INVESTIGATION OF SURFACE ROUGHNESS AND TOOL WEAR IN MILLING OF ALUMINUM ALLOY BY NANO CUTTING FLUID

Sleman Yahya RASUL

Master Thesis
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Supervisor : Prof. Dr. Nihat TOSUN (Fırat Ü.)
Other Jury members : Prof. Dr. Bünyamin AKSAKAL (Munzur Ü.)
Assoc. Prof. Dr. Mete Onur KAMAN (Fırat Ü.)

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ABSTRACT

In this thesis, the effect of cutting parameters on the workpiece surface roughness and tool wear was investigated in end milling of 6061-T6 aluminum alloy using CNC milling machine. The experiments were carried out using full factorial experimental design method. The experiments were performed under different cooling methods (dry, minimum quantity lubrication (MQL) and nano cutting fluid) and different milling parameters (cutting speed and feed rate) using HSS and solid carbide end mill tools. The surface roughness was measured using Mitutoyo SJ-201 surface tester. The tool wear was measured using Mitutoyo optical microscope. The results obtained from the experiments show that both the surface roughness and the tool wear increased with the increasing feed rate and cutting speed. While the highest surface roughness and tool wear occurred in dry machining, the lowest surface roughness and tool wear obtained in machining with the nano cutting fluid. The optimum cutting performance was obtained using the nano cutting fluid and carbide cutting tool.

Keywords: Milling, Dry, MQL, Nano fluid, AA6160-T6, Surface Roughness and Tool Wear.

NANO KESME SIVISI KULLANILARAK ALÜMİNYUM ALAŞIMININ FREZE İLE İŞLENMESİNDE YÜZEY PÜRÜZLÜLÜĞÜ VE TAKIM AŞINMASININ İNCELENMESİ

ÖZET

Bu tezde, CNC freze tezgâhında 6061-T6 alüminyum alaşımının frezelenmesinde iş parçası yüzey pürüzlülüğü ve takım aşınması üzerinde kesme parametrelerinin etkisi incelenmiştir. Deneyler tam faktöriyel deney tasarım yöntemi kullanılarak yapıldı. Deneyler farklı soğutma yöntemleri (kuru, minimum miktarda yağlama (MMY) ve nano kesme sıvısı) ve farklı frezeleme parametreleri (kesme hızı ve ilerleme miktarı) altında HSS ve karbür parmak freze kesici takımları kullanılarak yapıldı. Yüzey pürüzlülüğü Mitutoyo SJ-201 yüzey pürüzlülüğü test cihazı kullanılarak ölçüldü. Takım aşınması ise Mitutoyo optik mikroskop kullanılarak ölçüldü. Deneylerde elde edilen sonuçlar, artan kesme hızı ve ilerleme miktarı ile iş parçası yüzey pürüzlülüğünün ve takım aşınmasının arttığını göstermiştir. En yüksek yüzey pürüzlüğü ve takım aşınması kuru işlemede elde edilirken, en düşük yüzey pürüzlülüğü ve takım aşınması nano kesme sıvı ile işlemede elde edildi. En iyi kesme performansı nano kesme sıvısı ve karbür kesici takım kullanılarak yapılan deneylerden elde edilmiştir.

Keywords: Frezeleme, Kuru, MMY, Nano kesme sıvısı, AA6160-T6, Yüzey pürüzlülüğü ve Takım aşınması.

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LIST OF ABBREVIATIONS

CAD	Computer Add Design
CAM	Computer Add Manufacture
CNC	Computer Numerical Control
HMC	Horizontal Machining Center
MRR	Material Removal Rate
MQL	Minimum Quantity Lubrication
VMC	Vertical Machining Center

LIST OF SYMBOLS

d: Depth (mm)

D: Diameter of the milling cutter (mm)

f: Chip load (mm/tooth)

f_r: Feed rate (mm/min)

L: Length mm (mm)

n: The number of sampling lengths

N: Spindle speed (rev/min)

$n_{t:}$ Number of teeth on the cutter

Pi: Profile peak height

R_a : Arithmetic mean difference of the profile

$R_{y\,:}$ Maximum Peak to Valley Roughness Height

R_z : Maximum height of the profile

T_m: Time

w: Width (mm)

Vi : Profile valley depth

Y_i : Absolute values of the profile differences from the mean line.

Y_p : Height sum of the highest peak from the mean line

Y_v : Depth of the deepest valley from the mean line.

Zi : Sum of profile height of the peak and profile valley depth within each sampling length

1. INTRODUCTION

In the manufacturing industries there are several different crucial tasks within using a cutting tool, but the most essential and challengeable one is machining. This involves a controlled removing of material from the substance by utilizing cutting tools. During the machining process there will be various types of cutting utilized in machining operation, but one of them will highly considered to be used nowadays. In this thesis, many things are discussed about the different types of cutting used in machining process used.

Dry machining operation is one of the environmental concerns, which is called for eliminating of the cutting fluid in metal cutting process. In the last few decades, there have been a lot of interests in the dry machining without using coolant. When the cutting fluid do not use in machining, this is called dry machining. Also, in such process, the metal is removed, but there is no use of wet cutting fluids because they are hazardous to environment and also cost sufficiently high. The dry machining process associates with low speeds of cutting and easily cuttable wok materials. Generally, this process is not suitable, when great surface quality and high dimensional stability are necessitated. This is due to the fact that dry machining contains the generation of high temperature which improves the formation of the built up layer. Surface deteriorates the surface finish. Also, in general cases of utilizing dry cutting without using any lubrication and cooling enhancement is not desirable and choose because certain valuable rising high temperatures may take place through the friction between cutting tool-workpiece and cutting tool-chip (Dudzinski et.al. 2004).

Consequently, the rising high temperature increases surface roughness, and oppositely decreases tool life and the dimensional sensitiveness of workpiece. This case is more important when machining of difficult to cut materials especially when more heat would be incurred. In the last decades certain prospective and explorative methods have been undertaken to preserve and giving higher quality to the cutting tool from the generated heat. Until the recent times, none was able to give a remarkable alternative solution clue, but the best has been declared and announced that selecting coated cutting tools are an expensive election and normally widely used. Fortunately, many considered that as a satisfactory and appropriate approach for cutting some materials like titanium alloys, heat resistance alloys etc. But unfortunately, there are disagreements about this and it may certainly face different ideas (Cakir et.al., 2007).

Another thing is that cutting fluid which is known as lubricants and coolants has a great role and keeps its importance as it accomplishes both the craved purposes. It keeps the cooling effect to reduce the negative effects of thermal and lubrication so as to provide better surface texture. Cutting fluids have been used comprehensively in cutting process for cooling the cutting zone. Thereby, temperature of workpiece, distortion, friction and wear reduce and tool life improves. Whereas developing surface finish and tool life reduces cutting forces and energy absorption as well as washes away the chips and protects the newly machined surfaces from environmental hazards. To fulfill the desired functions, cutting fluids must possess some essential properties, for example first, a good cutting fluid is described with its huge specific ability and high thermal conductivity. Secondly, it needs to have low viscosity so as to easily enter via the small gaps. Third, it must also be noncorrosive and nontoxic and should not react with work piece and tool material. Then, it must be at ease as per availability and must not be very expensive. Finally, it must have high flash point to keep up its properties and physically and chemically stable (Dudzinski et.al. 2004).

Cutting fluids can be classified into two parts. They are water miscible cutting fluids and mineral oil based cutting fluids. Water attends as a main base fluid in cutting fluids with water. Water has already an excellent cooling property (Groover, 2010; Signh and Bajpai, 2015). But in mineral oil based cutting fluids, the oil is a mixture of several vegetable or mineral oils without water concentration. Their properties of cooling and lubricating can improve by adding to base fluid some additive compounds such as sulphur, phosphorus, chlorine based (Groover, 2010).

Therefore, to minimize the impacts of the generated heat during the machining operation, coolants and cutting fluids are being designed. In wet machining, coolants and cutting fluids have a limited effect on the amount of heat produced in cutting. Alternatively, they carry away the heat that is produced by which the temperature of the tool and work piece will be reduced. This process helps to maintain the life of the cutting tool longer. Temperature reducing capability of a cutting fluid depends on its thermal properties (Trent and Wright, 2000).

Nowadays, another most preferably technique is minimum quantity lubrication (MQL) used as purpose of cutting fluid. Cutting fluid in MQL gives the good results with only low consumption of the resources such as power, cutting fluid. MQL which is the process of applying a small amount of a lubricant directly into the cutting tool work piece interface. And to progress the effect of MQL and flood cooling, another method has been undertaken that is called nano fluids. Nano fluids are engineered colloidal suspensions of nano particles of 10- 100 nm size in the base fluids. MQL is already famous for its better working ability over traditional coolants and is the best choice for nano particles as a base fluid (Eastman et al. 2004; Jafari et al. 2015).

The last thing, which is extremely variable in shape and size in cutting operations, is the chip. The formation of chips contains shearing of the work part in the region of a plane extending from the tool edge to the position where the upper surface of the chip leaves the surface of work. A large quantity of fluid cutting is forced to spray onto the cutting zone for the purpose of controlling friction between the tool-workpiece and the tool-chip, at the same time, it reduces the generated heat which machining lacks of it. This contributes a good surface quality, less tool wear, and less cutting forces in cutting process. In spite of all those positive aspects and good benefits, cutting fluids have also negative effects namely, carrying problems, disposal problems, environmental pollution and the toxic nature of the fluid. This devastates all the environment and atmosphere around us. Therefore, there is a need for minimizing the negative effects of using of cutting fluids. This need led the emergence of too some alternative techniques to minimize the usage quantity of cutting fluid. (Trent and Wright, 2000; Groover, 2010).

1.1. Problem Statement

The machining process involves the generation of heat as a result of friction between workpiece- cutting tool- chips. This leads to increase solid surface of the machined portions accompanied by tool wear’s increasing.

The focus of the current research is to control both surface roughness and tool wear. Among the methods used to control these problems is to apply cutting fluid in machining operations. To decrease the disadvantages of normally cutting compounds, recently the use of nano fluids as cutting fluids are promising in machining operations.

In this research, Al_2O_3 nano particles have been utilized to investigate its effect on decreasing both tool wear and solid surface in machining of aluminum alloy by using CNC milling machine.

Due to the increase usage of aluminum alloys in engineering practices, the 6061 T6 aluminum alloy is used in the research work with the objective of getting acceptable surface finishing and minimize the cutting tool wear. Alloy of aluminum 6061 T6 is a medium to high strength heat-treatable alloy. This type of alloy has a very good corrosion resistance and very good weldability and also reduced strength in the weld zone.

1.2. Scope of the Research

In order to explore hidden qualities and the benefits of Al_2O_3 nanoparticles, current research has been carried out and its effect has been investigated experimentally to improve the surface roughness and decreasing of the cutting tool wear of machining 6061 T6 aluminum alloy.

In this study, the Al_2O_3 particles in the range of nano meter (<50 nm) has been used to prepare nano fluid. Water soluble oil have been corresponded for base fluid. MQL cooling and lubricating technique have utilized for the milling process. This study has been carried out for different cooling and lubrication conditions, namely traditional dry, MQL technique, and MQL involving Al_2O_3 nanoparticles. Machining parameters such as cutting speed and feed rate have been varied in per running conditions.

