Fitting Regression Model and Optimization of Cutting Parameters In Order To Achieve Economical Machining Of a Cryogenic Soaked Magnesium Alloy

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ABSTRACT

The ultimate aim of a production engineer is to produce a product which is economical in terms of overall cost of production. This motive of attaining economical machining is achieved by analysing the machining process and identifying critical cutting parameters which has definite influence on the machining operation and optimization of these parameters leads to obtaining an economical machining output.

In present times, many industries are giving more importance in reducing the overall cost of production and in this regard reduction in weight of the work material has become necessary which in turn reduces the power consumption required for machining and hence leads to reduction in overall costs. Thus usage of light weight materials has garnered deep interest in the industries. This project deals with the turning of Mg AZ31B alloy for the above stated reasons.

The objective of this work is to optimize the influencing cutting parameters like speed, feed, depth of cut and approach angle of the cutting tool by using experimental engineering design techniques like Taguchi method of orthogonal array, analysis of variance method to compute contribution of each of these parameters on the quality of machined output. The response variables taken up for this analysis were surface roughness, material removal rate, tool wear rate and machining time as all these factors governs the quality of the machined product and hence relates to economics of machining. Regression models have been developed in order to study about the mathematical relation between the input cutting parameters and each of the output variables. Contour plots have been drawn to study about interactions between the input cutting parameters and its impact on the output variables. In order to study the effect of cryogenic soaking on the work specimen Vickers hardness test has been performed to check the enhancement of the hardness before and after cryogenic soaking.

The experimental data shows that surface roughness is mostly affected by approach angle of the cutting tool whereas material removal rate, tool wear rate and machining time were mostly affected by depth of cut. From the confirmatory test it was evident that Taguchi analysis helps in optimizing the output variables. It was also observed that cryogenic soaking suitably increases the hardness of the material thus making it more machinable.

Keywords: Economical Machining, Optimization, Taguchi method, CNC Turning, Mg AZ31B, Regression Modeling, Contour plots, Cryogenic Soaking.

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CHAPTER ONE

1. INTRODUCTION

1.1 MACHINING

The analysis of machining process is always considered to have its own attraction in the production engineering curriculum. It deals with the study of metal removing processes and machine tools. Machining of materials is generally being employed to get a high surface finish, closer dimensional tolerance and to obtain complex geometry shapes which are otherwise very difficult to manufacture.

Among all the manufacturing processes available among us it is being observed that metal removal processes are the most expansive ones. It is primarily due to the fact it requires more amount of energy to perform the intended function of removing excess material from the work metal in form of chips to obtain the desired shape and size of the final product. So from the economics point of view, the metal removal process must be employed only when no other manufacturing process is feasible even though all other manufacturing process undergoes metal removal operation at some point in time.

There are multiple kinds of machining processes available that can be used to achieve the desired part shape and surface integrity. These operations are different from one another based on factors like shape formed, cutting tool, cutting conditions and surface roughness produced.

The following are the different varieties of machining operations that are known:

Turning

Shaping

Milling

Drilling

Boring

Planning

Breaching

Threading

There are two kinds of machining variables present; independent variables and dependent variables.

The tool material, tool shape, machine tool and fixture, cutting condition etc. are considered in the category of independent variable

Dependent variable includes type of chip formed, force and energy consumed, wear, temperature, surface finish and use of cutting fluid etc.

1.2 MACHINE TOOL

A machine tool is the one which despite of holding cutting tool would be able to remove metal from a workpiece to generate the requisite shape, size, configuration and surface finish. It is quite different with respect to a machine which is essentially a means of converting the source of power from one form to another. Basically, machine tools are considered as mother machines since without them it becomes impossible to produce any component with finished form. These are very old and have played an important role in the evolution and growth of the industrial sector.

The presence of some crude form of machine tools has been detected back in 700 B.C. The first was John Wilkinson's horizontal boring machine, which was introduced in 1775, followed by Henry Maduslay's engine lathe in 1794. A later machine tool which got invented was the planner by Roberts in 1817. Eli Whitney is credited with discovering the milling machine in 1818. Around 1840, John Naysmith invented the drill press, the next machine tool. The first completely automatic turret lathe consists of a cam provided for feeding the tool in and out of the workpiece thus automating most of the machining works. In addition, he is known for developing the multi-spindle lathe. In the end surface grinder was developed around 1880. This concludes the development of all basic machine tools which are relevant even during the present time.

Over the period of time, these basics machining tools have undergone many adjustments with regard to its various attachments as well as automating the movements. With the development of many precision measuring techniques helps in improving accuracy and productivity of the machine tools.

1.3 TURNING

Among all the various kind of machining process available which can be performed in a lathe machine, turning is the most prominent of them. During turning process, a tool removes material from the outer diameter by rotating the workpiece. The main aim of turning operation is to reduce the workpiece diameter to the required dimension. There are two types of turning i.e. rough and finish turning.

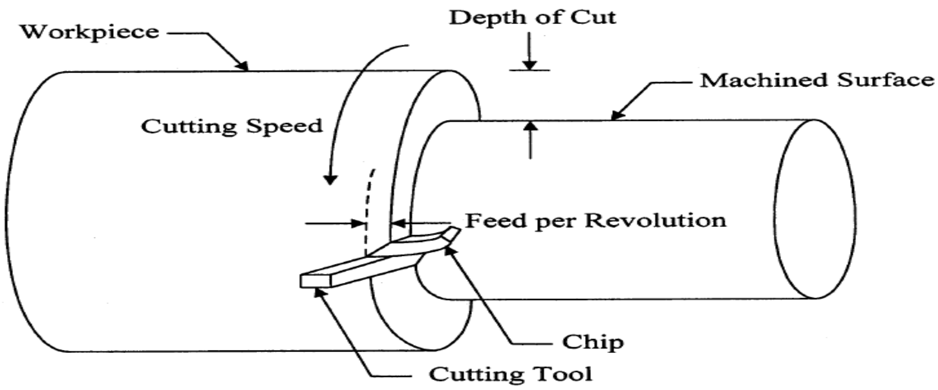

Fig 1.3.1 Basic turning operation

In case of rough turning more importance is given to reducing the dimension of the outer diameter of the rotating workpiece with minimum possible machining time required and it has poor surface finish and accuracy whereas in case of finish turning more concentration is devoted towards obtaining smooth surface finish and workpiece with final accurate dimensions.

By having high feed rate and larger depth of cut we can undergo rough turning. The rough turning should be done in such a way that the machine, the tool and the workpiece can bear the load and it does not make too rough surfaces and spoil the centres. In order to generate smooth surface, the finished turning is the most preferable one which necessarily requires larger cutting speed and lower values of feed and depth of cut.

In a lathe machine operation, finish turning is followed by rough turning and factors such as cutting condition of tool bit, the rigidity of the machine and workipece, lathe speed and feed rate may have direct implication of surface finish produced.

After turning, different section of turned parts has different outer dimensions. There are various different topological features present between the surfaces having two different reduced dimensions namely step, taper, chamfer, and contouring. In order to obtain this different feature multiple passes at small radial depth of cut may be required.

When a workpiece with two different diameters is turned, the surface creating the step from one diameter to the other is known as the shoulder, and shoulder turning is the process of machining this area of the workpiece. The various types of shoulder available are square shoulder, angular or bevelled shoulder, radius shoulder and the undercut shoulder.

1.4 ALUMINUM ALLOYS

When aluminium is alloyed with a little amount of other elements, it has the broadest range of applications. The soft, weak aluminium metal is converted into a hard, strong metal while preserving its light weight qualities when a limited fraction of other elements is added. The alloys are divided into two categories: cast and wrought, both of which are age-hardened. It can also be divided into subcategories based on the type of heat treatment process that they respond to.

For the casting of general engineering purpose, aluminium is alloyed with small amount of copper and zinc in the proportion of 12.5 to 14.5 percent zinc and 2.5 to 3 percent copper. An important and interesting wrought alloy is known as duralumin, it consists of 3.5 to 4.5 percent copper, 0.4 to 0.7 manganese, 0.4 to 0.7 magnesium and aluminium the remainder. It is widely used in wrought condition for forging, stampings, bars, sheets, tubes and rivets. It is primarily attributed to its age hardening property. After working if metal is allowed to age for 3 or 4 days, it will be hardened this is called as age-hardening. In the heat treated and aged condition duralumin may have a tensile strength up to 40 kgf/mm^2.

Another alloy known as Y-alloy contains 3.5 to 4.5 percent copper, 1.8 to 2.3 percent nickel, and 1.2 to 1.7 percent magnesium. This alloy has the characteristic of retaining good strength at high temperatures. Y-alloy is mostly used in case of piston and other components of aero engines. After heat treatment this can be brought to minimum tensile strength of about 35 kgf/mm^2.

Aluminium bronzes containing more than 10 percent aluminium are quenched from 650˚ C and subsequently tempered at a lower temperature.

1.5 MAGNESIUM ALLOYS

Magnesium alloys are well known as lightest density alloys. They are made up of magnesium, the lightest structural metal and are mixed up with various other elements like aluminium, zinc, silicon, copper, zirconium and other rare-earth metals. The use of magnesium alloys in manufacturing of automobile parts leads to reduction in overall weight of the vehicle which in turn reduces amount of pollutant discharges (CO_2, NO_x ,SO_x emissions) and energy consumption. In industry, commonly used magnesium alloys

Magnesium alloys, like aluminium alloys, are divided into cast and wrought categories. As a principal alloying ingredient, a cast magnesium alloy contains varying amounts of aluminium, manganese, and zinc, but not more than 10% by weight. Cast magnesium alloys can have their mechanical characteristics enhanced by undergoing appropriate heat treatment techniques.

On the other hand, wrought magnesium alloys are subjected to mechanical working such as forging, extrusion, and rolling operation. The major alloying components are aluminium, manganese, and zinc. Heat treatable and non-heat treatable wrought magnesium alloys are two types of wrought magnesium alloys.

In industry, commonly used magnesium alloys could be classified as AZ (aluminium, zinc), AM (aluminium, manganese), and AS (aluminium, silicon)

Magnesium alloys are one of the most popular non-ferrous casting materials. The physical properties of these alloys can be altered by changing their chemical composition. Adding different alloying elements would give different properties at different conditions

- Aluminium promotes ductility, hardness, and strength.
- Zinc enhances casting fluidity, strength, and corrosion resistance at room temperature.
- Manganese, by producing intermettalic compounds, increases the corrosion resistance of aluminium-manganese (AM) alloys and aluminium-zinc-manganese alloys against saltwater.
- Rare earth metal adds strength and resistance to high-temperature creep and corrosion.
- Beryllium aids in surface oxidation reduction during casting and welding.
- Calcium improves grain refinement, allowing the alloy's metallurgy to be better controlled.

1.6 IMPORTANT MACHINING PARAMETERS

- **Cutting Speed**

The cutting speed of a tool can be described as the rate at which the cutting edge moves through the material. It's basically the tool's and workpiece's relative motion. Cutting speed is usually represented in m/min, and it's also referred to as surface speed in m/min. The lathe spindle must rotate at a quicker rate for smaller diameter workpieces and at a slower rate for bigger diameter workpieces to achieve uniform cutting speed. Cutting speed is determined by the strength and hardness of the material to be cut, the material of the tool bit, the amount of cutting force required, and other factors.

Mathematically it is defined as,

$$\mathbf{V_c = [(\pi * D * N)/60]} \quad \text{mm/s}$$

Where D = diameter of the workpiece (mm)

N = rpm of the workpiece (rev/min)

- **Feed Rate**

The feed of a cutting tool is the distance that the tool travels into or along the workpiece each time the tool passes a certain position in its travel over the surface. In case of turning on a lathe, feed is the distance that the tool advances in one revolution of the workpiece whereas in case of shaping, feed is the distance that the tool moves with respect to the work for each cutting stroke.

Feed rate along with the cutting speed plays an important role in determining the surface finish, power consumption, material removal rate. For harder material more cutting forces is required to remove the chip and more rapid will be the wear and tear, so to avoid this problem lower cutting speed and smaller feed rate is required.

Feed rate is expressed with a unit mm/rev.

- **Depth of cut**

The perpendicular distance measured from the machined surface to the uncut surface of the workpiece is termed as the depth of cut. The standard machine practice is to employ a depth of cut which is five times the feed rate. It is the entire amount of material removed by the cutting tool in one pass. It is measured in millimeters. It varies depending on the tool and the material of the workpiece.

Mathematically, it is defined as half of the difference between the diameters.

$$\mathbf{d = [(D_1 - D_2)/2]} \quad \text{mm}$$

Where D_1 = outer diameter (mm)

D_2 = inner diameter (mm)

- **Shape, angles and dimension of the cutting tool**

A change in the principle cutting edge angle of the cutting tool leads to changes in the cutting force required for the cutting action as well as it changes the conditions required for transmission of heat through the cutting elements of the tool. The heavier the cutting element easier will be the flow of heat into the body of the tool. Therefore the tool wear will depend upon on the shape and dimension of the cutting elements and even on the body of the tool.

In the machining process, the principle cutting edge angle is very vital. By increasing the principle cutting angle, the transverse component of cutting force gets decreased but it results into increase in cutting temperature which needs to be taken care off.

1.7 SURFACE FINISH & SURFACE ROUGHNESS

The ultimate aim of the manufacturing processes particularly the machining or metal cutting operation is to generate products having high surface quality, good dimensional tolerance etc. Each of the various metal cutting processes like turning, milling, drilling, reaming, grinding, honing, WJM, AWJM, USM, ECM, EDM etc have varying level of capabilities in terms of surface quality.

Surface finish and surface roughness are commonly used to characterize surface properties in machining. Even though they are being used interchangeably for another but in true sense they do not convey the same technical meaning.

Surface roughness provides the measure of macro and micro unevenness and irregularities observed on a finished surface after machining. There are many different types of instruments that may be used to make such measurements easier.

On the other side, surface finish is the qualitative approach to designate the surface quality either by observing the surface or by looking at its roughness value. To designate the finish quality, several elements such as good, terrible, shiny, fine, and so on are utilized. It purely depends on human intuition.

The failure of an engineered component is more typically attributed to the surface, either as a result of a specific manufacturing issue or as a result of a steady deterioration in surface quality. This leads to the adoption of finishing operation as an ideal methodology for obtaining desired surface finish on various manufactured parts.

Obtaining precise roughness is challenging as it is an expansive affair. Lowering a surface's roughness always increases its production cost. As a result, there is a trade-off between a part's manufacturing cost and its performance.

Even though surface finish provides many advantages which are well known to everyone but some of the noteworthy help that it provides are as follow:

- In terms of chemical and corrosion resistance, it is quite important.
- It gives the goods a pleasing appearance.
- Enhance electrical surface conduction and improves conductivity.
- It tends to boost the strength of the product by reducing frictional wear

1.8 TOOL WEAR RATE & MATERIAL REMOVAL RATE

It is a well known fact that a newly ground tool having hard sharper cutting edges and smooth flanks when is being used for prolonged period of time will ultimately get worn out. The chip slides over the rake face and the machined surface rubbed over the flank surface of the tool respectively. As a result the temperature over this contact surface remains pretty high and there will be mechanical and thermal shock on the tool during the period of machining. All this reasons leads to tool wear.

In general tool failure can be broadly classified as:

- **Fracture failure:** When exceeding cutting force leads to failure of tool.
- **Thermal failure:** When extreme cutting temperature is responsible for tool failure
- **Gradual failure:** Failure or wear of tool due to continuous usage of tool which leads to change in shape and size of the tool and reduction in cutting efficiency.

The two main types of tool wear can be distinguished as follows:

- **Crater wear:** Occurs on the rake face of the tool, it generates high thermal stresses at the tool-chip contact surface. It is measured either by its depth or its area.
- **Flank wear:** Occurs on the relief face or flank face of the tool, an extreme condition of flank wear appears on the cutting edge of the tool called as notch wear.

Mathematically, tool wear rate can be calculated as

$$\mathbf{TWR = [(W_i - W_f) / (\rho_{tm} * t_m)]} \quad mm^3/min$$

Where W_i = Initial weight of the tool before cutting (g)

W_f = Final weight of the tool after cutting (g)

ρ_{tm} = Density of the cutting tool material (g/mm^3)

t_m = machining time required for cutting (min)

In order to have economic machining the tool wear rate of the cutting tool should be as low as possible.

Material removal rate is an important parameter in a quest to know about the efficiency of cutting process and it also tells about how profitable the cutting process would turn out. Basically it is the volume of workpiece material removed per unit time when machining operation has been performed on the workpiece. Higher the material removal rate better is the cutting efficiency hence higher values of MRR is always preferable.

However in case of finishing operation low MRR is preferable which is in complete contrast to the machining operation as surface roughness as well as precision dimensional tolerance becomes an important factor for finishing operation.

Mathematically, material removal rate can be evaluated same as the tool wear rate but with a slight difference as slated below:

$$\mathbf{MRR = [(W_i - W_f) / (\rho_{wm} * t_m)]}$$

Where W_i = Initial weight of the workpiece before cutting (g)

W_f = Final weight of the workpiece after cutting (g)

ρ_{wm} = Density of the workpiece material (g/mm^3)

t_m = machining time required for cutting (min)

1.9 CRYOGENIC TREATMENT

Cryogenic treatment is a metal treatment technique which is performed at a much lower temperature usually around -196˚ C in order to improve mechanical properties, to remove stresses, to reduce wear resistances, and to provide stabilization.

The metal is gently cooled during cryo processing, mainly by utilizing liquid nitrogen. This lowering of temperature helps to prevent stress on the material with an intention to reduce the risk of damaging the parts.

The cryogenic metal treatment and heat treatment are two different aspects of metal treatment operation. While heat treatment tends to improve strength of the material and changes the microstructure of the material but it may lead to some sort of imperfection. The cryo treated materials shows better dimensional accuracy, are resistant to creep, and are less subjected to stress fracturing.

One of the important attributions of cryogenic metal treatment is that it increases the density of the metal materials, making them stronger and more solid. This improves their durability and wear resistance while also reducing surface roughness. As a result, the cost and associated machining time are reduced.

In case of rough machining, the cryogenic treatment is preferred for increasing the tool life. It is also helpful in providing safeguard against the integrity and the quality of the machined surface in case of finish machining operations.

1.10 ECONOMICAL MACHINING

The ultimate requirement with regard to any of the available machining operation is that it should result into lowest possible unit cost and highest possible production rate.

In any of the manufacturing operation, the cost involved plays an important role in determining how much should be the rate of production. If we keep on cutting the work material at much lower speed this will have detrimental effect on production rate and hence the production cost will keep on piling up. Having much higher speed then the required value also have negative impact on production rate as the tool will get wear out quickly and we have to replace the tool frequently which leads to slowing down of the production rate which culminates with increase in cost of production.

Some of the components of cost associated with machining operation are given below:

- **Cost of labour:** It includes salaries and wages of the workers involved in machining.
- **Cost of operation:** It includes interest on cost of machines; its depreciation and cost of maintain the machine.
- **Overhead cost:** It covers the cost of establishment which includes land, office equipments etc.

- **Tooling cost:** It comprises of cost of the tool involved while machining of the workpiece.

- **Cost of resetting of tool:** It includes the cost incurred while regrinding and resetting the cutting tool.

In order to have economic machining, all these above stated costs needs to optimize and to do so the cutting parameters involved in machining must be thoroughly investigated and the parameters which have significant influence in machining operation must be optimized which will ultimately leads to a more economical approach.

CHAPTER TWO

2. REVIEW OF LITERATURE AND OBJECTIVES OF PRESENT WORK

2.1 LITERATURE REVIEW

The demand for alloys as compared to its pure metal is continuously growing in present time as the properties of the alloys are mostly being augmented in contrast to their base parent metal, as they can be easily tweaked as and when need arises during machining the component.

