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Surface Texturing Potential on Carbide Insert in Reducing Aluminium Alloy Adhesiveness during Machining

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ABSTRACT

Aluminum alloy is a widely used material which contributes greatly in numerous engineering applications. Aluminum alloy can be considered as having low strength and it is less likely to experience tooling difficulty. However, the complexity of machining aluminum alloy is related to its adhesive behavior, which capable to impede the machining operations where build-up-edge can be observed easily to occur. Since machining process generates a lot of energy due to friction and adhesive contact between tool and material, it is suggested to apply wet cutting method during machining of aluminum alloy to decrease the likeliness of aluminum alloy chip to adhere onto the tool surface. However, this method of machining is still having low effectiveness whereas the limitation of cutting fluid to enter the tool-chip sticking zone. Thus, the fabrication of textures on carbide insert rake surface is one of the predominant methods to enhance the sustainability of turning process with aluminum alloy workpiece. In this study, grinding process was utilized using Okamoto ACC52ST surface grinding machine to fabricate textures, where it is assumed that high effectiveness of lubricant can be retained and friction at tool-chip interface can be reduced. Turning process was conducted with the application of ROMI C420 lathe machine to investigate the adhesive behavior of aluminum alloy. It is observed that, the adhesive behavior of aluminum alloy was minimized with the application of textured carbide insert especially in wet cutting condition in general. Additionally, it can observed that, even at relatively high cutting speed and depth of cut, less adhesion behavior of aluminum alloy is obtained for textured carbide insert in wet cutting condition. This can be considered as a gain in productivity, whereas the adhesive behavior for non-textured carbide insert can only be reduced if only low cutting speed condition and wet cutting method are utilized.

INTRODUCTION

Surface texture is the characteristic or consistency of a surface, where it is known as surface topography, which constitutes all the small, topical deviations and erroneous tendency of a surface from the true plane that looks like perfectly flat by naked eyes. Meanwhile, surface roughness is known as roughness or surface finish, which comprises of finely spaced micro surface irregularities resulted from different machining operations. A study had shown that an uncoated cemented tungsten carbide insert was capable to be grinded with a micro-depth on its rake surface using diamond grinding wheel [1]. The cutting speed and feed rate were maintained constant as various structures or grain sizes of insert was utilized for the investigation. In addition, another research was proposed in machining steel materials using the predesigned textured cutting tools to enhance wear resistance. A newly developed cutting tool was introduced by having grooves with micro-stripe on the rake surface. The study shows that the insert with micro-stripe grooves parallel to the cutting edge enhanced the wear resistance and lubricity of insert surface effectively during the milling process with steel materials. The micro periodic grooves parallel to the cutting edge of insert perform effectively in preserving cutting fluid and minifying the tool and chip actual contact area [3].

In recent studies, application of laser technology helps in preparing three types of textured, parallel grooves, circular dimples and rectangular dimples on the rake surface of cemented carbide insert. The study was then investigated to undergo dry cutting with aluminium alloys workpiece. A low cutting speed was found to result in a good cutting performance as using textured inserts especially the insert which was textured with rectangular dimples [4]. Micro/Nano fine scales, patterns and structures on the rake surface of cutting tool were proven to be able to reduce the frictional behaviour at the tool-chip or tool-workpiece interface zone [5].

In order to improve the machinability of aluminium alloy, micro-textured cemented carbide insert was developed using focused ion beam (FIB) machining. It was discovered that the parallel grooves which is perpendicular to the chip flow direction performed effectively in reducing the friction for cutting process of aluminium alloy [6]. Textured and non-textured inserts were used to conduct cutting test using lathe machine in dry condition. A constant cutting speed, feed rate, and depth of cut were the cutting parameters used to cut the aluminium and mild steel work pieces [7]. Turning experiments in both dry and cryogenic minimum quantity lubrication (CMQL) conditions were conducted using textured cemented carbide cutting tool and lathe machine. Lubricant oil was applied in the CMQL condition. Titanium alloy was used as the work piece in this experiment. However, this textured preparation method can be considered as expensive.

