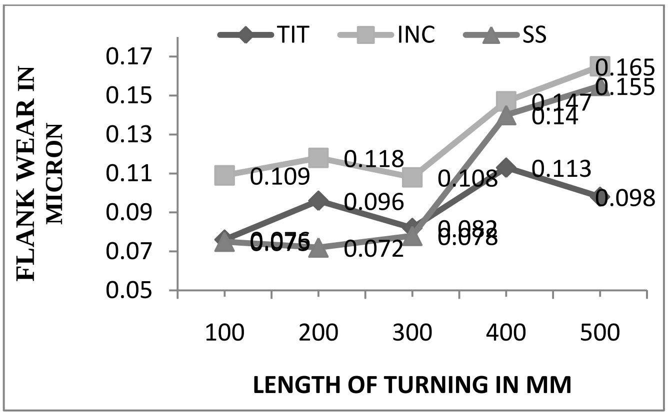

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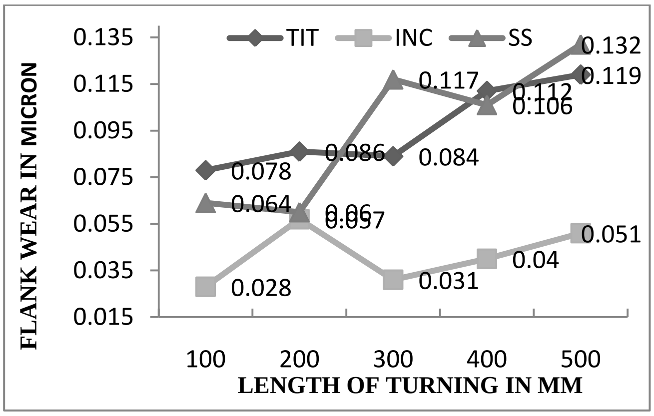
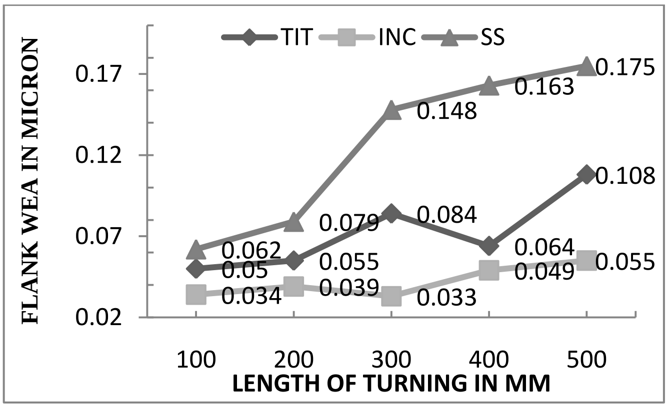
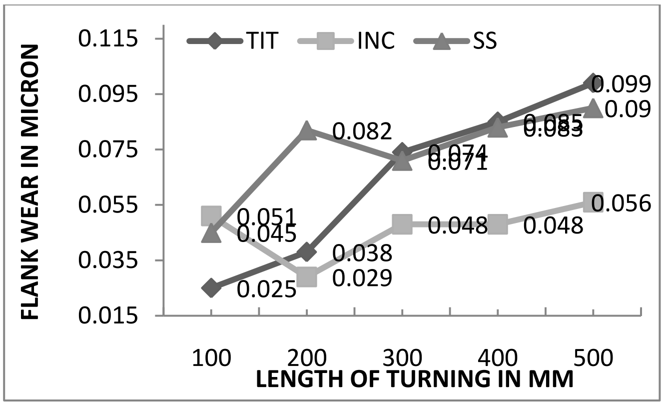


