American Journal of Materials Engineering and Technology, 2016, Vol. 4, No. 1, 1-5
Available online at http://pubs.sciepub.com/materials/4/1/1

DOI:10.12691/materials-4-1-1

Experimental Investigation on Surface Finish during Turning of Aluminum under Dry and Minimum Quantity Lubrication Machining Conditions

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Abstract In the last decades, light materials, such as aluminum, are increasing their use in wide range of industrial applications. The growing use of aluminum encourages the study of its use under different production processes. In this sense, the present study shows an experimental investigation in turning of aluminum, with the use of dry and minimum quantity lubrication (MQL) system. To evaluate turning process, continuous bars was used. The process is evaluated taking the surface roughness as response variable. The cutting conditions include feed rate, cutting speed and the coolant flow rate. The work-piece material and its size, the cutting tool (HSS) and the depth of cut were kept constant for the study. It has been observed that a small amount of supply of coolant at the point of cutting, largely improves the surface finish. In many cases further amount of coolant administration has very little effect on the surface quality. Thus Minimum Quantity Lubrication (MQL) can achieve the required surface quality eliminating the problems of flood cooling.

Keywords: *turning, coolant, aluminum, surface roughness*

Cite This Article: A Hemaid, Tarik Tawfeek, and A. A. Ibrahim, "Experimental Investigation on Surface Finish during Turning of Aluminum under Dry and Minimum Quantity Lubrication Machining Conditions." *American Journal of Materials Engineering and Technology*, vol. 4, no. 1 (2016): 1-5. doi: 10.12691/materials-4-1-1.

1. Introduction

Coolant is used in machining to evacuate swarf from the surface, to cool the cutting tool and components to reduce thermal cracking, and to cool work-piece. Swarf can be controlled by air blasts and vacuum when machining materials such as cast iron, and tooling has been developed which can withstand the extreme temperatures generated in the process.

The cost of purchasing, maintaining and disposing of cutting fluids is becoming an increasingly significant part of machine operating cost. That tends to drive people to other solutions. It is environmental concerns as much as costs that are driving manufacturers to curb their use of coolants in machining. It has been driven by the need to get a hazardous material out of the machine. Some companies have successfully removed coolant from their processes altogether in a process known as dry machining. However, dry machining is not always an option.

Minimum Quantity Lubrication (MQL) or near dry Machining eliminates conventional flood coolant from the machining processes. In doing so, MQL reduces oil mist generation, biological contamination of coolant, waste water volume, costs for capital. MQL also improves recycling and transport of coolant contaminated chips [1].

Metal cutting fluids change the performance of machining operations because of their lubricating, cooling, and chip flushing functions. Minimum quantity lubrication (MQL) presents a viable alternative for dry machining with respect to tool wear, heat dissertation, and machined surface quality.

This paper presents an overview of major advances in techniques as minimum quantity lubrication (MQL)/near dry machining (NDM), high pressure coolant (HPC), cryogenic cooling, compressed air cooling and use of solid lubricants/coolants. These techniques have resulted in reduction in friction and heat at the cutting zone, hence improved productivity of the process. A brief survey of modeling/FEA techniques is also performed [2].

The study helps to provide an understanding of the surface texture of the work-piece under different cutting conditions. In the study, the lubrication was provided from near dry condition to flooding. During each test, surface roughness, was measured and compared. The results indicate that the use of minimum quantity lubrication leads to reduced surface roughness which is very promising in the industrial environment.

Complete dry machining of aluminum is difficult [3]. In the case of aluminum, coolant is mainly used to stop the swarf plasticizing under the extreme cutting temperature. When it plasticizes, it adheres to the cutting material and then you get a breakdown in the cutting material. The cutting fluid for machining aluminum using traditional coolant-based methods is typically more costly than for other materials because the coolant must have a higher concentration of oil in the mixture. Therefore MQL would have massive benefits for machining aluminum. When machining volatile materials such as aluminum manganese alloys, MQL is also useful, because manganese reacts to contact with water, which can be dangerous using traditional coolant-based cutting processes.

Traditional machining operations such as turning, is easily performed on aluminum and its alloys. The machines that are used can be the same as for use with steel, however optimum machining conditions such as rotational speeds and feed rates can only be achieved on machines designed for machining aluminum alloys. The specific properties of aluminum alloys must be considered:

Their density allows high speeds of rotation and translation as the inertia of aluminum alloy swarf is less than that of steel, their modulus of elasticity is one third that of steel requires appropriate chucking and clamping arrangements that avoid deformation and distortion. The alloy's thermal conductivity assists with heat dissipation. Given the high rate of chip removal, the heat generated by the machining process is taken away with the swarf without having the time to diffuse into the metal, a coefficient of linear expansion that is twice that of steel makes heating undesirable if criteria of dimensional stability are to be satisfied [4].

