Comparison between submerged machining and wet machining of AISI 1020 steel

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APRIL, 2019

Declaration

I certify that this research work titled "*Comparison between submerged machining and wet machining of AISI 1020 steel*" is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

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Copyright Statement

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Abstract

This thesis presents comparative study of submerged and wet machining using Taguchi approach for AISI 1020 steel. Bridgeport series 1 vertical CNC (Computerized Numeric Control) milling machine was used by employing Taguchi $L_9(3^3)$ orthogonal array to conduct the experimental runs. The cutting speed, feed rate and depth of cut were the machining parameters used for both types of machining, while the selected control factors were surface roughness and hardness. Temperature variations were also recorded in submerged machining. The Taguchi design is a proficient and powerful test strategy where a output parameters can be optimized, using numerous components, utilizing less examinations than a factorial design. Minitab software is used to analyze experimental results. The main effects plots and variances of different parameters that directly varying surface roughness and hardness were discussed, and the most desirable cutting conditions were determined. The optimum results for submerged and wet machining for roughness calculated were a spindle speed of 1200 rev/min, a feed rate of 300 mm/min and a depth of cut of 0.3 mm. In correlation with the wet machining, submerged machining results 1-13% lower surface roughness values, for similar parameters in most of the runs. Hardness also varied reasonably in submerged machining. Hardness of machined parts that comes after submerged machining were slightly different as compare to part that comes after wet machining because abrupt cooling of workpiece taking place within the tank. Main effect plots shows that feed rate is most promising parameter in submerged machining process to change the hardness, following spindle speed and depth of cut. During the experimental runs of submerged machining, temperature variations also recorded and corresponding energy gain were calculated. For nine experimental runs average of 4467.54 J energy gain were noticed. Although heat created in machining operation essentially impact the process effectiveness and the quality of surface of the workpiece however can later be utilized as a source of energy.

Key Words: *Taguchi technique, submerged machining, wet machining, orthogonal array, heat gain*

Table of Contents

List of Figures

List of Tables

1. INTRODUCTION

The thesis work has been presented in two parts. First part is related to research setup and tactics to perform the whole dissertation involving literature reviews and experimentation. The second part includes the analysis of the both the processes of machining and recommendations based on which future works may ensue.

1.1 Background

Machining process have been the essential part of the industries since the industrial revolution [1]. Machined part mainly needs to meet the required specifications including dimensional accuracy, roughness, finishing, aesthetics etc. In milling process friction plays a significant role [2]. If not cautiously observed, rubbing between cutter and part to be machined generates huge amount of heat resulting in variation in dimensional accuracy and surface finishing. One of the issues which possibly will get up in utilizing the milling process is that the machined part achieved is differed what actually planned. It is because of the friction between tool and workpiece [3]. Amount of heat raised during machining process although problematic to the surface quality and may compromise on dimensional accuracy but can be used as a source of energy [4].

1.1.1 Machining

Machining process have been the essential part of the industries since the industrial revolution. Its due to the eminence of dimensional accuracy, machining used for production especially in CNC machines computers which increase speed of manufacturing process providing automation. Otherwise, a technician would take more time [5]. In the world of manufacturing processes, CNC machining facilities have numerous advantages such as cost effective because of time saving also complex shapes and high dimensional tolerances are possible [6-9].

1.1.2 Milling process

Milling is the process through which new surfaces came out as a result of removing planned amount of material from workpiece. Milling machine is classified as slab milling, face milling and end milling. End milling is very common manufacturing process as compared to other types of milling which majorly includes automotive industry and aviation sector where quality is an central factor. In end milling, the cutting process takes place when the tool rotates on an axis vertical to the machining part [10-11].

1.1.3 Milling Machine

There are several types of milling machine that cuts metal with the help of cutter, bed movement and sometimes coolant flow. The workpiece is clamped to the milling machine table and is feed against the revolving milling cutter. The milling cutter owned cutting teeth on the periphery or side or both [12]. Milling machine can be classified into three main headings:

- Column and knee type (horizontal and vertical machines)
- Fixed beds – (horizontal types)
- Rotary table type – (double end types)

1.1.4 Conventional milling process

Milling is broadly used machining process in the world of manufacturing in which machining is done by chip removal process. Conventional milling process perform in dry or wet environment usually. During milling process, number of parameters and their outcome on the quality of workpiece surface, needs to be monitored. Conventional milling process usually takes place in dry environment in which machining in done without coolant flow. For the machining of soft materials like aluminum alloys etc., cutting fluid are not needed because of the fact that they possess comparatively low cutting temperatures. But sometimes there are the case where machining cause temperatures reasonably as in case of hard steels. When the cutting edge goes into and out of the cut the temperature variations becomes very severe. Tools real life may leads to early end because of the cutting edge is subjected to fatigue and stresses. In order to cater this problem coolant usually applied at machining area, a fluid eliminates a greater quantity of heat, enhancing tool life and better surface finish [13].

1.1.5 Milling in Submerged environment

In addition to dry and wet machining, another type of machining is now recognizing in which the part being machined is dipped completely into submerged environment providing coolant to the machining area all the time. Machining of the components needs good quality surface and if someone needs to achieve this, appropriate coolant flow has to be supplied to the workpiece. This approach will help in achieving desired output.

Methodologies used in other researches pertaining to machining have provided very useful information for industrial use however there is a lack of research in the submerged machining regime specifically with milling process. Therefore, this research will aim to highlight the importance of this technique. By comparing the wet machining and submerged machining it could be recommended that which of the process methodology is more useful if the prominence of the surface is major consideration. As machining is a versatile process in manufacturing industries, more researches are required in this field.

1.1.6 Chip removal process during milling

The purpose of machining is the formation of a fresh surface having a dimensions according to requirement. However, this fresh surface is obtained by the chip removal process, in which nearly all the machining parameters are utilized for the creation of chips [14]. During machining process chips needs to be controlled, otherwise the resulting surface may be uneven and not according to specifications [15]. During chip formation, also huge amount of thermal energy is generated. Thermal energy is considered as the prime factor that affect the quality of output part because of resistance of the tool and the workpiece [16].

1.2 Area of research

This research work eventually aims towards the application of machining process of a steel sample; this may include wet machining as well as submerged machining which is completely new type of machining. For both these methods, surface roughness is selected as the comparative factor, which allows us to generalize after analyzing the results of experimental runs. Moreover, surface hardness and temperature profile are additional influences that primarily affecting in submerged machining. Surface hardness and energy gain are the two advantages of submerged machining over wet machining.

1.3 Research objectives

The prime objective of this thesis is to compare of submerged machining and wet machining and analyzing the effect on roughness, hardness and solution temperature on workpiece. Some of the basic goals are:

- To analyze and compare the roughness and hardness of AISI 1020 steel after performing number of experimental runs in both types of machining by choosing most suitable parameters applying Taguchi's design of experiment technique.
- To propose best combination of parameters at which roughness and hardness are optimized using signal to noise (S/N) ratio and Analysis of Variation (ANOVA) tool.
- Comparison of hardness before and after submerged machining.
- Study the temperature profile and energy gain in coolant during submerged machining.

1.4 Methodology

A methodology employed for this research is shown in flowchart presented in Figure below. Firstly, detailed literature review of submerged machining and wet machining were carried out. Literature survey of submerged machining lead to the conclusion that there is a lack of research in the submerged machining regime specifically with milling process.

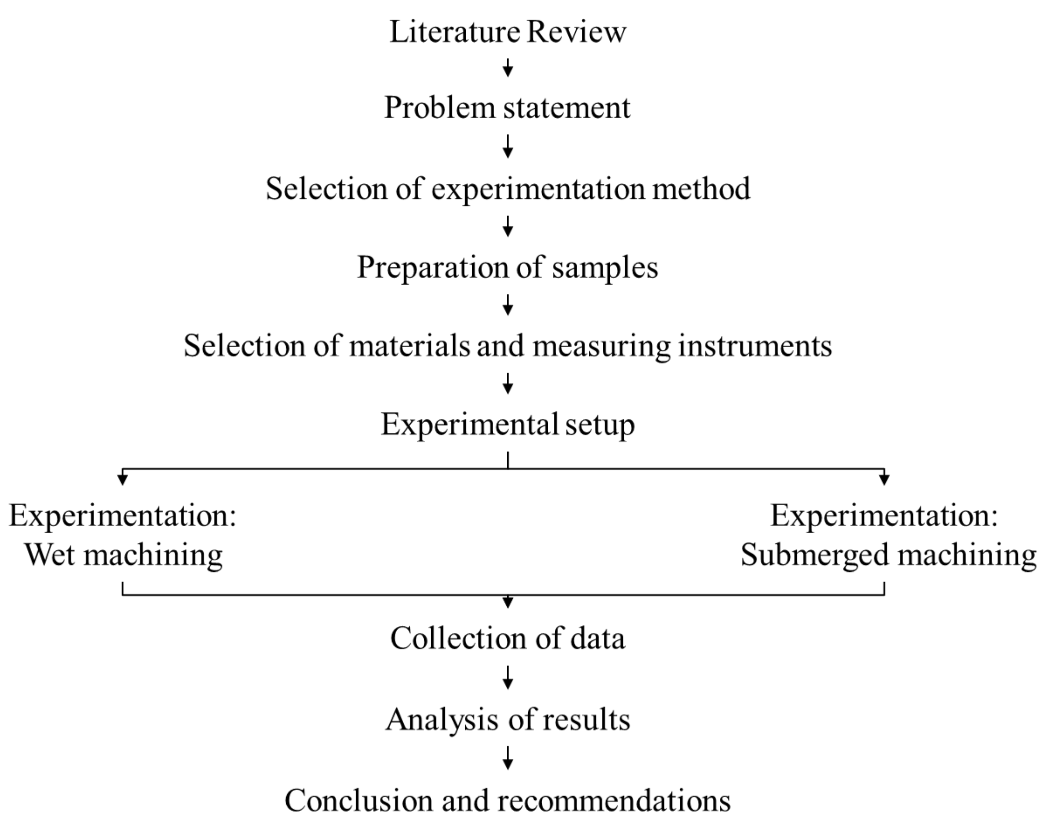

Figure 1: Flow chart of methodology of this research

1.5 Contributions

This work extends the research in machining of low carbon steel employing two types of machining i.e. wet machining and submerged machining. More specifically, it includes the following contributions:

- Roughness and hardness comparisons of low carbon steel by wet machining and submerged machining.
- Record of energy gain during submerged machining process that can later be used as source of energy for some other purpose.
- Development of submerged machining method as new machining technique.
- The result of the research from this thesis has generated one journal manuscript.

2. LITERATURE REVIEW

2.1 Background

Milling is a broadly utilized method in the world of machining. Famous for its flexibility and capacity to accomplish exact output as compare to other processes [17]. It produces machined surface by getting rid of pre-defined amount of thickness of material from workpiece [18]. During machining process shear process, bending process and compression in workpiece occurs. Heat generation also occurs which is due to plastic deformation. Because of its broad application in many diverse field, machining processes has become a global phenomenon. End milling is extensively employed in the manufacturing industries, particularly in the automotive area [19]. In end milling process, due to the friction of workpiece and tool, huge quantity of heat is produced, due to which the machined part is not according to required specification usually. Problems like dimensional variance, surface roughness, poor finishing etc. occurs which need to eliminated. The procedure of end milling is that workpiece place on the bed of CNC machine horizontally and cutter comes vertically in order to remove material. Cutting process occurs when bed moves against cutter which is rotating [20]. Various cutting fluids are proposed by researchers in machining world in order to get rid of friction which is directly applied at the interface of workpiece and tool during machining process going on. This process in which coolant is provide by external source like pumps and motors are called wet machining. Another new type of machining is proposed in this thesis, called submerged machining, in which workpiece is completely dipped into coolant and machining takes place in submerged environment providing opportunity to direct reduction of friction and heat generation [21-22].

