CRYOGENIC IN REDUCTION OF UNCOATED CARBIDE INSERT WEAR ON TURNING S45C

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Abstract

Currently, with the expansion of various industries, there is a demand for many cutting tools. Carbide-cutting tools are widely used in many industrial sectors due to their high strength and wear resistance. However, machining S45C steel without coolant tends to cause rapid tool wear. As a result, coated carbide cutting tools are preferred because of the fact that coating can increase tool life. However, the coated carbide tool is fairly costly, which raises the overall cost of the product. Thus, reducing tool wear has become an important issue. The application of cryogenic methods is an alternative way to decrease tool wear and expand tool life. This research studied the tool wear of uncoated carbide-cutting tools performed on the S45C steel shafts under different conditions including no special treatment inserts with no cooling while turning, cryogenically treated inserts with no cooling while turning, and cryogenically treated inserts with cryogenic cooling while turning. The result of this experiment indicated that the cryogenic treatment can reduce tool wear of uncoated carbide inserts when compared with non-treatment. Furthermore, the use of cryogenic treatment together with cryogenic cooling demonstrates outstanding performance in increasing tool life because the tool wear was down to more than half when turning at the cutting speed and feed rate of 200 mm/min and 0.26 mm/rev, respectively.

Keywords: *Cryogenic treatment. Cryogenic cooling, Tool wear, S45C, Machining*

1. Introduction

In industrial sectors such as automotive, aircraft, and heavy equipment, the demand for cutting tools is increasing with every passing year. A carbide-cutting tool is the first choice in industrial applications due to its good mechanical properties. For example, high wear resistance, resilience to deformation, and corrosion resistance. However, the cost of the cutting tool is 20% of the total production cost. The longevity of cutting tools or prolonging the service life of cutting tools can reduce production costs. Therefore, chemical coats such as TiN, TiCN, TiAlN and AlTiN are used for coating carbide-cutting tools in order to reduce damages from high temperatures during machining processes, which eventually enhances the life of tools [1]. Nevertheless, the coating method must be taken into account by experts because it has a high cost during the process [2]. Actually, coated carbides are expensive and enhance production costs [3]. Although the coating increases the durability of the cutting tool, it decreases the sharpness of the cutting tool. This causes poor surface finishes for non-metallic materials when machined with coated carbide [4].

Cryogenic is an alternative way to reduce tool wear before and during the machining processes [5]. Pre-tool wear reduction is achieved by the cryogenic treatment. In this method, we immerse the desired material from room temperature into the coolant storage and hold it for the desired time along with slowly bringing it to room temperature [6]. Varghese et al.[7] studied the tool wear of the carbide cutting tool at cryogenic treatment periods of 18, 24, and 36 hours. They reported that the 36-hour treatment of carbide cutting tools treatment provided the least tool wear compared to 24-hour, 18-hour, and no treatment following the machining. Similarly, Kalsi et al.[8] cryogenically treated uncoated carbide cutting tools under different periods. They found that the increment of wear resistance is due to the increased hardness of the cutting tool after the cryogenic treatment. To determine the cause of the increased hardness following the cryogenic treatment, Abdullah and Osman [9] investigated the microstructural changes in carbide-cutting tools. They explained that the occurrence of hardness after the cryogenic treatment is due to the martensitic transformation in the structure of the WC-Co material. In addition, Thamizhmanii et al. [10] believed that the benefits of cryogenic treatment include the ability to improve the core of the tools. As a result, this process guarantees the properties of cutting tools after re-sharpening compared to coatings that only protect the tool's external surface.

Moreover, cryogenic cooling is also a way to reduce tool wear during the machining process. In this method, coolant is sprayed onto the tool chip interface to eliminate high temperatures during the machining process, which reduces tool wear from high temperatures [11]. Sivaiah and Chakradhar [11] studied the effect of temperature during machining stainless steel with carbide cutting tools under different conditions, such as no cooling, minimum quality lubrication (MQL), flood cooling, and cryogenic cooling. The result indicated that cryogenic cooling was the most effective way to reduce the temperature during machining followed by MQL flood cooling and no cooling.

