بسم الله الرحمن الرحيم

Experimental Validation for Energy Consumption in Conventional Machining of Al alloy

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DEDICATION

To my Beloved Parents,

Without whom none of my success
would have been possible

&

To my Respected Teachers,

Who acted like compass
that activated the magnets of
curiosity, knowledge and wisdom in me

ABSTRACT

Machine tools are accountable for environmental influence owing to their energy consumption. It is also a challenge for modern manufacturing how to reduce the environmental impacts related to machining processes. The environmental studies about machine tool that used in machining reveals that more than 99% of environmental impacts are due to the consumption of electrical energy.

This paper presents the experimental validation of energy consumption at conventional machining of Aluminum alloy Al 6061-T6. In literature, most energy consumption was analyzed at low machining speed (in the ranges of 500 m/min), whereas in this study analyze the energy consumption and surface roughness in the machining of Al alloy 6061-T6 at conventional machining range (up to 750m/min). Design of experiments were done with the help of Taguchi L_9 orthogonal array. The set of experiments were performed on two different machine tools using single point cutting methodology. Aluminum alloy 6061-T6 used as a work-piece material and it is widely used materials in automobiles, aerospace, defence and bio-medical industries.

All these experiments were performed by using fresh cutting inserts, that’s why the effect of tool wear was not considered for power and energy measurements. The main purpose of this research is to validate the benchmark results and acquire the minimum value of energy consumption and surface roughness while maximizing the material removal rate of the process.

The experimental results were analyzed with the help of ANOVA and main effects plots. During ANOVA analysis, feed rate was most significant factor for minimizing the SCE consumption and surface roughness. In main effect plots, the minimum value of specific cutting energy was obtained at highest level of feed rate, depth of cut and cutting speed.

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Chapter 1

Introduction:

The introductory survey of environment related to machining of machine tools has shown that more than 99% of environmental influences are due to electrical energy consumption. The consumption is due to use of machine tools in material removal process for turning, milling etc. if some reduction occurs in consumption of electrical energy, it not only benefits for manufacturer's but also enhances the environmental performance [1].

The main goals of manufacturing companies have always been time, costs & quality but due to increases demand and price of energy, it also become an extra goal for manufacturers. So reduction in energy consumption is important for cost saving and environment friendly. [Negrete] To improve the energy efficiency of manufacturing processes, it is necessary to understand the relationship among energy consumption, machine tools and cutting process. Turning is most commonly used process in manufacturing. A lot of work has been printed by optimizing this process based on cost & productivity but no one has given appropriate attention by optimizing turning process on basis of energy consumption. [Li]

Specific energy consumption (SEC) is the machine tools energy that consumed for removing 1 cm^3 of material. It value is different for different material removal process. A complete investigation of SEC breaks down it into four different components according to consumption of input energy, such as specific fixed energy, operational energy, tool tip energy and un-productive energy. It has been manifest that input energy not only used to detach the material, but also make sure the machine readiness, spindle rotation and change energy into heat because of friction. [1]

Al is the 3rd most abundant of all elements after silicon and oxygen. It consists of face centred cubic structure. It has relatively low melting temperature as compared to other metals. [Mario C. Santos Jr, Alisson R. Machado] Aluminium alloys are the most commonly used lightweight metallic material since it provides many various attractive mechanical and thermal properties. They can easily be used for shape making process. Aluminium alloys show maximum level of machining with respect to other materials that are lightweight such as magnesium and titanium alloys. Machinability express the performance of machining and it can also be checked by different criteria such as surface roughness, material removal rate and machine tool power etc. [2]

1.1 Research Aims:

The aim of this research is to validate the results of machine power, energy consumption and surface roughness of Aluminum alloy at conventional machining speed. In this research a single point cutting methodology was used for machining of aluminium alloy. A development of main effects plots and ANOVA analysis are very helpful for selection of cutting parameters that would minimized energy consumption and this progress is also supportive for future work.

1.2 Research objectives:

The objectives of research work are followings:

- Literature review on energy consumption of machine tools.
- Through literature review to check the effect of cutting parameters on energy consumption of machine tools.
- In literature review to examine the behaviour of surface roughness by varying the level of cutting parameters.
- Selection of cutting parameters and response variables.
- Preparation of experimental design.
- Power of air cut cycle and actual cut cycle recorded through energy analyser.
- Measurement of cutting power and SCE through proper calculations.
- Measurement of surface roughness after every experiment.
- Analyse the results of experimental data through main effects plots and Analysis of variance.
- Comparison of these consequences with the benchmark to check the confirmation of results.

Chapter 2

Literature review:

2.1 Literature survey:

Taguchi technique was used to optimize the cutting parameters (depth of cut, feed rate and cutting speed) for turning process. In this research aluminium alloy AISI 6061 T6 was used as a machined material. Aluminium alloy 6061 T6 having cylindrical dimensions that consist of 100mm length but cutting tool that is used in turning process was made up of silicon carbide. L9 orthogonal array was used to design cutting parameters. Total number of experiments were nine, in which three factors (depth of cut, feed rate and cutting speed) were connected and each level has three level of design. These experiments were performed on 10 HP HAAS SL10 lathe. [3]

In the work of C. Camposeco-Negrete [3], response variables were energy consumption and surface roughness. Energy was calculated by multiplying time with power value. Power was measured with the help of LabVIEW interface during machining process and power meter was attached to the main supply of lathe machine. Each experiment was carried out three times to calculate the average value of power. In this research paper power is divided into two categories such as machining power and cutting power. Machining power was measured when there is no contact between work piece and cutting tool but when physically tool contact with work piece material then power meter used to measure cutting power. Other response variable was surface roughness; it was measured with the help of roughness meter Mitutoya. Analysis of variance (ANOVA), main effects plot and S/N ratio were employed to analyse the effect of cutting parameters for response variables such as machining power and machining energy, cutting power and cutting energy and surface roughness.

Deepak et al. [4] used Taguchi method to study on material removal rate of aluminium alloy 6061 while turning process. He had studied this effect with coolant and non-coolant condition. In this research, three parameters (cutting speed, feed rate and depth of cut) were selected and each parameter consists of three level of design.

These experiments were performed on CNC turning centre and silicon carbide insert was used as cutting tool. The experimental plan was divided into two conditions. In first condition, machining is performed without supply of coolant means to say, in dry machining while in other condition machining performed under supply of coolant. After every experiment, volume loss method was used to calculate the material removal rate (MRR).

Main effects plot and analysis of variance (ANOVA) were used to study the effect and contribution of each factor on MRR. Main effects plots shown that feed rate is eminent factor that has more influence on material removal rate during turning process and the same pattern followed by depth of cut and cutting speed. It was also observed that more volume of MRR was produced when coolant supply was on as compared to when there is no supply of coolant. [4]

S Kara and W. Li [1] develop an empirical model for unit process energy consumption. This model is used to monitor and perceive an energy consumption that is linked with process variables. In this case, response variable was only material removal rate. Three cutting parameters cutting speed, feed rate and depth of cut were selected. Response surface methodology (RSM) was used for design of experiments and their experimental schedule was created with Minitab software using face centred composite approach.

These experiments were executed on eight different CNC turning and milling machines. On milling operation, multi-point cutter is used and the cutting edges on cutter have some impact on material removal rate. So that’s why involvement of width of cut and cutter diameter was necessary in milling process. Power consumption of machine tools was continuously measured with the help of LabVIEW interface by an interval of 0.1sec. The observed data was analysed on SPSS tool and the curve estimation indicates a best relation between specific energy consumption (SEC) and material removal rate (MRR). In ANOVA analysis, large value of F also shows a robust co-relation between SEC and MRR. [1]

In the work of Balogun and Mativenga [5] machine tools are classified into two states, basic state and cutting state. In basic state the purpose of electrical energy is just to actuate the different units of machine and assure that machine is in ready state. In cutting state, energy is used to detach the material from the work-piece in the form of chips and some energy is lost due to friction and noise of machine. In this research, author explained another type of state, that is lies between basic state and cutting state. This state is called ready state and it is used in machining process when the machine is started. Ready state demands additional energy for the movement of other components of machine such as engage tool to cutting position, correct position of work-piece.

2.2 Aluminium alloys:

Aluminium is available both in pure and alloyed shapes. It is soft and weak material. Commercially aluminium is accessible up to 99.8 percent pure. Both at low and high temperature, aluminium shows a weak strength. The main supremacy of aluminium is its small density, excellent strength to weight ratio, good workability, weldability & ductility, resistance to corrosion, high conductivity & reasonable cost. It is regularly used for engineering purposes because of its properties of good surface finish and wonderful corrosive resistance. It can also be used for decorative purposes. [6]

Aluminium alloy is basically a chemical compositions of different elements in pure aluminium. These elements are added to enhanced the properties of pure aluminium specially its strength. That's why aluminium alloy remarkably shows high strength as compared to pure aluminium. The following elements consist of silicon, manganese, magnesium, iron, copper & zinc and added up to 5% by weight in pure aluminium. [the Al association]. Aluminium alloys have broadly used in aircraft and automobiles industries. The 2000 and 6000 series of aluminium alloys have regularly used for design applications. [6]

Table 2.1: Mechanical and Physical properties of Aluminium alloy 6061.

