OPTIMIZATION OF HIGH SPEED TURNING PARAMETERS OF SUPER ALLOY INCONEL 718 MATERIAL USING TAGUCHI TECHNIQUE

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ABSTRACT:

Super alloy, Inconel 718 is widely used in sophisticated applications due to its unique properties designed for the engineering applications. Due to its peculiar characteristics machining of Super alloy Inconel 718 is difficult and costly. The present work is an attempt to make use of Taguchi optimization technique to optimize cutting parameters during high speed turning of Inconel 718 using tungsten carbide cutting tool.

Taguchi method is a powerful Design of Experiments (DOE) tool for engineering optimization of a process. It is an important tool to identify the critical parameters and predict optimal settings for each process parameter. Analysis of variance (ANOVA) is used to study the effect of process parameters and establish correlation among the cutting speed, feed and depth of cut with respect to the major mach inability factor, cutting forces such as cutting force and feed force. Validations of the modelled equations are proved to be well within the agreement with the experimental data.

I. INTRODUCTION

The word quality cannot have a specific meaning when applied to the manufacturing industry. This is basically because the word quality changes within the context it is being used. For a long time, manufacturing industries in European and American countries have worked from the basis of a tolerance. This tends to suggests that the manufactured item would be passed as acceptable if its quality was within the specified tolerance range.

Taguchi's response to quality contrasts rather significantly from the goalpost logic of the European and American nations. The Japanese usage of Taguchi's idea sees them taking a shot at the rule that when outlining an item, it ought to be composed with least misfortune, with the relative item being planned as near the ideal incentive as is attainably conceivable. This would bring about the item being made with respect to its life cycle and consumer loyalty from the plan stages. It would likewise imply that less repair work would be required over the long haul.

The Authors of the article would like to thank you for showing interest in this article. The setup has been built for simplicity of route. It comprises of a chapter by chapter guide with connections to all segments. Each area at the base involves helpful connects to explore between and inside the applicable areas. In-content referencing is additionally actualized widely thought the article. To come back to the landing page of the article, please tap on the Taguchi Home Page symbol.

Courbon et al. examined machining execution of Inconel 718 under high weight fly cooling conditions. They utilized coolant weight in the range 50 to 130 MPa and three spout distances across (0.25, 0.3 and 0.4 mm). The investigations were led by utilizing PVD TiAlN-covered carbide devices at different cutting paces and sustain rates, and at consistent profundity of cut (ap=2mm). They found that high weight fly cooling gives better chip flimsiness and lower cutting powers. It can likewise enhance surface complete and profitability for ideal weight/spout breadth/cutting velocity blend.

Palanisamy et al. [18] explored the impact of coolant weight on chip arrangement and device life, while turning Ti6Al4V combination with uncoated straight tungsten carbide embeds. The examination demonstrated that the utilization of high weight coolant straightforwardly between the chip back face and the device comes about for the most part in littler chips and normal chip thickness contrasted with customary weight (0.6MPa). They likewise found that the use of high weight coolant draws out apparatus life by almost three times.

This examination principally concentrates on the assessment of the cutting device wear and wears attributes, cutting power parts and chip shape, while machining Inconel 718 under the high weight and customary cooling conditions. In this way, various machining tests with Inconel 718 were directed in customary and different high weight levels of cooling/grease liquid. The tests were composed by the arrangement of examinations techniques and Taguchi L18 orthogonal exhibit [19], at three diverse cutting velocity (Vc), encourage rate (f) and weight (p) levels, and two distinctive profundity of cut (ap) levels. Test comes about, in particular cutting powers (Fc, Fr, Ff) and the normal apparatus flank wear (Vb) were broke down by utilizing ANOVA and relapse investigation. Because of ANOVA, the impacts of test parameters (Vc, f, p, ap) all things considered instrument flank wear and cutting powers were measurably decided.

At last, multi relapse conditions that show the connection between cutting powers, device flank wear and test parameters were acquired and utilized as a model forward HPJA machining process.