In recent years, Sankaran & Mishra et al (2017) reviewed that the demands of Mg alloys are increasing in various different machining techniques[1]. This can be attributed to the fact that Mg alloys can be used in case of lighter workload as its main element magnesium has a substantially lower density, around 1800 kg/m^3, and is one of the lightweight metallic materials. Even more noteworthy is that Mg alloys are 35 percent more lightly as compared to the Al alloys.

Viswanathan et al. (2014) aimed to optimize cutting parameters such as cutting speed, feed rate, and depth of cut while dry turning an AZ91D Mg alloy. Among the multiple factors listed above, feed rate was shown to be the most impacting parameter[2].

Carou et al. (2014) conducted an experiment to evaluate turning of Mg alloy with different cutting speeds, depths of cut, and feed rates while having dry machining with minimal lubrication. The statistical experimental analysis assured that feed rate is the major factor among all other parameters and increased depth of cut and feed rate leads to higher temperature generation[3].

Depth of cut emerged as the most important factor in determining cutting force when Guozhong Chai et al (2010) investigated dry cutting properties of Mg AZ91D alloy using kentanium cutting tools[4].

Since magnesium alloys have a low melting point ranging from 400 to 600 ° C, they can catch fire during machining because their auto ignition temperature is around 430 ℃, which is lower than the melting point. We should avoid using water or water-based coolants to extinguish such fires which may develop while machining Mg alloys since water gets decomposed by magnesium and produces hydrogen gas, which is highly explosive in nature, thus dry sand or an appropriate extinguisher should be used instead.

But using such lubricants and coolants while machining Mg alloys may lead to increase in cost of production which is detrimental with regard to economics of machining along with that it has several environmental consequences. As a result it is advisable to perform machining of magnesium under dry conditions[2].

Eker et al (2014) investigate about the machining of Mg alloy under dry and MQL conditions. It was proven that MQL is beneficial technique in reducing the cutting temperature which in turn improves tool life as well as it helps in eliminating BUE formation[5].

Adel et al (2018) built an artificial neutral network using matlab to predict surface roughness over minimal machining time at prime machining cost. The ANN model achieved a reliable prediction accuracy of 1.35 %[6].

Dutta & Narala et al (2021) successfully optimized turning parameters for newly developed AM Mg alloy using Taguchi technique. It was concluded that depth of cut bears maximum influence on cutting forces and feed has maximum influence of surface roughness[7].

Ashvin & Nanavati et al (2013) observed that surface roughness is an important index to evaluate the cutting performance. The average surface roughness (R_a) is mostly used parameter in industries as a deciding factor for evaluating quality of the machined component. The RSM model used predicted that feed rate is the main factor followed by tool radius in affecting surface roughness[8].

Danish et al (2019) investigated the influence of cryogenic treatment while performing turning operation of AZ31C alloy in order to analyse surface integrity parameters. It concluded that cryogenic machining improves surface quality, corrosion resistance and reduces ignition risk[9].

In contrast to other researchers, Nalbant et al (2007) and Rafai et al (2013) found that depth of cut is not a significant factor while machining unless there is built up edges formed around the cutting tool. It was proved by them that dry cutting produces lesser surface roughness compared to flood cutting[10].

Many pieces of research have been performed focussing on optimizing the cutting parameters while machining Mg alloys keeping the interest of the aerospace industries where there is ever increasing demand for light weight material[6].

The work done by Villeta et al (2012) confirms that surface roughness plays a vital role in efficiently optimizing the machining parameters. It also takes a note regarding productivity and control of production criteria based on safety and environmental aspects[11].

In another study, Pu et al (2014) performed a finite element simulation in order to study about micro structural changes, heat affected zone, grain size of a Mg AZ31C alloy under both dry condition as well as cryogenic condition to obtain a relation between them and it was found that cryogenic machining effectively induce grain refinement[12].

Astakhov P.A et al (2010) observed that the approach angle (K_r), the angle between cutting edge and feed direction is an important angle while selecting the tool in turning operation. It influences the direction of cutting forces, the length of the cutting edge engaged in a cut, the way in which cutting edge makes contact with the workpiece and the variation of the cut[13].

Over the last few decades it can be observed that the advantages associated with certain mechanical properties of Mg alloy is playing an important role in the increasing popularity and demand of these alloys over other traditional materials like titanium alloy and stainless steel in medical science field[14].

Chakraborty Banerjee et al (2019) investigated various types of material to analyse about their natural biocompatibility which includes magnesium, titanium, cobalt chromium alloys as well as stainless steel. Among these materials, it was observed that magnesium alloys were found to be having best potential for biomaterial implants as it has lower corrosion rate in human blood fluid as compared to others[15].

Song et al (2013) stated that AZ91D Mg alloys has the potential to be the implant biomaterial as it is harmless for human being, due to the fact that magnesium alloys are biodegradable in fluid of human body and Mg^{+2} helps in quick growth of bone tissue .

In the field of medical science, orthopaedic application has high demand for magnesium alloys. For orthopaedic purpose, having good machined surface of magnesium alloy is strongly needed as it has importance with respect to service life and corrosion behaviour of magnesium[14].

Bruschi et al (2018) have experimentally performed the turning operation on AZ31 alloy under three different cutting conditions i.e. dry cutting, wet cutting and cryogenic cooling. It was concluded by them that the process with cryogenic treatment results into machined surface with improved corrosion resistance[16].

Dutta et al (2020) explained that even nose radius has an important role in deciding machined surface quality by performing turning operation on a magnesium work specimen. The result indicated that larger the nose radius better will be the surface produced[17].

Wojtowicz et al (2013) commented that surface integrity is a very important factor in analysis of machined component as it carries importance as significant as fatigue life of a machined component. Its experimental investigation concluded that cutting tool nose radius has significant influence over the surface roughness while turning the magnesium alloy component[18].

In contrast to other research and experimental observation, Singh & Rao et al (2007) reviewed that after feed rate the most significant influencing factors on surface roughness are nose radius and rake angle.

For more in-depth analysis of surface roughness many different and unique methods were undertaken by many researchers. Risbood, Dixit & Saharabudhe et al (2003) make use of neutral network for estimating surface roughness with HSS tool and Tin coated tool which was generally a very good attempt[19].

Hessainia et al (2013) make a use of responsive surface methodology as an attempt to determine surface roughness of a steel alloy even before the machining. However it can only be used effectively when the tool is made up of Al_2O_3 or TiC ceramic cutting tool[20].

2.2 RESEARCH GAP & MOTIVATION

In present times, many industries are giving more importance in reducing the overall cost of production which raises the need for innovative ways in which the cost involved gets reduced. In a nutshell, it was decided to reduce the weight of the material which ultimately leads to a decrease in overall energy consumption. As a result of this deliberation, usage of light weight material gains significant momentum in the industries.

Material like aluminium, magnesium, and titanium were taken into consideration for using it for industrial purposes thus emerging as an alternative to the traditionally used material such as steel etc. With growing demand for alloys of these light weight materials, engineers are now enabled to use these materials which were earlier considered inappropriate for industrial usage.

Among the above stated light weight materials, aluminium alloys are vastly used in various industrial applications. From its utility in coke canes to aircraft fuselage, aluminium alloys due to its cheaper cost, ease of fabrication and lighter weight enjoys most popularity among the other materials.

But there are some drawbacks with regards to aluminium alloys like it results in abrasive and scratchy machined surface due to its poor wear resistance which becomes detrimental for using it in case of precise engineering output as required in making propeller blades of aircraft, in making of transmission casing used in helicopters where there is need for even lighter material. Along with this poor biocompatibility of aluminium when it is used in case of food packaging and cooking utensils it might link to Alzheimer’s disease as stated by Christopher exley et al (2014)[21]

To solve the above mentioned problems of aluminium alloys, demand for new options emerged, and magnesium alloys proved to be a viable alternative.

The Mg alloys are generally 35 times lighter as compared to aluminium alloys which make it more suitable to be used in application like in making transmission casing of helicopters, in making propeller blades of aircrafts and the biggest advantage with the magnesium alloy is that it has good biocompatibility, which allows it to be used in the medical area, notably in the orthopaedic department. The magnesium alloy requires 45% less power consumption as compared to the aluminium alloy which is an added advantage in order to achieve economic machining. It has the ability to resist electromagnetic radiations and gets least effected by vibrations thus making it more machining friendly compared to the aluminium alloys.

Another aspect regarding the machining of magnesium alloy is that since it has low melting point and the auto ignition temperature of magnesium alloy is higher than its melting point temperature as a result of which there is chances of ignition of the material while machining it which makes it a challenging material to deal with.

Looking at the future scope of magnesium alloy particularly its utility in the medical field and aircraft sector it is important to analyse the cutting parameters with its implication on the surface finish obtained after machining of magnesium alloys. In order to avoid the inflammation of Mg alloys while machining it is advisable to undergo cryogenic treated machining of magnesium alloys.

From the above discussed literature review in section 2.1, it was observed that most of the researchers have performed optimization analysis by considering feed, speed, and depth of cut as their likely input parameters. Very few out of them have taken up the aspect of cutting tool geometry as their input parameter and most of them have not even considered this aspect. Similarly the output variable has revolved mostly around surface roughness and very few of them have considered other variables as well.

Based on a comprehensive analysis of the literature, it was determined to include the aspect of cutting tool geometry in this project, and therefore, in addition to speed, feed, and depth of cut, the approach angle of the cutting tool would be one of the input parameters. We will use surface roughness, material removal rate, tool wear rate, and machining time as output parameters to examine economical machining, which is directly related to the quality of the product produced after machining..

2.3 OBJECTIVES

The aim of this project is to optimise the cutting parameters in order to investigate their impact on the output variables by using various statistical tools like Taguchi analysis and ANOVA analysis

- To investigate the impact of various cutting parameters on the surface roughness material removal rate, tool wear rate and machining time obtained after turning magnesium alloy.

- To develop relation among the various chosen influencing parameters in order to evaluate the percentage of contribution among them in case of the surface finish, material removal rate, tool wear rate and machining time obtained after performing the turning operation.

- To make a comment regarding the overall cost of production based on the quality of the surface finish, material removal and tool wear rates & machining time obtained by optimizing the influencing cutting parameters.

CHAPTER THREE

3. METHODOLOGY

3.1 MATERIAL SELECTION

The experiment has been performed on a single piece magnesium AZ31B alloy. The specimen was of cylindrical bar shape with diameter Φ20 mm and the length of the specimen was taken as 300 mm. As per the taguchi design of experiment combination the specimen was divided into 9 different parts with each of the parts having a length of 3.3 cm or 33 mm.

The primary reason for selecting AZ31B magnesium alloy was due its lightweight nature and having high machinability. It is widely available as compared to other magnesium grades and is viable alternative to the aluminium alloys since it is having high strength to weight ratio. The chemical composition of the material AZ31B has been shown in the table 3.1.1 followed by the mechanical properties are being listed in table 3.1.2.

Table 3.1.1 Chemical composition of AZ31B alloy

COMPONENTS	% BY WEIGHT
Mg	97
Al	2.50 – 3.50
Zn	0.60 – 1.40
Man	0.20
Si	0.10
Cu	0.05
Ca	0.04
Fe	0.005
Ni	0.005

Table 3.1.2 Mechanical properties of AZ31B alloy

PROPERTIES	METRIC	US UNITS
Density	1.77 g/cm^3	110 lb/ft^3
Modulus of elasticity	45 Gpa	6530 ksi
Specific heat capacity	1000 J/Kg*K	0.239 BTU/(lb* ˚F)
Thermal Conductivity	96 W/m*k	667 BTU*in/(hr*ft^2* ˚F)
Tensile strength (annealed)	255 Mpa	37000 psi
Yield strength (annealed)	150 Mpa	21800 psi
Shear strength (annealed)	160 Mpa	23200 psi
Hardness (annealed)	73 HB	73 HB

The AZ31B alloy falls under the wrought magnesium alloy category having good room temperature strength, ductility, corrosion resistance and weld ability. Along with its utility in aircraft and medical sectors it is mostly used in making camera casing, cell phones, laptop cases, speaker cones and concrete tools.

Fig 3.1.1 Mg AZ31B alloy workpiece

3.2 CUTTING TOOL SELECTION

The magnesium AZ31B has been turned by using carbide inserts. In order to study the effect of cutting tool while machining the Mg alloy it has been decided to take the tool insert angle or approach angle as one of the input variables and for that reason three different carbide tools having angles 35˚, 55˚, 80˚ are being considered. These three different angles will be used to perform the turnig operation on the AZ31B alloy as per the various combination of machining obtained through Taguchi design of experiments.

Table 3.2.1 Key specifications of watler cutting tool

CUTTING TOOL PARAMETERS	SPECIFICATIONS
ANSI Number	CNMG120408
Brand Name	W-Walter
Class	Turning
Code	CNMG120408-MV5 WPV20
Grade	MV5 WPV20
Fixing hole diameter	5.16 mm
Insert style	CNMG
Insert size	432
Material	Carbide
Corner radius	0.8 mm
Insert thickness	4.76 mm
Type	Turning insert

Fig 3.2.1 Carbide cutting tool with different inert angles 35˚, 55˚ and 80˚

The reason for selecting carbide cutting tool for turning Mg AZ31B alloy can be attributed to the fact that it gives us the assurance of safe machining environment as there is chances of ignition of Mg alloy due to overheating of the material. While machining the Mg alloy there remains a chance of buit up edge formation which can be avoided by using carbide tool and the cost of carbide tool also plays an important role as it is less expansive as compared to polycrystalline diamond tools.

3.3 MACHINE SPECIFICATIONS

3.3.1 LATHE SPECIFICATIONS

The experimental work has been carried out on CNC LT-16 XL having machine number 381 using CNMG inserts having tool corner radius 0.8 mm. The CNC system used is Fanue Oi Mate-TD and the CNC package used is Beeta 8i s (feed motor- 2 Nos), Beeta 6i (spindle), with SVPM-11 i.

Table 3.3.1.1 Lathe Specifications

TITLE	DESCRIPTION	STANDARD
	Swing over bed	Φ 500 mm
Capacity	Swing over carraige	Φ 260 mm
	Distance between centres	425 mm
	Maximum machining diameter	270 mm
	Maximum longitidnal travel (Z-axis)	400 mm
	Maximum transverse distance (X-axis)	140 mm
	Maximum power requirement	16 KVA
	Approximate weight	4000 Kg
	Spindle centre height from floor	1050 mm
Spindle	Spindle nose	A2-5
	Bore through spindle	Φ 47 mm
	Maximum bar capacity	Φ 36 mm
	Front bearing ID	Φ 80 mm
	Spindle speed	50 – 4000 rpm
	Spindle motor (A.C) /15 min	Fanuc Beeta 6/6000i, 5.5 Kw/7.5 Kw
TITLE	DESCRIPTION	STANDARD
	Tailstock quill diameter	80 mm

Tailstock	Tailstock taper in quill	MT – 4
	Tailstock quill stroke	100 mm
	Tailstock base travel	235 mm
	Thrust (max recommended)	500 Kg @ 20Kg/cm^2
X & Z axes	Cross slide inclination	30˚
	Number of turret station	8
	Standard cutting tools	25 x 25 mm
	Ball screw diameter X-axis	Φ 32 mm; Pitch = 10 mm
	Ball screw diameter Z-axis	Φ 32 mm; Pitch = 10 mm
	Feed motor X-axis & Z-axis	Fanuc Beeta 8s/3000 I
	Rapid transverse rate X-axis & Z-axis	20 m/min

Table 3.3.1.2 Machine power capacity chart

ELEMENTS USED	POWER REQUIRED
Spindle & Servo drives	12.04 KVA
Electrical control unit	1.00 KVA
Hydraulic pump motor	1.40 KVA
Coolant pump motor	0.30 KVA
Lubricant pump motor	0.15 KVA
Chip conveyor	0.20 KVA
Air cooler	1.00 KVA
Total	16.09 KVA

Fig 3.3.1.1 CNC LT-16 XL Lathe machine

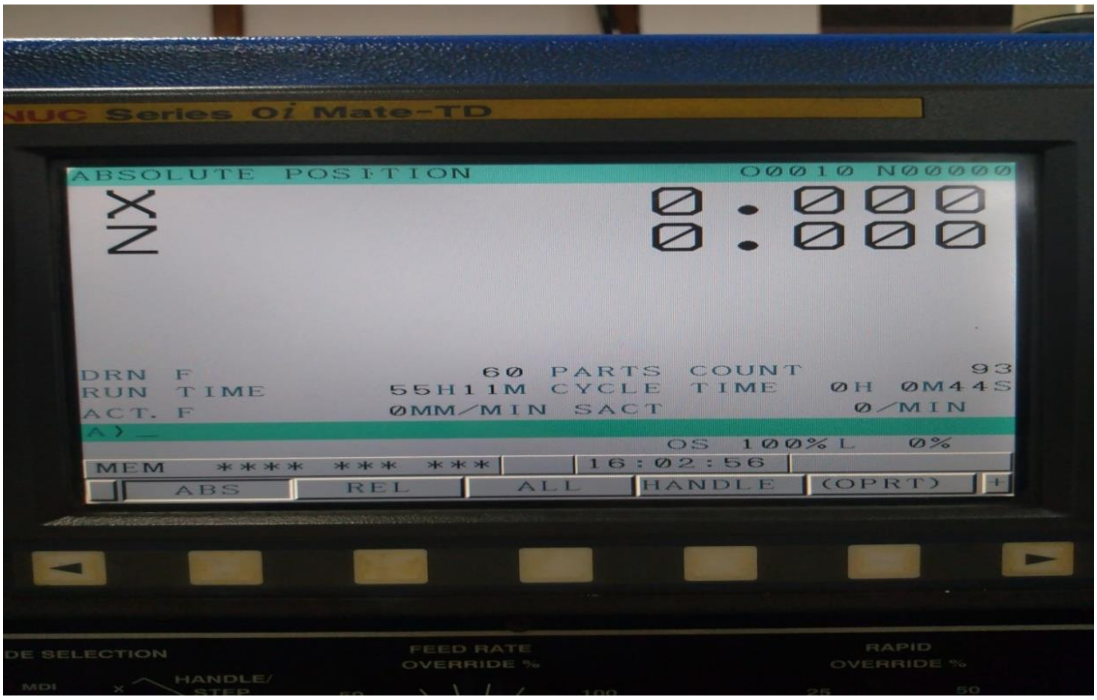

Fig 3.3.1.2 Digital display for readings and observation after performing each operation

The reason for opting CNC lathe turning operation inspite of conventional lathe turning option being available can be supported by the fact that it results in faster production rate with superior accuracy as the the whole turning operation for the required 9 specimens in this project was completed within 1.5 hrs. The turning operation of the AZ31B alloy has been carried out at the MSME Tool room and training, Amingaon, Guwahati.

3.3.2 SURFACE ROUGHNESS TESTER SPECIFICATIONS

In order to analyse about the quality of the machining output of a component, one of the most important characterstic being investigated is the measurement of surface roughness. The surface roughness measurement of the 9 turned out specimens with regard to this project was done on a portable surface roughness tester named as Mitutoyo surftest SJ210 series having a model number UI312-0913.

