International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-9 Issue-2, December, 2019

Effectiveness of Near-Dry Machining on Tool Performance in Bull Nose Milling of Aluminum Alloy 7075-T6

M.Z.A. Yazid, Azreen Zainol

Abstract*: The paper investigated the effectiveness of near-dry machining also known as minimum quantity lubrication (MQL) on tool wear when aluminum alloy 7075-T6 was milled using bull nose carbide insert. The foregoing study found that the high tool wear was occurred in machining aluminum alloy 7075-T6 with uncoated carbide under dry machining. Due to that, dry machining was performed to examine its result with MQL. Different values of cutting parameter selected were cutting speed of 500 and 600 m/min, the feed rate of 0.12 and 0.15 mm/tooth, and axial depth of cut of 1.40 and 1.70 mm. 100 mL/h was set as MQL flow rate. Eight samples were performed on five axes milling machine according to a full factorial design. The tool wear was examined and measured progressively at every time interval using an optical microscope. From the analysis, MQL 100 mL/h at 500 m/min, 0.12 mm/tooth, and 1.40 mm was found to be better than dry machining. The adhesion wear mechanism was observed at both machining conditions. Near-dry machining with appropriate flow rate and machining parameters has the potential to contribute to long-term environmental friendly machining in line with the industrial revolution phase.

***Keywords* : Near-Dry Machining, Tool Wear, Aluminum Alloy 7075-T6, Dry Machining.**

I. INTRODUCTION

Over recent years, the metal cutting industry has experienced a demanding situation in generating a working environment in good condition, low operating costs, and high production efficiency [1]. Metal cutting is defined as the machining part shapes, divergent parts, and components as well as material removal into a form of chip slides from a workpiece using a designated cutting tool. Notwithstanding, the operation of metal cutting has potential in leading to many severe events occur that cannot be perceived by the naked eye, particularly tool deterioration, chip flow, and cutting temperature, which may only be appraised through analytical technique. This occurs due to the absence of cutting fluid application in the cutting zone. Cutting fluid is crucial in numerous machining processes. Cutting fluids referred to any liquids used directly onto the tool face and workpiece to cool and lubricate them while facilitating the process of metal cutting [2]. Nearly 20 % of the engagement of cutting fluid in machining costs [3]. Its prime purpose is to reduce the tool wear and flush away the chips from the cutting zone and indirectly it could lengthen the tool lifespan [4]. Furthermore, it is composed of various green approaches to suit to the machining processes as dry machining, flood, cryogenic, and near-dry machining [5]. Typically, near-dry machining is associated with the more contemporary term, which is minimum quantity lubrication (MQL). MQL and dry machining were amongst intelligent approach in many machining processes as it brings to viable economic growth in terms of a cost-effective fluid, green manufacturing, and exhibiting preferable machinability [6], [7]. MQL is an approach where a small amount of cutting fluid between 10 and 100 mL/h was dispersed with the aid of air to cutting zone in the form of mist whilst dry machining refers to the cutting operation regardless the aid of cutting fluids [8]-[11]. Moreover, a good cutting fluid approach is typically applied in the machining of high-performance materials at high-speed cutting in short processing span.

Aluminum alloy is synonymous with high-speed cutting in milling operation for machining of complex structural components which are primary material employed in the manufacture of aircraft [12]-[14]. A popular aluminum alloy material for machining in the various industrial sectors, particularly aerospace, is a 7000 series group [15]. Aluminum alloy 7075-T6 has been one of the popular materials in the 7000 series due to possessing exceptional mechanical behavior and combined elements such as zinc, magnesium, and copper to improvise their strength [16], [17].

In metal cutting, the needs for a suitable cutting tool is increasingly important in enhancing productivity, including facing the challenges for increasingly higher cutting speed. The carbide tools are common cutting tools to replace other tools due to their better performance, price, and availability [18]. It is appropriate for machining light-weight and soft alloys in a continuous or interrupted the cutting process. Shokrani et al., (2012) proved that 75 to 85 % of the cutting tools used in the industry were carbide tools [19].

