Machinability Investigation on drilling of cobalt alloy cladded die steel produced by TIG cladding process

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CERTIFICATE

This is to certify that the Project Report entitled **"Machinability Investigation on drilling of cobalt alloy cladded die steel produced by TIG cladding process"** being submitted by **T. Monish (319126520205), P. Kodanda (319126520199), K. Vasanth Raju (319126520185), P. Sai Kiran (319126520200), A. Kiran Kumar (319126520170)** to the Department of Mechanical Engineering, ANITS is a record of the bonafide work carried out by them under the esteemed guidance of **Mr. M. Prithvi Raj.** The results embodied in the report have not been submitted to any other University or Institute for the award of any degree or diploma.

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ABSTRACT

In the Hot-forging process, the life of the dies is short due to harsh operating conditions. Among all the failure modes, die failure due to wear accounts for about 70%. Therefore, to counteract wear and improve the die life, the surface of the dies is coated with hard materials. There are many ways by which the coatings can be applied on the surface of the dies. Coatings deposited using Tungsten Inert Gas (TIG) welding technique is one such technique to improve the wear resistance of dies. Due to coating, four different zones are formed: clad zone, dilution zone, heat-affected zone (HAZ) and unaffected zone (substrate). The formation of these zones results in hardness variation along the material's vertical cross-section.

The hardness variation along the material's cross-section results in machinability variation. This effect will be more signification while machining holes in the cladding samples. As the drill bit must penetrate the material of variable hardness, improper selection of machining parameters may result in dimensional errors and drill bit breakage. Therefore, suitable process parameters must be selected before drilling holes to avoid such defects. Hence, our present works deal with optimising process parameters for drilling Stellite 6 cladded die steel produced by TIG cladding technique.

In the present work, DIN 1.2714 die steel was used as the substrate material, and Stellite 6 was used as the cladding powder. Stellite 6 was cladded on the DIN 1.2714 die steel using TIG cladding. Preplaced powder technique was used for developing claddings. Three process parameters, depth of cut (D), speed (V) and feed (f), are considered as process parameters. For each process parameter, three levels were selected, and L9 orthogonal array was used to design experiments. With each set of parameters, drilling was done using CNC milling. Circularity and material removal rate were considered as the measure of machinability. It was observed that the optimal process parameters for both base material and cladded sample are D-4mm, V-1050rpm, f-0.3mm/rev.

Keywords: *TIG Cladding, Die Steel, Drilling, Machinability, Circularity, Coordinate Measuring Machine*

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NOMENCLATURE

CNC	Computerised Numerical Control
CMM	Coordinate Measuring Machine
S/N Ratio	Signal-to-Noise Ratio
V	Cutting speed, m/min
f	Feed, mm/rev
D	Depth of cut, mm
MRR	Material Removal Rate
GRG	Grey Relation Grades
TIG	Tungsten Inert Gas

CHAPTER-1
INTRODUCTION

1.1. Forging

Forging is a manufacturing process in which metal is formed by hammering, pressing or rolling. The required clamping force is provided by a hammer or die set. In addition, various metals such as carbon steel, alloy steel, stainless steel, aluminum, brass and copper can be forged.

The basic methodology is to shape the original metal to the desired geometry , giving it more fatigue and strength. The process is economical, can be done in many places, and complements the mechanical parts in the finished product .Hence, components with superb mechanical properties can be produced with minimum material waste.

Forging has been done by smiths for thousands of years; classic items included kitchenware, hardware, hand tools, edged weapons, cymbals, and jewellery. The usage of forged components in mechanisms and machines has increased dramatically since the Industrial Revolution, especially when a Such forgings typically need additional processing (such as machining) to produce an almost completed item when a component demands high strength.

Forging is a significant global business nowadays.Cold forging, warm forging, and hot forging are common classifications used to describe forging. At temperatures below 0.3 Tm, cold forging is performed. Between 0.3 T_m and 0.6 T_m, warm forging is carried out. Above 0.6 T_m, hot forging is done. Forging is often categorized according to the temperature at which it is performed cold, warm, or hot forging. In accordance with the type of dies employed, forging may also be divided into open-die and closed-die forging. If the flow of material is not restricted in at least one direction, it is called open die forging.

1.1.1. Closed-die forging

Closed-die forging is also known as impression-die forging. First, the metal is placed in a die and attached to an anvil. In closed-die forging, the impression of the component is cut in the dies. Then, the workpiece is placed in the cavity, and compressive forces are applied to the metal to flow and fill the die cavities. The standard process of impression die forging is shown in Figure 1.2.

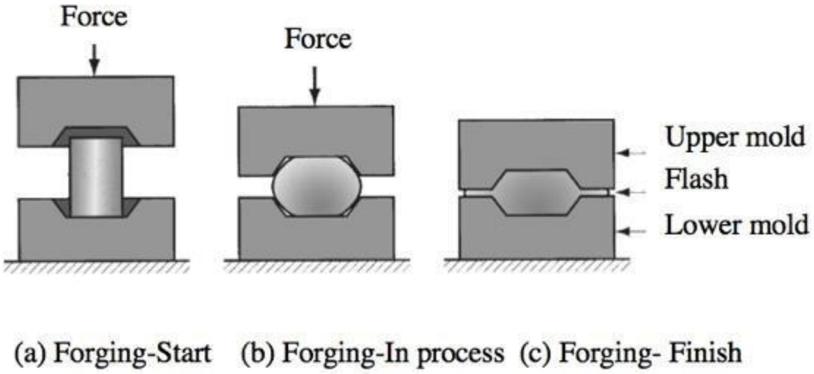

Figure 1.1. Impression Die Forging

Advantages

- Produces parts up to 25 tons
- Produces near net shapes that require only a small amount of finishing
- Economic for heavy production

1.2. Surface Modification

Surface modification is the act of changing a material's surface by introducing physical, chemical, or biological properties that differ from those present on the material's original surface. Metal surface modification mostly enhances performance.