Similarly, Halim et al. [12] studied machining hardened Inconel 718 with carbide cutting tools under no cooling and cryogenic cooling. They found that machining under cryogenic cooling can reduce the heat temperature during the machining process by 80% and increase tool life by 80% when compared with no cooling.

As per the existing literature, there are many pieces of research in which cryogenic cooling is applied together with other cooling methods. Pusavec et al. [13] machined Inconel 718 with carbide cutting tools under cryogenic cooling together with MQL. The results indicated that this method provided the least tool wear and the lowest cutting force compared to MQL, dry, and single cryogenic cooling. In some of the tests, Sales et al. [14] investigated the effect of the hybrid cooling method (cryogenic cooling + MQL) on tool wear in Ti6Al4V machining. It was discovered that it is possible to reduce tool wear and pressure on the rake face area when compared with dry machining and MQL. Danish et al [15] stated that the hybrid cryogenic-MQL cooling can reduce rake wear by 60.6% and 37% during machining Inconel 718 compared to dry machining, and cryogenic cooling alone, respectively. In addition, Sartori et al**.** [16] claimed that cryogenic cooling can reduce adhesion and abrasion wear during the machining process.

Therefore, it can be concluded that cryogenic treatment and cryogenic cooling are the methods that can reduce the tool wear of cutting. Moreover, the application of cryogenic cooling together with MQL can significantly reduce tool wear compared to using cryogenics or MQL alone.

To conclude, MQL is a lubricant during machining and cryogenic cooling can reduce the temperature in the machining process. Moreover, there are not many researchers which examine the application of cryogenic cooling with other cryogenic methods. Therefore, the purpose of this paper is to study and compare the flank wear effects of carbide-cutting tools under cryogenic cooling and cryogenic treatment in machining S45C steel with different machining parameters.

2. Methodology

In this paper, the experiments were carried out using uncoated carbide inserts (ISO WNMG080404-HA, 80° cutting angle, 0.8 mm nose radius) as shown in Fig.1. Table I shows the elements of the carbide inserts from energy dispersive X-ray spectrometer (EDS) observation.

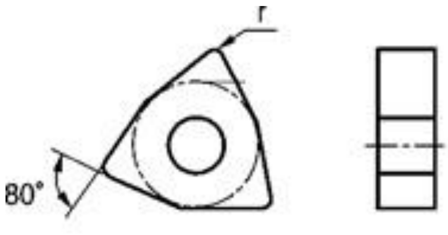


Fig. 1 Insert characteristics

Table I EDS analysis of cutting inserts

Element	Weight %
Ti	17.15
Co	7.57
W	75.28

As shown in Fig. 2, for the cryogenic treatment, the carbide inserts were soaked in a chamber at -196°C for 35 hours. The treatment under this temperature level is also called a deep cryogenic treatment. The carbide inserts were then tempered at 200°C for 2 hours. The microhardness of the carbide inserts was measured before and after the cryogenic treatment by using the Vickers hardness test machine under a load of 1 kg and a holding time of 15 sec. We achieved five measurement points on each sample in terms of data collection.

The S45C material was selected for turning in this study. The reason was that many industries choose S45C for engineering parts, such as line shafts, pins, and gears [17], due to its good mechanical properties (high strength, high toughness, and the ability to improve qualities by hardening). The outside diameter of 49 mm and length of 300 mm shafts, shown in Fig. 3, were used in this research.

