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OPTIMIZATION OF DRILLING PARAMETERS OF SS304 BY TAGUCHI METHOD

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Abstract - *Drilling operation is widely used in metal cutting industries, although modern metal cutting methods have improved in the manufacturing industries, but conventional drilling still remains one of the most common machining. In this study, focuses on the optimization of drilling parameters using the Taguchi technique to obtain minimum surface roughness (Ra) and hole diameter, cylindricity &Machining timing. A number of drilling experiments were conducted using the L9 orthogonal array on conventional drilling machine. The experiments were performed on SS 304 using HSS, TiN coated & M42 twist drills were used under dry cutting conditions with various end point angle speed and feed. The measured results were collected and analyzed with the help of the commercial software package MINITAB17.*

Key Words: drilling, Taguchi method, Analysis of Variance, SS304..

1.1 INTRODUCTION

Hole making is among the most important operations in manufacturing. Drilling is a major and common of hole making process. Drilling is the cutting process of using a drill bit in a drill to cut or enlarge holes in solid materials, such as wood or metal. Different tools and methods are used for drilling depending on the type of material, the size of the hole, the number of holes, and the time to complete the operation. It is most frequently performed in material removal and is used as a preliminary step for many operations, such as reaming, tapping and boring. The cutting process in which a hole is originated or enlarged by means of a multipoint, fluted, end cutting tool. As the drill is rotated and advanced into the work piece, material is removed in the form of chips that move along the fluted shank of the drill.

Although long spiral chips usually result from drilling, adjustment of the feed rate can result in chips with a range of many different shapes and sizes. Material of work piece can also change the range of different chip shapes and sizes generally, the hole diameters produced by drilling are slightly larger than the drill diameter (oversize). The amount of oversize depends on the quality of the drill and also the equipment that used as well as the machinist skill.

1.2 DRILL GEOMETRIC ATTRIBUTES

Drill bits are cutting tools used to create cylindrical holes. Bits held in a tool called a drill, which rotates them and provides torque and axial force to create the hole. Different point angle drills and different diameter drills and of different length of drills can be used according to the application of work. Drills with no point angle are used in situations where a blind, flat-bottomed hole is required. These drills are very sensitive to changes in lip angle, and even a slight change can result in an inappropriately fast cutting drill bit that will suffer premature wear. Diameters range of twist drill is about 0.15 to 75 mm. Body, Point, and Shank are three basic parts of twist drill twist drill has two spiral or helical grooves called flutes separated by Lands. Angle of spiral flute is call as the helix angle around 30°. Flutes helps for extraction of from the hole. Web is the thickness of the drill between the flutes and it support the drill support over its length. Point of the twist drill has the general shape of a cone having a typical value of 118°. Point can be design in various ways. However, most common design is a chisel edge. The spiral, or rate of twist in the drill, controls the rate of chip removal in a drill. A fast spiral drill is use in high feed rate applications under low spindle speeds.

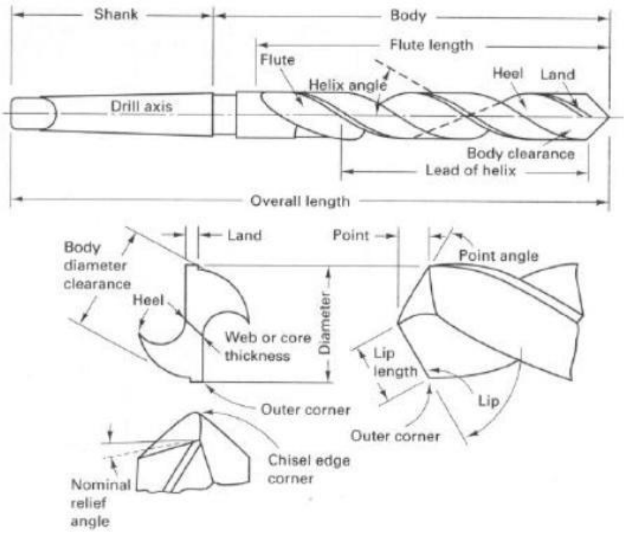

Fig 1.1 Nomenclature and Geometry of Twist Drills

1.3DRILLING PARAMETERS

Main drilling parameters that are involved in the machining on the vertical milling center are 1.Speed 2.Feed 3.Tool MaterialThe above three drilling parameters are the key factor for the machining properties of the work piece. The various constrained such as machining time, surface roughness, tool wear, material removal rate are based on the selection of the drilling parameters.

Speed

Speed always refers to the spindle and the work piece. When it is stated in revolutions per minute (rpm) it tells their rotating speed. But the important feature for a particular drilling operation is the surface speed or the speed at which the work piece material is moving past the cutting tool.It is simply the product of the rotating speed time and 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 thickness on a work piece will have a different drilling speed, even though the rotating speed remains the same.

Feed

Feed always refers to the drilling tool and it is the rate at which the tool advances along its drilling path. On most VMC's, the feed rate is the directly related to the spindle speed and it is expressed in mm per revolution or mm/rev.Feed rate is dependent on the: 1.Type of tool (a small drill or a large drill, high speed or carbide) 2.Surface roughness desired.3.Power available at spindle. 4. Rigidity of the machine and tooling setup.5.Strength of the work piece.

Tool Material

Many different materials are used for or on drill bits, depending on the required application. Many hard materials, such as carbides, are much more brittle than steel, and are far more subject to breaking, particularly if the drill is not held at a very constant angle to the work piece; e.g., when hand-held. Soft low-carbon steel bits are inexpensive, but do not hold an edge well and require frequent sharpening. They are used only for drilling wood; even working with hardwoods rather than softwoods can noticeably shorten their lifespan. Bits made from high-carbon steel are more durable than low-carbon steel bits due to the properties conferred by hardening and tempering the material. If they are overheated (e.g., by frictional heating while drilling) they lose their temper, resulting in a soft cutting edge. These bits can be used on wood or metal. High (HSS) is a form of tool steel; HSS bits are hard and much more resistant to heat than high-carbon steel. They can be used to drill metal, hardwood, and most other materials at greater cutting speeds than carbon-steel bits, and have largely replaced carbon steels. Cobalt steel alloys are variations on high-speed steel that contain more cobalt. They hold their hardness at much higher temperatures and are used to drill stainless steel and other hard materials. The main disadvantage of cobalt steels is that they are more brittle than standard HSS. Tungsten carbide and other carbides are extremely hard and can drill virtually all materials, while holding an edge longer than other bits. The material is expensive and much more brittle than steels; consequently they are mainly used for drill-bit tips, small pieces of hard material fixed or brazed onto the tip of a bit made of less hard metal. However, it is becoming common in job shops to use solid carbide bits. In very small sizes it is difficult to fit carbide tips; in some industries, most notably PCB manufacturing, requiring many holes with diameters less than 1 mm, solid carbide bits are used.