Furthermore, the performance of machining process depend upon the parameters selected in CNC milling. Machined surface influenced majorly by input parameters selected. Numerous researches are conducted to see the necessary responses of input parameters on machined part. Quality of machined surface is the most crucial condition in machining processes, therefore thousands of researches are carried out to improve surface roughness in milling process [23]. That is the reason, suitable combination of input parameters need to be selected to acquire the necessary requirement. This chapter includes some of the research papers that are conducted aiming to understand the result of input factors on roughness, hardness and energy gain during machining process.

2.2 Surface roughness improvement:

Researchers explored how the input parameters of machining effect of surface roughness. Lou and Chen [24] established a model named as “multiple regression prediction model”. The factors selected for study are depth of cut, feed rate and spindle speed. When this model is applied the result was impressive and predicted surface roughness with 90% accuracy. Out of the remaining input parameters, feed rate is the most important factor noticed in this model.

Raju and Gedela [25] examined three basic parameters, feed rate, spindle speed and depth of cut as input factors. Surface roughness and material removal rate (MRR) are taken as output parameters . FANUC controlled vertical milling CNC is used for this experiment using Taguchi’s approach. It was observed that for Aluminum 6063, highest effecting parameters on surface roughness is spindle speed with 31% contribution and that of material removal rate is feed rate with 35.99% contribution on output. Similarly, for Aluminum A380, highest effecting parameter on surface roughness is feed rate with 34.78% contribution, also feed rate is highest effecting parameter in case of material removal rate with 34.30% contribution on output.

Prasadraju et. al [26] considered the outcome of each milling parameters like depth of cut, feed rate and spindle speed for the improvement of output parameters by reducing production times. By employing Taguchi’s ‘smaller-the-better’ approach, optimized factors for surface roughness were spindle speed of 1500rpm, depth of cut 0.50mm of and feed rate of 100mm/min, and that of material removal rate is optimized at spindle speed of 1000rpm, feed rate of 100mm/min and that of depth of cut is 0.25mm. Analysis shows that feed rate possess highest percentage of 53.64% on output therefore feed rate is highest effecting parameter as compare to other input parameters. Similarly with percentage of 48.19%, feed rate is also most effecting parameter on material removal rate amongst other input parameters.

Kumar and Paswan [27] observed the outcome of cutting speed. feed, and depth of cut on tool wear and roughness using design of experiment. The sample being machined was made of hard material AISI H-13. Response surface methodology is employed to adjust the process parameters. Tool used is made of carbide coated. Result of this study shows that as feed and depth of cut rise, surface roughness also enhance. Likewise, tool wear is directly proportional to spindle speed, if speed increases, tool wear also increases.

Philip et al. [28] employed the response surface methodology (RSM) to study the effects of spindle speed, axial depth of cut and feed rate of duplex stainless steel. Runs were performed in dry milling environment. Employing Box-Behnken design of RSM, mathematical expression has been established in order to foresee selected machining parameters. After applying response surface methodology, it is concluded that feed rate is the prominent parameter effecting on the output, then axial depth of cut is second most effecting parameter and spindle speed is last parameters that effects the output least. The experimental results also shows that main effects of process parameters are most considerable whereas interaction effect of selected input parameters are less likely to effect the output.

Tammineni and Yedula [29] conducted research on Aluminum 1050 using three factors i.e. cutting speed, feed and depth of cut. Surface roughness and flatness are the factors which needs to control using response surface methodology (RSM). Fifteen number of experiments were conducted with the variations of three parameters on CNC milling machine using Box-Behnken design. The roughness of machined surface was tested using TR-200 surface roughness tester and in order to measure flatness, Coordinate measuring machine (CMM) is used. Result illustrates that feed rate is promising parameter that effect most on surface roughness, however, flatness changed by depth of cut.

Tlhabadira et al. [30] employed Taguchi's approach to suggest best possible combination cutting process parameters of milling operation on AISI P20. Aim was to decrease surface roughness which was observed using Mitutoyo SJ–201. Cutting tool and workpiece possess stresses, displacements and temperature distributions, which were modelled using Autodesk Fusion 360 (2.0.5357) software. Nine number of experiments were carried our as there were three parameters and three levels. Using carbide inserts and cutting tools on CNC vertical milling machines, experimentation were performed. The machining parameters at which surface roughness reduced to minimum were depth of cut of 2-3mm, cutting speed of 275 m/min, spindle speed of 5471 rpm and feed of 2188mm/rev. However, the difference in resulting displacement were caused by increase in cutting forces.

Thakre [31] used additionally coolant flow as process parameters other than the basic machining parameters and corresponding roughness were observed. With four process parameters and three levels, experiments were performed using Taguchi's L9 orthogonal array. Experiments performed on 1040 mild steel. With contribution of 60.69%, coolant flow was most promising parameters that effects the output most. Other scholars, such as the one showed by Bagci and Aykut [32] also studied the cutting parameters to improve surface properties using carbide tool in CNC milling process of cobalt-based alloy (stellite 6) material.

In more related work, Abbas et al. [33] used full factorial (4^3) technique employed to adjust the process parameters like spindle speed, depth of cut and table feed. Sixty-four number of experiments were conducted following full factorial. Surface roughness (R_a and R_t) was the controlling factor during face milling operation. High strength steel was used for experimentation purpose in this study. ANOVA conducted to check the interaction of each parameters and the responses of each parameters individually.

Madl [34] examined roughness of newly formed surface after machining using PCA and Taguchi method. Using these methods experimental runs were carried out and results shows that with the rise of feed rate, surface roughness also rise. Feed rate was identified as the most promising factor, followed by the speed and depth of cut [17] .

Hayajneh et al. [35] built a regression model to examine the outcome of spindle speed, feed rate and depth of cut on the surface roughness. Roughness of the surface was the output parameter, whereas the feed rate, speed and depth of cut are the input parameters. Along with the responses of input parameters, this model also includes the interaction of any two variables on surface roughness and has accuracy of 12%.

Rawangwonga et al. [36] used semi-solid AA 7075 for experimentation purpose with carbide tool on CNC milling vertical machine. Factorial design was employed in this research. The outcomes of the runs shows that feed rate and speed were the factors that affect the output whereas, depth of cut remain unaffected. [36] used below linear equation to find the roughness with 2 edge cutting tool at 2600-3800 rpm and feed rate of 1000-1500 mm/min:

$$R_a = 0.156 - 0.000024\ x\ Speed + 0.000047\ x\ Feed\ rate$$

Rawangwonga et al. [37] considered key parameters of surface roughness semi-solid 2024 face milling. Carbide tool with two cutting edge was used in this process. The linear equation used in [37] is below which was used to check the research outcomes:

$$R_a = 0.205 - 0.000022\ x\ Speed + 0.000031\ x\ Feed\ rate$$

This formula was used along with the speed ranging from 2400-3600 rpm, feed rate range of 1000-1500 mm/min and the depth of cut of below 1 mm. Using this equation, it is concluded that the average total percentage error of surface roughness was 3.48%.

Sutar et al. [38], additionally used coolants in dry and wet machining along with depth of cut, feed and speed. L18 runs were carried out as there are four parameters and three level selected. Surface roughness were analyzed of a machined part i.e. AISI 316L and optimum values of input parameters were suggested.

2.3 Work hardening

Petru et al. [14] studied the hardness and microstructure machined part after milling with varying feed rate. The sample used for the experimentation purpose was high speed steel ASP 2023. Cutting speed was also varied along with feed rate and response on the surface was noticed. Enhanced hardness values were observed in high-speed machining. Hardness of a sample steel reduced with the increase in feed rate up to 20 m/min, after that the value of hardness becomes persistent. The results also shows that production time of the machining also reduced with rise in feed rate, which ultimately maximize the productivity and saves time.

Similarly, Tian et al. [39], used carbide cutting tool for milling of Titanium alloy TC-17. Purpose was to see the behavior of milling parameters on surface hardness.

Thakur et al. [40] used Nickel based alloys i.e. Inconel 825 for experimentation purpose during dry turning. Their purpose was to study the hardness with varying speed of cutting and chemical vapor deposition. Hardness of this alloy were analyzed, and results shows that this material has capacity for work hardening and the hardness decreased gradually when reading taken towards the center of the machined part.

In his study, Sai et al. [41] aimed to investigate residual stress along with roughness and hardness. Two types of steel samples were used in this study, first was carbon steel and second was duplex stainless steel.

Shahri et al. [42], analyze the grinding process parameters in to check the behavior of hardness parameter of a workpiece. The material been used for experimentation purpose was AISI 1045 annealed steel. The input factors to analyze includes depth of cut, wheel speed, workpiece speed, cross speed and mode of dressing. By selecting three levels along with these parameters Taguchi's L18 orthogonal was selected for experimentation purpose. Possible combinations of a parameters at which best grinding condition were meet were suggested after ANOVA.

2.4 Cutting Fluids

Kuram et al. [43] used vegetable-based cutting fluids (VBCFs) in drilling process aiming to examine the effects on thrust force and surface roughness. The material used for machining purpose was AISI 304 and cutting took place using HSS-E cutting tool. L9 orthogonal array was used for experimentation purpose.

In end milling process, Najih et al [44] used material of AA6061T6 in order to examine the process parameters using genetic algorithm (GA) approach. In this study "minimum quantity lubrication" tactic was used. For modeling purpose, response surface methodology (RSM) is used. A non-dangerous kind of vegetable oil-based coolant (Coolube 2210, UNIST, Inc.) is employed in this research.

In his work, Shankar et al. [45] considered four different vegetable based coolants like palm, coconut, sunflower, soya bean oils, and a commercial type of coolant to examine the effect of coolant with calculating the cutting force and vibration during milling. Sample being used for this study was made up of 7075–T6 hybrid aluminum metal matrix composite and the cutting took placed with the help of carbide tool. The rate of flow of the vegetable based coolants were preserved at same level and the outcomes were analyzed with a commercial coolant. The conclusion of this study shows that palm oil were best than other types of coolant minimizing cutting force and vibration. Also, the cutting fluid was found to be the promising parameter which directly effects the force and vibration.

2.5 Submerged machining

Naik et al. [46] proposed new design in machining reign representing a submerged cooling system. A CAD model of workpiece, tank and cooling system were made in Solid works and finite effect analysis done in Ansys. The benefit of this technique was quite interesting, the chip elimination go well and disperse of the cutting fluid outside of the machining area was evaded. This analysis also studied the stresses developed within the system. It is justified from this study that this cooling method is beneficial in numerous conducts, for example low-cost of method, surface roughness and cracks generated in the machining part the machining process.

Zhang et al. [47] used ceramic material in new method of machining. Material being machine is to hold into vice and the whole assembly will be submerged into the coolant while machining. Individual responses were discussed along with the responses of interaction of parameters. Results shows that surface roughness enhance by 50 - 60% using submerged machining in comparison to dry machining.

3. EXPERIMENTAL SETUP AND PROCEDURE

The machining of a steel samples were conducted using the CNC Bridgeport series 1 vertical milling machine. Moreover, prime focus of this research is to compare milling in wet and submerged environment. Performing submerged machining in which workpiece being machined is completed dipped into the coolant, on vertical milling is relatively performable and easy as compared to lathe, drilling or grinding machine.

3.1 Material and properties

In this thesis, grade AISI 1020 of mild steel is chosen because of its comparatively low price and most abundant type of steel. The properties that owned by mild steel are suitable for many applications. The chemical composition of AISI 1020 mild steel is shown in below table (material test certificate also included in Appendix A being tested from private sector university).