There were several prior studies related to the tool wear have emphasized that MQL provides satisfactory results in practical machining processes at high-speed cutting compared to the dry cutting. Imbrogno et al., (2018) carried out the experiment to investigate the machinability of aluminum alloy 7075-T6 on the tool wear at high-speed turning using carbide tools under three different fluid approaches, mainly dry machining, MQL, and cryogenic. The cutting speed comprised of 1000, 1250, and 1500 m/min and feed rate were 0.1 and 0.3 mm/rev.

Revised Manuscript Received on December 30, 2019.

* Correspondence Author

M.Z.A Yazid*, Manufacturing Section, Universiti Kuala Lumpur-Malaysia Italy Design Institute, Kuala Lumpur, Malaysia. Email: mzaiday@unikl.edu.my

Azreen Zainol, Manufacturing Section, Universiti Kuala Lumpur-Malaysia Italy Design Institute, Kuala Lumpur, Malaysia. Email: azreen_zainol@yahoo.com.my

Fluid approaches, as well as machining parameters, were effective variable affect the tool wear. They found that the application of MQL and cryogenic with reducing the merger of machining parameter values tend to produce low tool wear [20]. Davim (2011) reported in the Modern Machining Technology that the phenomenon that is known as Built Up Layer (BUL) was occurring in high-speed milling with tungsten carbide with multilayer AlTiN under dry machining. This phenomenon occurred due to the trend of cutting tool material to adhere to tool edges, indirectly affect the tool performance. Consequently, the recommended minimal application of cutting fluid is an approach of minimum quantity lubrication after taking into consideration the impossibility of dry machining to avoid the BUL phenomenon [21].

This paper presents the comparative performance of near-dry and dry machining towards tool wear when milling of aluminum alloy 7075-T6 with bull nose uncoated carbide tools. The investigation on the influence of machining parameters towards tool wear was carried out.

II. METHODOLOGY

The study was performed on DECKEL MAHO DMU 50 eVolution five-axis milling machine under MQL and dry machining. The MQL flow rate was 100 mL/h. The cutting tool was uncoated carbide insert with bull nose cutter of 14 mm in nominal diameter. In order to avoid deflection and vibration, the tool overhang of 50 mm was kept constant. A block of the aluminum alloy 7075-T6 has been chosen as the work piece material has a dimension of 300 × 150 × 40 mm3. The chemical composition of the material was 90.3 %, 5.6 %, 2.5 %, and 1.6 %, which represented the respective element of aluminum, zinc, magnesium, and copper in accordance with specification from the manufacturer.

A thickness of the work piece surface almost 1 to 2 mm was faced milled to eliminate any defect that could adversely interfere with the machining result. A full factorial design was applied for the convenience of settings three variations of machining parameters with two levels to serve eight samples for both fluid approaches as summarized in Table 1. The step-over (ae) keep to 7 mm.

Table- I: Machining parameter employed in the experiment

Factor	Level	
	-1	+1
Cutting speed (vc), m/min	500	600
Feed rate (fz), mm/tooth	0.12	0.15
Axial depth of cut (ap), mm	1.40	1.70

The tool wear on the flank face was examined and measured at every pass interval employed an Olympus BX53M optical microscope with 20x magnifications. The different cutting tool has used for an experiment so that the effect of cutting flank wear at each runs order could be observed and evidently avoid the biased results. The cutting tool will be temporarily removed from the tool holder to examine and measure the wear progression. The machining was stopped when the tool reaching primary tool failure, namely the tool flank wear (VB) of 0.30 mm based upon ISO 8688-2-1989 [15]. A scanning electron microscope (SEM) equipped with energy dispersive X-ray (EDX) was employed to examine and analyze a micrograph of the tool wear.

III. RESULTS AND DISCUSSION

Figure 1 and 2 exhibit the flank wear progression against cutting time at a cutting speed of 500 and 600 m/min, the feed rate of 0.12 and 0.15 mm/tooth and axial depth of cut of 1.40 and 1.7 mm, respectively under both fluid approaches. Normally, the wear shows the increasing progression which classified into three typical regions, which are the break-in, steady-state, and failure.