II. LITERATURE REVIEW

Akhyar G. et al. (2008) has utilized the utilization of taguchi technique in streamlining of cutting parameters for surface unpleasantness in turning Ti-6%, Al-4%V additional low interstitial with different apparatus grades covered and uncoated established carbide devices on, it is extremely hard to choose the slicing parameters to accomplish the high surface wrap up. This investigation would help the administrator to choose the cutting parameters.

The work material utilized for the present investigation is AISI 1045 medium carbon steel of organization {Carbon (0.43 - 0.50%), Silicon (0.2 - 0.3%), Magnesium (0.60 - 0.90%), Phosphorus (0.05%), Sulfur (0.05%)}. Its rigidity is 620 - 850 Mpa. This Carbon steel is reasonable for shafts and apparatus parts. It is for the most part utilized as a part of Automobile parts, in riggings and machine building industry.

Under dry cutting condition and high cutting velocity. The investigation of results demonstrate that the ideal blend of parameters are at cutting pace of 75 m/min, nourish rate of 0.15 mm/min, profundity of cut of 0.10 mm and instrument review of KC9225. Srikanth and Kamala (2008) proposed a Real Coded Genetic Algorithm (RCGA) for discovering ideal cutting parameters and clarified different issues of RCGA and its points of interest over the current approach of Binary Coded Genetic Algorithm (BCGA). Roy, R. K. (2001). The very expectation of Taguchi Parameter Design is for amplifying the execution of a normally factor creation process by adjusting the controlled variables.

Hassan, K. et al. (2012) has done the exploratory examination of Material Removal Rate (MRR) in CNC turning of C34000 utilizing taguchi technique utilizing L" 27 cluster. At the point when the MRR is streamlined alone the MRR turns out to be 8.91. The ideal levels of process parameters for synchronous improvement of MRR have been distinguished. Ideal outcomes were checked through affirmation tests. It was presumed that MRR is fundamentally influenced by cutting velocity and encourage rate.

III. INCONEL 718

Inconel 718 is an alloy with many good mechanical properties such as high yield and ultimate tensile strengths, good creep and rupture strengths and high resistance to fatigue. It is the most commonly used nickel-based super alloy of all, due to both its excellent material properties and its relatively low cost. It contains a large amount of iron and is therefore often referred to as a nickel-iron super alloy. Inconel 718 is usually used in polycrystalline condition and with the normal composition (in weight %).

Like all modern super alloys it is precipitation hardened and like most super alloys with large amounts of Fe it contains both coherent 0 particles and 00 particles, even though it has been shown that the main strengthening precipitate is the latter which is in contrast to what was initially believed when the material was introduced on the market in the 50's. Despite the good strength attributed to the 00 particles, it is also these particles that set the operating temperature limit of the material to about 650_C. Above this temperature the 00 can transform to-phase, as described above, in which case the hardening effect of 00 is lost.

CONSTITUTIVE BEHAVIOR OF INCONEL 718

The choice of constitutive description to be set up for the material must be based on the specific needs, i.e., in this case the fatigue crack initiation characteristics. Thus, it must be able to give a correct prediction of a stable hysteresis loop throughout its expected life. For the fatigue analysis, we need the typical stabilised stress/strain cycle. The analysis must therefore start by a rigorous analysis of the first few cycles, during which an important stress redistributions will always take place in an inelastic structure.

INCONEL® composite 718 (UNS N07718/W.Nr. 2.4668) is a high-quality, consumption safe nickel chromium material utilized at - 423° to 1300°F. Regular structure limits are appeared in Table 3.1. The age-hard enable composite can be promptly manufactured, even into complex parts. Its welding qualities, particularly its protection from post weld breaking, are remarkable. The straightforwardness and economy with which INCONEL combination 718 can be manufactured, joined with great tractable, weariness, crawl, and break quality, have brought about its utilization in an extensive variety of uses. Cases of these are segments for fluid powered rockets, rings, housings and different framed sheet metal parts for flying machine and land-based gas turbine motors, and cryogenic tankage. It is additionally utilized for latches and instrumentation parts.