Table 1: Chemical composition of AISI 1020

Chemical Composition Wt.%								
Composition	C	Si	Mn	Cr	Ni	S	P	Mo
Wt. %	0.17	0.12	0.48	0.082	0.085	0.031	0.014	0.018

Further, mechanical properties of AISI 1020 steel are shown in below table [48]:

Table 2: Mechanical Properties of AISI 1020

Mechanical Properties of AISI 1020	
Mechanical Properties	**Metric**
Rockwell Hardness	64
Ultimate Tensile Strength	394.72 MPa
Yield Tensile Strength	294.74 MPa
Elongation at Break (in 50 mm)	36.5 %
Modulus of Elasticity	200 GPa
Bulk Modulus	140 GPa
Poisson’s Ratio	0.290
Mass Density	7900 kg/m^3
Specific Heat	420 J/(kg·K)

3.2 CNC Machine

CNC machines are typically categorized according to their axes [49]. Where, horizontal axes represents by X and Y axes, while Z axis represents by tool spindle movement. CNC Milling machines is the most common machines utilized in manufacturing industries. The parameter studied (spindle speed, feed rate, depth of cut etc.) are altered in accordance with orthogonal array and controlled by feeding G and M coding into this machine which is shown in below picture:

Figure 2: Bridgeport Series 1 CNC Machine

Firstly, after fastening a workpiece on the bed, machinist has to define machine zero and part zero then metal removing process will starts running following G and M program (included in appendix A). Below is the specifications of Bridgeport series 1 CNC which were used for the experimentation purpose in this study:

Table 3: Bridgeport series 1 CNC Specifications

Bridgeport series 1 CNC Specifications	
3 axis continuous path contouring.	
2 axis circular interpolation in switchable planes.	
Table Size	228mm x 1066mm
X axis (Table)	456mm
Y axis (Saddle)	305mm
Z axis (Quill)	125mm
Knee Vertical Adjustment	407mm
Spindle Motor	2 HP
Spindle Taper	R8
Spindle Speeds range	60 to 4200 RPM

3.3 Sample preparation

Machining takes place on metal sample after detailed literature study and discussions as heat gain can well-monitored using low carbon steel or high carbon steel. Machining of soft materials like aluminum alloys possess comparatively low cutting temperatures. Sample is prepared by mild steel of grade AISI 1020 for wet machining and submerged machining. Dimensions of sample prepared are as below:

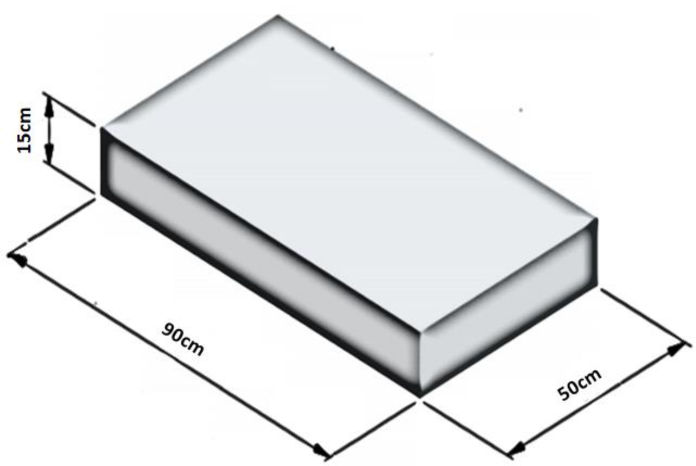

Figure 3: Dimension of sample

One long bar of uniform thickness and width been searched in the market from which required length of samples were cut by means of cutter as shown in below picture. Samples are prepared by means of cutter instead of gas cutting so that no changes in properties of material become apparent.

Figure 4: Sample cutting

Chemical and mechanical properties of AISI 1060 are already discussed in previous chapter however hardness of all the samples used for submerged and wet machining were examined using Rockwell hardness tester (CV-600BDL/MBDL) and shown in below table:

Table 4: Hardness measurements of a samples

Hardness measurements of Samples										
S / N	**Samples for Wet Machining**					**Samples for Submerged Machining**				
	Obs. 1	**Obs. 2**	**Obs. 3**	**Obs. 4**	**Mean (HRB)**	**Obs. 1**	**Obs. 2**	**Obs. 3**	**Obs. 4**	**Mean (HRB)**
Sample 1	69.180	65.660	67.260	71.950	68.513	76.560	68.330	68.980	78.410	73.070
Sample 2	68.380	66.810	68.640	71.450	68.820	64.660	70.970	73.980	72.120	70.433
Sample 3	65.500	63.610	63.300	56.920	62.333	67.280	73.510	72.690	80.090	73.393
Sample 4	57.990	68.160	68.030	59.730	63.478	74.560	71.620	69.320	73.470	72.243
Sample 5	53.560	61.410	68.410	67.510	62.723	62.500	69.320	69.090	64.960	66.468
Sample 6	69.350	79.910	79.000	77.240	76.375	69.780	67.750	75.370	77.500	72.600
Sample 7	63.790	63.120	64.710	68.310	64.983	71.560	72.890	69.120	73.120	71.673
Sample 8	67.610	66.640	68.850	70.970	68.518	70.270	73.370	67.430	80.380	72.863
Sample 9	73.620	77.830	71.480	81.520	76.113	79.410	82.240	79.900	74.410	78.990

3.4 Tank

Submerged machining took place in a tank made up of acrylic sheets, of dimensions 28cm x 17cm x 15cm (shown in below figure). Acrylic sheets been selected because of the reason that it is nonconductor of heat and heat generated by machining process cannot goes out of the tank. During the process of chip removal the variation of temperature needs to be measured. Tank been used for submerged machining provides cutting fluids between workpiece and cutter to remove quantity of heat generated between the cutting interface and the tool. Moreover, in order to place tank firmly onto the bed of CNC mill, two holes were created at the bottom by means of which workpiece to be mounted.

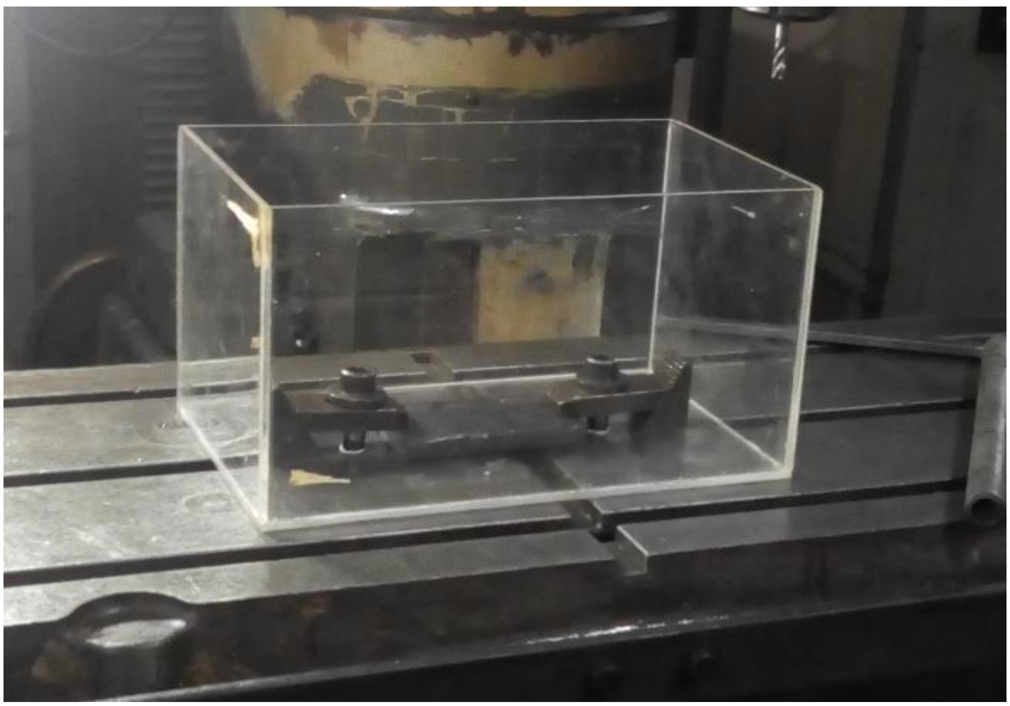

Figure 5: Acrylic sheet tank

3.5 Coolant

Coolant is used broadly in machining of a steel as a cutting fluid. It is mainly employed to lubricate the area of interaction of the tool and the material being machined. Soluble oils need to be mixed with water to effectively provide the manufacturers lubrication and heat removal benefits. Cutting fluids generally were the mixture of water and oil in a predefined ratios ranging from 10:1 to 50:1. Vegetable-based cutting fluid (VBCF) been mixed with water following Chevron Soluble Oil Mixing Recommendations chart (attached in Appendix A) that is 15:1.

Volume of coolant is 28 x 3 x 17=1428 cm^3. Coolant is filled into the tank such that workpiece is completely dipped when machining also shown in blow figure.

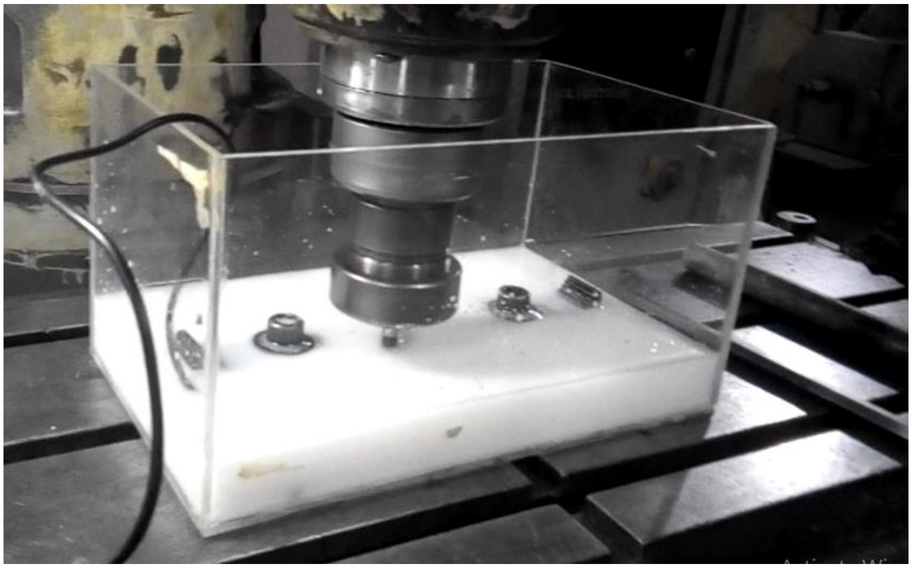

Figure 6: Vegetable-based cutting fluid (VBCF) mixed with water

3.6 Cutting tools

Tool is used to eradicate predefined amount of material from the workpiece. Types of tool being used for any machining process have a large influence on final product. From slab milling to end milling, types of tools vary for all milling process. Selection of tools like high speed steel (HSS) to carbides tool rely upon the material being machined. For low carbon steel, HSS cutting tool is best recommended. End mill cutter made of HSS of diameter 8mm is used for both types of machining.

Figure 7: HSS cutting tool 8mm dia

3.7 Roughness test

Roughness of each sample after machining was analyzed using Surftest SJ-201 Portable Surface Roughness Tester. This measures Ra, which is defined as “the average of the absolute values of the profile both above and below its center-line”.