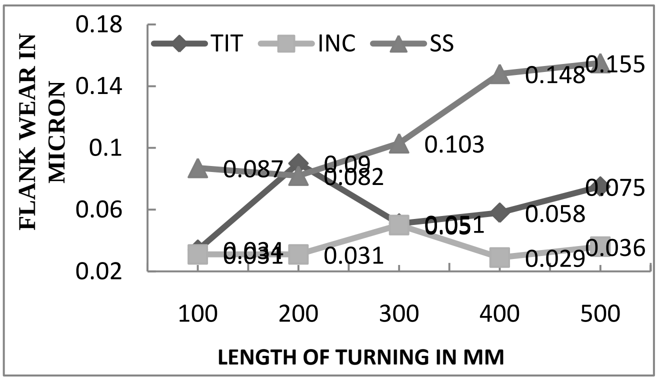
(f) 40-0.10-1.00



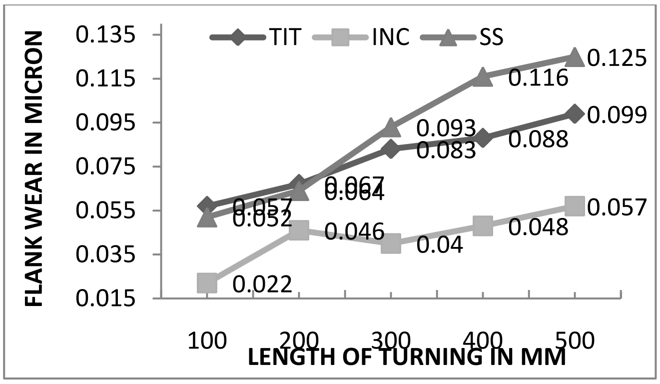
(c) 30-0.50-1.00



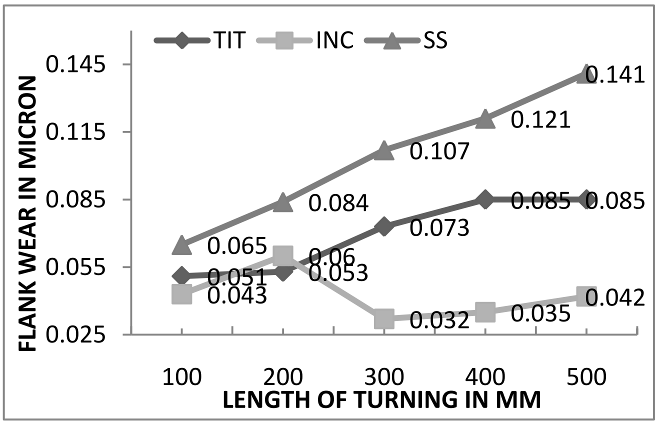
(g) 50.15-0.50



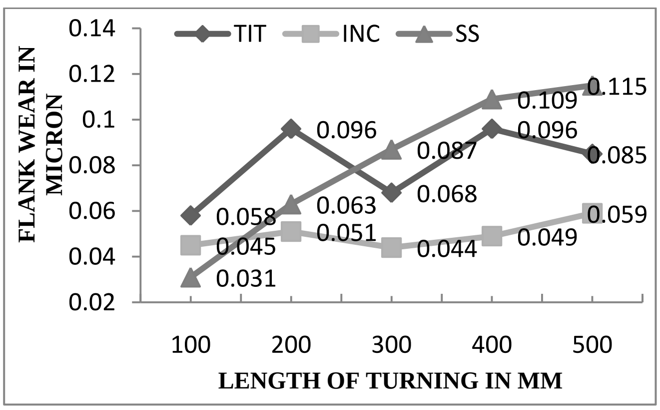
(d) 40-1.00-0.50



(h) 50-.15-0.75



(e) 40-1.00-0.75



(i) 50-.15-1.00

Fig.1. Flank wear at various cutting parameters are given in the order as: cutting speed –feed rate and depth of cut.

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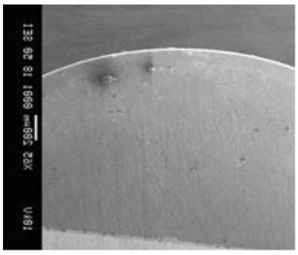
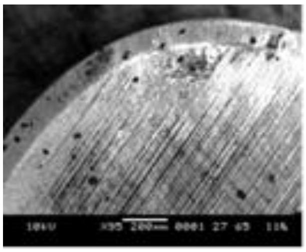

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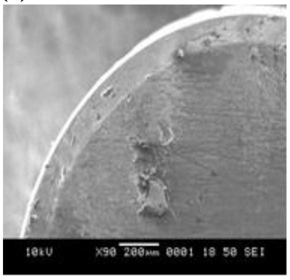
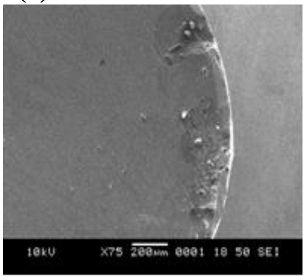
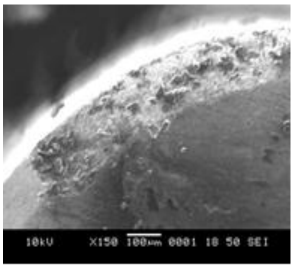
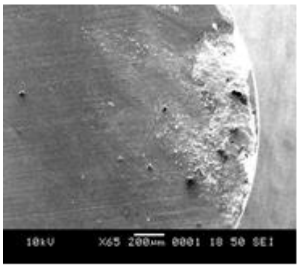
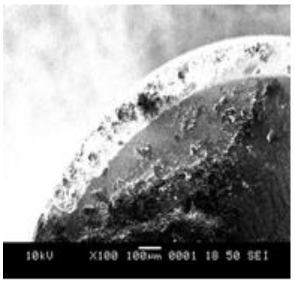
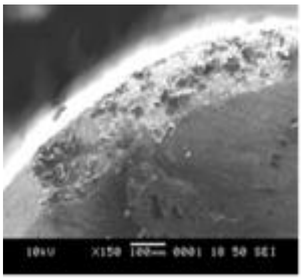



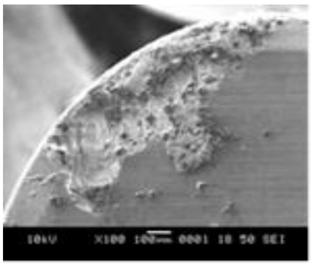
(c) INC-50-0.15-1.00 (d) AISI 440C - 30-0.05-1.00

(e) AISI 440 C-40-0.10-1.00 (f) AISI 440C -50-0.15-1.00

(g) TIT-30-0.05-1.00 (h) TIT-40-0.10-1.00



(i) TIT-50-0.15-1.00

Fig.2. Crater wear formation on Inconel, AISI 440C and Titanium materials

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