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Optimization of Cutting Parameters in CNC Milling by Using Taguchi-ANOVA Technique

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Abstract: Today, industry needs quality and productivity. The increase of consumer needs for quality metal cutting products has driven the metal cutting industry to continuous improve quality control of metal cutting process. The end milling process is one of the most fundamental processes of metal removing process. In order to obtain better surface roughness, the proper setting of cutting parameters is crucial before the process takes place. Several factors will influence the final surface roughness in a CNC milling operation. The final surface roughness might be considered as the sum of two independent effects: 1. the ideal surface roughness is are sult of the geometry of tool and feed rate. 2. The natural surface roughness is a result of the irregularities in the cutting operation. Factors such as spindle speed, feed rate, tool diameter and depth of cut that control the chip formations, or the material properties of both tool and work piece are even in the occurrence of chatter or vibrations of the machine tool, defects in the structure of the work material.

For improving the surface roughness of part, CNC end milling, influence of various machining parameters like, tool feed (mm/min), tool speed (rpm), tool diameter (mm) and depth of cut (mm) & output parameters are consider to increases MRR & decreases surface roughness of material . In the present study, experiments are conducted on AL 6063 and AL 6082 material with three levels and four factors to optimize process parameter and surface roughness. An L9 (3*4) Taguchi standard orthogonal array (OA) is chosen for design of experiments and the main influencing factor are determined for each given machining criteria by using Analysis of variance (ANOVA).

I. MACHINING OF METALS

The important goal in the modern industries is to manufacture the products with lower cost and with high quality in short span of time. There are two main practical problems that engineers face in a manufacturing process. The first is to determine the values of process parameters that will yield the desired product quality (meet technical specifications) and the second is to maximize manufacturing system performance using the available resources.

Machining is the process of removing the unwanted material from the work piece in the form of chips. If the work piece is a metal, the process is often called as metal cutting process or chip forming processes. Metal cutting is a machining process by which a work piece is given as follows

A. A desired shape
B. A desired size
C. A desired surface finish

To achieve one or all of these, the excess (undesired) material is removed (from the work piece) in the form of chips with the help of some properly shaped and sized tools. Metal cutting processes are performed on metal cutting machines, more commonly termed as Machine Tools by means of various types of cutting tools.

A machine tool is a power driven metal cutting machine which changes the size and shape of the work piece material. A cutting tool is a body having teeth or cutting edges on it. A single point cutting tool (such as a lathe tools) has only one cutting tool (such as a milling cutter) has a number of teeth or cutting edges on it periphery.

In metal cutting (machining) process, working motion is imparted on to the work piece and cutting tool by the mechanisms of machine tool so that the work and tool travel relative to each other and cut the work piece material in the form of chips. The work-piece can be effectively shaped by using various other manufacturing processes. Among them metal cutting plays an important role, being one of the most versatile processes in manufacturing. Its versatility can be attributed to so many factors, of some which are:

1) Machine tools do not require elaborate tooling.
2) The process of machining can employed to all engineering materials
3) The wear of tool is not costly, if it is kept within limits.
4) A large number of parameters which come into play during machining can be suitably controlled in order to overcome technological and economical difficulties.

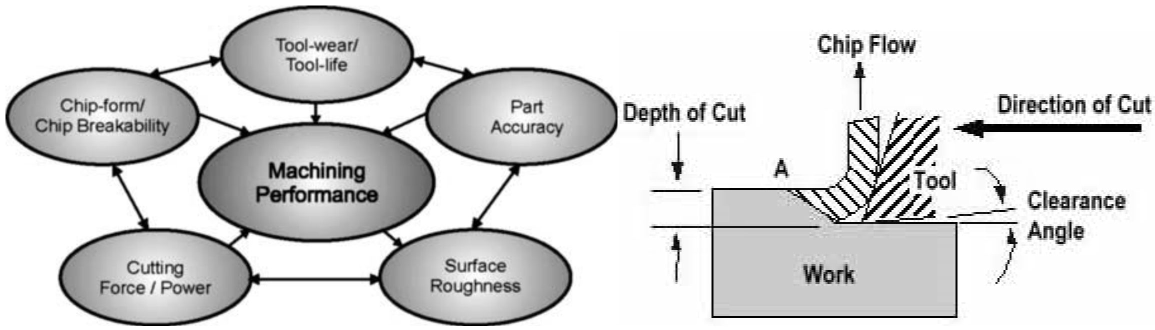

Figure1.1 Basic metal cutting theories

II. ASPECTS OF MACHINING

Machining has been regarded as one of the most fascinating topic for the researchers. It is oneof the frequently used manufacturing operations to get permissible dimension in tolerance zone, good surface finish as well as required complicated geometry. The growing demand of machining leads the researcher to investigate and eradicate several problems during the operation and insists them to make the process economic. As per the definition machining deals with the removal of unwanted material from the work piece surface in the form of chips to get the desired dimension. Several technologies have been developed for removal of material. The suitability of each technology for the process depends on factors like material property of tool and work piece, economic and favorable cutting conditions, cutting environment etc. The machining process is broadly classified as traditional and non-traditional. The traditional method involves removal material due the relative motion between tool and work piece and metal removes due to the plastic deformation of work piece material caused by the shear force. Whereas, non-traditional method involves use of energy sources like electric energy, heat energy, laser ray, electron bombardment etc. for removal of material.

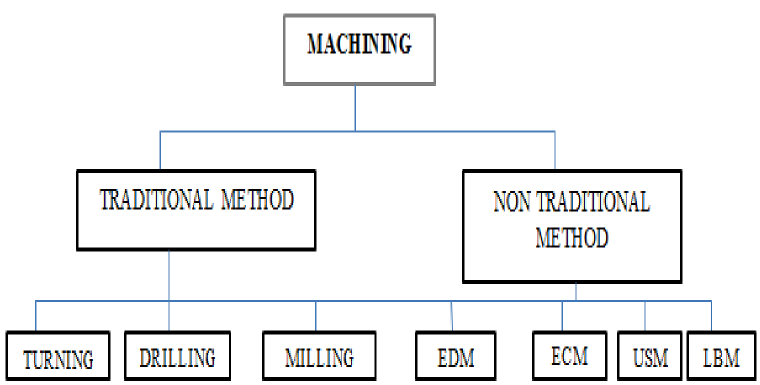

Fig 1.2: Classification of machining

The non-traditional methods are quite costly as well as their metal removal rate is also low. Hence its application is limited to the materials having low machinability and finishing operations. In tradition method metal removal rate is comparatively higher. The concept behind metal cutting is that the metal gets compressed by the tool and deforms both elastically and plastically at the shear zone and then removed by shear from parent material. The separation of the material from the work piece surface occurs due to the yielding or fracture depending upon the cutting conditions. The effectiveness of the process is measured in the form of material removal rate, surface finish, tool wear rate, cutting forces etc. known as qualities. Hence it is necessary to study about the quality in order to enhance the productivity.