Probe is to be moved over the surface of the workpiece and its give the roughness value in digital format. For more accuracy, this process needs to repeated several time at different locations of the surface been machined in order to get more precise result. The obtained value will be the average of all these readings which can be used later for calculations. Specification of Surftest SJ-201 are as below [50]:

Table 5: Technical Specification of Surftest SJ-201 Portable Surface Roughness Tester

Technical Specification of Surftest SJ-201 Portable Surface Roughness Tester	
Drive unit type	Standard
Detector type	4mN measuring force, 5µm stylus tip radius
Measuring range	X-axis: 17.5mm; Z-axis 25µm / 0.002µm
Resolution	360µm / 0.02µm,100µm /0.006µm, 25µm / 0.002µm
Assessed profile	Primary profile (P), roughness profile (R), DIN4776 [Primary profile (P), Roughness profile (R), MOTIF (R): M-type
Overall dimensions	52.1 x 65.8 x 160 mm (H x W x D)
Weight	500g including display unit, drive unit, and detector

3.8 Hardness test

Hardness is a mechanical property defined as the resistance to penetration. In the Rockwell test, hardness is measured by the depth of depression made by the indenter into the specimen. The indenter may be either a hardened steel ball with diameter 1.5875mm, 3.175mm or a spherical diamond cone of 120º angle. Hardness of machined workpiece were studied with the help of Rockwell hardness tester (CV-600BDL/MBDL). For this study, ball indenter of diameter 1.5875mm is used of scale HRB. The resulting hardness value is in HR. Below is the technical specification of Rockwell hardness used for study [51]:

Table 6: Technical Specification of Rockwell hardness tester

Technical Specification of Rockwell hardness tester (CV-600BDL/MBDL)	
Rockwell scales Standard	A,B,C,D,E,F,G,K,L,M,P,R,S,V
Hardness resolution	1 of a Rockwell unit
Test loads Rockwell	10kgf preload / 60, 100, 150kgf main load
Display	Full color multi-function indicator
Dwell time	0-99 sec (1 sec. step)
Measuring protocol	ISO / ASTM / JIS
Indications on display	Progress bar for preload, preload applied, main load applied, dwell time, invalid reading, invalid measurement, invalid procedure, Rockwell value, scale applied
Accuracy	Conforms to EN-ISO 6508 and ASTM E-18
Specimen accommodation	Vertical space 170mm Horizontal space (from center-line) 165mm
Specimen access	External surfaces Cylindrical surfaces down to 3mm diameter
Machine dimensions	150mm x 485mm x 700mm (WxDxH)

3.9 Temperature Variation

During the formation of chips, the generation of temperature in the interface between workpiece and cutting tool and in the coolant in case of submerged machining, are very important aspects of the process [14]. Therefore, temperature distribution have great influence in results of machining. Temperature of coolant in tank will vary up to certain temperature that need to be recorded. The dissipation of heat occurs through, mainly by the chip, the body of the test piece, the tool and the environment [14]. DS18B20 Waterproof Temperature Sensor along with Arduino Mega 2560 (picture below) used to record temperature variation during submerged machining.

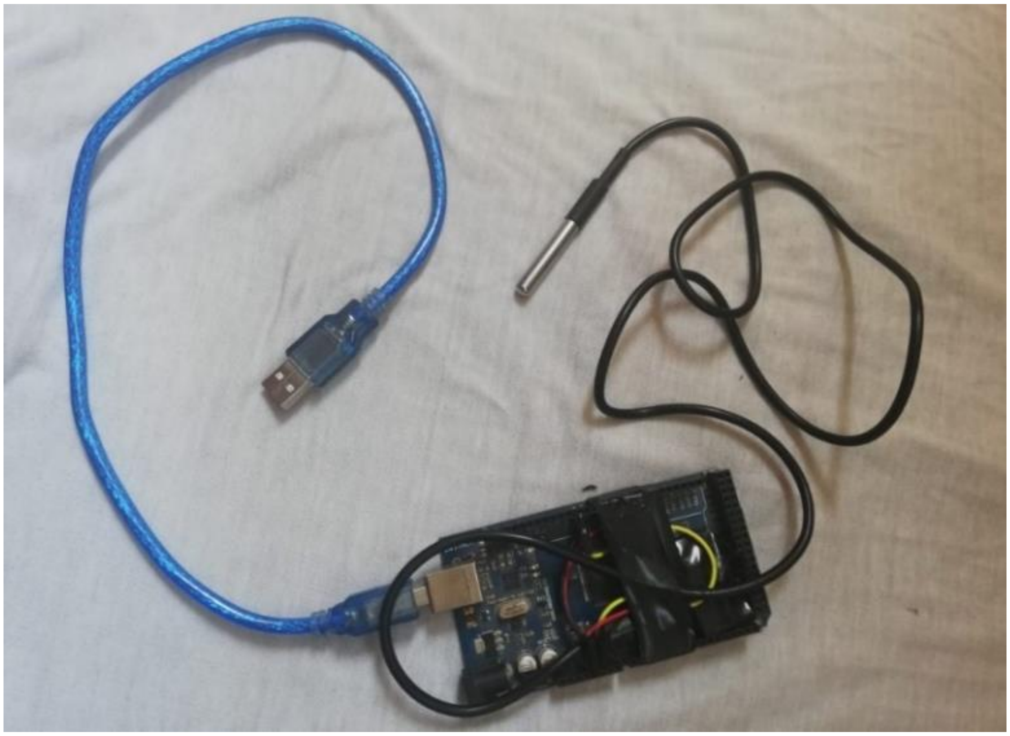

Figure 8: Arduino Mega 2560 with DS18B20 Temperature sensor

Sensor, which connected and programmed with Arduino, were carefully placed into the coolant in order to record the difference in temperature. The datasheet of this DS18B20 are given below [52]:

Table 7: Technical Specifications of DS18B20 Waterproof Temperature Sensor

Technical Specifications of DS18B20 Waterproof Temperature Sensor	
Power supply range:	3.0V to 5.5V
Operating temperature range:	-55°C to +125°C (-67F to +257F)
Storage temperature range:	-55°CC to +125°C (-67F to +257F)
Accuracy over the range of - 10°C to +85°C:	±0.5°C
3-pin 2510 Female Header Housing	
Stainless steel sheath	
Size of Sheath:	6mmx50mm
Connector:	RJ11/RJ12, 3P-2510, USB.
Pin Definition:	RED: VCC Yellow: DATA Black: GND

Programming of Arduino for to record the temperature is included in Appendix A. further technical Specifications of Arduino Mega 2560 are as below [53]:

Table 8: Technical Specifications of Arduino Mega 2560

Technical Specifications of Arduino Mega 2560	
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	54 (of which 14 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	40 mA

3.10 Selection of Taguchi Approach

To compare the two machining processes i.e. submerged machining and wet machining, number of experiments need to be carried out and corresponding results are analyzed and compared. Instead number of experiments carried out randomly, Taguchi method is employed for this research. Taguchi approach provides best opportunity to compare both these along with possible combination of parameters at which roughness is least. This new method provides the decrease in number of runs by using orthogonal arrays, suggested by Taguchi, as compare to factorial design of experiment [54]. Besides that, it provides best way to analyze the results in simple way instead of solving complex equations. This method has been functional in the production industries to solve the intricate problems particularly to see the effect of the machining parameters on the output parameters and in choosing the best possible set of conditions of already defined parameters.

3.11 Selection of factors and levels

Selection of input parameters and number of level is the most important stage in Taguchi's approach based on which orthogonal array will be selected to conduct experimental runs [56]. For milling process, depth of cut, feed rate and spindle speed are the prime dependent variables. There process parameters in milling are all those parameters that are inherent and have efficient role in removal of material. Thus the parameters at three levels are finalized at below table:

Table 9: Selection of levels

Parameters	**Level 1**	**Level 2**	**Level 3**
Depth of cut (mm): A	0.2	0.3	0.4
Feed rate (mm/min): B	300	500	800
Spindle speed (rpm): C	1200	1500	1800

3.12 Selection of Taguchi's orthogonal array

Using the array selector table shown below, appropriate array can be selected for three variables and three levels:

Number of Levels	Number of Parameters (P)														
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	L4	L4	L8	L8	L8	L8	L12	L12	L12	L12	L16	L16	L16	L16	L32
3	L9	L9	L9	L18	L18	L18	L18	L27	L27	L27	L27	L27	L36	L36	L36
4	L'16	L'16	L'16	L'16	L'32	L'32	L'32	L'32	L'32						
5	L25	L25	L25	L25	L25	L50	L50	L50	L50	L50	L50				

Number of Levels	Number of Parameters (P)														
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32
3	L36	L36	L36	L36	L36	L36	L36								
4															
5															

Figure 9: Taguchi's Array Selector [55]

The first step of Taguchi's design of experiment is done by selecting orthogonal array (L9) as we have three parameters and three levels. It is represented by L_9 (3^3). This representation of orthogonal array tells us that nine experimental runs is need to check the capability of three input parameters on the output, when you have three levels. Using Minitab software, orthogonal array of nine experimental runs is generated that need to run with the number of levels selected for each parameters. The selected parameters are showed in below table-10 and respective values for the application in Taguchi orthogonal array is shown in table-11.

Table 10: Taguchi's orthogonal array

S/N	**Depth of Cut: A**	**Feed Rate: B**	**Spindle Speed: C**
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 11: Taguchi's L9 Orthogonal Array for runs

S/N	Depth of Cut: A	Feed Rate: B	Spindle Speed: C
1	0.20	300	1200
2	0.20	500	1500
3	0.20	800	1800
4	0.30	300	1500
5	0.30	500	1800
6	0.30	800	1200
7	0.40	300	1800
8	0.40	500	1200
9	0.40	800	1500

3.13 Conditions to perform experiments

Comparison of wet machining and submerged machining are to be done quantitively therefore, data assembled needs to be identical. In order to compare both the process deliberately, conditions at which wet machining and submerged machining are performed should be identical. Therefore, during experimentation of both machining below are the states that kept same:

- Samples are prepared from same AISI 1060 bar.
- Experiments are performed on same CNC machine.
- 8mm HSS Tool used for both processes.
- Taguchi’s orthogonal array was used for experimentations therefore parameters in G and M coding used are same for corresponding runs.
- Coolant made up of Vegetable-based cutting fluid (VBCF) mixed with water with the proportion of 15:1.
- Surftest SJ-201 Portable Surface Roughness Tester used to measure roughness.
- For the measurement of hardness, Rockwell hardness tester (CV-600BDL/MBDL) is used.
- Machining time for corresponding runs are same.
- Machining takes place for single number of cut only.

4. RESULT AND DISCUSSION

Following Taguchi's orthogonal array nine experiments has been performed for wet machining and nine for submerged machining. Aim was to compare the output parameters from both machining processes as well as to optimize three input parameters in both types of milling. For each of nine runs, roughness and hardness values were recorded multiple times in order to get more precise result.

4.1 Wet Machining

Wet machining experiments were performed using vegetable based cutting fluid as a continuous coolant flow. Machining was programmed for just one cut, and the friction between cutter and machining part needs to minimize. During the machining of steel huge quantity of temperature is generated between the contact point of cutter and the workpiece. These amount of heat are responsible for part inaccuracy, dimensional variations and poor surface finishes. Coolant come into play an important role when ones need to cater the above mentioned problems. Machining takes please once workpiece clamped on the bed of CNC vertical milling machine as shown in below picture:

Figure 10: Workpiece clamp for wet machining

Material removal process takes place when the bed, that carrying workpiece, moves against the tool. Below picture shows the workpiece obtained as a result of wet machining:

Figure 11: Workpiece after wet machining

4.1.1 Roughness

For each of nine experiments, multiple times roughness were analyzed at different point of machined area in order to get more precise result. There are numerous S/N ratios presented by researchers to find the impact of input parameters on output : lower is better, nominal is best, or higher is better. As less surface roughness is required, so smaller is better S/N ratio was employed in this study. S/N ratio formula for smaller is better is given below:

$$\eta = -10 \text{ x} \log\left[\frac{1}{n}\left(\sum Y^2\right)\right]$$

Where Y is the result for factor-level assigned for runs and n is number of results for factor-level assigned for runs [56].

Experimental runs for wet machining employed by coolant flow continuously till the end of machining are shown in below table. Roughness are measured using Surftest SJ-201 Portable Surface Roughness Tester.

Table 12: Experimental runs of wet machining

Parameters				Roughness (microns)									
S/N	**A**	**B**	**C**	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**Mean**	**S/N Ratio**
1	0.20	300	1200	4.286	3.166	3.326	2.752	3.125	3.180	4.125	3.256	3.402	-10.63
2	0.20	500	1500	4.136	5.210	4.931	4.435	4.152	5.120	5.200	5.910	4.887	-13.78
3	0.20	800	1800	3.962	4.199	4.685	3.509	4.520	4.900	5.210	5.612	4.575	-13.21
4	0.30	300	1500	1.730	3.920	3.269	3.200	4.120	4.990	3.158	3.825	3.527	-10.95
5	0.30	500	1800	3.388	3.536	4.017	3.442	3.925	3.182	3.015	3.562	3.508	-10.90
6	0.30	800	1200	4.007	4.978	4.922	3.959	4.010	4.220	4.350	4.208	4.332	-12.73
7	0.40	300	1800	4.406	4.331	3.241	3.484	3.522	3.255	3.528	4.667	3.804	-11.61
8	0.40	500	1200	3.666	3.684	3.765	3.515	3.625	3.562	3.687	3.768	3.659	-11.27
9	0.40	800	1500	6.002	6.171	6.655	7.008	6.128	6.125	6.175	6.015	6.285	-15.97

4.1.1.1 Main effect plot

Taguchi's "the smaller the better" performance approach has been chosen, as the performance characteristic is surface roughness. Using Minitab software the main effect plots of S/N ratios and means for surface roughness (Ra) is plotted and represented in graph. Analysis of variation (ANOVA) is performed in order to optimize the process parameters.