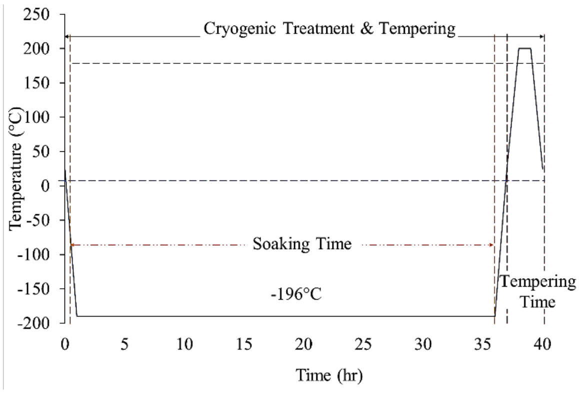


Fig. 2 Cryogenic treatment process

Fig. 3 The S45C shaft turning

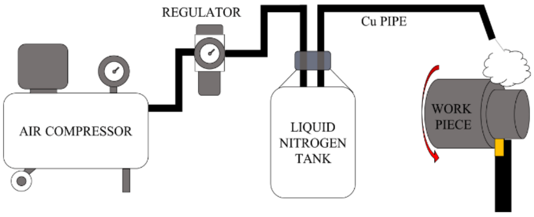


Fig. 4 Cryogenic cooling system

Table II Parameters and conditions

Cutting speed (mm/min)	100, 150, 200
Feed rate (mm/rev)	0.22, 0.24, 0.26
Cryogenic condition	NT, CT, CTC

Table III Cyrogenic condition

Code	Carbide inserts	Turning process
NT	No treatment	No cooling
CT	Deep cryogenic treatment with tempering	No cooling
CTC	Deep cryogenic treatment with tempering	Cryogenic cooling

Table II shows the parameters and conditions in turning, and Table III shows the cryogenic conditions. Fig.4 illustrates the setup in this research. The turning was performed under various cutting speeds and feed rates, while the depth of cut was fixed at 1 mm because the existing literature suggests that it has less influence on tool wear when compared with other cutting parameters [18]. Cooling in the turning process consists of two forms. First, no cooling is the operation without coolant during the machining process. Second, cryogenic cooling is the cooling process that makes use of liquid nitrogen in cooling down by injecting liquid nitrogen into the tooltip interfaces.

This experiment used a full factorial design [19]. A new cutting insert was used for each trial. Finally, tool wear was observed by using an optical microscope following the ISO3685 flank wear investigation.

3. Result and discussion

In order to confirm the increased hardness of the cutting tools, all cryogenic cutting inserts were tested for microhardness by the Vickers hardness test machine before and after the cryogenic treatment process. The results are shown in Fig. 5**.**

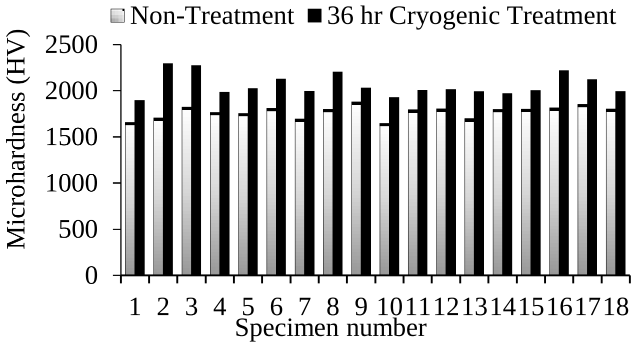


Fig. 5 Microhardness result before and after treatment

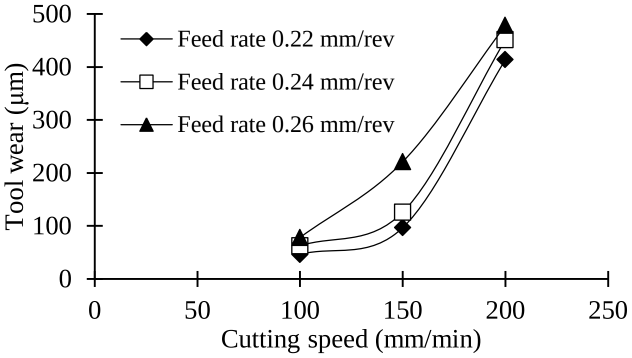
In the machining process, there are often various wear patterns depending on the material and type of machining process. However, the main effect of wear on part quality after machining is flank wear, which is usually caused by the abrasion of the workpiece against the cutting tool [20], resulting in deformation of the cutting-edge area. Therefore, this paper aims to investigate the flank wear effect of a carbide insert after cryogenic processing.