Physical constants and thermal properties:

Some physical constants of INCONEL alloy 718 are shown in Table 3.2. Modulus data appear in Tables 3.3 and 3.4, and thermal properties in Table 3.5. The values in these tables will vary slightly, depending on the composition and condition of the specimen tested. They are typical but are not suitable for specification purposes.

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Table 3.1: Limiting Chemical Composition

Nickel (plus Cobalt)	:	50.00 – 55.00
Chromium	:	17.00 – 21.00
Iron	:	Balance*
Niobium (plus Tantalum)	:	4.75 - 5.50
Molybdenum	:	2.80 - 3.30
Titanium	:	0.65 - 1.15
Aluminum	:	0.20 - 0.80
Cobalt	:	1.00 max
Carbon	:	0.08 max
Manganese	:	0.35 max
Silicon	:	0.35 max
Phosphorus	:	0.015 max
Sulfur	:	0.015 max
Boron	:	0.006 max
Copper	:	0.30 max

Table 3.2: Physical Constants: Density, lb/in³

Annealed	:	0.296
Annealed and Aged	:	0.297
Melting Range, °F	:	2300 – 2437
°C	:	1260 – 1336
Specific Heat at 70°F, Btu/lb °F (at 21°C, J/kg °C)		
Curie Temperature, °F (°C)	:	0.104 (435)
Annealed Material	:	< -320 (< -196)
Annealed and Aged Material	:	-170 (-112)
Permeability at 200 oersted and 70°F		
Annealed Material	:	1.0013
Annealed and Aged Material	:	1.0011

Table 3.3: Modulus of Elasticity at Low temperatures*

Temperature, °F	Modulus of Elasticity, ksi x 10³		Poisson's Ratio
	Young's modulus	Torsional Modulus	
-308	31.3	12.5	0.25
-86	30.6	11.8	0.30
70	29.0	11.6	0.29
100	29.8	11.5	0.30
200	29.4	11.3	0.31
300	28.8	11.1	0.30
400	28.5	10.9	0.31
500	28.0	10.6	0.32

*Cold-rolled sheet heat-treated in accordance with AMS 5596B

Temperature, °F	Modulus of Elasticity, ksi x 10³		Poisson's Ratio[b]
	Young's modulus	Torsional Modulus	
70	29.0	11.2	0.294
100	28.8	11.2	0.291
200	28.4	11.1	0.288
300	28.0	10.9	0.280
400	27.6	10.8	0.280
500	27.1	10.6	0.275
600	26.7	10.5	0.272
700	26.2	10.3	0.273
800	25.8	10.1	0.271
900	25.3	9.9	0.272
1000	24.8	9.7	0.271
1100	24.2	9.5	0.276
1200	23.7	9.2	0.283
1300	23.0	8.9	0.292
1400	22.3	8.5	0.306

Table 3.5: Thermal Properties

Temperature, °F	Thermal conductivity, * BTU*		Electrical Resistivity, *		Mean Linear Expansion
	Ann. 1800°F / 1 hr	Ann + aged	Ann. 1800°F / 1 hr	Ann + aged	
-320	-	-	-	-	5.9[a]
70	77	79	753	725	-
200	86	87	762	733	7.31
400	98	100	772	755	7.53
600	111	112	775	768	7.74
800	123	124	784	775	7.97
1000	135	136	798	788	8.09
1200	147	148	805	794	8.39
1400	160	161	802	797	8.91
1600	173	173	799	796	—
1800	185	186	801	800	—
2000	196	199	811	798	—

Material in this condition will meet the following minimum requirements:
AMS 5596
Sheet, Strip & Plate.