III. CNC MILLING

Milling is a versatile and useful machining operation. End milling is the most important milling operation and it is widely used in most of the manufacturing industries due to its capability of producing complex geometric surfaces with reasonable accuracy and surface finish. However, with the inventions of CNC milling machine, the flexibility has been adopted along with versatility in end milling process.

In CNC end milling precise understanding in controlling of process parameters is indeed required to provide good surface finish as well as high material removal rate (MRR). The surface finish may be viewed as product quality attribute and material removal rate directly related to productivity.

In the present research work, material removal rate (MRR) and surface roughness of the product prepared by CNC end milling operation have been studied experimentally and the results, thereof, obtained have been interpreted analytically.

A. Overview of CNC Machining

As far as machining processes are concerned CNC has evolved over the conventional machine tools. Some of the advantages of CNC machine tool over conventional machine tool are listed below:

1) Consistency of work pieces produced- Since a CNC machine executes a program, and it will do so in exactly the same fashion time and time again, the consistency of work pieces produced is much better than work pieces run on conventional machine tools.
2) Faster work piece machining- Since current model CNC machine tools are guarded (splash guards, windows, etc.) in a much better manner than most conventional machine tools, users can apply the most efficient cutting conditions to attain the best cycle times. Manual machinists tend to nurse-along their machining operations to minimize the chips and coolant is constantly thrown from the work area.
3) Lowered skill level of machinist- Though there are some misconceptions in this area (some people believe that anyone can run CNC machines without training), the level of skill required to run (but not program) a CNC machine is much lower than that required to run a conventional machine tool - especially in a production environment when the same work piece is run over and over again.
4) Complexity of work pieces to be machined- CNC machines can generate very complex motions, making it possible to machine shapes that cannot be generated (or are extremely difficult to generate) on conventional machine tools.
5) Flexibility, faster turn-around, and smaller lots- Because they're programmable, a given CNC machine can be used to machine a large variety of different work pieces. Most are also designed to minimize downtime between production runs (setup time). Some conventional machines they're replacing (screw machines and transfer lines, for example) are extremely difficult to setup, making them feasible only for larger lot sizes.

IV. INTRODUCTION TO ALUMINIUM

Aluminium is the world’s most abundant metal and is the third most common element, comprising 8% of the earth’s crust. The versatility of aluminium makes it themost widely used metal after steel. Although aluminium compounds have been used for thousands of years, aluminium metal was firstproduced around 170 years ago.In the 100 years since the first industrial quantities of aluminium were produced, worldwide demand foraluminium has grown to around 29 million tons per year. About 22 million tons is new aluminium and 7million tons is recycled aluminium scrap. The use of recycled aluminium is economically and environmentally compelling. It takes 14,000 kWh to produce 1 tonne of new aluminium. Conversely it takes only 5% of this to remelt and recycle one tonne of aluminium. There is no difference in quality between virgin and recycled aluminium alloys. Pure aluminium is soft, ductile, and corrosion resistant and has a high electrical conductivity. It is widely used for foil and conductor cables, but alloying with other elements is necessary to provide the higher strengths needed for other applications. Aluminium is one of the lightest engineering metals, having strength to weight ratio superior to steel. By utilizing various combinations of its advantageous properties such as strength, lightness, corrosion resistance, recyclability and formability, aluminium is being employed in an ever-increasing number of applications. This array of products ranges from structural materials through to thin packaging foils.

Table.1.1 Different Aluminium alloys and their applications

Aluminium Alloy	Common Use
1050/1200	Food and Chemical Industry
2014	Airframes
5251/5052	Vehicle panelling, Structures exposed to marine atmospheres, mine cages.
6063	Architectural extrusions (internal and external) window frames, Irrigation pipes.
6061/6082	Stressed Structural Members, Bridge cranes, roof trusses, beer barrels.
7075	Armoured vehicles, military bridges, motor cycle and bicycle frames.

There are different types of aluminiumseries, in our project I considered the material is Al 6082 and Al 6063 materials.
Aluminium alloy 6063 is a medium strength alloy commonly referred to as an architectural alloy. It is normally used in intricate extrusions. It has a good surface finish; high corrosion resistance is readily suited to welding and can be easily anodized. Most commonly available as T6 temper, in the T4 condition it has good formability.

Table 1.2 Chemical composition of AL-6063 T6

Chemical element	% Present
Manganese (Mn)	0.0 - 0.10
Iron (Fe)	0.0 – 0.35
Magnesium (Mg)	0.45 – 0.90
Silicon (Si)	0.20 – 0.60
Zinc (Zn)	0.0 – 0.10
Titanium (Ti)	0.0 – 0.10
Chromium (Cr)	0.0 – 0.10
Copper (Cu)	0.0 – 0.10
Aluminium (Al)	Balance

Table 1.3 General properties of AL-6063 T6

Physical Property	Value
Density	2.70 g/cm³
Melting Point	655 °C
Thermal Expansion	23.5 x10^-6 /K
Modulus of Elasticity	69.5 GPa
Thermal Conductivity	201 W/m.K
Electrical Resistivity	0.033 x10^-6 Ω .m
Electrical Resistivity	52 % IACS

Mechanical properties of AL-6063 T6

Mechanical Property	Value
Proof stress	170 Min Mpa
Tensile Strength	215 Min Mpa
Hardness Brinell	75 Typical HB
Elongation	8 Min %

The properties listed above are for material in T6 condition.

A. Applications of Al 6063

1) Architectural extrusions (internal and external),
2) Window frames,
3) Irrigation pipes.

Aluminium alloy 6082 is a medium strength alloy commonly referred to as an architectural alloy. It is normally used in intricate extrusions. It has a good surface finish, high corrosion resistance is readily suited to welding and can be easily anodized. Most commonly available as T6 temper, in the T6 condition it has good formability.