Fig. 6(a), 6(b) and 6(c) demonstrate the relationship between cutting speeds and wear rates. It can be seen that in all machining conditions, increasing cutting speeds and feed rates resulted in increasing tool wear. The most prominent wear is seen at the cutting speed of 200 mm/min. This phenomenon can be explained using Taylor's theory and cutting tool wear can be divided into three phases: the break-in period, the steady-state wear region, and the failure region [21]. Break-in-period happens when the cutting tool starts to wear due to the impact of the workpiece against the raw materials surface. The steady-state wear region is where the tool wear increases steadily with the machining duration. Finally, the failure region is when cutting tools wear out rapidly due to the increased heat in the machining process. These result in decreasing machining efficiency and eventually the cutting tool becomes unusable.

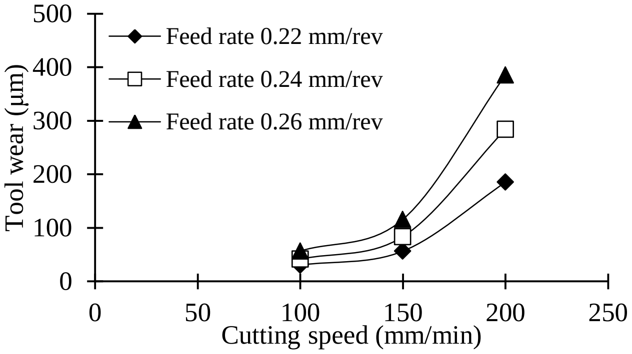
It can be seen from Fig. 6 that the cutting speed of 200 mm/min falls within the failure region due to the relatively outstanding change in tool wear. Table IV also shows values of the flank wear.

Fig. 7 depicts the tool wear of the carbide insert at the cutting speed of 150 mm/min and the feed rate of 0.26 rev/mm. It can be observed that the main wear formation found in all 3 conditions is flank wear.

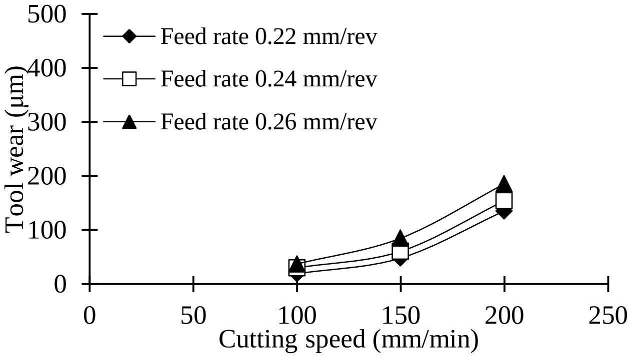
Fig 7(a) shows the tool wear of the cutting tool under the NT condition. The results demonstrate that the tool wear was 221.172 µm. The shape of the cutting tool changed on the nose tip radius, and it is known as plastic deformation. The occurrence of plastic deformation is the result of the high temperature during the cutting process or the loss of important chemical constituents of the cutting tool, resulting in the deformation or softening of the tool material [22]. Furthermore, burns on the cutting tool can be seen as a result of high heat temperatures during machining.



(a) NT



(b) CT



(c) CTC

Fig. 6 Tool wear under different conditions

Fig. 7(b) depicts tool wear from the cutting tool under the CT condition which the tool wear was 116.021 µm. Flank wear was also found in the flank area due to the attrition between the hard particles with the cutting tool and the material [23]. Furthermore, the burn marks were similar to those seen in Fig. 7(a). However, when compared with NT working condition, the cutting tool under CT working condition indicated lower tool wear. It can be explained that cryogenic treatment improves mechanical and cutting tool properties and reduces the possibility of plastic deformation. Therefore, this method preserves the shape of the cutting tool and increases tool life [24].