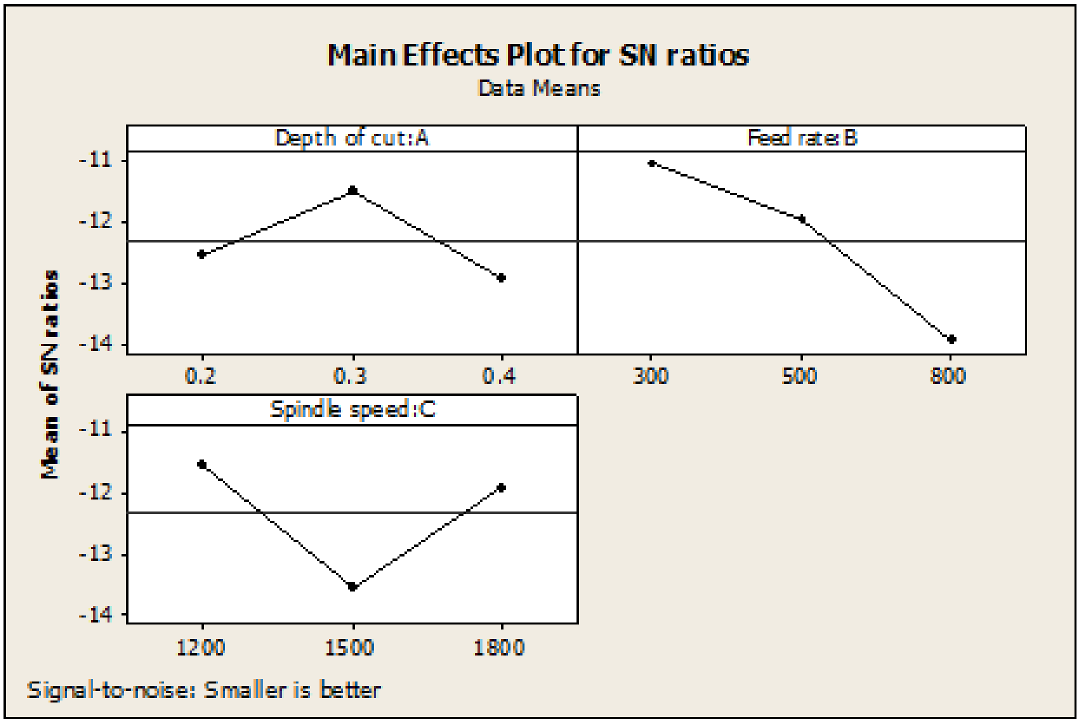

Figure 12: Wet machining-roughness: main effect plot of S/N Ratio

The main effect plot shows that feed rate is one of the most dependent parameters that directly effecting on output because it is largely deviating from mean as compare to other parameters. The second parameter which is dependent on surface roughness is spindle speed and then third is depth of cut. From the main effect plot of S/N ratio, optimized parameters comes out to be A2-B1-C1. i.e. depth of cut to be 0.30mm, feed rate of 300mm and spindle speed of 1200rpm.

Table 13: Roughness-wet machining: Optimized result by ANOVA

	Depth of cut: A	**Feed Rate: B**	**Spindle Speed: C**
Level	2	1	1
Values	0.30	300	1200

4.1.2 Hardness

Hardness measurement of a steel using Rockwell hardness testing machine is quite easy. Indenter penetrates into the surface of a sample by automatically generated pressure and gives results in digital format. At different point of a machined sample, hardness were measured and taken an average of all the measured values in order to get more accurate result. It depends on the requirement of the particular case that whether hardness values need to be larger or smaller. In this study, “larger-the-better” criteria is used assuming that larger values of hardness are more likely. The formula for Signal to Noise ration calculation are given below [56]:

$$\eta = -10 \text{ x} \log \sum \left[\frac{1/Y^2}{n} \right]$$

Where Y is the result for factor-level assigned for runs and n is number of result for factor-level assigned for runs.

Parameters				Hardness (HRB)					
S/N	**A**	**B**	**C**	**H1**	**H2**	**H3**	**H4**	**Mean**	**S/N Ratio**
1	0.20	300	1200	68.38	66.81	68.64	71.45	68.82	36.754
2	0.20	500	1500	69.18	65.66	67.26	71.95	68.51	36.715
3	0.20	800	1800	65.50	63.61	63.30	56.92	62.33	35.894
4	0.30	300	1500	57.99	68.16	68.03	59.73	63.48	36.052
5	0.30	500	1800	53.56	61.41	68.41	67.51	62.72	35.948
6	0.30	800	1200	69.35	79.91	79.00	77.24	76.38	37.659
7	0.40	300	1800	63.79	63.12	64.71	68.31	64.98	36.255
8	0.40	500	1200	67.61	66.64	68.85	70.97	68.52	36.716
9	0.40	800	1500	73.62	77.83	71.48	81.52	76.11	37.629

4.1.2.1 Main effect plot

Main effect plot of ‘Larger-the-better’ has been employed in order to optimize hardness of machined part. Below is the main effect plot of S/N ratio:

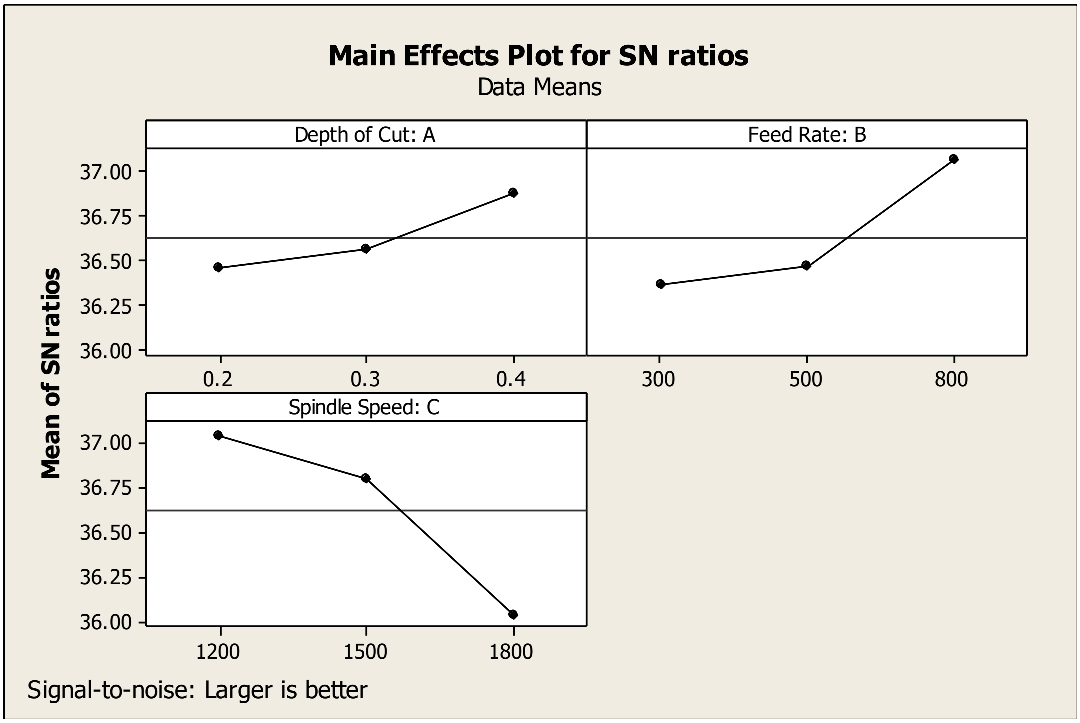

Figure 13: Wet machining hardness: Main effect plot

It is evident from above ANOVA plot for signal to noise ratio that spindle speed is the most prominent factor that effect on the hardness most, followed by feed rate and depth of cut. From the main effect plot, optimized parameters at which hardness comes largest are A3-B3-C1 i.e. depth of cut of 0.40mm, feed rate of 800mm/min and spindle speed of 1200rpm, also shown in below table:

Table 14: Hardness-wet machining: Optimized result by ANOVA

	Depth of cut: A	**Feed Rate: B**	**Spindle Speed: C**
Level	3	3	1
Values	0.40mm	800mm/min	1200rpm

4.2 Submerged Machining

Initially, design and fabrication of a container was carried out of size 280 mm x 17 mm x 150 mm which was mounted on the bed of vertical milling machine in such a way that it is able to hold the work piece that is to be cut. Workpiece of size 90mm x 50mm x 15mm of material AISI 1020 mounted inside the container by means of two clamps at sides as shown in below figure.

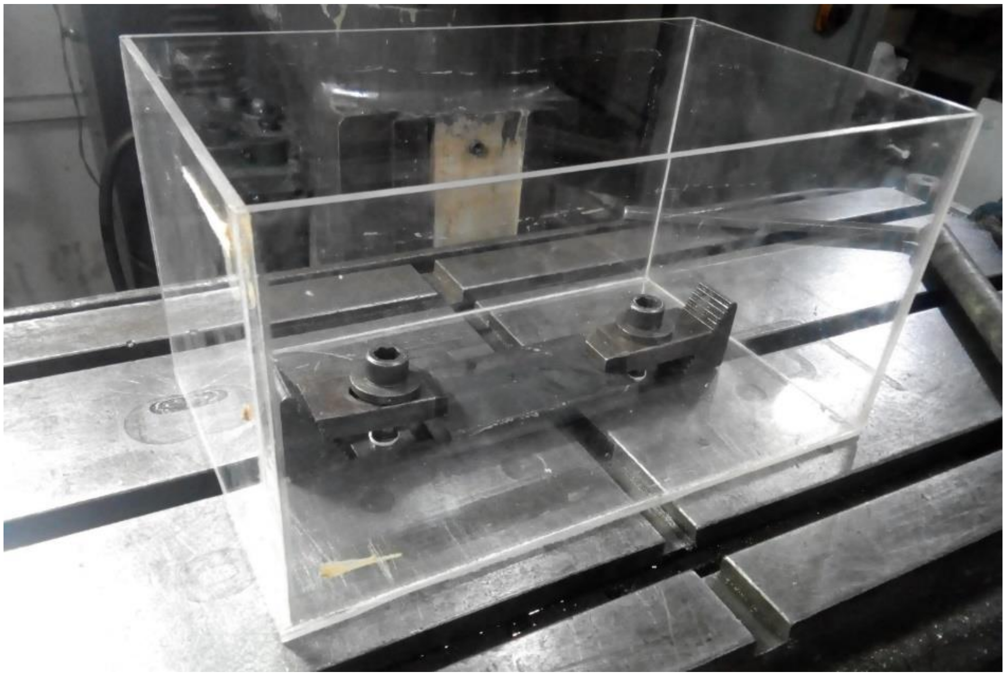

Figure 14: Acrylic sheet tank for submerged machining

Ensuring that workpiece is mounted correctly, container were filled with coolant of volume 28 x 3 x 17=1428cm3 in such a way that workpiece completely dipped under coolant as shown in below figure. Coolant is the ratio of water and Vegetable-based cutting fluid i.e. 15:1. As no piping and pumps were designed for this system therefore drainage and filling pack of a coolant need to repeat for each experiments.