1.3. Objectives of the Research

The purpose and significance of this research are widely comprehensive for those who in need and admire the machining process and its problems and solutions. Researchers who want to have a better deep understanding and points of view, recommendations, and different clues about the subject of machining and cooling will find this study useful. Thus, the present study has been designed and performed with major objectives as follow:

1. To experimentally investigate the effect of Al_2O_3 nanoparticles on the following characteristics of machining of AA6061-T6.
2. To select the most suitable machining parameters compatible with the use of Al_2O_3 nanoparticles of AA6061-T6.

1.4. Organization of the Thesis

There are five chapters in this thesis. The first chapter is a brief introduction followed by problem statement, scope of the research, objectives of the study and conclusion. The second chapter presents the theory of machining, cooling, and surface roughness. In addition, in the third chapter, the experimental method and the equipment being used are presented. In the fourth chapter, the results and discussions are explained. Furthermore, in the fifth chapter, conclusions and recommendations for the future works has been presented. Finally, the last chapter, which chapter six includes the references.

1.5. Literature Survey

The current section is a literature review of the study which is concerned with modeling about the investigation of solid surface and tool wear of aluminum alloy by nano cutting fluid in CNC milling, experimental and numerical analysis.

Prabhu and Vinayagam (2010) examined to understand the impact of using CNT in grinding process of surface generation four distinctive oils were used, dry, based nano fluid MWCNT, SAE20W40 cutting oil, and SAE20W40 cutting oil in particular. Consequently, the study has discovered that there is fluctuation in surface roughness in this way: 0.251, 0.137, 0.096 and 0.057 mm, if compared with greasing up conditions. It can easily be seen from the results of this survey that novelty of nanoparticles' inclusion performs as per its features.

Park et al. (2011) concentrated on the tribology conduct of the nanomaterial added substances in various cutting operation fields, for example, water solvent oil, dry, and vegetable oil. Different tribology tests, for example, wet edge estimation, grating tests utilizing a ball point setup and MQL ball processing exam was directed under a verity of arrangements of burdens and speeds. That was noted that the expansion of shed the particles of nano grapheme in the cutting fluid enhanced the wet-ability and surface completion of the surface cut effectively

Shandekar et al.. (2012) investigated tool wear, surface roughness of workpiece, cutting force, thickness of chip under dry machining, machining with traditional cutting fluid, and nano-cutting fluid. The study clearly shows that the tool wear, surface roughness of workpiece, thickness of chip and cutting force reduced by the using nano-cutting fluid class with machining with traditional cutting fluid and dry machining.

Sarhan et al. (2012) used two types of lubrication the first one is the SiO_2 nano particles (0.2 % wt) with the same mineral oil inclusion. The second is the ordinary medicinal oil itself marks capable decrement in the force, cutting power, and particular vitality necessities are unmistakably seen on incorporation of oil nano particles in experiment with conventional medicinal oil.

Setti et al. (2012) noticed the impact of Al_2O_3 nano fluid with MQL in grinding process which was carried out on a surface grinder. The researchers look after the Taguchi test plan method and have made a model to forecast surface completion quality and partake granulating strengths. Thus, this research found that nano fluid was compared with the results found with pure water and traditional coolant. They found that Al_2O_3 nano particles cut down the granulating constrains more in contrast with the traditional liquid as well as immaculate water with the MQL framework.

Sayuti et al. (2013) examined the findings of milling processing operation on aviation duralumin work piece. The operation was led on vertical processing machine. The test was done with onion enriched nano fluid based cutting liquid and the outcomes were results as enhanced the quality of surface and lessened cutting. Under various cutting settings of greasing oil with most noteworthy fixation (1.5 wt %) of carbon onion accomplished the base cutting drive and solid surface. According to exploratory results, they were guaranteed 21.99% diminishment in the cutting strengths and 46.32% decrease in the surface roughness when it contrasted and the outcomes got with typical grease oil.

Prasad and Srikant (2013) watched the execution of nano graphite submersion by using MQL method; it has been observed that on augmentation of nano particles cutting grouping surface roughness and tool wear values diminishes. In any case, for the same cutting situation, it was similarly discovered that solidified carbide tool performed superior to anything (HSS) apparatus in terms of giving less benefit of cutting strengths, surface harshness, cutting temperature, or tool wear. On the other side, it is seen that as the graphite rate of the floe considerations expands outcomes reflected in lessened qualities temperature and tool wear. In conclusion 0.3% nano graphite made in incorporation with an ordinary stream rate of 15 mL/min.

Amrita et al. (2014) investigated the effect of inclusion during steel machining of cemented carbide, the powder of nano graphite based soluble oil cutting fluid. Chip morphology, flank wear, cutting forces, machined surface quality, and cutting temperature were observed during the examination. Best quality obtained when nano fluid was implemented as compare to dry, conventional flood cooling and MQL cutting environment.

Nagarajan et al (2014) investigated the utilization of nano fluids is to accomplish the most note highest possible thermal properties at the littlest conceivable fixations, by homogeneous scattering and stable suspension of nanoparticles in the host liquids. In this paper, an extensive writing on thermophysical properties of nano fluid and the use of sun based gatherer with nano fluid have been accumulated and assessed. Late written works show the ordinary warmth exchange utilizing nano fluid and their particular applications in the sun powered authority.

Mohd et al. (2014) enhanced a machining execution for example tool and workpiece surface completion the oil is normally introduced into the cutting zone amid the machining procedure. Utilizing nano lubrication as a part of machining could likewise minimize the utilization the grease oil, therefore little contamination will be brought on. To guarantee surface quality of workpiece, an examination of AA6061-T6 subsequent to machining with SiO_2 nano lubricant is explored at various nano lubricant fixation utilizing Field Emission Scanning Electron Microscopy and Energy-dispersive X-ray diffraction (EDXRD) machines. From the outcomes and examination the addition of nano lubricant focus at 0.2% would expand the development of slight defensive film on machined surfaces because of the breaking procedure from the moving activity.

Sayuti et al. (2014a) examined the effect of milling processing operation on aviation duralumin workpiece. As a result of utilizing advanced nano fluid onion liquid, the quality of surface was enhanced and cutting was lessened. Nonetheless, utilizing various oils to grease the surface, most noteworthy focus of (1.5 % wt.) of carbon onion was accomplished.

Zabata et al. (2016) proposed approach permitted to acquire low scatter in the lingering stress measurements as exhibited in the results. The most critical varieties in the leftover hassles conduct and size were connected with the alteration of the rotational pace. The effect of expanding the rotational velocity is a lessening in the size of the longitudinal lingering stresses.

Shokoobi et al. (2016) investigated the cutting liquids in minimizing production generation time, expense and vitality in various machining operations. In this examination, at in the first place, the part of machining in assembling and significance of lubrication fluids during cutting has been introduced, then distinctive machining forms have been clarified lastly some issues about nano fluid have been outlined. Also, impact of cutting parameters, for example cutting, force, machining temperature, surface roughness and environmental effects were investigated. Moreover, some instances of using nano fluid in machining operations have been accounted for quickly in a table. In this table a few things like kinds of nanoparticle, tool and workpiece material and machining processes milling are mentioned.

Results uncover that on account of reasonable nano fluid qualities, ideal using of them for cooling and lubrication purpose, can be beneficial in different machining operations.

2. GENERAL INFORMATION

Besides having a precise idea about influence of nanoparticles in the investigation of surface roughness and tool wear in milling of aluminum alloy by nano cutting fluid from the previous literature reviews, it was found that inclusion of nanoparticles in the cutting fluid always verified the benefit as each providing developed performance for the milling processes. This is due to nanoparticles' phenomenal lubricating and cooling effects.

In this chapter, there will be enough information about machining and milling to comprehend operations, results, and discussions that has been presented in this thesis. Readers who want a deeper understanding about machining and milling process can be directed to textbooks on this subject.

2.1. Machining

The traditional or conventional machining processes include turning, drilling, sawing, molding, reaming, arranging, and tapping. In such conventional machining forms machining tools for example, machines, processing machines, drilling pressers, or others are put to use with a sharp slicing tool for moving out materials to accomplish a coveted geometry.

Relative movement is necessary between the tool and the workpiece to carry out the action. That relative movement will be obtained in the majority machining operations by means of an early movement called cutting speed and a secondary movement called feed rate. The state of that tool and its entrance into the working surface are joined together with these two movements and then this creates the coveted state of the subsequent work surface as appeared in Figure 2.1 (Miltiadis, 2010).

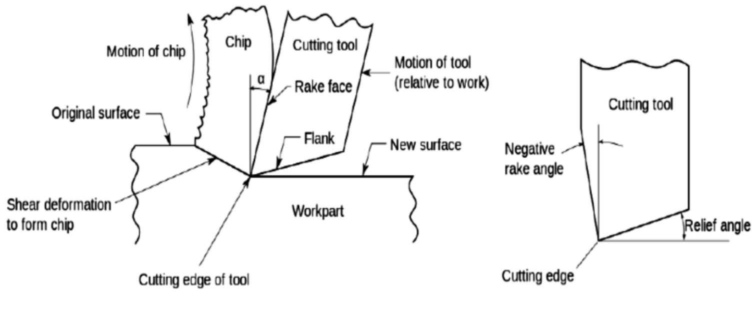

Figure 2.1. Machining process (Groover, 2010)

The commercial and technological importance of machining is stated for several reasons (Groover, 2010). Milling will be widely performed with several machining tools. The primitive class of machining tools for milling is the milling machine which is often called a mill.

After appearance of computer numerical control (CNC), milling machines have changed to machining centers such as milling machines with CNC control, tool magazines, automatic tool changers, coolant systems and carousels.

In the commonly classified as vertical machining centers (VMCs) and horizontal machining centers (HMCs), the cutter is a rotating cutting tool. In the most practical cases, the milling cutter possesses some teeth from 2-flutes to perhaps 20. Each tooth forms a helix moving around the cylindrical tool body (Patil and Shinde, 2013).

In VMCs in which the experiments have been carried out, the axis of the cutter are upright to the surface being milled. The machining is accomplished by cutting edges on both the end and the outer edge of the cutter. Thus, there are various forms of face milling and several of which are presented in Figure 2.2. In this study end milling has been used.

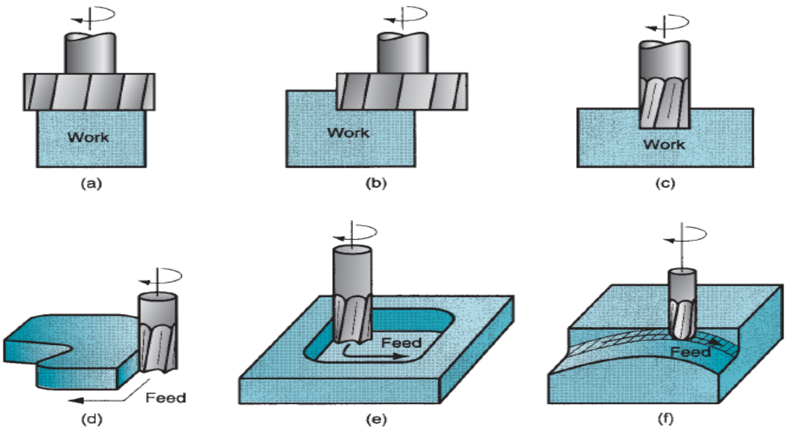

Figure 2.2. Face milling: (a) conventional face milling, (b) partial face milling, (c) end milling, (d) profile milling, (e) pocket milling, and (f) surface contouring

2.1.1. Cutting Conditions in Milling

The cutting speed is expressed in units of distance along the surface of workpiece per unit of time. It is found by the outside measurement of a processing cutter. This can be changed to spindle speed rotation utilizing a recipe that should be recognizable.

$$N = 1000.\frac{V}{\pi D} \tag{2.1}$$

where, N is spindle speed (rev/min), V is cutting speed (mm/min), D is diameter of end mill (mm).