All wrought alloys can be machined very rapidly. With special machines (high speed spindles) the machining speed can attain (and exceed) up to 3000 m/min with 2000 and 7000 series alloys. Thus for a 12 mm diameter tool the cutting rate can be as high as 50,000 r.p.m. for a feed rate of 10 m/min. With very high cutting rates it is possible to obtain very thin sheet and much lighter components.

Given the low modulus of aluminum alloys, high rates of advance are not advisable, even for rough machining. The feed rate should be limited to 0.3mm per revolution. For finishing operations the rate of advance will be determined by the specified surface roughness for the finished product. The depth of cut will depend on the specified accuracy [5,6].

The concept of minimum quantity lubrication, sometimes referred to as "near dry lubrication" [7] or "micro lubrication" [8], has been suggested as a means of addressing the issues of environmental intrusiveness and occupational hazards associated with the airborne cutting fluid particles on factory shop floors. The minimization of cutting fluid also leads to economic benefits[9] by way of saving lubricant costs and work piece /tool/machine cleaning cycle time. A recent survey conducted on the production of the European automotive industry revealed that the expense of cooling lubricant comprises nearly 20% of the total manufacturing cost [10].In comparison to cutting tools (7.5%), the cooling lubricant cost is significantly higher. As a result, the need to reduce cutting fluids consumption is strong. Furthermore, the permissible exposure level (PEL) for metalworking fluid aerosol concentration is 5 mg/m^3 as per the U.S. Occupational Safety and Health Administration (OSHA) [10], and is 0.5 mg/m^3according to the U.S. National Institute for Occupational Safety and Health (NIOSH) [11]**.** The oil mist level in U.S. automotive parts manufacturing facilities has been estimated to be generally on the order of 20-90 mg/m^3 with the use of traditional flood cooling and lubrication [1,3,12].

2. Experimental Setup And Procedure

A typical lathe was used for performing the experiments. The coolant used was a triglyceride and propylene glycol ester solution (Oil mixed with water). The work-piece material used was aluminium. The cutting tool used was HSS with rake angle of 5°, chamfer length of 0.12 mm, horn radius of 0.03 mm, and nose radius of 0.8 mm.

Thirty aluminum specimens were prepared with a diameter of 50 mm and a length of 100 mm. On each specimen, 3 surfaces were generated with different cutting conditions. The selected speeds were 425, 570, 770, 1030 and 1380 rpm. The depth of cut was kept constant (2 mm) for all experiments. The feed rates selected were 0.03, 0.1 and 0.5 mm/rev.

The surface roughness parameter Ra (Roughness average) was obtained in microns for each of the surfaces and tabulated in Table 1 and Table 2. At least three Ra values were obtained to get the net Ra value, the experimental and measuring setup was the same throughout the experiments.

The flow rates of the coolant were selected to cover the full range starting from dry to full flooding. The coolant supply was measured to know the flow rate. Minimum quantity was supplied using a burette. The change in flow rate due to change in height was taken care by updating the quantity of coolant in the burette. Fig.1 shows the dry machining and Figure 2 shows the minimum quantity coolant supply.

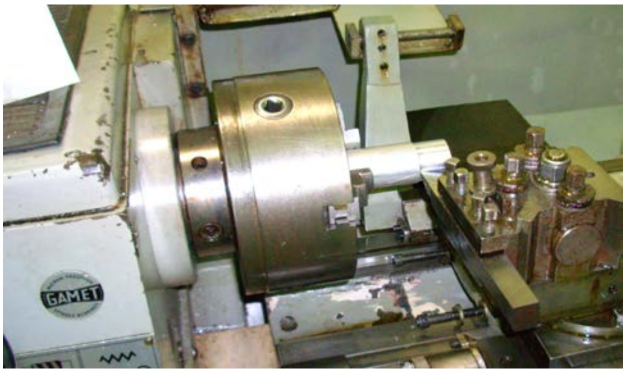

Figure 1. Dry machining

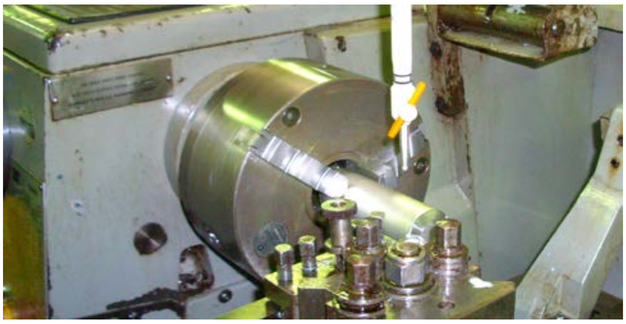

Figure 2. Arrangement for MQL for a feed rate of 0.5 mm/rev

The surface roughness Ra value was found out using MITOTOYO surface roughness measuring instrument SJ-201P.