1.4 STAINLESS STEEL

Stainless steel sections have been increasingly used in architectural and structural applications because of their superior corrosion resistance, ease of maintenance and pleasing appearance. The mechanical properties of stainless steel are quite different from those of carbon steel. For carbon and low-alloy steels, the proportional limit is assumed to be at least 70 % of the yield point, but for stainless steel the proportional limit ranges from approximately 36 % - 60 % of the yield strength. Therefore the lower proportional limits would affect the buckling behavior of stainless steel structural members. Stainless steel structural members are more expensive than carbon steel. Therefore, more economic design and the use of high strength stainless steel could offset some of the costs.

Austenitic Chromium-nickel-iron alloys with 16-26% chromium, 6-22% nickel (Ni), and low carbon content, with non-magnetic properties (if annealed - working it at low temperatures, then heated and cooled). Nickel increases corrosion resistance. Harden able by cold-working (worked at low temperatures) as well as tempering (heated then cooled). Type 304 (S30400) or "18/8" (18% chromium 8% nickel), is the most commonly used grade or composition.
Martensitic Chromium-iron alloys with 10.5-17% chromium and carefully controlled carbon content, harden able by quenching (quickly cooled in water or oil) and tempering (heated then cooled). It has magnetic properties. Commonly used in knives.

Ferritic Chromium-iron alloys with 17-27% chromium and low carbon content, with magnetic properties. Cooking utensils made of this type contain the higher chromium levels. Type 430 is the most commonly used ferritic. Two additional classes worth mentioning include Duplex (with austenitic and ferritic structures), and Precipitation Hardening stainless steel, used in certain extreme conditions. Austenitic stainless steel is also called 200 and 300 series, stainless steels have an austenitic crystalline structure, which is a face-centered cubic crystal structure. Austenite steels make up over 70% of total stainless steel production. They contain a maximum of 0.15% carbon, a minimum of 16% chromium, and sufficient nickel and/or manganese to retain an austenitic structure at all temperatures from the cryogenic region to the melting point of the alloy.

200 Series—austenitic chromium-nickel-manganese alloys. Type 201 is hardenable through cold working; Type 202 is a general purpose stainless steel.

300 Series. The most widely used austenite steel is the 304, also known as 18/8 for its composition of 18% chromium and 8% nickel. 304 may be referred to as A2 stainless. The second most common austenite steel is the 316 grade, also referred to as A4 stainless and called marine grade stainless, used primarily for its increased resistance to corrosion.

Table: 1.1 Chemical Composition of various SS 300 Grade

Stainless Steel								
SI NO	GRADE NAME	%C	%Si	% MN	%P	% Cr	%Ni	%Fe
1	301	0.15	1	2	0.045	16-	6-8	Balance
2	304	0.08	0.75	2	0.045	18-	8-	Balance
3	305	0.12	1	2	0.045	18	12	Balance
4	310	0.25	1.5	2	0.045	24-	19-	Balance
5	316	0.08	0.75	2	0.045	16-	14	Balance
6	321	0.08	0.75	2	0.045	17-	9-12	Balance

1.5 PROBLEM IDENTIFICATION

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. Second is to maximize manufacturing system performance using the available resources.

1.6 OVERCOME THE EXISTING PROBLEM

Machining SS 304 material conventionally is a critical work due to high carbon content. To avoid this: Titanium Nitride Coated drill bit used. To optimize the input parameters Taguchi method used.

2. LITERATURE REVIEW

A. Navanth et al. [1] studied and focuses on the optimization of drilling parameters using the Taguchi technique to obtain minimum surface roughness (Ra) and hole diameter. J. Prasanna et al. [2] were experimentally analyzed in a Ti–6Al–4V plate of 0.4 mm thickness using twisted carbide drill bits of 0.4 mm diameter by conventional dry drilling. Ulaş Çaydaş et al. [3] were performed of HSS, K20 solid carbide, and TiN-coated HSS tools in dry drilling of AISI 304 austenitic stainless steel. M. Balajia et al. [4] were deals with the effect of cutting parameters namely cutting speed, feed rate and helix angle on the tool life. The experiments were performed on drilling of AISI304 steel with carbide drill bits. drill bit vibration and surface roughness.. Optimum levels of cutting parameters for acceleration of vibration are obtained as 25 degrees of helix angle, 10mm/min of feed rate and 600rpm spindle speed.Gaurav Chaudharya et al. [5] were analyzed with metal matrix composites (MMCs) consisting of two or more physically/chemically distinct phases are potential material for aerospace, automobile, defense, sport and research industries. Suman Chatterjee et al. [6] were presented attempts to analyze the effect of various drilling parameters such as spindle speed, feed rate and drill bit diameter on performance characteristics such as thrust force, torque and circularity at entry and exit of the holes in drilling of titanium alloy using coated drill bit. A three dimensional machining model based on Lagrangian approach is developed using DEFORM-3D software. V.Balakumaran et al [7] were investigated through methodology of Modified Taguchi optimization method for simultaneous minimization and maximization of Surface roughness (Ra), machining time and material removal rate of EN31 Alloy steel affect the aesthetical aspect of the final product and hence it is essential to select the best combination values of the CNC drilling process parameters to minimize as well as maximize the responses. Nayan G Kaneriya et al. [8] were investigated of that work is to reduce temperature caused in drill tool while dry drilling of AISI 304 austenitic stainless steel by optimizing drilling parameters and selecting suitable drill tool material.Sumesha S et.al. [9] The objective of the present work is to optimize process parameter such as cutting speed, feed, and drill diameter. Arshad Noor Siddiqueea et al. [10] were focused on optimizing deep drilling parameters based on Taguchi method for minimizing surface roughness. Himanshu Gupta et al. [11] were focused on Optimization of Influencing Drilling Parameters in HSS T1 Using Response Surface Methodology.A. madhankumar et al. [12] were investigated drilling time in ss304 (austenitic stainless steel) with different cutting environments Almost half of the world's industrial and production is done by using stainless steel between the machining parameters and performance characteristics. Kunal Sharma et al. [13] were focused on Optimization of Machining Parameters in Drilling of Stainless Steel Almost half of the world's industrial and production is done by using stainless steel. Mr. N.S.Kurzekar et al. [14] had discussed A review on optimization of drilling process parameters of AISI 304 austenite stainless steel by using response surface methodology Sudha Kumari et al. [15] studied optimization of cutting parameters for surface roughness of stainless steel ss304 in abrasive assisted drilling in which This paper is concerned with optimization of surface roughness when drilling of stainless steel SS304 with HSS drill.

