

Reducing Tool Wear with Hybrid Microwave Treated TiCN Coated Tool and Recycled Cooking Oil in MQL Machining of T6061 Aluminium Alloy

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ABSTRACT

Titanium carbo-nitride (TiCN) inserts are vital for cutting operations, particularly in high-temperature conditions. Conventional machining methods lead to rapid wear of tools, frequent need for tool changes, high costs associated with tool replacement, and extensive usage of synthetic cutting fluids that are environmentally damaging. This study aims to minimise tool wear and promote circular economy. This study examines the process of machining T6061 aluminium alloy using TiCN inserts treated with hybrid microwave (HMW) energy at 220°C for 20 minutes, with silicon dioxide (SiO₂) as the susceptor. Recycled cooking oil is utilised for Minimum Quantity Lubrication (MQL). Analysed were the density, hardness, and microstructural images. Tool wear of TiCN was assessed during dry and wet machining using three different cutting speeds (166, 210, 263 m/min) while maintaining a constant feed rate of 0.6 mm/rev and depth-of-cut of 0.4 mm. The findings show the density and hardness of TiCN (HMW) increased by 4% and 7% respectively compared to the TiCN (untreated) insert. The tool wear of TiCN (HMW) has reduced by 5% (MQL) and 24% (dry) compared to the TiCN (untreated) insert. MQL with recycled cooking oil decreased tool wear by 40% compared to dry machining. The microstructural images of the TiCN (HMW) and TiCN (untreated) structures reveal no noticeable variations. TiCN (HMW) has improved wear resistance, and it is particularly beneficial when utilising recycled cooking oil in MQL machining.

Keywords: T6061 Aluminium alloy; TiCN insert; hybrid microwave treatment; MQL machining; recycled cooking oil

INTRODUCTION

Tool wear is unavoidable in machining, defined as the loss of cutting tool efficiency induced by the material removal process (Okokpujie et al. 2017). In machining processes, tool performance is measured by tool life, which is defined by the tool wear rate. According to Khatri and Jahan (2018), the rate is heavily controlled by the tool wear mechanisms generated by a particular process. Furthermore, determining the wear mechanism is a vital step in cutting tool development. The tool wear mechanism, on the other hand, is determined by parameters such as tool material properties, cutting process and settings, workpiece material, and cooling system. Tool wear increases

proportionally with the mechanical and physical properties of the workpiece material, necessitating tool replacement. The most expensive component of machining is tool replacement. As a result, various changes must be made to extend the tool life and sustain manufacturing efficiency.

Manufacturers, particularly those in the aerospace and medical industries, favour titanium carbo-nitride (TiCN) and TiCN-based cermets. The company prefers it for parts and components because of its superior mechanical and physical qualities, which include low wear resistance, high hardness, and low friction coefficient (Liang et al. 2019). The mechanical properties of both pure and coated TiCN continue to meet the requirements for a cutting tool for a hard workpiece (Uddin et al. 2021; Sangeevi et al. 2022). Better grain densification and homogenous grain size have

been demonstrated in several investigations on the microstructure of hybrid microwaved sintered TiCN (Tang et al. 2011; Pang et al. 2017; Iizuka 2022).

Hybrid microwave sintering is an approach whereby electromagnetic waves penetrate the workpiece with a direct supply of energy and interact with thermal and nonthermal processes through the application of a susceptor. The main aim of the sintering process is to densify the characteristics of the microstructure and increase the mechanical properties of sintered materials through grain growth. Microwave sintering uses less time and energy than conventional sintering (Ye et al. 2020). However, the sintering temperature must be suitable to the material to obtain the greatest hardness and density. This additionally applies to the sintering time. At a given temperature and time, the hardness of sintered material decreases. As a result, substantial research has been conducted to establish the optimal temperature and sintering duration (Chicardi et al. 2013; Qiao et al. 2019; Togashia, 2023). The silica foundry sand used in mould preparation is mainly microwave transparent and has been embedded with susceptors that absorb microwave radiation and act as a heat source. Wiedenmann et al. (2014) found compressed and chemically bound silicon carbide as the most appropriate material among a range of microwave absorption materials due to its heating performance and mould stability.