Feed rate is the relative velocity at which the cutter is moved along the workpiece. Feed depend on the movement of the workpiece and tool. The feed in milling, which is normally given as a feed of each cutter tooth is called the chip load. It shows the size of the chip formed by each cutting edge. This can be changed to the feed rate by taking the spindle speed and the number of teeth on the cutter into consideration as follows:

$$f_r = N n_t f \tag{2.2}$$

where: f_r feed rate, mm/min (in/min), n_t number of teeth on the cutter; and f chip load in mm/tooth (in/tooth).

The ratio of material removal in milling process is determined by using the product of the cross-sectional area of the cutting and the feed ratio. Accordingly, if a slab milling process cuts a workpiece with width w at a depth d, and then the material removal ratio will be

$$\text{MRR} = w\, d\, f_r \tag{2.3}$$

2.2. Surface roughness

Roughness of the surface is a significant feature hinged on the roughness differences as previously defined. Therefore, surface texture is a subjective term representing softness and the quality of a surface. In popular use, surface texture is often applied as a same meaning for surface roughness. So, the surface roughness is often shortened to the roughness which is a constituent of surface texture. It is measured by the differences in the direction of the normal vector of a real surface from its ideal form. If these differences are large, the surface is rough. But, if they are small, the surface is not rough. Roughness commonly considers the high frequency and short wave length element of a measured surface. However, in practice, it is essential to know both the amplitude and the frequency to make sure that a surface is suitable for any purpose (Rajendra et al. 2014). It is a largely used index of the quality items and much of the necessary time is specialized to mechanical items. Reaching the desired surface quality has a great significance for the functional behavior of each part. Then again, the procedures of the subordinate nature of the solid surface development tool alongside the various wild components, which impact applicable marvels, make practically an incomprehensible arrangement (Viktor and Paulo, 2008).

There are two fundamental issues engineers face in a manufacturing procedure. The first is deciding the estimations of the procedure's parameters by which the sought item quality will yield (meet specialized particulars) and the second is increasing the performance of manufacturing system using the accessible resources. The choices made by manufacturing engineers are not only hinged on the experience and their expertise they have, but it also depends on the conventions regarding the phenomena that occur during processing. In the machining field, a large portion of such wonders are exceptionally overwhelming. Thus, they interface with a substantial number of variables and subsequently keep high process execution from what is being accomplished.

The qualities of made items are prescribed by their surface quality. The high friction between the tool and workpiece prompts the tool wear, high temperatures, and poor surface quality. To decrease the friction, cutting fluids is important to be connected to amid machine. In any case, using of the traditional cutting liquids turns into a wellspring of ecological contamination and makes organic issues to the administrators (Rajendra and Ashish, 2013).

2.2.1. Definition of roughness parameters

Since surface roughness is a significant measurement of quality product, it largely affects the performance of mechanical portions as well as the producing cost. It has also effect on the mechanical properties like corrosion resistance, fatigue behavior, creep life, etc. In addition, solid surface affects other functional attributes of the parts like friction, lubrication, wear, heat transmission, light reflection, electrical conductivity, etc. Variety of catastrophic failures producing high costs have sometimes brought the surface roughness of the work parts into question (Prabhu and Vinayagam, 2010; Chockalingam and Hong, 2012).

There have been a large number of exploration improvements in demonstrating of solid surface and streamlining of the parameters' controlling to acquire surface finish of a wanted level. The desired level is subsequent to just legitimate the determination of cutting parameters. Thus, this can deliver a superior surface finish.

In the manufacturing commercial ventures, different machining procedures are utilized for expelling the raw material from the workpiece to a superior item. Thus, this last processing procedure is a standout amongst the most indispensable and regular metal cutting operations. This last processing procedure is also utilized for machining the parts in regards of its capability to evacuate materials quicker with a sensible decent surface quality. Nowadays, CNC machining tools have been actualized to acknowledge full mechanization in the process. Since they give more noteworthy changes in profitability, they expand the nature of the machined portions and require less administrator information as well (Hassan, 2005).

Each of the roughness parameters is ascertained utilizing a formula to portraying the surface. There is a wide range of roughness parameters being used, yet R_a is by a long shot the most well-known, however, that is regularly for verification reasons not for specific legitimacy as the former roughness meters was able to only measure R_a. Other regular parameters include R_q, R_y and R_z. This area gives the computation techniques for the harshness parameters that can be measured (Figure 2.3-Figure 2.6). Every parameter clarified underneath is characterized as ascertained inside an examining length. Particular parameters which are acquired over the length assessment will be noted as necessary (Ema and Mauri, 2003; Atabey et.al., 2003).

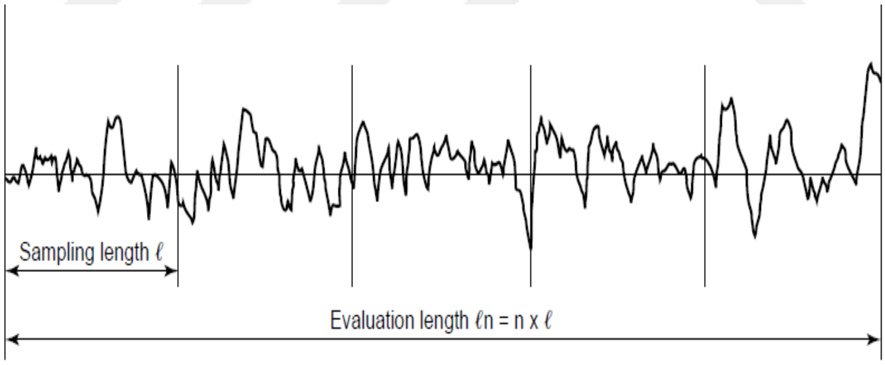

Figure 2.3. Sampling length and evaluation length (Ema and Mauri, 2003)

Arithmetic mean difference of the profile, R_a is the arithmetic mean of the absolute values of the profile differences (Y_i) from the mean line.

$$R_a = \frac{1}{N}\sum_{i=1}^{N}|Y_i| \tag{2.4}$$

Figure 2.4. Profile deviations (Ema and Mauri, 2003)

Maximum Peak to Valley Roughness Height (R_y) is the height sum (Y_p) of the highest peak from the mean line and depth (Y_v) of the deepest valley from the mean line.

$$R_y = Y_p + Y_v \quad (2.5)$$

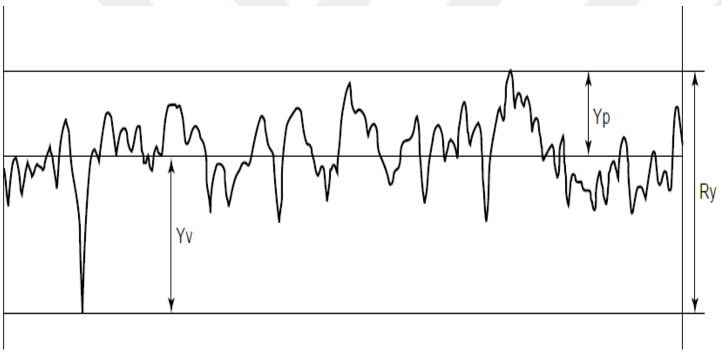

Figure 2.5. Maximum Peak-to-Valley Roughness Height (Ema and Mauri, 2003)

Maximum height of the profile (R_z) is obtained a sum (Z_i) of profile height of the peak (Pi) and profile valley depth (Vi) within each sampling length. The maximum value of all Z_i's over the evaluation of the length is described as R_y and the mean value is R_z.

$$R_z = \frac{Z_1 + Z_2 + Z_3 + Z_4 + Z_5}{5} \quad (2.6)$$

The number of sampling lengths $n = 5$.

Profile peak/highest peak is equal to profile valley/deepest valley of assessed profiles. A part that tasks upward (arched) from the mean of the surveyed profile is known as the "profile peak", and that extends descending (concave) is known as the profile valley. The highest point of each profile peak is named the highest peak while the deepest point of each profile valley is named as deepest valley.

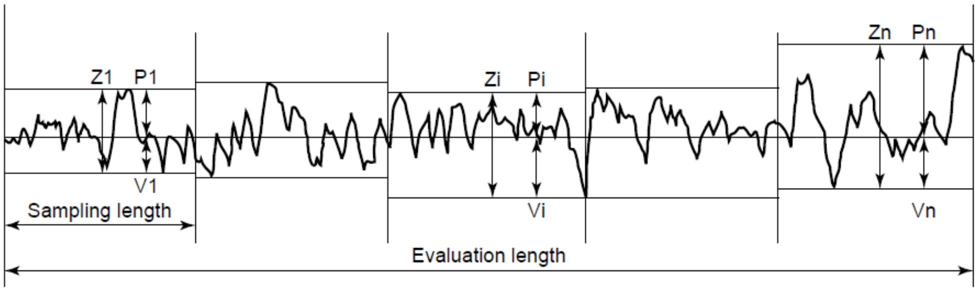

Figure 2.6. Maximum height of the profile (Ema and Mauri, 2003)

2.3. Cutting Operation and Cutting Tool

Machining operations refer the applications of cutting tools. High forces and temperatures during removing of materials from the operation field create a very tough environment for the tool. If the cutting force becomes extremely high, the tool cracks down. Similarly, if the cutting temperature becomes too high, the tool material becomes soften and fails.

The tool has two main properties: tool material and tool geometry. Tool material has to resist the cutting forces, temperatures, and wearing activity in machining process. Geometry manages resulting geometry of the cutting operation. Those parameters also affects the life of the tool. The cutting liquids are frequently applied in order to increase the tool life (Groover, 2010).

Wear resistance is for the most part characterized for the fulfillment of worthy tool life before necessary replacement of the tools. In spite of the fact that appearing to be attire basic, this trademark is the minimum comprehended (Groover, 2010), (Tomas et.al., 2015). Before examining these individual materials, obtaining technical knowledge will be helpful (Esford, 2000). Drilling and milling apply rotating multiple cutting edge tools (Figure 2.7). Figure 2.8 represents a helical milling cutter (Trent and Wright, 2000; Groover, 2010).

Many of the principles applied to single-point tools are also applied to the multi cutting-tool types.