3. EXPERIMENTAL DETAILS

3.1 BASE MATERIAL

Grade 304 is the standard "18/8" stainless; it is the most versatile and most widely used stainless steel, available in a wider range of products, forms and finishes than any other. It has excellent forming and welding characteristics. The balanced austenitic structure of Grade 304 enables it to be severely deep drawn without intermediate annealing, which has made this grade dominant in the manufacture of drawn stainless parts such as sinks, hollow-ware and saucepans. For these applications it is common to use special "304DDQ" (Deep Drawing Quality) variants. Grade 304 is readily brake or roll formed into a variety of components for applications in the industrial, architectural, and transportation fields. Grade 304 also has outstanding welding characteristics. Post-weld annealing is not required when welding thin sections. Grade 304L, the low carbon version of 304, does not require post-weld annealing and so is extensively used in heavy gauge components (over about 6mm). Grade 304H with its higher carbon content finds application at elevated temperatures. The austenitic structure also gives these grades excellent toughness, even down to cryogenic temperatures.

Table: 3.1 Mechanical Properties of SS304

Sl No	Grade	Tensile Strength (MPa)	Yield Strength (MPa)	Elongation (% in mm)	Hardness	
					Rockwell B (HR B) max	Brinell (HB) max
1	304	515	205	40	92	201
2	304L	485	170	40	92	201
3	304H	515	205	40	92	201

Table: 3.2 Physical Properties of SS304

Sl No	Grade	Density (kg/m^3)	Elastic Modulus (GPa)	Thermal Conductivity (W/m.K) at 100 °C	Specific Heat 0-100 °C (J/kg.K)	Electrical Resistivity (nΩ.m)
1	304/L/H	8000	193	16.2	500	720

Fig 3.1 Base Metal before Drilling

3.2 DRILL BITS

HSS Drill Bit is a subset of tool steels, commonly used as cutting tool material. It is often used in power-saw blades and drill bits. It is superior to the older high-carbon steel tools used extensively. It can withstand higher temperatures without losing its temper (hardness). This property allows HSS to cut faster than high carbon steel, hence the name high-speed steel. At room temperature, in their generally recommended heat treatment, HSS grades generally display high hardness (above Rockwell hardness 60) and abrasion resistance (generally linked to tungsten and vanadium content often used in HSS) compared with common carbon and steels. The addition of about 10% of tungsten and molybdenum in total maximizes efficiently the hardness and toughness of high speed steels and maintains those properties at the high temperatures generated when cutting metals.

HSS Chemical Composition

Table 3.3 HSS drill bit Chemical Composition

Sl No	Carbon	Silicon	Manganese	Chromium	Tungsten	Vanadium
1	2.0	-	2.5	-	7.0	-

Fig 3.2 HSS Drill Bit

M42 Drill Bit a molybdenum-series high-speed steel alloy with an additional 8% or 10% cobalt. It is widely used in metal manufacturing industries because of its superior red-hardness as compared to more conventional high-speed steels, allowing for shorter cycle times in production environments due to higher cutting speeds or from the increase in time between tool changes. M42 is also less prone to chipping when used for interrupted cuts and costs less when compared to the same tool made of carbide. Tools made from cobalt-bearing high speed steels can often be identified by the letters HSS-Co.

Table 3.4 M42 drill bit Chemical Composition

Sl N0	Carbon	Chromium	Molybdenum	Tungsten	Vanadium	Cobalt
1	1.10	3.75	9.50	1.50	1.15	8.00

Fig 3.4 M42 Drill Bit

TIN COATED DRILL Bit Surface coatings on drill bits allow greater feeds and speeds when operating at higher temperatures, increasing tool life and thus productivity sometimes by 4 or 5 times. TiN (Gold) – Titanium Nitride: A gold coloured film of Titanium Nitride with a hardness of approximately 85Rc is deposited on the tool which extends tool life by reducing friction and enables greater speeds and feeds. Lesser quality drills often imitate TiN coating, but more often this is purely cosmetic. Coatings are for use at high speeds where the temperature is high enough to bring the coatings functional use into play.

Table 3.6 TiN coated drill bit chemical composition

Sl No	Carbon	Chromium	Molybden	Vanadium	Manganese	Silicon
1	2.00	1.75	-	0.75	3.50	1.82

Fig 3.5 TiN Coated Drill Bit

4. EXPERIMENTATION

The HAAS TM1 Vertical Milling machine was used for experimentation. The twist drill bit was used in machining the work-piece. Preparing the slurry by taking concentration (gm/ml) of 15%, 25%, and 35%, with abrasive powder of Silicon carbide which has grit size 1200 µm. Stop-watch was used to determine material removal rate (MRR). For measuring surface roughness Mitutoyo (Surftest-4) was used. The corresponding MRR and surface finish was recorded for each experiment.

4.1 Machining Setup

A VMC is a type of CNC machine, typically enclosed and most often used for cutting metal. They are usually very precise and very expensive. VMC stands for vertical milling center and refers to a particular type of milling machine where the spindle runs in a vertical axis known as the "z" axis. There are two subcategories of vertical mills: the bed mill and the turret mill. A turret mill has a stationary spindle and the table is moved both perpendicular and parallel to the spindle axis to accomplish cutting. This type of machine provides two methods of cutting in the vertical (Z) direction: by raising or lowering the quill, and by moving the knee. In the bed mill, however, the table moves only perpendicular to the spindle's axis, while the spindle itself moves parallel to its own axis.

