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Performance Evaluation of Cryogenically Treated Worn CBN Insert by Turning Process

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Abstract. Machining of materials is to produce desired shape and size with smooth surfaces for the performance. Machining is carried out using various cutting tools starting from high speed steel to recently developed tools like CBN and PCBN inserts etc. These tools are used to machine difficult to cut materials like high strength alloy steels, stainless steel, Inconel 718, Titanium etc. The inserts used are disposed off or no longer used for finish machining. It can be used for rough machining where smooth surface is not important and subjected to subsequent machining using fresh inserts. The used inserts can be used subsequently by subjecting them cryogenic treatment at – 196° C in a closed chamber. It is a long process for more than 30 hours in a liquid nitrogen chamber. This treatment gives additional strength to cutting inserts to improve cutting ability and wear resistance. The components used in high strength applications like an aerospace, automobile industries are treated with cryogenic process to improve wear strength. The operating parameters are cutting speed, feed rate and constant depth of cut. In this research, CBN inserts after turning for 750 mm length was cryogenically treated and again used with same operating parameters as previous machining conditions. Each inserts were measured for flank wear by Scanning Electron Microscope (SEM) after treatment and re-used with same turning conditions as before. Performances of all inserts used were producing the same results or approximately similar results. The treated inserts were acts like as fresh cutting edges. The results showed that cryogenically processed CBN inserts performed very close to new cutting inserts.

Introduction

The study of metal cutting focuses on the features of the behavior of tool and work material 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 lives are 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 temperatures 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 retained a austenite at room temperature can have their wear resistance significantly increased by subjecting them to cryogenic treatment. Quek [1&3] concluded that cryogenically treated tool inserts exhibited better wear characteristics than untreated ones at low turning speeds and feed rates. F.J.Da Silva et al [4] conducted trails using cryogenic treated HSS tools and found that tool life increased between 82-91 % after being treated at −196° C. The hardness and wear resistance of tool steels can be improved simultaneously through cryogenic treatment [5-6]. In this research work, CBN tool which was used for turning SCM 440 alloy steel and this CBN inserts achieved maximum flank wear of 0.30 mm as per ISO 3685 of 1977. Currently, not many researches have been carried out on a used CBN inserts.

Principle of the cryogenic treatment.

Cryogenic expresses study and use of materials at very low temperatures, below – 186° C. Normal boiling point of permanent gases such as helium, hydrogen, neon, nitrogen, oxygen, normal air as cryogens lie below -180° 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 -201.01° C and boils at – 198.79° C, it is the most abundant gas, composes about four-fifths (78.03 %) by volume of the atmosphere. It is colourless, odourless, tasteless and non-toxic gas [7].