3. Results and Discussion

The results of the experimental investigations are tabulated in Table 1 and Table 2. The coolant flow rate for each case has been presented in Table 3.

Table 1. Surface Roughness of work-piece for different machining conditions

Expt. No:	Speed rpm	Feed mm/rev	Surface Roughness- Ra (Microns)		
			Dry	Wet 1	Wet 2
1	425	0.03	1.87	0.65	0.6
2	425	0.1	2.15	.8	1.2
3	425	0.5	10.38	8.8	11.1
4	570	0.03	1.43	0.65	0.53
5	570	0.1	1.60	0.73	0.8
6	570	0.5	9.20	8.7	8.1
7	770	0.03	1.40	1.2	0.7
8	770	0.1	2.00	1.2	1.4
9	770	0.5	10.4	10.2	9.9
10	1030	0.03	1.60	0.65	0.6
11	1030	0.1	2.00	1	1.7
12	1030	0.5	10.2	9.2	9.4
13	1380	0.03	1.80	1.15	1.0
14	1380	0.1	1.50	1.1	0.9
15	1380	0.5	11.5	9.85	10.5

Table 2. Surface Roughness of work-piece for different machining conditions at wet 3, wet 4 and flood

Expt. No:	Speed rpm	Feed mm/rev	Surface Roughness- Ra (Microns)		
			Wet 3	Wet 4	Flood
1	425	0.03	0.78	0.65	1.3
2	425	0.1	1.35	0.95	1.5
3	425	0.5	9.4	10.9	10
4	570	0.03	0.65	0.8	0.8
5	570	0.1	0.85	0.84	1.0
6	570	0.5	7.1	8.4	8.1
7	770	0.03	0.53	0.5	0.6
8	770	0.1	0.9	0.8	0.8
9	770	0.5	9.9	10.1	10
10	1030	0.03	1.5	0.8	0.9
11	1030	0.1	1.7	1.0	0.85
12	1030	0.5	9.5	9.3	9.5
13	1380	0.03	1.1	0.95	0.65
14	1380	0.1	0.9	0.95	1.1
15	1380	0.5	11.4	10.4	9.3

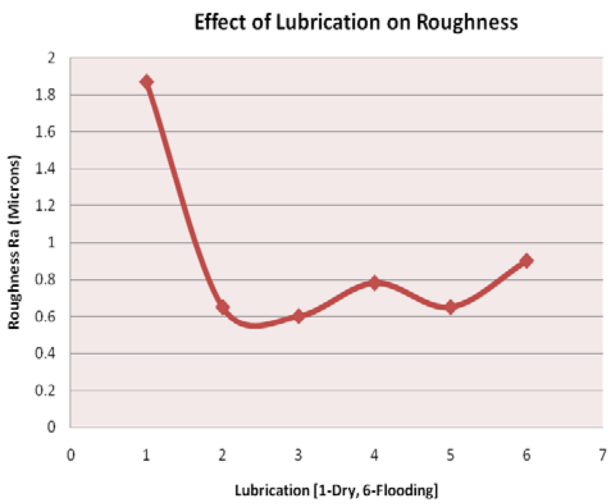

Figure 3. Variation of the surface roughness with lubrication flow rates under speed 425 rpm and feed rate 0.03 mm/rev

Table 3. Coolant flow rates

Case #	Lubrication flow rate	
1	Dry	0 ml/hour
2	Wet 1	80 ml/hour
3	Wet 2	200 ml/hour
4	Wet 3	400 ml/hour
5	Wet 4	600 ml/ hour
6	Flood	Full flow(more than 800 ml/hour