Meanwhile, it was concluded that the cutting tool with microgroove arrays gave better cutting performance in CMQL condition compared to dry condition. This is due to existence of the microgroove preserves the lubricants on the rake surface which is capable to reduce the friction at the tool and chip interface during cutting process [8]. Besides, the anti-adhesive behaviour of aluminium alloy can be improved under wet cutting with textured cutting tool. The micro stripe textured surface was developed on cutting tool to effectively diminish the adhesive behaviour of aluminium alloy in both dry and wet cuttings [9]. Plus, the micro-textures acted as reservoir to store lubricant and reduce the contact area during cutting [10].

This paper is discussing on the effect of surface textured turning carbide insert to the aluminium alloy Al6061 workpiece through turning process. The surface texture on the turning carbide insert is fabricated by grinding process. The depth of grinding process (feed rate) will be investigated as one of the critical parameters to result different textures on the carbide insert rake surface. The surface textures fabricated on the rake surface of carbide insert will be investigated using metallurgical microscope and surface roughness tester. Furthermore, this paper also determines and compares the effects of textured and non-textured carbide insert to the turning process with aluminium alloy Al6061. The surface of cutting tools was investigated to have textures in micro scale via grinding process in order to alter the tribological condition at the tool-work piece interfaces and thus improve the overall machining performance.

METHODOLOGY

The methodology in this paper is separated in two major components, which were texture fabricating process and workpiece cutting process. Texture fabricating process was conducted by grinding test while the machining process was conducted via turning test. Firstly, an appropriate model DNMA 150608 of carbide insert cutting tool was selected to undergo surface texturing fabrication via grinding process.

I. *Texture preparation*

Okamoto ACC52ST surface grinding machine was applied to fabricate textures on the carbide insert rake surface as illustrated in Figure 1. The carbide insert was first being clamped firmly on a vice which is electromagnetically to be held on the magnetic work table. A conventional abrasive grinding wheel was used to grind the carbide insert. Grinding wheel rotational speed and coolant flow rate is set to be constant. The speed of reciprocating work table and the depth of cut for grinding the carbide inserts were chosen as the controlled parameter. The cutting tip of the carbide insert was grinded in a direction parallel to the grinding wheel as illustrated in Fig. 2. The speed of reciprocating work table was tested with 0.036 m/s, 0.050 m/s and 0.083 m/s while the depth of cut was tested with 2 μm and 4 μm. The total depth to be cut was 1 mm. However, 0.083 m/s and 2 μm were selected as the optimal speed of reciprocating work table and depth of cut in order to fabricate the largest roughness of textures on carbide insert. The texture roughness was investigated using metallurgical microscope and surface roughness tester.

II. *Machining process*

ROMI C420 lathe machine was utilized for the turning test of the textured carbide insert and the **aluminium** alloy work piece. The workpiece was clamped and held firmly on the mandrel of the lathe machine. The textured carbide insert was clamped or secured on the cutting tool holder and be ready to cut the work piece. The textured rake surface of the carbide insert should be facing upwards when being secured on the cutting tool holder. The overall experiment setup for this turning test was illustrated in Fig. 3. Cutting speed and depth-of-cut were the controlled variables for this turning test. Additionally, the cutting fluid supply is one of the parameters used in this experiment. An overall depth of 30mm of the workpiece will be machined by the specially textured carbide insert during the experiment. The optimized textured carbide insert with the highest surface roughness in the grinding test was selected to be used for this turning test. In addition, a non-textured carbide insert was used for this turning test to validate the cutting performance with the textured carbide insert. The cutting speed applied in this experiment was 40 and 80 [m/min], while depth-of-cut was 0.2 and 0.4 mm. Feed rate of 1 [mm/rev] was set to machine the Ø25 mm aluminium alloy Al6061 workpiece. There were 12 experiments conducted in this turning test. Table 1 summarize the cutting condition parameters, while Table 2 indicates the characteristic of each experimental design with the combination of cutting speed, feed rate, textured availability and lubricant availability.