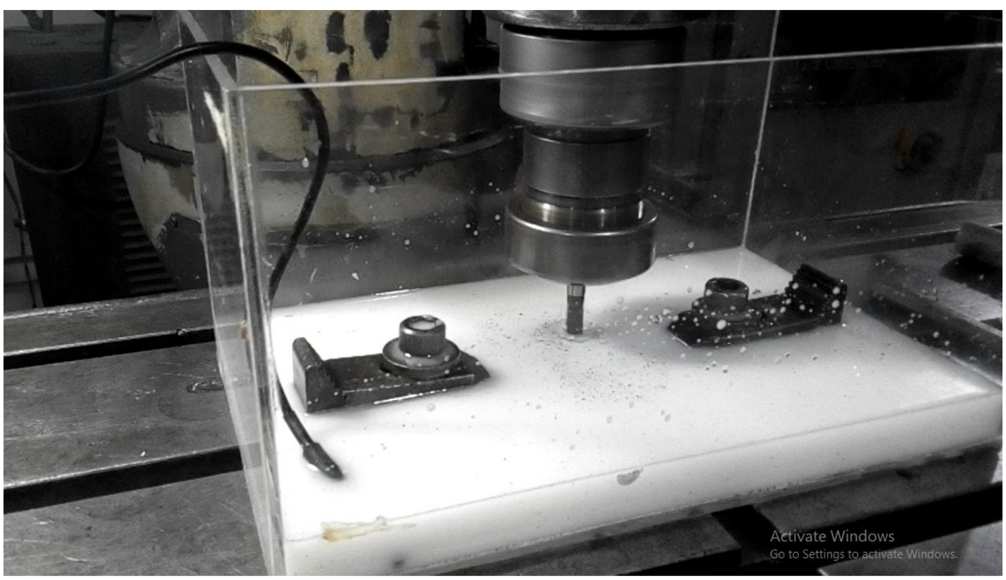

Figure 15: View of Submerged machining process

Moreover, in order to record variation in temperature throughout the submerged machining process, sensor positioned within the coolant. Temperature recorded by means of Arduino Mega 2560 that connected directly to the DS18B20 sensor.

4.2.1 Roughness

Experimental runs for submerged machining were conducted in such a way that workpiece is completed dipped into the coolant till the end of machining. Roughness are measured using Surftest SJ-201 Portable Surface Roughness Tester.

Table 15: Experimental runs of Submerged machining

Parameters				**Roughness(micorns)**									
S/N	**A**	**B**	**C**	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**Mean**	**S/N Ratio**
1	0.20	300	1200	3.644	3.717	3.093	2.564	3.521	3.245	3.125	3.712	3.328	-10.44
2	0.20	500	1500	6.347	5.678	6.458	3.458	6.215	5.982	4.258	4.568	5.371	-14.60
3	0.20	800	1800	4.786	4.114	4.445	5.017	5.012	4.012	3.925	3.125	4.305	-12.68
4	0.30	300	1500	3.973	4.659	4.013	2.016	3.125	4.059	2.910	2.999	3.469	-10.80
5	0.30	500	1800	3.371	3.781	3.363	3.986	3.872	3.012	3.254	2.922	3.445	-10.74
6	0.30	800	1200	3.218	4.489	3.767	2.259	3.222	3.550	3.225	3.114	3.356	-10.52
7	0.40	300	1800	3.512	3.915	4.012	3.992	3.987	3.615	3.411	3.014	3.682	-11.32
8	0.40	500	1200	3.944	4.252	3.046	4.158	3.013	3.657	3.152	3.225	3.556	-11.02
9	0.40	800	1500	4.985	5.975	4.229	4.321	5.124	5.667	5.889	5.985	5.272	-14.44

4.2.1.1 Main effect plot

In this section, an ANOVA tool was employed to interpret the outcomes of experimental runs and identify the trending factors on the surface roughness. Main effect plot of the three machining parameters i.e. speed, feed rate and depth of cut against S/N ratio is analyzed. Similar to ANOVA test for wet machining, “smaller the better” approach is the criteria for optimization.

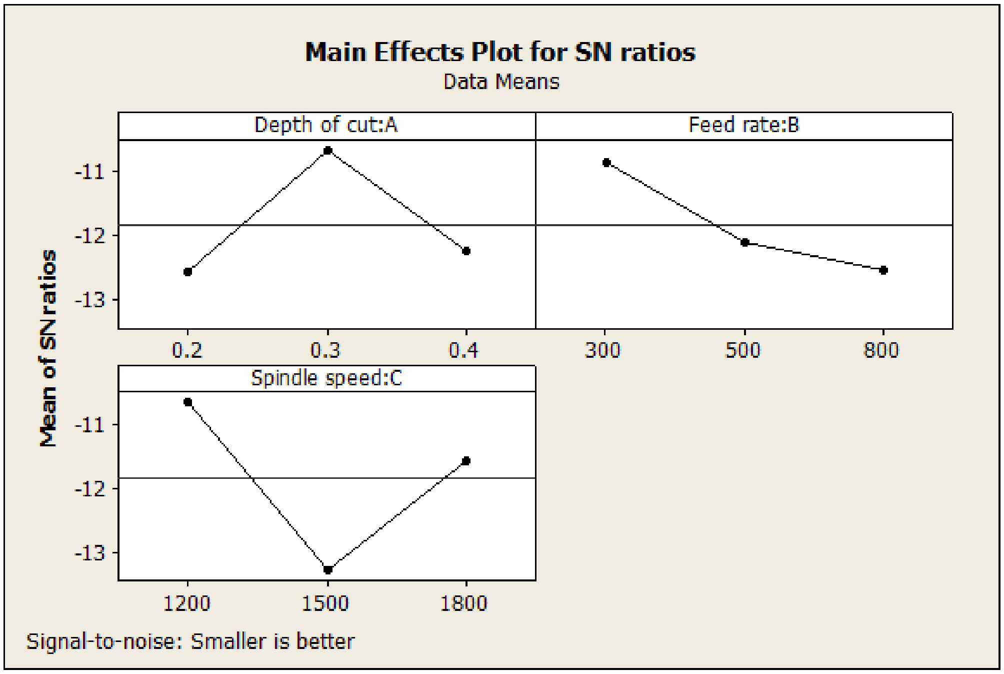

Figure 16: Submerged machining-roughness main effect plot of S/N Ratio

The main effect plot shows that spindle speed is one of the most dependent parameters that effect on output because of it is varying larger from mean as compare to other parameters. The second dependent parameter is depth of cut and then third is spindle speed. From the main effect plot of S/N ratio, optimized parameters comes out to be A2-B1-C1. i.e. depth of cut to be 0.30mm, feed rate of 300mm and spindle speed of 1200rpm. This shows that optimized parameters for both submerged and wet machining are same.

Table 16: Optimized parameters by ANOVA

	Depth of cut: A	**Feed Rate: B**	**Spindle Speed: C**
Level	2	1	1
Values	0.30	300	1200

4.2.2 Hardness

Hardness is an important property that needs to be tested when machining process takes place. Rises and falls of heat energy within workpiece are responsible for the variation in hardness. Work piece being dipped into the coolant throughout the machining process, submerged machining provides best event opportunity to change in hardness property abruptly. Below table shows the hardness values after nine experimental of submerged machining and 'larger-the-better' signal to noise ratio is calculated:

Parameters				Hardness (HRB)					
S/N	A	B	C	H1	H2	H3	H4	Mean	S/N Ratio
1	0.20	300	1200	64.66	70.97	73.98	72.12	70.43	36.955
2	0.20	500	1500	76.56	68.33	68.98	78.41	73.07	37.275
3	0.20	800	1800	67.28	73.51	72.69	80.09	73.39	37.313
4	0.30	300	1500	74.56	71.62	69.32	73.47	72.24	37.176
5	0.30	500	1800	62.50	69.32	69.09	64.96	66.47	36.453
6	0.30	800	1200	69.78	67.75	75.37	77.50	72.60	37.219
7	0.40	300	1800	71.56	72.89	69.12	73.12	71.67	37.107
8	0.40	500	1200	70.27	73.37	67.43	80.38	72.86	37.250
9	0.40	800	1500	79.41	82.24	79.90	74.41	78.99	37.951

4.2.2.1 Main effect plot

Employing ''larger-the-better' criteria, it can be seen for main effect plot that feed rate is the most promising parameter that effect the hardness most following spindle speed and depth of cut.

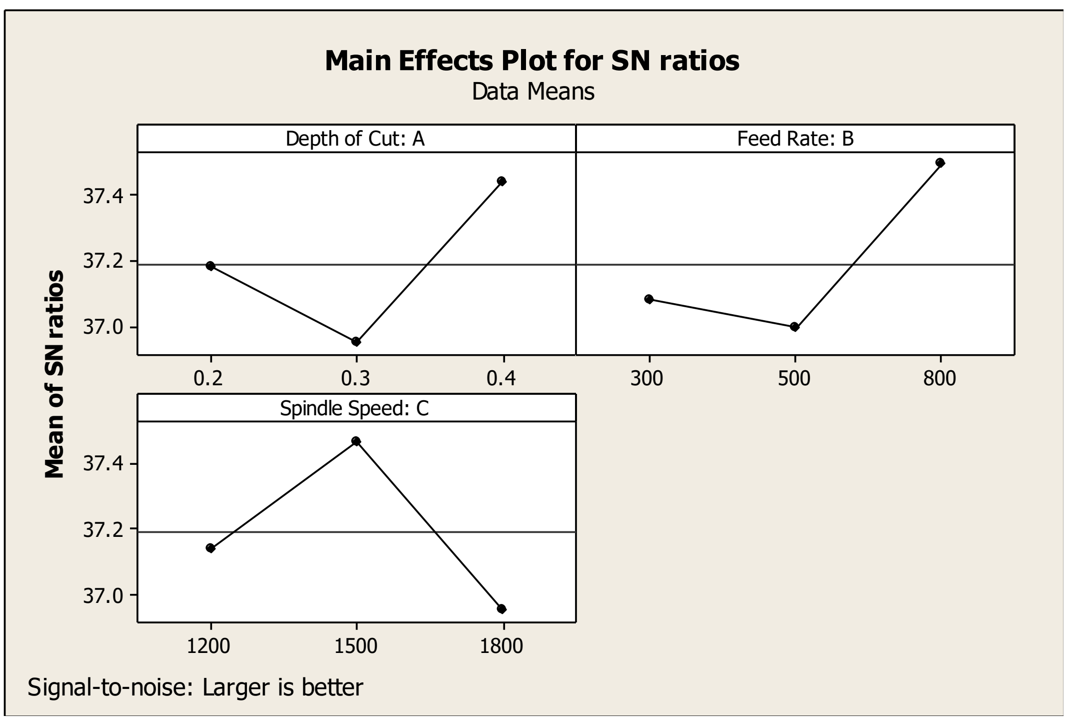

Figure 17: Submerged machining-hardness: Main effect plot of S//N ratio

From above ANOVA plot it can be derived that optimized parameters for larger hardness value in submerged machining are A3-B3-C2 i.e. depth of cut of 0.40mm, feed rate of 800mm/min and spindle speed of 1500rpm as shown in below table:

	Depth of cut: A	**Feed Rate: B**	**Spindle Speed: C**
Level	3	3	2
Values	0.40mm	800mm/min	1500rpm

4.3 Wet Machining v/s Submerged Machining

Prime focus was to compare wet machining and submerged machining. The process methodology of both the types were same instead, submerged machining introduced coolant in the tank providing cooling effect throughout the machining. The main concern regarding submerged milling are following:

- The extent of the table would be limited to within the box size , which would mean no overhanging long parts, even simple things such as cranking the vise handle within a confined space can be troublesome.
- To clamp workpiece within tank is problematic, especially when machining of complex part that requires jigs for clapping purpose and time consuming.
- The chips cannot get away from the tank. Machining for extended time require to remove chips and special cleaning.