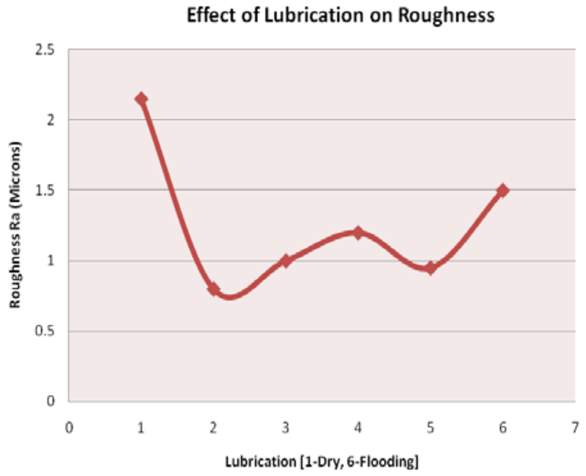

Figure 4. Variation of the surface roughness with lubrication flow rates under speed 425 rpm and feed rate 0.1 mm/rev

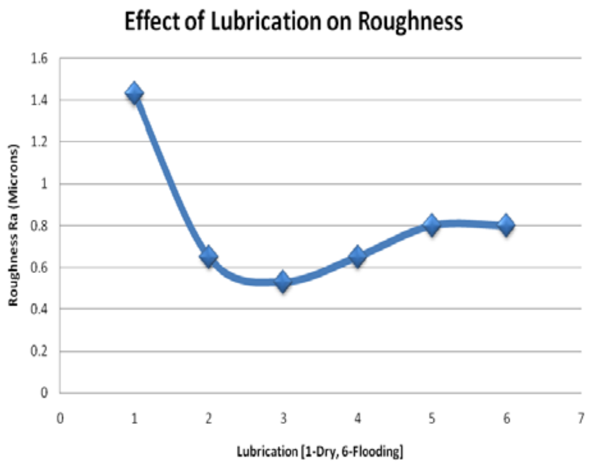

Figure 5. Variation of the surface roughness with lubrication flow rates under speed 570 rpm and feed rate 0.03 mm/rev

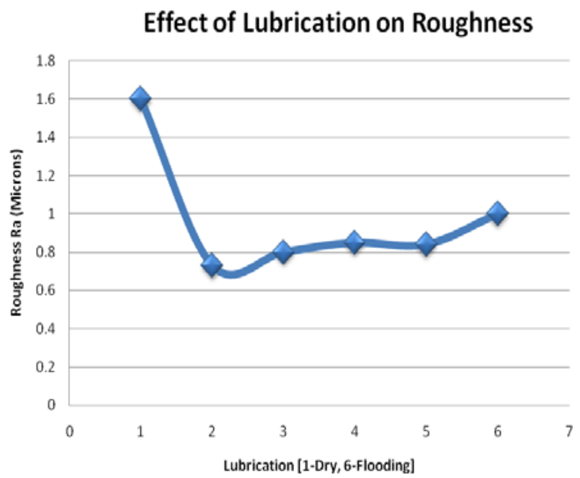

Figure 6. Variation of the surface roughness with lubrication flow rates under speed 570rpm and feed rate 0.1 mm/rev

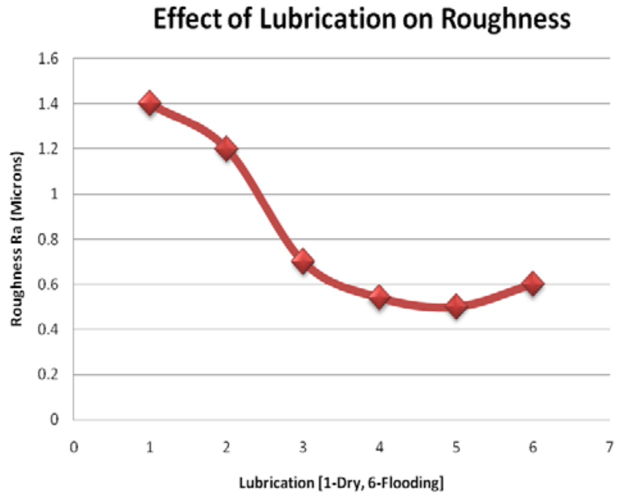

Figure 7. Variation of the surface roughness with lubrication flow rates under speed 770 rpm and feed rate 0.03 mm/rev