III. *Evaluation of* aluminium alloy Al6061 *adhesion*

After completed turning test, the rake surfaces of the carbide insert were observed using metallurgical microscope and video measuring system, where condition of the cutting tip and the adhesion of aluminium alloy Al6061 material on the rake surface were inspected, as shown in Fig. 4. The video measuring system was applied to observe the adhesion of work piece material and the condition of textures on the rake surface of each carbide insert as illustrated in Figure 5. In addition, Motic Image Plus 3.0 software was used to analyse the rake surface area of carbide insert coated with aluminium alloy Al6061 material after this turning test.

Fig. 1 Surface texturing by grinding process

Fig. 2 Parallel grinding direction of wheel to the cutting tip of insert

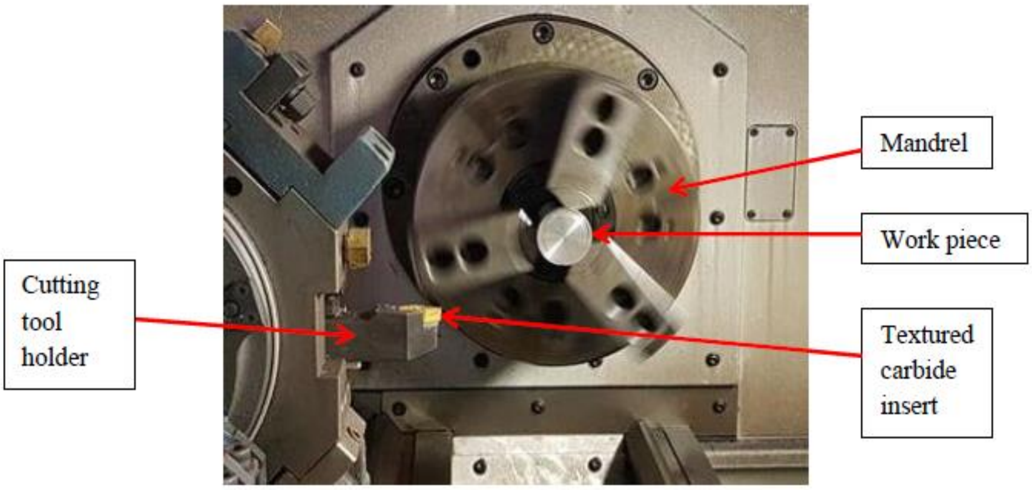

Fig. 3 Experimental setup utilizing turning process with ROMI C420

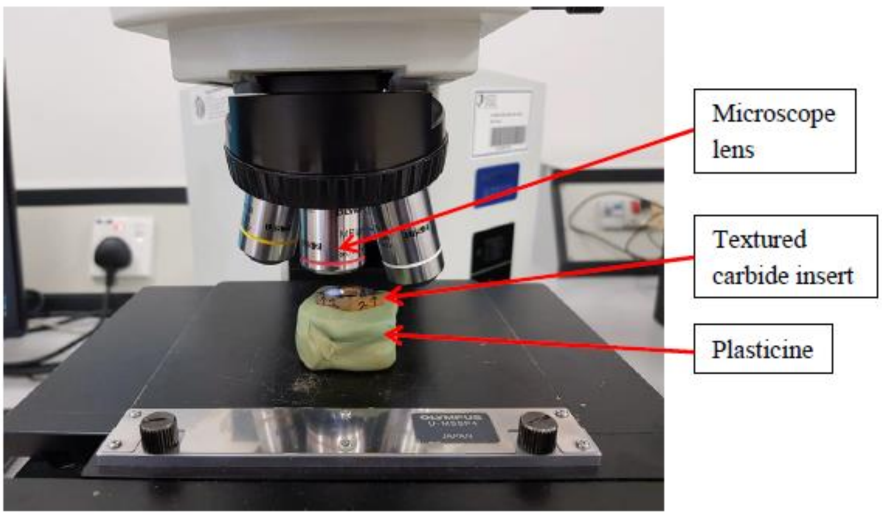

Fig. 4 Texture on tool rake surface observation process

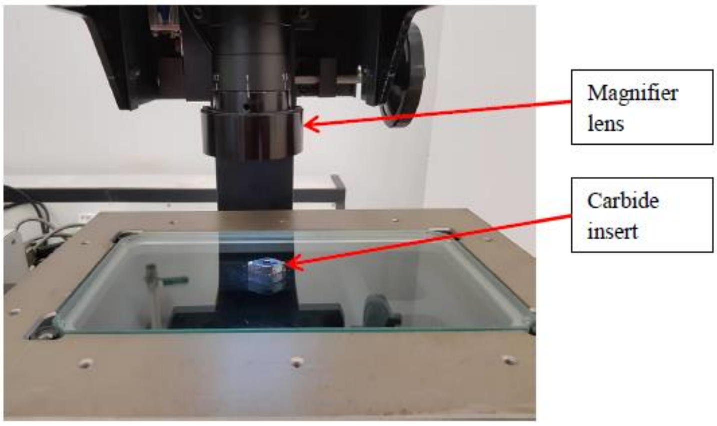

Fig. 5 Inspection of alloy adhesion on tool rake surface

Table 1 Cutting conditions

Cutting Tool	DNMA 150608 Carbide Insert
Rake angle (°)	0
Workpiece	Aluminum Alloy Al6061
Workpiece diameter [mm]	25.0
Feed rate f [mm/rev]	1.0
Depth of cut a [mm]	0.2, 0.4
Cutting speed v_c [m/min]	40, 80

Table 2 Pre-set experiment combination

EXP	Cutting speed [mm/min]	Depth of Cut a [mm]	Surface textured availability	Cutting fluid lubrication
1	40.0	0.2	Present	Absent
2	80.0	0.2	Present	Absent