4.3.1 Roughness

Milling of both the process are performed based on Taguchi's L9 orthogonal array such that CNC milling machining(Bridgeport series 1 CNC) and tool used (8mm diameter) were same for eighteen experimental runs of submerged and wet machining. Below chart is the comparison of roughness of nine experiments of submerged machining and nine experiments of wet machining. It is apparent from the results that as the speed and feed rate is amplified the surface finishing become better. The impact of speed can be credited to the fact that as speed builds, the shear angle rises and the friction reduces. Comparison shows that roughness of experiment no. 2 of wet machining is 5.731 µm and submerged machining is 4.887 µm, rest of the results shows that roughness are minimum in case of submerged machining. The -5% varied result in experiment no. 2 can be attribute to the fact that clamping of workpiece into the submerged environment in the tank was quite challenging. Larger difference noticed at experiments no. 8 at which wet machining roughness is 6.285 µm and roughness after submerged machining comes out to be 5.272 µm.

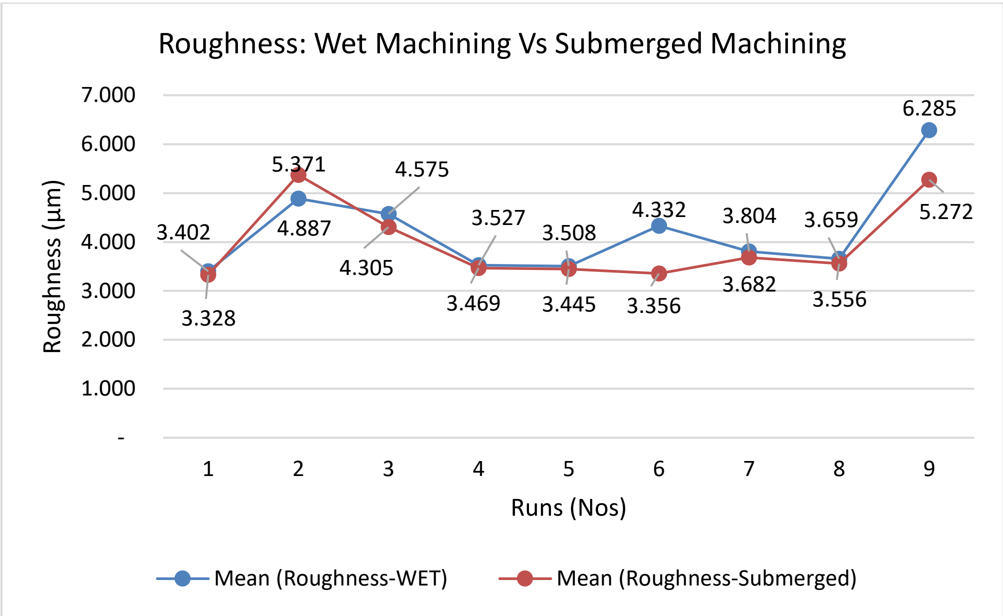

Figure 18: Roughness chart: Wet Machining Vs Submerged Machining

4.3.2 Hardness

Hardness is an important property of a steel. Workpiece been machined in submerged environment provide a change of variation in hardness. Hardness of machined parts comes after submerged machining were noticed slightly different as compare to that comes after wet machining because abrupt cooling of workpiece taking place within the tank. Therefore hardness of steel sample were analyzed before and after submerged machining and shown in below table.

Table 17: Before and after hardness in submerged machining table

Parameters				Before Machining-Hardness(HRB)					After Machining-Hardness(HRB)				
S / N	**A**	**B**	**C**	**H1**	**H2**	**H3**	**H4**	**Mean**	**H1**	**H2**	**H3**	**H**	**Mean**
1	0.20	300	1200	72.15	65.13	68.13	70.97	69.09	64.66	70.97	73.98	72.12	70.43
2	0.20	500	1500	72.12	69.59	70.56	75.55	71.95	76.56	68.33	68.98	78.41	73.07
3	0.20	800	1800	80.45	70.12	75.22	73.51	74.82	67.28	73.51	72.69	80.09	73.39
4	0.30	300	1500	69.98	72.56	73.16	72.62	72.08	74.56	71.62	69.32	73.47	72.24
5	0.30	500	1800	64.56	66.53	70.06	69.32	67.61	62.50	69.32	69.09	64.96	66.47
6	0.30	800	1200	68.75	76.50	73.16	68.75	71.79	69.78	67.75	75.37	77.50	72.60
7	0.40	300	1800	69.27	72.37	66.43	79.38	71.86	71.56	72.89	69.12	73.12	71.67
8	0.40	500	1200	76.41	69.24	74.90	68.41	72.24	70.27	73.37	67.43	80.38	72.86
9	0.40	800	1500	80.13	70.36	78.56	82.24	77.82	79.41	82.24	79.90	74.41	78.99

Hardness of steel sample AISI 1020 were analyzed before and after submerged machining. Minor change in hardness were observed and shown in the figure below:

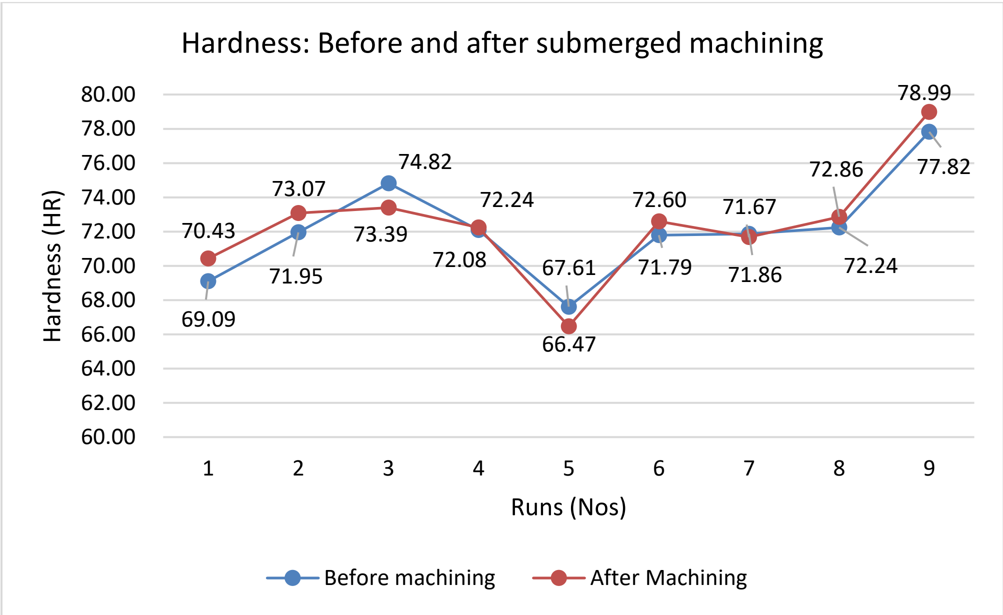

Figure 19: Hardness chart before and after machining

4.4 Heat gain submerged machining

During submerged machining process, due to occurrence of permanent distortion of a workpiece, extensive measure of the machine energy is moved into the cutting fluid. The temperature distribution occurred in the fluid because of extensive friction at contact point between tool and machining part, also chips dispersed possessed of high energy. Temperature distribution relies upon the heat conductivity and specific heat capacity of the cutter and the machining part and lastly the measure of heat dissipation by conduction and convection. Temperature variation of a coolant were noticed from the point where machining starts till the end of a machining as shown in below figure.

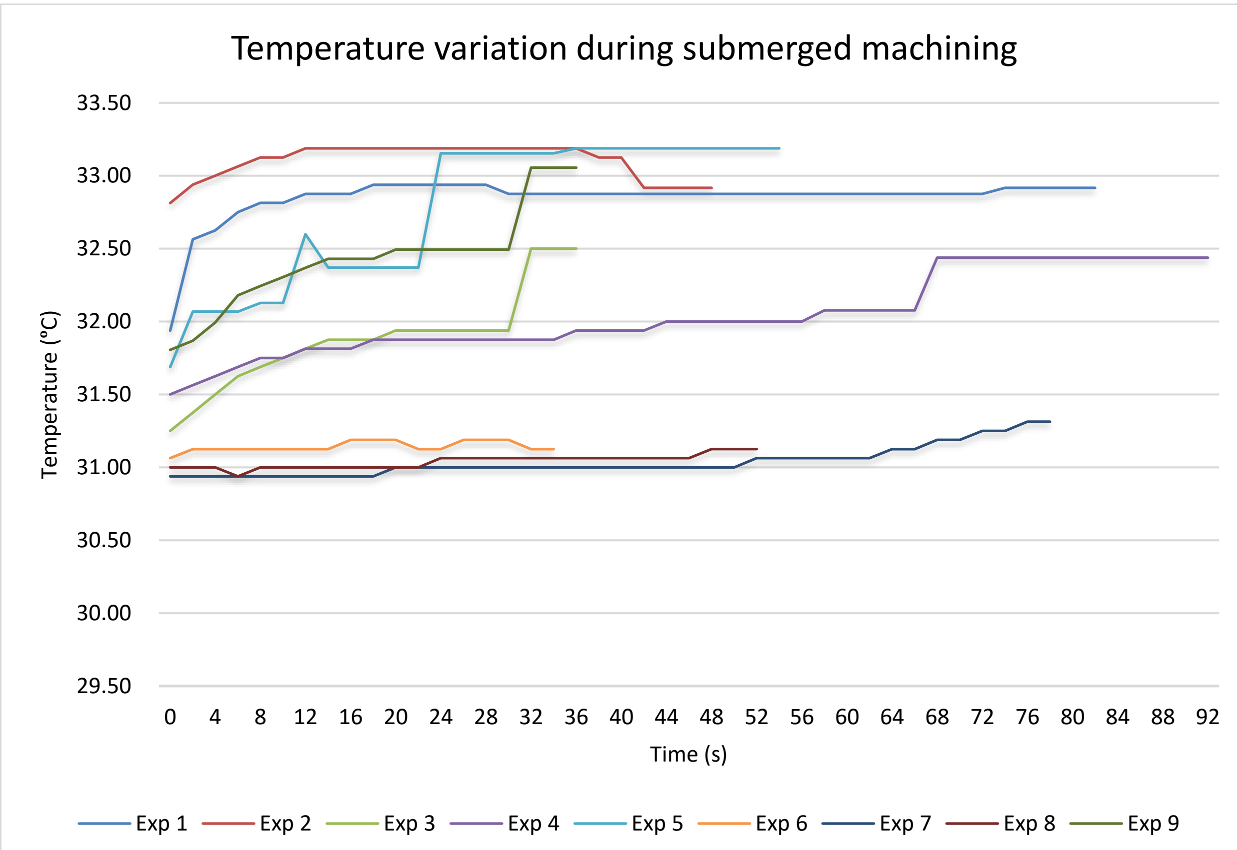

Figure 20: Temperature Variation during submerged machining

Heat capacity is a is a quantifiable physical amount equivalent to the proportion of the heat added to an item to the subsequent temperature change. Using the principle of mixture the heat capacity of a cutting fluid can be calculated. The new heat capacity relies upon the extent of every portion, which can be determined from mass or volume. C_p of mixture can be determined by following formula [57].

$$C_{p\,mixture} = \left(\frac{m_1}{m_{mixture}}\right) C_{p1} + \left(\frac{m_2}{m_{mixture}}\right) C_{p2}$$

Whereas, m_1=mass of water, m_2=mass of oil, $m_{mixture}$=mass of mixture, C_{p1}=Heat capacity of water, C_{p2}=Heat capacity of oil. Putting values C_p of mixture can is found as:

$$C_{p\,mixture} = \left(\frac{1338.75}{1423.5375}\right) 4.18 + \left(\frac{84.785}{1423.5375}\right) 1.80$$

$$C_{p\,mixture} = 4035\, J/kg \bullet K$$

The amount of heat achieved by each experiment can be calculated by below formula

$$\mathrm{Q} = m_{mixture}\ x\ C_{p\,mixture}\ x\ \Delta T$$

Table 18: Energy gain in submerged machining

S/N	**A**	**B**	**C**	**Min Temperature (ºC)**	**Max Temperature (ºC)**	**Difference (ºC)**	**Energy Gain (J)**
1	0.20	300	1200	31.94	32.94	1.00	5,743.97
2	0.20	500	1500	32.81	33.19	0.38	2,153.99
3	0.20	800	1800	31.25	32.50	1.25	7,179.97
4	0.30	300	1500	31.50	32.44	0.94	5,386.57
5	0.30	500	1800	31.69	33.19	1.50	8,615.96
6	0.30	800	1200	31.06	31.19	0.13	718.00
7	0.40	300	1800	30.94	31.31	0.37	2,153.99
8	0.40	500	1200	30.94	31.13	0.19	1,075.40
9	0.40	800	1500	31.81	33.06	1.25	7,179.97

Below graph shows the energy gain against the experimental runs in submerged machining. Maximum energy recorded in experiment no. 5 that is 8615.96 J and minimum energy recorded at experiment no. 6 which is 718.00 J. The reason can be attribute to the circumstance that increase in speed results in increase in temperature and consequently increase in energy gain as shown in above table.