T6061 Aluminium alloy has been widely used in the manufacturing of automobile parts, communication components, and other industries. Aluminium has a density that is one-third of steel. Despite having lesser tensile properties than steel, they have an excellent strength-to-weight ratio. Also, they are easy to work with due to their excellent thermal and electrical conductivity, and it does not transition from ductile to brittle at low temperatures. Because of its non-toxic properties, aluminium can be recycled and requires less energy to get done. However, they have a low endurance limit. Therefore, fatigue failure can occur even at low forces. Aluminium alloys, on the other hand, are advantageous as structural materials due to their high specific strength and stiffness (Okonkwo et al. 2015).

According to Madanhire et al. (2016), cutting fluid has primarily been used in the wet machining method to minimize the friction between the workpiece and cutting edge of the tool during machining, reduce the temperature and reduce cutting tool wear. However, harmful additives in cutting fluids have an environmental effect and cause health hazards to workers; there are more eco-friendly and user-friendly alternatives to consider. The first is to use dry machining, where no lubricant oil is used in this method. The drawbacks of this method are increased heat generation during machining, causing high friction forces and leading

to high tool wear and built-up edge formation. But the advantages of dry machining are no hazard to worker health, no environmental pollution and lower operation cost. The second is to replace the mineral-based lubricant oil or harmful additive with vegetable oil such as palm oil or canola oil. It covers the advantages of using common cutting fluids, but it also solves the problem of harmful additives in cutting fluids. Dry machining using TiCN coated tool inserts seem promising on various materials such as brass, T6061 Aluminium alloy, 4140 steel, high strength steel and Inconel 825 (Ariff et al. 2013a; Ariff et al. 2013b; Revuru et al. 2020; Zheng et al. 2020; Behera et al. 2023).

This research investigates the tool wear of untreated and hybrid microwaved TiCN coated cutting tools when machining T6061 aluminium alloy using eco-friendly methods in both dry and MQL (recycled cooking oil) cutting conditions. The

TiCN inserts are subjected to a hybrid microwave treatment at 220°C for 20 minutes using silicon dioxide (SiO₂) foundry sand as susceptors. Treated TiCN-coated tools often exhibit enhanced wear resistance and reduced friction relative to untreated alternatives. The selection of treated versus untreated tools frequently depends on the particular application, the materials used in machining, the nature of the cutting environment, and cost considerations. Treated tools can offer significant benefits for high-performance applications, resulting in enhanced productivity and extended tool life in both dry and lubricated conditions. This study aims to assist manufacturers and machining industries in reducing tool changing costs, disposal costs, and potential health hazards. The recycled cooking oil was utilised in wet machining as a substitute for mineral-based cutting fluid containing harmful additives to minimise environmental contamination and reduce the need for toxic waste disposal. Moreover, a machine operator will not encounter hazardous circumstances when machining. Reusing cooking oil supports a circular economy when buying it from local vendors or cafeterias. Local machining industries can help contribute to the growth of gross domestic product and stimulate the business cycle within our country, which is referred to as the economic cycle.

METHODOLOGY

HYBRID MICROWAVE TREATMENT

The titanium carbo-nitride (TiCN) coated triangular inserts from Sandvik Coromant (TNMG 16 04 08-PM 1525) were used in this experiment. One sample was left untreated to be used in its original form, while another sample of the

TiCN insert was subjected to hybrid microwave energy. Susceptor powders were weighed using a weighing scale (AND GR-200). 140g of SiO₂ foundry sand was placed inside the larger alumina crucible (65 mm diameter opening). The TiCN insert was placed inside a small alumina crucible with an opening diameter of 30 mm (Figure 1) and was later covered with a lid and plunged

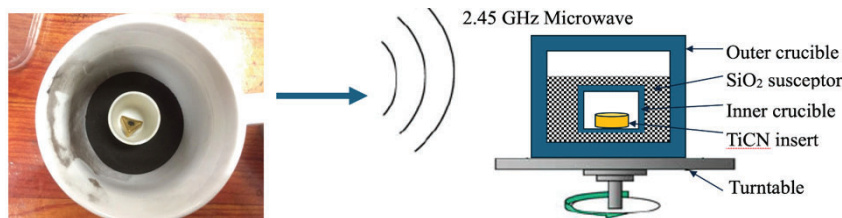


FIGURE 1. TiCN insert inside the small crucible that is surrounded by the SiO₂ susceptor