Sr No.	Mechanical Properties		Physical Properties	
1	Tensile Strength	310 MPa	Density	2.70 g/cm^3
2	Proof Stress	270 MPa	Thermal Expansion	23.4 x 10^{-6} /K
3	Shear strength	190 MPa	Modulus of Elasticity	70 GPa
4	Elongation	12%	Thermal conductivity	166 W/m K
5	Brinell Vickers	100 HV	Melting Point	650 ^{0}C

2.3 Series of Aluminum Alloy:

Alloys are given four digits' number, the 1st number represents the general class of alloying elements. Some alloys series of aluminium are followings.

The series 1xxx composed of 99 percent pure aluminium and this series represent some eminent properties such as corrosion resistance, greater thermal and electrical conductivity. It is frequently used for transmission purposes. Copper is major alloying element in 2xxx series. They have no corrosive resistance against environment but show a valid combination of greater strength and toughness. These alloys are specially painted to avoid corrosion.

Magnesium is very effective alloying element used in 5xxx series and it is extensively used with aluminium. The combination of Al-Mg alloys extensively employed in construction work, storage vessels and pressure vessels. Alloys of this series exhibit an excellent property of weldability and corrosion resistance. Zinc is primary alloying element in 7xxx series. It will become very high strength alloy when magnesium is appended in minor amount. The most ordinary alloys of 7xxx series are 7050 & 7075, are extensively used in aircraft industry. [8]

Table 2.2: Major alloying elements in different series of Aluminium alloys.

Series	**Major Alloying Elements**	**Secondary Alloys**
1xxx	Commercially Pure 99%	$None$
2xxx	$Copper\ (Cu)$	Mg, Mn, Si
3xxx	$Maganese\ (Mn)$	Mg, Cu
4xxx	$Silicon\ (Si)$	$None$
5xxx	$Magnesium\ (Mg)$	Mn, Cr
6xxx	$Magnesium\ (Mg) \&\ Silicon\ (Si)$	Cu, Mn
7xxx	$Zinc\ (Zn)$	Mg, Cu, Cr

Magnesium and silicon are the major alloying elements in 6xxx series. 6061 is mostly used alloying element of this series and it is widely employed in truck and marine frame. Alloys of this series have shown some mechanical and chemical properties such as good formability, weldability and superb corrosion resistance.

Extrusion products of 6xxx series are frequently used in structural applications. [8] Structure applications of 6061 alloy is due to its good weldability. [6]

Table 2.3: comparison of chemical composition of Aluminum alloy 6061-T6 with other work materials. [9] [10]

Alloys	Chemical Composition									
	Elements	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	others
Al 6061-T6	%	0.62	0.22	0.29	0.07	1.1	0.18	0.01	0.01	< 0.5
Al 6061		0.4-0.8	0.7	0.15-0.4	0.15	0.8-1.2	0.04-0.35	0.25	0.15	0.15
Al 7075-T6		0.4	0.5	1.2-2.0	0.3	2.1-2.9	0.18-2.8	5.1-6.1	0.2	0.15
Al 2024		0.5	0.5	3.8-4.9	0.3-0.9	1.2-1.8	0.1	0.25	0.15	0.15
Inconel 718	Elements	Ni (+ Co)	Cr	Fe	Mo	Ti	Al	Mn	Si	C
	%	50 + 55	17-21	18.5	2.8-3.30	0.65-1.15	0.2-0.8	0.35 max	0.35 max	0.08 max

Table 2.4: Comparison of mechanical and physical properties of Aluminum alloy 6061-T6 with other work-piece materials. [9] [10]

Properties	Materials					
	Al 6061-T6	Al 6061-O	Al 6061-T6	Al 7075-T6	Al 2024-T4	Inconel 718
Tensile Strength, Ultimate (Mpa)	310.3	124.1	241.3	572.3	468.8	1375
Tensile Strength, Yield (Mpa)	275.8	55.2	144.8	503.3	324.1	1100
Modulus of Elasticity (Gpa)	69	68.9	68.9	71.7	73.1	200
Thermal Conductivity (W/m-K)	167	170	154	130	121	11.4
Ductility (%)	12	25	22	11	20	25
Density (g/cm^3)	2.7	2.7	2.7	2.81	2.77	8.19

2.4 Metal cutting process:

It is a machining process in which material of work-piece is removed in the form of chips. It is called metal cutting process when the work-piece material is metallic. The nomenclature and geometry of wedge shaped cutting tool is basically an intricate matter. It is hard to understand the different angles of single point cutting tool and also tough to determine the slope of the tool face. In machining philosophy, the wedge shaped tool is used to detach the material from the work piece in the form of chips (continuous or dis-continuous). The geometry of wedge shape cutting edge is obtained when two surface of cutting tool bisect with each other's. This surface consists of two faces, the first one is rake face and the other is flank face. The surface through which chips remove is known as rake face and the other which contact with machined work piece surface is called flank face. [11]

The machining processes are divided into two categories.

I. Orthogonal cutting
II. Oblique cutting

2.4.1 Orthogonal cutting process:

It is the most common cutting operation that takes place when the single point cutting tool moves in the direction that is normal to the cutting chips of the tool. In this process, the cutting force of the tool is at right angle to the line of action of the tool and tool with a constant velocity.

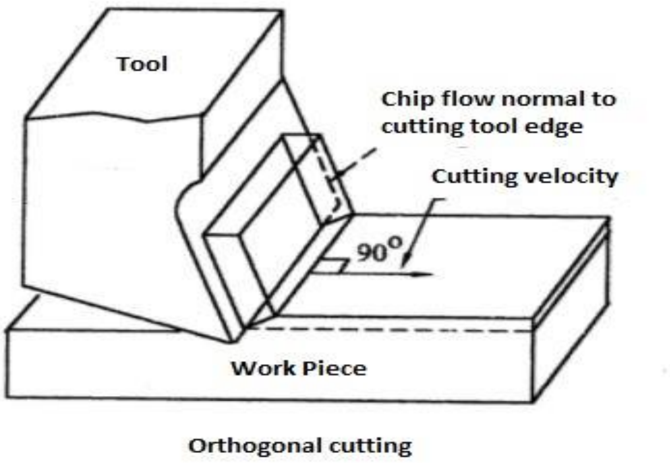

Fig.1 Orthogonal cutting

In cutting process, some sections of plastic deformation occur in the work piece. This sections of deformation basically occurred between the chips and the elastically deformed material. The deformation zones which are produced due to the generation of chips are listed into primary and secondary shear zones. Primary zone is generated when material is squeezed both by elastically and plastically while secondary zone is produced where chips are generated. This is due to the presence of friction between chips and rake face. The shape of plastically deformed section depends on the cutting speed conditions. The value of deformed section is large at low cutting conditions but it decreases in size at comparatively high cutting conditions.

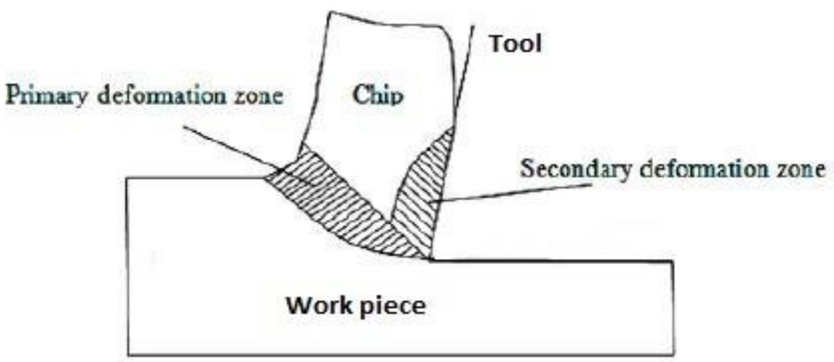

Fig. 2 Deformed primary and secondary zone

2.4.2 Oblique cutting process:

It is a type of metal cutting process in which cutting edge of wedge shaped tool is not normal to the direction of flow of chips. Orthogonal is a specific case of oblique cutting. Oblique is basically a 3-dimensional cutting while orthogonal is a 2-dimensional.