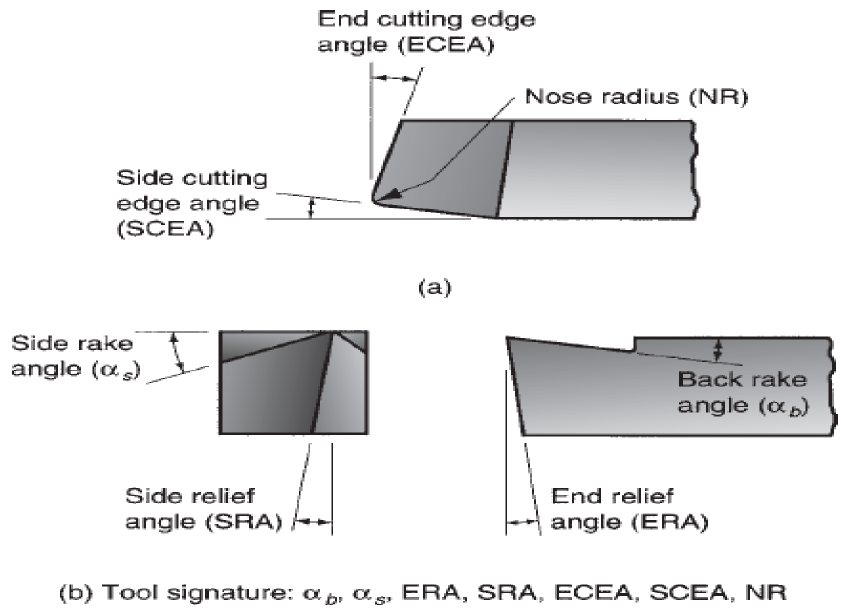

Figure 2.7. (a) Seven elements of single point tool geometry, and (b) the tool signature convention that defines the seven elements (Trent and Wright, 2000)

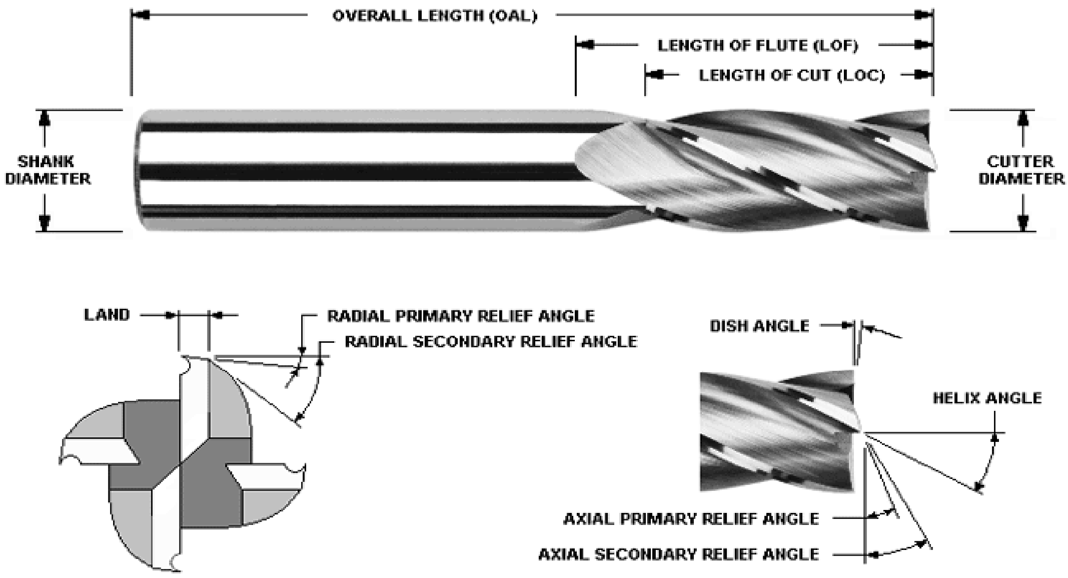

Figure 2.8. Tool wear and tool life (Trent and Wright, 2000)

Tool wear is a period subordinate procedure. While cutting continues, the measure of tool wears increments bit by bit. But tool wear must not be permitted to go past a specific cutoff keeping in mind the end goal to maintain a strategic distance from apparatus disappointment. As a result, life of a cutting tool can be ended by various means (Chockalingam and Hong, 2012; Azuan, 2013):

- Gradual wearing of particular regions regarding the face and flank of the cutting tool
- Abrupt failure in a tool.

Three main types of tool wear has been shown in Figure 2.9. The Figure 2.10 shows the impact of cutting parameters on tool wear (Groover, 2010; Sayuti et.al., 2014a).

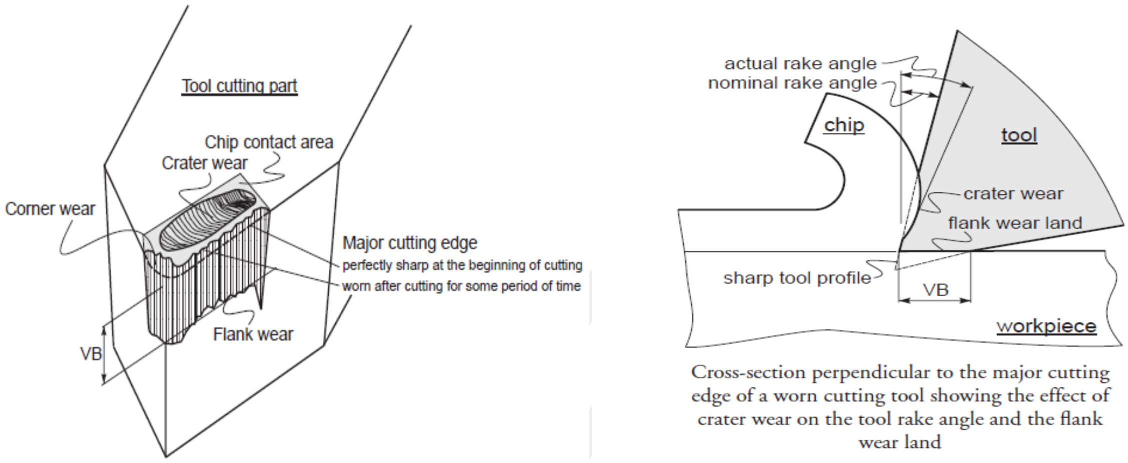

Figure 2.9. Types of wear obscured in cutting tool

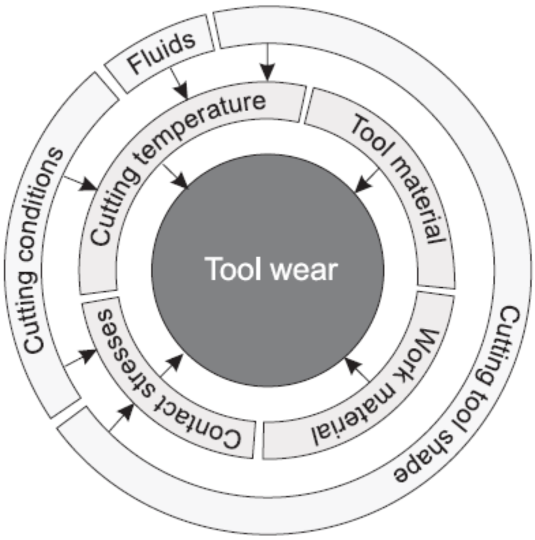

Figure 2.10. Impact of cutting parameters on tool wear

2.4. Cutting fluid

There are two general classifications of cutting liquids, coolants and oils. Coolants are slicing liquids intended to reduce the effects of temperature.

Coolant-sort slicing liquids appear to be best at moderately high cutting velocities, in which warm era and high temperatures are concerns. They are most effective on tool materials, for example, rapid steels, and are utilized oftentimes as a part of turning and processing operations, in which a lot of warmth are created (Cakir et.al. 2007).

Oils are generally oil-based liquids (since oils have great greasing up qualities) planned to decrease grinding between the tool, chip and workpiece (Cakir et.al. 2007; Groover, 2010).

Dissecting machinability is an entangled assignment in light of the extensive number of impacting components. The beneficial outcomes on machinability are reflected in expanding apparatus life, decreasing vitality utilization, enhancing of the surface roughness, and so forth. The impact of cooling and greasing up relies on upon liquid stream parameters, liquid attributes and conveyance system (Groover, 2010; Branislav et.al., 2013).

2.4.1. Dry machining

Dry machining is the machine without cutting liquids as a result of developing worry about natural contamination and related enactment, arranging old liquids has ended up both excessive and as opposed to the overall population welfare (Groover, 2010). Cutter's producers have developed the carbides and coated carbides in certain grades to use in dry machining as show in Figure 2.11 (Nouari et.al., 2005).

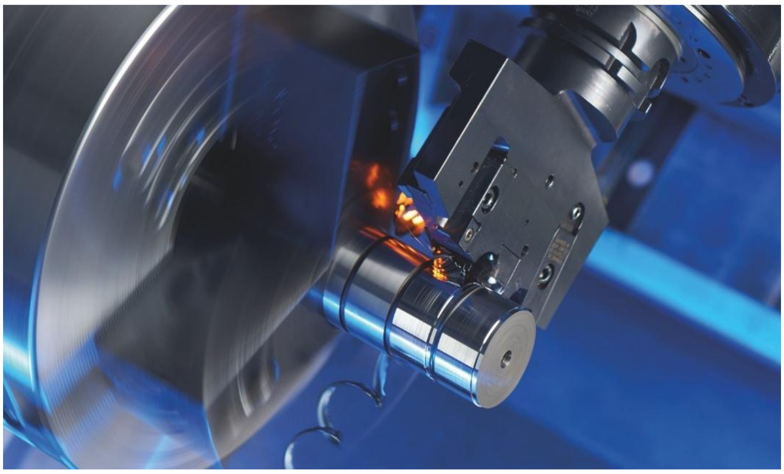

Figure 2.11. Dry machining (Esford, 2000)

Dry machining can give cost point of interest and machine-tool adaptability if huge sumps are not required. Some procedures can be effectively completed even without a cutting liquid, e.g., cast iron can be promptly machined without a coolant if the tool is arranged legitimately for simple chip clearing. The aluminum parts can be turned and processed with polycrystalline jewel (PCD) apparatuses with no issues. Unique low-grinding tool coatings and machine design can help the dry machining further (Shokoohi et.al., 2016).

Some situations that are difficult without coolant are as follows:

a. High temperature.
b. Materials that form a built up edge.
c. It's very hard to get the chips up out of deep holes without coolant.
d. You can often pick up the lost feed rate and more using chip thinning (Goodarzi, 2010).

2.4.2. Minimum quantity lubrication (MQL)

MQL is a technique that the cutting fluid applied as spray with help of a pressurized air at generally 5 bar. With 50-500 ml/h consumption, very little amount of cutting fluid is used, and disposal system is not required. When spray reaches to machining zone, it quickly evaporates and takes away heat from the machining zone. This evaporative heat transfer is more efficient over flood coolant (Heisel vd., 1994).

There are two basic types of MQL systems. MQL external sprinkler framework comprises of cooling tank or store, which is connected with funnels fitted with one or a greater amount of the openings. In addition, MQL framework can be collected close to the machine or on the gadget as per the administrator's solace. The pump permits the client an extensive variety of coolant conveyance framework. Also, the framework has movable freely and cooling wind stream, which accomplishes a harmony between the conveyances of coolant. The framework is not modest, compact and reasonable for all machining operations (Table 2.1) (Chengdong et.al., 2015), (Dhar et.al., 2006). In internal mixing or two channel frameworks, this methodology requires an extraordinarily planned axle. Standard high-weight spindle coolant can be balanced by including a different external container of the axle for oil is conveyed to the axle nose. These frameworks have less scattering and spillage, and can give mist beads bigger sizes of the outer blending gadgets.

Table 2.1. Advantages and disadvantages in external MQL

Advantages	Disadvantages
• Simple adaptation • Low investment costs • Little work required to retrofit conventional machine tools • Rapid response characteristics • No special tools required	• Limited adjustment options for the nozzles due to different tool lengths and diameters • Possible shadowing effects of the spray jet when machining • Possible shadowing effects of the spray jet when machining

In internal mixing or two channel frameworks, this methodology requires an extraordinarily planned axle. Standard high-weight spindle coolant can be balanced by including a different external container of the axle for oil is conveyed to the axle nose. These frameworks have less scattering and spillage, and can give mist beads bigger sizes of the outer blending gadgets (Table 2.2).