Roughness, hardness, wear resistance, and corrosion resistance are examples of surface properties.

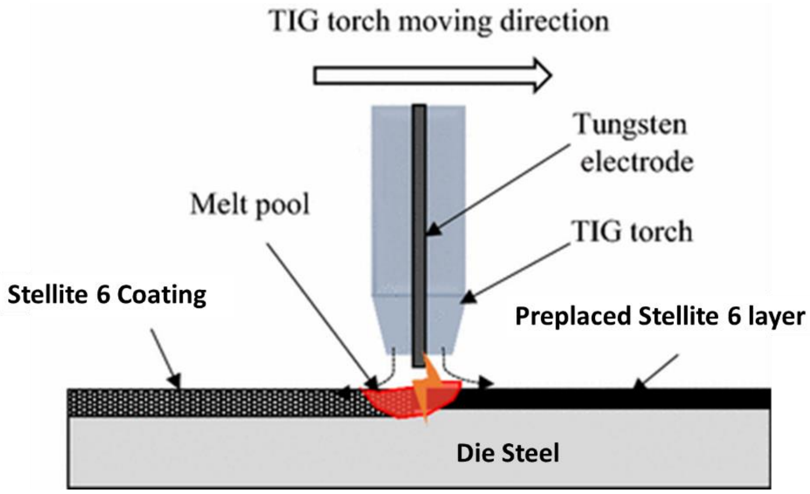

Figure 1.2. TIG Cladding

The surface modifications that are done for dies are mainly to improve the hardness and wear resistance. There are various methods to improve the surface characteristics of the dies. In the present work, Tungsten Inert Gas (TIG) cladding is used to enhance the dies' surface properties. However, after TIG cladding, it is observed that the hardness varies along the vertical cross-section. This variation of the hardness results in variable machinability. Hence, studying the machinability of the cladded surface is a reliable study.

1.3. Machining

Machining refers to any procedure in which a cutting tool removes tiny material chips from a workpiece (the workpiece is often called the "work"). To complete the procedure, relative motion between the tool and the job is necessary. As the TIG cladded samples have variable hardness, the machinability of the dies varies. To study the variation of machinability, a drilling operation is selected in the present work.

1.3.1 Drilling

Drilling is a critical process that allows the creation of holes for various purposes, from extracting resources to constructing buildings and infrastructure. The drilling process typically involves rotating a drill bit at high speed while applying a downward force to penetrate into the material. The drill bit is usually made of hard materials such as steel, tungsten carbide, or diamond. It is designed to cut through the material depending on its intended use.

Drilling can be performed using various methods, including rotary drilling, percussion drilling, and directional drilling, depending on the type of material being drilled and the desired outcome. Drilling can also be performed on various machines like lathes, milling machines, and drilling machines. However, manually operated machines have less precision and result in more dimensional errors. To machine components with better accuracy, CNC machine tools can be used.

1.3.2. Computer Numerical Control (CNC) Machining

CNC stands for 'computer numerical control,' and CNC machining is a subtractive manufacturing method that generally combines computerised controls and machine tools to remove layers of material from a stock component (known as the blank or workpiece) and generates a custom-designed item. This method is appropriate for machining a wide range of materials, including metals, plastics, wood, glass, foam, and composites. CNC machining is used in a variety of sectors, including milling components and prototypes for telecommunications and machining aerospace parts, which demand stricter tolerances than other industries. A CNC machine is a programmed machine capable of conducting CNC machining operations independently.

CNC Milling Machines are machine-operated cutting tools that are controlled and managed by Computer Numerical Control (CNC) systems to precisely remove materials from a workpiece. The end product of the machining.

Figure 1.3. CNC Milling Machine

Advantages compared to conventional machines

- CNC Machining Produces Little to No Waste.
- Zero Defects and Greater Accuracy.
- Faster and Efficient Production.
- Quicker Assembly.
- Enhanced Personnel Safety.
- Reduction in Energy Consumption.

- CNC Machining Leads to Lower Production Costs.

Owing to the above advantages, the CNC milling machine is used for drilling operations in the present study.

1.4. Machinability

The ease with which a substance may be sliced is characterised as machinability. It is determined by numerous parameters such as tool material, work material, coolant utilised, and so on. That is measurable. Tool life, material removal rate, surface roughness, and dimensional mistakes are all factors to consider.

In the present work, material removal rate and form error (circularity) are considered as machinability measures.

1.5. Material removal rate (MRR)

It is the amount of material extracted in a unit of time. It is measured in mm3/min. Drilling material removal rate is affected by drill diameter (D), cutting speed (Vc), and feed rate (Fr).The material removal rate formula for drilling is

$$MRR = \frac{DV_cF_r}{4}$$

1.6. Form Errors

Form errors are variations from the geometrical surface of the machined surface that do not include position errors, waviness, or roughness. These are of different types of form errors: circularity, cylindricity, eccentricity, sphericity, flatness, and straightness.