DENSITY AND HARDNESS

The densities of TiCN (untreated) and TiCN (HMW) inserts were measured using Densimeter (MD-2005). Then, the surface hardness test was performed using Vickers Micro-Hardness Tester (INNOVATEST FALCON 400) with a setting test force of 20 kgf (Kilogram-Force), 10 seconds dwell time and 10x magnification. The measurements were repeated 3 times, and the average results were recorded and evaluated.

SCANNING ELECTRON MICROSCOPE

TiCN (untreated) and TiCN (HMW) inserts were observed under the Scanning Electron Microscope (JSM-IT100). These inserts were ground and polished using the BUEHLER Phoenix Beta Grinder/Polisher. The inserts were ground to remove the top coating surface layer. This was repeated further until a smoother surface appearance of the substrate was obtained. Hydrochloric acid (HCL) with 37% was used as an etching reagent for 10 minutes at room temperature.

MACHINING

The aluminium alloy rod was fixed into the three jaw-lathe machine (HARRISON M600). The raw T6061 Aluminium alloy with a diameter of 88 mm and length of 630 mm was used in dry and MQL machining. The work material was straight turned several times to perform the skinning operation which took approximately 20 minutes and was then divided into five sections of equal length (70 mm) and marked with a groove (2.4 mm) as shown in Figure 2. The

inside the SiO₂ susceptor. The SiO₂ susceptors were used to bury the small crucible from top to bottom and the lid was used to cover the large crucible. The microwave oven (Panasonic ST 55M) was preheated for 15 minutes at 220°C before the crucible with TiCN insert was placed inside the microwave. Finally, the crucible with TiCN insert was placed inside the microwave for 20 minutes at 220°C.

initial diameter of the aluminium alloy rod was measured every time before machining.

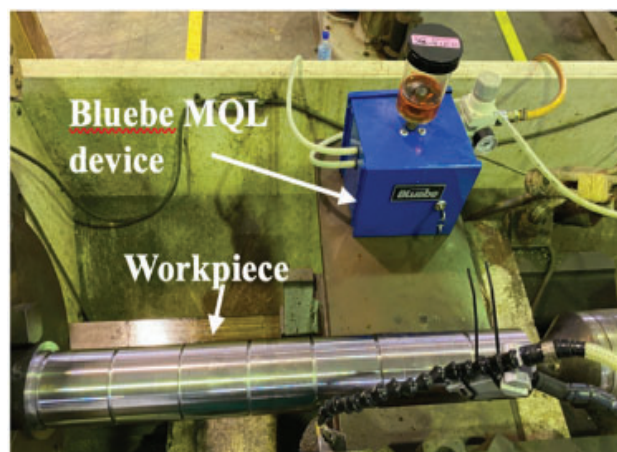


FIGURE 2. The segmented T6061 Aluminium alloy clamped in the lathe machine (HARRISON M390) with the MQL setup