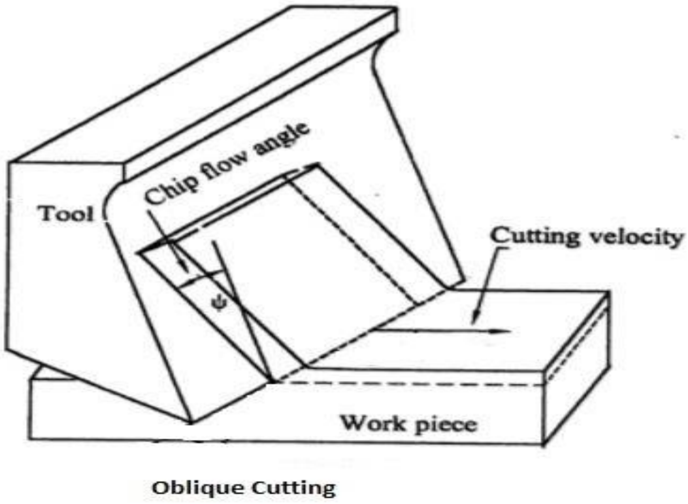

Fig.3 Oblique cutting

There are very limited investigations at the subject of oblique cutting because the procedure of it is much more difficult comparatively to orthogonal cutting. In oblique cutting, chip passes through rake face but the direction of chip is not perpendicular to the cutting edge. It is removed at some angle which is less than 90^0. [12]

2.5 Comparison of orthogonal and Oblique cutting:

2.5.1 Orthogonal cutting:

1. It is two dimensional (2-D) cutting process. In this process two components of forces are involved, feed or thrust force and cutting force. So that's it is called as 2-D cutting process.
2. The cutting edge of single point cutting tool is normal to the direction of tool travel or tool feed.
3. Cutting edge is also at right angle to orientation of chip moves.
4. The heat produced because of friction per unit area is greater as compared to oblique cutting.
5. Tool life is lower than oblique cutting. (at identical cutting conditions)
6. In orthogonal cutting process, smaller amount of material is removed.

7. Cutting edge of the tool is bigger than the width of the cut.

2.5.2 Oblique cutting:

1. It is three dimensional (3-D) cutting process. In this case three sections of forces are involved, cutting force, feed or thrust force and radial force. So it is referred as 3D cutting process.
2. The cutting edge of the tool is inclined at an angle which is less 90^0, to the direction of tool feed.
3. The direction of chip flows is not perpendicular to the cutting edge.
4. The amount of heat that is produced in this process per unit area is less.
5. Hence, tool has longer life comparatively to orthogonal cutting.
6. In oblique cutting process, much rapid and larger amount of material is removed.
7. Cutting edge of the tool may be smaller than the tool width.

Chapter 3

Taguchi Methodology:

Design of experiments (DOE) was first established by R.A Fisher. This is a statistical technique that is employed to check the response of several variables simultaneously. Dr Taguchi basically was a researcher in electronics lab that further pursue research on design of experiments. He spent a lot of time to make this technique very effective and easy to use. DOE is very productive technique to enhance the qualities of manufacturing activities. [13]

Taguchi methodology allows to design less number of experiments. Sometimes the result acquired from Taguchi may not be optimum but their consequences very close to target values so ultimately it can be used as a process effective or improvement technique. By applying this technique, engineers and scientist spent minimum number of time for experimental investigation. [3]

Aggarwal [14] studied response surface methodology (RSM) and Taguchi approach to optimized the power consumption of turning process. Both techniques are used to conduct fewer number of experiments for optimization of cutting parameters. These optimized parameters give minimum value of response variables. when response surface methodology was used for design of experiments it almost took double time as compared to Taguchi's technique but techniques have almost given same result. Taguchi methodology found a values that are very close to target and also consume less time.

3.1 Design of Experiments:

The design of experiments was done through Taguchi L_9 orthogonal arrays. Machining parameters were selected according to sandvik coromant, 2015 and their level selection according to tool manufacturer. Three cutting parameters feed, cutting speed and depth of cut were selected. The levels of machining parameters have shown in the table 5.

Table 3.1: machining parameters and their level

Parameters	Level 1	Level 2	Level 3
Cutting speed (m/min)	250	500	750
Feed (mm/rev)	0.1	0.2	0.3
Depth of cut (mm)	1	2	3

The purpose of this work is to validate the results of benchmark up to the range of conventional machining. In Jaffery and Mativenga's [15] research, cutting speed ranges for different materials has been given in table form. Cutting speed for machining different materials has been categories into three areas name as: conventional, transition and HSM range.

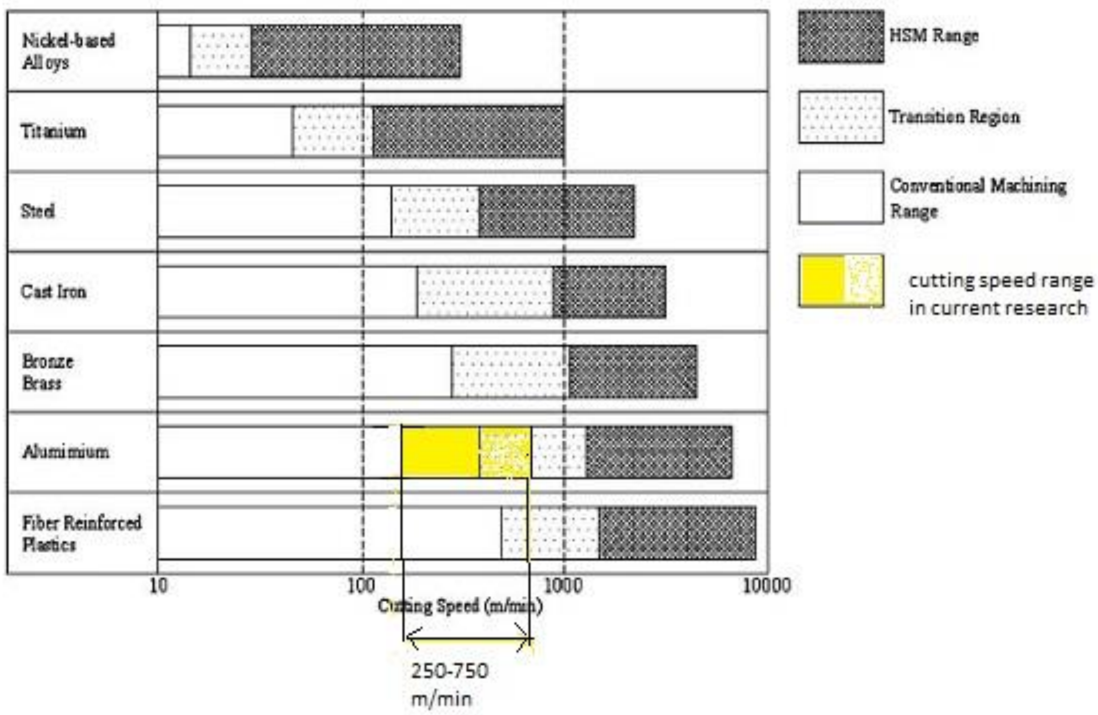

Fig.4 Cutting speed ranges for machining of different materials. [15]

3.2 Experimental setup:

A shafts of Aluminum Alloy 6061-T6 having diameter 160mm and cutting length in the range of 65mm used as a work-piece material in this research. It is commonly used as a light weight metallic material and having good mechanical and thermal properties. It shows maximum level of machinability comparatively other materials. Is has also widely applicable in industrial sectors such as automotive and aerospace etc. [2]

All these experiments were carried out at two different CNC turning machines having a special feature of turret centre. These machines are manufactured by different companies and their specifications are also different. First test of experiments was performed on CNC turning machines (Model: DOOSAN PUMA 280 ML) manufactured by Doosan Infracore machine tools Korea, at Gujranwala tools, dies and moulds centre (GTDMC). Second test was carried out on CNC Lathe machine (Model: CK 6150) manufactured by Nanjing Erjichunang CNC machine tool chine at Light engineering services centre (LESC) Gujranwala. Some specifications of these machines are listed below.

Table 3.2: Specifications of machine tools.

Description	**Items**	**PUMA 280LM**	**CK 6150**
		Specifications	Specifications
Machine capacity	Max turning Dia	420 mm	300 mm
	Max turning length	1078 mm	1000 mm
Axis's Travel	X-axis travel	242 mm	260 mm
	Z-axis travel	1100 mm	600 mm
Main spindle	Spindle speed	3500 rpm	30-1600 rpm
Turret	No. of stations	12	4 or 6
	Max tool size	25 x 25	16 x 16
Motor	Main spindle motor	18.5-22 kW	12 kW

All these tests were done with cutting insert (uncoated) H13A. Fresh cutting insert was used for each experiment to avoid the effect of tool wear. Due to fresh cutting insert, tool wear effect has not been considered for analysis of energy consumption. All these experiments were performed under dry cutting conditions. Single point cutting methodology was employed for these experiments.