4.2RESPONSE PARAMETERS

Surface Roughness Test

Surface roughness often shortened to roughness, is a component of surface texture. It is quantified by the deviations in the direction of the normal vector of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small, the surface is smooth.
Roughness plays an important role in determining how a real object will interact with its environment. In tribology, rough surfaces usually wear more quickly and have higher friction coefficients than smooth surfaces. Roughness is often a good predictor of the performance of a mechanical component, since irregularities on the surface may form nucleation sites for cracks or corrosion. On the other hand, roughness may promote adhesion

Table 3.7 Surface Roughness Result

Experiment No	Surface Roughness (microns)			Average surface roughness (microns)
	Trial 1	Trial 2	Trial 3	
1	2.476	2.190	2.197	2.287
2	1.682	1.398	1.358	1.479
3	1.570	1.318	1.293	1.393
4	0.881	0.769	0.834	0.828
5	0.403	0.445	0.434	0.427
6	2.451	2.666	2.038	2.285
7	2.848	2.750	2.787	2.795
8	3.616	3.655	3.735	3.668
9	1.983	1.869	1.826	1.892

Although a high roughness value is often undesirable, it can be difficult and expensive to control in manufacturing. For example, it is difficult and expensive to control surface roughness of fused deposition modelling (FDM) manufactured parts.[3] Decreasing the roughness of a surface usually increases its manufacturing cost. This often results in a trade-off between the manufacturing cost of a component and its performance in application. There are many different roughness parameters in use, but R_a is by far the most common, though this is often for historical reasons and not for particular merit, as the early roughness meters could only measure R_a. Other common parameters include R_z, R_q, and R_{sk}. Some parameters are used only in certain industries or within certain countries. Roughness can be measured by manual comparison against a "surface roughness comparator", but more generally a surface profile measurement is made with a profilometer.

4.3 Surface Roughness Meter

Roughness Meter is a portable measuring instrument for determination of surface roughness according to Ra, Rz, Rq and Rt in just one device. The small roughness meter is especially designed for fast measuring of roughness. The roughness is a term of surface physics that describes unevenness of surface height. The roughness meter works according to the same piezoelectric micro probe principle like the highly accurate laboratory measuring instruments.

Fig 4.1 Surface Roughness Meter

The easy handling of the roughness meter as well as the high repetitive accuracy characterizes this device. After touching the button the piezoelectric micro probe of the roughness meter scans the surface within seconds and shows digitally, according to the preselected cut-off length, either the value Ra, Rz, Rq or Rt.For example, engine parts may be exposed to lubricants to prevent potential wear, and these surfaces require precise engineering – at a microscopic level – to ensure that the surface roughness holds enough of the lubricants between the parts under compression, while it is smooth enough not to make metal to metal contact.

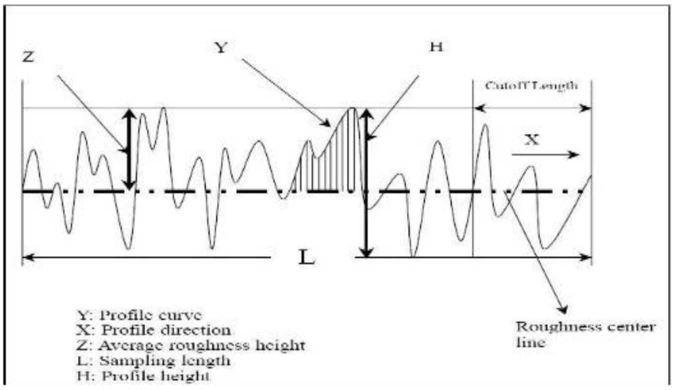

Fig 4.2 Graph for Surface Roughness

4.4 Amplitude parameters

Amplitude parameters characterize the surface based on the vertical deviations of the roughness profile from the mean line. Many of them are closely related to the parameters found in statistics for characterizing population samples. For example, R_a is the arithmetic average value of filtered roughness profile determined from deviations about the center line within the evaluation length and R_t is the range of the collected roughness data points.

4.5 Areal roughness parameters

Areal roughness parameters are defined and the resulting values are Sa, Sq, Sz, Many optical measurement instruments are able to measure the surface roughness over an area. Area measurements are also possible with contact measurement systems. Multiple, closely spaced 2D scans are taken of the target area. These are then digitally stitched together using relevant software, resulting in a 3D image and accompanying areal roughness parameters.

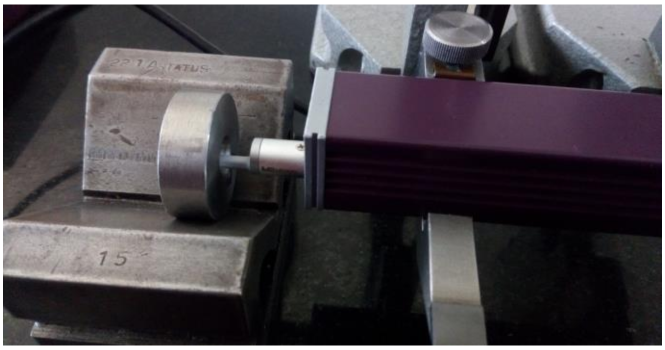

Fig 4.3 Test on Base Metal

Probe used in Surface Roughness Testing

Fig 4.4 Probe

Surface Roughness Test Result

Fig 4.5 Surface Roughness Result

4.6CIRCULARITY ERROR TEST

Circularity is the measure of how closely the shape of an object approaches that of a mathematically perfect circle. Circularity applies in two dimensions, such as the cross sectional circles along a cylindrical object such as a shaft or a cylindrical roller for a bearing.

Table 4.1 Circularity Error Result

Experiment No	Diameter (mm)	Radius (mm)	Circularity Error (mm)
1	10.132	5.066	0.501
2	10.170	5.060	0.228
3	10.094	5.047	0.518
4	10.048	5.024	0.729
5	10.123	5.061	0.169
6	10.025	5.013	0.330
7	10.016	5.008	0.192
8	10.032	5.016	0.022
9	10.124	5.062	0.280

In geometric dimensioning and tolerancing, control of a cylinder can also include its fidelity to the longitudinal axis, yielding cylindricity. The analogue of circularity in three dimensions (that is, for spheres) is sphericity.

Circularity is dominated by the shape's gross features rather than the definition of its edges and corners, or the surface roughness of a manufactured object. A smooth ellipse can have low circularity, if its eccentricity is large. Regular polygons increase their circularity with increasing numbers of sides, even though they are still sharp-edged. In geology and the study of sediments (where three-dimensional particles are most important), circularity is considered to be the measurement of surface roughness and the overall shape is described by sphericity.