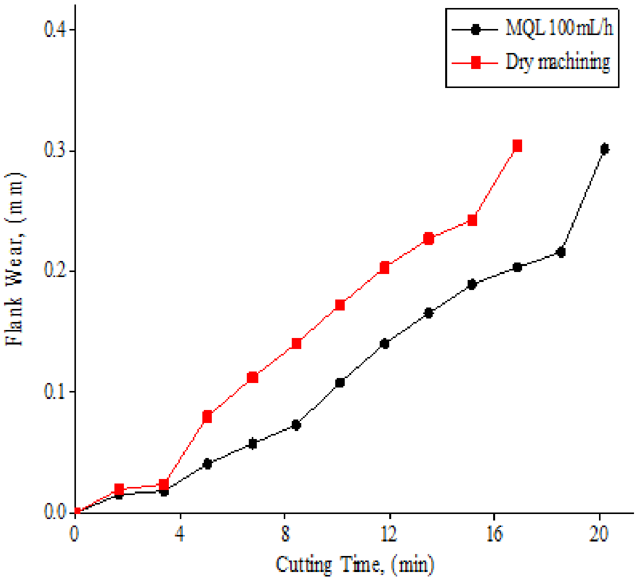

Fig. 1. Flank wear against cutting time under MQL and dry machining at 500 m/min, 0.12 mm/tooth and 1.40 mm

According to Figure 1, the progression of flank wear was apparent occurred gradually raised in the break-in region. Freshly tool gradually worn out due to the small friction at the tool and work piece interface. It ends with a minute of 3.36. In the steady-state region, the wear displays nearly similar progression for both fluids approaches. The wear under dry machining seems a quicker progression than MQL 100 mL/h. The wear of dry machining ends with a minute of 15.11 at the wear of 0.243 mm, meantime, the wear of MQL 100 mL/h was 0.189 mm. In the failure region, when the tool edge became greater worn out, flank wear progression has increased substantially due to high friction force and temperature in the tool-work contact area. The tool life of dry machining was failed at the minutes of 16.79 where wear ended at 0.305 mm, while MQL 100 mL/h ends with a minute of 20.14 with a wear rate of 0.302 mm.

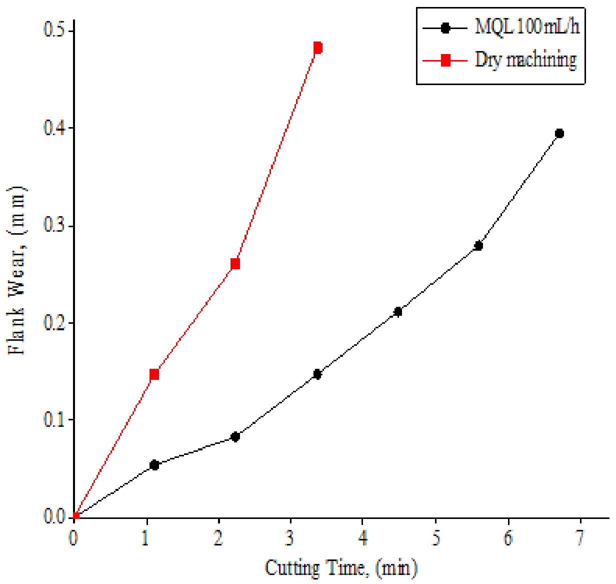

Fig. 2. Flank wear against cutting time under MQL and dry machining at 600 m/min, 0.15 mm/tooth and 1.70 mm

In Figure 2, it shows clearly that the rapid progression of the flank wear arises in the break-in region under both fluids approaches. The fresh tool edge was quickly worn out beyond 1.12 minutes. The wear progression under dry machining was dramatically increased until the tool totally damaged and fail as a result of the phenomenon of thermal shock on the tool edge. It ends beyond 3.36 minutes at the wear of 0.483 mm. Meanwhile, in this period, the wear under MQL 100 mL/h demonstrate uniform progression until the wear was observed at 0.279 mm beyond 5.60 minutes in the steady-state region. The tool life of MQL 100 mL/h was failed at the wear of 0.395 mm with a minute of 6.72. In agreement with Zhong (2018), the wear of dry cutting showed a faster progressed in comparison with MQL 100 mL/h when milling aluminum 7050-T7451 [22].