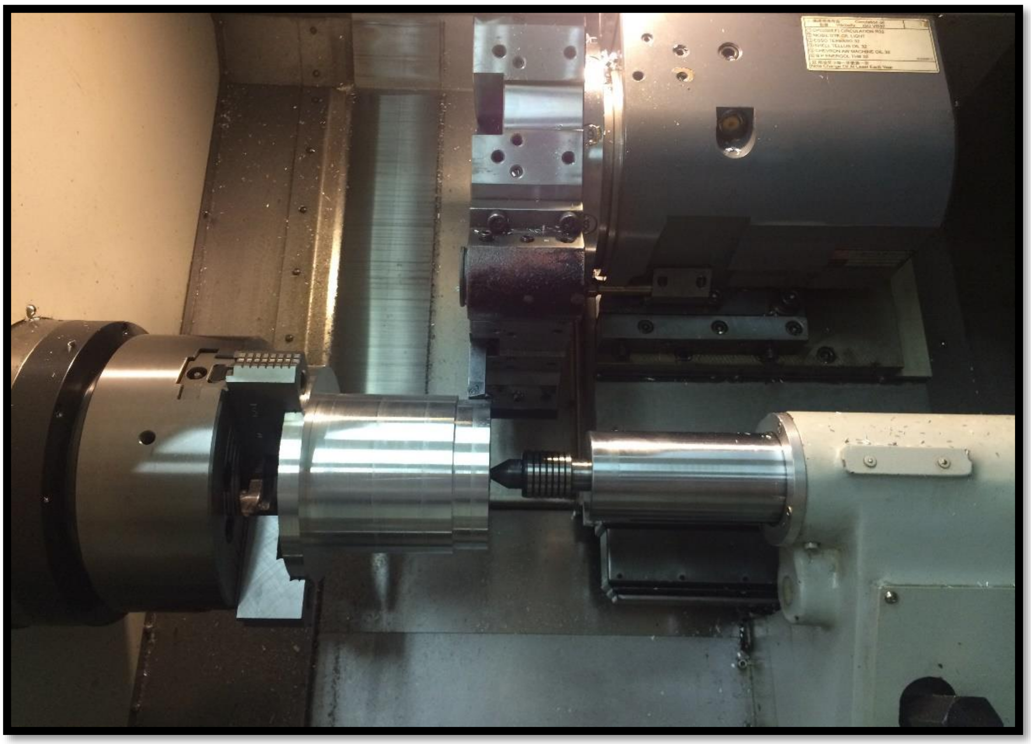

Fig.5 Single point cutting setup

Three cutting parameters (cutting speed, feed & depth of cut) were selected and each parameter consists of three level. Cutting speed is in the range of 250 m/min to 750 m/min to check the effect of conventional machining on energy consumption. The basic purpose of these experiments are to measure the machine power during running state. The power meter Yokogawa CW 240-F has been used to measure the machine power and it was installed at the main bus of machine tool. It measured the following factors such as current, voltage and Power after 0.1s interval of time. The arrangement of power analyser is given below.

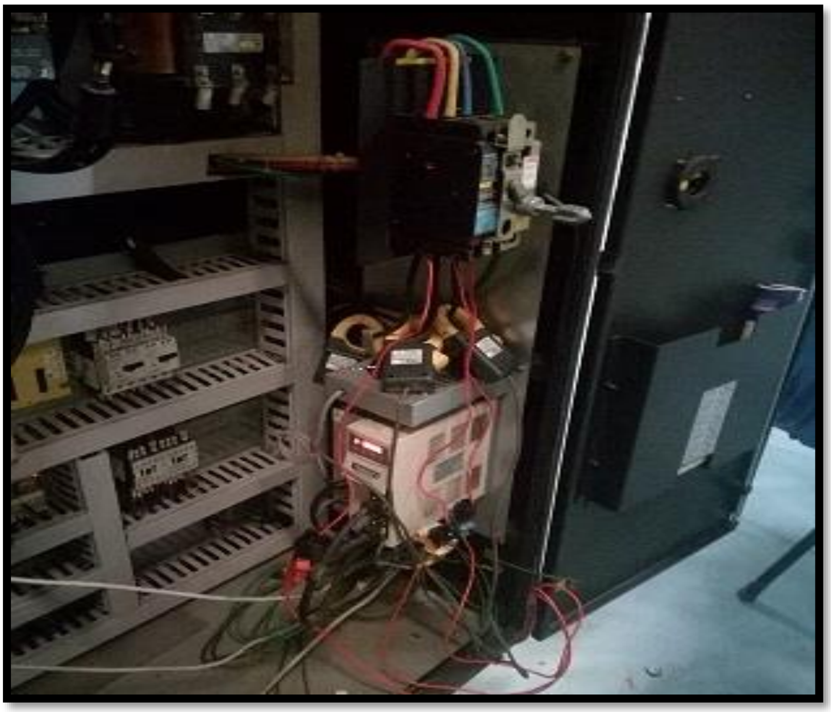

Fig.6 power analyser setup

3.3 Requirements for power measurement:

Consumption of energy in machining processes depend upon the factors i.e. constant factors and variable factors. Constant factors do not depend upon the type of machining and utilized fixed amount of energy. These factors have following units such as control system power supply, lighting system for cutting, motor drive and so on. These components consume continuous supply of energy regardless of machining. But another side Variable factors utilized variable amount of energy and also utilized more energy as compared to constant factors. Mostly variable factors consist of drive units of machine tool and they are load-dependent. Variable amount of energy was consumed due to different types of machining processes. Drive units provide motion to machine tool components and drive system includes following units: [16]

- Feed drive units
- Spindle drive units
- Tool altering & fixing units
- Work-piece altering & fixing units

- Supplementary drive units such as fans, coolant pump & chips conveyor.

Standby mode or idle power of machine is a constant amount of power that require for machine and its supplementary components such as control unit, fans, motors and pumps etc. The purpose of these components in active mode is to show that machine is in ready state. [17]

The actual power that required for material removal is incorporate both normal cutting and air cutting. W. Li & S. Kara [17] have been used two cycle approach, so a same type of methodology was used in this research. In air cycle there is no contact between tool and work piece. Cutting tool moves along the length of work piece just to check the correctness of program and to ensure that machine components such as rotation of spindle and tool moves accordance to numeric control program. This is also called non-productive approach. Due to these requisite there is a need of extra power comparatively to idle power or fixed power. So the power measured in this cycle was indicated as P_{air}.

When tool moves along cutting length then there is a physical contact between cutting tool and work piece. Material was removed in this cycle and it is also called productive approach. So the power recorded in actual machining was indicated as P_{actual}. The power difference between actual cut and air cut is basically an energy that was used for material removal from work piece. It was indicated as P_{cut} and calculated by following equation.

$$P_{cut} = P_{actual} - P_{air}$$

The power measured through this formula was the actual power that consumed in the duration at which cutting tool and work piece are in contact with each other.

Material removal rate mm^3/sec was calculated through following formula;

$$MRR\ \left(\frac{mm^3}{sec}\right) = vfd$$

Where

$$v = cutting\ speed, m/min$$

$$f = feed, mm/rev$$

$$d = depth\ of\ cut, mm$$

Specific cutting energy (SCE) was calculated by dividing the average cut power of machine tool by material removal rate (MRR). It is generally measured in N-m/mm³ or J/mm³.

$$Specific\ cutting\ energy, SCE\ \left(\frac{J}{mm^3}\right) = {P_{cut}\ (W)}\Big/{MRR\ (mm^3/sec)}$$

Chapter 4

Result and discussion:

As described earlier this research work is the experimental validation of a work done by Mr. M Salman Warsi. Aluminum alloy Al 6061-T6 was used as a work-piece material, having diameter 164 mm and length 160 mm. The value of specific cutting energy obtained after the experimental runs has shown in the table. Benchmark

Table 4.1: Benchmark results of experimental data for SCE**:**

Sr No.	Cutting speed m/min	Feed (mm/rev)	Depth of cut A_p	MRR (mm^3/sec)	SCE (J/mm^3)
1.	250	0.1	1	416.75	0.72
2.	250	0.2	2	1667.0	0.67
3.	250	0.3	3	3750.75	0.63
4.	500	0.1	2	833.00	0.72
5.	500	0.2	3	3332.00	0.63
6.	500	0.3	1	7497.00	0.62
7.	750	0.1	3	2500.5	0.71
8.	750	0.2	1	7501.5	0.65
9.	750	0.3	2	3750.75	0.58

Table 4.2: experimental results of SCE for validation test I:

Sr No.	Cutting speed m/min	Feed (mm/rev)	Depth of cut A_p	MRR (mm^3/sec)	SCE (J/mm^3)
1	250	0.1	1	416.75	0.72
2	250	0.2	2	1667.0	0.66
3	250	0.3	3	3750.75	0.59
4	500	0.1	2	833.00	0.71
5	500	0.2	3	3332.00	0.62
6	500	0.3	1	7497.00	0.62
7	750	0.1	3	2500.5	0.70
8	750	0.2	1	7501.5	0.66
9	750	0.3	2	3750.75	0.59

4.1 Main effects Plots:

The main effects analysis is basically used to check the effects of individual factor on response variable. Main effects plots recognize us the level of each factor that allocate the minimum value of response variable.