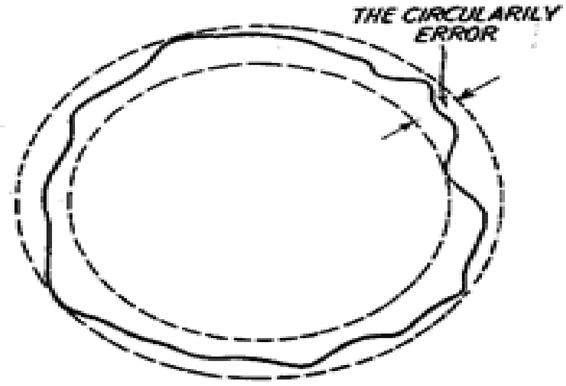

Fig 4.6 Circularity Error

Fig 4.7 Co-ordinate Measuring Machine (CMM)

Fig 4.8 CMM Testing for Circularity Error

4.7 MACHINING TIME

Machining time is the time when a machine is actually processing something. Generally, machining time is the term used when there is a reduction in material or removing some undesirable parts of a material.

Table 4.2 Machining Time Data

Experiment No	Factors			Machining Time (sec)
1	1	1	1	92
2	1	2	2	88
3	1	3	3	62
4	1	1	2	86
5	1	2	3	84
6	1	3	1	88
7	1	1	3	90
8	1	2	1	87
9	1	3	2	86

For example, in a drill press, machining time is when the cutting edge is actually moving forward and making a hole. Machine time is used in other situations, such as when a machine installs screws in a case automatically. One of the important aspects in manufacturing calculation is how to find and calculate the machining time in a machining operation. Generally, machining is family of processes or operations in which excess material is removed from a starting work piece by a sharp cutting tool so the remaining part has the desired geometry and the required shape. The most common machining operations can be classified into fourtypes: turning, milling, drilling and lathe work.

4.8 TIME TAKEN FOR DRILLING

Drilling Time = $L/(f * N)$
Where;
L = sum of hole depth approach and over travel distances (mm)
f = feed (mm/rev)
N = rotational speed (rpm)

In industrial engineering, the standard time is the time required by an average skilled operator, working at a normal pace, to perform a specified task using a prescribed method. It includes appropriate allowances to allow the person to recover from fatigue and, where necessary, an additional allowance to cover contingent elements which may occur but have not been observed.

5. DESIGN OF EXPERIMENTS

The design of experiments (DOE, DOX, or experimental design) is the design of any task that aims to describe or explain the variation of information under conditions that are hypothesized to reflect the variation. The term is generally associated with experiments in which the design introduces conditions that directly affect the variation, but may also refer to the design of quasi-experiments, in which natural conditions that influence the variation are selected for observation.In its simplest form, an experiment aims at predicting the outcome by introducing a change of the preconditions, which is represented by one or more independent variables, also referred to as "input variables" or "predictor variables." The change in one or more independent variables is generally hypothesized to result in a change in one or more dependent variables, also referred to as "output variables" or "response variables." The experimental design may also identify control variables that must be held constant to prevent external factors from affecting the results. Experimental design involves not only the selection of suitable independent, dependent, and control variables, but planning the delivery of the experiment under statistically optimal conditions given the constraints of available resources. There are multiple approaches for determining the set of design points (unique combinations of the settings of the independent variables) to

be used in the experiment.Main concerns in experimental design include the establishment of validity, reliability, and replicability. For example, these concerns can be partially addressed by carefully choosing the independent variable, reducing the risk of measurement error, and ensuring that the documentation of the method is sufficiently detailed. Related concerns include achieving appropriate levels of statistical power and sensitivity.
Obtaining good results from a DOE involves these seven steps:

1. Set objectives
2. Select process variables
3. Select an experimental design
4. Execute the design
5. Check that the data are consistent with the experimental assumptions.
6. Analyze and interpret the results

5.1 TAGUCHI OPTIMIZATION

Taguchi method are statistical methods, or sometimes called robust design methods, developed by Genichi Taguchi to improve the quality of manufactured goods, and more recently also applied to engineering, biotechnology, marketing and advertising. Professional statisticians have welcomed the goals and improvements brought about by Taguchi methods, particularly by Taguchi's development of designs for studying variation, but have criticized the inefficiency of some of Taguchi's proposals. Taguchi's work includes three principal contributions to statistics:A specific loss function,The philosophy of off-line quality control,Innovations in the design of experiments.Taguchi developed his experimental theories independently. Taguchi read works following R. A. Fisher only in 1954. Taguchi's framework for design of experiments is idiosyncratic and often flawed, but contains much that is of enormous value.

5.2 SMALLER IS BETTER

The signal-to-noise (S/N) ratio is calculated for each factor level combination. The formula for the smaller-is-better

S/N ratio using base 10 log is:
$S/N = -10*\log(S (Y^2)/n)$
Where Y = responses for the given factor level combination and n = number of responses in the factor level combination

5.3 LARGER IS BETTER

The signal-to-noise (S/N) ratio is calculated for each factor level combination. The formula for the larger-is-better S/N ratio using base 10 log is:
$S/N = -10*\log(S(1/Y^2)/n)$
Where Y = responses for the given factor level combination and n = number of responses in the factor level combination.

5.4NOMINAL IS BEST

The signal-to-noise (S/N) ratio is calculated for each factor level combination. The formula for the nominal-is-best I S/N ratio using base 10 log is:
$S/N = -10*\log(s^2)$
Where s = standard deviation of the responses for all noise factors for the given factor level combination

6. INEFFICIENCIES OF TAGUCHI'S DESIGNS

Interactions are part of the real world. In Taguchi's arrays, interactions are confounded and difficult to resolve. Statisticians in response surface methodology (RSM) advocate the "sequential assembly" of designs: In the RSM approach, a screening design is followed by a "follow-up design" that resolves only the confounded interactions judged worth resolution. A second follow-up design may be added (time and resources allowing) to explore possible high-order univariate effects of the remaining variables, as high-order univariate effects are less likely in variables already eliminated for having no linear effect. With the economy of screening designs and the flexibility of follow-up designs, sequential designs have great statistical efficiency. The sequential designs of response surface methodology require far fewer experimental runs than would a sequence of Taguchi's designs.

7. ORTHOGONAL ARRAY

In mathematics, in the area of combinatorial designs, an orthogonal array is a "table" (array) whose entries come from a fixed finite set of symbols (typically, {1,2,...,n}), arranged in such a way that there is an integer t so that for every selection of t columns of the table, all ordered t-tuples of the symbols, formed by taking the entries in each row restricted to these columns, appear the same number of times. The number t is called the strength of the orthogonal array. Here is a simple example of an orthogonal array with symbol set {1,2} and strength 2: Notice that the four ordered pairs (2-tuples) formed by the rows restricted to the first and third columns, namely (1,1), (2,1), (1,2) and (2,2) are all the possible ordered pairs of the two element set and each appears exactly once. The second and third columns would give, (1,1), (2,1), (2,2) and (1,2); again, all possible ordered pairs each appearing once. The same statement would hold had the first and second columns been used. This is thus an orthogonal array of strength two.