It is essential to characterize these form errors. An optical profiler is used to measure and characterize form errors such as circularity and cylindricity of cylinder surfaces. Some process parameters such as spindle speed, feed, depth of cut, and L/D ratio can affect these form errors. CMM can be used to measure the form errors

1.6.1. Circularity

Circularity is an important performance criterion in micro-hole drilling in micro-EDM. The degree of roundness of a circular hole is defined as its circularity. The circularity of the micro-hole is determined using the equation.

$$\text{Circularity} = 4\pi \frac{\text{Area of through micro} - \text{hole}}{[\text{Perimeter of through micro} - \text{hole}]^2}$$

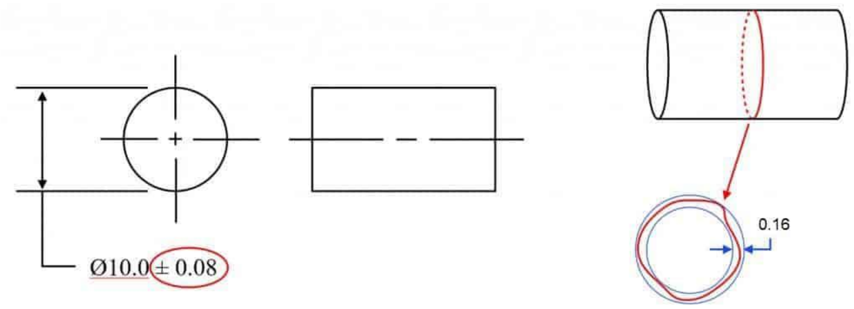

Figure 1.4. Circularity

1.7. Coordinate Measuring Machine

A coordinate measuring machine (CMM) is a device that measures the geometry of physical things by using a probe to detect discrete points on the object's surface. CMMs employ a variety of probes, the most popular of which are mechanical and laser sensors, while optical and white light sensors are also available. Depending on the machine, the probe position may be regulated manually by an operator or automatically by a computer. In a three-dimensional Cartesian coordinate system, CMMs generally indicate a probe's displacement from a reference location (i.e., with XYZ axes). Several machines allow the probe angle to be changed in addition to moving the probe along the X, Y, and Z axes, allowing measurement of surfaces that would otherwise be inaccessible.

CHAPTER-2

LITERATURE REVIEW

Yogendra Tyagi, Vedansh Chaturvedi, et al. (2012) [1] Spindle speed, feed rate, and depth of cut were examined for their effects on the rate of material removal and surface roughness in mild steel drilling. It employs the Taguchi L9 orthogonal array. The programme Taguchi DOE is used to analyse the results. They came to the conclusion that feed rate is important for material removal rate while spindle speed is important for surface roughness.

M Sundeep et al. (2014) [2] conducted an experimental examination on drilling austenitic stainless steel (AISI 316).Using a Taguchi L9 array, Process parameters were spindle speed, feed rate, and drill diameter. Spindle speed was discovered to be the most important factor in drilling surface quality and material removal rate.

Kadam Shirish, M. G. Rathi (2013) [3] concentrated on utilising the Taguchi approach to optimise drilling settings. On EN-24 steel blocks, drilling has been done using a L9 orthogonal array. In dry circumstances, an uncoated M32 HSS twist drill was employed. As process parameters, cutting speed, feed rate, and hole depth were used. Cutting speed was discovered to be the primary important factor in surface roughness and tool life when the S/N ratio was used to get the best control variables.

B.Shivapragash, K. et al.(2013) [4] Spindle speed, feed rate, and depth of cut optimisation were tested to determine their effects on drilling composite Al-TiBr2. To optimise the variables, the Taguchi technique and grey relational analysis were utilised. A higher surface quality has been achieved using the L9 orthogonal array with the following settings: spindle speed (1000 rpm), feed rate (1.5 mm/rev), and depth of cut (6 mm).

Nala Wade P.S. et al. (2015) [5] For improved Surface finish and Hole accuracy while dry drilling EN-31 material, the cutting parameters speed, depth of cut, feed, and type of tool were tuned. The best settings were determined using the Taguchi L9 orthogonal array, S/N ratio, ANOVA, and regression analysis. Cutting speed (30 m/min), feed (0.2 mm/min), and tool type were the best parameters for surface roughness (HSS uncoated).

Arshad Noor Siddiquee et al. (2014) [6] focuses on improving drilling parameters for drilling AISI312 material, such as cutting fluid, speed, feed, and hole depth. A solid carbide cutting tool was used in experiments on a CNC lathe. During the experiment, a Taguchi L18 orthogonal array has been employed. The impact of cutting settings on surface roughness was assessed using signal-to-noise ratio (S/N) analysis of variance (ANOVA). The ideal value for surface roughness in the presence of cutting fluid was 500 rpm, feed of.04 mm/sec, and hole depth of 25 mm. Speed was the most important component for surface roughness value, followed by cutting fluid, feed, and hole depth, according to an Anova study.

Nisha Tamta et al. (2015) [7] The influence of spindle speed, feed rate, and drilling depth on drilling Aluminium alloy 6082 using a CNC machine was investigated. To conduct the experiment, a Taguchi L9 orthogonal array was employed. The effects of drilling settings on surface roughness were investigated using signal-to-noise ratio (S/N) analysis of variance (ANOVA). The optimal combination values were found to be 3000 rpm spindle speed, 15 mm/min feed rate, and 9 mm drilling depth. It was also discovered that drilling depth was the most important determinant for surface roughness, followed by spindle speed.