Table 2.2. Advantages and disadvantages in internal MQL

Advantages	**Disadvantages**
• Optimal lubrication at the cutting point (for each tool, even for inaccessible points) • No scattering or spray losses (see external feed) • Optimized lubricant quantity for each tool	• Special tools required • High investment costs • Suitability of the machine is required

2.4.3. Nano fluid

Nano fluids are fluids with nanometer sized particles added. Nanoparticles is added in a cutting fluid. Cutting fluid can be applied as flood and MQL. Since the size of added particles are too low, solidification of fluid doesn’t occur on nano fluids. This behavior make them usable on machining process.

In addition, the most important nano cutting fluid application in CNC milling machining issue is the solidity of nano fluids and it is a great challenge to attain a desired solidity of nano fluids. Recently, nano fluids attracted more attention of people due to its importance in all aspects of life and its wide range of application though some research articles including the progress of nano fluids published the majority of researches are related to experimental and theoretical studies of the thermos physical properties or the convective heat transfer of nano fluids (Shokoohi et.al., 2016), (Cui et.al., 2013).

Nano fluids show better steadiness and rheological properties, higher thermal conductivity, and no penalty in pressure drop when compared with suspended particles of millimeter-or micrometer dimensions. In fact, this new composite fluid is very crucial and lack of research and information has not been noticed by researchers which include preparing and solidity issues of nano fluids, expectations of thermal conductivity of nano fluids accurate for industrial condition. Furthermore, prediction of viscosity of nano fluids for industrial condition with heat transfer fluid are important some aspects (Shokrani et.al., 2012). It is obvious that extensive studies are needed in a variety of fields due to the fact that, the existence of industrial development and requests of new procedures for improving production process. In addition, producers are always looking for higher yields and incomes. Actually the main goal in producing is to minimize the production time, cost, energy and resources along with improving the function (Das et.al., 2003).

3. MATERIALS AND METHODS

In this study, the effect of milling process parameters on the performance parameters in end milling of 6061-T6 aluminum alloy was investigated using CNC milling machine. The experimental studies were carried out in the laboratory of Mechanical Engineering Department at Engineering Faculty of Firat University. The experiments were performed on a CNC vertical milling center (model 2414 challenger) as shown in Figure 3.1. The vertical milling center has three controlled axes, which can move in xy, yz and xz planes as shown in Figure 3.2.

Figure 3.1. CNC vertical machining center

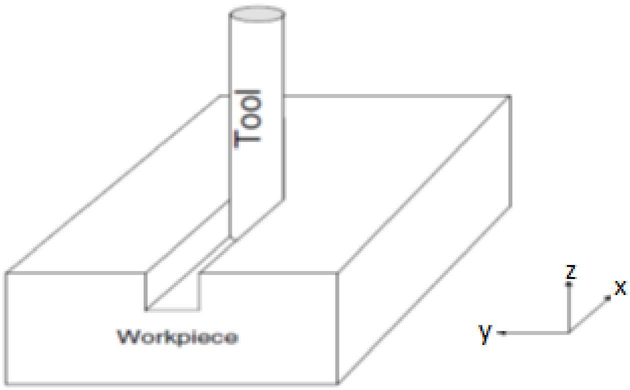

Figure 3.2. Machining directions

The workpiece surface roughness and the tool wear were considered as the performance parameters. Those performance parameters were measured by changing cutting speed and feed rate, cutting tool and cooling method as given Table 3.1. The experimental set up is shown in Figure 3.3. Aim of the experiments are to determine the relationship between the cutting parameters (cutting speed, feed rate, tool material and cooling method) and the performance characteristics, and their effects on tool wear and surface roughness. For this reason, a total of 54 unlike combinations of process parameters were established to calculate the effect of the different levels of the parameters on the outputs by using a factorial experimental design method. A full factorial design may also be called a fully crossed design. Such an experiment allows the investigator to study the effect of each factor on the response variable, as well as the effects of interactions between factors on the response variable. The experimental design are shown in shown in Table 3.2. The 18 of the experiments were dry machining with HSS and carbide tool and the other 36 experiments were performed with the MQL (minimum quantity lubrication) and nano MQL coolant fluids. Each experiment was repeated three times with unused tools.

Table 3.1. Cutting conditions

Process Parameters	**Value**
Cooling method	Dry, MQL , Nano MQL
Cutting speed (m/min)	180, 200, 220
Feed rate (mm/rev)	0.05, 0.06, 0.07
Tool material	HSS, Carbide

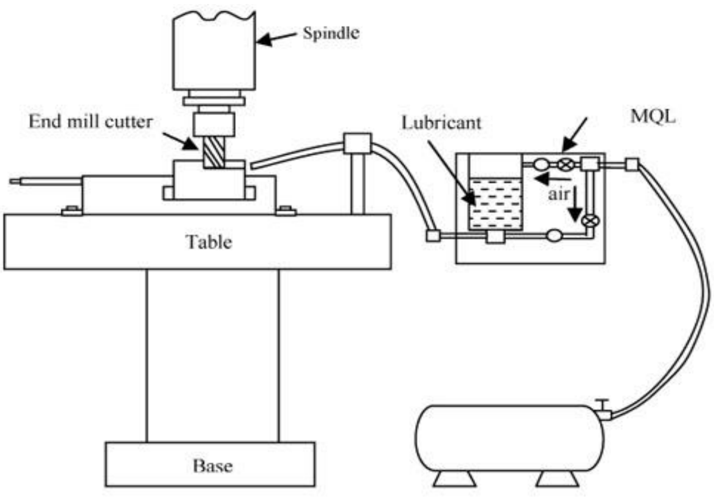

Figure 3.3. Schematic diagram of the experimental setup

Table 3.2. Experimental design

Exp. No	Type tool	Cooling method	Cutting speed (m/min)	Feed rate (mm/rev)	Exp. No	Type tool	Cooling method	Cutting speed (m/min)	Feed rate (mm/rev)
1	HSS	Dry	180	0,05	**28**	Carbide	MQL	180	0,05
2	HSS	Dry	180	0,06	**29**	Carbide	MQL	180	0,06
3	HSS	Dry	180	0,07	**30**	Carbide	MQL	180	0,07
4	HSS	Dry	200	0,05	**31**	Carbide	MQL	200	0,05
5	HSS	Dry	200	0,06	**32**	Carbide	MQL	200	0,06
6	HSS	Dry	200	0,07	**33**	Carbide	MQL	200	0,07
7	HSS	Dry	220	0,05	**34**	Carbide	MQL	220	0,05
8	HSS	Dry	220	0,06	**35**	Carbide	MQL	220	0,06
9	HSS	Dry	220	0,07	**36**	Carbide	MQL	220	0,07
10	Carbide	Dry	180	0,05	**37**	HSS	Nano+MQL	180	0,05
11	Carbide	Dry	180	0,06	**38**	HSS	Nano+MQL	180	0,06
12	Carbide	Dry	180	0,07	**39**	HSS	Nano+MQL	180	0,07
13	Carbide	Dry	200	0,05	**40**	HSS	Nano+MQL	200	0,05
14	Carbide	Dry	200	0,06	**41**	HSS	Nano+MQL	200	0,06
15	Carbide	Dry	200	0,07	**42**	HSS	Nano+MQL	200	0,07
16	Carbide	Dry	220	0,05	**43**	HSS	Nano+MQL	220	0,05
17	Carbide	Dry	220	0,06	**44**	HSS	Nano+MQL	220	0,06
18	Carbide	Dry	220	0,07	**45**	HSS	Nano+MQL	220	0,07
19	HSS	MQL	180	0,05	**46**	Carbide	Nano+MQL	180	0,05
20	HSS	MQL	180	0,06	**47**	Carbide	Nano+MQL	180	0,06
21	HSS	MQL	180	0,07	**48**	Carbide	Nano+MQL	180	0,07
22	HSS	MQL	200	0,05	**49**	Carbide	Nano+MQL	200	0,05
23	HSS	MQL	200	0,06	**50**	Carbide	Nano+MQL	200	0,06
24	HSS	MQL	200	0,07	**51**	Carbide	Nano+MQL	200	0,07
25	HSS	MQL	220	0,05	**52**	Carbide	Nano+MQL	220	0,05
26	HSS	MQL	220	0,06	**53**	Carbide	Nano+MQL	220	0,06
27	HSS	MQL	220	0,07	**54**	Carbide	Nano+MQL	220	0,07

In the experiments, 6061-T6 aluminum alloy was used as the workpiece material. The chemical composition of workpiece material is shown in Table 3.3. 6061-T6 aluminum alloy has a hardness of 89 HB, a yield strength of 250 MPa, and a tensile strength of 280 MPa (Seykoç, 2016). HSS and solid carbide end mills used as tool materials have a 10 mm diameter, 4 flutes and 30 degree helix angle. The depth of cut of 1 mm was kept constant throughout the experiments.

Table 3.3. Chemical composition of 6061 Al alloy (Seykoç, 2016)

Fe	**Si**	**Cr**	**Mn**	**Mg**	**Zn**	**Cu**	**Ti**	**Another**	**Al**
0,5	0,6-1,0	0,1	0,2-0,8	0,8-1,2	0,25	0,6-1,1	0,1	0,15	balance

In the experiments, the boron oil to water ratio was selected as 1/9 in preparation of the coolant fluid in MQL and nano MQL. The nano cutting fluid was prepared by adding Al_2O_3 nanoparticles to the conventional cutting fluids (the mixture of oil-water). The concentration of Al_2O_3 nanoparticles in nano MQL was kept constant as 0.5 vol%. The properties of Al_2O_3 nanoparticles is shown in Table 3.4. Werte STN40 micro lubrication system was used for MQL and nano MQL as shown in Figure 3.4. The cooling fluid in MQL and nano MQL was delivered by spraying with air pressure of 5 bar. A flow rate of 0.2 mL/min was applied in MQL contacted with interface of tool and workpiece.

Table 3.4. Properties of aluminum oxide (Al_2O_3) (Seykoç, 2016)

Molecular formula	Al_2O_3
Molar mass	101.96 g/mol
Appearance	White solid
Density	3.95 g/cm^3
Melting point	2072°C
Solubility in water	Insoluble
Crystal structure	Various
Particle size	<50 nm (avg. size)

Figure 3.4. MQL system

3.1. Measurements

The surface roughness of workpiece was measured by the surface roughness tester device (Mitutoyo SJ-201), after machining this tool measured (R_a) recorder direct. After the workpiece machined length of 500 mm, the surface roughness measurements was taken. The surface roughness was measured from tool enter and exit side as shown in Figure 3.5 and Figure 3.6. In measurements, a cutoff length of 0.8 mm and sampling number of 5 were used. In this case, traverse length is to $0.8 \times 5 = 4$ mm.

In experiments, the tool was entered into part from leftmost side and proceed on x direction until it exits from right as shown in Figure 3.6.