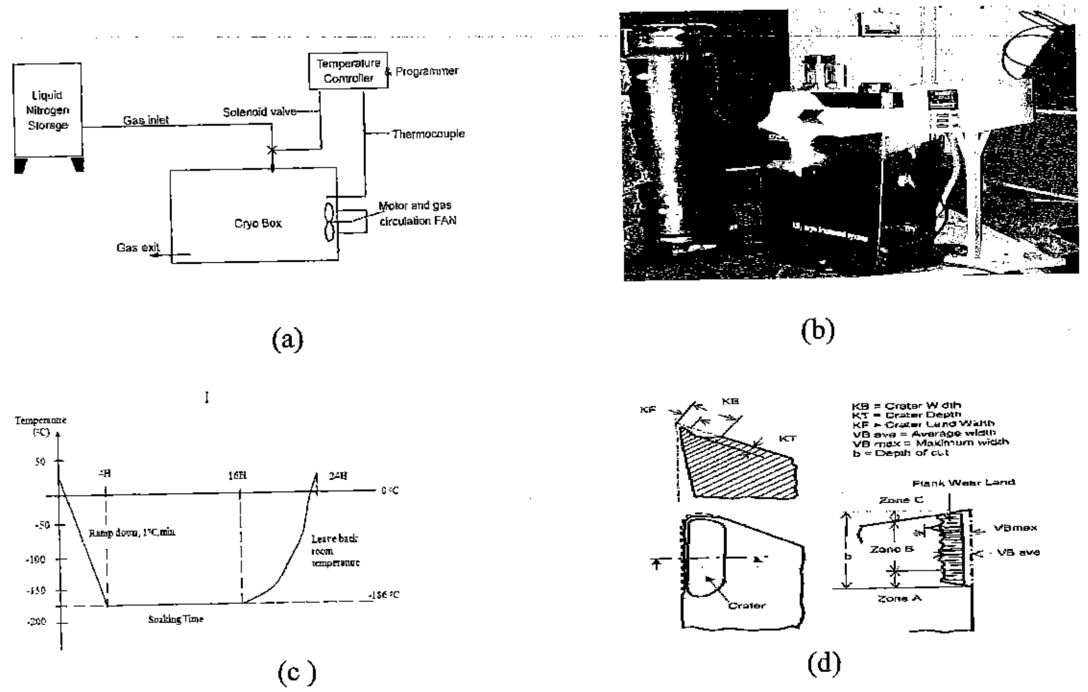


Fig.1. Line sketch and photo of cryogenic treatment equipment –(a). process diagram, (b), equipment, (c). treatment cycle, (d) tool wear in single point tool [8].

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 hour. 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. Figure 1 (a) shows block diagram for the process, (b) shows equipment used, (c) shows the treatment cycle. 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 minus 196 °C and raised to room temperature with a 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.

Experimental procedures.

The turning experiments were conducted using NC Harrison 400 Alpha Lathe with 7.5 kw capacity. Five cutting speed of 100, 125, 150, 175 and 200 m/min with feed rates of 0.10, 0.20 and 0.30 mm/ rev with a constant depth of cut 1.00 mm have been selected. 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 is manufactured by Mitsubishi and PCBN tool is by Kennametal. CBN inserts already reached the maximum flank wear of 0.30 mm as per ISO 3685 – 1977. The tool holder used was by MTJNR 2020 KL16N by Mitsubishi. The SCM 440 material is used in gears and shafts manufacturing. The SCM 440 material is best known as Cr-Mo. alloy steel. This grade steel is used in high tensile applications where wear resistance is of prime importance. This material is heat treated as other alloy steels. Tables 1 and 2 give chemical and mechanical properties of both materials. 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 work materials were heat treated by induction hardening process and hardness between 45 to 55 HRC was maintained. Table 3 shows operating parameters used in the research. The used CBN inserts were treated with cryogenic process as mentioned before.

Table1. Chemical composition of SCM 440 alloy steel

Grade	C %	Mn.	Cr.	Mo.
SCM 440	0.35/0.43	0.75/1.00	0.75/0.80	0.15/0.25

Table2. Mechanical properties of SCM 440 alloy steel

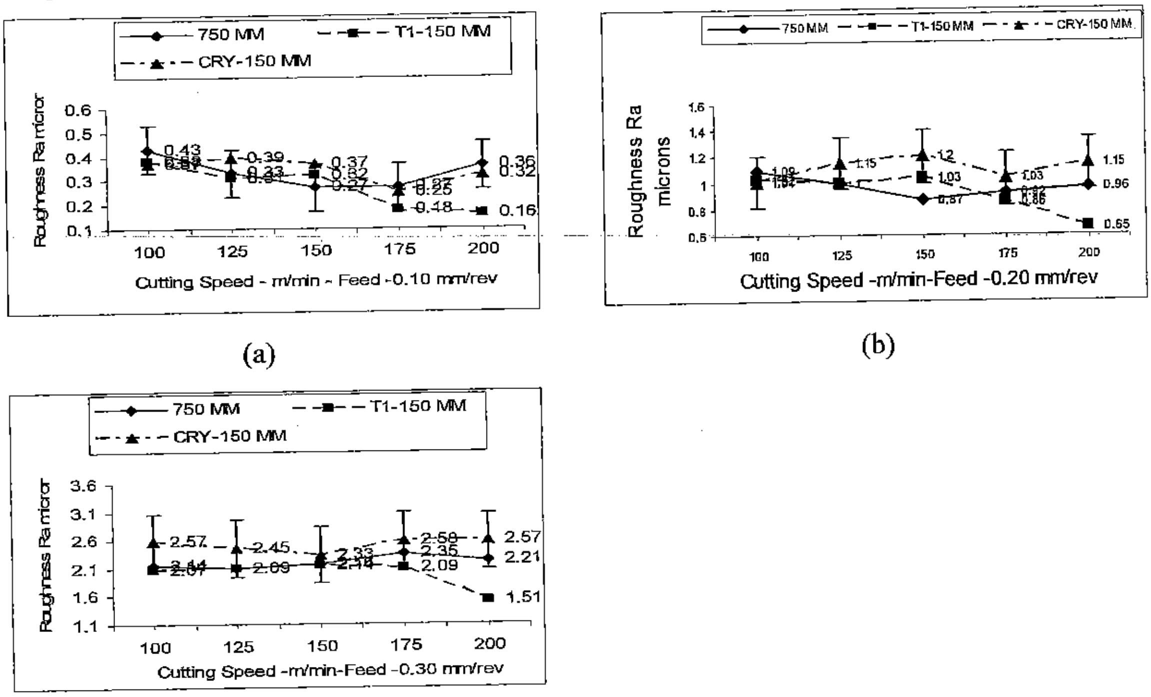
Grades	Tensile strength (MPa)	Yield strength (MPa)	% elongation
SCM 440	664	556	--