Machining aluminum alloy 7075-T6 has the tendency to be exposed to elevated mechanical stress resulting in high tool wear. The comparison of tool flank wear for both fluid approaches with a low and high combination of machining parameters is depicted in Figure 3. The low and high tool wear of 0.302 and 0.395 mm under MQL 100 mL/h was observed in Figure 3 (a) and (c), respectively. In the dry cutting, the low and high tool wears were 0.305 and 0.483 mm also observed in the condition similar to MQL 100 mL/h. It seems that the severe wear on the flank face under the dry machining occurred at the higher cutting speed due to the absence of aerosol in the cutting zone, subsequently generated the adhesion and build-up edge (BUE). Apart from that, the finest wear has been obtained at varying machining parameters under MQL 100 mL/h. It can be seen that the competency of MQL onto the uncoated carbide tools was effective in penetrating far into the tool and work piece in order resulted in improved tool wear at the extreme machining parameters. Islam et al. (2017) have identified a similar result after turning aluminum alloy 6061 with MQL application [23].

In the machining process, the cutting speed usually has an impact on the wear mechanism. Figure 4 and 5 illustrates the comparatives of the wear mechanism between MQL 100 mL/h and dry machining when milling aluminum alloy 7075-T6 at cutting speed of 500 m/min, feed rate of 0.15 mm/tooth and axial depth of cut of 1.40 mm. It can be seen the observation from the SEM analysis of both fluid approaches reveals that the phenomenon of the adhesion wear grew in the tool flank face. It grew on almost all cutting tools regardless of taking into account the environmental conditions. In addition, the hike of the axial depth of cut leads to the high adhesive layer, indirectly tends to the tool failure and broken.