Table 3.3.3.1 Surface roughness tester specifications

TITLE	DESCRIPTION
Measuring range (X-axis)	17.6 mm
Measuring range (Z-axis)	14200 µin (-7900µin to 6300µin)
Measuring speed	0.25 mm/s, 0.5mm/s, 0.75mm/s; returning 1mm/s
Skid force	Less then 400 mN
Assessed profile	Primary profile/ Roughness profile/ DF profile
Evaluation parameters	Ra, Rc, Rmax, Ry, Rq, Rz, Rv etc.
Analysis graph	Bearing area curve/ Amplitude distribution curve
Cut off length λ_c	0.08 mm, 0.25 mm, 0.8 mm, 2.5 mm
Cut off length λ_s	2.5 µm, 8µm or none
Sampling length	0.08 mm, 0.25 mm, 0.8 mm, 2.5 mm
LCD dimensions	36.7 x 48.9 mm

Fig 3.3.3.1 Surface roughness measurement using Mitutoyo surftest SJ210 series

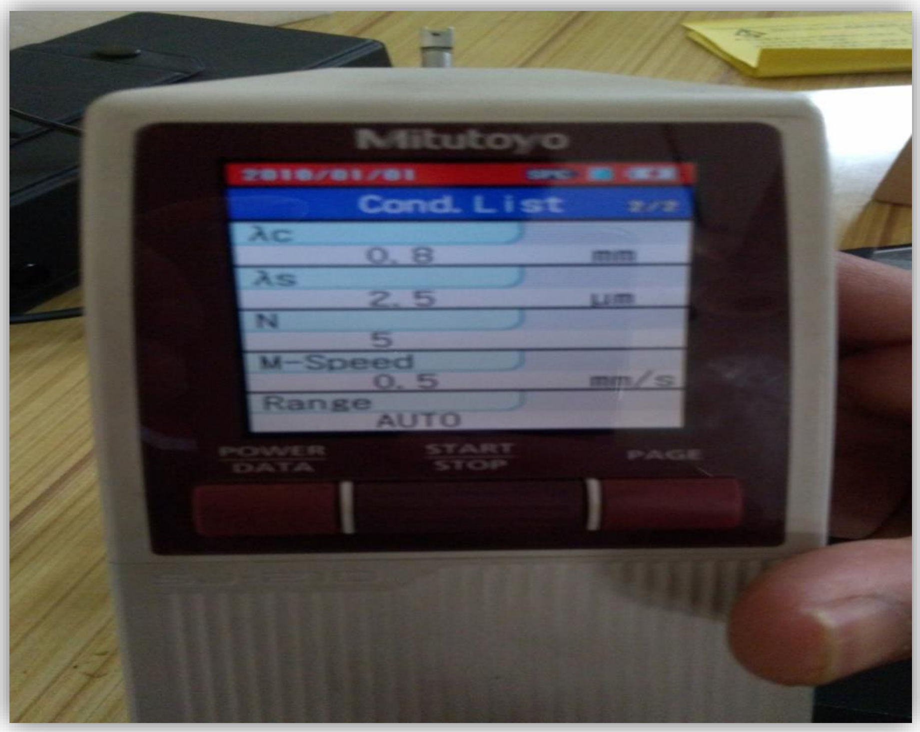

Fig 3.3.2.2 Fixed parameters while measuring surface roughness measurement

The surface roughness measurement of the 9 turned out specimens required for this project has been perfromed in the Metrology and Inspection lab of Assam Engineering College, Jalukbari, Guwahati.

3.3.3 VICKERS HARDNESS TESTING MACHINE SPECIFICATIONS

As discussed earlier that magnesium alloys while machining has a tendency to get iginited which makes it a bit challenging material for machining purpose. One of the prime reason for the ignition can be stated that it results into higher cutting temperature while machining the Mg alloy. In order to reduce the chances of self ignition of the material, cryogenic soaking can be an effective method. As per Gunasekhran et al (2021)[22], cryogenic soaking of duration about 60 minutes was found to be effective in reducing the chances self iginition of the Mg AZ91D alloy.

From the concepts of cryogenic treatment, it helps in enhencing the mechanical properties of the workpiece material particularly the hardness value, density, strength of the material.

In order to check the enhenced hardness of the material vickers hardness test was performed on the Mg AZ31B alloy. Since the workpiece was smaller in length and size vickers hardness test was preferred over the brinell hardness test.

Table 3.3.3.1 Vickers hardness machine specification

TITLE	DESCRIPTION
Load range	10gmf – 1000 gmf
Loding/ Unloading	Automatic
Dwel time	5 – 60 seconds
Magnification	100X & 400X
Measurement	175 microns manual
Speciment height	65 mm
Test table	100 x 100 mm

Fig 3.3.3.1 Vickers hardness testing machine

The vickers hardness test of the AZ31B alloy after cryogenic soaking was performed at Material testing lab at Assam Science and Technology University, Jalukbari, Guwahati.

3.3.4 WEIGHT BALANCE SPECIFICATION

For obtaining economic machining of AZ31B alloy, along with the analysis of surface roughness some other output parameters like tool wear rate, material removal rate needs to be examined. To assess tool wear and material removal rates after each experiment, we required to know the weight differential between the tool and the workpiece before and after the experiment.

In order to measure this weight difference we used SF 400A weighing machine and all these readings were taken at the MSME Tool room and training, Amingaon, Guwahati.

Table 3.3.3.4.1 Weight balance specifications

TITLE	DESCRIPTION
Brand	Atom
Material	Plastic
Item weight	0.45 Kg
Weight limit	10 Kg
Item dimensions	16.5 x 23.5 x 5.5 cm
Length & Width	23.01 cm & 16.01 cm
Special features	Automatic shut down

Fig 3.3.3.4.1 Weight balance

3.4 DESIGN OF EXPERIMENTS

Design of experiments is a statistical tool for developing relation among the input parameters which affect the process and the output parameters in relation to that process. It is widely used in manufacturing as well as non manufacturing industries. It is an extremely popular tool which is being effectively used in medical, engineering, biochemistry, physics etc.

Ronald A. Fisher in the late 1920's has been credited for introducing a new method in comparison to the existing traditional method by conducting research in agriculture with an aim of increasing yeild of the crop. He later wrote a book on DOE in which he gave explaination how the final outcome can be drawn from the experiment with regard to the input factors.

In a nutshell, the goal of design of experiments is to test the hypothesis in terms of cost effectiveness and process efficiency.

3.4.1 TAGUCHI ORTHOGONAL ARRAY DESIGN

Genichi Taguchi, a Japanese engineer proposed some experimental designs which are generally referred as "Taguchi designs" comprising of two level, three level or mixed level set of design.

Taguchi orthogonal array (OA) design is a type of factorial design. It is a highly fractional orthogonal design that is based on the matrix proposed by Taguchi which allows to consider multiple factor combinations at different levels.

Available Taguchi Designs (with Number of Factors)

	Single-level designs			
Designs	**2 level**	**3 level**	**4 level**	**5 level**
L4	2-3			
L8	2-7			
L9		2-4		
L12	2-11			
L16	2-15			
L16			2-5	
L25				2-6
L27		2-13		
L32	2-31			

Single-level | Mixed 2-3 level | Mixed 2-4 level | Mixed 2-8 level

Fig 3.4.1.1 Available Taguchi Designs for various levels

In general taguchi design of experiments consists of the following steps as shown in the table below:

Table 3.4.1.1 Steps involved in Taguchi designs

STEPS	DESCRIPTION
Brainstoming	Decide how many factors and level are involved in achieving the aim of the process.
Designing experiments	Decide the required orthogonal array and the order of the design runs.
Running experiments	Run experiments in random order as possible.
Analyzing results	Determine the optimum design and performance at the optimum condtion.

In order to achieve the specific aim of the research analysis, three different criteria are available for that purpose as stated below in the following table:

Table 3.4.1.2 Avalilable criteria for Taguchi analysis in Minitab 19

SIGNAL TO NOISE RATIO	AIM OF THE EXPERIMENT	DATA CHARACTERSTICS	S/N RATIO FORMULAS
Larger the better	Maximize the response	Positive	**$S/N = -10 * \log(\Sigma(1/Y^2)/n)$**
Smaller the better	Minimize the response	Non negative with a target value of zero	**$S/N = -10 * \log(\Sigma(Y^2)/n))$**
Nominal the best	Target the response as close as possible to standard deviation	Positive, zero or negative	**$S/N = -10 * \log(\sigma^2)$**

Where, Y = Responses for the given factor level combination

n = Number of responses in the factor level combination

3.4.2 RESPONSIVE SURFACE METHODOLOGY

Responsive surface methodology (RSM) can be describe as a statistical tool which can be effectively used in optimization techniques in order to indentify inter relation among the variables which has an influence on the process outcome

Responsive surface methodology was introduced by Box and Wilson with sole purpose of analyzing by using emperical models to the various research problems as the one posed.

It can be used in order to optimize the certain process and the variables invoved in that process by plotting various plots namely contour plots, surface plots etc. between the variables thus showing the interactions among them which might have an impact on the process output.

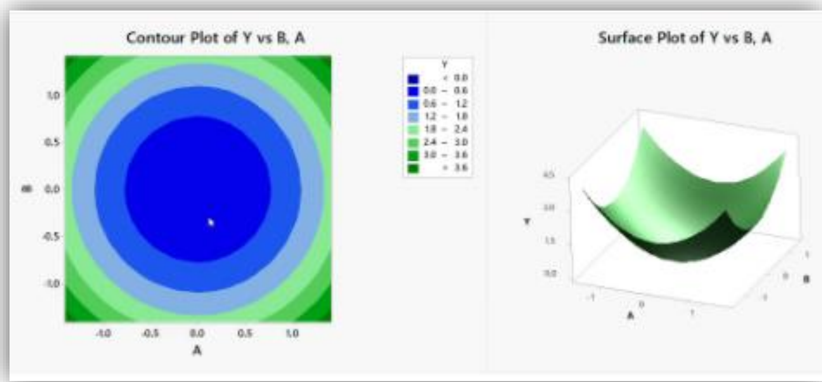

Fig 3.4.2.1 Contour plots & Surface plots obtained by RSM

3.5 STEPS INVOLVED IN THE PROJECT

In order to carry out the effective excecution of this project work, the experimental work involved in this project can divided into the following steps as given below:

- Cut the magnesium AZ31B alloy specimen of Φ20 mm and length 300 mm into 9 smaller parts as suggested by Taguchi orthogonal array design.

- Since there is a chance of ignition while machining this magnesium alloy, soak all those nine parts in liquid nitrogen (LN_2) solution for around 30 minutes in order to lower down the cutting temperature.

- Split the cutting speed, feed rate, depth of cut ranges into three levels and take into the consideration of three various insert angles of the carbide cutting tool thus making it a 3-level and 4-factor design of experiments.

- Perform the turning operation on each of this nine components as per the various experimental combinations available as per Taguchi designs.

- Measure the response output variable like surface roughness, material removal rate, tool wear rate, machining time of all those nine parts.

- Using Taguchi techniques and responsive surface methodology in the Minitab 19 software, analyze the data and optimise the response variable to accomplish the project's desired goal.

- At the end, perform the confirmatory test in order to know the deviation from predicted optimized results and the optimized experimental results.

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1 TAGUCHI ORTHOGONAL ARRAY DESIGN

In order to execute this project, the first most important step is to create the taguchi orthogonal array. For generating this taguchi orthogonal array using MINITAB19 software we need to first identify the important input parameters and divide those input parameters into three different levels from the available working ranges with regard to the material AZ31B alloy used in this project work.

The ranges of each of the input parameters which are selected on the basis of the manufacturer's catalogue are shown in the table given below:

Table 4.1.1 Input parameters and their levels

SYMBOL	INPUT PARAMETERS	UNITS	LEVEL 1	LEVEL 2	LEVEL 3
v	Cutting Speed	rpm	800	1000	1200
f	Feed	mm/rev	0.2	0.3	0.4
d	Depth of Cut	mm	0.2	0.3	0.4
θ	Approach Angle	degree	35	55	80

With the following above stated input parameters and the various levels of those input parameters, the next step is to choose out of the available number of runs L9 or L27 for four factors and three levels taguchi design in order to create the taguchi orthogonal array. The same has been depicted in the fig 4.1.1.

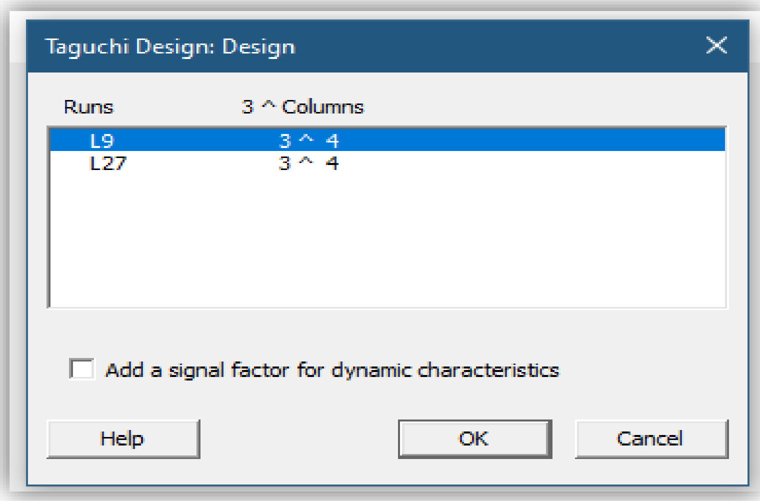

Fig 4.1.1 Available number of runs for 4-factors 3-levels design

Due to limited size of the work specimen AZ31B alloy, we opted for L9 orthogonal array design as it is more compact and will help us to perform the requisite engineering experimental design in order to achieve our goal with minimum number of experiments to perform. The standard taguchi L9 orthogonal array design has been shown in the table 4.1.2 given below.

Table 4.1.2 Taguchi L9 orthogonal array

Run	Parameter A	Parameter B	Parameter C	Parameter D
1	L1	L1	L1	L1
2	L1	L2	L2	L2
3	L1	L3	L3	L3
4	L2	L1	L2	L3
5	L2	L2	L3	L1
6	L2	L3	L1	L2
7	L3	L1	L3	L2
8	L3	L2	L1	L3
9	L3	L3	L2	L1

By substituting the values of various levels of input parameters associated with this project work, we will obtain the required L9 taguchi orthogonal array as given in the table 4.1.3 below.

Table 4.1.3 Required L9 array of the project

Run	Cutting Speed (rpm)	Feed (mm/rev)	Depth of Cut (mm)	Approach Angle (˚)
1	800	0.2	0.2	35
2	800	0.3	0.3	55
3	800	0.4	0.4	80
4	1000	0.2	0.3	80
5	1000	0.3	0.4	35
6	1000	0.4	0.2	55
7	1200	0.2	0.4	55
8	1200	0.3	0.2	80
9	1200	0.4	0.3	35

4.2 ANALYSIS OF SURFACE ROUGHNESS

As discussed earlier in the introduction chapter, the quality of the machined component plays an important role in deciding the outcome of the machining process. The most prominent parameter in deciding this aspect is the surface roughness. Lower the value of surface roughness better will be the surface finish and the machining output will be satisfactory.

In this project, nine experiments were performed as per taugchi L9 array and surface roughness for each of them has been measured. As we know that lower surface roughness is desirable so while analysing the surface roughness using MINITAB19 software we choose the lower-the-better for its optimization. The various signal to noise ratio values has been recorded. The experimental values of surface roughness and S/N ratios are listed below in the table 4.2.1.

Table 4.2.1 Experimental values of surface roughness and S/N ratios

Run	Cutting Speed (rpm)	Feed (mm/rev)	Depth of Cut (mm)	Approach Angle (˚)	Surface Roughness (μm)	S/ N Ratio (dB)
1	800	0.2	0.2	35	5.084	-14.1241
2	800	0.3	0.3	55	7.290	-17.2546
3	800	0.4	0.4	80	3.448	-10.7513
4	1000	0.2	0.3	80	1.801	-5.1103
5	1000	0.3	0.4	35	7.729	-17.7625
6	1000	0.4	0.2	55	12.335	-21.8228
7	1200	0.2	0.4	55	3.353	-10.5087
8	1200	0.3	0.2	80	2.833	-9.0449
9	1200	0.4	0.3	35	15.037	-23.5432

In order to check whether the obtained surface roughness values are within the permissible limit for further analysis, we need to perform the normality test of these values which will be indicated by the probability plot having 95% confidence interval. The p-value indicated in the probability plot should be more than 0.05 otherwise it will fail the normality test. The probability plot for the surface roughness is shown in the figure below.

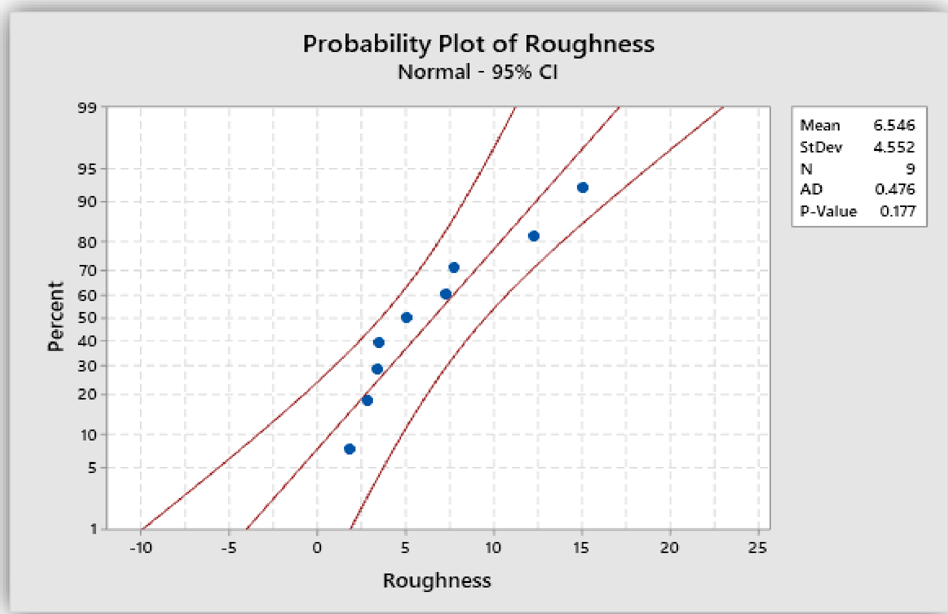

Fig 4.2.1 Probability plot of surface roughness

As discussed for analysing surface roughness we will choose lower-the-better criteria, this will generate S/N ratio plot as well as mean effects plot which will help us to decide the levels of the corresponding input parameters resulting into the desired outcome.

For analysing and optimizing the surface roughness, the response table for S/N ratio plays an important role in deciding the levels of the input parameters that must be selected which will give us the desired lower-the-better criteria for analysis. The response table has been provided below in the table 4.2.2.

Table 4.2.2 Response table for S/N ratios of surface roughness

LEVEL	CUTTING SPEED	FEED	DEPTH OF CUT	APPROACH ANGLE
1	**-14.043**	**-9.914**	-14.997	-18.477
2	-14.899	-14.687	-15.303	-16.529
3	-14.366	-18.706	**-13.007**	**-8.302**
DELTA	0.855	8.791	2.295	10.174
RANK	4	2	3	1

This response table for S/N ratios has been appropriately supported by main effects plot for S/N ratio and main effects plot for means. This plots along with the response table helps in determining the required levels for input parameters. The main effects plots for S/N ratios and means are shown in figure below.

