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Environmentally Friendly Approaches Assisted Machining of Aluminum Alloy 7075-T6 for Automotive Applications: A Review

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Abstract: Nowadays, aluminum alloy 7075-T6 has received a high demand in the automotive industry due to its advantages in the aerospace industry, which possessing exceptional mechanical combinations and chemical elements such as high tensile strength, high strength, high corrosion resistance, zinc, magnesium, and copper to increase their strength. Nevertheless, environmentally friendly approaches are necessary to improvise surface quality and machining performances as well as minimize the adverse environment. This has directly influenced the trend of approach or strategy of cutting fluids towards the machining of high-performance material in the automotive industry. There have been some probations to decrease the volume of cutting fluid application in machining. The approach of cutting fluids become prominent indicator in contribution to minimize the application of cutting fluid so that the machining of aluminum alloy 7075-T6 become more effective and environmental friendly. Thus, results can be found in the low tool wear, minimum heat energy generated and reduced machining cost in encouraging the application of MQL as viable formulations to enhance the machining performance and machined surface quality. The primary objective of review work is summarized all the emerging environmentally friendly approaches towards the high-performance material. Impact of machining process parameters on dependent variables such as surface integrity, tool wear, chip formation, and mechanical properties have been discussed in the light of the findings of the recent study.

Keywords: Cutting fluid, automotive industry, environmentally friendly, aluminum alloy 7075-T6.

1. Introduction

In recent years, environmentally friendly approach have been the trend and crucial aspect in numerous manufacturing industries in minimization of manufacturing cost, deterioration of cutting tools and control the diseases risk among the employees [1],[2]. The environmentally friendly approaches are referred to the development of manufactured products that apply procedures to reduce the severe impacts on the environment and natural resources as well as improve the safety of workers and consumers. It comprised of several common approaches or strategies, including dry machining, minimum quantity lubrication (MQL) and cryogenic machining as shown in Figure 1 [3],[4],[5]. Dry machining is referred to as the machining process in the absence of cutting fluids. MQL or pseudonym of near-dry is modern machining that applies a small amount of fluid into a form of mist particles and then penetrate into the cutting zone. The definition of this approach is synonym with the cutting fluid in which capable to act in reducing friction, wear and flush away the chips at desired cutting speeds in manufacturing processes [6],[7],[8]. Cryogenic means the viable operation to propel the liquid gases form to the cutting zone and operated at lower

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temperatures, which is below 123 K and 77.4 K for carbon dioxide (CO_2) and liquid nitrogen (LN_2), respectively [9]. It will appear whitish on the cutting tool and machined surface. In addition, according to a review conducted by Boubekri and Shaikh [10], Najiha, Rahman, and Yusoff [11] and Amiril, Rahim, and Syahrullail [12] reported that the cutting fluid application is 7% to 17% of the total manufacturing cost and only 4% for cutting tools expenditures. In the context of the automotive industry, cutting fluid costs was reached 16% to 18% compared than 7% to 8% of tool costs [13]. Besides that, cutting fluid application is seen appropriate in machining high-performance material, namely aluminum due to it is lead to lower maintenance and manufacturing costs.

Aluminum becomes the popular and ideal material in the aerospace industry to substitute wood in the 1920s. The aluminum widely employed as airframe components before it is covered with composite materials because of lightweight, moderate strength, easy to fabricate and relatively low cost [14],[15],[16],[17]. An earliest preferred material has been identified that primarily employed in the aerospace industry, namely aluminum alloy 7075-T6. This material possesses unique properties such as fairly-high tensile strength, fairly-high hardness, fairly-high toughness and high corrosion resistance [18],[19],[20],[21]. Besides that, this material is selected in order to meet the high demand of the automotive industry, in which looking the high strength and lightweight materials to substitute heavy materials in the manufacturing of car and light truck that resulted in the reduction of fuel consumption and without compromising safety [22],[23],[24]. In order to expand the application of selected materials for the automotive industry, the cutting fluid should be further improved for cooling and lubrication purposes in machining process. Therefore, this paper describes a comprehensive overview of performances for a various environmentally friendly approach in the numerous machining of aluminum alloy 7075-T6. Subsequently, creates the summary for merging their opportunities in the automotive applications for future growth.