Table3. Operating parameters

Parameters	Range
Cutting speed –m/min	100, 125, 150, 175 & 200
Feed rate –mm/rev	0.10, 0.20 & 0.30
Depth of cut	1.00 mm constant

Results and discussion.

Surface roughness. The surface roughness is the one of the criteria for performance of machined components and for service life. This is affected by surface roughness, nature of residual stresses, presence of surface or sub surface micro-cracks, if that components are used in dynamic applications or used with other mating parts [9]. The irregularity occurred on the surface was due to choice of tool, feed rate, cutting speed and environmental conditions [10]. Figure 2 (a), (b) and (c) shows the graphical results at feed rate of 0.10, 0.20 and 0.30 mm rev^{-1} with new un-treated and worn out treated CBN inserts. In the figure 3, —□— *T1* represents roughness obtained at first 150 mm length of turning with fresh CBN insert, —◊— represents roughness by 750 mm length of turning and —Δ— roughness obtained by cryogenically treated inserts for 150 mm length of turning.

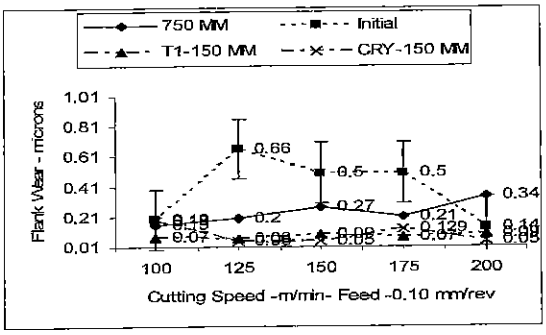


(a) (b) (c)

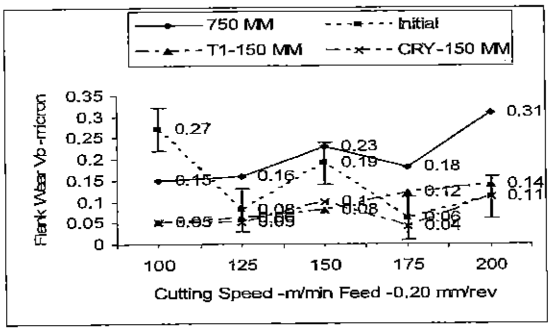
Fig.2. Cutting speed Vs surface roughness – a) 0.10 feed rate, b) 0.20 feed rate and c) 0.30 feed rate.

The variations between new inserts after turning 750 mm length and worn out treated turned for 150 mm was very narrow. It was clear from the experimental work that cryogenic treated worn cutting inserts performance were good after performing for 750 mm length of turning. The surface roughness obtained at all feed rate by treated inserts was nearly equal to the new untreated inserts.