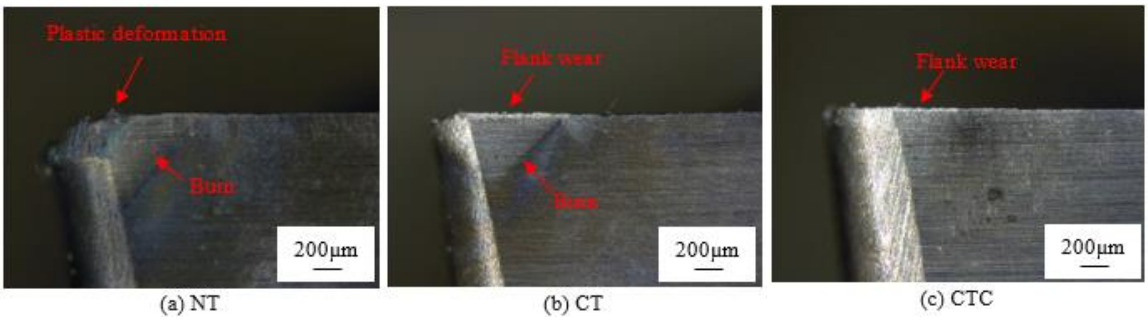
Table IV The wear result of the turning process

Cutting speed (mm/min)	Feed rate (mm/rev)	Cutting condition	Tool wear (µm)
100	0.22	NT	46.330
100	0.22	CT	30.564
100	0.22	CTC	19.092
100	0.24	NT	62.419
100	0.24	CT	41.493
100	0.24	CTC	29.974
100	0.26	NT	78.313
100	0.26	CT	56.826
100	0.26	CTC	37.113
150	0.22	NT	96.783
150	0.22	CT	56.618
150	0.22	CTC	48.068
150	0.24	NT	126.033
150	0.24	CT	83.799
150	0.24	CTC	60.562
150	0.26	NT	221.172
150	0.26	CT	116.021
150	0.26	CTC	84.845
200	0.22	NT	413.872
200	0.22	CT	185.342
200	0.22	CTC	135.387
200	0.24	NT	451.461
200	0.24	CT	284.257
200	0.24	CTC	154.246
200	0.26	NT	478.542
200	0.26	CT	385.844
200	0.26	CTC	185.420

In the case of the CTC working condition shown in Fig 7(c), there was also flank wear at the flank area of the cutting tool. Following the turning process, the results demonstrated that tool wear was 84.845 µm**.** When compared with NT and CT working conditions, the CTC working condition stimulates an outstanding performance in terms of reducing tool wear.

In addition, Mahendran et al. [**26]** studied the effect of microhardness and tool wear on carbide-cutting tools under cryogenic treatment and non-cryogenic treatment in milling EN**8** carbon steel. They reported that the decrease in wear of carbide cutting tools undergoing cryogenic treatment was due to the increase in hardness of the cutting tools.

In the case of a cutting speed of 100 mm/min, which is the lowest cutting speed in this experiment. Fig 8 shows tool wear of the cutting tool at the cutting speed of 200 mm/min and feed rate of 0.26 rev/mm. Fig. 8**(**a) shows tool wear under the NT working condition, non-treatment, which the area of flank wear was **478.542** µm. In addition, it can be observed that there was large plastic deformation at the flank area. From Fig 8(b), the result shows 385.844 µm wear under the CT working condition, which was lower than the NT working condition. Furthermore, no plastic deformation was seen in the flank area. Cryogenic treatment prevents softening of the cutting tool at high temperatures during machining **[25].**