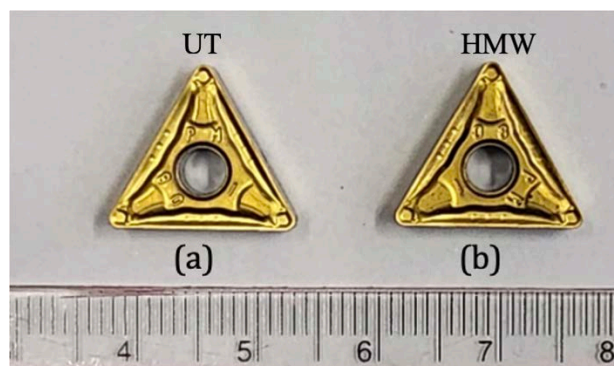


FIGURE 3. The TiCN samples (a) Untreated (b) HMW treated

Three different cutting speeds (166, 210, 263 m/min) were employed by using 630, 800 and 1000 rpm respectively, accompanied by a feed rate of 0.6 mm/rev and a depth of cut of 0.4 mm, in accordance with the cutting parameters used by Ariff et al. (2013a), which indicated that for dry machining of T6061 Aluminium alloy, these were the suitable cutting parameters. The flank wear was recorded after machining each section using a microscope (Meiji techno FU 1010). The recycled cooking oil used was collected, and filtered three times to ensure no contaminants were present in the oil prior to its utilisation in the Bluebe MQL device. The flow rate of the MQL device was fixed at 10 drops/min. According to Leung and Guo (2006), the recycled cooking oil has a viscosity of 31.2 mm²/s which is quite similar to the neat palm oil with a viscosity value of 30.2 mm²/s. To optimize the cost and performance of the machining operation, oil emulsion was not utilized since cooling is not an essential criterion in low to moderate speed interrupted cutting operations. On the other hand, lubrication is looked upon as more crucial

to avoid the formation of built-up edges and friction (Yang et al. 2023). Therefore, in this case, an oil-based cutting fluid was considered sufficient.

RESULTS AND DISCUSSION

DENSITY AND HARDNESS

Figure 3 shows the TiCN coated samples that were utilized in this experiment. After being treated with hybrid microwave energy for 20 minutes at 220°C, there are no changes at all in the dimensions or its physical appearance. However, the density for the TiCN (HMW) has increased by 4% from 6.41 g/cm³ to 6.68 g/cm³ as shown in Figure 4(a) Comparing the HMW treated insert to the untreated insert, shows an improvement in surface hardness of up to 7%. Figure 4(b) shows the average microhardness readings for the TiCN inserts used.

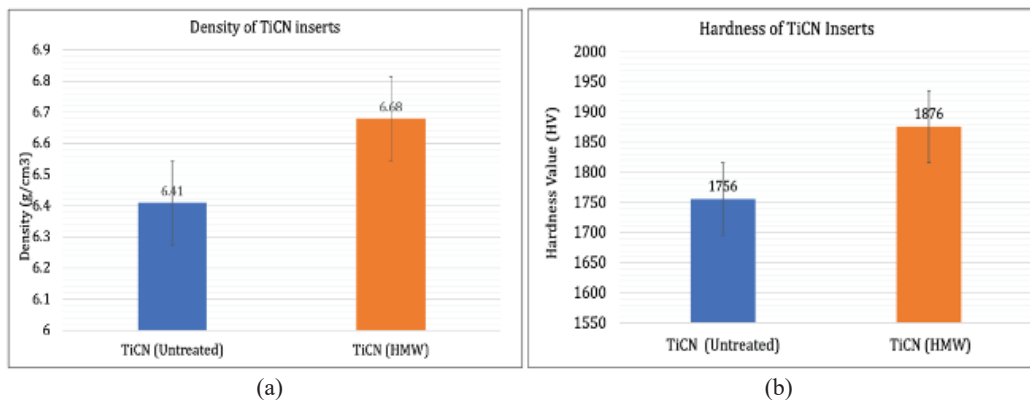


FIGURE 4. Mechanical properties of the TiCN inserts (a) Density (b) Microhardness measurements

SCANNING ELECTRON MICROSCOPE

Figure 5 displays the scanning electron microscope (SEM) pictures of the TiCN microstructure for both the untreated and HMW treated samples. Generally, the microstructure exhibits a degree of similarity characterised by a uniformly distributed and densely packed grain structure. The microstructure of TiCN, treated with hybrid microwave (HMW) energy at a temperature of 220°C for a duration of 20 minutes, remained mostly unchanged except appears to have a slightly coarser appearance than the untreated sample.

The improved hardness of the TiCN (HMW) insert can be attributed to the increased heat generated by the micro plasma (spark effect) which is efficiently transported to the SiO₂ particles. The improved quick heating is a result of the absorption of the electromagnetic energy

from SiO₂ and its remarkable ability to convert it to heat (Ebrahimi-Tazangi et al. 2021) Therefore, the SiO₂ heating rate is higher than that of the microwave energy alone. Because heat permeates the skin deeper and faster with decreasing conductivity, it is believed that when the silica sand containing SiO₂ are used as susceptors, there is a stronger interfacial bonding between all the compositions of TiCN at elevated temperature even as low as 220°C.