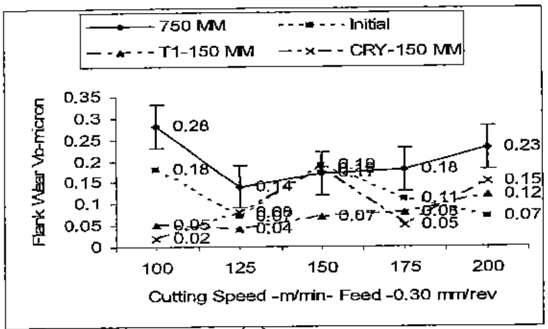
Flank wear. Flank wear is the most important tool wear occurring in machining operation. The flank wear is the primary wear attributed to rubbing of the flank along the work surfaces, causing abrasive, diffusive and adhesive wear mechanisms and also high temperature, which affect the tool materials properties as well as the work material surface [11]. The wear occurs on two reasons: (i) the sliding distance of cutting inserts increases with increase in cutting speed for a given period and (ii) increasing in cutting speed increases cutting temperatures, which leads to increase in wear and plastic deformation of the cutting edge [12]. Figure 3 show the flank wear obtained for the untreated and worn cryogenic treated inserts for the three feed rates. It was observed that new inserts the flank wear was high due to sharpness of the cutting edges. In the figure 4, —□— *T1* represents flank wear obtained at first 150 mm length of turning with fresh CBN insert, —◊— represents flank wear after 750 mm length of turning, —Δ— flank wear after 150 mm length of turning and —*x*— flank wear obtained by cryogenically treated inserts. After turning 750 mm length, the flank wear was high. After 150 mm length of turning, flank wear obtained by CBN was high than worn cryogenic treated cutting inserts. It was clear from the experimental work that worn cryogenic treated inserts cutting was effective and hard enough to resist tool wear. The worn treated inserts, flank wear was less compared to corresponding to 150 mm length of turning. At cutting speed of 200 m/min. the wear was nearly equal to 150 mm length of turning. If the process is followed for all the inserts with cryogenic treatment the life of the inserts may be improved many fold. This was results obtained in all the three feed rates. Figure 4 shows the flank wear image obtained after 750 mm length of turning with out treatment. Figure 5 shows the flank wear image obtained by SEM after cryogenic treatment.



(a)



(b)

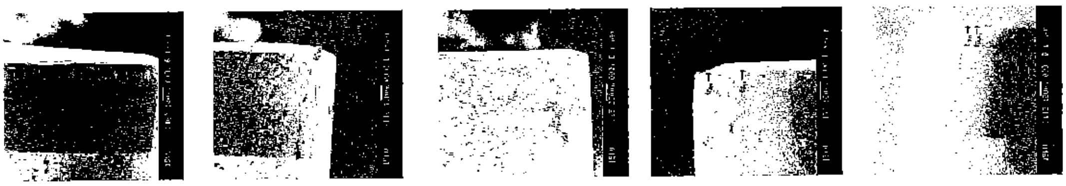


(c)

Fig.3. Cutting velocity Vs Flank wear – (a). 0.10 feed rate, (b). 0.20 feed rate and c). 0.30 feed rate.

a) 100-0.10-750 b) 125-0.10-750 c) 150-0.10-750 d) 175-0.10-750 e) 200-0.10-750

Fig.4. SEM image flank wear at the end of 750 mm length of turning for 0.10 feed rate.



a) 100-0.1-Cry-150 b. 125-0.1-Cry -150 c) 175-0.10-Cry-150 d) 175-0.10-Cry-150 e) 200-0.10-Cry-150

Fig.5. SEM image on flank wear at the end of 150 mm turning by cryogenic treated inserts.

Summary

Based on the performance and test results of the various set of experiments conducted, the following conclusions were drawn:

i. The surface roughness obtained at high cutting speed with low feed rate of 0.10 mm rev^{-1} was low in untreated and worn cryogenic treated inserts. The worn cryogenic treated inserts performance was near to fresh insert.
ii. Flank wear obtained at low speed with low feed rate was high using untreated inserts.
iii. Flank wear obtained by worn cryogenic treated inserts was lower than new inserts without treatment.
iv. The worn inserts without cryogenic treatment can be re-used be after cryogenic treatment without taking cryogenic process cost. The life of the inserts would be extended by the process.

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