Table 1.4 chemical composition of Al6082 is as

Chemical element	% Present
Manganese (Mn)	0.4 – 1.0
Iron (Fe)	0.0 – 0.5
Magnesium (Mg)	0.6 – 1.2
Silicon (Si)	0.7 – 1.3
Zinc (Zn)	0.0 – 0.20
Titanium (Ti)	0.0 – 0.10
Chromium (Cr)	0.0 – 0.25
Copper (Cu)	0.0 – 0.10
Aluminium (Al)	Balance

Mechanical properties of Al6082 is

Mechanical Properties	Value
Tensile Strength	290 mpa
Elongation	6%
Hardness brinell	95hbn

B. Applications of Al 6082

1) Stressed structural members,
2) Bridges,
3) Cranes,
4) Beer barrels.

C. Advantages of Aluminium

1) Light weight
2) Low co-efficient of thermal expansion
3) Capacity to withstand compression and shear loading
4) Improved wear resistance and corrosion resistance
5) Anti-chemical properties
6) High resistance to weathering attack
7) Higher endurance limit and elastic modulus
8) Higher strength
9) Low density
10) High specific strength and specific modulus

D. Disadvantages of Aluminium
1) Properties not established until manufactured
2) High raw material cost
3) Poor public acceptance

V. CUTTING PARAMETERS

A. Cutting Speed

Speed refers to the spindle and the work piece. When it is stated in rpm, it tells their rotating speed. But the important feature for a particular turning operation is the surface speed that is the speed at which the work piece material is moving past the cutting tool. It is simply the product of the rotating speed times the circumference of the work piece before the cut is started.

It is expressed in meter per minute (m/min), and it refers only to the work piece. Every different diameter on a work piece will have a different cutting speed, even though the rotating speed remains the same.

v = 3.14DN/1000 (m/min)

Here, v is the cutting speed in turning; D is the initial diameter of the work piece in mm.

B. Feed Rate

Feed refers to the cutting tool and it is the rate at which the tool advances along its cutting path. In most of power-fed lathes, the feed rate is directly related to the spindle speed and is expressed in mm (of tool advance) per revolution (of the spindle), or mm/rev.

C. Depth of Cut

Depth of cut is the thickness of the layer being removed (in a single pass) from the work piece or the distance from the uncut surface of the work to the cut surface, expressed in mm. It is important to note that the diameter of the work piece is reduced by two times the depth of cut because this layer is being removed from both sides of the work piece.

VI. RESPONSE PARAMETERS

A. Surface Roughness (RA)

Surface roughness refers to the magnitude of irregularities of material resulted during machining operation. There are several ways to describe surface roughness. One of them is Average roughness, which is denoted as R_a. R_a is the most commonly used and internationally recognized parameter for measuring surface roughness. Theoretically, R_a represents the arithmetic average value of departure of the profile from the mean line throughout the sampling length.

B. Metal Removal Rate (MRR)

Material removal rate has been counted as one of most important output characteristics for thequality measurement and represents the volume of metal removed per unit time. Higher material removal rate is always desirable in a machining operation as it increases the productivity.

Mathematically it can be expressed as:

$$MRR = \frac{\text{Weight before machining} - \text{Weight after machining}}{\text{Density of workpiece} * \text{machining time}}$$

1) Drill Tools Used

a) High Speed Steel (HSS): Advent of HSS in around 1905 made a break through at that time in the history of cutting tool materials though got later superseded by many other novel tool materials like cemented carbides and ceramics which could machine much faster than the HSS tools. The basic composition of HSS is 18% W, 4% Cr, 1% V, 0.7% C and rest Fe. Such HSS tool could machine (turn) mild steel jobs at speed only up to 20 ~ 30 m/min

HSS is used as cutting tool material where;

i) The tool geometry and mechanics of chip formation are complex, such as helical twist drills, reamers, gear shaping cutters, hobs, form tools, broaches etc.

ii) Brittle tools like carbides, ceramics etc. are not suitable under shock loading
iii) The small scale industries cannot afford costlier tools
iv) The old or low powered small machine tools cannot accept high speed and feed.
v) The tool is to be used number of times by resharpening.

HSS tools remarkably, HSS, TiN, and TiAlN coated tools are shown in figure 4.2

b) *Titanium Nitrade (TiN):* The first coating to be used successfully to machine steel in industry and still the most recognized, distinguished by it's attractive bright gold colour. The PVD TiN coating was first used on High Speed Steel (HSS) tooling because it could be applied below 500 deg C, the temperature at which HSS starts to soften. However the many advantages of the PVD TiN coating were obvious to the cemented carbide industry and in 1985 the first PVD TiN coated cemented carbide cutting tool inserts were introduced for milling applications.

The TiN coating is a wear resistant ceramic coating suitable for a wide range of applications, materials, and cutting conditions where tool life extended and elevated feeds and speeds are required. The friction coefficient helps chip flow, prevents build-up of work piece material at the tool edge and reduces cutting forces and tool temperature. However the TiN coating has been superseded in many applications by TiAlN, TiCN and CrN.

2) *Applications:* The TiN coating is used for machining (carbon, alloy, and stainless steels, cast irons, and aluminium alloys) and protecting dies, moulds, punches, and a range of metal stamping and forming tools. It is also used for decorative components and as a direct gold plating replacement as it approximately the same colour

a) *Titanium Aluminium Nitride (TiAlN) coating:* It is dark/ purple in colour with a surface hardness in the upper 81Rc range with a coefficient of friction which is less than Tin. It is a high performing coating, which excels at machining abrasive and difficult to machine materials such as cast iron, aluminium alloys, tool steels and nickel alloys. This coating targets dry or near dry machining applications. It is improved ductility makes it an excellent choice for interrupted cutting operations. Its superior oxidation resistance provides unparalleled performance in high temperature machining. It does not exhibit edge brittleness and can be used for interrupted cuts without chipping.Hardness:2800HV, coating thickness: 2-5microns, thermal stability:750^{0}c.

Figure4.1: HSS and coated TiN,TiAlN tools

The CNC milling machine and its specifications are given in Fig.4.1 and Table-4.1 respectively.