4.1.1 Main effects Plots for validation test I:

In this main effects plots three factors (depth of cut, cutting speed and feed) was used as a input but the response variable was specific cutting energy. The value of energy consumed by machine tool during single point cutting was minimized at highest level of feed rate, depth of cut and cutting speed.

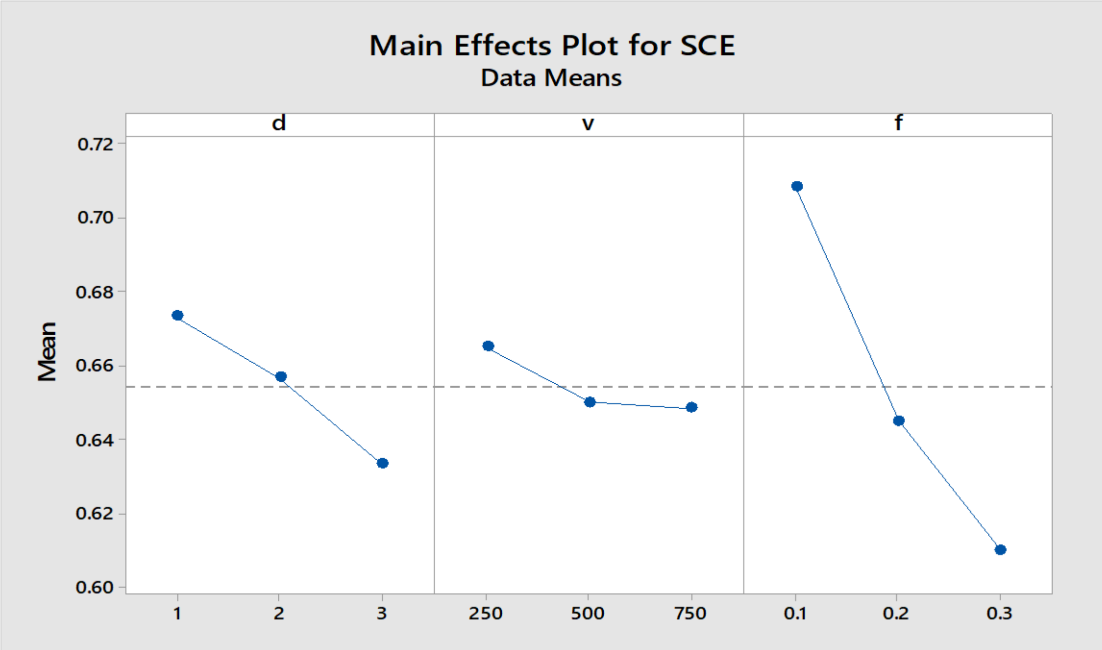

Fig.7 Main effects plots of SCE consumption

When this result was compared with the original result of main effects plots then the result was totally endorsed.

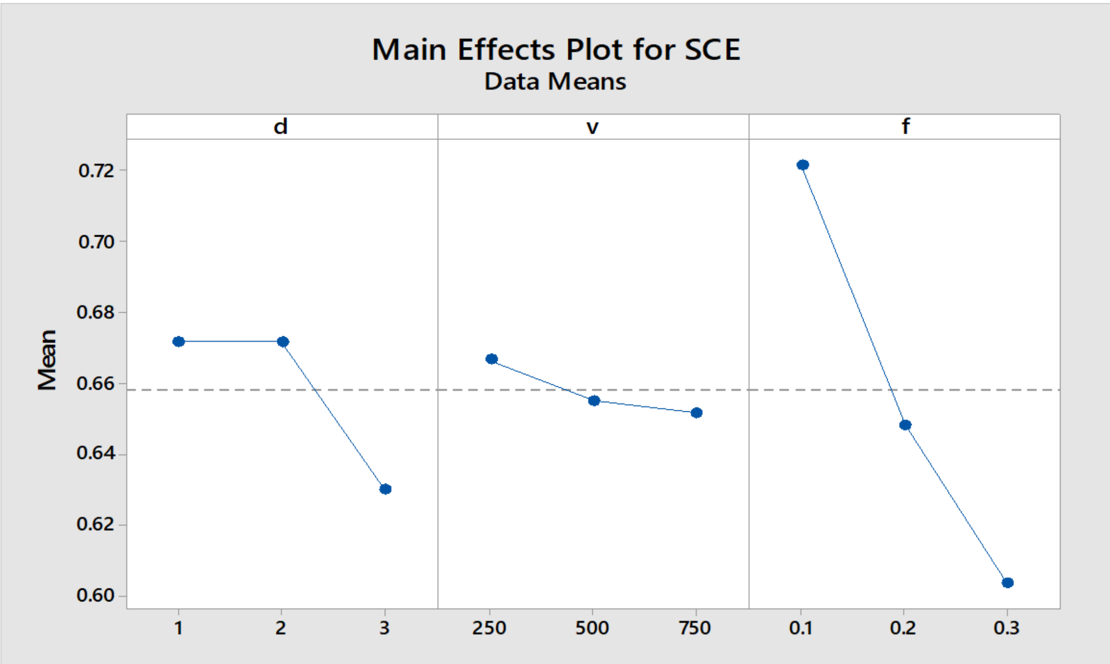

Fig.8 Main effects plots of SCE consumption from previous work.

Camposeco Negrete [1] has optimized the energy consumption of machine tool at conventional speed. He has selected the same type of parameters like feed rate and depth of cut but value of cutting speed in the rnage of 150 m/min to 250 m/min. In his research work he showed that minimum value of energy consumption was obtained at highest level of feed rate & depth of cut and at lower level of cutting speed. so moslty findings of this research further endorsed by the result of Camposeco Negrete.

To check further validation of experimental data another machine tool was used. The value of energy consumed after the experimental runs has shown in the table.

Table 4.3: experimental result of SCE for validation test II:

Sr No.	Cutting speed m/min	Feed (mm/rev)	Depth of cut A_p (mm)	MRR (mm^3/sec)	SCE I (J/mm^3)
1	250	0.1	1	416.75	0.925
2	250	0.2	2	1667.0	0.795
3	250	0.3	3	3750.75	0.685
4	500	0.1	2	833.00	0.90
5	500	0.2	3	3332.00	0.73
6	500	0.3	1	7497.00	0.675
7	750	0.1	3	2500.5	0.82
8	750	0.2	1	7501.5	0.725
9	750	0.3	2	3750.75	0.715

4.1.2 Main effects plot for validation test II:

The main effects plots were used to check the drift of each factor on energy consumption. In this case the trend of input parameters is obtained is similar to previous one. So the value of energy consumed during turning was minimized when the feed rate, depth of cut and cutting speed at their highest level.

Camposeco Negrete has two research on conventional speed. In both research he has optimized energy consumption at high value of feed rate and depth of cut. so the result of main effects plots for optimum energy consumption was endorsed by Camposeco Negrete except cutting speed.

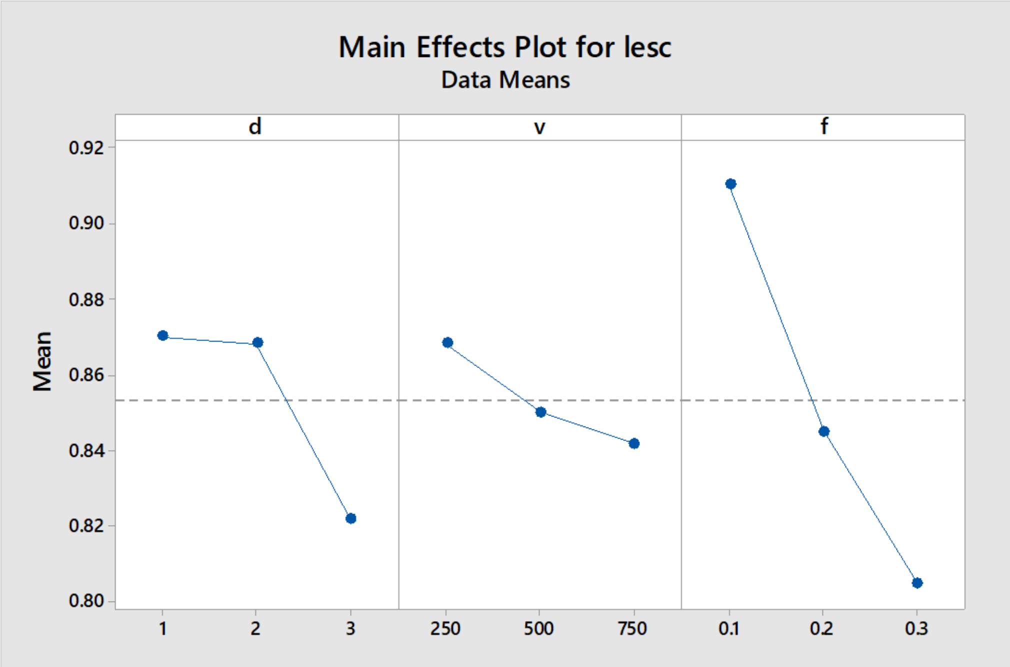

Fig.9 Main effects plots of SCE for validation test II

The amount of energy consumption was determined when the machining time taking into account. The value of energy consumed was minimum when feed rate at his highest level. At high level of feed rate, the overall time required to machine the work-piece was decreased. So therefore a less amount of energy was required for machining purpose.