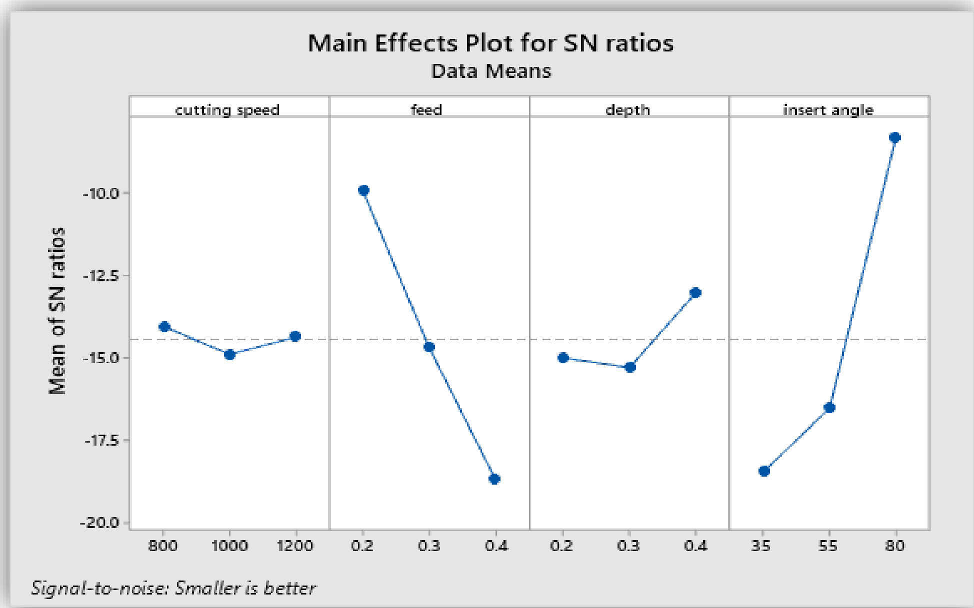

Fig 4.2.2 Main effects plot for S/N ratios

Fig 4.2.3 Main effects plot for means

For analysis purpose we must choose that S/N ratio for a given level of an input parameter which is highest among the others or we have to select that S/N ratio which closer to zero (0) value. From the above plots and response table we can clearly observe that level-1 for cutting speed, level-1 for feed, level-3 for depth of cut and level-3 for approach angle must be selected in order to achieve our objective of lowering the surface roughness for obtaining an optimal value of it. Thus the predicted combination for optimum surface roughness value using Taguchi method can be represented as $\mathbf{v_1\text{-}f_1\text{-}d_3\text{-}\theta_3}$.

The increase in approach angle resulting into maximum impact on surface roughness can be attributed to the fact that icrese in approach angle gives increment in tool-workpiece contact along the direction of cutting edge and this increase in contact length results in higher surface roughness[23].

In order to check the contribution of each the input parameters in the analysis of surface roughness, ANOVA analysis has been performed. The result of the ANOVA analysis for surface roughness is listed in the table given below.

Table 4.2.3 ANOVA for surface roughness

Source	Degree of Freedom	Sum of Squares	Mean Squares	% Contribution
Cutting Speed	2	1.119	0.5596	0.3709
Feed	2	116.219	58.1093	38.5282
Depth of Cut	2	9.320	4.6602	3.0897
Approach Angle	2	174.988	87.4941	58.0110
Total	8	301.646		100

From the above ANOVA table we can conclude that approach angle of the cutting tool has the most influence on surface roughness with 58.01% contribution followed by feed with 38.53% contribution. The depth of cut and cutting speed has the minimum influence on surface roughness with 3.09% and 0.37% contribution respectively. The pie chart given below represents percentage of contribution of the various input parameters involved.

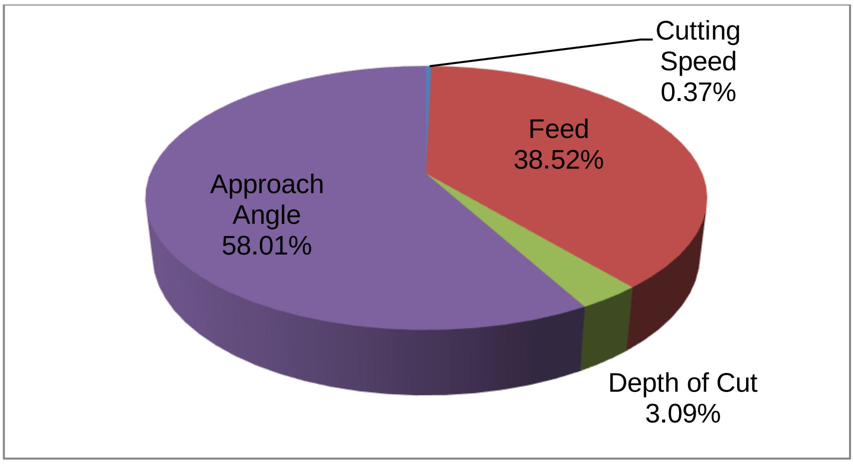

Fig 4.2.4 Pie chart representation of PCR for surface roughness

4.3 ANALYSIS OF MATERIAL REMOVAL RATE

As the machining operation deals with removal of excess material from the work specimen, in this regard material removal rate becomes an important aspect of machining outcome. The material removal rate in case of cutting operation is desired to be higher which is in contrast with the finishing operation.

In this project we are concerned with turning of Mg AZ31B alloy, so in order to achieve our goal of economic machining the material removal rate must be as high as possible. So to analyse the material removal rate using taguchi method we have to choose larger-the-better criteria while dealing with the S/N ratio values.

For evaluating material removal rate in this project, we will be using the equation as stated in the introduction chapter. Since in this project we have to perform nine combinations of experiments hence we will be evaluating nine different MRR values. The equation to be used is again written below with nomenclature of the symbols remains same as earlier. The density of the workpiece AZ31B alloy has been taken as 1.77 g/cm^3.

$$MRR = [(W_i - W_f)/(t_m * \rho_{wm})] \quad mm^3/min$$

As we can observe that for evaluating MRR we need the weight differentials. The difference in weight of the workpiece before and after the experiment along with the machining time for nine different combinations of experiments is shown in the table below.

Table 4.3.1 Weights before and after the experiment along with the machining time

Run	Weight before experiment (g)	Weight after experiment (g)	Machining time (min)
1	20	16	1.83
2	17	12	1.36
3	17	12	0.85
4	19	14	1.16
5	18	13	0.93
6	18	14	1.26
7	20	15	0.90
8	19	14	1.28
9	20	15	0.73

By using the above stated values and through taguchi method analysis the experimental value of MRR and S/N ratios are listed in the table below.

Table 4.3.2 Experimental values of material removal rate and S/N ratios

Run	Cutting Speed (rpm)	Feed (mm/rev)	Depth of Cut (mm)	Approach Angle (˚)	Material Removal Rate (mm^3/min)	S/ N Ratio (dB)
1	800	0.2	0.2	35	1234.91	61.8327
2	800	0.3	0.3	55	2077.10	66.3492
3	800	0.4	0.4	80	3323.36	70.4316
4	1000	0.2	0.3	80	2435.22	67.7308
5	1000	0.3	0.4	35	3037.48	69.6503
6	1000	0.4	0.2	55	1793.56	65.0743
7	1200	0.2	0.4	55	3138.73	69.6503
8	1200	0.3	0.2	80	2206.92	66.8757
9	1200	0.4	0.3	35	3869.67	71.7535

In order to check whether the obtained material removal rates are within the permissible limit for further analysis, we need to perform the normality test of these values which will be indicated by the probability plot having 95% confidence interval. The p-value indicated in the probability plot should be more than 0.05 otherwise it will fail the normality test. The probability plot for the material removal rate is shown in the figure below.

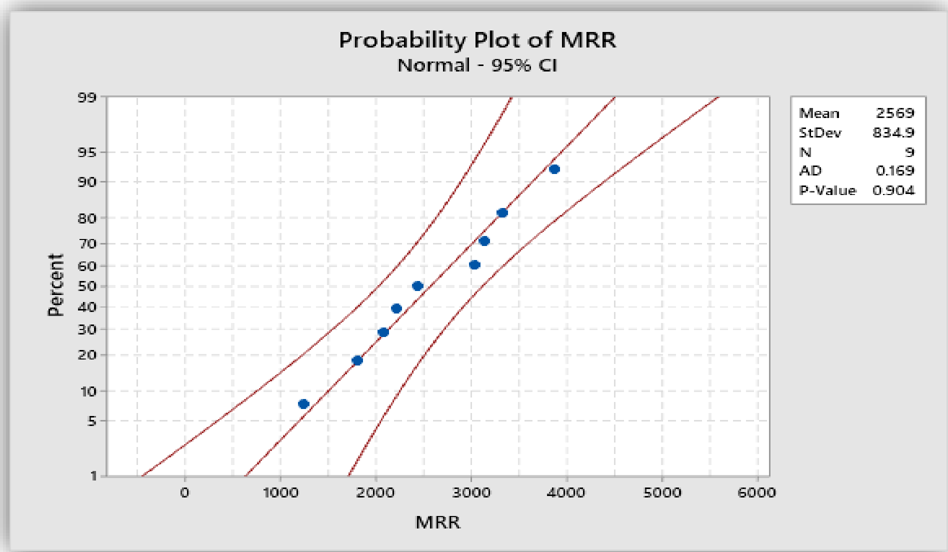

Fig 4.3.1 Probability plot of material removal rate

As discussed for analyzing material removal rate we will choose larger-the-better criteria, this will generate S/N ratio plot as well as mean effects plot which will help us to decide the levels of the corresponding input parameters resulting into the desired outcome.

For analysing and optimizing the material removal rate, the response table for S/N ratio plays an important role in deciding the levels of the input parameters that must be selected which will give us the desired criteria for analysis. The response table has been provided below in the table 4.3.3.

Table 4.3.3 Response table for S/N ratios of material removal rate

LEVEL	CUTTING SPEED	FEED	DEPTH OF CUT	APPROACH ANGLE
1	66.20	66.50	64.59	67.75
2	67.49	67.63	68.61	67.12
3	**69.52**	**69.09**	**70.01**	**68.35**
DELTA	3.32	2.59	5.41	1.23
RANK	2	3	1	4

This response table for S/N ratios has been appropriately supported by main effects plot for S/N ratio and main effects plot for means. This plots along with the response table helps in determining the required levels for input parameters. The main effects plots for S/N ratios and means are shown in figure below.

Fig 4.3.2 Main effects for S/N ratios

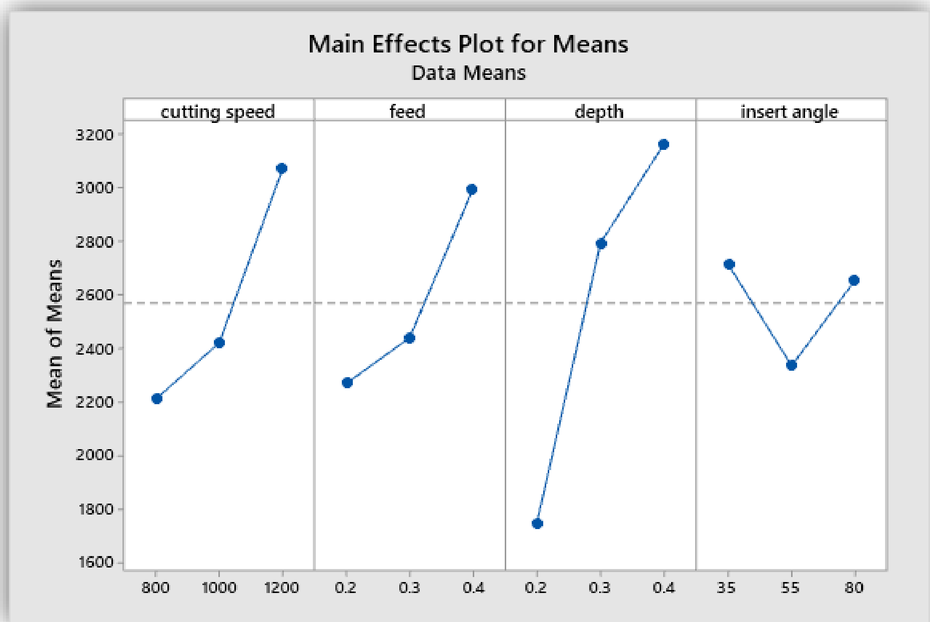

Fig 4.3.3 Main effects plot for means

For analysis purpose we must choose that S/N ratio for a given level of an input parameter which is highest among the others or we have to select that S/N ratio which is away from zero (0) value. From the above plots and response table we can clearly observe that level-3 for cutting speed, level-3 for feed, level-3 for depth of cut and level-3 for approach angle must be selected in order to achieve our objective of maximizing the material removal rate for obtaining an optimal value of it. Thus the predicted combination for optimum material removal rate value using Taguchi method can be represented as $\mathbf{v_3\text{-}f_3\text{-}d_3\text{-}\theta_3}$.

This higher material removal rate corresponding to higher depth of cut can be explained from the theoretical background that material removal rate is a function of depth of cut, speed and feed. As a result, a significant depth of cut leads to a high MRR, which boosts productivity and makes machining more cost-effective[24].

In order to check the contribution of each the input parameters in the analysis of material removal rate, ANOVA analysis has been performed. The result of the ANOVA analysis for material removal rate is listed in the table given below.

Table 4.3.4 ANOVA for material removal rate

Source	Degree of Freedom	Sum of Squares	Mean Squares	% Contribution
Cutting Speed	2	16.7888	8.3944	21.9441
Feed	2	10.0947	5.0474	13.1950
Depth of Cut	2	47.3630	23.6815	61.9096
Approach Angle	2	2.2568	1.1284	2.9499
Total	8	76.5034		100

From the above ANOVA table we can conclude that depth of cut has the most influence on material removal rate with 61.91% contribution followed by cutting speed with 21.94% contribution. The Feed has 13.2% contribution on the material removal rate and approach angle of the cutting tool has least impact with 2.95% contribution on the material removal rate. The pie chart given below represents percentage of contribution of the various input parameters involved.

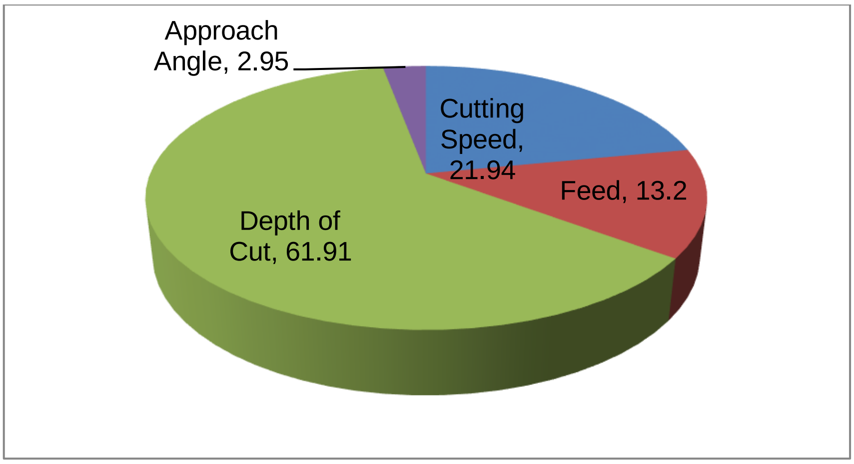

Fig 4.3.4 Pie chart representation of PCR for material removal rate

4.4 ANALYSIS OF TOOL WEAR RATE

As we know that in order to achieve economical machining, tool wear rate is an important parameter in this regard. Higher tool wear rate is somewhat a spoilsport in case of economical machining as it will make the cutting tool to get wear out quickly and hence there will be a need for frequent change of the cutting tool which will lead to slower production rate and ultimately it result into loss for the manufacturing organization.

In this project we are trying to find out the optimal cutting conditions with an aim of reaching our objective of economical machining. Hence while analysing tool wear rate using taguchi method we will choose lower-the-better criteria while performing the requisite optimization technique.

For evaluating tool wear rate in this project, we will be using the equation as stated in the introduction chapter. Since in this project we have to perform nine combinations of experiments hence we will be evaluating nine different TWR values. The equation to be used is again written below with nomenclature of the symbols remains same as earlier. The density of the carbide cutting tool material has been taken as 15.63 g/cm^3.

$$TWR = [(W_i - W_f)/(t_m * \rho_{tm})] \quad mm^3/min$$

As we can observe that for evaluating TWR we need the weight differentials. The difference in weight of the cutting tool before and after the experiment along with the machining time for nine different combinations of experiments is shown in the table below.

Table 4.4.1 Weight of tool before and after experiments along with the machining time

Run	Type	Weight before experiment (g)	Weight after experiment (g)	Machining time (min)
1	35°	9	8.95	1.83
2	55°	15	14.95	1.36
3	80°	9	8.92	0.85
4	80°	8.92	8.86	1.16
5	35°	8.95	8.89	0.93
6	55°	14.95	14.89	1.26
7	55°	14.89	14.82	0.90
8	80°	8.86	8.80	1.28
9	35°	8.89	8.84	0.73

By using the above stated values and through taguchi method analysis the experimental values of TWR and S/N ratios are listed in the table below.

Table 4.4.2 Experimental values of tool wear rate and S/N ratios

Run	Cutting Speed (rpm)	Feed (mm/rev)	Depth of Cut (mm)	Approach Angle (°)	Tool Wear Rate (mm^3/min)	S/N Ratio (dB)
1	800	0.2	0.2	35	1.748	-4.8508
2	800	0.3	0.3	55	2.352	-7.4287
3	800	0.4	0.4	80	6.021	-15.5934
4	1000	0.2	0.3	80	3.309	-10.3939
5	1000	0.3	0.4	35	4.127	-12.3127
6	1000	0.4	0.2	55	3.044	-9.6689
7	1200	0.2	0.4	55	4.976	-13.9376
8	1200	0.3	0.2	80	3.001	-9.5453
9	1200	0.4	0.3	35	4.382	-12.8334

In order to check whether the obtained tool wear rates are within the permissible limit for further analysis, we need to perform the normality test of these values which will be indicated by the probability plot having 95% confidence interval. The p-value indicated in the probability plot should be more than 0.05 otherwise it will fail the normality test. The probability plot for the tool wear rate is shown in the figure below.

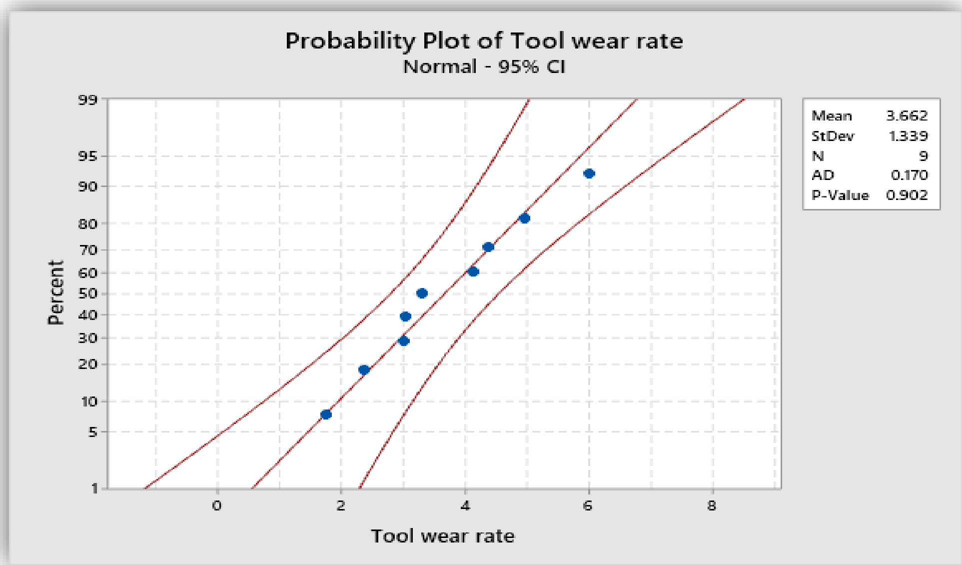

Fig 4.4.1 Probability plot of tool wear rate

As discussed for analysing tool wear rate we will choose lower-the-better criteria, this will generate S/N ratio plot as well as mean effects plot which will help us to decide the levels of the corresponding input parameters resulting into the desired outcome.

For analysing and optimizing the tool wear rate, the response table for S/N ratio plays an important role in deciding the levels of the input parameters that must be selected which will give us the desired lower-the-better criteria for analysis. The response table has been provided below in the table 4.4.3.