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Table 4.1: CNC MILLING machine specifications

DESCRIPTION	SPECIFICATION
Model	MTAB XLMILL
Table clamping area	6 TOOLS ATC STANDARD
Travel X-axis	225 mm
Y-axis	150 mm
Z-axis	115mm
Table size	360 X 132mm
	0.5 HP
Spindle Motor Capacity	BT 30
	150 - 4000RPM
Spindle taper	230V, Single Phase, 50 Hz
Spindle speeds	0-1 m/min
Power Source	1.2 m/min
Feed rates	0.010mm
Rapid traverse x,y,z-axis	±0.005mm
Positioning accuracy	415 V,50Hz, 3 phase
Repeatability	PC Based 3 Axis Continuous Path
Power supply	PNEUMATIC
CNC control system	16mm
Tool clamping	1000 x 575 x 650mm
Max. tool dia	170Kg
Machine Dimensions	Centralized Lubrication System
Machine weight	
Lubrication System	

Figure 4.2: CNC milling machine XLMILL.

The work piece used for the present investigation is Cast Aluminium of flat work pieces of 100mm*100mm*10mm and the density of the material in metric units. The chemical composition of the work material is given in the Table 4.2. The different coated carbide cutting tool inserts (TN450) used for the present project work are shown in Fig. 4.1.

C. Experiment Details

Machine tool - Milling machine
Work material - Cast Aluminum.
Tool material - HSS.
Drill tool diameter - 8, 10, 12mm
Cutting speed (rpm) - 1000, 1500, and 2000.
Feed (mm/rev) - 30, 40, 50.
Depth of cut (mm) - 0.5, 0.6, and 0.7.
Cutting environments - Dry

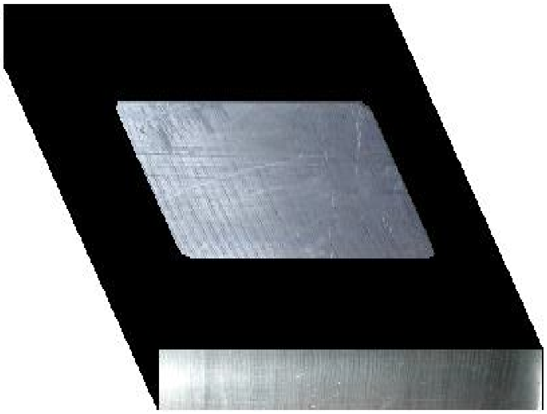

Figure 4.3: Work material after milling

Procedural steps for the present work have been listed below.

1) Selection of process parameters and domain of experiment. (Range of parameter Variation available in the machine).
2) Selection of an appropriate design of experiment (DOE).
3) Material Selection.
4) Experimentation.
5) Measurement of MRR.
6) Collection of experimental data related to surface roughness of the machinedProduct.
7) Data Analysis using proposed methodology.
8) Conclusion and recommendation.

The machining parameters used and their levels chosen are given in Table 4.3.

Table 4.2: Machining Parameters and Their Levels

Control parameters	Units	Symbol	Levels		
			Level 1	Level 2	Level 3
Cutting speed	Rpm	N	1200	1500	2000
Feed rate	mm/min	F	50	100	150
depth of cut	Mm	D	0.3	0.6	0.8
Tool type		TT	Uncoated Hss	Hss+TiN	Hss+TiAlN

Taguchi's orthogonal array of L_9 (**3**^{4}) is most suitable for this experiment. Because, cutting speed, cutting feed, depth of cut and Diameter with Three levels each and then 3×3×3×3=81 runs were required in the experiments for four independent variables. But using Taguchi's orthogonal array the number of experiments reduced to 9 experiments from 81 experiments. This needs 9 runs (experiments) and has 8 degrees of freedom's (DOFs). The L_9 orthogonal array is presented in Table- 4.3

Table 4.3: L_9 (3^4) orthogonal array

L9 (3^4)				
S.NO	Cutting speed (rpm)	Feed rate (mm/min)	Depth of cut (mm)	Tool type
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

In the above Table-4.3, 1, 2, and 3 in columns represents the levels of factors corresponding to the particular variable presented in the column. For the above coded values of machining parameters, actual setting values are presented in Table- 4.4.

Table 4.4: Actual Setting Values for the Coded Values

S.NO	Cutting speed (rpm)	Feed rate (mm/min)	Depth of cut (mm)	Tool type
1	1200	50	0.3	HSS
2	1200	100	0.6	HSS+TiN
3	1200	150	0.8	HSS+AlTiN
4	1500	50	0.6	HSS+AlTiN
5	1500	100	0.8	HSS
6	1500	150	0.3	HSS+TiN
7	2000	50	0.8	HSS+TiN
8	2000	100	0.3	HSS+AlTiN
9	2000	150	0.6	HSS

The surface roughness was measured by using stylus type instrument i.e., Talysurf Surface Roughness meter.

VII. ANALYSIS OF RESPONSES

A. Introduction

In this chapter, the responses (output parameters) are analysed using ANOVA and the influence of input parameters on responses is determined and also the plots of S/N ratio for responses (output) and charts of percentage contribution are presented in this chapter.

B. Determination Of Optimum Level Factors

1) *Determination of Optimum Parameters:* The Taguchi calculated for each sequence is taken as a response for the further analysis. Thesmaller-the-better quality characteristic was used for analysing the TAGUCHI, since a smaller value indicates the better performance of the process. The number of repeated test is one,since only one relational grade was acquired in each group for this particular calculation of S/N.

The Taguchi calculated for each sequence is taken as a response for the further analysis. Thelarger-the-better quality characteristic was used for analyzing the TAGUCHI, since a smaller value indicates the better performance of the process. The number of repeated test is one,since only one relational grade was acquired in each group for this particular calculation of S/N.

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Table5.1 Response tables for different output parameters for Al 6063 material

Response table for Surface Roughness				
Level	Cutting speed	Feed rate	Depth of cut	Tool type
1	-7.686	-7.998	-6.185	-8.225
2	-10.035	-8.226	-11.161	-8.993
3	-9.824	-11.322	-10.199	-10.327
Response table for MRR				
1	17.63	12.26	12.97	17.67
2	18.03	18.94	19.20	17.87
3	17.89	22.36	21.38	18.02

Table 5.1shows the taguchi calculation results. The taguchi relation are now analysed with Taguchi in Minitab software. Thisresult shows that the best processing condition is the (N2, f3, d2, tt3).