3	80.0	0.4	Present	Absent
4	40.0	0.2	Present	Present
5	80.0	0.2	Present	Present
6	80.0	0.4	Present	Present
7	40.0	0.2	Absent	Absent
8	80.0	0.2	Absent	Absent
9	80.0	0.4	Absent	Absent
10	40.0	0.2	Absent	Present
11	80.0	0.2	Absent	Present
12	80.0	0.4	Absent	Present

RESULTS AND DISCUSSION

I. Surface textures fabrication

After grinding test, the surface roughness R_a of the carbide insert textured rake surface was measured using surface profilometer. The measurement setting was given to be 3.0 [mm] in length, while measurement speed of 0.3 [mm/s], and cut off value = 0.25. According to Fig. 6, both of the 2 µm and 4 µm depth-of-cut resulted in the largest average surface roughness with the highest speed of reciprocating work table which were 0.553 μm and 0.499 μm respectively. In other words, the larger the speed of reciprocating worktable, the larger the average surface roughness of insert will be fabricated. Thus, the experiment parameters v_r=0.083 m/s and d_c=2.0 μm were selected to be applied on the turning test in order to achieve a large surface roughness that is capable for retaining lubricants and reducing friction at the tool-chip interface. With applying the error bars to represent the uncertainty of the data collected, we can interpret that the data of roughness is reliable since the standard deviations showed in the graph are relatively small, which is within a range of 0.01 to 0.02. The condition of fabricated textures was inspected via metallurgical microscope. The carbide insert rake surface before and after textured was illustrated in Fig. 7.