Orthogonal arrays generalize the idea of mutually orthogonal latin squares in a tabular form. These arrays have many connections to other combinatorial designs and have applications in the statistical design of experiments, coding theory, cryptography and various types of software testing.

Table 7.1 Orthogonal Array

1	1	1
2	2	1
1	2	2
2	1	2

7.1 L-9 ORTHOGONAL ARRAY

Before Constructing an Array We must define:

1. Number of factors to be studied
2. Number of levels for each factor
3. 2 factor interactions to be studied

STANDARD ORTHOGONAL ARRAYS

Table 7.2 Standard Arrays

Sl No	Orthogonal Arrays	Number of Rows	Maximum Number of	Maximum Number of Columns			
				2	3	4	5
1	L4	4	3	3	-	-	-
2	L8	8	7	7	-	-	-
3	L9	9	4	-	4	-	-
4	L12	12	11	11	-	-	-
5	L16	16	15	15	-	-	-
6	L'16	16	5	-	-	5	-
7	L18	18	8	1	7	-	-
8	L25	25	6	-	-	-	6
9	L27	27	13	1	13	-	-
10	L32	32	31	31	-	-	-
11	L'32	32	10	1	-	9	-
12	L36	36	23	11	12	-	-
13	L'36	36	16	3	13	-	-
14	L50	50	12	1	-	-	1
15	L54	54	26	1	25	-	-
16	L64	64	63	63	-	-	-
17	L'64	64	21	-	-	21	-
18	L81	81	40	-	40	-	-

7.2NOTION FOR MATRIX EXPERIMENTS

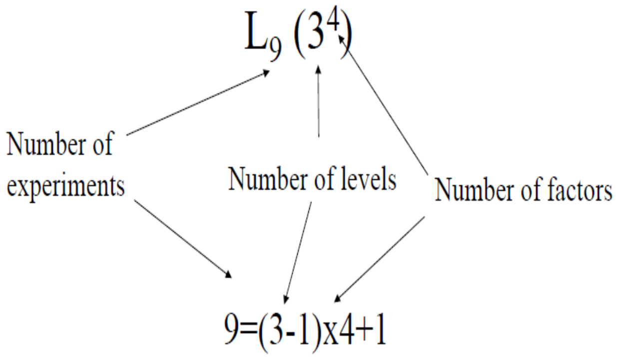

Fig 7.1 L-9 Array Selection

SI. No.	Spindle Speed (RPM)	Feed (mm /rev)	Total Material	Surface Roughness (microns)	SN Ratio
1	600	0.2	HSS	2.287	-7.18532
2	600	0.4	M42	1.479	-3.39936
3	600	0.6	TiN	1.393	-2.87902
4	800	0.2	HSS	0.828	1.63939
5	800	0.4	M42	0.427	7.39144
6	800	0.6	TiN	2.285	-7.17772
7	1000	0.2	HSS	2.795	-8.92764
8	1000	0.4	M42	3.668	-11.2886
9	1000	0.6	TiN	1.892	-5.53842

7.3ANOVA ANALYSIS

Analysis of variance (ANOVA) is a collection of statistical models and their associated procedures (such as "variation" among and between groups) used to analyze the differences among group means. ANOVA was developed by statistician and evolutionary biologist Ronald Fisher. In the ANOVA setting, the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether or not the means of several groups are equal, and therefore generalizes the t-test to more than two groups. ANOVA is useful for comparing (testing) three or more means (groups or variables) for statistical significance. It is conceptually similar to multiple two-sample t-tests, but is more conservative (results in less type I error) and is therefore suited to a wide range of practical problems

7.4 ASSUMPTIONS OF ANOVA

Like so many of our inference procedures, ANOVA has some underlying assumptions which should be in place in order to make the results of calculations completely trustworthy. They include: Subjects are chosen via a simple random sample. Within each group/population, the response variable is normally distributed. While the population means may be different from one group to the next, the population standard deviation is the same for all groups. Fortunately, ANOVA is somewhat robust (i.e., results remain fairly trustworthy despite mild violations of these assumptions). Assumptions (ii) and (iii) are close enough to being true if, after gathering SRS samples from each group, you: (ii) look at normal quantile plots for each group and, in each case, see that the data points fall close to a line. (iii) compute the standard deviations for each group sample, and see that the ratio of the largest to the smallest group sample s.d. is no more than two.

7.5 CONTROL FACTORS AND THEIR LIMITS

Table -7.1: Different control variables & their level

Factors	Levels	Level 1	Level 2	Level 3
Speed of Spindle (RPM) (A)	3	600	800	1000
Feed Rate (mm/rev) (B)	3	0.2	0.4	0.6
Total Material (C)	3	HSS	M42	TiN

7.6 SURFACE ROUGHNESS

Table 7.2 Response Table for SN Ratio

Graphical Representation Of SN Ratio

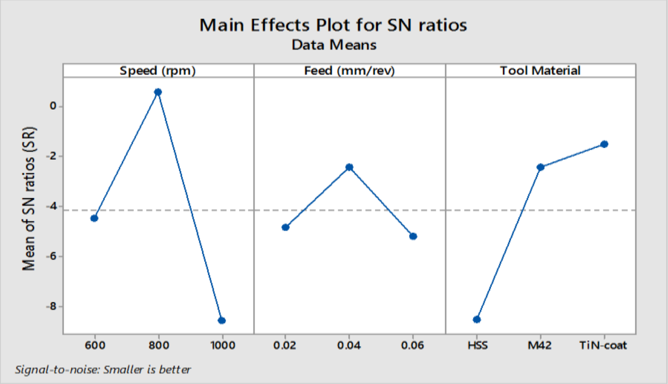

Fig 7.2 Interaction Plot for Surface Roughness

Taguchi Orthogonal Array Design

L9 (3^3) Factors: 3 Runs: 9

Columns of L9 (3^4) Array

7.7 SN Ratio Results for Surface Roughness

7.8 GRAPHICAL REPRESENTATION OF TAGUCHI

SI. No.	Source	DF	Adj SS	Adj MS	F	P
1	Spindle Speed	2	4.00220	2.00110	6.10	0.141
2	Feed	2	0.02539	0.01270	0.04	0.963
3	Tool Material	2	3.29371	1.64665	5.02	0.166
4	Error	2	0.65658	0.32829		
5	Total	8	7.97787			