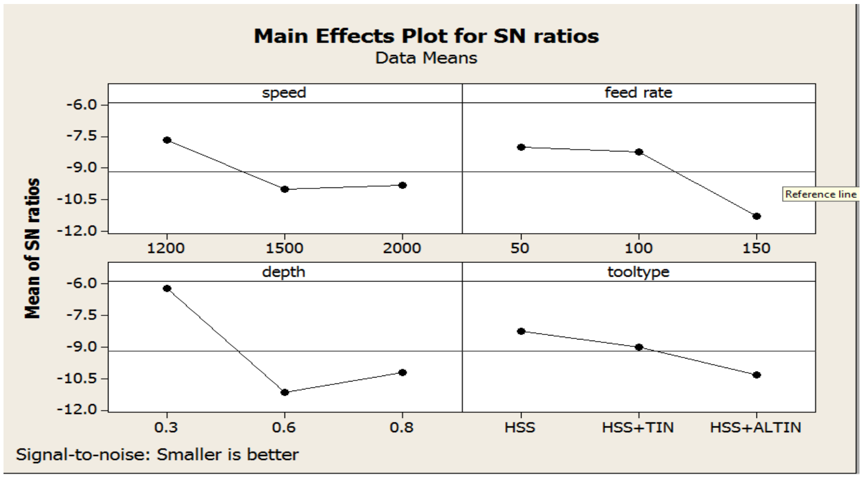

Figure 5.1: S/N ratio for surface roughness of Al 6063

The best optimum condition for thesurface roughness is (N2, f3,d2,tt3) i.e.,at a speed of 1500rpm, feed of 150 mm/min, depth of cut is 0.6 and tool material HSS+ALTIN is the optimum condition.

Table 5.1shows the taguchi calculation results. The taguchi relation are now analysed with Taguchi in Minitab software. Thisresult shows that the best processing condition is the (N2, f3, d3, tt3).

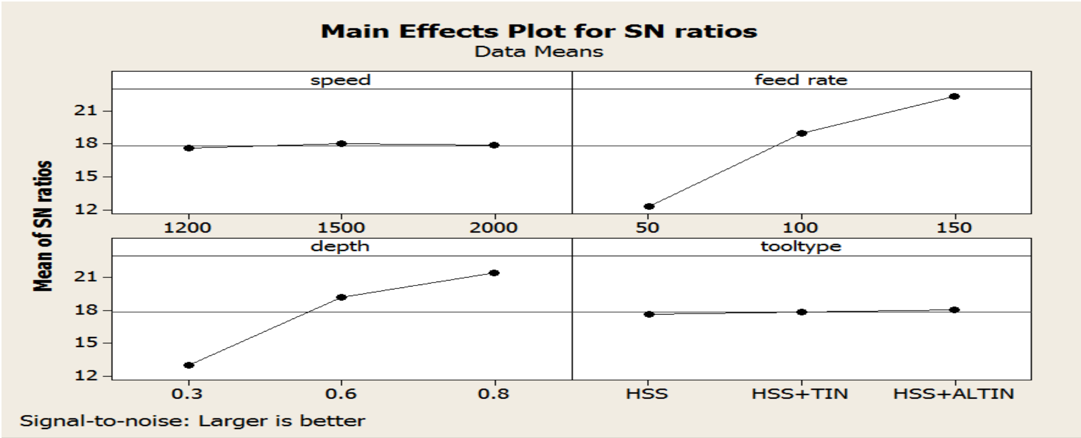

Figure 5.2: S/N ratio for MRR of Al 6063

The best optimum condition for the material removal rate is (N2, f3,d3,tt3) i.e.,at a speed of 1500rpm, feed of 150 mm/min, depth of cut is 0.8 and tool material HSS+ALTiN is the optimum condition.

Table5.2 Response tables for different output parameters for Al 6082 material

Response table for Surface Roughness				
Level	Cutting speed	Feed rate	Depth of cut	Tool type
1	-5.703	-6.122	-3.507	-8.072
2	-8.590	-6.040	-7.186	-5.092
3	-6.276	-8.407	-9.876	-7.404
Response table for MRR				
1	18.10	12.88	13.35	18.07
2	18.09	18.90	19.09	17.89
3	17.96	22.37	21.72	18.20

Table 5.2shows the taguchi calculation results. The taguchi relation are now analysed with Taguchi in Minitab software. Thisresult shows that the best processing condition is the (N2, f3, d3, tt1).

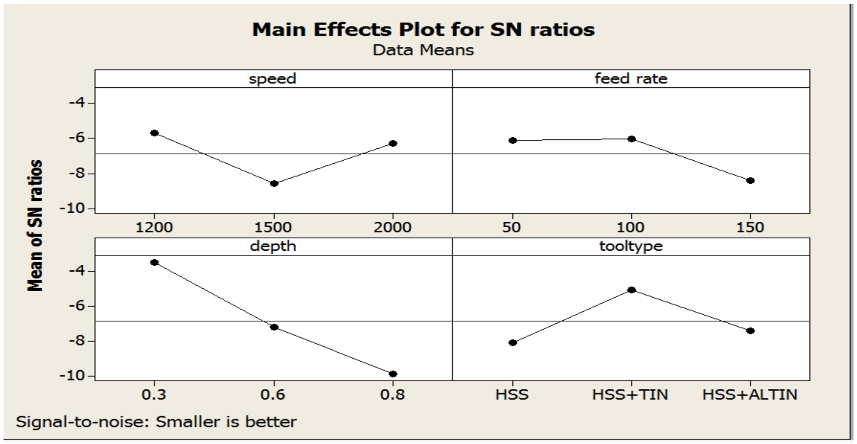

Figure 5.3: S/N ratio for surface roughness of Al 6063

The best optimum condition for thesurface roughnessis (N2, f3,d3,tt1) i.e.,at a speed of 1500rpm, feed of 150 mm/min, depth of cut is 0.8 and tool material HSS is the optimum condition.

Table 5.2shows the taguchi calculation results. The taguchi relation are now analysed with Taguchi in Minitab software. Thisresult shows that the best processing condition is the (N1, f3, d3, tt3).