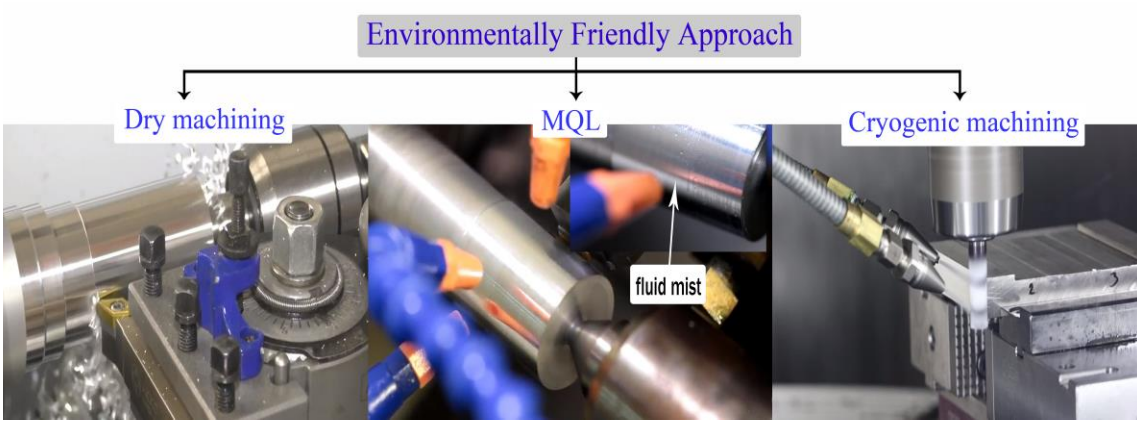

Fig. 1 - Environmentally friendly techniques [3],[4],[5].

2. Overview of Approach towards Aluminum Alloy 7075-T6

The selection of environmentally friendly approaches is become dominant aspect to ensure machining of aluminum alloy 7075-T6 is not affected. The following sections present the overview of recent studies involving performance of these materials and fluid approaches that may apply to the automotive industry.

2.1 Dry Machining

Dry machining has a significant mechanism in the effectiveness of reduce the cutting fluids cost and protect the environment. Under dry machining, the chips are easy to be collected for recycling purpose in spite there are drawbacks on dependent variables like surface roughness and tool wear.

In order to enhance the performance in the milling of aluminum 7075-T6, Vakondios et al. [25] carried out the study on end milling towards the surface roughness in dry machining. Regression analysis and analysis of variance were performed in order to assess a number of experiments testing with varying independent variables, including cutting speed, feed rate, and axial and radial depth of cut. The result was to develop a mathematical model series for the surface roughness. They concluded that the surface roughness was resulting from the cutting speed.

S.V.Alagarsamy [26] determined the impact of cutting parameters on surface roughness during turning of aluminum 7075-T6 with tungsten carbide tool. Three high impact parameters, namely the cutting speed, feed rate and depth of cut were taken into account to acquire a lower surface roughness value with determined using the Taguchi technique. The results exhibited that feed rate, resulting in the surface roughness the most. Finest parameters achieved for surface roughness were at a depth of cut equal to 0.3 mm and cutting speed of 500 m/min at a feed rate of 0.10 mm/rev.

Anwar et al. [27] conducted a study to optimize the surface roughness when dry milling of aluminum alloy 7075-T6. Method of Response Surface Methodology (RSM) with Central Composite Design (CCD) has been employed to study experimental results. The comparison between the actual and predicted was made to validate the model generated and found an error of 3.29% as illustrated in Figure 2. The results indicated that the model generated, is valid and the lesser surface roughness values have been obtained at a high cutting speed, low feed rate and additional depth of cut. They revealed that cutting speed of 5000 rpm, a feed rate of 900 mm/min and depth of cut of 0.25 mm can yield minimal surface roughness value. From the observation, the lowest cutting speed and feed rate generate the minimum surface roughness value.