Table 4.4.3 Response table for S/N ratios of tool wear rate

LEVEL	CUTTING SPEED	FEED	DEPTH OF CUT	APPROACH ANGLE
1	**-9.291**	**-9.727**	**-8.022**	**-9.999**
2	-10.792	-9.762	-10.219	-10.345
3	-12.105	-12.699	-13.948	-11.844
DELTA	2.814	2.971	5.926	1.845
RANK	3	2	1	4

This response table for S/N ratios has been appropriately supported by main effects for S/N ratio and main effects plots for means. This plots along with the response table helps in determining the required levels for input parameters. The main effects plots for S/N ratios and means are shown in figure below.

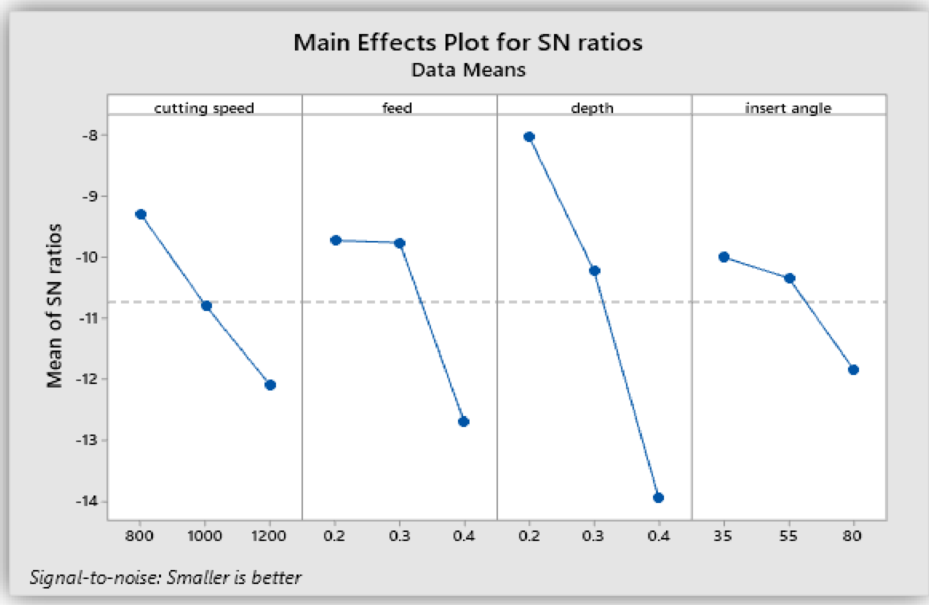

Fig 4.4.2 Main effects plot for S/N ratios

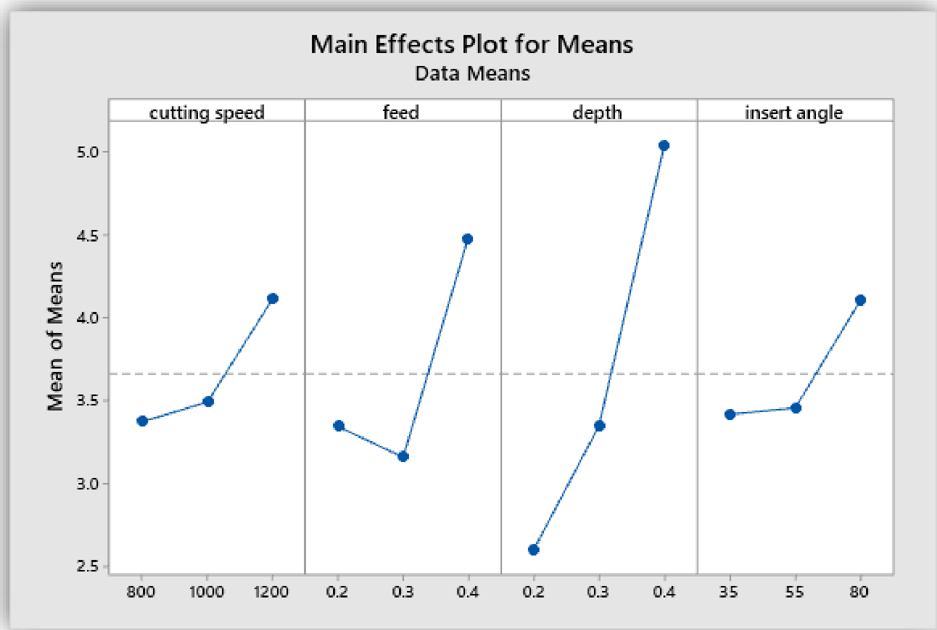

Fig 4.4.3 Main effects plot for means

For analysis purpose we must choose that S/N ratio for a given level of an input parameter which is highest among the others or we have to select that S/N ratio which closer to zero (0) value. From the above plots and response table we can clearly observe that level-1 for cutting speed, level-1 for feed, level-1 for depth of cut and level-1 for approach angle must be selected in order to achieve our objective of lowering the tool wear rate for obtaining an optimal value of it. Thus the predicted combination for optimum tool wear rate value using Taguchi method can be represented as $\mathbf{v_1}$-$\mathbf{f_1}$-$\mathbf{d_1}$-$\boldsymbol{\theta_1}$.

The decrease in tool wear rate at higher value of depth of cut can be attributed to the fact that the uncoated carbide tool used in this project has good toughness and high hardness properties[25].

In order to check the contribution of each the input parameters in the analysis of tool wear rate, ANOVA analysis has been performed. The result of the ANOVA analysis for tool wear rate is listed in the table given below.

Table 4.4.4 ANOVA for tool wear rate

Source	Degree of Freedom	Sum of Squares	Mean Squares	% Contribution
Cutting Speed	2	11.8994	5.9497	13.3737
Feed	2	17.4507	8.7253	19.6128
Depth of Cut	2	53.8537	26.9268	60.5262
Approach Angle	2	5.7720	2.8860	6.4871
Total	8	88.9758		100

From the above ANOVA table we can conclude that depth of cut has the most influence on tool wear rate with 60.53% contribution followed by feed with 19.61% contribution. The cutting speed has 13.37% contribution on the tool wear rate and approach angle of the cutting tool has the least impact with 6.49% contribution on the tool wear rate. The pie chart given below represents percentage of contribution of the various input parameters involved.

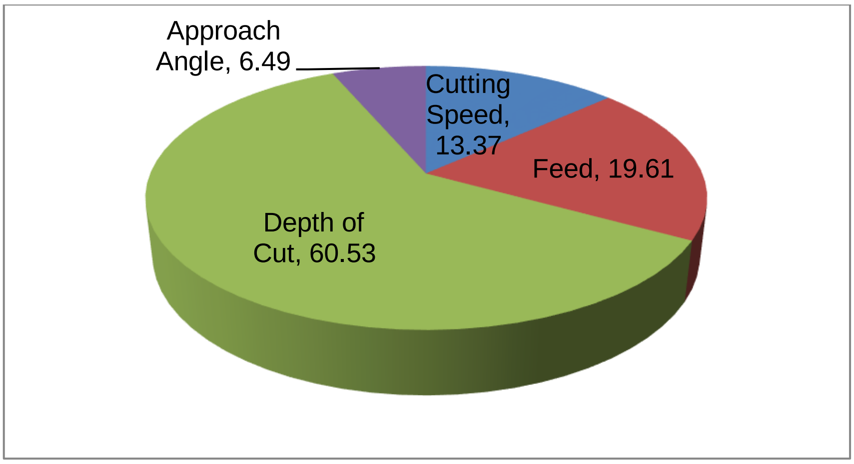

Fig 4.4.4 Pie chart representation of PCR for tool wear rate

4.5 ANALYSIS OF MACHINING TIME

From the concepts of economics of machining, it was evident that production rate is the most important parameter in achieving profits for the manufacturing organization. Slower production rate results in loss of revenue generation as the requisite number of components cannot be produced to meet the demand of the consumers. With respect to production rate, machining time required for each component becomes a vital cog in determining optimum production rate for the organization which will ultimately turn it into a profitable venture.

In this project, nine experiments were performed as per taugchi L9 array and machining time required for each of them has been recorded. As we know that lower machining time is desirable so while analysing the machining time using MINITAB19 software we choose the lower-the-better for its optimization. The various signal to noise ratio values has been recorded. The experimental values of machining time and S/N ratios are listed below in the table 4.5.1.

Table 4.5.1 Experimental values of machining time and S/N ratios

Run	Cutting Speed (rpm)	Feed (mm/rev)	Depth of Cut (mm)	Approach Angle (˚)	Machining Time (min)	S/N Ratio (dB)
1	800	0.2	0.2	35	1.83	-5.2490
2	800	0.3	0.3	55	1.36	-2.6707
3	800	0.4	0.4	80	0.85	1.4116
4	1000	0.2	0.3	80	1.16	-1.2891
5	1000	0.3	0.4	35	0.93	0.6303
6	1000	0.4	0.2	55	1.26	-2.0074
7	1200	0.2	0.4	55	0.90	0.9151

8	1200	0.3	0.2	80	1.28	-2.1442
9	1200	0.4	0.3	35	0.73	2.7335

In order to check whether the obtained machining time values are within the permissible limit for further analysis, we need to perform the normality test of these values which will be indicated by the probability plot having 95% confidence interval. The p-value indicated in the probability plot should be more than 0.05 otherwise it will fail the normality test. The probability plot for the machining time is shown in the figure below.

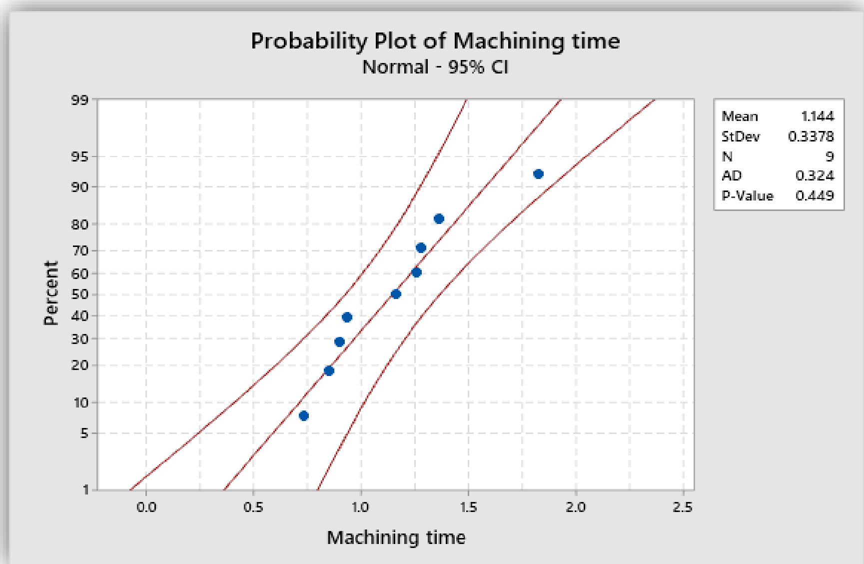

Fig 4.5.1 Probability plot of machining time

As discussed for analysing machining time we will choose lower-the-better criteria, this will generate S/N ratio plot as well as mean effects plot which will help us to decide the levels of the corresponding input parameters resulting into the desired outcome.

For analysing and optimizing the material removal rate, the response table for S/N ratio plays an important role in deciding the levels of the input parameters that must be selected which will give us the desired lower-the-better criteria for analysis. The response table has been provided below in the table 4.5.2.

Table 4.5.2 Response table for S/N ratios of machining time

LEVEL	CUTTING SPEED	FEED	DEPTH OF CUT	APPROACH ANGLE
1	-2.1694	-1.8743	-3.1335	**-0.6284**
2	-0.8887	-1.3949	-0.4088	-1.2543
3	**0.5015**	**0.7126**	**0.9857**	-0.6739
DELTA	2.6709	2.5869	4.1192	0.6260
RANK	2	3	1	4

This response table for S/N ratios has been appropriately supported by main effects plot for S/N ratio and main effects plot for means. This plots along with the response table helps in determining the required levels for input parameters. The main effects plots for S/N ratios and means are shown in figure below.

Fig 4.5.2 Main effects plot for S/N ratios

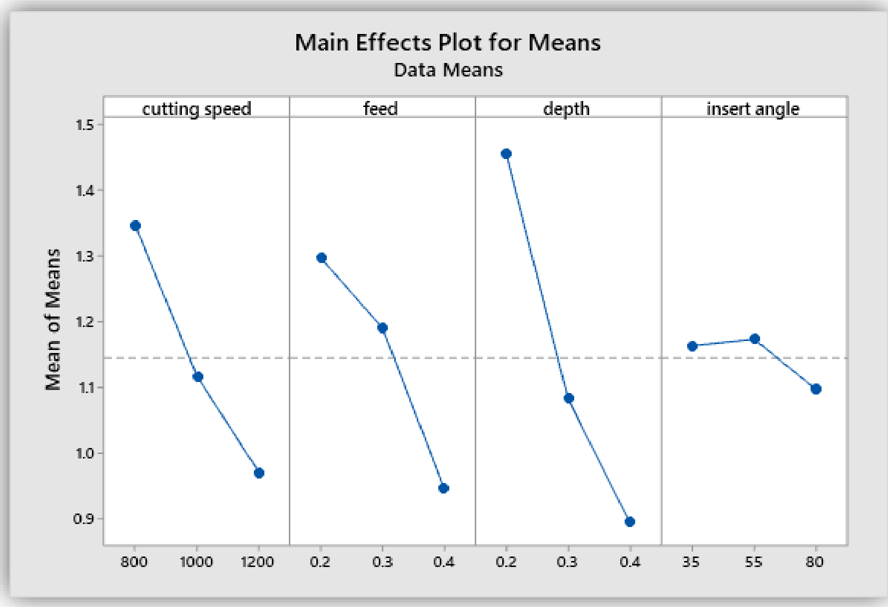

Fig 4.5.3 Main effects plot for means

For analysis purpose we must choose that S/N ratio for a given level of an input parameter which is highest among the others or we have to select that S/N ratio which closer to zero (0) value. From the above plots and response table we can clearly observe that level-3 for cutting speed, level-3 for feed, level-3 for depth of cut and level-1 for approach angle must be selected in order to achieve our objective of lowering the machining time for obtaining an optimal value of it. Thus the predicted combination for optimum machining time value using Taguchi method can be represented as $\mathbf{v_3\text{-}f_3\text{-}d_3\text{-}\theta_1}$**.**

The higher depth of cut resulting into lower machining time can be explained by the theoretical concept that high depth results into high material removal rate which enables to remove maximum material from the workpiece thus increases the rate of production which in suggests reduced processing or machining time[24].

In order to check the contribution of each the input parameters in the analysis of machining time, ANOVA analysis has been performed. The result of the ANOVA analysis for machining time is listed in the table given below.

Table 4.5.3 ANOVA for machining time

Source	Degree of Freedom	Sum of Squares	Mean Squares	% Contribution
Cutting Speed	2	10.7065	5.3532	21.7886
Feed	2	11.3635	5.6817	23.1257
Depth of Cut	2	26.3371	13.1685	53.5983
Approach Angle	2	0.7308	0.3654	1.4872
Total	8	49.1379		100

From the above ANOVA table we can conclude that depth of cut has the most influence on machining time with 53.6% contribution followed by feed with 23.12% contribution. The cutting speed has 21.79% contribution on the machining time and approach angle of the cutting tool has the least impact with 1.49% contribution on the machining time. The pie chart given below represents percentage of contribution of the various input parameters involved.

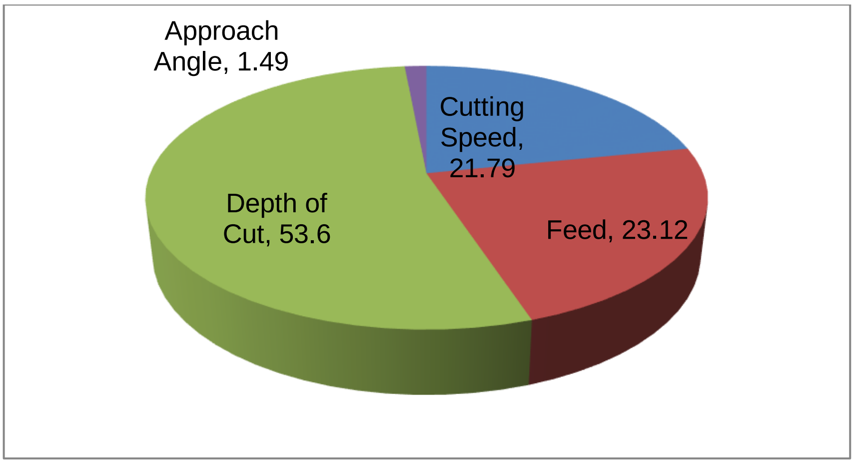

Fig 4.5.4 Pie chart representation of PCR for machining time

4.6 PREDICTION AND CONFIRMATORY TEST ANALYSIS

After obtaining the optimum levels of the input parameters i.e. cutting speed, feed, depth of cut and approach angle we can use them in predicting the optimal value for each of the concerned output i.e. surface roughness, material removal rate, tool wear rate and machining time. All these optimized value of the outputs will help us to reach the ultimate objective of economical machining which is the most important aspect of this project.

These predicted optimum values of the concerned outputs are done by using the equation as stated below[26]

$$\eta = \eta m + \sum_{i=0}^{n} (\eta o - \eta m)$$

Where, Ƞ = predicted optimum value of the output

Ƞm = Total mean value of the output

Ƞo = mean value of the output corresponding to each optimum level

The above stated equation can also be used for predicting the S/N ratio of the output parameters at the concerned optimum level of the input parameters.

In the table 4.6.1 we are enlisting the predicted optimum values of the outputs i.e. surface roughness, feed, depth of cut, approach angle as well their corresponding optimum S/N ratio value.

Table 4.6.1 Predicted optimum values of the output parameters and corresponding S/N ratios

Output Parameters	Optimum Levels	Predicted Values	Predicted S/N ratio
Surface Roughness	$\mathbf{v_1\text{-}f_1\text{-}d_3\text{-}\theta_3}$	3.475 µm	-1.96 dB
Material Removal Rate	$\mathbf{v_3\text{-}f_3\text{-}d_3\text{-}\theta_3}$	4183.33 mm^3/min	73.74 dB
Tool Wear Rate	$\mathbf{v_1\text{-}f_1\text{-}d_1\text{-}\theta_1}$	1.753 mm^3/min	-4.85 dB
Machining Time	$\mathbf{v_3\text{-}f_3\text{-}d_3\text{-}\theta_1}$	0.516 min	3.45 dB

In order to compare this predicted value whether they have successfully delivered the desired results expected out of them, we need to select an initial level for all the input parameters along with which the comparison will be made. The initial level must be selected in such a way that it should lie centrally in between the maximum and minimum limits of all the input parameters.

As a result we decided to select level-2 as initial level for all the input parameters and evaluate the predicted values of all the output parameters as well as the S/N ratio values by using the above stated equation.

The table 4.6.2 given below is illustrating the comparison between the predicted values of output for initial level-2 for all the input parameters and the predicted values of all the output at their corresponding optimum levels for input parameters. The same has been illustrated for S/N ratios.

Table 4.6.2 Comparison between predicted values of initial level and optimum level

Output Parameters	Initial input level	Predict-ed value of output	Predicted S/N Ratio	Predicted optimum level	Predicted optimum value of output	Predicted optimum S/N Ratio	Improve-ment achieved or Not
Surface Roughness (µm)	**v_2-f_2-d_2-θ_2**	9.304	-18.78	**v_1-f_1-d_3-θ_3**	3.475	-1.96	**Yes**
Material Removal Rate (mm^3/min)	**v_2-f_2-d_2-θ_2**	2287.4	67.61	**v_3-f_3-d_3-θ_3**	4183.33	73.74	**Yes**
Tool Wear Rate (mm^3/min)	**v_2-f_2-d_2-θ_2**	2.46	-8.93	**v_1-f_1-d_1-θ_1**	1.753	-4.85	**Yes**
Machining Time (min)	**v_2-f_2-d_2-θ_2**	1.13	-1.39	**v_3-f_3-d_3-θ_1**	0.516	3.45	**Yes**

The final step involved in any of the engineering experimental design project is to perform a confirmatory test with an aim of checking if there is any significant difference in the predicted optimum value of the outputs and the experimentally obtained value of the outputs by conducting experiments at the prescribed optimum level of the input parameters.