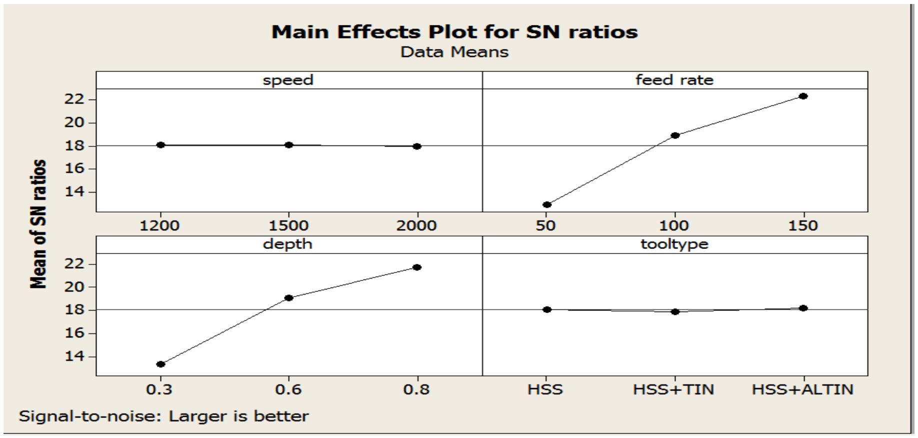

Figure 5.4: S/N ratio for MRR of Al 6082

The best optimum condition for the material removal rate is (N1, f3,d3,tt3) i.e.,at a speed of 1200rpm, feed of 150 mm/min, depth of cut is 0.8 and tool material HSS+ALTiNis the optimum condition.

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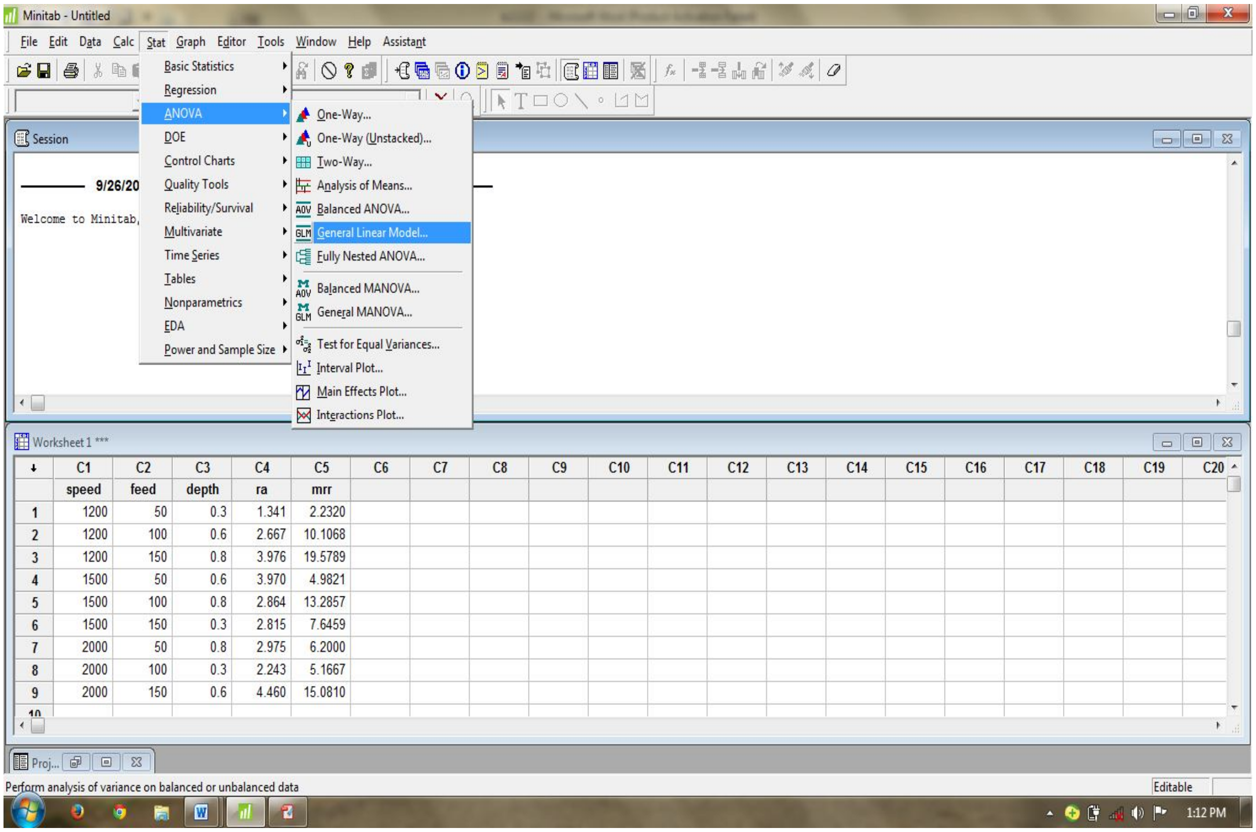
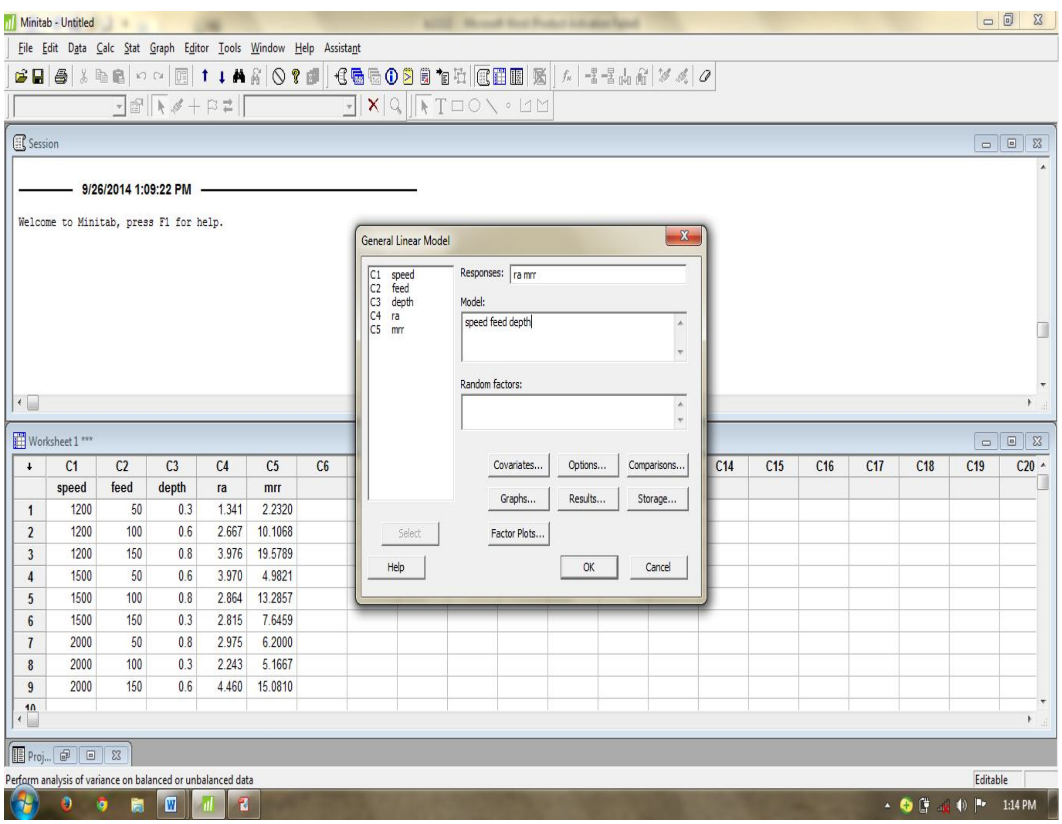
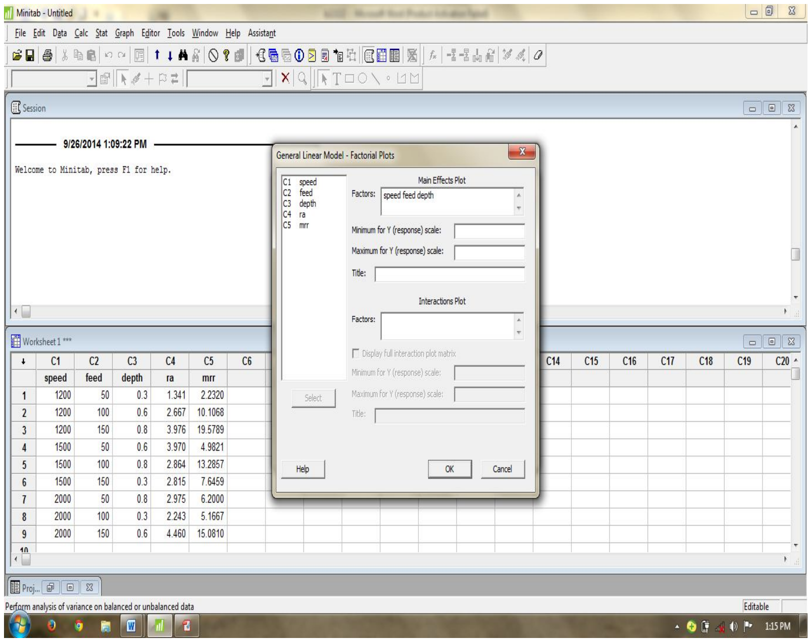
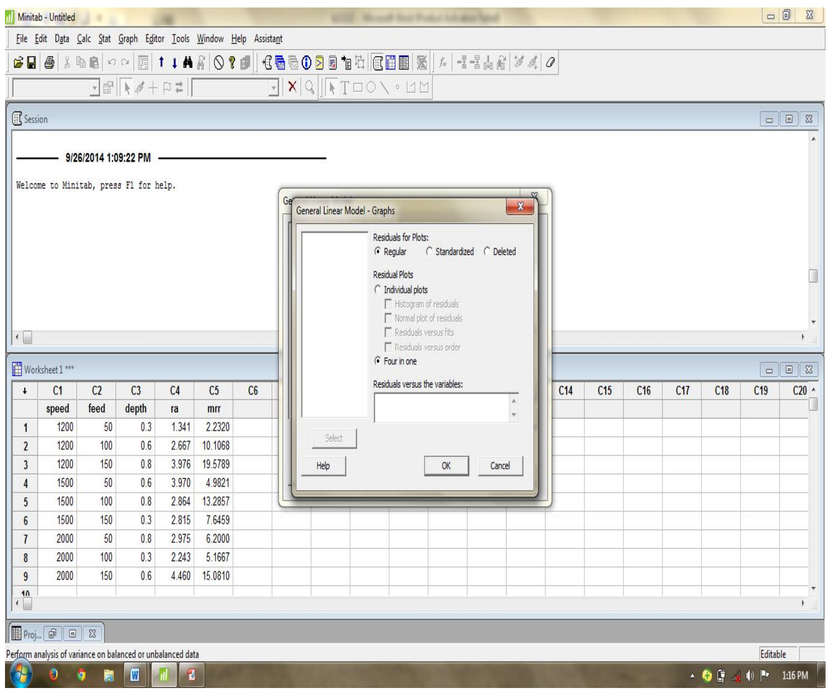
C. Procedure For Anova