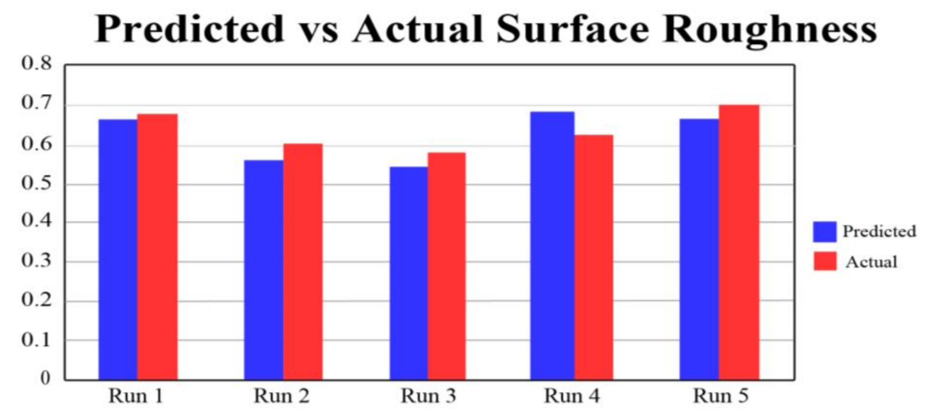

Fig. 2 - Predicted versus actual values of surface roughness [27].

Rawangwong et al. [28] conducted a study to optimize the surface roughness in face milling of aluminum 7075-T6 utilizing Design of Experiment (DOE). They utilize factorial designs and the result reported that the factors affecting the surface roughness were the feed ratio and the speed, meanwhile the effect of depth was obtained on the surface roughness to be negligible. The minimum values of surface roughness were obtained at a speed of 2930 rpm and feed of 808 mm/min as shown in Figure 3. It concluded that increased speed and decreased feed tend to lower values of surface roughness.

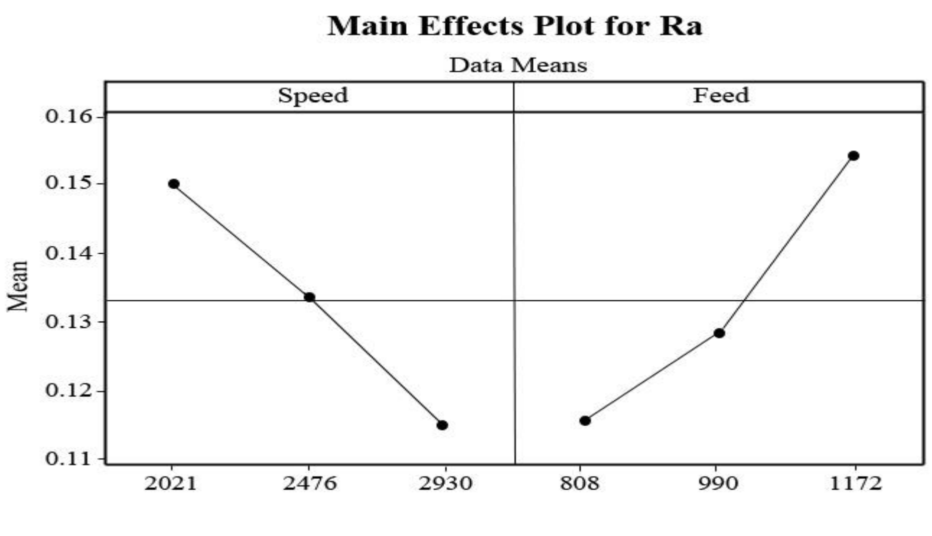

Fig. 3 - The main effects plot of surface roughness [28].

Cai et al. [29] carried out experiments on the milling of aluminum 7075 in term of surface roughness with different cutting conditions. The values of surface roughness were measured in two directions which are perpendicular and parallel to feed. Average surface roughness, Ra was obtained by take three times at different locations on machined surfaces. Based upon result, the lower Ra values were determined in the direction along feed than in the perpendicular direction as illustrated in Figure 4. It concluded that the cutting speed (Vc) was 800 m/min, feed rate (fz) was 0.16 mm/tooth, axial depth of cut (ap) was 10 mm and radial depth of cut (ae) was 2 mm are effective parameters in effect of surface roughness.