Indumathi V. et al. (2014) [8] The effects of spindle speed, feed rate, and drilling depth on drilling Aluminium alloy 6082 using a CNC machine were studied. A Taguchi L9 orthogonal array was used to carry out the experiment. Using signal-to-noise ratio (S/N) analysis of variance, the effects of drilling parameters on surface roughness were examined (ANOVA). The best combination of parameters was 3000 rpm spindle speed, 15 mm/min feed rate, and 9 mm drilling depth. It was also revealed that drilling depth, followed by spindle speed, was the most important factor of surface roughness.

Sumesh A. S. et al. (2013) [9] conducted a study utilising the Taguchi approach to achieve the lowest possible surface roughness (Ra). The investigations were carried out on cast iron with the use of HSS twist drills. Moreover, various drilling tests were carried out on a radial drilling machine using the L9 orthogonal array; it was discovered that the variation in drilling parameters is adjusted for multiple performances in order to produce high hole quality in drilling. Eventually, it was determined that a spindle speed of 80 rpm, a drill diameter of 4mm, and a feed rate of 0.1 mm/rev is the best combination of drilling parameters for achieving high S/N ratios of hole roughness.

A.Navanth et al. (1985) [10] On a typical drilling machine, tests were carried out to optimise the drilling parameters using the Taguchi approach to attain the minimal surface roughness (Ra) and hole diameter. The L18 orthogonal array was used for drilling experiments. The material Al 2014 alloy block was drilled under dry cutting circumstances using HSS twist drills, and the measured data were analysed using MINITAB16 and Analysis of variance (ANOVA). It indicates that a spindle speed of 300 rpm, a point angle and helix angle of 1300/200, and a feed rate of 0.15 mm/rev are the best drilling parameters for producing high s/n ratios of hole roughness. It was also discovered that a spindle speed of 200 rpm, a point angle, The ideal combination of drilling settings provided a high value of s/n ratios of hole diameter with a helix angle of 900/150 and a feed rate of 0.36 mm/rev.

Heiple et al. (1982) [11] discovered that dynamic surface components in the liquid pool change the temperature coefficient of surface strain from negative to positive, causing the Marangoni convection heading to change from outward to internal. The joint entry increases substantially when the liquid stream in the liquid pool turns out to be internal.

Howse et al. (2000) [12] The more notable entry of implemented TIG welding was connected to narrowing the circular section. The information on these forms is critical in determining the begun transition's TIG entry ability improvement capability. Austenitic tempered steels can cause a lot of shrinkage and mutilation after welding because they have a greater coefficient of warm development and poorer warm conductivity than carbon and composite steel. As a result, determining the effect of the initial transition on weld contortion is critical to enhancing the presentation of the treated steel with TIG method. This study used five different types of oxide movements to investigate the effect of single-part transition on the morphology and twisting of Type 316L treated steel TIG welds. In addition to evaluating the microstructure and hardness of begun TIG weld metal. This investigation looked on hypothetical and test methods for increasing the A-TIG entry capabilities.

Paulo et al. (2000) [13] It is assumed that without an actuating transition, weld profundity achieved is substantially lower and dab breadth is excessively large. The best results are obtained if silicon dioxide and the most elevated entry occur. CaO and Al oxide are incompatible because they provide the same or similar results as standard TIG welding.

Tseng et al. (2001) [14] It was discovered that austenitic-treated steel has much greater warm extension than other hardened steels, and its warm conductivity is often lower than that of carbon steel. Such characteristics generate actual concern in applications involving temperature fluctuations, heat treatment of whole structures, and welding. Additionally, the bend locally heats a joint plate when welding, and temperature distributions in the weldment are not uniform.

Cheng Hsien Kuo (2011) [15] discovered that residual slag developed on the surface of TIG welds made using oxide flux. The angular distortion of the dissimilar weldment can be decreased, however, by TIG welding using SiO2 powder since it can enhance joint penetration and weld depth-to-width ratio. Moreover, the welded's sensitivity to flaws can be decreased.

Chih-Yu Hsu et al. (2011) [16] TIG welding is said to enhance penetration. The flux paste that is placed prior to welding is used for A-TIG welding. Compared to standard TIG welding procedures, this flux restricts the welding arc and enhances penetration. During the A-TIG welding operations, several fluxes including MnO2, TiO2, MoO3, and SiO2 are employed for a variety of materials. The molten pool's temperature coefficient of surface tension in ATIG shifted from a negative to a positive value. As a result, the centre of the pool had higher surface tension than the perimeter. This demonstrated that the centripetal Marangoni convection induced by the surface tension differential occurs in the molten pool. The fluid flow of the molten pool surface may readily transition from the edge to the centre and subsequently downward in this situation.

CHAPTER-3

METHODOLOGY

The methodology used in the present work is shown in the below flow chart.