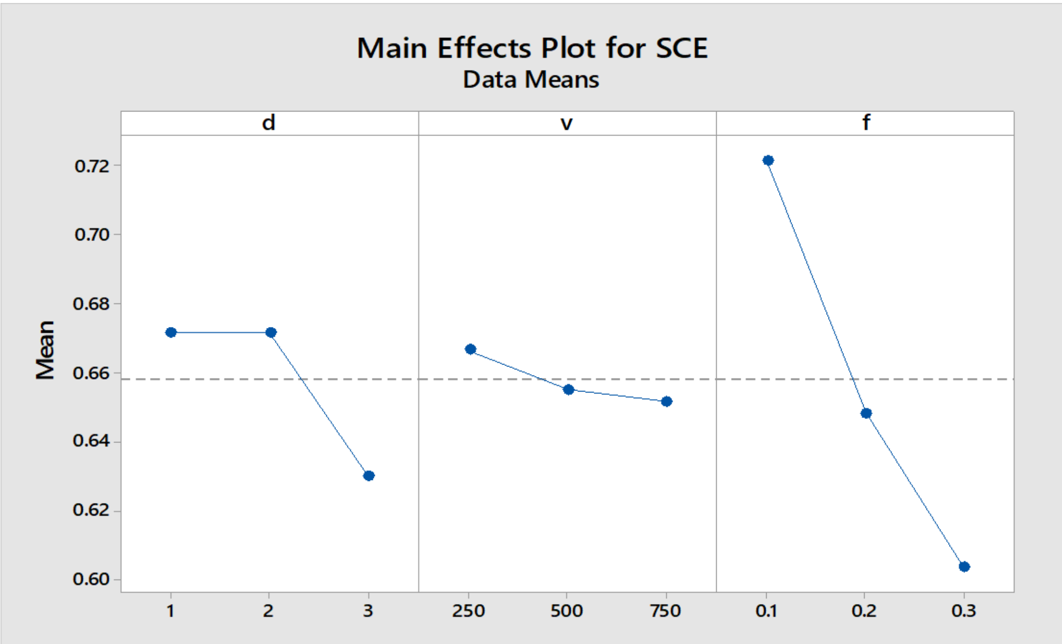

Fig.10 Main effects plots of SCE consumption from previous work

But high level of depth of cut also consumed minimum value of energy. When value of depth of cut was at highest level, greater volume of material was removed from the surface of work-piece in a single pass. So overall the time required to machine the work-piece was reduced. Therefore, the value of energy consumed was also reduced.

4.3 Analysis of variance (ANOVA):

Analysis of variance (ANOVA) is a statistical tool that is used to explain the experimental data and also employed to check the variation in average performance of groups of items tested. The purpose of ANOVA is to check the variation of individual factor relative to the total variation observed in the result. In ANOVA analysis, three factors (feed rate, depth of cut and cutting speed) was investigated to check the effect of response variable i.e. SCE.

ANOVA analysis was accomplished with Minitab version 18 software and determine the impact of input factors towards response variable i.e. SCE. The analysis was carried out at confidence level of 95%. In ANOVA analysis the value of P and F play a key role to decide the significance of factors. If the value of P is less than 0.05 then the factor was considered has significant. Moreover, the larger value of F showed the importance of input factor.

4.3.1 Analysis of variance (ANOVA) for Validation test I:

In order to probe the sway of feed rate, depth of cut and cutting speed on energy consumption at conventional speed. Analysis of variance was conducted at 95% confidence level. The result of SCE consumption for validation test I has shown below in the table.

Table 4.4: ANOVA- SCE consumption for validation test I:

Source	DF	Adj SS	Adj MS	F-Value	P-Value	CR(%)
d	2	0.002072	0.001036	15.2	0.001	6.27%
v	2	0.001011	0.000506	7.41	0.009	2.83%
f	2	0.027039	0.013519	198.29	0	87.14%
Error	11	0.00075	0.000068			3.75%
Total	17	0.033644				100%

The result of ANOVA table has confirmed that all the factors are significant for minimum energy consumption because value of P is less than 0.05 in all three factors. When I compared the significance level of individual factor with each other than feed rate has found most prominent effect on SCE consumption because the P value is very small as compared to other factors such as depth of cut and cutting speed. In previous research, the effectiveness of factors has shown in following way,

Feed rate > depth of cut > cutting speed

ANOVA result of previous work has expressed that feed rate has played more influence role on SCE consumption. So value of energy can be minimized by optimizing the feed rate. Depth of cut and cutting speed have also play some role for minimizing energy consumption. The result of analysis of variance show below in the table.

Table 4.5: ANOVA- SCE consumption for previous test:

Source	DF	Adj SS	Adj MS	F-Value	P-Value	CR (%)
d	2	0.003144	0.001572	12.69	0.000	4.64%
v	2	0.002956	0.001478	11.93	0.000	4.32%
f	2	0.049478	0.024739	199.69	0.000	84.45%
Error	11	0.002478	0.000124			6.60%
Total	17	0.058056				100.00%

According to ANOVA analysis depth of cut played a vital role as compared to cutting speed. So the following effective order has indicated here.

Feed rate > depth of cut > cutting speed

4.3.2 Analysis of variance (ANOVA) for Validation test II:

It is confirmed from table data that all three factors (feed rate, depth of cut and cutting speed) are significant as all the P values are less than 0.05. In all three factors, feed has more prominent effect on SCE due to small value of P comparatively to remaining factors. The role of other two factors was not so effective because of that their P-values have near to 0.05. So their contribution for the evaluation of response was not enough but the depth of cut has contributed a little bit more as compared to cutting speed. The result of ANOVA has shown below in the table:

Table 4.6: ANOVA- SCE consumption for validation test II:

Source	DF	Adj SS	Adj MS	F-Value	P-Value	CR(%)
d	2	0.010906	0.005453	18.08	0	13.44%
v	2	0.007344	0.003672	12.18	0.002	8.79%
f	2	0.055106	0.027553	91.38	0	71.08%
Error	11	0.003317	0.000302			6.69%
Total	17	0.135244				100.0%

So the effective order of validation test II has following:

Feed rate > depth of cut > cutting speed

This result was also verified by previous research through analysis of variance. Camposeco Negrete also did research at conventional speed to check the effect of cutting parameters (feed, depth of cut and cutting speed) on energy consumption. At the end of research work he investigated that feed is the most momentous factor for minimum energy consumption, followed by depth of cut and cutting speed. so result of validation test II was also verified by Camposeco Negrete [1]

Table 4.7: ANOVA- Benchmark analysis of SCE consumption:

Source	DF	Adj SS	Adj MS	F-Value	P-Value	CR (%)
d	2	0.003144	0.001572	12.69	0.000	4.64%
v	2	0.002956	0.001478	11.93	0.000	4.32%
f	2	0.049478	0.024739	199.69	0.000	84.45%
Error	11	0.002478	0.000124			6.60%
Total	17	0.058056				100.00%

The response that is direct recorded through machine and others that are calculated through equation are examined to check their inclinations in the data. Material removal rate directly depends upon cutting parameters such as feed, cutting speed and depth of cut. It values increased if any of its parameter increased.

4.4 Effect of MRR on cutting power and SCE:

When values of cutting parameters were increased then machine required more power to cut the materials. In other words, cutting power increased. The graph of cutting power and MRR has shown in the fig. 1. The graph obtained between cutting power and material removal rate was non-linear this is due to the load components of machine tool and their values varied non-linearly.