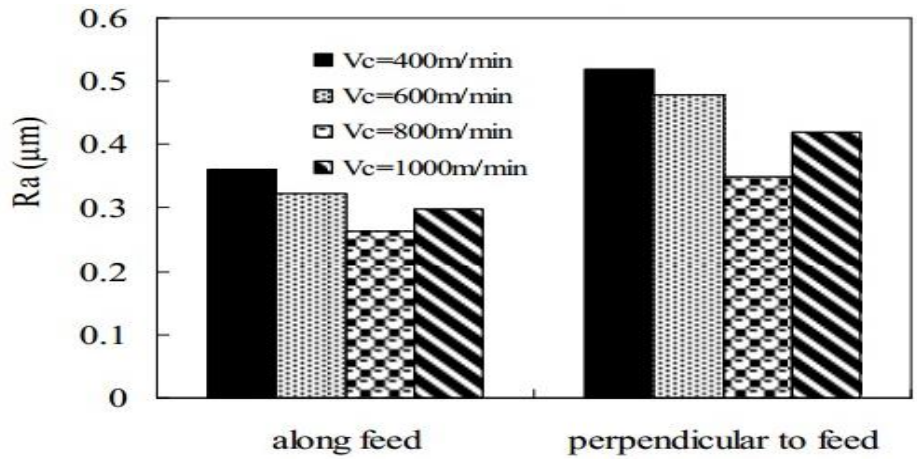

Fig. 4 - Average surface roughness Ra affected by cutting speed [29].

Gatto et al. [30] analyzed the optimization of cutting conditions on tool wear in high speed face milling of aluminum alloy 7075, 7050 and 2219-T6. The cutting speed ranged from 600 to 2200 m/min and feed per tooth between 0.075 and 0.18 mm/tooth·rev. The results showed that the low tool wear was produced from low values of cutting speed and feed per tooth for 7075-T6. By increasing cutting speed, wear is near unaffected at middle values of feed per tooth. The outstanding results were achieved at a quite low cutting speed values and lower feed per tooth values compared to two other work pieces. The best parameter has obtained on tool wear which cutting speed 925 m/min and feed rate 0.075 mm/tooth·rev.

Davim [31] reported in the Modern Machining Technology that the phenomenon that known as Built Up Layer (BUL) is occurring as depicted in Figure 5 during high speed milling under dry machining in which utilize the tungsten carbide with multilayer AlTiN as cutting tool. This phenomenon has occurred due to the trend of cutting tool material to adhere to tool edges. Hence, the recommended minimal application of cutting fluid is MQL technique after taking into account the impossibility of dry machining to avoid the BUL phenomenon.

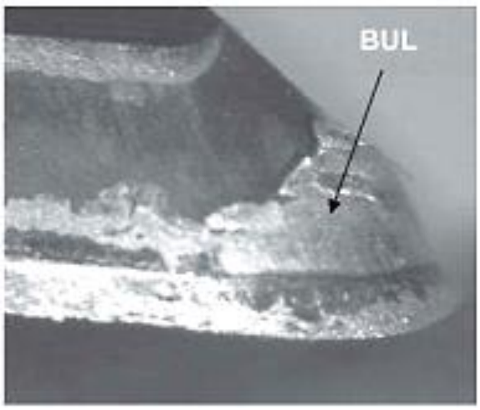

Fig. 5 - Generalized BUL Later On [31]**.**

From the point of the dependent variable of surface roughness and tool wear, it was observed that the parameter of the depth of cut became a less effective factor in the contribution of the dry machining. On the other hand, two cutting parameters which are cutting speed and feed rate were an extremely superior factor in order to generate the lower value of surface roughness and improved tool wear in the dry machining. High and low values in respective cutting speed and feed rate are important in managing the reduction of built-up edge (BUE), thus reducing the shear strength as well as result in worsening the surface quality as claimed by Yi et al. [32] after end milling aluminum alloy 6061-T6. However, it promotes the detrimental effect towards the tool wear.

2.2 Minimum Quantity Lubrication

Minimum quantity lubrication (MQL) is a remarkable approach to minimize the fluid application in machining operations. With respect to the potential of the MQL strategy in the machining process, several recent studies were conducted to investigate their performance in assisting the machining of aluminium alloy 7075-T6.

The effect of MQL and flood conditions on the surface roughness in milling of aluminum 7075-T6 was examined by Tosun and Huseyinoglu [33]. MQL and flood applied the flow rate of 5 and 1000 ml/min respectively. The experimental result revealed that lowest value of surface roughness was obtained on the ratio of MQL of 1:10 technique because of effective lubrication at the work-tool interface. They make a conclusion that the surface roughness will be decreased when spindle speed was increased under MQL.