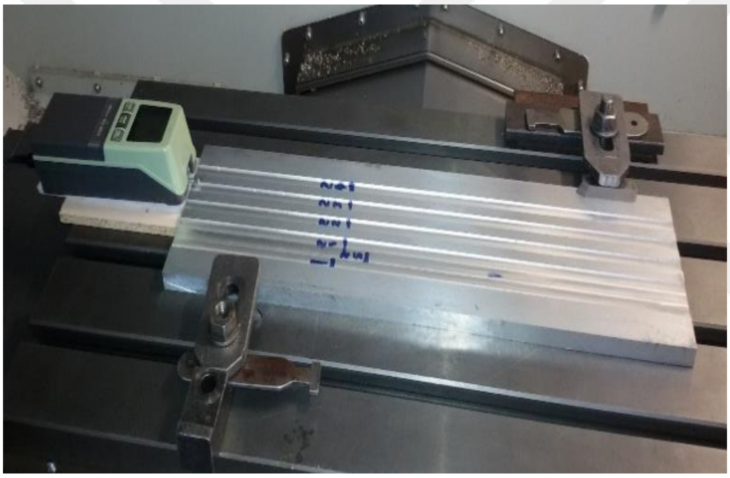

Figure 3.5. Measurement of surface roughness

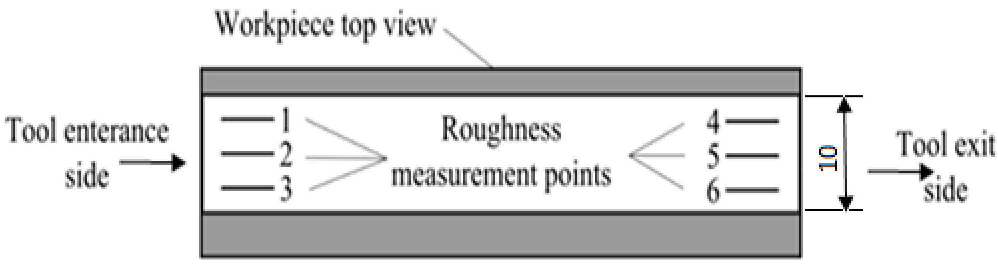

Figure 3.6. Measurement points for surface roughness

The tool wear was measured using an optical microscope as shown in Figure 3.7 that connected with a computer by Material Plus 4.2 program. Flank wear of the tool was measured on an optical microscope with 7x zooming that shown in Figure 3.7.

Figure 3.7. Measurement of tool wear

4. RESULTS AND DISCUSSIONS

The workpiece was welded on the tool at the end of the first pass in all cutting speed and feed rate, when the workpiece machined with carbide tool without coolant. In other words, the tool wear did not measure in dry machining with carbide tool. Because the workpiece welded on the carbide tool as shown in Figure 4.1. The welding was occurred on HSS tool too. In this case, there are unplotted values on some of the following graphics. Those values represents that the welding of the workpiece (built-up edge) on cutting tool.

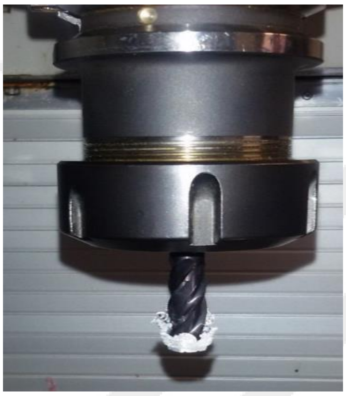

Figure 4.1. The welding of the workpiece on the carbide tool in dry machining

4.1. Effect of Cutting Speed on Surface Roughness

Graphics given in from Figure 4.2 to Figure 4.5 shows the changing trend of the surface roughness of workpiece with the different cutting speed. From Figure 4.2 to Figure 4.4, it is seen that in feed rates of 0.05, 0.06 and 0.07 mm/rev, respectively. The average values of all feed rates are shown in Figures 4.5 in order to see the changing trend of the surface roughness versus cutting speed. In mentioned graphics, the surface roughness (R_a) values were increased with cutting speed in use of both HSS and carbide tool. This is an expected result. According to Equation 2.1, the rotation speed of the tool increases, when cutting speed is increased. In this case, the feed per minute increases (Equation 2.2) and the advancing step of the tool per second is getting bigger, and this causes the surface roughness to increase.

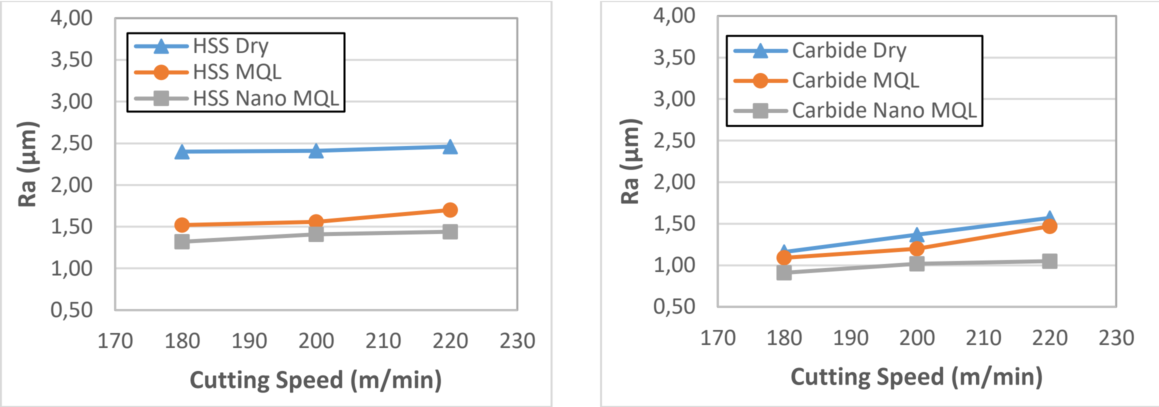

Figure 4.2. Effect of cutting speed on surface roughness at 0.05 mm/rev feed rate

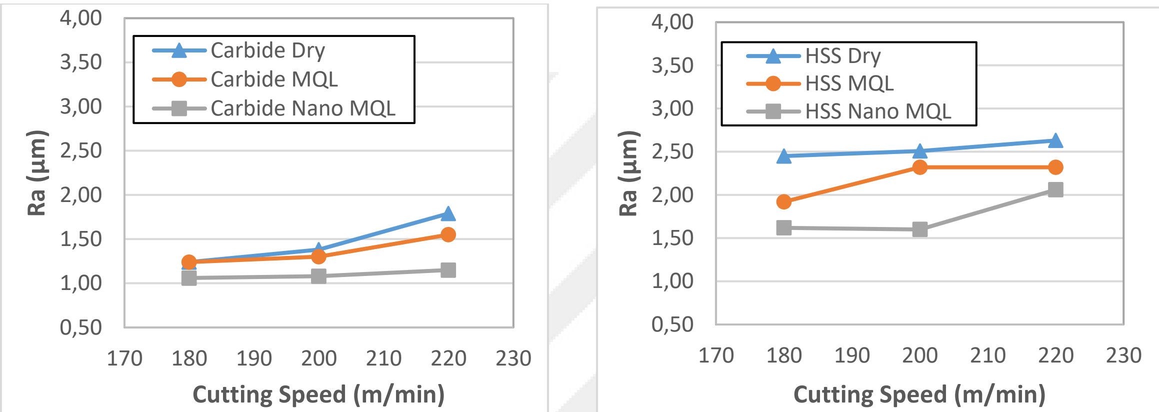

Figure 4.3. Effect of cutting speed on surface roughness at 0.06 mm/rev feed rate

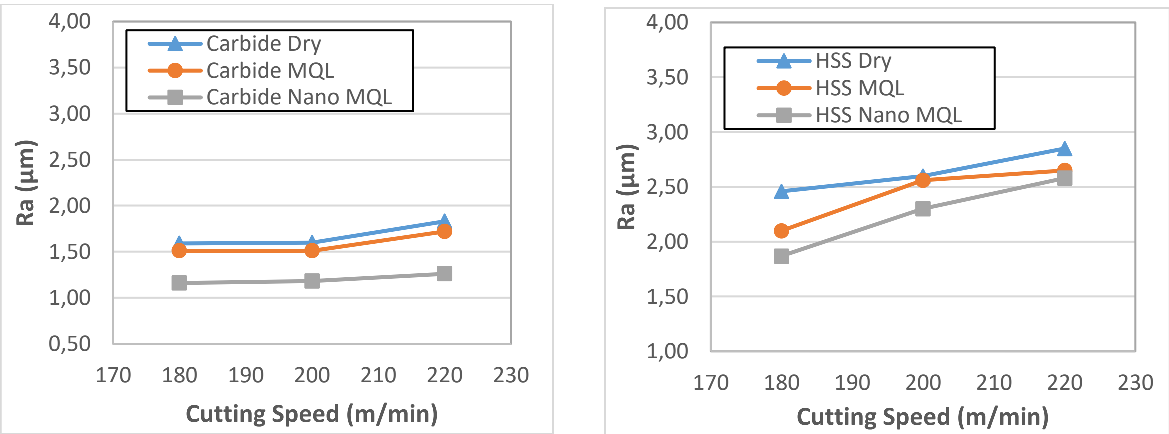

Figure 4.4. Effect of cutting speed on surface roughness at 0.07 mm/rev feed rate

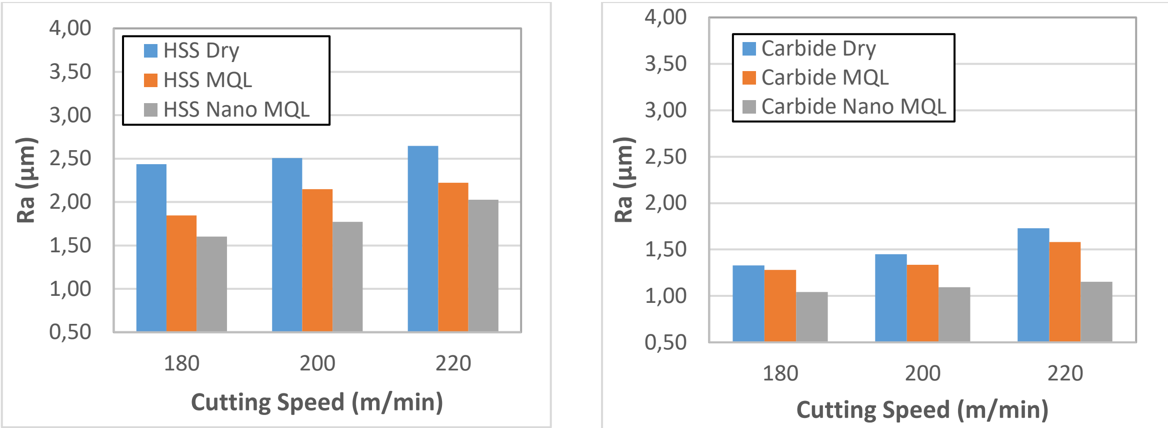

Figure 4.5. Effect of cutting speed on surface roughness for the average of feed rates

4.2. Effect of Feed Rate on Surface Roughness

In this section, the effect of the feed rate on the workpiece surface roughness value has been presented in from Figure 4.6 to Figure 4.9. The surface roughness increased with the increasing feed rate at 180, 200 and 220 m/min cutting speeds (Figure 4.6-Figure 4.8). Figure 4.9 shows the variation of the mean surface roughness values in all cutting speeds with feed rate. According to Equation 2.2, the feed per minute also increase, when the feed rate increases. In this case, the tool moves in longer distance in the same time interval and the material removal rate from the workpiece in unit time increases. Thus, the surface roughness gets higher. This effect can be seen in Figure 4.6-Figure 4.9. The workpiece surface roughness increased with the increasing feed rate in machining with both HSS tool and carbide tool.