TOOL WEAR

Figure 6 shows the flank wear progression in dry and MQL machining for the cutting speeds of 166, 210, and 263 mm/min for the untreated and HMW treated TiCN inserts. In both dry and MQL machining, the wear rates of the TiCN (UT) insert are seen to be greater (0.01-0.04 mm/min) in comparison to the TiCN (HMW) insert (0.01-0.02 mm/

min) at cutting speeds of 166, 210, and 263 mm/min. The TiC(HMW) insert exhibited a reduction in tool wear by 24%, 21%, and 13% in dry machining at cutting speeds of 166, 210, and 263 mm/min, respectively. In the context of MQL machining, it was observed that the tool wear for

cutting speeds of 166, 210, and 263 mm/min resulted in reductions of 5.2%, 5%, and 3.7% correspondingly. The hybrid microwave treatment generates electromagnetic radiation that facilitates the fast heating and absorption of the radiated energy into the TiCN insert, leading to an enhancement in both hardness and wear resistance.

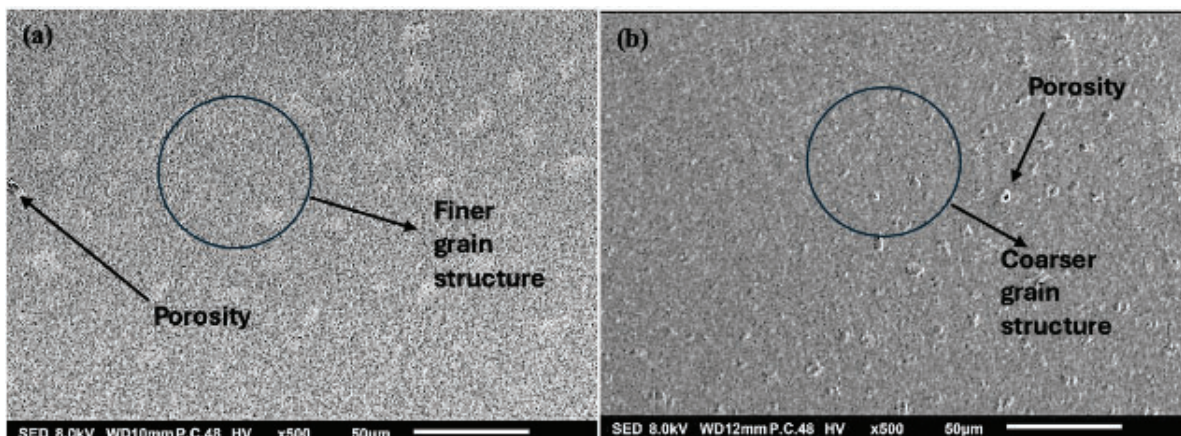


FIGURE 5. SEM images of TiCN coated inserts (500x) (a) TiCN (Untreated) (b) TiCN (HMW)