The table 4.6.3 listed below provides the confirmatory test results for all the concerned output parameters in this project work.

Table 4.6.3 Confirmation test results of all the output parameters

Output Parameters	Initial level values	Predicted optimum level values	Experimental values at optimum level	Difference between predicted & experimental values	% reduction/ expansion obtained w.r.t initial level
Surface Roughness (µm)	9.304	3.475	4.187	0.712	**54.98**
Material Removal Rate (mm^3/min)	2287.4	4183.33	3967.69	215.64	**73.46**
Tool Wear Rate (mm^3/min)	2.46	1.753	1.839	0.086	**25.24**
Machining Time (min)	1.13	0.516	0.783	0.267	**30.71**

Thus from the above confirmation result table, we can conclude that taguchi method used for optimization of these cutting parameters has helped in improving machinability of the work specimen AZ31B used in this project. With desired improvement in these critical output parameters has helped us in achieving the objective of economical machining of the work specimen used.

The trend obtained in the improvement of output parameters is similar to the results obtained by P.Siviah et al (2019) while machining 17-4 PH stainless steel having surface roughness and flank tool wear as the output parameters[27].

4.7 REGRESSION MODELLING

Regression modeling is basically a statistical approach that defines mathematical relationship between one or more independent variables with as many numbers of dependent variables.

Regression modeling helps to improve the service quality of the product by providing detailed information in this regard. It helps in establishing cause and effect relation between the dependent and independent variables.

In this project, we will be dealing with linear regression modelling which is the most basic and commonly used regression model. In this model the dependent and independent variables are related to one another through a linear equation as stated below.

$$y = a + bx + e$$

Where, y = dependent variable
x = independent variable
a = intercept value of y when x is 0
b = regression coefficient
e = error of the estimate

In order to fit a linear regression equation between the dependent and independent variable, it must satisfy the assumption that all the concerned data are having normal distribution.

After performing the linear regression analysis in this project, we can develop a linear equation which will show the mathematical relation between the output parameters and pre defined input parameters.

We will obtain various tables which will provide interpretation of the results obtained after performing regression analysis. Some plots will also be provided in order to discuss about the residual analysis.

The most important table among all the tables provided after performing regression analysis is the model summary table. Some of the key elements which will feature in the model summary table are pointed out as below:

- **S:** It is the deviation between fitted value and data value. Lower the value of S better will be the model in describing the model, however lower value of S not always provide correct scenario

- **R-Sq:** It is used to explain the percentage variation of response by the model. Higher of R-Sq provides better fit to the model. Its value lies between 0 to 100%

- **R-Sq (adj):** It is used to compare models that have different number of predictors. It helps in determining which of the parameters might not be helpful in improving the model and hence that can be discarded.

Another important table which needs to be explained is the Coefficient table. In this table, the column Coefficient is describing the values which are being multiplied to the respective described term in the regression equation. It represents change in the response with respect to variation in the term. The column SE Coefficient represents the standard error of the coefficient estimates. Smaller the value of SE more precise will be the estimates. The next column represents T-value which is the ratio of Coefficient to its standard error. It can be used to reject null hypothesis but more often P-value is used for that purpose. The column P-value represents the probability measure that provides evidence against the null hypothesis. A P-value of less than or equal to 0.05 for a 95% CI indicates that it is statistically significant. The last column represents VIF value which represents how much multi-collinearity exists in the regression analysis. A VIF value of more than 5 represents that the regression coefficient is poorly estimated due to extreme multi-collinearity.

4.7.1 REGRESSION ANALYSIS OF SURFACE ROUGHNESS

After fitting the regression model for surface roughness using MINITAB19 software following results was obtain as stated below.

The regression equation was obtained as

$$Ra = 3.03 + 0.00450*v + 34.30*f - 9.54*d - 0.1486*\theta$$

Where, Ra = surface roughness (µm)
v = cutting speed (rpm)
f = feed (mm/rev)
d = depth of cut (mm)
θ = approach angle (˚)

Along with this regression equation, the first important table which we obtained was the Coefficients table. The table has been listed below as table 4.7.1.1.

Table 4.7.1.1 Coefficients table of surface roughness

Term	Coefficient	SE coefficient	T- Value	P- Value	VIF
Constant	3.03	6.05	0.50	0.642	
Cutting Speed	0.00450	0.00428	1.05	0.352	1.00
Feed	34.30	8.55	4.01	0.016	1.00
Depth of Cut	-9.54	8.55	-1.12	0.327	1.00
Approach Angle	-0.1486	0.0379	-3.92	0.017	1.00

Thus from the table 4.7.1.1 we can conclude that that feed has the maximum influence on the surface roughness having a P-value of 0.016 which is closely followed by approach angle of the cutting tool as the second most influencing parameter with a P-value of 0.017. The other parameters like cutting speed and depth of cut with P-values 0.352 and 0.327 respectively are not much significant as per regression analysis. All the input parameters have a VIF value of 1.00 which shows that the regression coefficients are not correlated among themselves.

The next important table which we obtain as a part of the regression analysis is model summary table. The table 4.7.1.2 listed below represents the model summary.

Table 4.7.1.2 Model summary

S	R-sq	R-sq (adj)
2.09471	89.41 %	78.83 %

From the above table, it can be concluded that the regression model for surface roughness has a R^2 value of 89.41 %.

The next important table which we obtain after performing the regression analysis was that of analysis of variance also called as ANOVA table. It helps in determining the percentage of contribution of the input parameters in case of this regression model.

Table 4.7.1.3 ANOVA table for regression model of surface roughness

Source	DF	Adj SS	Adj MS	F-value	P-value	%contribution
Cutting Speed	1	4.862	4.862	1.11	0.352	3.28
Feed	1	70.603	70.603	16.09	0.016	47.63
Depth of Cut	1	5.457	5.457	1.24	0.327	3.68
Approach Angle	1	67.321	67.321	15.34	0.017	45.41
Error	4	17.551	4.388			
Total	8	165.794				100

From the above table we can conclude that Feed has maximum influence on surface roughness with 47.63 % and is closely followed by approach angle of cutting tool with 45.41%. The cutting speed and depth of cut has a minimal contribution of 3.28 % and 3.68 % respectively.

The above results can also be described by using a pareto chart for standardized effect with surface roughness being the response. The figure provided below showing the requisite pareto chart.

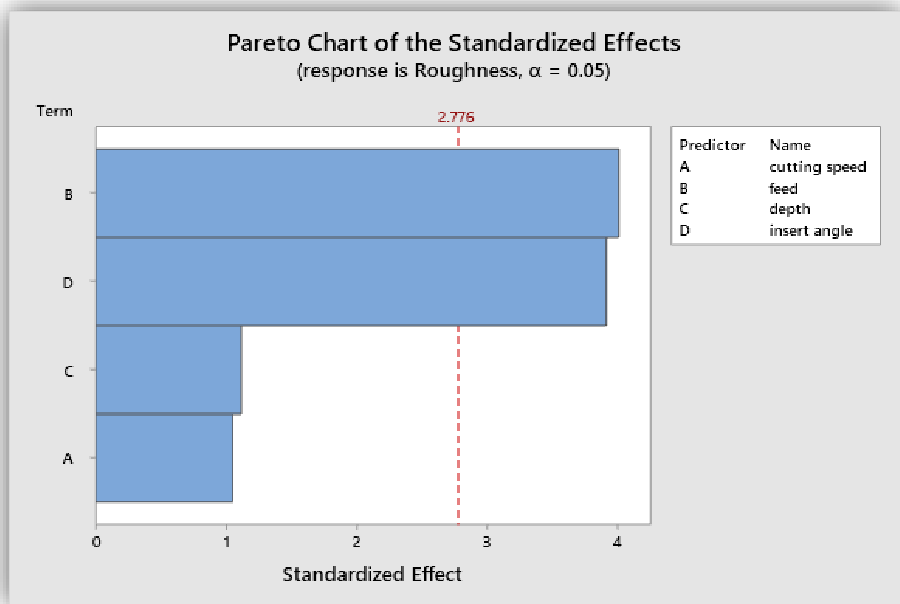

Fig 4.7.1.1 Pareto chart of standardized effects for surface roughness

The last outcome which we obtain after performing a regression analysis was residual plots for surface roughness. This is a combination of four plots namely histogram, normal probability plot, versus fits and versus order. The residual plots for surface roughness are shown in the figure below.

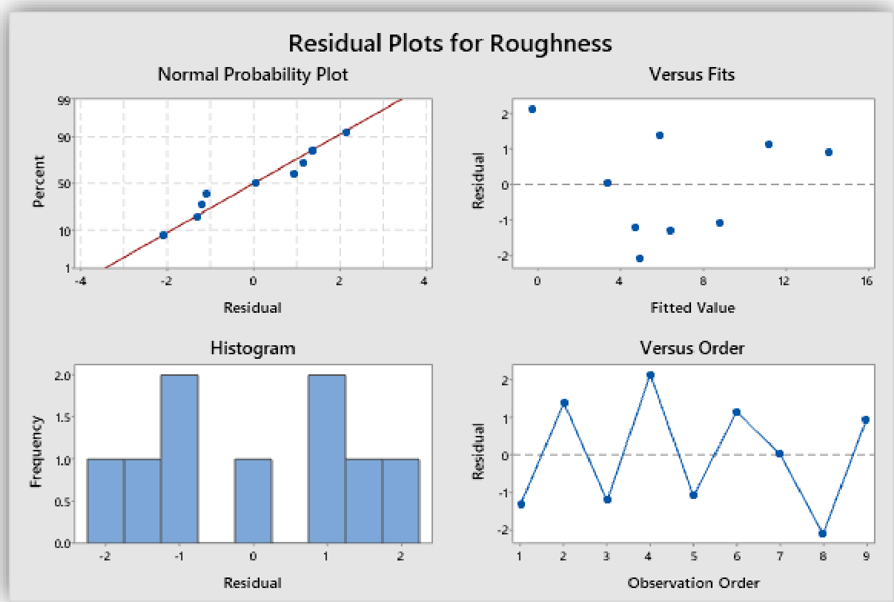

Fig 4.7.1.2 Residual plots for surface roughness

From the figure we can observe that the histogram has no outliers and is somewhat skewed. The normal probability plot is approximately linear which means it is in consistent with a normal distribution. The residual versus fitted value shows random pattern which suggest that residual has constant variance. The residual versus observation order shows random pattern which means that the data was collected and can be used to obtain non-random error.

4.7.2 REGRESSION ANALYSIS OF MATERIAL REMOVAL RATE

After fitting the regression model for material removal rate using MINITAB19 software following results was obtain as stated below.

The regression equation was obtained as

$$MRR = -2761 + 2.150*v + 3630*f + 7107*d - 0.73*\theta$$

Where, MRR = material removal rate (mm^3/min)

v = cutting speed (rpm)

f = feed (mm/rev)

d = depth of cut (mm)

θ = approach angle (˚)

Along with this regression equation, the first important table which we obtained was the Coefficients table. The table has been listed below as table 4.7.2.1.

Table 4.7.2.1 Coefficients table of material removal rate

Term	Coefficient	SE coefficient	T- Value	P- Value	VIF
Constant	-2761	1159	-2.38	0.076	
Cutting Speed	2.150	0.820	2.62	0.059	1.00
Feed	3630	1639	2.21	0.091	1.00
Depth of Cut	7107	1639	4.34	0.012	1.00
Approach Angle	-0.73	7.27	-0.10	0.925	1.00

Thus from the table 4.7.2.1 we can conclude that that depth of cut has the maximum influence on the material removal rate having a P-value of 0.012 followed by cutting speed as the second most influencing parameter with a P-value of 0.059. The other parameters like feed and approach angle of cutting tool with P-values 0.091 and 0.925 respectively are not much significant as per regression analysis. All the input parameters have a VIF value of 1.00 which shows that the regression coefficients are not correlated among themselves.

The next important table which we obtain as a part of the regression analysis is model summary table. The table 4.7.2.2 listed below represents the model summary.

Table 4.7.2.2 Model summary

S	R-sq	R-sq (adj)
401.555	88.43 %	76.87

From the above table, it can be concluded that the regression model for material removal rate has a R^2 value of 88.43 %.

The next important table which we obtain after performing the regression analysis was that of analysis of variance also called as ANOVA table. It helps in determining the percentage of contribution of the input parameters in case of this regression model.

Table 4.7.2.3 ANOVA table for regression model of material removal rate

Source	DF	Adj SS	Adj MS	F-value	P-value	%contribution
Cutting Speed	1	1109353	1109353	6.88	0.059	22.49
Feed	1	790417	790417	4.90	0.091	16.03
Depth of Cut	1	3030546	3030546	18.79	0.012	61.45
Approach Angle	1	1633	1633	0.01	0.925	0.033
Error	4	644985	161246			
Total	8	5576934				100

From the above table we can conclude that depth of cut has maximum influence on material removal rate with 61.45 % and is followed by cutting speed with 22.49%. The feed has 16.03% contribution and approach angle of cutting tool has a miniscule contribution of 0.033%.

The above results can also be described by using a pareto chart for standardized effect with material removal rate being the response. The figure provided below showing the requisite pareto chart.

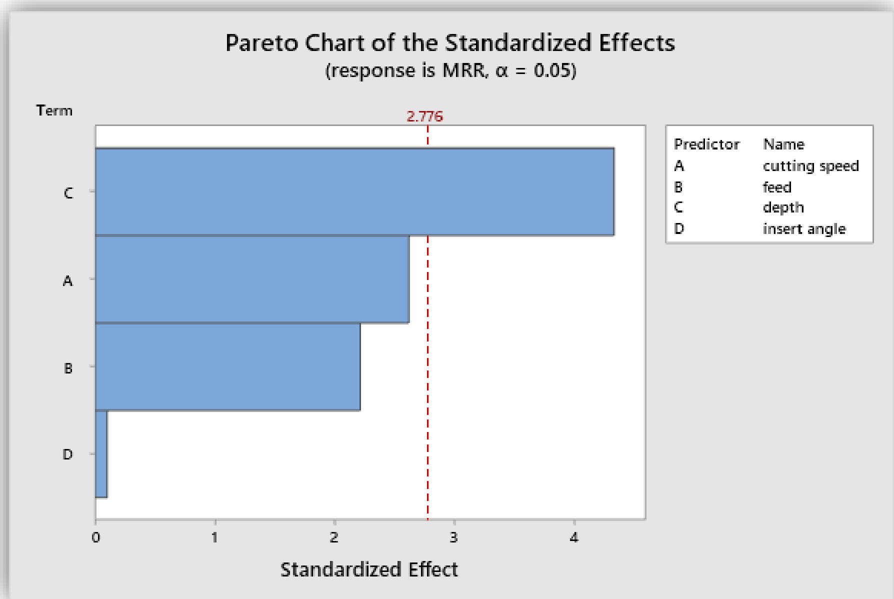

Fig 4.7.2.1 Pareto chart of standardized effects for material removal rate

The last outcome which we obtain after performing a regression analysis was residual plots for material removal rate. This is a combination of four plots namely histogram, normal probability plot, versus fits and versus order. The residual plots for material removal rate are shown in the figure below.

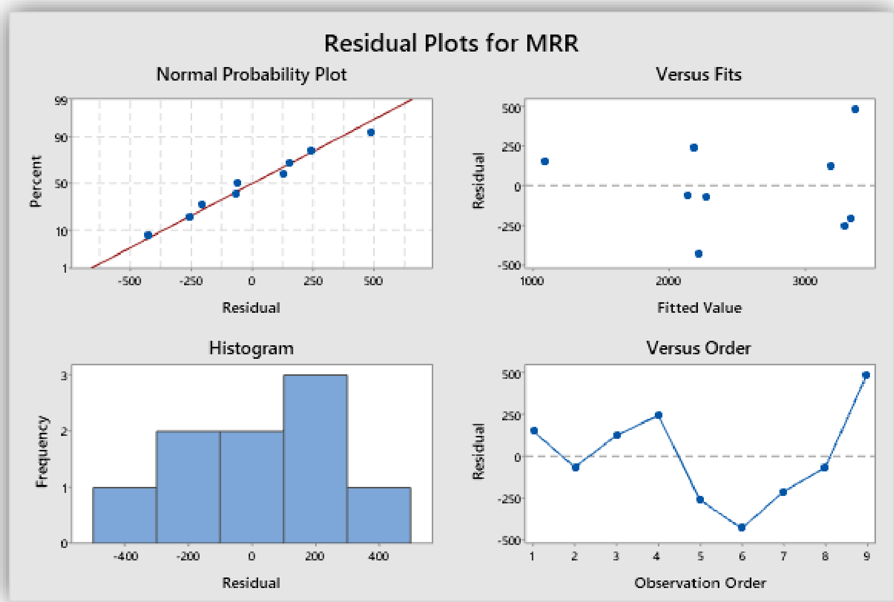

Fig 4.7.2.2 Residual plots for material removal rate

From the figure we can observe that the histogram has no outliers and is somewhat skewed. The normal probability plot is approximately linear which means it is in consistent with a normal distribution. The residual versus fitted value shows random pattern which suggest that residual has constant variance. The residual versus observation order shows random pattern which means that the data was collected and can be used to obtain non-random error.

4.7.3 REGRESSION ANALYSIS OF TOOL WEAR RATE

After fitting the regression model for tool wear rate using MINITAB19 software following results was obtain as stated below.

The regression equation was obtained as

$$TWR = -4.47 + 0.00186*v + 5.69*f + 12.22*d + 0.0158*\theta$$

Where, TWR = Tool wear rate (mm^3/min)

v = cutting speed (rpm)

f = feed (mm/rev)

d = depth of cut (mm)

θ = approach angle (˚)

Along with this regression equation, the first important table which we obtained was the Coefficients table. The table has been listed below as table 4.7.3.1.

Table 4.7.3.1 Coefficients table of tool wear rate

Term	Coefficient	SE coefficient	T- Value	P- Value	VIF
Constant	-4.47	1.96	-2.28	0.085	
Cutting Speed	0.00186	0.00139	1.34	0.251	1.00
Feed	5.69	2.78	2.05	0.110	1.00
Depth of Cut	12.22	2.78	4.40	0.012	1.00
Approach Angle	0.0158	0.0123	1.28	0.269	1.00

Thus from the table 4.7.3.1 we can conclude that that depth of cut has the maximum influence on the tool wear rate having a P-value of 0.012 followed by feed as the second most influencing parameter with a P-value of 0.110. The other parameters like cutting speed and approach angle of cutting tool with P-values 0.251 and 0.269 respectively are not much significant as per regression analysis. All the input parameters have a VIF value of 1.00 which shows that the regression coefficients are not correlated among themselves.

The next important table which we obtain as a part of the regression analysis is model summary table. The table 4.7.3.2 listed below represents the model summary.

Table 4.7.3.2 Model summary

S	R-sq	R-sq (adj)
0.680566	87.09%	74.18%

From the above table, it can be concluded that the regression model for tool wear rate has a R^2 value of 87.09 %.

The next important table which we obtain after performing the regression analysis was that of analysis of variance also called as ANOVA table. It helps in determining the percentage of contribution of the input parameters in case of this regression model.