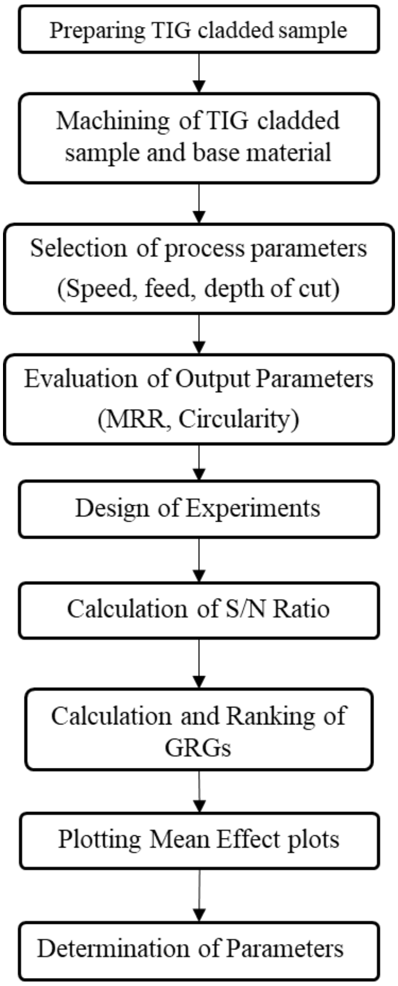

Figure 3.1 Flow chart

Stellite 6 powder was deposited on the surface of the die steel using the TIG welding technique. Then holes were drilled in the cladded samples using a CNC milling machine. First, the process parameters (speed, feed, and depth of cut) for machining were varied to study the effect on machinability. Next, the drilled holes were examined, and the output parameters (Material Removal Rate, Circularity) were evaluated. Then, circularity was evaluated using CMM. Then the S/N ratios are calculated using larger the better for MRR and smaller the better criteria for circularity. Finally, as the problem is a multi-response problem, Grey analysis is used to find the optimal parametric settings and is compared with the optimal parametric settings for base material.

CHAPTER-4

EXPERIMENTAL DETAILS

4.1. Base material

DIN 1.2714 is utilised as the basic material in this work. DIN 1.2714 is a hot work alloy steel material grade from Germany that is also known as 56NiCrMoV7. It is made of shock-resistant steel and meets the DIN 17350 standard. It's a type of die steel that's used in extrusion moulds, Hot Cast moulds, and forging dies.

DIN 1.2714 cold working tool steel is a general-purpose tool and die steel with high abrasion resistance and hardness. Spindles, forming rolls, punches, blanking and forming dies, trimmer dies, clutch parts, pawls, bearings, chuck components, rollers, knuckle pins, clutch pins, shear blades are typical applications.Table 4.1 and 4.2 shows the chemical composition and mechanical properties of DIN 1.2714 steel

Table 4.1. Chemical Composition of DIN 1.2714

Element	C	Si	Mn	Ni	Cr	Mo	V	P	S
%	0.55	0.3	0.8	1.6	0.9	0.45	0.1	0.35Max	0.35 Max

Table 4.2. Mechanical Properties

Hardness (BHN)	Yield Strength (MPa)	Tensile Strength (MPa)	% Elongation	Elastic modulus (GPa)
376	1045	1270	10	205

4.2. Cladding material

Stellite 6 powder with spherical morphology and a particle size of 80-150 microns is used as cladding material. Stellite 6 is a cobalt alloy with a chromium content of 27%-32%, tungsten content of 4%-6%, carbon content of 1%-2%, nickel content of 3%-4%, silicon content of 1%-2%, and iron content of 3%-4%. Stellite 6 comprises a matrix comprising complex carbides as a result of alloying, making it particularly appropriate for applications requiring high hardness and wear resistance. The Rockwell hardness value is 36-45 HRC and the Vickers hardness value is 380-490 HV. This alloy shows excellent wear, scratches and damage at ambient and high temperatures thanks to its special hardness. These materials' particular wear resistance properties are unique and are associated with the breakdown of the hard carbide layer in the CoCr alloy matrix. The chemical composition of stellite 6 is shown in Table 4.3

Table 4.3. Chemical composition

Elements	C	Cr	Si	W	Fe	Mo	Ni	Co	Mn
% weight	1.20	29.00	1.20	4.50	3.00	1.00	3.00	Bal	1.00

4.3. Drilling Material:

In the present work, cobalt drill bits are used. Cobalt drill bits offer the following advantages compared to other hard drill bits.

- Cobalt drill bits feature extra strength and durability as they contain 5-8 % cobalt.
- It has an advantage over high-speed steel, which is effective against hard metals, stainless steel, and cast iron.
- It is more wear-resistant than HSS and can perform at high temperatures.
- This requires a smaller flute which is less likely to snap during use and gives a better impact than HSS drill bits.

Figure 4.1 shows the drill bits used in the present work.

Figure 4.1. Drill bits

4.4. CNC milling machine

In the present work, the experiments were conducted on a vertical CNC milling machine and the specifications are shown in Table 4.4.

Table 4.4. Specifications of CNC milling machine

PARAMETERS	DETAILS
Clamping area	450mm x 900 mm
Maximum Safe load on Table	600kg
Distance from table to Spindle face	100-600(300-800)
Traverse	
X-axis	600mm
Y-axis	450mm
Z-axis	500mm
Axis Drive	
Feed rates	1-10000mm/min
Rapid Traverse X/Y/Z	36m/min
Spindle	
Power	5.5/7.5kw
Speed	6000rpm
Taper	BT45
Auto Tool Changer	
No of tools	20
Maximum Tool diameter with Adj pocket full/empty	75/140
Maximum Tool length	250mm
Maximum Tool weight	8kg
Tool change time(tool to tool)	2.5sec
Accuracy	
Positioning	±0.005mm
Repeatability	±0.003mm

CNC stands for 'computer numerical control,' and CNC machining is a subtractive manufacturing method that generally combines computerised controls and machine tools to remove layers of material from a stock component (known as the blank or workpiece) and generates a custom-designed item. This method is appropriate for machining a wide range of materials, including metals, plastics, wood, glass, foam, and composites. CNC machining is used in a variety of sectors, including milling components and prototypes for telecommunications and machining aerospace parts, which demand stricter tolerances than other industries. A CNC machine is a programmed machine capable of conducting CNC machining operations independently.

CNC Milling Machines are machine-operated cutting tools that are controlled and managed by Computer Numerical Control (CNC) systems to precisely remove materials from a workpiece. The end product of the machining as shown in the figure 4.2.