AMS 5596
Sheet, Strip & Plate

Property	Room Temperature	1200°F
Tensile Strength, ksi	180	140 145
Yield strength (0.2% Offset), ksi	150	115 120
Elongation in 2 in., %	12	5
Hardness	36 or equivalent	—
Stress Rupture		
Stress, ksi	— —	95 100
Life, hr	—	23
Elongation, %	—	4

Bars, Forgings & Rings

Property	Room Temperature	1200°F
Tensile Strength, ksi	183 180 180	145 140 140
Yield strength (0.2% offset), ksi	150	125
Elongation in 2 in., %	12 10 8	12 10 6
Reduction of Area, %	15 12 86	15 12 86
Hardness	331 BHN or equivalent	
Stress Rupture		
Stress, ksi	—	100
Life, hr	—	23
Elongation, %	—	4

Seamless Tubing

Property	Room Temperature	1300°F
Tensile Strength, ksi	185	—
Yield strength (0.2% offset), ksi	150	—
Elongation in 2 in., %	12	—
Hardness	Rc 36 or equivalent	
Stress Rupture		
Stress, ksi	—	72.5
Life, hr	—	23
Elongation, %	—	5

Property*	AMS 5664 Bars, Forging & Rings	AMS 5597 Sheet, Strip & Plate	AMS 5590 Seemless Tubing
Tensile Strength, ksi	180	180	170
Yield strength (0.2% offset), ksi	150	150	145
Elongation in 2 in., %	10 12	15	15
Reduction of Area, %	12 15	--	--
Hardness	341 BHN or equivallent	RC 38 or equivlent	

Other heat treatments:

Table 3.6: Mechanical Properties Aged Material for oil Tool Applications

Room Temperature Tensile and Hardness, and Room Temperture and -75°F Impact

Codition	Diameter, in. (mm)	Tensile strength, ksi (Kg/cm²) min	Yield strength (0.2% Offset) ksi (Kgcm²)		Elongation in 2 in. (50.8mm) or 4D% min.	Reduction of area, % min.	Impact Strength, ft*lb (Kg*m) min. aver	Hardness, Rockwell C	
			Min.	Max.				Min.	Max.
Cold worked solution annealed & aged	0.5(12.7) to 3(76.2), inclusive	150 (10,545)	120 (8436)	140 (9842)	20	25	40 (5.55)	30	40
Hot worked, solution annealed & aged	0.5(12.7) to 8 (203.2) inclusive	150 (10,545)	120 (8436)	140 (9842)	20	25	40 (5.55)	30	40
Hot worked, solution	8 (203.2) to 10 (25.4)	150 (10,545)	120 (8436)	140 (9842)	20	25	40 (5.55)	30	40

Room temperature tensile properties:

The following data are representative of the effects of the above annealing and aging treatments on room-temperature properties of a variety of products. More properties are shown under the section, High- and Low-Temperature Tensile Properties, Fatigue Strength, and Weld Properties.

Room Temperature Tensile Properties of Annealed Hot-Rolled Round

[a]Eight separate heats represented

[b]Annealing for 1 hr, A.C.

[c]L is longitudinal test orientation; T is transverse.

Room Temperature Tensile Properties of Hot-Rolled Bar

[a]Five separate heats represented, All tests are longitudinal.

[b]When annealing is at 1750°F, aging is 1325°F/8 hr, F.C. to 1150°F for total aging time of 18 hr. When annealing is at 1950°F, aging is 1400°F/10 hr, F.C. to 1200°F for total aging time of 20 hr.

Tensile properties of Hot-Rolled Round (4-in. Diameter)

[a]In stress-rupture tests under conditions of 1300°F and 75 ksi, results were: 68.2 hr life, 10.0% elongation and 13.0% reduction of area.

Room Temperature Tensile Properties of Forged Flats (1x2-in, Thick, Annealed 1950°F/1 hr, A.C. and Aged).

*1400°F/10 hr, F.C. to 1200°F, hold at 1200°F for total aging time of 20 hours.