II. Surface textures fabrication

As the machining process is completed, the carbide inserts were inspected attentively via the related equipment. Due to the adhesive behaviour of aluminium alloy Al6061, the material was adhered to the cutting tips and rake surface of carbide inserts during the turning process. However, the severity of aluminium alloy Al6061 adhesion was strongly dependable on the condition of carbide insert, which was the presence of textures on the rake surface. By analysing the total area coated with adhesion via Motic Image Plus 3.0 software, the results were displayed as Figs. 8 and 9. According to Fig. 8, textured carbide insert without lubricant during turning process contributes to the largest adhesion when involving the highest cutting speed and depth of cut, which was 30.77 % in experiment 3. Oppositely, textured carbide insert with lubricant applied during turning process offered to the smallest adhesion when machining with the highest cutting speed and depth of cut, which was 24.93 % in experiment 6. It indicated that the when utilizing textured carbide insert, lubricant was effective to improve the anti-adhesion of aluminium alloy Al6061 when the machining parameters were high enough. Without lubricant, the adhesion can be minimized by using textured carbide insert at low cutting speed and depth of cut.

Additionally, it can be observed from Fig. 9, the presence of lubricant was effective to diminish the aluminium alloy Al6061 adhesion on non-textured carbide insert as comparing experiment 7 to 10, 8 to 11, and 9 to 12. The total area with adhesion was reduced from 39.84 % to 32.10 % in experiment 7 and 10 respectively with having the similar cutting parameters. The graph also indicated that lower cutting speed and depth of cut for non-textured carbide insert gave less adhesion. Experiment 10 contributed to the lowest percentage of total area with adhesion among the six experiments, which was 32.10 %.

As comparing Figs. 8 and 9, it implied that the textured carbide inserts had relatively less adhesion of aluminium alloy Al6061 after the turning test. This could be explained as the textures on carbide insert rake surface were capable to reduce the friction at the tool-chip interface and also to act as reservoir for retaining lubricant during the turning process. Textured carbide insert which was machined with the presence of lubricant at the highest cutting speed and depth of cut contributed to the smallest percentage of adhesion. On the contrary, non-textured carbide insert which was machined without lubricant at the highest cutting speed and depth of cut resulted in the largest percentage of adhesion. Therefore, a set of

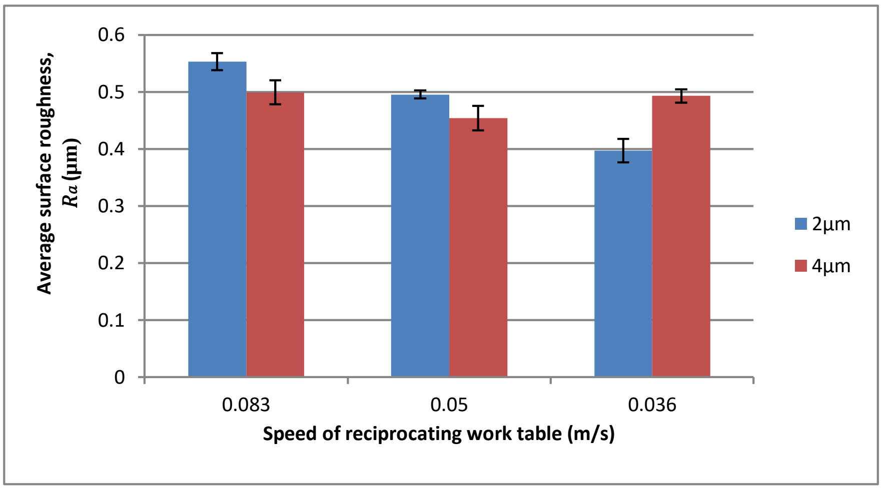

Fig 6 Relationship of depth of cut and grinding speed with average surface roughness R_a