ANALYSIS

Surface Roughness (microns) versus Speed (rpm), Feed (mm/rev), Tool Material

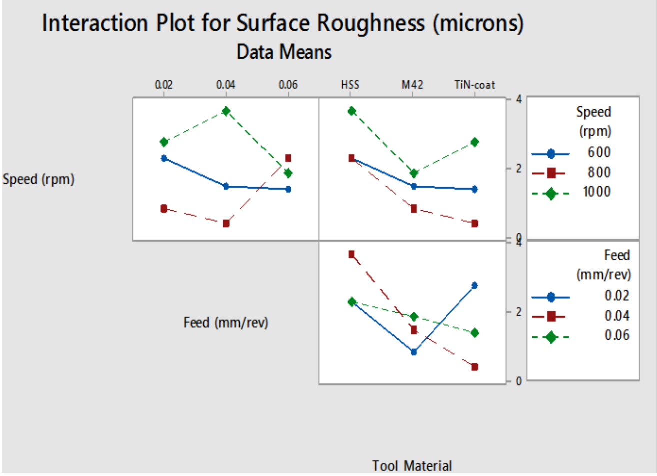

Fig 7.3 Interaction Plot for Surface Roughness

7.4 GENERAL LINEAR MODEL

Surface Roughness versus Speed (rpm), Feed (mm/rev), Tool Material

Table 7.4 General Linear Model

Sl No	Factors	Type	Levels	Values
1	Spindle Speed	Fixed	3	600,800,1000
2	Feed	Fixed	3	20, 40,60
3	Tool Material	Fixed	3	HSS M42 TiN Coated

Analysis of Variance for Surface Roughness, using Adjusted SS for Test.

S = 0.512965 R-SQ = 91.77% R-SQ (adj) = 67.08%

SI NO	Level	Speed (rpm)	Feed (mm/rev)	Tool Material
1	1	-4.4879	-4.8245	-8.5505
2	2	0.6177	-2.4322	-2.4328
3	3	-8.5849	-5.1984	-7.4717
4	DELTA	9.2026	2.7662	7.0788
5	RANK	1	3	2

8. CIRCULARITY ERROR

GRAPHICAL REPRESENTATION OF SN RATIO

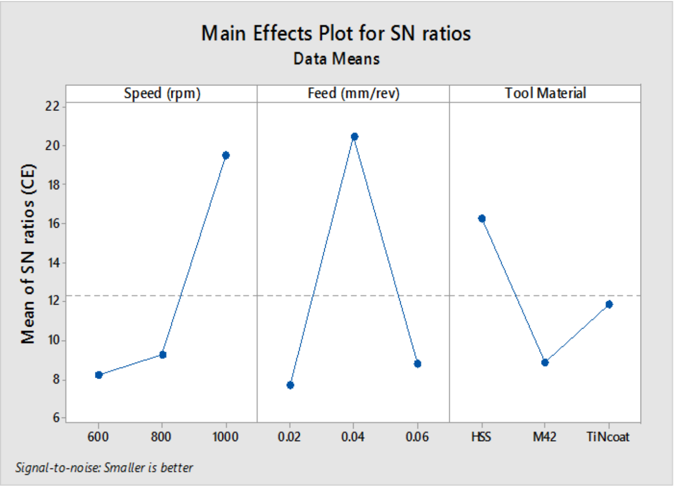

Fig 8.1 SN Ratio Results for Circularity Error

Taguchi Orthogonal Array Design

L9 (3^3)

Factors: 3

Runs: 9

Columns of L9 (3^4) Array

8.1 GRAPHICAL REPRESENTATION OF TAGUCHI ANALYSIS

Table 8.1 Response Table for SN Ratio

Sl No	Level	Speed (rpm)	Feed (mm/rev)	Tool Material
1	1	8.186	7.694	16.262
2	2	9.272	20.478	8.881
3	3	19.514	8.800	11.830
4	Delta	11.328	12.784	7.380
5	Rank	2	1	3

8.2 Machining Time versus Speed (rpm), Feed (mm/rev), Tool Material

Fig 8.2 Interaction Plot for Circularity Error

Sl PNo	Speed (rpm)	Feed (mm/rev)	Tool Material	Circularity Error (mm)	SN Ratio
1	600	0.02	HSS	0.501	6.00325
2	600	0.04	M42	0.228	12.8413
3	600	0.06	TiN Coated	0.518	5.71340
4	800	0.02	M42	0.729	2.74545
5	800	0.04	TiN Coated	0.169	15.4423
6	800	0.06	HSS	0.330	9.62972
7	1000	0.02	TiN Coated	0.192	14.3340
8	1000	0.04	HSS	0.022	33.1515
9	1000	0.06	M42	0.280	11.0568

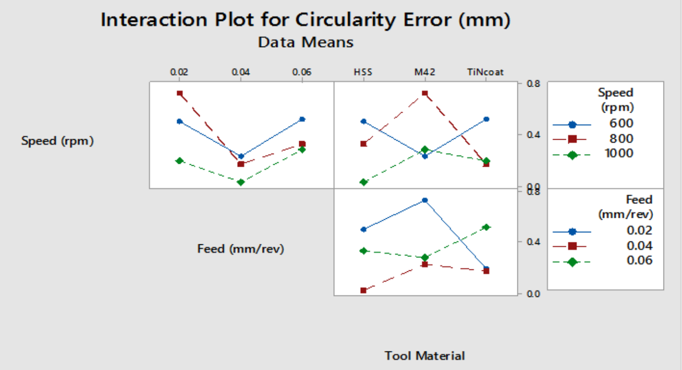

Table 8.2 Rank of the Results

GENERAL LINEAR MODEL

Circularity Error versus Speed (rpm), Feed (mm/rev), Tool Material

Table 8.3 General Linear Model

Sl No	Speed (rpm)	Feed (mm/rev)	Tool Material	Circularity Error (mm)	SN Ratio
1	600	0.02	HSS	92	-39.2758
2	600	0.04	M42	88	-38.8897
3	600	0.06	TiN Coated	62	-35.8478
4	800	0.02	M42	86	-38.6900
5	800	0.04	TiN Coated	84	-38.4856
6	800	0.06	HSS	88	-38.8897
7	1000	0.02	TiN Coated	90	-39.0849
8	1000	0.04	HSS	87	-38.7904
9	1000	0.06	M42	86	-38.6900

Analysis of Variance for Circularity Error, using Adjusted SS for test

S=0.151129 R-SQ=87.87% R-SQ(adi)=51.47%

Table 8.4 Variance for Circularity Error

Sl No	Factors	Type	Levels	Values
1	Spindle Speed	Fixed	3	600,800,1000
2	Feed	Fixed	3	20,40,40
3	Tool Material	Fixed	3	HSS,M42,TiN Coated