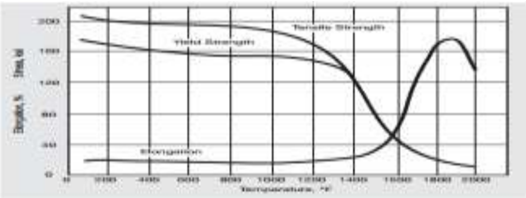
Cold finished products:

Properties of cold-rolled sheet aged at 1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hours are shown in Table 3.15. Table 3.16 gives the effect of the heat treatment specified by AMS 5597 on material of various thicknesses. Some properties of tubing are given in Table.
*Aging-1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hours.

Effect of Aging on Room Temperature Properties of Tube Reduced 70% to 0.133-in. Wall, 1.513-in. O.D.

Condition	Tensile Strength, ksi	Yield Strength, (0.2% offset), ksi	Elongation, %	Hardness, Rc
As Tube Reduced	247.0	211.0	6.0	42.0
Aged 1325°F/8hr, F.C. 100°F to 1150°F/8 hr A.C.	266.0	261.0	4.0	51.5

High and low temperature properties



Low Temperature Properties of Forging (Short Transverse Tests)*

Test Temperature, °F	Tensile Strength, ksi	Yield Strength (0.2% offset), ksi	Elongation in 4D, %	Reduction of Area, %	Notch Strength, Tensile Strength Ratio†
1800°F/45 min, A.C. plus 1325°F/8 hr, F.C. to 1150°F, Hold at 1150°F for Total Aging Time of 18 hr					
Room	187.0	165.9	17.0	23.0	1.45
-110	198.9	174.4	17.2	20.0	1.37
-320	229.0	186.6	14.0	14.0	1.30
-423	237.2	194.9	13.5	11.5	1.30
1950°F/45 min, A.C. plus 1400°F/10 hr, F.C. to 1200°F, Hold at 1200°F for Total Aging Time of 20 hr					
Room	181.5	147.7	19.0	24.5	1.37
-110	195.9	158.1	15.0	18.5	1.41
-320	228.7	178.7	17.3	19.5	1.28
-423	244.2	188.8	16.5	18.0	1.19

*Specimens machined from forging with dimensions 4 by 9 by 15-in.
†Notch concentration factor K_t, 6.3.

Cold finished products

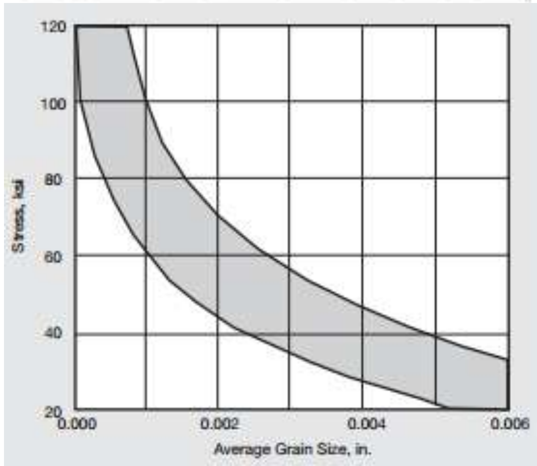
High-temperature tensile properties of cold-rolled sheet annealed in accordance with AMS 5596 are shown in Table 3.23. More data on 5596-processed material appear in Table 3.24. Table 3.25 shows room-temperature tensile properties of sheet annealed and aged per AMS 5596. Low-temperature properties of sheet processed in accordance with AMS 5596 are shown in Table 3.26. These data indicate the effects of sheet thickness as well as annealing and aging treatment. Large increases in strength are achieved by cold working and aging. Additional data on notch tensile strength are shown in Figure 2. Table 3.27 compares data on annealed and aged sheet with direct-aged sheet over a temperature range from -110° to 1000°F.