Cakir et al. [34] investigated the optimum conditions on the cutting speed and feed rates when turning of aluminum 7075-T6 by employed MQL technique. The flow rate of 0.25, 0.45, 0.90 and 3.25 ml/min were used together with cutting speed of 150, 187.5, 240 and 300 m/min and feed rate of 0.1 and 0.2 mm/rev. An analysis of variance (ANOVA) was employed to determine the significant effect of the process parameters. They concluded that the value of surface roughness is increased and decreased when increasing feed rate and flow rate, respectively. According to ANOVA, the flow rate followed by cutting speed became a real effect of the process parameters in turning aluminum 7075-T6.

Similar work was carried out by Kouam et al. [35] who analyses the effect of MQL and dry machining when turning of aluminum 7075-T6. Two different flow rates, which are 1.75 and 3 ml/min were applied. The chip formation and surface roughness were selected as the output parameters. They observed that the MQL flow rate of 1.75 ml/min gave a lowest surface roughness compared to the MQL flow rate of 3 ml/min and the dry machining. In terms of chip formation, the flow rate of 3 ml/min at cutting speed of 657 m/min shows more long chips compared to flow rate of 1.75 ml/min and dry as illustrated in Figure 6. They revealed that the effective lubrication was 1.75 ml/min at feed rate of 0.3 mm/rev.

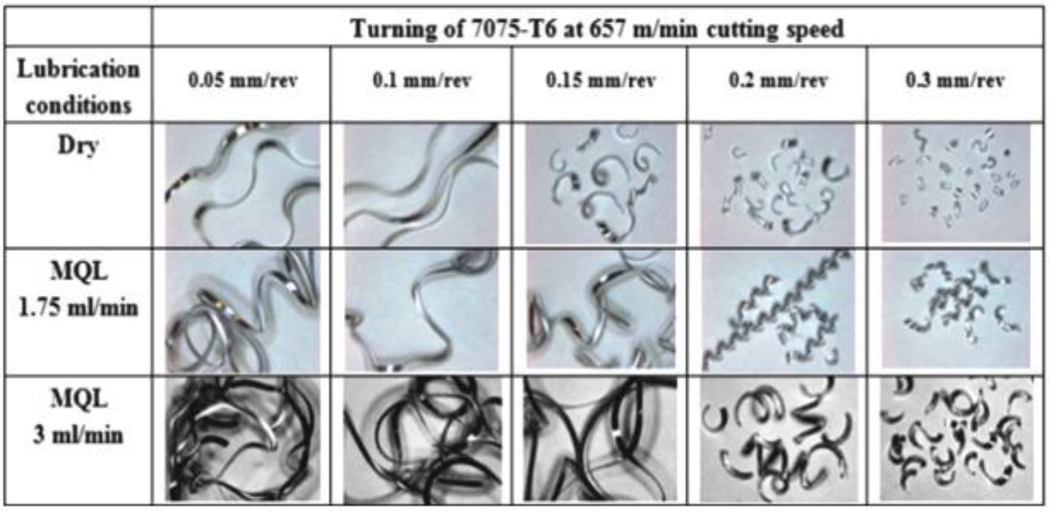

Fig. 6 – Chip formation image at 657 m/min [35]**.**

It was observed that there are different finding with respect to usage of the flow rate amount of MQL between Kouam et al. and Cakir et al. in achieving the desired results. It has a possibility influenced by the machining parameter to allow the MQL flow rate to penetrate deep the work piece and tool interface. Discontinuous chip found to offer the reduction of energy consumption under MQL 1.75 ml/min at high feed rate.

2.3 Cryogenic Machining

Cryogenic machining is the latest advancement that employed liquefied gas like liquid nitrogen and frozen carbon dioxide as the major fluid. Liquid nitrogen is an inert gas, where produces 78% of the atmosphere while carbon dioxide is a chemically gas. Both gases are lighter comparable to the air. Usage of nitrogen is very vital in terms of pressure and flow rate [36]. Cryogenic machining has involved the fluid application that contains the boiling point lower than -150°C to dispersed directly into cutting zone via a nozzle [37].