Figure 4.2 CNC milling machine

Experiments are conducted on a CNC milling machine. To assess machinability, three process parameters, depth of cut (mm), speed (rpm) and feed, are varied at three levels. L9 orthogonal array is used for the design of experiments. The drilling depth of cut is half of the drill diameter; hence, drill bits of diffent diameters are used to vary the depth of cut. With each set of parameters obtained by an orthogonal array, holes were drilled in the cladded sample and base material. Hence total of 18 holes were machined, and MRR and circularity associated with each hole were evaluated. The process parameters and levels are shown in Table 4.5.

Table 4.5. Process parameters and levels

Parameters/Levels	**Level 1**	**Level 2**	**Level 3**
Depth of cut(mm)	4	3.5	3
Speed (rpm)	1050	90	810
Feed(mm/min)	0.3	0.2	0.1

4.5. Evaluation of machinability

In the present work, machinability is assessed based on the material removal rate and circularity of the drilled hole

4.5.1. Evaluation of Material Removal Rate(MRR)

The material removal rate (MRR) refers to the material removal volume per unit of time during machining. The units of material removal rate are mm^3/s, cm^3/min, or in^3/min. The general calculation of the material removal rate is as follows:

$$MRR = \frac{DV_cF_r}{4}$$

Where D is drill diameter, Vc is cutting speed, and Fr is feed rate.

4.5.2. Evaluation of Circularity

Circularity can be evaluated in different contexts, depending on what is being measured. Geometric circularity can be evaluated by measuring the deviation of a circle from its ideal form. This can be done by comparing the circumference and diameter of the circle or by measuring the roundness error of a circular object using a coordinate measuring machine (CMM). Geometric circularity is a measure of how well a circular object or feature conforms to its ideal circular shape. It is typically evaluated by measuring the roundness, or lack of deviation from a perfect circle, using various types of instruments such as micrometres, optical comparators, or laser scanners

4.6. Coordinate Measuring Machine(CMM)

A coordinate measurement machine measures a sequence of discrete points from the geometry of a solid part using a very sensitive electronic probe. These measurements are used to validate that the product meets the requirements specified in the manufacturing drawing.

Items to be measured are firmly installed on a strong table that has been ground flat, commonly made of granite. The probes, which are available in a variety of sizes and kinds, are mounted on a spring-loaded stylus, which is attached to a gantry that travels in an X-Y-Z coordinate plane.

The probe and stylus may also swivel independently to access various component characteristics. All gantry and probe motions may be controlled manually or automatically using a joystick. This is significant. This makes the CMM a true computer-numerical-controlled machine.

Figure 4.3. CMM Machine

4.7. Taguchi Method

Dr Genichi Taguchi has developed a systematic statistical approach to product and process improvement. The method stresses bringing the quality issue upstream to the design stage and focuses on defect prevention through process improvement. Taguchi emphasised the necessity of limiting variance as the key way of improvement quality. Taguchi defines a product's quality level as the overall loss paid by society as a result of the product's failure to fulfil the intended performance and as a result of the product's detrimental side effects, including the operational cost. According to the principle, loss is inescapable when a product is supplied to a consumer, and lower loss offers more attractive items.

It is critical to quantify this loss by comparing different product designs and production techniques. A quadratic loss function is used to do this. In standard manufacturing procedure,

4.7.1. Signal-to-Noise (S/N) ratio

The word'signal' denotes the desirable value (mean) for the output characteristic in the Taguchi method, whereas the term 'noise' reflects the undesirable value (standard deviation). The S/N ratio assesses the sensitivity of the quality attribute under consideration.

External influencing elements (noise factors) that are not under control are explored in a controlled manner. As a result, Taguchi employs the S/N ratio to assess the quality feature that deviates from the ideal value. Depending on the sort of feature, there are primarily two S/N ratios available: lower-the-better and higher-the-better..

Smaller-the-Better:

$$\frac{S}{N} = -10\log_{10}[y^2]$$

Higher-the-Better:

$$\frac{S}{N} = -10\log_{10}\left[\frac{1}{y^2}\right]$$

Where y is the response value.
After evaluation of the material removal rate and circularity of the hole, there are converted to the S/N ratio. The higher criterion is used for the material removal rate, and the lower criterion is used for circularity. As Taguchi cannot handle multi-objective optimization problems, grey relation analysis is used in conjugation with Taguchi analysis.

4.8. Grey relational analysis

The grey analysis offers adequate solutions when multiple parameters and responses are present. Initially, the multi-objective problem was converted into a single grey relation grade. Then these grades were ranked from highest to lowest. The conversion of responses into grey relation grades involves a three-step procedure normalizing the responses, calculating grey relation coefficients, and calculating grey relation grades (GRG).

Initially, the response parameters were normalized to a value between 0 and 1. Then, the normalization was done to convert the response parameters to a comparable grade. To normalize the responses, the following formula is used.

$$x_j(k) = \frac{y_j(k) - \min y_j(k)}{\max y_j\,(k) - \min y_j(k)}$$

where $x_j(k)$ is the normalized value for jth experiment, $y_j(k)$ is the response data for jth experiment, t(k) is the target value of $y_j(k)$, and $|y_j(k) - t(k)|$ is called deviation which represents the deviation from the target value.