1) For work material al 6063









2) *For Material 6063:* Analysis of Variance for ra, using Adjusted SS for Tests

Table 5.3: Analysis of variance for Ra of Al 6063

Source	DF	Seq SS	Adjss	Adj MS	F	P
Speed	2	0.6270	0.6270	0.3135	1.05	0.487
Feed rate	2	2.3492	2.3492	1.1746	3.94	0.202
Depth of cut	2	3.9315	3.9315	1.9658	6.59	0.132
Error	2	0.5962	0.5962	0.2981		
Total	8	7.5039				

Analysis of Variance for MRR, using Adjusted SS for Tests

Table 5.4: Analysis of variance for MRR of Al 6063

Source	DF	Seq SS	Adjss	Adj MS	F	p
Speed	2	7.362	7.362	3.681	0.85	0.542
Feed rate	2	139.230	139.230	69.615	16.01	0.059
Depth of cut	2	98.317	98.317	49.158	11.30	0.081
Error	2	8.698	8.698	4.349		
Total	8	253.606				

3) For Material 6082: Analysis of Variance for Ra, using Adjusted SS for Tests

Table 5.5: Analysis of variance for Ra of Al 6082

Source	DF	Seq SS	Adjss	Adj MS	F	P
Speed	2	0.9678	0.9678	0.4839	0.66	0.601
Feed rate	2	0.6389	0.6389	0.3194	0.44	0.0696
Depth of cut	2	4.3703	4.3703	2.1852	2.99	0.250
Error	2	1.4606	1.4606	0.7303		
Total	8	7.4376				

Analysis of Variance for MRR, using Adjusted SS for Tests

Table 5.6: Analysis of variance for MRR of Al 6082

Source	DF	Seq SS	Adjss	Adj MS	F	P
Speed	2	9.701	9.701	4.851	0.92	0.522
Feed rate	2	135.685	135.685	67.843	12.80	0.072
Depth of cut	2	106.877	106.877	53.439	10.08	0.090
Error	2	10.599	10.599	5.299		
Total	8	262.863				

D. Results Obtained From The Analysis Of Al6063 And Al6082

The contributions of input parameters on individual response are identified by ANOVA.