Application of this approach was demonstrated by Lulay [38] who conducted the investigation on the effect of cryogenic treatment towards the foundational mechanical properties of aluminium 7075. T-test was employed to analyze two variation length of time which are 2 hours and 48 hours in order to ascertain whether there any changes between the two time-independents. An investigation on mechanical testing include the proportional limit, yield strength, ultimate tensile, hardness and Charpy impact toughness were performed at room temperature. The result indicates that there is truly differentiating in which a slight increase of 11% in the toughness, 1% in the proportional limit and yield strength and a half of a percent in the ultimate tensile and hardness, respectively under 48 hours cryogenic treatment. It concluded that the 48-h cryogenic treatment has the potential to act as an appropriate cryogenic treatment could impact the properties of aluminum 7075.

Arunkumar [39] carried out the experimental on turning aluminum 7075 under cryogenic liquid nitrogen (LN_2) and wet as coolant conditions. The lower values of cutting force were obtained at a feed rate of 0.079 mm/rev at a constant cutting speed of 51 m/min under LN_2 as shown in Figure 7. The result shows the application of LN_2 decreases the value of cutting force compared to the wet machining. It occurred due to the increasing of material removal rate and work done per unit time. Vanishing of Built-up Edge (BUE) formation at elevated temperature is a factor in the reduction in the cutting force. It concluded that the application of LN_2 was effective in minimizing the cutting force with the variation of feed rate.

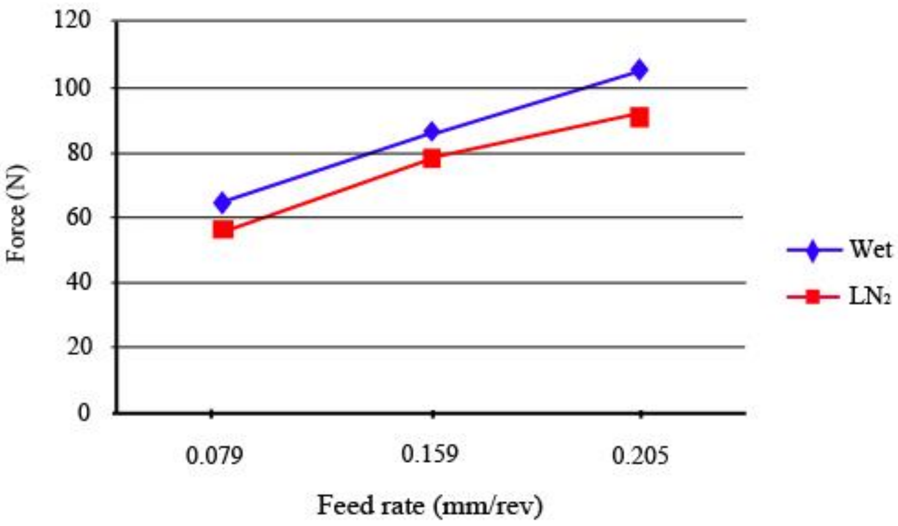

Fig. 7 – The variation of cutting force with different feed rate [39]**.**

Rotella et al. [40],[41] have make an experimental work in turning of aluminum 7075 under cryogenic and dry conditions in term of surface hardness. The micro-hardness, Vickers $HV_{0.05}$ has been measured as much as five hardness on each depth below the machined surface. Three different cutting speeds were applied, which are 180, 320 and 720 m/min with a constant tool nose radius of 0.8 mm for both conditions. In holistic, the results revealed that the higher hardness was generated consistently at a cutting speed of 720 m/min under the cryogenic condition as exhibited in Figure 8. Meanwhile, cutting speed of 720 m/min for dry condition seems to quite grow compared than the rest of cutting speeds. They concluded that a higher cutting speed with the application of cryogenic engenders higher hardness values and also indirectly resulting in deeper microstructural alteration.