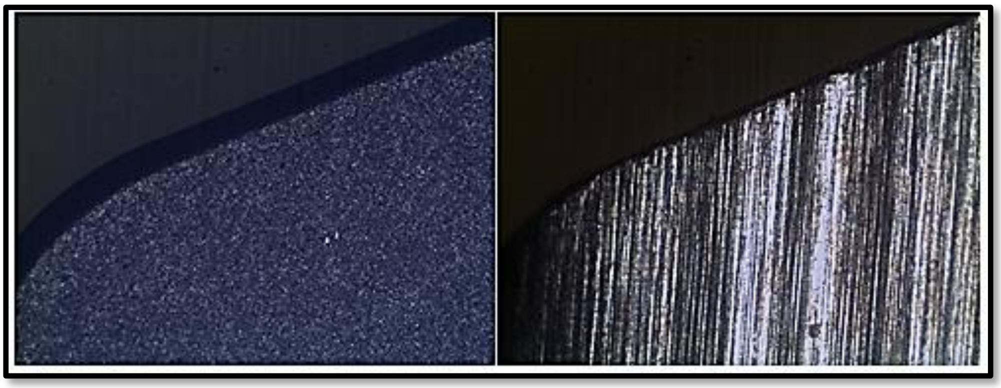

Fig 7 Rake surface of carbide insert before (left – smooth surface) and after (right – rough surface) being textured via grinding process

optimal cutting parameters as illustrated in Table 3 was determined in this paper to achieve the lowest percentage of total area with adhesion on carbide insert cutting tool in turning process.

Table 3. Optimal cutting parameters

Cutting Parameters	
Cutting speed v_c [m/min]	80
Depth of cut a [mm]	0.4 mm
Tool Surface Texture	Present
Lubricant	Present

By capturing the condition of carbide insert rake surface via vision equipment, the results were illustrated in the Figure 10. The software differentiated the aluminium alloy Al6061 material from the carbide insert rake surface and then calculated its surface area from the image. The silver colour material with green contour line was aluminium alloy Al6061 while the triangle shape was the rake surface of carbide insert. It was indicated obviously that both the inserts were having aluminium alloy Al6061 adhesion focused on the tip part of rake surface rather than the middle part. However, textured carbide insert involved relatively less adhesion at the middle part of rake surface as illustrated in Figure 10.

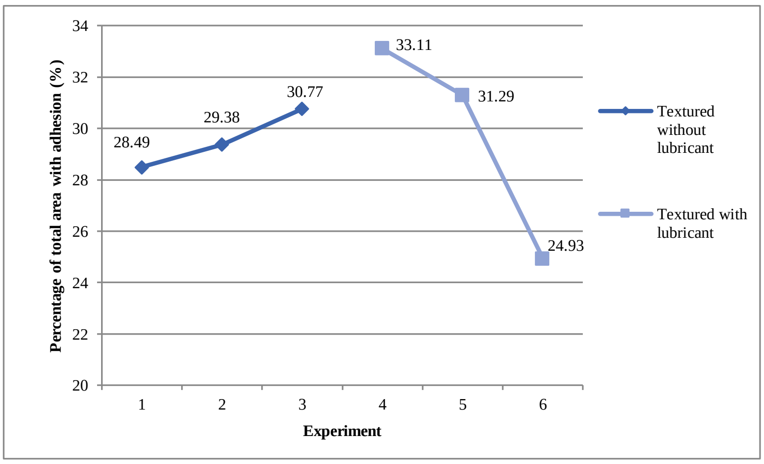

Fig 8 Percentage of total area with adhesion for textured carbide insert turning without lubricant and with lubricant to the experiments in turning test

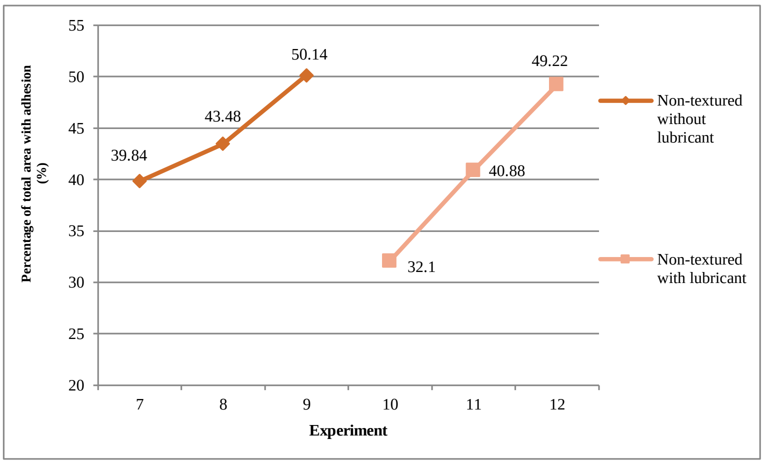

Fig. 9 Percentage of total area with adhesion for non-textured carbide insert turning without lubricant and with lubricant to the