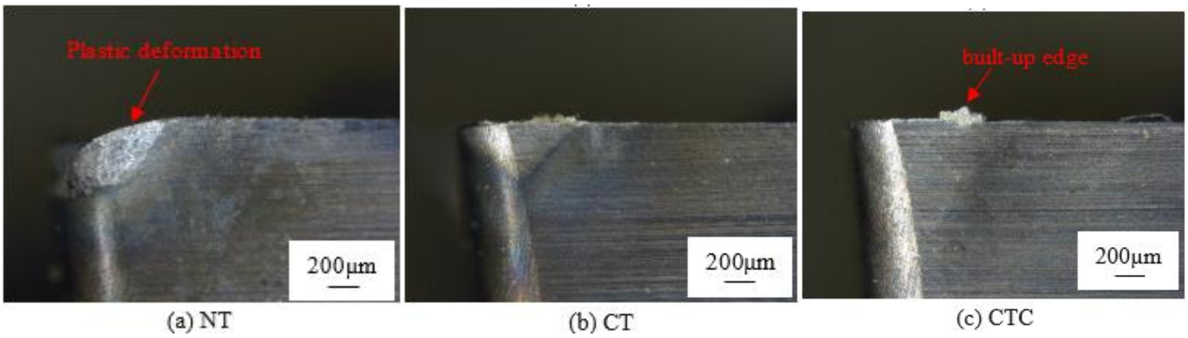


(a) NT (b) CT (c) CTC

Fig. 7 Wear formation under the different cutting conditions at 150 mm/min F0.26 rev/mm

Fig**.** 8(c) shows tool wear under the CTC working condition and the results showed 185.42 µm of flank wear, which was lower than the NT and CT working conditions. It can be concluded that the combination of cryogenic treatment together with cryogenic cooling indicates superior results in terms of reducing tool wear when compared with non-treatment and cryogenic treatment alone. In addition, it can be noticed that the built-up edge at flank wear gets emerged. Therefore, it is confirmed that the application of both cryogenic methods cannot reduce the possibility of a built-up edge.

Finally, Fig. 9 shows the results of the experiments. The carbide inserts under cryogenic processing are outstanding in reducing tool wear when compared with non-treatment in turning S45C.



(a) NT (b) CT (c) CTC

Fig. 8 Wear formation under the different cutting conditions at 200 mm/min F0.26 rev/mm

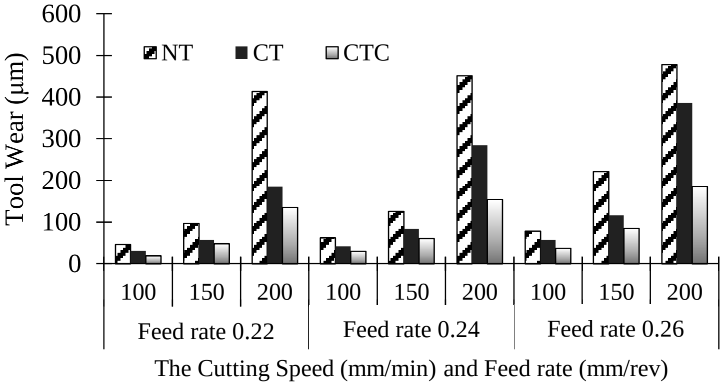


Fig.9 the result of the experiment

4. Conclusions

In this study, we performed the machining of S45C by turning process with an uncoated carbide insert under different conditions and cutting parameters. Based on our observations, we can conclude:

1) Cutting speed and feed rate are the machining parameters which influence tool wear of uncoated carbide inserts in turning S45C steel. When we increase the cutting speed and feed rate, tool wear increased as well. The trend is also found in all three conditions, including NT working conditions, CT working conditions, and CTC working conditions.
2) The cryogenic treatment process can reduce tool wear when compared with carbide insert under non-treatment because the cryogenic treatment improves mechanical properties in terms of hardness, which results in extending its service tool life.
3) In turning S45C with an uncoated carbide insert**, c**ryogenic treatment on the cutting tool combined with cryogenic cooling during the machining results in better wear resistance when compared with non-treatment and cryogenic treatment alone.
4) In this experiment, it was found that the cryogenic methods cannot reduce the occurrence of built- up edges in machining S45C steel.

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