Table 4.7.3.3 ANOVA table for regression model of tool wear rate

Source	DF	Adj SS	Adj MS	F-value	P-value	%contribution
Cutting Speed	1	0.8348	0.8348	1.80	0.251	6.68
Feed	1	1.9426	1.9426	4.19	0.110	15.55
Depth of Cut	1	8.9573	8.9573	19.34	0.012	71.67
Approach Angle	1	0.7618	0.7618	1.64	0.269	6.1
Error	4	1.8527	0.4632			
Total	8	14.3491				100

From the above table we can conclude that depth of cut has maximum influence on tool wear rate with 71.67 % and is followed by feed with 15.55%. The cutting speed has 6.68% contribution and approach angle of cutting tool has a contribution of about 6.1%.

The above results can also be described by using a pareto chart for standardized effect with tool wear rate being the response. The figure provided below showing the requisite pareto chart.

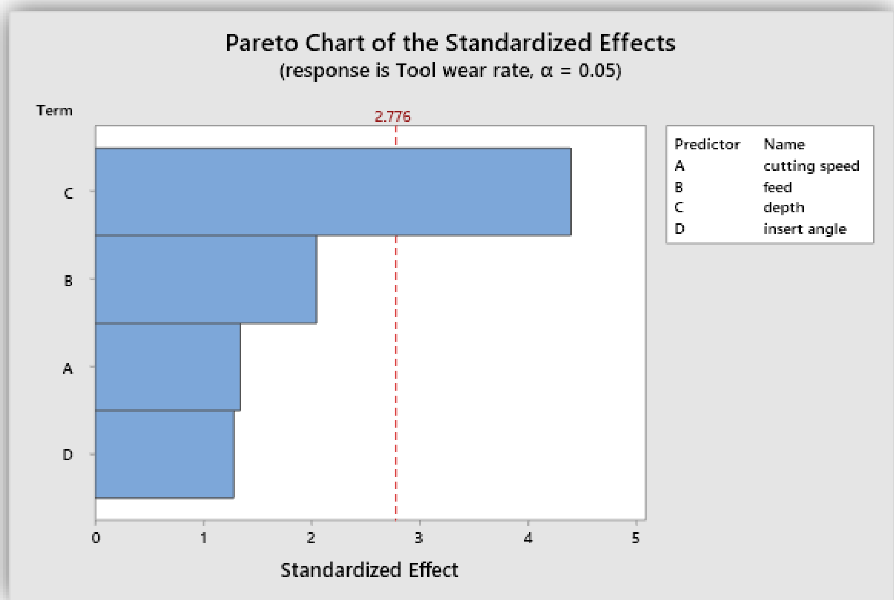

Fig 4.7.3.1 Pareto chart of standardized effects for tool wear rate

The last outcome which we obtain after performing a regression analysis was residual plots for tool wear rate. This is a combination of four plots namely histogram, normal probability plot, versus fits and versus order. The residual plots for tool wear rate are shown in the figure below.

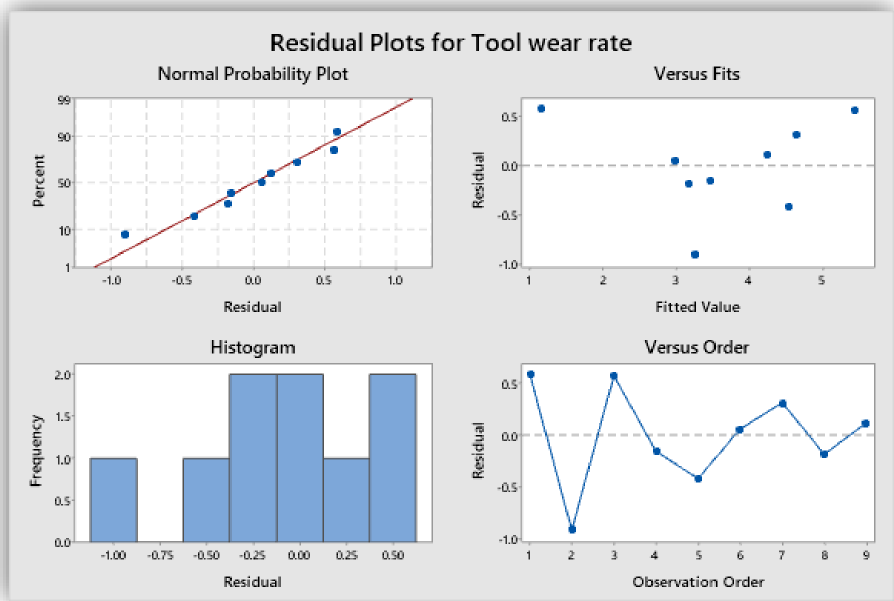

Fig 4.7.3.2 Residual plots for tool wear rate

From the figure we can observe that the histogram has no outliers and is somewhat skewed. The normal probability plot is approximately linear which means it is in consistent with a normal distribution. The residual versus fitted value shows random pattern which suggest that residual has constant variance. The residual versus observation order shows random pattern which means that the data was collected and can be used to obtain non-random error.

4.7.4 REGRESSION ANALYSIS OF MACHINING TIME

After fitting the regression model for machining time using MINITAB19 software following results was obtain as stated below.

The regression equation was obtained as

$$MTM = 3.3544 - 0.000942*v - 1.750*f - 2.817*d - 0.00155*\theta$$

Where, MTM = Machining time (min)
v = cutting speed (rpm)
f = feed (mm/rev)
d = depth of cut (mm)
θ = approach angle (˚)

Along with this regression equation, the first important table which we obtained was the Coefficients table. The table has been listed below as table 4.7.4.1.

Table 4.7.4.1 Coefficients table of machining time

Term	Coefficient	SE coefficient	T- Value	P- Value	VIF
Constant	3.544	0.261	13.57	0.000	
Cutting Speed	-0.000942	0.000185	-5.10	0.007	1.00
Feed	-1.750	0.369	-4.74	0.009	1.00
Depth of Cut	-2.817	0.369	-7.63	0.002	1.00
Approach Angle	-0.00155	0.00164	-0.94	0.399	1.00

Thus from the table 4.7.4.1 we can conclude that that depth of cut has the maximum influence on the machining time having a P-value of 0.002 followed by cutting speed as the second most influencing parameter with a P-value of 0.007. The feed has much significance as per regression analysis with P-value 0.009.The approach angle of cutting tool has minimum impact with P-value 0.399. All the input parameters have a VIF value of 1.00 which shows that the regression coefficients are not correlated among themselves.

The next important table which we obtain as a part of the regression analysis is model summary table. The table 4.7.4.2 listed below represents the model summary.

Table 4.7.4.2 Model summary

S	R-sq	R-sq (adj)
0.0904776	96.41 %	92.82 %

From the above table, it can be concluded that the regression model for machining time has a R^2 value of 96.41 %.

The next important table which we obtain after performing the regression analysis was that of analysis of variance also called as ANOVA table. It helps in determining the percentage of contribution of the input parameters in case of this regression model.

Table 4.7.4.3 ANOVA table for regression model of machining time

Source	DF	Adj SS	Adj MS	F-value	P-value	%contribution
Cutting Speed	1	0.212817	0.212817	26.00	0.007	24.18
Feed	1	0.183750	0.183750	22.45	0.009	20.88
Depth of Cut	1	0.476017	0.476017	58.15	0.002	54.11
Approach Angle	1	0.007294	0.007294	0.89	0.399	0.83
Error	4	0.032745	0.007294			
Total	8	0.912622				100

From the above table we can conclude that depth of cut has maximum influence on machining time with 54.11 % and is followed cutting speed with 24.18%. The feed has 20.88% contribution and approach angle of cutting tool has a miniscule contribution of about 0.83%.

The above results can also be described by using a pareto chart for standardized effect with machining time being the response. The figure provided below showing the requisite pareto chart.

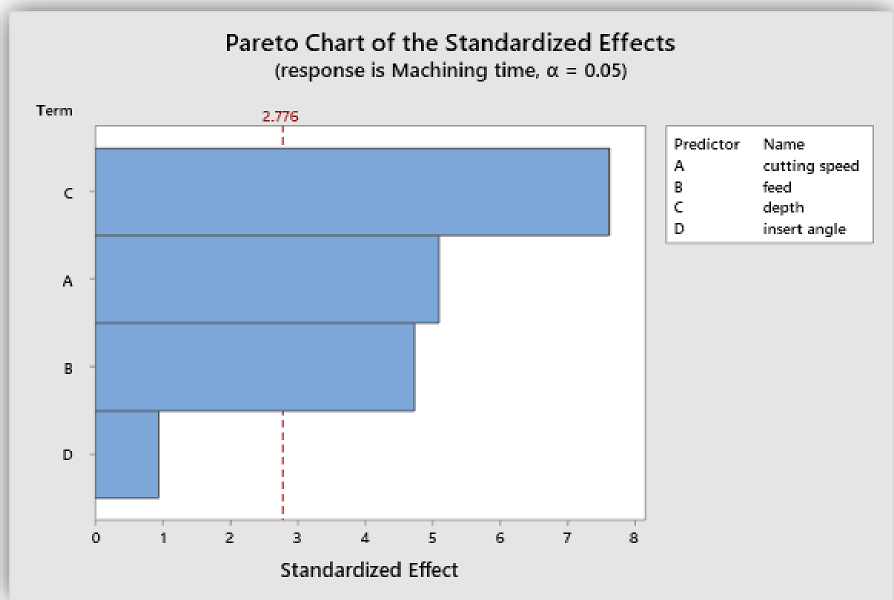

Fig 4.7.4.1 Pareto chart of standardized effects for machining time

The last outcome which we obtain after performing a regression analysis was residual plots for machining time. This is a combination of four plots namely histogram, normal probability plot, versus fits and versus order. The residual plots for tool wear rate are shown in the figure below.

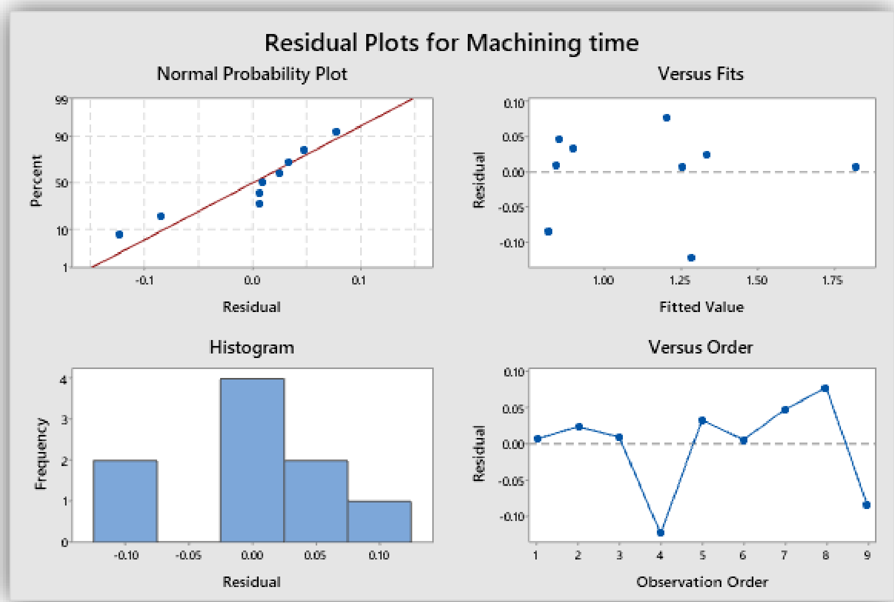

Fig 4.7.4.2 Residual plots for machining time

From the figure we can observe that the histogram has no outliers and is somewhat skewed. The normal probability plot is approximately linear which means it is in consistent with a normal distribution. The residual versus fitted value shows random pattern which suggest that residual has constant variance. The residual versus observation order shows random pattern which means that the data was collected and can be used to obtain non-random error.

4.8 CONTOUR PLOT ANALYSIS

Contour plots are generally used to show the relation among the two input variables on an individual output parameter. Contour plots can be used to investigate desired output parameters and operating variables.

A contour plot consists of following elements:

- On the x- and y-axes, there are predictors.
- Contour lines are drawn between places with the same response value.
- Ranges of response values are shown by coloured contour bands.

At first, we will draw contour plots with surface roughness being the response variable and there will be combinations of two input predictors chosen from cutting speed, feed, depth of cut and approach angle of the cutting tool. The contour plots for surface roughness is shown by the figure given below.

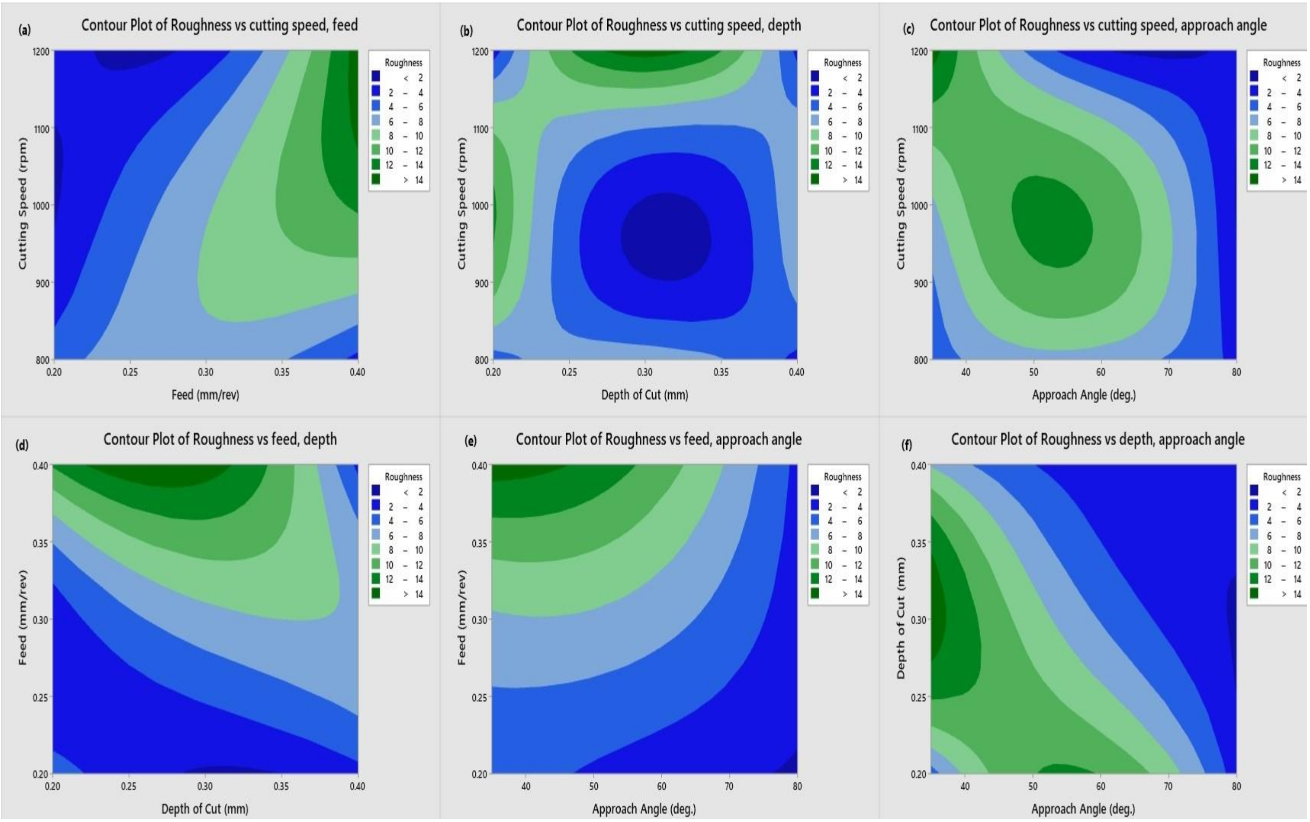

Fig 4.8.1.1 Contour plot for surface roughness (a) Cutting speed Vs Feed (b) Cutting speed Vs Depth of cut (c) Cutting speed Vs Approach angle (d) Feed Vs Depth of cut (e) Feed Vs Approach angle (f) Depth of cut Vs Approach angle

From the above figure 4.8.1.1(a) we observe that in order to obtain lower surface roughness mid values of cutting speed and low values of feed is suitable. From (b) we can conclude that for having lower surface roughness mid values of cutting speed and depth of cut is to be preferred. From (c) the outcome drawn is that in order to have lower surface roughness higher value of cutting speed and approach angle must be chosen. From (d) it can be observed that for lower surface roughness low values of feed and mid values of depth of cut is preferred. From (e) for having lower value of surface roughness low values of feed and high values of approach angle must be chosen. From (f) it was found that lower value of surface roughness corresponds to mid values of depth of cut and higher values of approach angle.

Next we will discuss about the contour plots obtained for material removal rate. The contour plots for MRR is shown in the figure below.

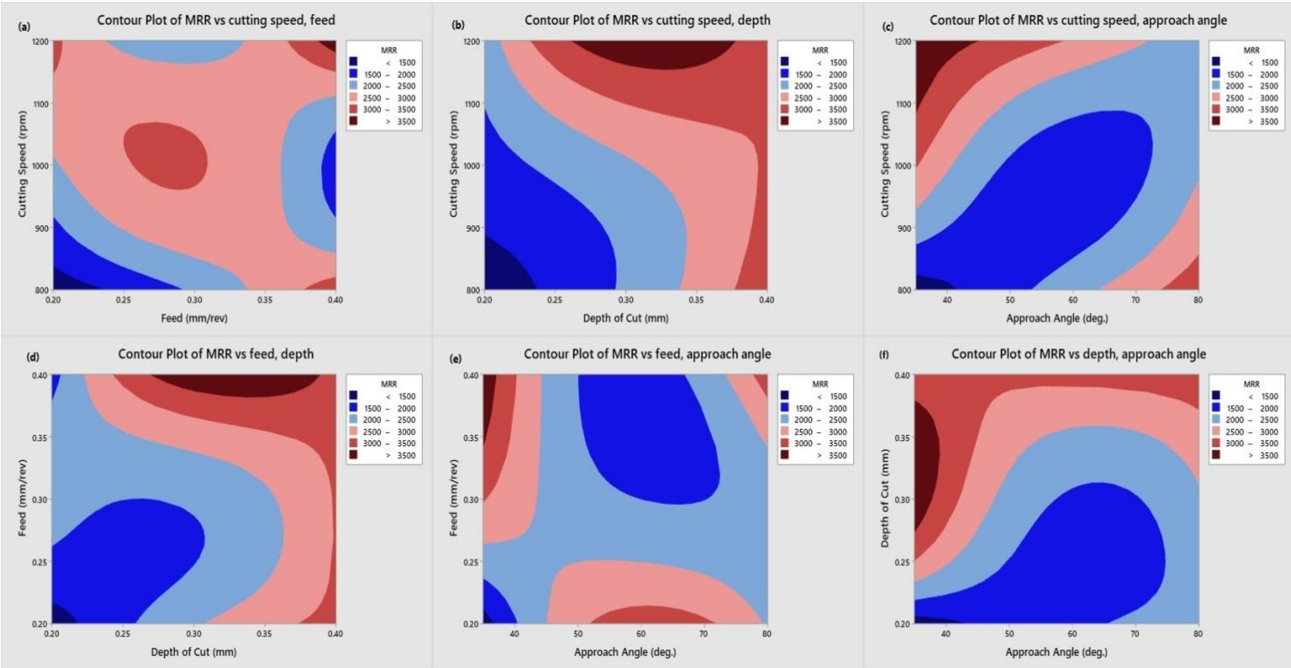

Fig 4.8.1.2 Contour plot for material removal rate (a) Cutting speed Vs Feed (b) Cutting speed Vs Depth of cut (c) Cutting speed Vs Approach angle (d) Feed Vs Depth of cut (e) Feed Vs Approach angle (f) Depth of cut Vs Approach angle

From the above figure 4.8.1.2 (a) we observe that in order to obtain high material removal rate higher values of cutting speed and higher values of feed is suitable. From (b) we can conclude that for having high material removal rate high values of cutting speed and mid values of depth of cut is to be preferred. From (c) the outcome drawn is that in order to have high material removal rate higher value of cutting speed and low values of approach angle must be chosen. From (d) it can be observed that for high material removal rate higher values of feed and mid values of depth of cut is preferred. From (e) for having high material removal rate high values of feed and lower values of approach angle must be chosen. From (f) it was found that higher value of material removal rate corresponds to mid values of depth of cut and lower values of approach angle.