9. MACHINING TIME

GRAPHICAL REPRESENTATION OF SN RATIO

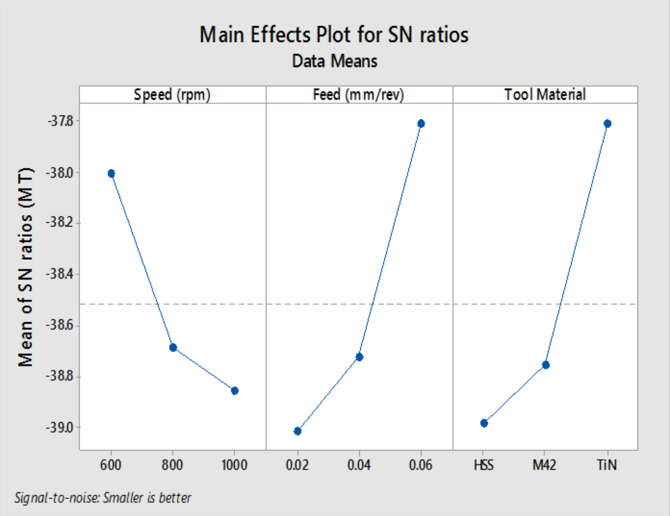

Fig 9.1 Graphical Representation Of SN Ratio

9.1 SN Ratio Results for Machining Time

Table 9.1 Response Table for SN Ratio

SI. No.	Source	DF	Adj SS	Adj MS	F	P
1	Spindle Speed	2	0.12290	0.06145	2.69	0.271
2	Feed	2	0.17724	0.08862	3.88	0.205
3	Tool Material	2	0.03070	0.01535	0.67	0.598
4	Error	2	0.04568	0.02284		
5	Total	8	0.37652			

Taguchi Design

Taguchi Orthogonal Array Design

L9 (3^3)

Factors: 3

Runs: 9

Columns of L9 (3^4) Array

9.2 GRAPHICAL REPRESENTATION OF TAGUCHI ANALYSIS

Machining Time(Sec) Versus speed(rpm),Feed(mm/rev) Tool material

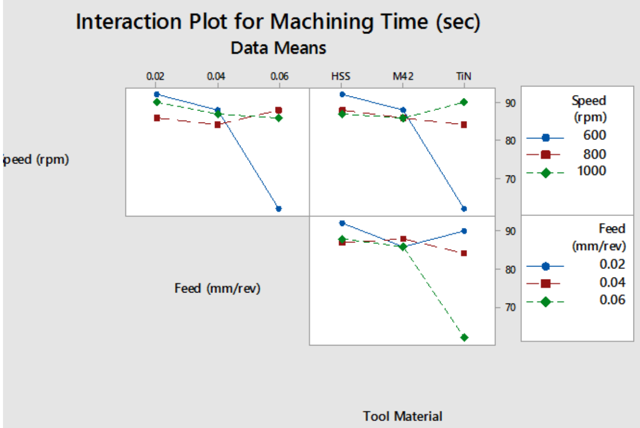

Fig 9.2 Interaction Plot for Machining Time

Table 9.2 Rank of the Results

Sl No	Level	Speed (rpm)	Feed (mm/rev)	Tool Material
1	1	-38.00	-39.02	-38.99
2	2	-38.69	-38.72	-38.76
3	3	-38.86	-37.81	-37.81
4	Delta	0.85	1.21	1.18
5	Rank	3	1	2

9.4 GENERAL LINEAR MODEL

Machining Time versus Speed (rpm), Feed (mm/rev), Tool Material

Table 9.3 Variance for Machining Time

Sl No	Factors	Type	Levels	Values
1	Spindle Speed	Fixed	3	600 800 1000
2	Feed	Fixed	3	0.02 0.04 0.06
3	Tool Material	Fixed	3	HSS M42 TiN Coated

9.5 Analysis of Variance for Machining Time, using Adjusted SS for Test

SI. No.	Source	DF	Adj SS	Adj MS	F	P
1	Spindle Speed	2	80.22	40.11	0.42	0.703
2	Feed	2	181.56	90.78	0.96	0.511
3	Tool Material	2	176.22	88.11	0.93	0.518
4	Error	2	189.56	94.78		
5	Total	8	627.56			

S = 9.73539 R-SQ = 69.79% R-SQ (adj) = 0.00%

10. RESULT AND DISCUSSION

10.1 L-9 ORTHOGONAL ARRAY

By the design of experiments conducted the various input parameters have been set and designed as an orthogonal array. Here three factor and three levels have been considered. For the given inputs L-9 orthogonal array table is available.

Table 10.1 The L-9 orthogonal array for the given set of inputs are as follows:

Experiment No	Spindle Speed (rpm)	Feed (mm/rev)	Tool Material	Surface Roughness (microns)	Circularity Error (mm)	Machining Time (sec)
1	600	0.02	HSS	2.287	0.501	92
2	600	0.04	M42	1.479	0.228	88
3	600	0.06	TiN Coated	1.393	0.518	62
4	800	0.02	M42	0.828	0.729	86
5	800	0.04	TiN Coated	0.427	0.169	84
6	800	0.06	HSS	2.285	0.330	88
7	1000	0.02	TiN Coated	2.795	0.192	90
8	1000	0.04	HSS	3.668	0.022	87
9	1000	0.06	M42	1.892	0.280	86

11. CONCLUSION

In this study, the Taguchi technique and ANOVA were used to obtain optimal drilling parameters under dry conditions. The experimental results were analyzed using Minitab 17. The following conclusion can be drawn.As a result of the Taguchi experimental trials, it was found that the speed is the most significant factor for the surface roughness with contribution percentage of 50% respectively. The optimum process parameter for surface roughness is spindle speed 1, 600rpm, feed rate 3, 0.06 mm/rev and Tool Material 2, M42 drill bit. The optimum parameter for Circularity Error was spindle speed 2, 800rpm, feed rate 1, 0.02 mm/rev and Tool Material 3, TiN coated drill bit and feed was the most significant factor for Circularity Error with contribution percentage of 47 % respectively. The optimum parameter for Machining timing were spindle speed 3, 1000rpm, feed rate 1, 0.02 mm/rev and Tool Material 2, M42 drill bit and feed was the most significant factor the MT with contribution percentage of 29 % respectively.

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