The normalized values were converted into grey relation coefficients using Eq.

$$\xi_j(k) = \frac{\min\left|x_j^0 - x_j(k)\right| + \zeta\ \max\left|x_j^0 - x_j(k)\right|}{\left|x_j^0 - x_j(k)\right| + \zeta\ \max\left|x_j^0 - x_j(k)\right|}$$

where x_j^0 is the normalized ideal response for the jth experiment. In this case, its value is 1. The distinguishing coefficient "ζ" ranges from 0 to 1. Therefore, ζ value was considered as 0.5 in the present study.

At last, the combined grade of the three parameters was calculated using Eq.

$$\gamma_j = \frac{1}{n}\sum_{k=1}^{n} \xi_j\,(k)$$

Where n is the number of response parameters.

CHAPTER-5

RESULTS AND DISCUSSION

Figure 5.1 shows the base material after drilling. Figure 5.2 shows the cladded material after drilling. After drilling holes, MRR and circularity are calculated.

Figure 5.1. Base Material

Figure 5.2. TIG Cladding Samples

5.1. Experimental results for base material

The Volume of material removal rate (VMRR) and Circularity is considered as the quantity and quality responses in the present work. The measured values of VMRR in mm^3/min and circularity are shown in Table 5.1.

Table 5.1. Experimental results for base material

Sl. No	Depth of cut(mm)	Speed (rpm)	Feed (mm/min)	Experiment		S/N Ratios	
				Circularity	MRR (mm^3/min)	Circularity	MRR
B1	4.0	1050	0.3	0.026	31.667	31.7005	30.0121
B2	4.0	900	0.2	0.007	18.095	43.0980	25.1512
B3	4.0	810	0.1	0.004	8.143	47.9588	18.2157
B4	3.5	1050	0.2	0.087	16.163	21.2096	24.1704
B5	3.5	900	0.1	0.083	6.927	21.6184	16.8109
B6	3.5	810	0.3	0.065	18.703	23.7417	25.4382
B7	3.0	1050	0.3	0.110	17.812	19.1721	25.0143
B8	3.0	900	0.1	0.034	5.089	29.3704	14.1326
B9	3.0	810	0.2	0.037	9.16	28.6360	19.2379

5.2. Grey-Taguchi analysis for base material

The multiple performance characteristics of the experimental results were analysed using the Grey-Taguchi analysis. In this analysis, the larger-the-better characteristic is applied to determine the individual values for the volume of material removal rate (VMRR). The smaller-the-better characteristic is applied to determine the individual values of circularity. The output characteristics of the base material are tabulated in Table 5.2

Table 5.2. Grey-Taguchi analysis for base material

S.NO	Normalization		Deviation Sequence		Grey Relation Coefficient		GRG	
	Circularity	MRR	Circularity	MRR	Circularity	MRR	Values	Rank
B1	0.4352	1.0000	0.565	0.000	0.470	1.000	0.7348	1
B2	0.8311	0.6939	0.169	0.306	0.748	0.620	0.6839	3
B3	1.0000	0.2571	0.000	0.743	1.000	0.402	0.7011	2
B4	0.0708	0.6321	0.929	0.368	0.350	0.576	0.4630	6
B5	0.0850	0.1687	0.915	0.831	0.353	0.376	0.3645	9
B6	0.1587	0.7120	0.841	0.288	0.373	0.634	0.5036	4
B7	0.0000	0.6853	1.000	0.315	0.333	0.614	0.4735	5
B8	0.3543	0.0000	0.646	1.000	0.436	0.333	0.3849	8
B9	0.3288	0.3215	0.671	0.678	0.427	0.424	0.4256	7

5.3. Response Table for GRGS of base Material

Table-5.3 Response Table for GRGS of base Material

Response Table			
Parameters	D	V	F
1	**0.7066**	**0.5571**	**0.5411**
2	0.4437	0.4777	0.5242
3	0.4280	0.5435	0.5130
Delta	0.2786	0.0794	0.0281
	1	2	3

From the above response table, the optimised values of the base material are as follows

D1,V2 and F3.

5.4. Mean effective plot for GRGs of the base material

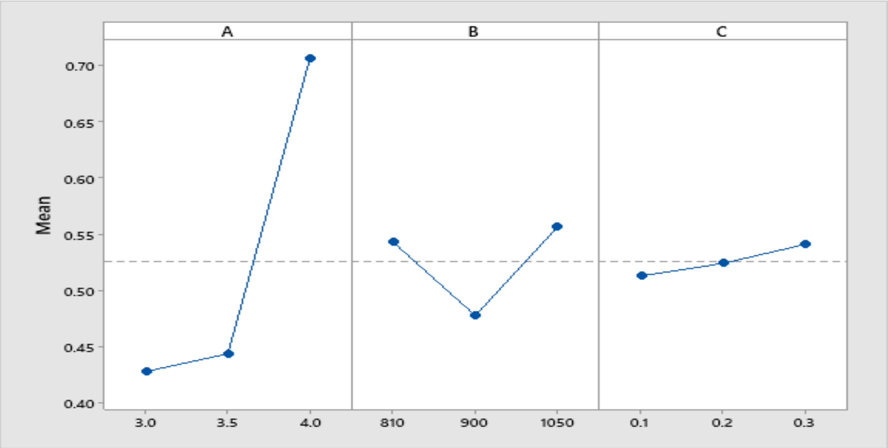

Figure 5.3. Mean effective plot for GRGs of base material

From the above graph and by comparing with the response table, we get the optimised values of base material as D-4mm, V-1050rpm and f- 0.3mm/rev

5.5. Experimental results for TIG cladded samples

The Volume of material removal rate (VMRR) and circularity of the drilled holes are considered as the quantity and quality responses in the present work. The measured values of VMRR in cm^3/min and circularity were given in Table 5.4.