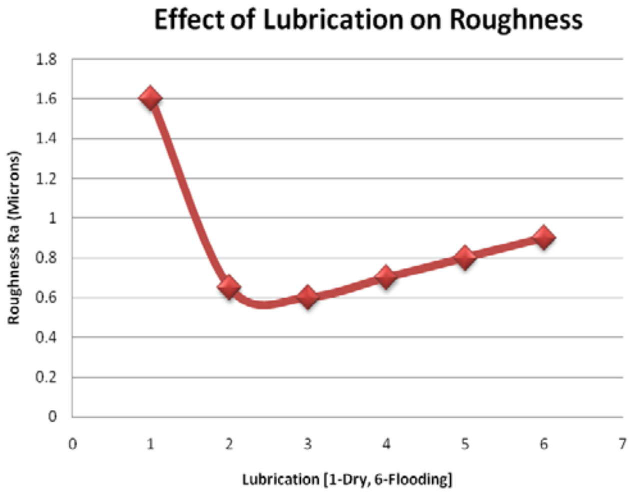

Figure 8. Variation of the surface roughness with lubrication flow rates under speed 1030 rpm and feed rate 0.03 mm/rev

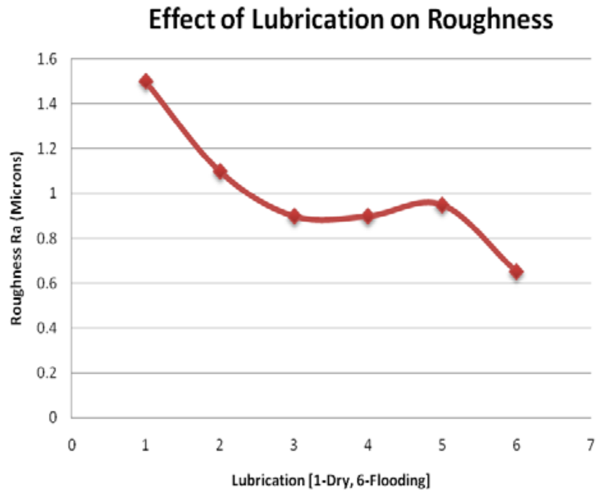

Figure 9. Variation of the surface roughness with lubrication flow rates under speed 1380 rpm and feed rate 0.1 mm/rev

Figure 3-Figure 12 show the variations of the roughness value (Ra) with varied Lubrication from dry to flooding under different speeds and feed rates. All the experiments have been carried out under constant depth of cut 2 mm, while the speeds were varied from 425 rpm to1380 rpm, three different values of feed rates (0.03 mm/rev,0.1 mm/rev and 0.5 mm/rev) have been applied to study the effect of coolant (lubrication) on surface roughness under different cutting conditions.