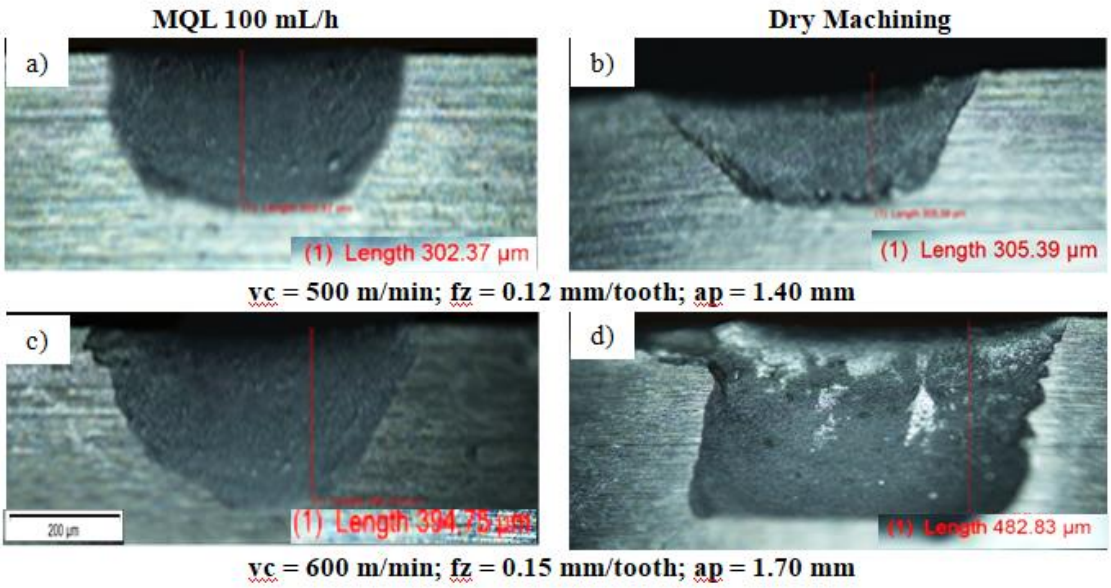

Fig. 3. Tool flank wear under MQL 100 mL/h and dry machining

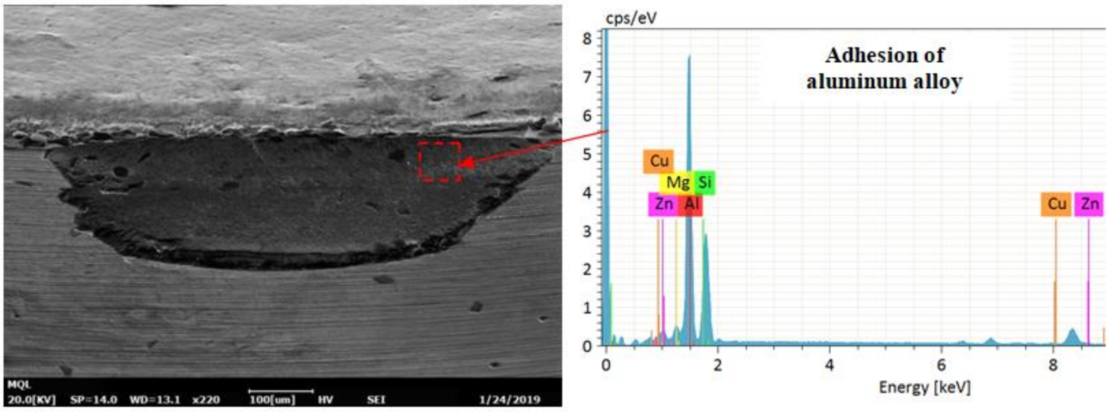

Fig. 4. The phenomenon of the adhesion wear on the flank and rake face and EDX analysis under MQL 100 mL/h