1) Al6063

a) Cutting speed (A), feed rate (B), depth of cut (C) affect surface finish by 48.7%, 20.2%, and 13.2% respectively

b) Cutting speed (A), feed rate (B), and depth of cut (C), affect MRR by 54.2%,5.9%, and 8.1% respectively

2) Al6082

a) Cutting speed (A), feed rate (B), depth of cut (C) affect surface finish by 60.1%, 6.96%, and 25.0% respectively.

b) Cutting speed (A), feed rate (B), and depth of cut (C), affect MRR by 52.0%,7.2%, and 9.0% respectively.

VIII. CONCLUSION

A Taguchi was proposed to study the optimization of cnc milling process parameters. Surface roughness, material removal rate are selected as quality targets. Nine experimental runs based on orthogonal arrays were performed. The conclusions based on the Taguchi are summarized as follows:

The recommended levels of milling parameters for the for AL6063 Surface roughness, material removal rate are simultaneously considered are :speed, 1500rpm; feed rate, 150 mm/min; depth of cut, 0.6 mm; tool material HSS+ALTiN.speed, 1500rpm; feed rate, 150 mm/min; depth of cut, 0.8 mm; tool material HSS+ALTiN.

The recommended levels of milling parameters for the for AL6082 Surface roughness, material removal rate are simultaneously considered are : speed, 1500rpm; feed rate, 150 mm/min; depth of cut, 0.8 mm; tool material HSS. speed, 1200rpm; feed rate, 150 mm/min; depth of cut, 0.8 mm; tool material HSS+ALTiN.

The contributions of input parameters on individual response are identified by ANOVA. From ANOVA surface finish and material removal rate, are mostly affected bycutting speed, depth of cut. Present work is useful to optimize the multiple responses in drilling process and it can further be extended for other machining process. This work may also help in reducing the experimental cost while modelling of complex machining process.

IX. APPENDIX

Appendixes, if needed, appear before the acknowledg-ment.

X. ACKNOWLEDGMENT

The preferred spelling of the word “acknowledgment” in American English is without an “e” after the “g.” Use the singular heading even if you have many acknowledgments. Avoid expressions such as “One of us (S.B.A.) would like to thank ... .” Instead, write “F. A. Author thanks” Sponsor and financial support acknowledgments are placed in the unnumbered footnote on the first page.

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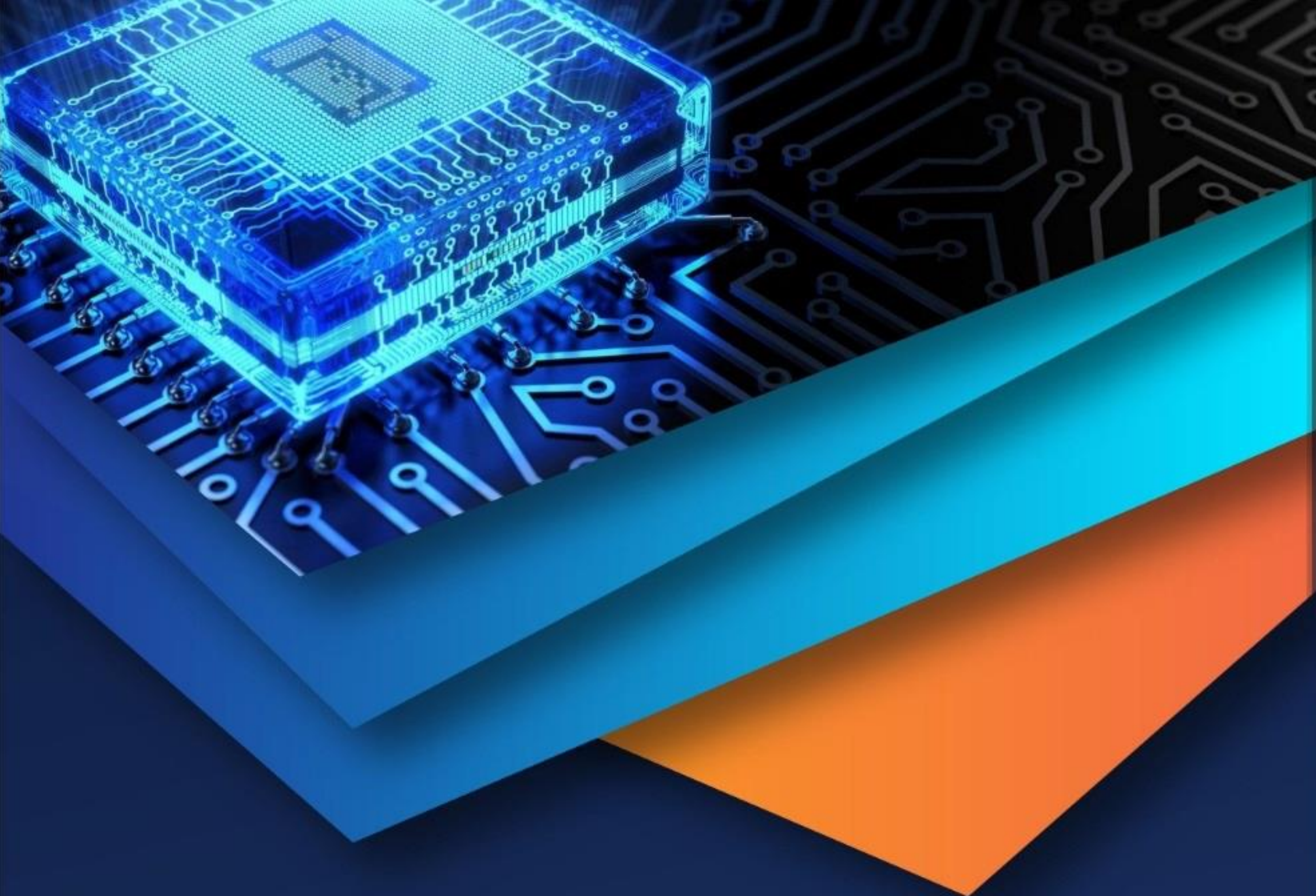

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