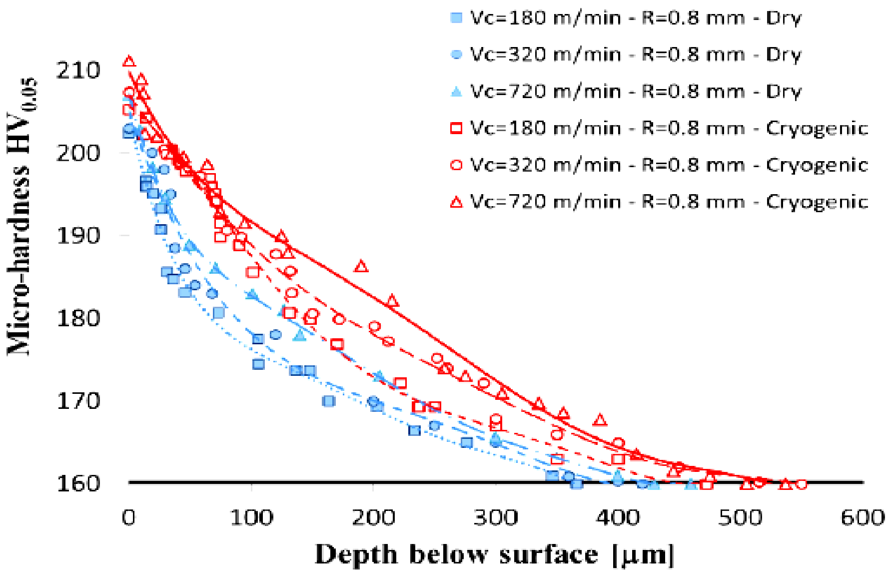

Fig. 8 – Micro-hardness under dry and cryogenic conditions at different cutting speeds [40],[41]**.**

Based upon the observation, it is evident that liquid nitrogen based cryogenic and application of a higher length of time treatment has the potential to produce the benefit towards several of the output response due to it has the ability to absorb the heat energy generated between the tool and machined surface. In the meantime, the higher cutting speed which is a part of common machining parameters has become a vital aspect to obtain the better hardness value.

3. Summary

Several findings have been executed pertaining to the use of environmentally friendly approaches in the machining of aluminum alloy 7075-T6 that was seen offers the merits in most terms, especially technical and environmental economic point specifically and generally as summarized in Table 1. It can be remarked that a majority of published findings has owned their strengths and weakness. It also has been considered as adequate efforts in order to correspond with their advancement influences for improving machining performance of a lightweight material in automotive applications for the future work despite strongly correlate to some dominant machining parameters. Due to the high priority in the automotive applications, the common viable approach is necessary in order to enhance the performance of machining and machined surface quality as well as could avoid the major drawbacks. Obviously, MQL is a great alternative approach to be practical in automotive applications after taking into account the significant contribution to the trends of machining processes. Overall, this is due to its offers favourable performances in term of improved output variables, cost-effectiveness in the period of long-term usage, and reduction in health hazards as well as applicable for high-speed steel (HSS) and carbide tools as claimed by Chetan et al. [3]. In the future, further work is should be extended associated with environmentally friendly approaches to advance machining performance of aluminum alloy 7075-T6 for the use of automotive.

Table 1 - Merits of the environmental friendly approaches [42]**,**[43]**,**[44]**,**[45]**.**

Approaches/ trends	Technical aspect							Environmental economic aspect						
	Improves the output machining							Reduces machining cost						
	Tool wear	Surface quality	Cutting force	Mechanical properties	Chip formation	Avoid Built-up Layer (BUL)	Effective for tools of HSS and carbide	Energy consumption	Maintenance	Disposal	Reduces operator health hazards	No requires the additional supply	Easy disposes	Trend Rating
Dry machining	√	√						√	√	√		√		6
MQL		√			√	√	√	√		√	√		√	8
Cryogenic machining			√	√		√		√		√	√		√	7

4. Conclusion

This paper provides an overview of essential published experimental involving the environmentally friendly approaches in the machining of aluminum alloy 7075-T6 for automotive benefits. Most of the recent study's findings present that the option of environmentally friendly approaches is growing substantially for each machining process for contributing in automotive applications.

From the literature that were presented, the major conclusions are drawn as follows:

- The significant factors on the surface roughness under dry machining are cutting speed followed by feed rate.
- Surface roughness and mechanical properties is the most superior aspect in machining of aluminum alloy 7075-T6 to measure the performance.
- Lesser MQL flow rate is the dominant parameter on chip formation.
- The inclusion of MQL could generate better surface roughness and proper chip formation.
- Cryogenic machining via LN_2 manages to reduce the cutting force wherein indirectly as increase productivity.

- The ability of a longer period of cryogenic time treatment can result in the improved impact on the mechanical properties of aluminum alloy 7075-T6.

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