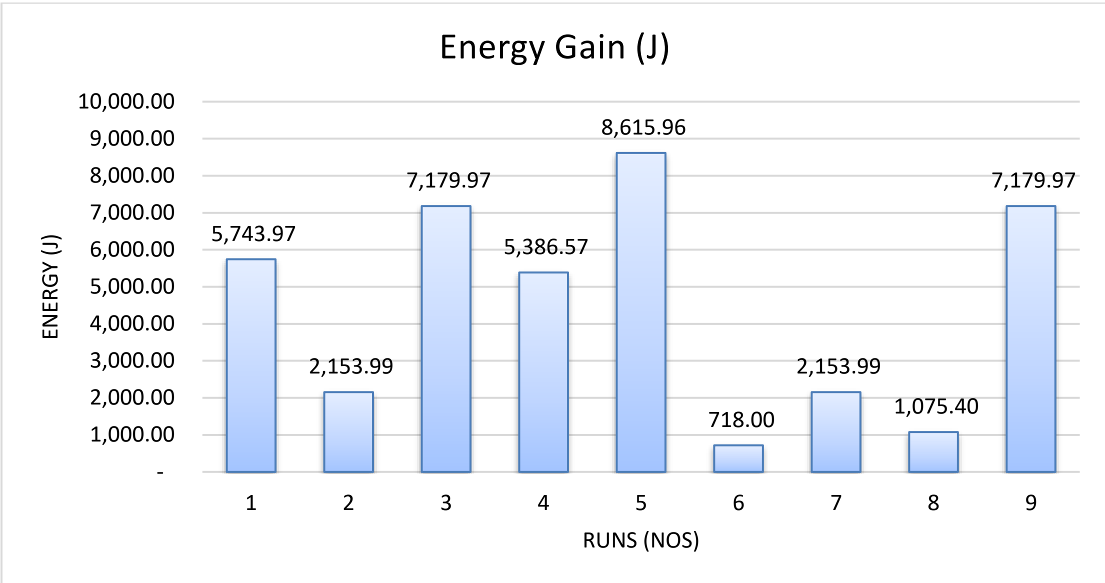

Figure 21: Energy Gain in submerged machining

5. CONCLUSION AND FUTURE RECOMMENDATIONS

5.1 Conclusion

In this thesis, two process methodologies were employed for milling of AISI 1020 i.e. submerged machining and wet machining aiming to show comparative study of both machining processes. Moreover, parameters at which roughness and hardness results reduced to minimum also optimized using Taguchi L9 orthogonal array. The key findings drawn are:

1. Taguchi method has been effectively applied for optimizing the input parameters of Milling of AISI 1020 mild steel. The optimum results for reducing surface roughness value are A2-B1-C1 i.e. a depth of cut of 0.3 mm, a feed rate of 300 mm/min and spindle speed of 1200 rev/min. The optimized parameters were apparently found same for both wet machining and submerged machining.

2. It is apparent from the results that as the speed is increased the surface finishing become better. The impact of cutting speed can be credited to the fact that as speed builds, the shear angle rises and the friction reduces. Roughness result of experiment no. 2 of wet machining is 5.731 µm and submerged machining is 4.887 µm, rest of the results shows that roughness are minimum in case of submerged machining. Larger difference noticed at experiments no 8 at which wet machining roughness is 6.285 µm and roughness after submerged machining comes out to be 5.272 µm. In comparison with the wet machining, submerged machining results 1-13% lower surface roughness values, for similar parameters in most of the runs.

3. At different point of a machined sample for both machining processes, hardness are measured. "larger-the-better" criteria is used in this study assuming that larger values of hardness are more likely. ANOVA plots shows that feed rate is most promising parameter in submerged machining process to change the hardness property, following spindle speed and depth of cut.

4. Hardness before submerged machining and after submerged machining were compared and it is noticed that hardness varied. In some experiments like experiment no. 3, 5 and

8, it is noticed that softening of workpiece takes place whereas, in rest of the experiments works hardening of the material is observed.

5. Heat dissipation by chips formation, rubbing of tool and work piece and workpiece plastic deformation into the fluid were measured from temperature difference and average of 4,467.57 J is noticed. Maximum heat gain measured in experiment no. 5 which is 8,615.96 J at which spindle and feed rate is 1800 rpm and 500 mm/min respectively. Furthermore, it is evident from results that increase in cutting speed results in increase in temperature.

6. Experiments carried out for single number of cut, therefore roughness, hardness and temperature changes was not that significant. For remarkable output values, experiments needs to carried out for longer times.

5.2 Future recommendations

1. The extent of the table are limited to within the box size , which would mean no overhanging long parts, even simple things such as cranking the vise handle within a confined space can be troublesome. For such problem, need modifiable tank considering coolant follow in a process.

2. To clamp workpiece within tank is problematic and time consuming, especially when machining of complex part that requires jigs for clapping purpose. For this, vice within the tank can better proposed.

3. The chips cannot get away from the tank. Machining for extended time require to remove chips and special cleaning. For this, setup need to remove chips during process.

4. To achieve more precise outcomes, more runs are needed for longer time, selecting Taguchi's L27 orthogonal array.

5. Comparison of submerged machining and wet machining can be done by using different coolants.

6. Perform Submerged machining by continuous flow of coolant using pumps and heat exchanger.

7. Detailed research on submerged machining principles and applications.

8. Effect of different coolant on workpiece in submerged machining and corelate the different parameters.

APPENDIX A

Chevron Soluble Oil Mixing Recommendations chart

MIXING RECOMMENDATIONS

First figure indicates parts of water. Second figure indicates parts of Chevron Soluble Oil B.

Material	Turning, Shaping, Planing, Drilling	Milling	Pipe and Plain Threading	Automatic Screw Machines	Grinding	Thread Grinding	Deep Drilling	Gear Shaving or Cutting
Plain, medium, and high carbon steels	20:1	20:1	→	20:1	50:1	20:1	→	20:1
Alloy steels	15:1	15:1	→	15:1	50:1	15:1	→	15:1
Ingot iron, wrought iron, low carbon steels	15:1	15:1	→	15:1	50:1	15:1	→	15:1
Stainless steels, tool and die steels	10:1	10:1	→	10:1	50:1	10:1	→	10:1
Aluminum and aluminum alloys	25:1	25:1	30:1	30:1	50:1	30:1	20:1	30:1
Copper and brass	25:1	25:1	30:1	30:1	→	→	20:1	30:1
Zinc and zinc alloys	25:1	30:1	30:1	30:1	→	→	20:1	→
Bronze and high strength copper alloys	10:1	10:1	10:1	10:1	50:1	10:1	→	10:1
Magnesium and magnesium alloys	**FIRE HAZARD**							
Titanium and titanium alloys	10:1	10:1	→	→	→	→	→	→
Nickel and nickel alloys	10:1	10:1	→	10:1	50:1	10:1	→	10:1
Cast iron	Dry	Dry	Dry	→	Dry	Dry	Dry	Dry

→ Seldom used.

Emulsions of soluble metalworking fluids and water may become contaminated with harmful microorganisms such as bacteria and fungus, which can cause illness and infection. This can occur even in emulsions with fluids that initially contain some biocide because the biocide can be depleted during service. A metalworking fluid maintenance program should be followed in order to control this hazard. Such a program may require the use of biocides.

Material Test Certificate

NED UNIVERSITY OF ENGINEERING AND TECHNOLOGY
Department of Materials & Metallurgical Engineering
MATERIAL TESTING LABORATORIES

Off: 99261261-68, Ext.: 2516
Fax: 99261255
Email: alidad@neduet.edu.pk

Customer Name: NUST, PNEC.
Type of sample: STEEL
Date: April 29, 2019

Standard Test Method for:
OES: OES-DIN 55350

CHEMICAL COMPOSITION (OES)

Sr. No.	Sample	Chemical Composition Wt. %									
		Fe	C	Si	Mn	Cr	Ni	S	P	Mo	[illegible]
1	STEEL	97.9	0.17	0.12	0.48	0.082	0.085	0.031	[illegible]	[illegible]	[illegible]

Remarks
i. Results pertain to the sample received and sampling was done at your end.
ii. No counter portion/un-expended part of the sample has been retained.
iii. Test report cannot be made a part of the litigation/court proceedings.

For
Dr. Ali Dad Chandio
Associate Professor &
Testing Coordinator/Lab Incharge

Department of Metallurgical Engineering
NED University of Engineering
and Technology, Karachi.

Prof. Dr. Amir Iqbal
Chairman Materials & Metallurgical Engineering
Departments

Arduino Programming

```
#include <OneWire.h>
#include <DallasTemperature.h>
#include <LiquidCrystal.h>

LiquidCrystal lcd(7, 6, 5, 4, 3, 2);

#define ONE_WIRE_BUS 7

OneWire oneWire(ONE_WIRE_BUS);

DallasTemperature sensors(&oneWire);

double Celsius = 0;
double Fahrenheit = 0;
const int  buttonPin = 7;    // the pin that the pushbutton is attached to
const int ledPin = 13;       // the pin that the LED is attached to

// Variables will change:
int buttonPushCounter = 0;   // counter for the number of button presses
int buttonState = 0;         // current state of the button
int lastButtonState = 0;
void setup() {
  sensors.begin();
  Serial.begin(9600);
  lcd.begin(20, 4);
  lcd.print("Room Temperature");
```

```
  // initialize the button pin as a input:
  pinMode(buttonPin, INPUT);
  // initialize the LED as an output:
  pinMode(ledPin, OUTPUT);
  // initialize serial communication:
}

void loop() {
  sensors.requestTemperatures();

  Celsius = sensors.getTempCByIndex(0);
  Fahrenheit = sensors.toFahrenheit(Celsius);

  lcd.setCursor(0, 1);
  lcd.print(Celsius);

  Serial.print(Fahrenheit,3);
  Serial.print("\n");
  delay(200);
  lcd.print(" Celsius  ");
  lcd.setCursor(0, 2);
  lcd.print(Fahrenheit);
  lcd.println(" Fahrenheit ");

  delay(200);
 // read the pushbutton input pin:
  buttonState = digitalRead(buttonPin);

  // compare the buttonState to its previous state
  if (buttonState != lastButtonState) {
    // if the state has changed, increment the counter
    if (buttonState == HIGH) {
      // if the current state is HIGH then the button went from off to on:
      buttonPushCounter++;

    } else {
      // if the current state is LOW then the button went from on to off:

    }
    // Delay a little bit to avoid bouncing
    delay(50);
  }
  // save the current state as the last state, for next time through the loop
  lastButtonState = buttonState;


  // turns on the LED every four button pushes by checking the modulo of the
  // button push counter. the modulo function gives you the remainder of the
  // division of two numbers:
  if (buttonPushCounter % 4 == 0) {
    digitalWrite(ledPin, HIGH);
  } else {
    digitalWrite(ledPin, LOW);
  }

}
```

G & M Coding

```
G0 X-21 Y-30
G0 Z-0.2 M3 S1500
G1 Y30 F500 M08
X-14
Y-30
X-7
```

```
Y30
X0
Y-30
X7
Y30
X14
Y-30
X21
Y30
M05 M09
M30
```

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