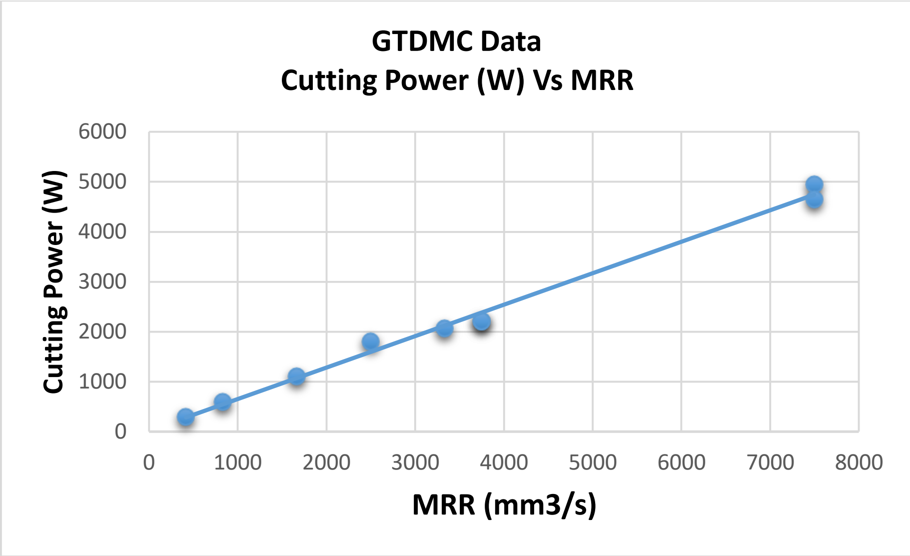

Fig.11 cutting power V MRR

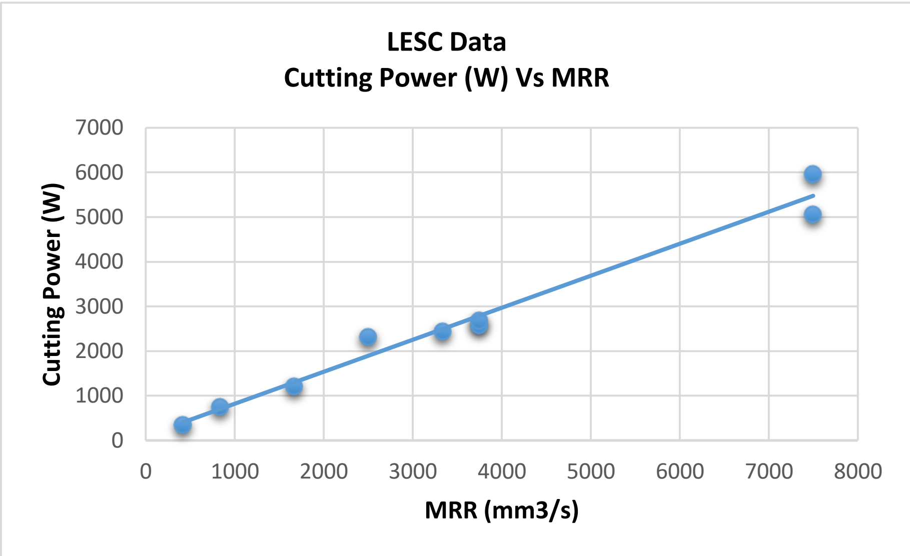

Fig.12 Cutting power V MRR

Both the response factors cutting power and MRR have direct relation with each other and their values also depends on the machining parameters. Both the responses increased in a non-linear way when machining parameters were at their higher values.

The graphs of material removal rate (MRR) and SCE has shown in the Fig.17 & Fig.18. The tendency of graph represents that there is inverse relation between MRR and SCE. The value of specific cutting energy decreased when MRR increased.

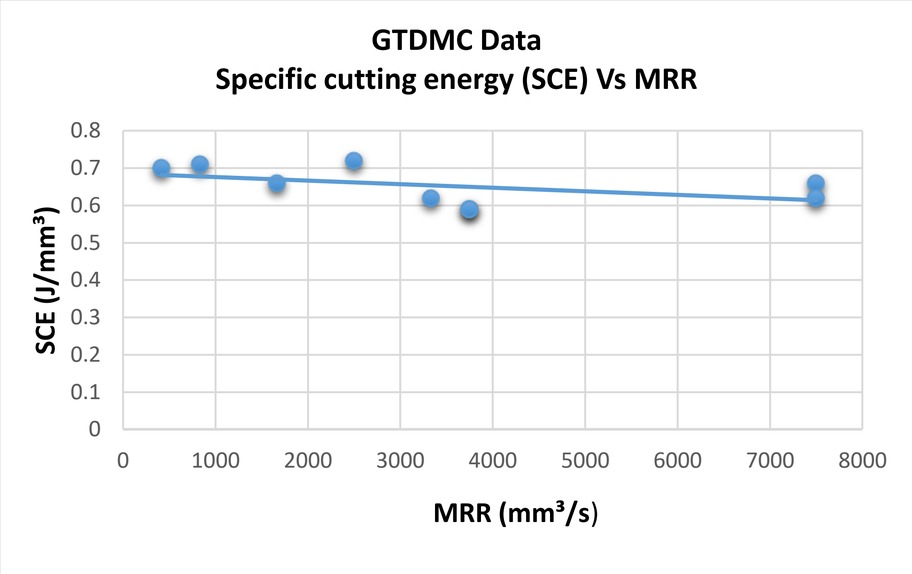

Fig.13 Specific cutting energy (SCE) V MRR

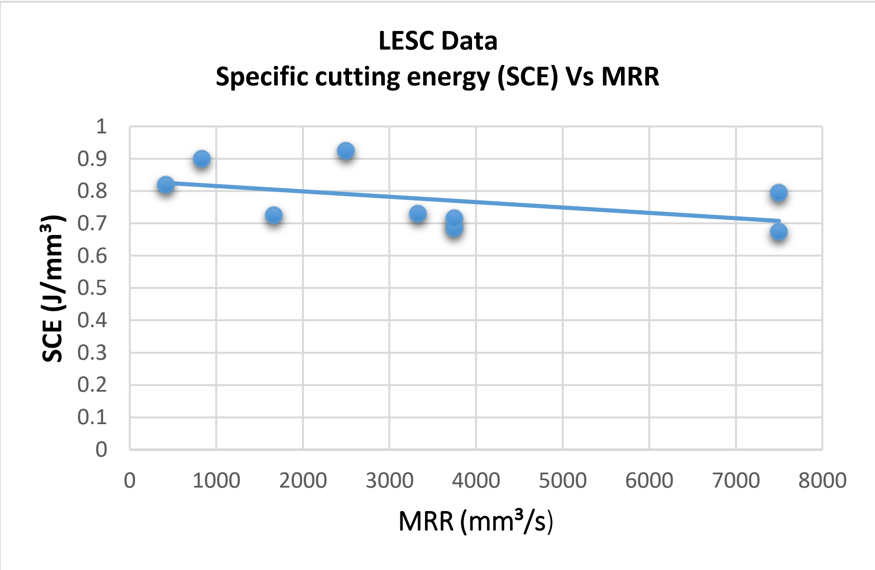

Fig.14 Specific cutting energy (SCE) V MRR

4.4 Surface roughness:

Surface roughness is a part of surface texture. The value of surface roughness obtained after the experimental runs has shown in the table 14.

Table 4.8: Surface roughness Ra for GTDMC and LESC.

Run	Ra (µm)			Ra (µm)		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
1	1.52	1.39	1.32	1.54	1.68	1.48
2	3.01	2.88	3.02	2.58	2.77	2.85
3	6.04	6.19	5.69	3.29	3.52	3.43
4	2.22	1.90	1.80	1.86	1.91	1.81
5	2.95	3.23	3.17	2.42	2.42	2.40
6	5.90	6.07	5.65	4.01	4.04	3.73
7	0.96	1.04	0.95	1.66	1.67	1.50
8	2.99	2.98	2.90	3.23	3.37	2.99
9	5.52	5.60	5.50	3.60	3.62	3.39

4.4.1 Main effects plot for surface roughness:

The main effects analysis is basically used to examine the effects of every factor on response variable. Main effects plot recognize us the level of each factor that assign the minimum value of response variable. In this main effects plots three factors (depth of cut, cutting speed and feed) was used as a input but the response variable was surface roughness.

These experiments were conducted to analyze the minimum value of surface roughness. In first validation test, feed rate minimized the value of surface roughness at its minimum level. Depth of cut and cutting speed have also some impact on response factor. The target value for surface roughness has been achieved at 1st level of feed rate & depth of cut and 3rd level of cutting speed (Fig 15). These results are further endorsed by the work of Bhattacharya et al. and Hanafi et al.