Table 5.4 Experimental results for TIG cladded samples

Sl. No	Depth of cut(mm)	Speed (rpm)	Feed (mm/rev)	Experiment		S/N Ratios	
				Circularity	MRR (mm^3/min)	Circularity	MRR
C1	4	1050	0.3	0.030	31.667	30.4576	30.0121
C2	4	900	0.2	0.140	18.095	17.0774	25.1512
C3	4	810	0.1	0.008	8.143	41.9382	18.2157
C4	3.5	1050	0.2	0.143	16.163	16.8933	24.1704
C5	3.5	900	0.1	0.191	6.927	14.3793	16.8109
C6	3.5	810	0.3	0.045	18.703	26.9357	25.4382
C7	3	1050	0.3	0.117	17.812	18.6363	25.0143
C8	3	900	0.1	0.006	5.089	44.4370	14.1326
C9	3	810	0.2	0.046	9.160	26.7448	19.2379

5.6. Results of Grey-Taguchi analysis for TIG cladded samples

The multiple performance characteristics of the experimental results were analysed using the Grey-Taguchi analysis. In this analysis, the larger-the-better characteristic is applied to determine the individual values for the volume of material removal rate (VMRR) and smaller-the-better characteristic is applied to determine the individual values of circularity. The output characteristics of TIG cladded samples are tabulated in Table 5.5

Table 5.5. Results of Grey-Taguchi analysis for TIG cladded samples

S.NO	Normalization of S/N Ratio		Deviation Sequence		Grey Relation Coefficient		Grey Relation Grade	
	Circularity	MRR	Circularity	MRR	Circularity	MRR	Values	Rank
C1	0.5349	1.0000	0.465	0.000	0.518	1.000	0.7590	1
C2	0.0898	0.6939	0.910	0.306	0.355	0.620	0.4874	6
C3	0.9169	0.2571	0.083	0.743	0.857	0.402	0.6299	3
C4	0.0836	0.6321	0.916	0.368	0.353	0.576	0.4646	7
C5	0.0000	0.1687	1.000	0.831	0.333	0.376	0.3544	9
C6	0.4177	0.7120	0.582	0.288	0.462	0.634	0.5482	4
C7	0.1416	0.6853	0.858	0.315	0.368	0.614	0.4909	5
C8	1.0000	0.0000	0.000	1.000	1.000	0.333	0.6667	2
C9	0.4114	0.3215	0.589	0.678	0.459	0.424	0.4418	8

5.7. Response Table for GRGS of TIG cladded samples

Table 5.6. Response Table for GRGS of TIG cladded samples

Response Table			
Parameters	D	V	F
1	**0.6254**	**0.5715**	**0.5411**
2	0.4558	0.5028	0.5242
3	0.5331	0.5400	0.5130
Delta	0.1697	0.0687	0.0281
	1	2	3

From the above table, we get the optimum process parameters for the TIG cladded samples D1, V2 and F3

5.8. Mean effective plot for GRGs of TIG cladded samples

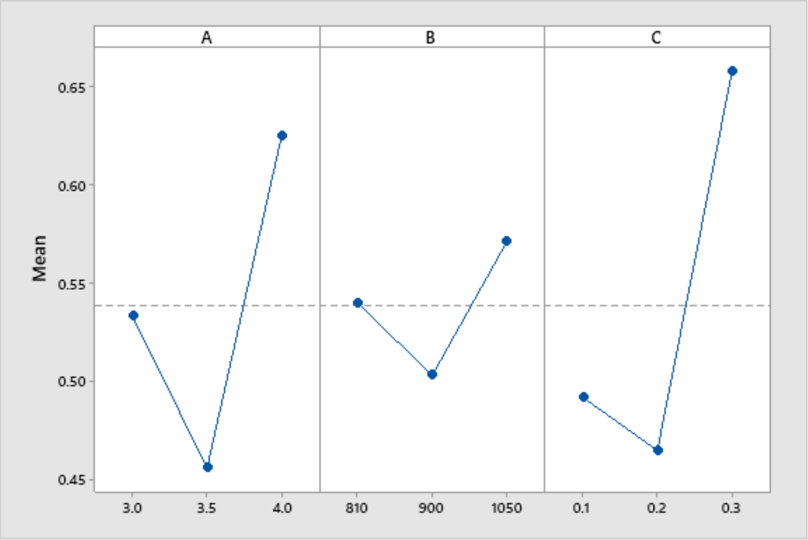

Figure 5.4. Mean effective plot for GRGs of TIG cladded samples

From the above graph, the optimised values are D-4mm, V-1050rpm and f-0.3mm/rev

CHAPTER-6

CONCLUSION

The present study deals with the machinability of TIG cladded die steel. Stellite 6 powder was cladded on DIN 1.2714 using TIG cladding process. Three process parameters, depth of cut (D), speed (V), and feed (f), were selected and varied to study the effect of process parameters on circularity and material removal rate. For each process parameter, three levels were selected, and a total of 9 holes were drilled on both base material and cladded material. L9 orthogonal array was used for the design of experiments. Circularity and material removal rate were considered as the measure of machinability. Grey-Taguchi analysis was used to optimize the process parameters. It was observed that the optimal process parameters for both base material and cladded sample are D-4mm, V-1050rpm, f-0.3mm/rev. At the optimum parametric setting for base material, circularity is 0.026, and MRR is 31.667mm^3/min. Whereas for the cladded sample, circularity is 0.03, and MRR is 31.667mm^3/min.

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