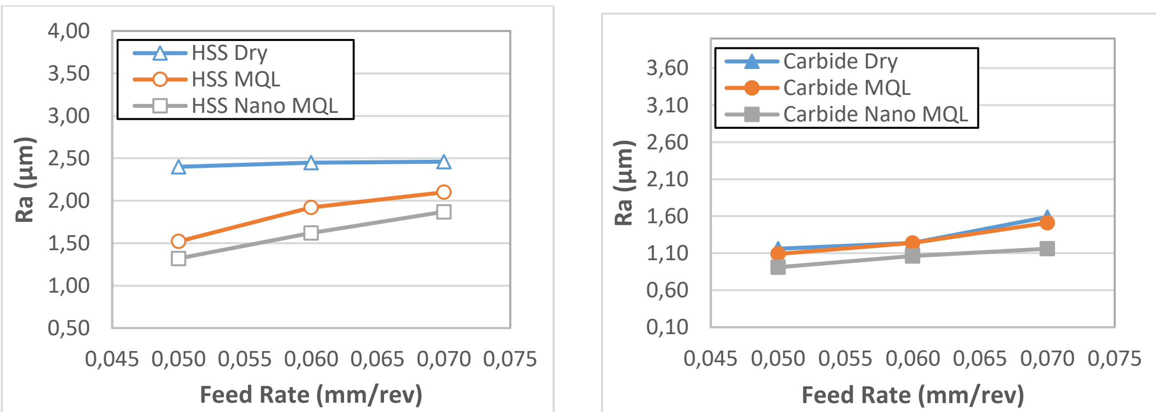

Figure 4.6. Effect of feed rate speed on surface roughness at 180 mm/min cutting speed feed

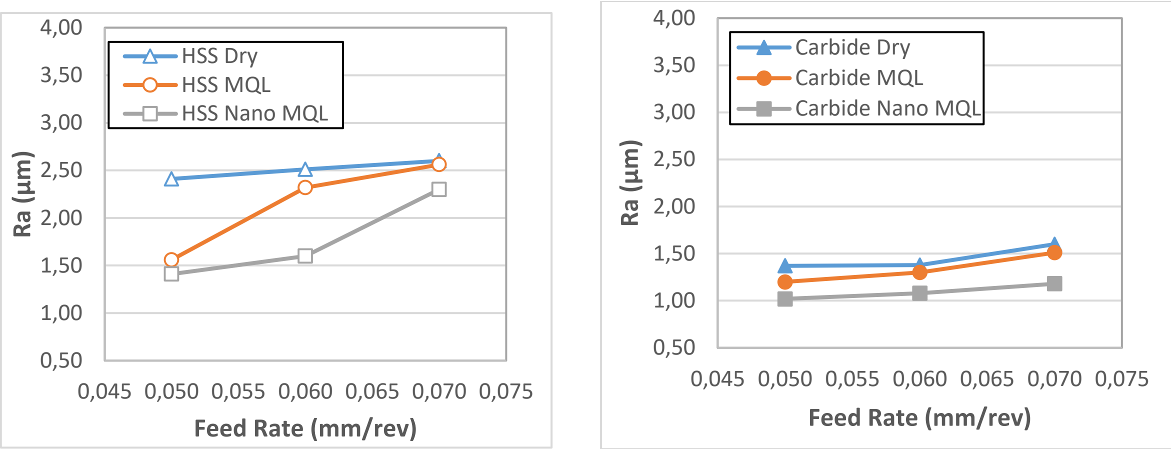

Figure 4.7. Effect of feed rate speed on surface roughness at 200 mm/min cutting speed feed

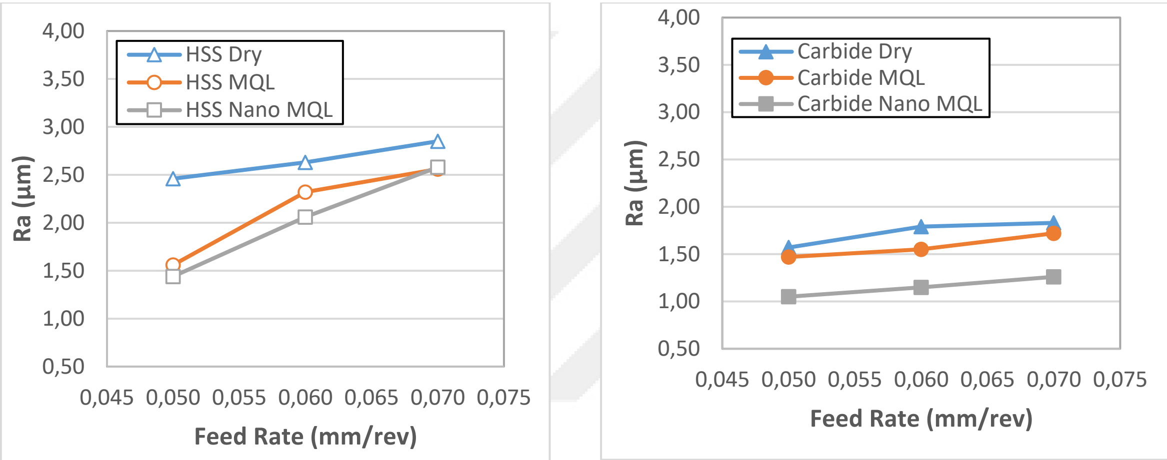

Figure 4.8. Effect of feed rate speed on surface roughness at 220 mm/min cutting speed feed

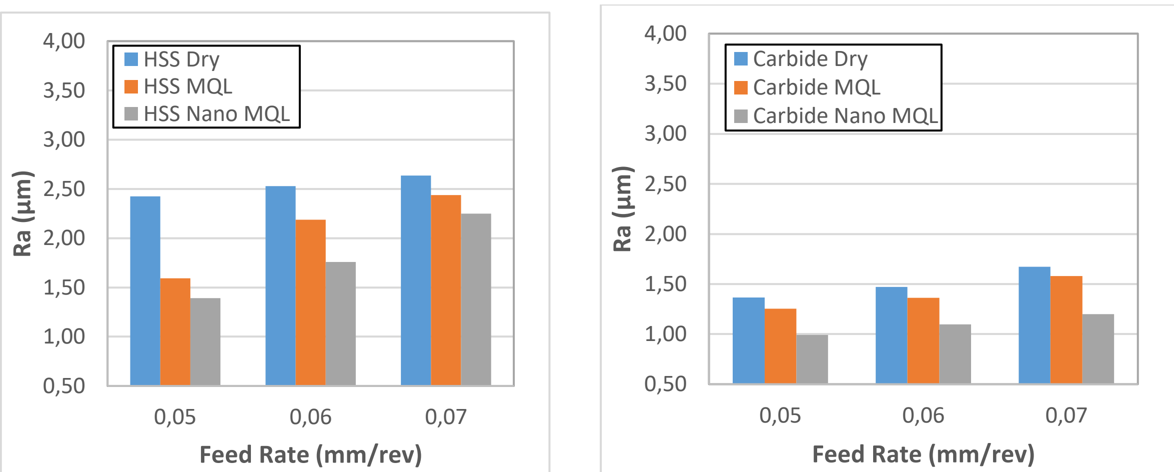

Figure 4.9. Effect of feed rate on surface roughness for average cutting speed

4.3. Effect of Cooling Method and Cutting Tool on Surface Roughness

The effect of the cooling conditions and the cutting tool material on the surface roughness is stated in Figure 4.10. While the highest surface roughness value occurred in dry machining, the lowest surface roughness in machining with the cutting fluid including nano particles. It can be seen that the surface roughness (*Ra*) values decreased by application of coolant. As shown in Figure 4.10, the worst surface quality was obtained in dry machining. The surface quality results obtained with the MQL method is better than that of the dry machining. When the MQL method compared to the dry machining, the coolant in MQL has both a lubricating and a cooling effect in the cutting region. Efficient lubrication allows the chips to slide more easily over the tool's surface, resulting in a better surface finish (Tosun and Huseyinoglu 2010). The surface quality obtained with nano MQL method is better than that of both dry machining and MQL method. Nano-cutting fluids are the mixtures of conventional cutting fluid and nanoparticles. Addition of the nanoparticles improves wettability, lubricating properties, and convective heat transfer coefficient (cooling properties) of nano-cutting fluid (Khandekar et al.., 2012). Thus, the surface quality in nano MQL is better than other two methods.

In Figure 4.10, the increase of surface roughness in machining by using HSS tool is more than that of carbide. The hardness of carbide cutting tools is higher than that of HSS cutting tools. Because HSS cutting tools wears faster than carbide, and the deformed cutting edge of tool causes higher surface roughness. In all the cooling conditions, the surface roughness results obtained in machining using carbide tools are lower than that of HSS tools. HSS tools is affected more from heat generation in the cutting process according to carbide tools. In this case, a tool wear can occur or a welding (built-up edge-BUE) being an accumulation of workpiece material to tool can occur.

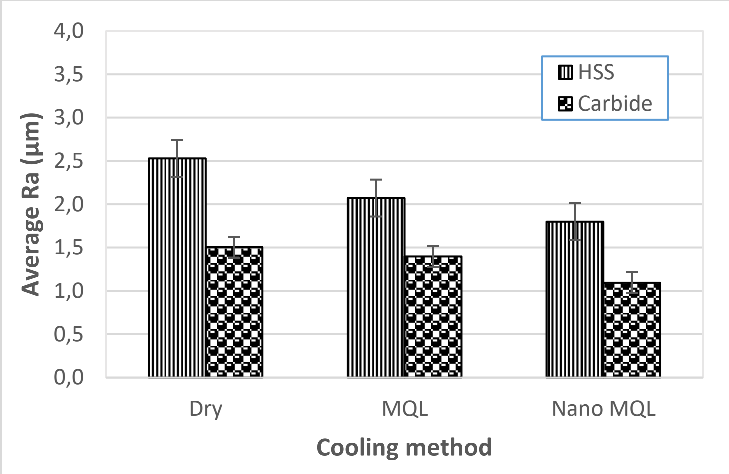

Figure 4.10. Effect of cooling condition and cutting tool on surface roughness for all cutting speed and feed rate

4.4. Effect of Cutting Speed on Tool Wear

In this study, flank wear considered as tool wear. The flank wear was measured for the same machining length. In order to see the effect of cutting speed on the tool wear, the average values of flank wear in all feed rates was first calculated, and categorized by cutting speed as shown in Figure 4.11 and Figure 4.12. The flank wear values in dry machining with carbide tool could not obtained because of welding of the workpiece on to cutting tool (Figure 4.12). In these graphics, the tool wear increased when the cutting speed increased in use of both HSS and carbide tool. When the cutting speed increase, the contact time between the tool and the workpiece increase. The more contact time with the increasing cutting speed increases in the temperature of tool-workpiece interface and with increasing cutting speed, the friction between the tool and the workpiece increase. This case accelerates the tool wear.