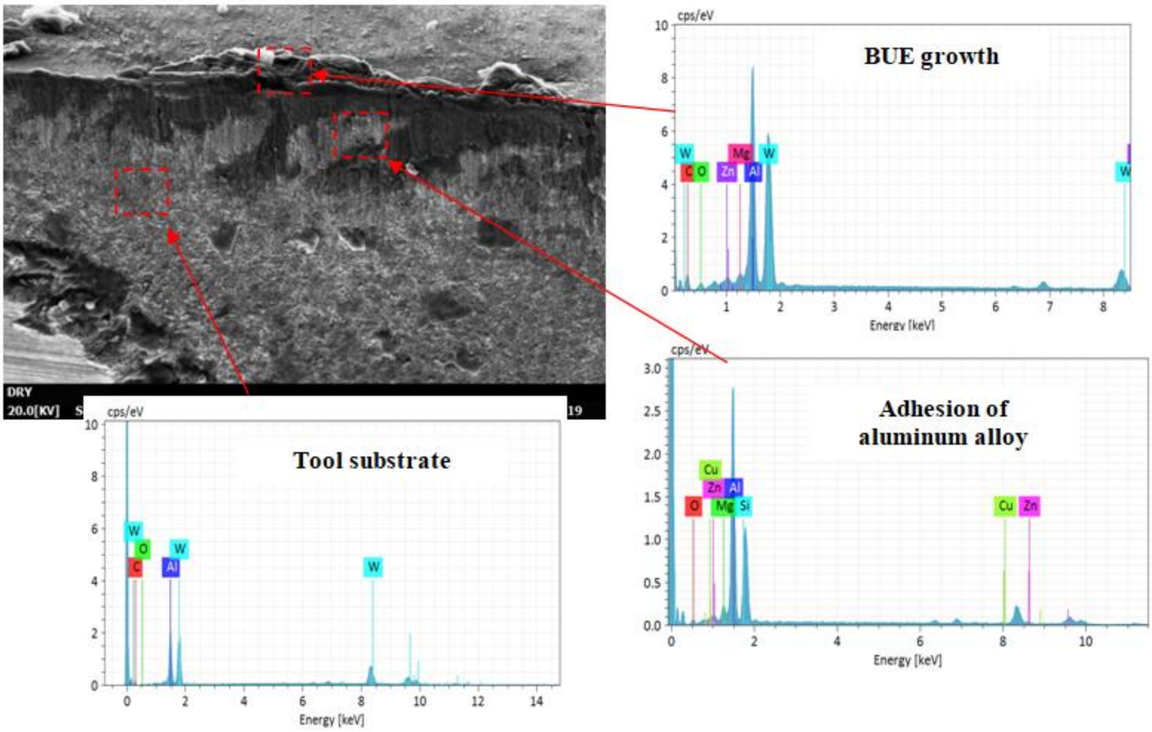

Fig. 5. The phenomenon of the adhesion wear on the flank and rake face and EDX analysis under dry machining

From Figure 4 and 5, it is evident that the presence of the alloy element of aluminum and magnesium in moderate percentage which are 18 and 1 under MQL 100 ml/h, whilst 17 and 1 under dry machining, respectively. Apparent adhesion growing from the phenomenon of welding between work piece and tool caused by elevated temperature and pressure. The exposure of the tool substrate material also emerges due to the existence of high tungsten elements. Furthermore, as a consequence of the adhesion to the rake face and the low cutting speed, the BUE appears to have formed where it is clearly noticeable near the lines of the depth of cut. In spite of that, BUE formation able arises at high speed because of the toughness of aluminum alloy 7075-T6 to adherence. Puvanesan et al. (2014) found that adherence between work-tool substrate contributes to the BUE formation at the cutting tool during end milling of aluminum alloy 6061-T6. The impact of different fluid approaches and machining parameters influence the tool wear pattern [24].

According to Figure 1 until 3, remarkable results towards the cutting tool performance were reached when MQL 100 mL/h was applied at low combinations of machining parameters. This result attributed to the potential of MQL in reducing friction from the lubricant and the cooling impact of the compressed air in the tool-work contact area.

IV. CONCLUSION

The experimental work on the tool wear in milling aluminum alloy 7075-T6 under MQL 100 mL/h and dry machining involving the selected machining parameters employing the uncoated carbide tools presents that MQL 100 mL/h with a low combination of machining parameters have offered promising performance on the cutting tool than dry machining. The tool wear progressed rapidly in high cutting speed and feed rate. Adhesion was the root cause of the occurrence of flank wear which is the principal wear mechanism observed at all the cutting conditions.

ACKNOWLEDGMENT

The authors sincerely to extend the highest gratitude to Universiti Kuala Lumpur Short-Term Research Grant (STR 15051) for the funding to make this research work viable and effective.

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AUTHORS PROFILE

M.Z.A. Yazid is Associate Professor in Manufacturing Section at Universiti Kuala Lumpur-Malaysia Italy Design Institute, Kuala Lumpur, Malaysia. He receives his Master of Science in Engineering Business Management and Ph.D. in Mechanical and Materials Engineering, from University of Warwick, United Kingdom and Universiti Kebangsaan Malaysia, Selangor, Malaysia, respectively. His research areas include Mechanical Properties, Corrosion, Machining, and Materials. A recent publication is "Environmentally friendly approaches assisted machining of aluminum alloy 7075-T6 for automotive applications: a review".

Azreen Zainol is currently pursuing Master of Engineering Technology (Manufacturing) in Universiti Kuala Lumpur-Malaysia Italy Design Institute, Kuala Lumpur, Malaysia. He holds a Bachelor of Engineering Technology in Manufacturing Systems in 2014 from Universiti Kuala Lumpur-Institute of Product Design and Manufacturing. He is a Registered Engineering Technologist in Malaysia. His research mainly focuses in Metal Cutting, Cutting Tools, and Fluid Techniques. He is performing research to develop sustainable machining processes, which are environmentally friendly and harmless to the machining operators.