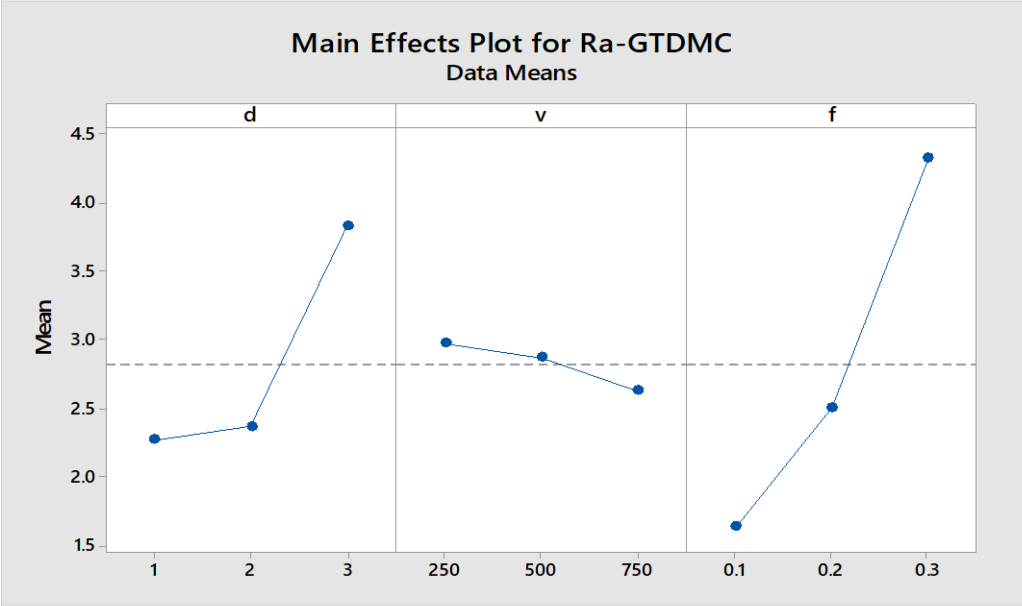

Fig. 15. Mean effects plot of surface roughness Ra for validation test I.

In second validation test, feed rate and depth of cut have minimized the value of surface roughness at its minimum level. Minimum value of surface roughness was achieved at maximum level of cutting speed. The target value for surface roughness has been achieved at 1st level of feed rate, 3rd level of cutting speed and 1st level of depth of cut (fig 16). These judgements are further authorized by earlier research and the work published by Camposeco Negrete and Hanafi et al.

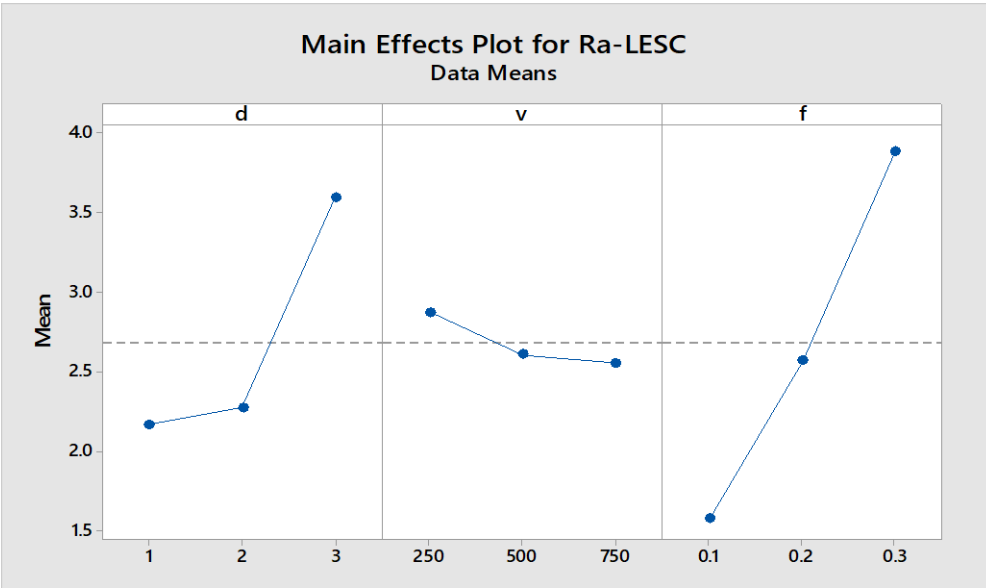

Fig.16. Mean effects plot of surface roughness Ra for validation test II.

4.5 Analysis of variance for Surface roughness:

Analysis of variance (ANOVA) was used to examine the key role of every factor. This analysis was done at confidence level of 95%. Feed rate is the most significant factor for optimizing the value of surface roughness (Ra). Less P-value and High F-value indicates the importance of feed rate for minimizing the Ra. but feed rate optimized both the responses at different level.

High feed rate minimized SEC consumption but will lead to maximize surface roughness. In ANOVA analysis feed is most significant factor followed by depth of cut and cutting speed. ANOVA analysis for both the test has shown in the table 15 and table 16.

Table 4.9: ANOVA- Surface roughness (Ra) for validation test I:

Source	DF	Adj SS	Adj MS	F-Value	P-Value	CR(%)
d	2	0.7557	0.37787	12.26	0	4.52%
v	2	0.5164	0.25818	8.38	0.002	2.96%
f	2	13.452	6.72602	218.24	0	87.29%
Error	20	0.6164	0.03082			5.22%
Total	26	25.9259				100.00%

Table 4.10: ANOVA- Surface roughness (Ra) for validation test II:

Source	DF	Adj SS	Adj MS	F-Value	P-Value	CR(%)
d	2	0.408	0.204	4.63	0.022	0.67%
v	2	0.2698	0.1349	3.06	0.069	0.38%
f	2	45.9727	22.9864	521.15	0	96.53%
Error	20	0.8821	0.0441			2.41%
Total	26	72.6159				100.00%

Chapter 5

Conclusions:

This study presents the optimization of energy consumption and surface roughness at conventional speed (up to 750 m/min) during single point cutting. Al 6061 T6 used as work piece material for machining and uncoated cutting inserts H13A have been used for all the experiments. During investigation it was found the optimum values of cutting parameters were used to minimize the response variables i.e. SCE consumption and surface roughness. In order to found out the value of energy consumption, initially find the value of cutting power through proper calculation then divided by material removal rate to obtain specific cutting energy. Surface finish is very imperative response variable because it gives the quality of product. Cutting parameters make sure that minimum value of surface roughness should be achieved regardless of energy consumption because if a product is rejected due to quality problems then it will go into scrap. It means re-machining is required so consequently more energy will be required to machined again. Following conclusions can be drawn from experimental work.

First validation test:

- In main effects plot, specific cutting energy (SCE) is inversely related to feed, cutting speed and depth of cut. The trend of Specific cutting energy in descending order shows that it value decrease while increasing the level of feed, cutting speed and depth of cut.
- Feed is found most significant factor, where reduction in SCE was observed 12%-17% by increasing the feed.
- The minimum results of SCE consumption were identified at feed 0.3 mm/rev, depth of cut 3 mm and cutting speed 750 m/min.
- The worst results of specific cutting energy (SCE) were examined when feed, cutting speed and depth of cut are their lowest level. Highest value of SCE at 0.1 mm/rev of feed, 250 m/min of cutting speed and 1 mm of depth of cut.

- In ANOVA analysis it was observed that the influence of feed was most significant followed by depth of cut and cutting speed.
- In first validation test, feed is most influential factor (87.14%) by minimizing SCE consumption, followed by depth of cut (6.27%) and cutting speed (2.83%).
- In Main effects plot it was observed that feed and depth of cut have directly link with surface roughness. Its value increase by increasing the level of feed and depth of cut but cutting speed has an inverse effect on surface roughness. Surface roughness decreased while increasing cutting speed. Minimum value of Ra has observed at maximum value of cutting speed.
- Minimum results of roughness (a good surface finish) were obtained at lower value of feed (0.1 mm/rev) and depth of cut (1 mm), while higher value of cutting speed (750 m/min).
- In ANOVA analysis, feed has most effective cutting parameters for minimizing the value of surface roughness and other parameters depth of cut and cutting speed have also play some role for minimizing surface roughness.
- Contribution of feed was 86.19%, depth of cut 5.10% and cutting speed 1.76%.

Second validation test:

- In main effects plot, specific cutting energy follows the same pattern as inspected in previous one. A downward trend of SCE was observed when increased the value of feed, cutting speed and depth of cut.
- The minimum value of SCE consumption was identified when feed rate was 0.3 mm/rev, depth of cut 3 mm and cutting speed was 750 m/min.
- In ANOVA analysis the influence of feed on SCE consumption was most significant followed by depth of cut and cutting speed.
- feed is most influential factor (71.80%) by minimizing SCE consumption, followed by depth of cut (13.44%) and cutting speed (8.79%).
- In Main effects plot it was observed that parameters i.e. feed and depth of cut have directly link with surface roughness. Its value increased by increasing the level of feed and depth of cut. but an inverse effect of cutting speed was investigated on surface roughness. Trend of Surface roughness moves from high to low by increasing the cutting speed from 500 m/min to 750 m/min.

- In second validation test, minimum results of surface roughness were obtained when feed 0.1 mm/rev, cutting speed 750 m/min and depth of cut of 1 mm.
- In ANOVA analysis it was examined that feed has played a significant role for minimizing surface roughness (Ra).
- Feed is most effective (87.59%) cutting parameter for minimizing surface roughness and contribution of depth of cut and cutting speed are 3.70% and 3.39%.
- Cutting power increased as the material removal rate increased although in a non-linear way.
- Specific cutting energy (SCE) showed a descending trend with increase in MRR.

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