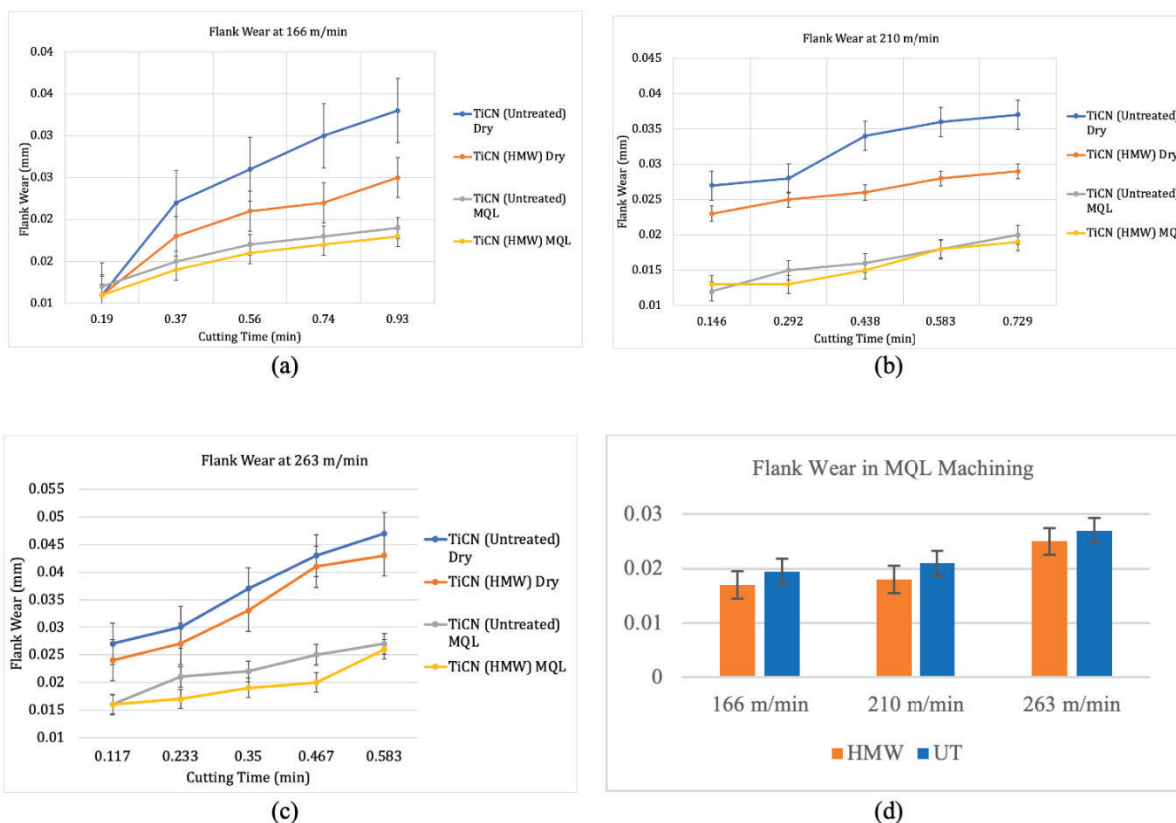


FIGURE 6. Flank wear in (a) 166 m/min (b) 210 m/min (c) 263 m/min (d) MQL machining

Dry machining has shown an increased tool wear by 73 – 85 % for the TiCN (UT) tool while 38 – 65% for the TiCN (HMW) tool when compared with the MQL machining. Dry machining typically demonstrates reduced efficiency in heat dissipation from the cutting zone, leading to unsatisfactory machining performance when measuring tool life parameters. Although dry machining is seen as sustainable, it can lead to problems such as tool overheating. Intense friction between the tool and workpiece during dry machining conditions significantly increases temperature at the tool chip interface, leading to increased abrasion, diffusion, and oxidation. (Debnath, 2014).

Figure 6(d) shows the summary of the flank wear in MQL machining for both the TiCN (UT) and TiCN (HMW) cutting tools. It can be seen clearly that the HMW treated inserts have lower flank wear compared to the untreated

TiCN tool for the three different cutting speeds. Nevertheless, lowest flank wear is observed in 166 m/min while the highest flank wear is observed in 263 m/min for both TiCN (UT) and TiCN (HMW). The utilisation of recycled cooking oil in MQL has demonstrated its efficacy in enhancing lubricating qualities and efficiently reducing tool wear. The lower value of flank wear has been observed under the MQL machining due to the more efficient lubrication mechanism. Figure 7 displays the image of the flank wear in MQL machining for all the three cutting speeds. The flank wear which is a result of abrasion due to the presence of friction at the tool tip and workpiece interface, can be seen progressively increasing in the image with higher cutting speeds. Larger flank wear can be seen in the untreated TiCN tool when compared with the HMW treated TiCN tool.