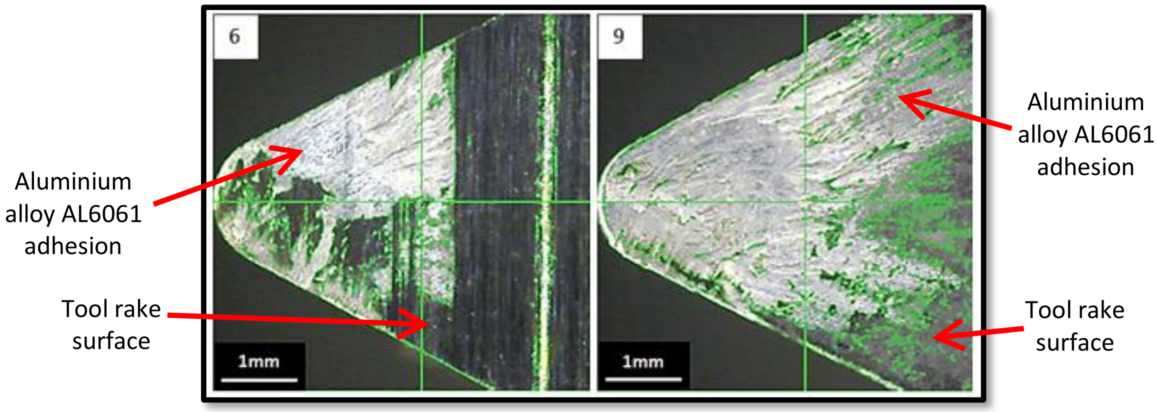

Fig 10 Condition of aluminum alloy material adhesion on textured [Exp 6 - left] and non-textured carbide insert after turning test [Exp 9 – right]

Furthermore, this figure indicated the adhesion condition of textured and non-textured carbide inserts from experiment 6 and 9 of turning test respectively. Experiment 6 was lower aluminium alloy Al6061 adhesion in turning test. For experiment 9, it was conducted without lubricant using non-textured carbide insert and it then contributed to the largest aluminium alloy Al6061 adhesion in turning test. With such comparison, it demonstrated the presence of lubricant was effective to diminish the adhesion of aluminium alloy Al6061 especially at the tip part of carbide insert rake surface.

CONCLUSIONS

This paper concluded that grinding process was capable to fabricate textures on carbide insert which were then effective to improve anti-adhesive behaviour of aluminium alloy Al6061. A higher speed of reciprocating work table and a lower depth of cut resulted in larger roughness of textures on carbide insert rake surface. This large roughness of texture had higher possibility to perform as lubricant reservoirs to reduce cutting friction in turning process. And thus the adhesive behaviour of aluminium alloy Al6061 was coped too. Additionally, the results clearly indicated that textured carbide insert performed relatively better on minifying the aluminium alloy Al6061 adhesion than non-textured carbide insert during turning process.

In dry cutting condition, textured carbide insert offered less aluminium alloy Al6061 adhesion with low cutting speed and depth of cut. In wet cutting condition, the aluminium alloy Al6061 adhesion could only be reduced with high cutting speed and depth of cut. For non-textured carbide insert, a set of low cutting parameters was preferable to contribute less aluminium alloy adhesion. However, the presence of lubricant was highly effective to minimize the adhesion for non-textured carbide insert. It not only acts as reservoir to retain lubricant at the textures but also reduce the actual contact at tool-chip interface. These results were corresponding to the research studied by Rathod et al. (2016). Textured carbide insert was valid to reduce cutting force, friction force, and material adhesion during machining process especially when lubricant or coolant was being applied [6].

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