The contour plot analysis of tool wear rate is the next one under proceeding. The contour plots for TWR is shown in the figure below.

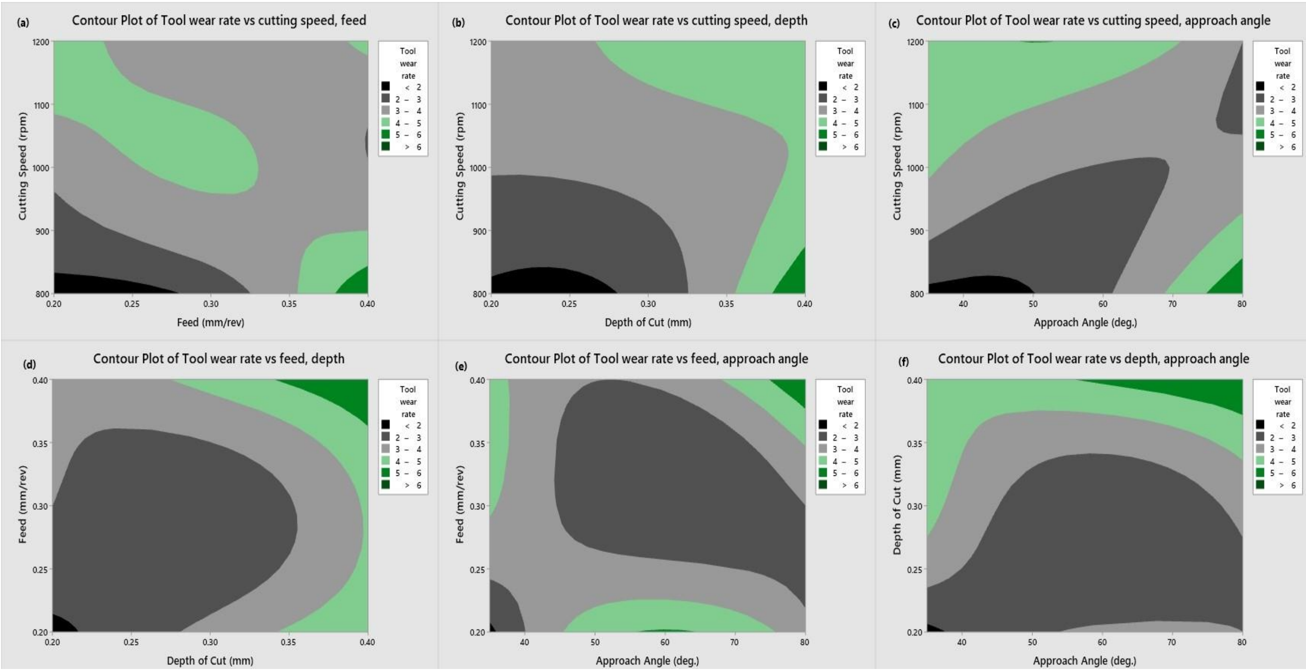

Fig 4.8.1.3 Contour plot for tool wear rate (a) Cutting speed Vs Feed (b) Cutting speed Vs Depth of cut (c) Cutting speed Vs Approach angle (d) Feed Vs Depth of cut (e) Feed Vs Approach angle (f) Depth of cut Vs Approach angle

From the above figure 4.8.1.3 (a) we observe that in order to obtain lower tool wear rate low values of cutting speed and low values of feed is suitable. From (b) we can conclude that for having lower tool wear rate low values of cutting speed and depth of cut is to be preferred. From (c) the outcome drawn is that in order to have lower tool wear rate lower value of cutting speed and approach angle must be chosen. From (d) it can be observed that for lower tool wear rate low values of feed and depth of cut is preferred. From (e) for having lower value of tool wear rate low values of feed and approach angle must be chosen. From (f) it was found that lower value of tool wear rate corresponds to lower values of depth of cut and approach angle.

Next we will discuss about the contour plots obtained for machining time. The contour plots for machining time are shown in the figure below.

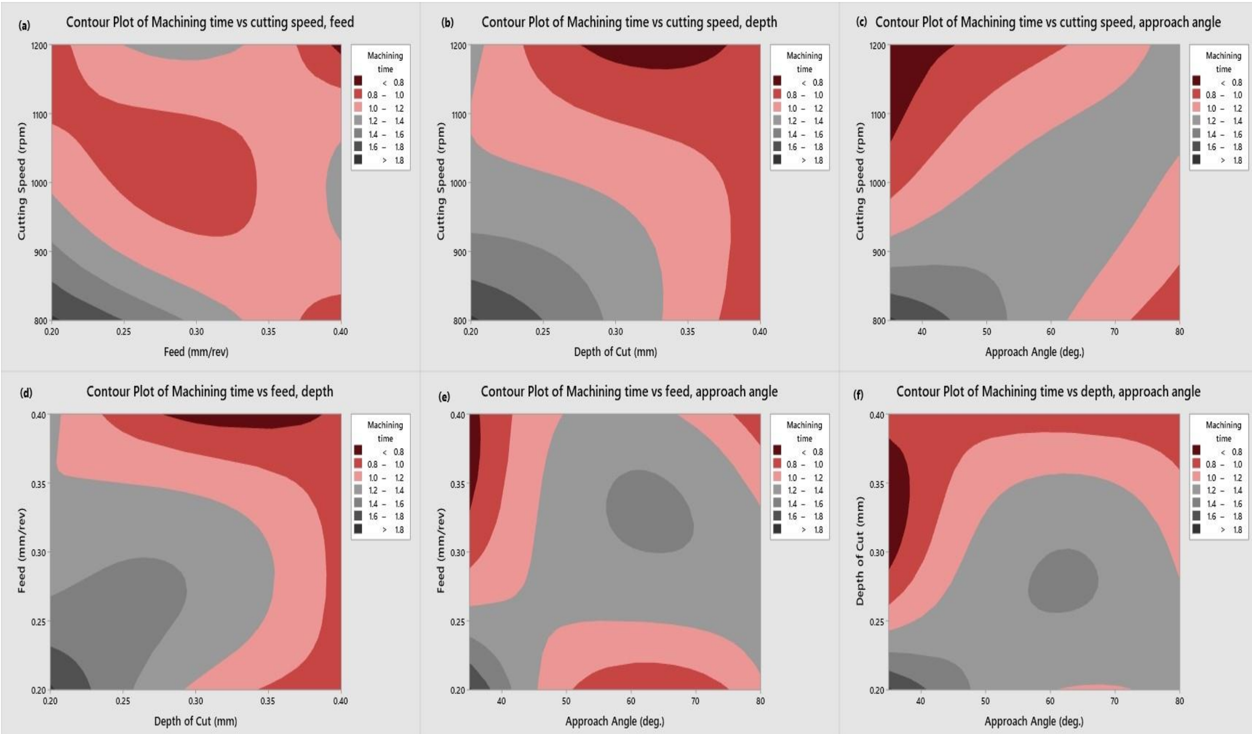

Fig 4.8.1.4 Contour plot for Machining time (a) Cutting speed Vs Feed (b) Cutting speed Vs Depth of cut (c) Cutting speed Vs Approach angle (d) Feed Vs Depth of cut (e) Feed Vs Approach angle (f) Depth of cut Vs Approach angle

From the above figure 4.8.1.4(a) we observe that in order to obtain lower machining time higher values of cutting speed and feed is suitable. From (b) we can conclude that for having lower machining time high values of cutting speed and mid values of depth of cut is to be preferred. From (c) the outcome drawn is that in order to have lower machining time higher value of cutting speed and lower value of approach angle must be chosen. From (d) it can be observed that for lower machining time high values of feed and mid values of depth of cut is preferred. From (e) for having lower value of machining time high values of feed and low values of approach angle must be chosen. From (f) it was found that lower value of machining time corresponds to mid values of depth of cut and lower values of approach angle.

4.9 HARDNESS ANALYSIS

Since magnesium alloys posses many challenges with regard to its machining, the most prominent among them is its ability to get ignited if it is being machined under adverse condition. There is also a chance that dull cutting tool not having sharper edges can cause friction which in turn increases temperature inside the machining chamber which can cause the chip formed to get ignited.

Hence the machining of Mg AZ31B alloy in this project has been carried out by using compressed air in order to felicitate air cooled treatment inside the machining chamber. Along with this in order to lower the cutting temperature of the Mg AZ31B cryogenic soaking of the component for about 30 minutes has been performed.

As we know that cryogenic soaking helps in improving mechanical properties of the component, an experimental investigation has been performed to check the hardness of the component after the soaking duration and to compare it with the hardness of the component before cryogenic soaking. It was done by Vickers hardness testing machine and a load of 100g has been applied on the specimen in 3 different trials for about 10 seconds of time.

Checking other mechanical properties was not possible as the length of the specimen after splitting it into 9 components were too short to carry out any other tests.

Table 4.9.1 Hardness of AZ31B alloy before and after cryogenic soaking

Trial	Hardness before soaking (HV)	Hardness after soaking (HV)	% improvement in hardness
1^{st} Trial	82	116	
2^{nd} Trial	86	109	**33.73**
3^{rd} Trial	81	108	
Average	**83**	**111**	

Thus an improvement of about 33.73 % has been observed after soaking the Mg AZ31B alloy for about 30 minutes in this project work.

The trend obtained in the improvement of hardness before and after cryogenic soaking of the component is similar to the results obtained by Kaveh Meshinchi Asl et al (2009)[28] while performing deep cryogenic treatment of Mg AZ91 alloy.

The figure given below depicts the SEM observation of the indentation obtained during Vickers hardness test on the component before and after cryogenic soaking

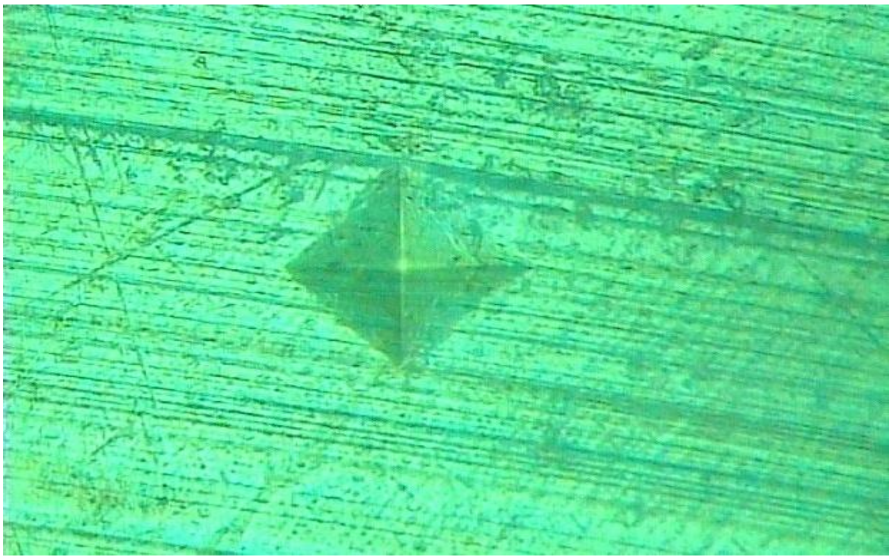

Fig 4.9.1 SEM observation of the component before cryogenic soaking

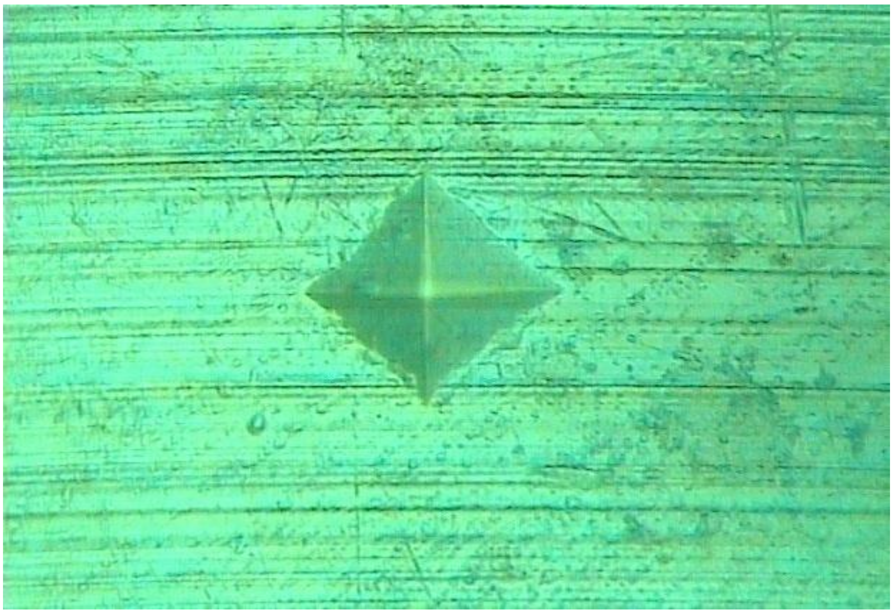

Fig 4.9.2 SEM observation of the component after cryogenic soaking

At the end we have enclosed the photographic evidence of performing cryogenic soaking of the Mg AZ31B alloy and also about collection of liquid nitrogen from the production unit located in Guwahati, Assam.

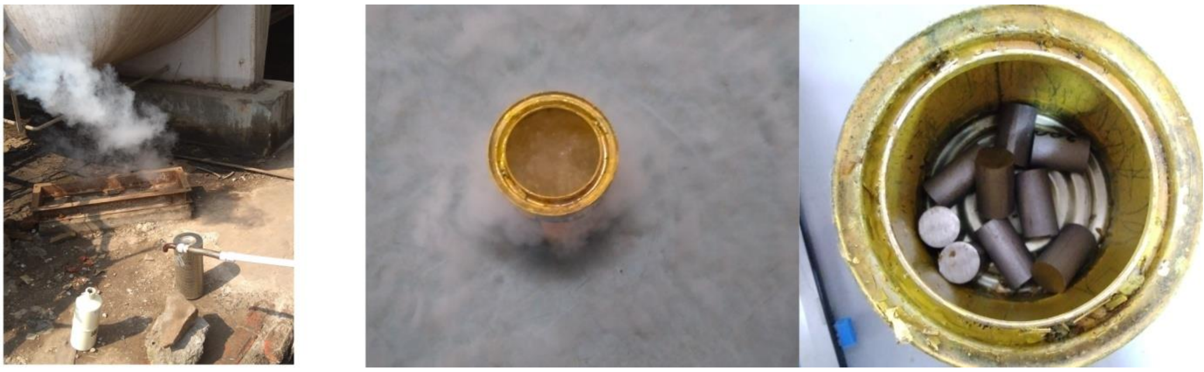

Fig 4.9.3 Sequence from collection of liquid nitrogen to performing cryogenic soaking to obtaining alloy pieces after cryogenic soaking

CHAPTER FIVE

5.1 CONCLUSIONS

After performing the required experimental analysis following conclusion has been drawn with regard to this project work as stated below:

- Optimum condition for obtaining lower value of surface roughness was found as v = 800 rpm, f = 0.2 mm/rev, d = 0.3 mm, and θ = 80˚ using Taguchi method and the reduction in surface roughness was about 54.98 % using Taguchi determined optimum conditions.

- Optimum condition for having higher value of material removal rate was found to be as v = 1200 rpm, f = 0.4 mm/rev, d = 0.4 mm and θ = 80 ˚ as per Taguchi method and the enhancement in material removal rate was around 73.46 % at the determined Taguchi optimum conditions.

- Optimum condition in order to obtain lower tool wear rate was found as v = 800 rpm, f = 0.2 mm/rev, d = 0.2 mm and θ = 35˚ following Taguchi method and at the Taguchi determined optimum conditions the tool wear rate was reduced by 25.24 %.

- Optimum condition in order to achieve lower machining time was found as v = 1200 rpm, f = 0.4 mm/rev, d = 0.4 mm and θ = 35˚ as per Taguchi method and the reduction of about 30.71% was obtained at Taguchi determined optimum cutting conditions.

- From the ANOVA analysis as per Taguchi method, it was observed that surface roughness gets significantly affected by approach angle of cutting tool with 58.01 % followed by feed with 38.52 %, depth of cut 3.09 % and cutting speed with 0.37 %.

- From the ANOVA analysis as per Taguchi method, it was observed that material removal rate gets significantly influenced by depth of cut with 61.91 % followed by cutting speed with 21.94 %, feed with 13.2% and approach angle of cutting tool with 2.95 %.

- From the ANOVA analysis as per Taguchi method, it was observed that tool wear rate gets significantly influenced by depth of cut with 60.53 % followed by feed with 19.61 %, cutting speed with 13.37% and approach angle of cutting tool with 6.49 %.

- From the ANOVA analysis as per Taguchi method, it was observed that machining time gets significantly affected by depth of cut with 53.6 % followed by feed with 23.12 %, depth of cut 21.79 % and approach angle of cutting tool with 1.49 %.

- Regression analysis has been performed in order to evaluate mathematical relation between the output parameters like surface roughness, material removal rate, tool wear rate, machining time and the input parameters like cutting speed, feed, depth of cut and approach angle of cutting tool.

- The model summary concluded that regression model for surface roughness has a R^2 value of 89.41 %, material removal rate with R^2 value of about 88.43 %. The R^2 value of regression model for tool wear rate and machining time was 87.09 % and 96.41 % respectively.

- As per ANOVA analysis for regression model, surface roughness was heavily influenced by feed with 47.63% closely followed by approach angle of cutting tool with 45.41 % and cutting speed along with depth of cut has a contribution of about 3.28 % and 3.68 % respectively.

- As per ANOVA analysis for regression model, depth of cut has maximum influence on material removal rate with 61.45 % and is followed by cutting speed with 22.49%. The feed has 16.03% contribution and approach angle of cutting tool has a miniscule contribution of 0.033%.

- As per ANOVA analysis for regression model, depth of cut has maximum influence on tool wear rate with 71.67 % and is followed by feed with 15.55%. The cutting speed has 6.68% contribution and approach angle of cutting tool has a contribution of about 6.1%.

- As per ANOVA analysis for regression model, depth of cut has maximum influence on machining time with 54.11 % and is followed cutting speed with 24.18%. The feed has 20.88% contribution and approach angle of cutting tool has a miniscule contribution of about 0.83%.

- In order to investigate about interactions between the input parameters and its impact on the output parameter contour plots has been drawn for each of the output parameters like surface roughness, material removal rate, tool wear rate and machining time against the two input parameters combination out of the available input parameters.

- As cryogenic soaking of the alloy specimen has been performed, an investigation has been performed to check increment in hardness of the specimen. It was found that hardness has been increased by 33.73 %.

5.2 FUTURE SCOPE OF WORK

- The project work can be extended by using different material like lithium based alloys, Aluminium-Lithium-Magnesium alloys, nano materials etc.

- Instead of having fixed cryogenic soaking duration, different ranges of cryogenic soaking and its impact must be studied.

- With different approach angle of cutting tools, different type of cutting tool must be selected in order to study about effect of different material of cutting tools on machining output.

- Instead of simple turning of the alloy component, some pattern cutting on the specimen using lathe machine must be done.

- Different methods like RSM, TOPSIS, fuzzy logic, artificial neural network etc must be used in order to optimize the cutting parameters and cross checking it with Taguchi method.

- Different diameter of the specimen must be used and check whether different size has any changes in the outcome obtained in this project.

- Different parameters like cutting force, cutting temperature generated, chip morphology etc must be analysed.

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