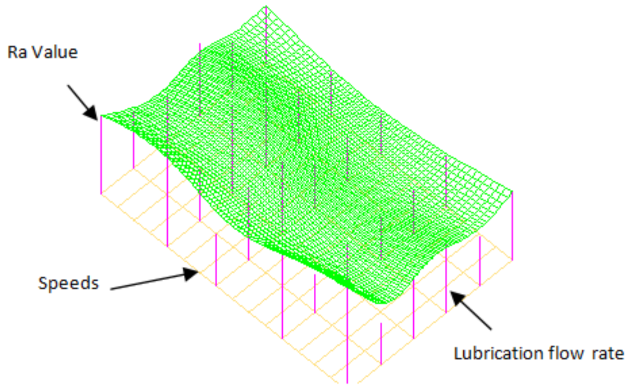

Figure 10. Plot of Ra for Feed rate 0.1 mm/rev and Speeds 425---1380

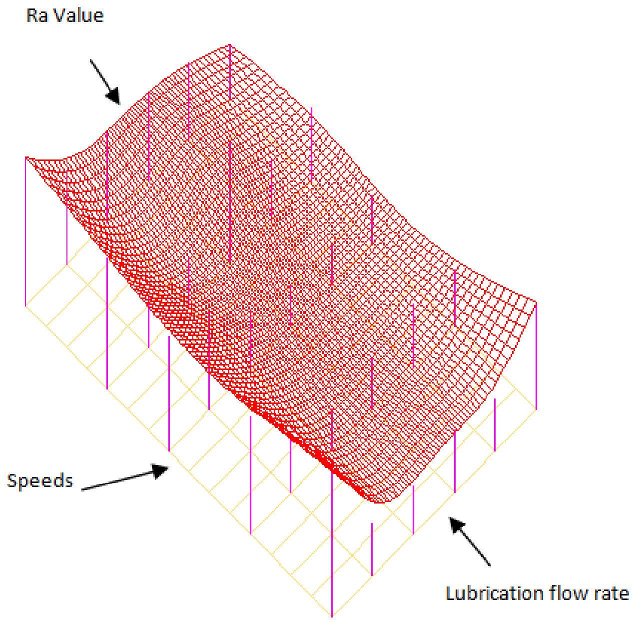

Figure 11. Plot of Ra for Feed rate 0.03 mm/rev and Speeds 425--1380

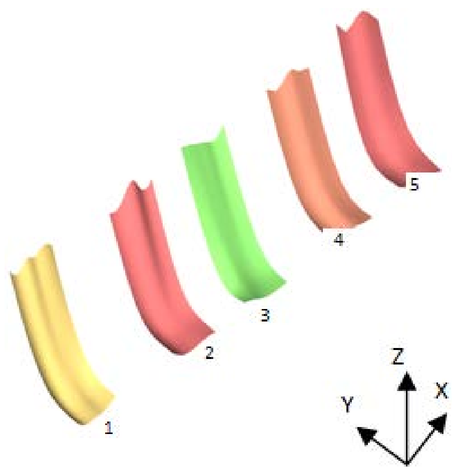

Figure 12. 3D Plot for Ra value for feed rate and speed

The various graphs presented through Figure 3 to Figure 12 explain the effect of cutting conditions on surface roughness. The observations and conclusions can be summarized as follows:

1. Dry machining (no coolant at all) always gives a higher roughness value for any cutting conditions. (All graphs)
2. Smaller the feed rate better is the surface finish. The overall Ra value (roughness average) is smaller for conditions presented in Figures 3 to 9. In all these cases the feed rate is the minimum (0.03 mm/rev). Figures 10 and 11 explain the effect of flow rate on Ra value for various feed rates. The Ra value increases with feed rates. After the initial dip along the x-axis, the curve remains almost smooth for all cases of flow rate.
3. Higher the speed better is the finish (keeping all other conditions constant).
4. The effect of coolant (lubricant) flow rate on surface roughness is very apparent in all cutting conditions presented through the figures. The coolant supply improves the surface finish. The difference in Ra value between dry and any wet conditions is quite large.
5. The effect of coolant flow rate on surface roughness is not consistent due to various factors such as varying stiffness, different clamping conditions and the location of that particular surface on the work-piece etc.
6. Even if a very small quantity of coolant is supplied to the cutting zone, there is a considerable change or improvement in surface finish. (All cases).
7. From all the observations it can be concluded that the minimum quantity lubrication improves the finish to that of dry machining and is comparable to the finish obtained at higher flow rates.
8. It can be observed from all the graphs presented in Figure 12 that near-dry or MQL results in a better finish eliminating the need for conventional flood cooling. Explanations of the Figure 12 are presented in Table 4.

Table 4. Explanation to the 3D graph

3D Graph No:	Feed (mm/rev) Y-axis	Speed (rpm)	x-axis	z-axis
1	0.03, 0.1, 0.5	425	Lubricant Flow rate	Ra (microns)
2	0.03, 0.1, 0.5	570		
3	0.03, 0.1, 0.5	770		
4	0.03, 0.1, 0.5	1030		
5	0.03, 0.1, 0.5	1380		

4. Conclusions

The purpose of this study is to find out the effects of minimum quantity lubrication on the quality of aluminium machined parts, as compared to completely dry cutting. An approach based on the tool work combination method has been performed to identify the ideal testing parameters range. The study helps to provide an understanding of the surface texture of the work-piece under different cutting conditions. In the study, the lubrication was provided from near dry condition to flooding. During each test, surface roughness, was measured and compared.

It can thus be concluded that the use of cutting fluid at minute amounts can potentially reduce the built-up edge and thereby improve the surface integrity. (Surface integrity involves all aspects of the surface and near surface regions of the work piece that may ultimately affect the functional behavior of the work piece. It includes, but is not limited to, things like: micro-geometry, hardness, microstructure, residual stress, and “surface texture” or finish). Other machining performance issues in terms of chip flushing and environmental consciousness have not been included in this study. Further research in these directions is suggested.

Many other effects and issues related to MQL can be studied such as:

- The effect of coolant composition during MQL can be studied..
- The heat generated and the heat dissipation during MQL can be studied.
- The influence of MQL on cutting forces can be studied for minimizing the effects.
- A better experimental setup can be designed which supply a metered amount of coolant at the same pressure can can be looked into. A mist or a coolant air mixture can also be tried.
- The effect of depth of cut on MQL can be studied for different cutter/material/lubricant combination. The study can be extended to other machining operations such as milling, drilling grinding etc.

The present study of machining aluminum parts shows that minimum-quantity lubrication (MQL) improves the bottom line while creating a clean and green operation.

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