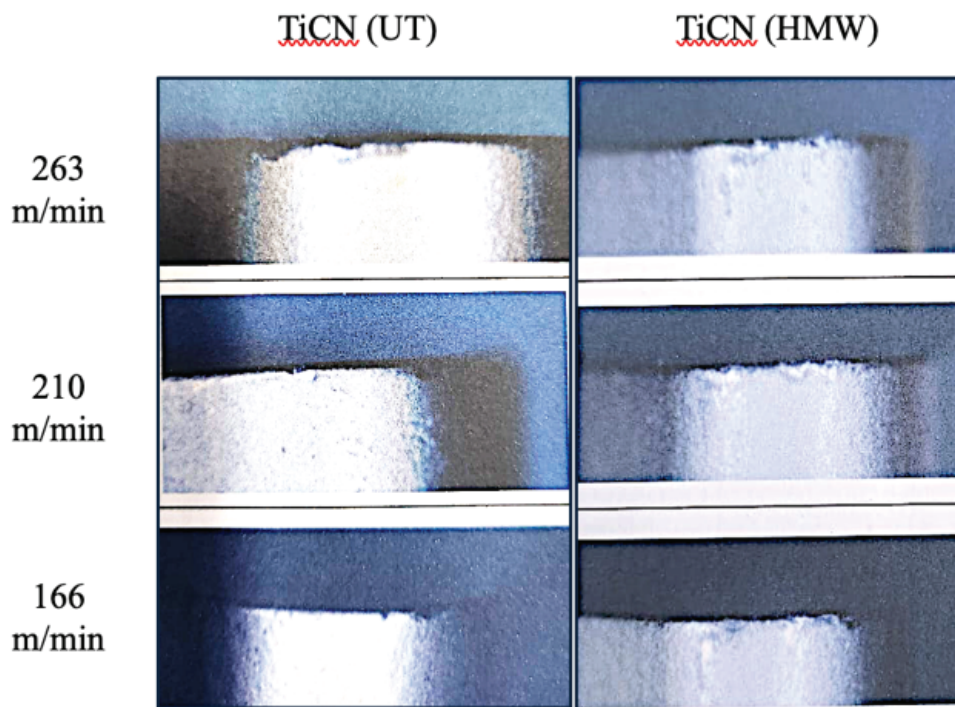


FIGURE 7. Flank wear of TiCN cutting tool in MQL machining

Cooking oils that are generated during the frying process consist mostly of triglycerides, monoglycerides, diglycerides, and free fatty acids, which are present in different proportions ranging from 5% to 20% by weight (Balasubramaniam et al. 2012). Triglycerides, consisting of saturated and unsaturated fatty acids, serve as the primary constituents for initiating the processing of added-value products across many industries. Undoubtedly, the process of frying alters the physical and chemical properties in the oil mainly noticed in the increased viscosity and specific heat. In addition, surface tension and colour

changes are apparent (Schuchardt et al. 1996). The health risks of using cooking oil repeatedly make recycling and reusing it in the machining industry a great idea. This is because used cooking oil is biodegradable and still has enough lubricating properties without releasing harmful fumes, making it an ideal bio lubricant. This is in line with the findings of Joshi et al. (2023) that claim using waste oil as a bio lubricant has the capability of keeping its tribological and environmental properties through chemical modification.

CONCLUSION

The hybrid microwave post-sintering technique improves the properties of the TiCN insert, resulting in a 4% rise in density and a 7% improvement in hardness. Therefore, the TiCN (HMW) insert exhibits a more compact microstructure with reduced porosity in comparison to the untreated TiCN insert. The TiCN (HMW) insert demonstrated enhanced machining performance with a 13-24% (dry) and 3.7-5.2% (MQL) reduction in tool wear compared to the TiCN (untreated) insert. Therefore, the inclusion of recycled cooking oil in MQL did indeed lead to a substantial reduction in tool wear at all three cutting speeds (166, 210, 263 m/min). The application of hybrid microwave treatment on TiCN inserts at a temperature of 220°C for a duration of 20 minutes has been proven to be highly successful for MQL turning of T6061 Aluminium alloy. The utilisation of recycled cooking oil in MQL demonstrates a notable efficacy in diminishing wear rates, ultimately leading to an extension in the lifespan of tools. Using recycled cooking oil for machining is a commendable effort to engage in a circular economy and contribute to environmentally responsible machining. However, it is not advisable to use TiCN (HMW) inserts in dry turning of T6061 Aluminium alloy since it leads to a significant and rapid rise in tool wear despite having reduced wear.

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DECLARATION OF COMPETING INTEREST

None.

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