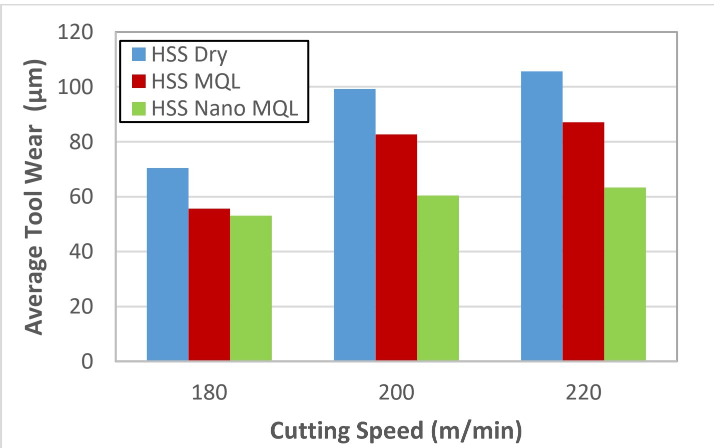

Figure 4.11. Variation of average tool wear with cutting speed in HSS tool for all feed rate

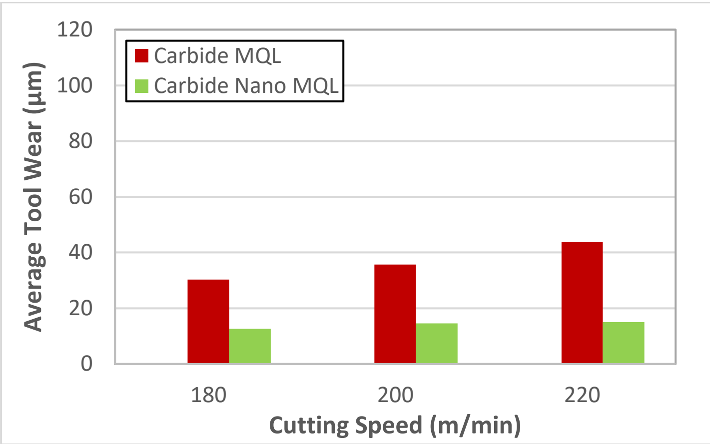

Figure 4.12. Variation of average tool wear with cutting speed in carbide tool for all feed rate

4.5. Effect of Feed Rate on Tool Wear

The average values of tool wear for all of cutting speeds was first calculated, and categorized by feed rates. In Figure 4.13 and Figure 4.14, the effect of the feed rate on the tool wear has been seen. The tool wear increased with the increasing feed rate for average of all cutting speeds (Figure 4.13 and Figure 4.14). According to Equation 2.3, when the feed rate increases, the tool moves in longer distance in the same time interval and the material removal rate from the workpiece in unit time increases. Thus, the tool wear gets higher. The tool wear in machining with both HSS tool and carbide tool increased with the increasing feed rate.

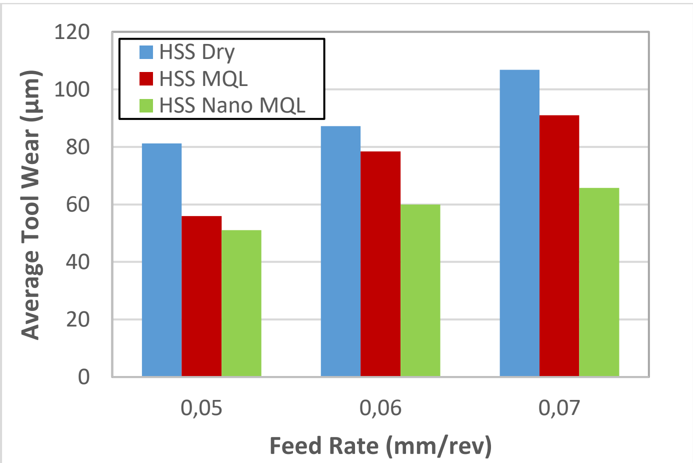

Figure 4.13. Variation of average tool wear with feed rates in HSS tool for all cutting speed

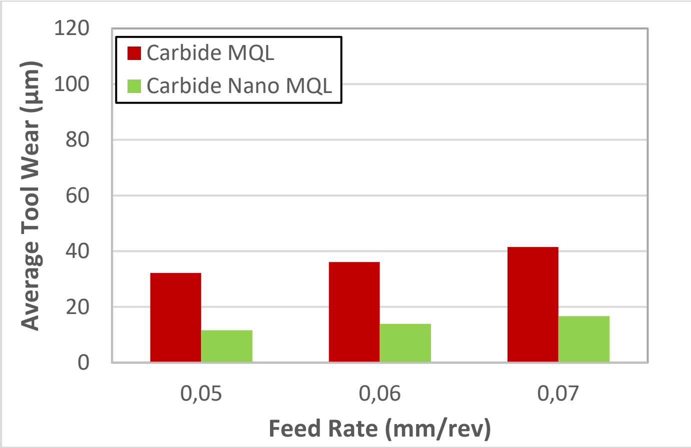

Figure 4.14. Variation of average tool wear with feed rates in carbide tool for all cutting speed

4.6. Effect of Cooling Method and Cutting Tool on Tool Wear

The effect of the cooling technics and the cutting tool material on the tool flank wear is seen in Figure 4.15. As seen in Figure 4.15, the tool wear values of dry machining with carbide tool did not obtain, because of the welding of the workpiece on the cutting tool. The tool wear on carbide tool is lower than that of HSS tool, because the hardness of carbide cutting tools is higher than that of HSS cutting tools.

Maximum tool flank wear is obtained at dry machining with HSS tool as shown in Figure 4.15. The tool flank wear decreased, when the coolant applied as MQL. But the nanoparticles added the cooling fluid has been made a significant effect on tool wear in machining with both HSS and carbide (WC) tool (Figure 4.15). The minimum tool wear values were obtained in machining with the nano MQL cooling method using carbide tool. The coolant in MQL has both a lubricating and a cooling effect in the cutting region. While an effective lubrication allows the chips to slide more easily over the surface of cutting tool, an effective cooling help to decrease the heat generated in both tool and workpiece. In this case, a lower tool wear will be obtain (Tosun and Huseyinoglu 2010). Addition of the nanoparticles improves wettability, lubricating properties and cooling properties of cutting fluid (Khandekar et al.., 2012). Thus, the tool wear in nano MQL is better than other two cooling methods.

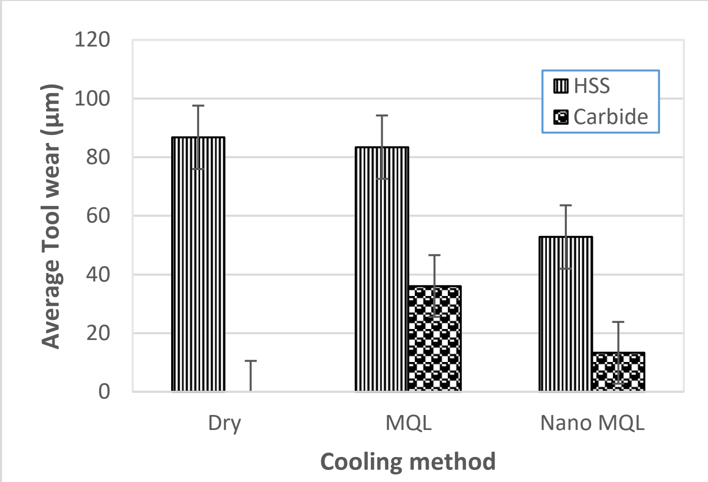

Figure 4.15. Flank wear versus cooling method at average of all cutting speed and feed rate

4.7. Variation of Tool Wear with Machining Length

The tool wear has been plotted respected to machining length as seen in Figure 4.16 and Figure 4.17. The tool wear values in graphics are the average of all milling process conditions. The tool wear in HSS cutter is higher than carbide cutter as shown in Figure 4.16 and Figure 4.17. If the change of the tool wear is assumed linearly, it can be said the carbide tool will last approximately 750s minimum and 2500s maximum (Figure 4.16 and Figure 4.17). This gives roughly 12 min minimum and 41 min maximum of machining time for the carbide tool until it reaches the wear criteria of 0.3 mm.

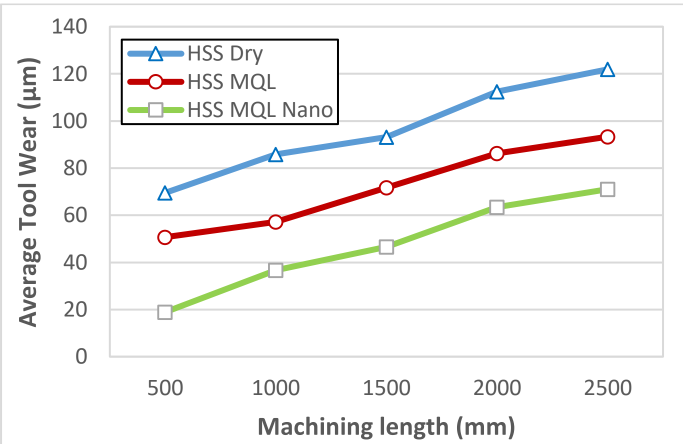

Figure 4.16. Variation of tool wear with machining time in HSS tool for all conditions

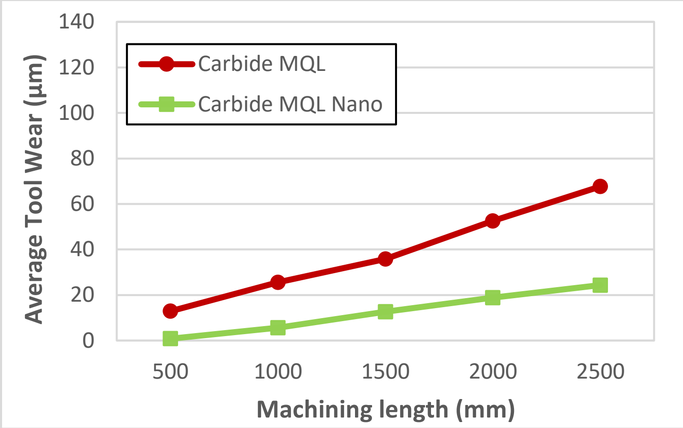

Figure 4.17. Variation of tool wear with machining time in carbide tool for all conditions

5. CONCLUSIONS

In this study, the effects of cutting tool, cooling method, feed rate and cutting speed on performance characteristics (surface roughness and tool wear) was investigated in milling of 60661-T6 aluminum alloy. Experiments were carried out different cutting tools (HSS and WC), different cooling methods (dry, MQL and nano cutting fluid), different cutting speeds (180, 200 and 220 m/min) and different feed rates (0.05, 0.06 and 0.07 mm/rev). The experimental design were performed by using a full factorial experiment design method. The results obtained this study are follow as:

1. The surface roughness and tool flank wear have been increased with the increasing cutting speed and feed rate.
2. The maximum surface roughness and tool wear were obtained in dry machining. But both the workpiece surface roughness and the tool wear has obtained lower when the cutting fluid was applied in machining.
3. Because adding nanoparticles in cutting fluid has been effected in positive direction to the performance characteristics, the minimum surface roughness and tool wear was obtained in nano cutting fluid.
4. The workpiece was welded on the tool at the end of the first pass in all cutting speed and feed rate, when workpiece machining with carbide tool without coolant. For this reason, the tool wear cannot measure in dry machining with carbide tool.
5. The surface roughness and tool flank wear in carbide tools in lower than that of HSS tools.
6. The best surface quality was obtained by using 180 m/min cutting speed, 0.05 mm/rev feed rate, carbide tool and nano cutting fluid, while the worst surface quality was obtained at 220 m/min cutting speed, 0.07 mm/rev feed rate, HSS tool and dry machining.

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Sleman Yahya RASUL

Address:
Qalat Dizah Sulaimaniah, Kurdish North Iraq
+9647501563363
+90 537 450 90 66
sleman.yahya23@gmail.com

EDUCATION

Firat University, Elazig / TURKEY
10 February 2017
MSc Degree in Construction and Manufacturing Engineering

Sulaimani Polytechnique University
Engineering College Sulaimany / IRAQ
20 June 2011
BSc Degree in Manufacturing and Materials Engineering (67.8 / 100)

Academic Preparing High School, Slemany / IRAQ
20 June 2007
English, Arabic, Maths, Physics, Chemistry, Biology…etc.

LANGUAGES

Kurdish – Native
English – General, advanced

CAPABILITIES

☐ Good ability using Microsoft Office Excel, Word and Powerpoint
☐ Work and tool offsetting on a CNC milling machine.