Table 3.27: Tensile Properties of 0.027-in Sheet Reduced 20% (Transverse Tests)

Samples	Test Temperature, °F	Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation, %	Notch Tensile Strength, ksi (k_t=6.3)	Tensile Strength / 0.297 lb/cu.in*	Ratio of Notch Tensile Strength to Tensile Strength	Ratio of Notch Tensile Strength to Yield Strength
Cold-Rolled, Annealed and Aged in Accordance with AMS 5596	-110	212.0	168.5	25.0	195.0	714,000	0.92	1.16
	85	196.0	163.0	21.0	183.8	660,000	0.93	1.12
	85*	197.0	162.5	21.0	178.8	-	0.91	1.10
	350	191.0	153.0	20.0	-	-	-	-
	650	171.5	141.5	20.0	158.8	578,000	0.92	1.11
	650*	172.0	137.5	23.0	163.8	-	0.95	1.19
	800	188.0	141.0	23.0	158.8	-	0.81	1.11
	1000	169.0	135.0	24.0	143.8	570,000	0.85	1.06
Cold-Rolled and Aged in Accordance with AMS 5596	-320	260.5	229.0	13.0	236.5	877,000	0.91	1.03
	-110	232.0	206.5	17.0	209.8	781,000	0.88	1.01
	85	221.0	198.5	12.0	196.5	745,000	0.89	0.99
	85*	212.0	195.5	13.0	199.8	-	0.94	1.02
	350	205.0	188.5	12.0	179.8	-	0.88	0.95
	650	193.5	179.0	12.0	175.3	652,000	0.90	0.97
	650*	198.5	182.0	13.0	172.8	-	0.87	0.95
	800	-	-	-	189.8	-	-	-
	1000	180.1	163.3	15.0	166.5	608,000	0.92	1.01

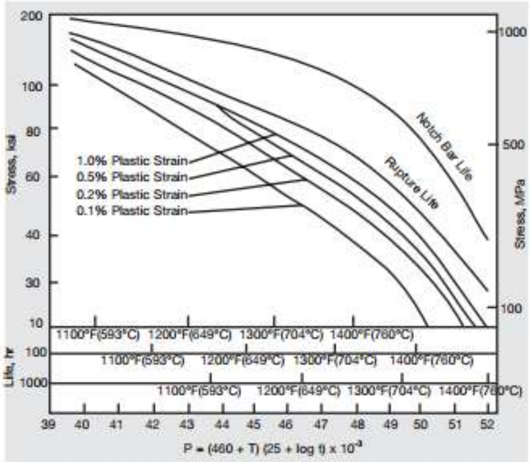
Room Temperature Fatigue Strength of 6-by 9-in Forging

Condition	Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation, %	Reduction of Area, %	Grain size, in	Fatigue Strength, ksi: 10^6 cycles	10^7 cycles	10^8 cycles
Annealed	143.0	99.5	32	32	0.0023	74.0	67.5	66.5
Annealed and Aged	191.25	169.5	10.1	20	0.0021	77.1	71.0	69.5



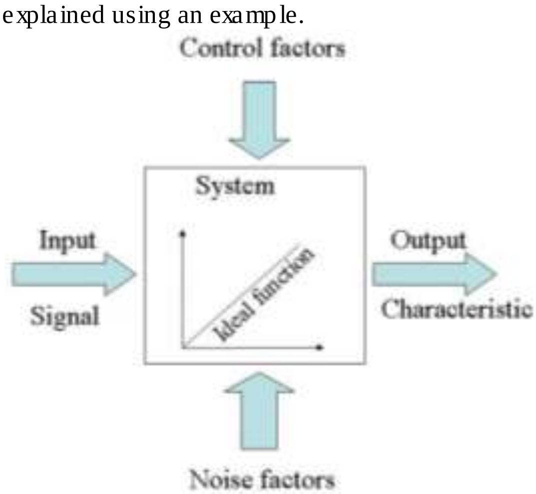
Effect of grain size on endurance limit (10^8 cycles) of plate annealed and aged in accordance with AMS 5596.

Rapture and creep properties



4. TAGUCHI TECHNIQUES

It is known that many experimenters use the techniques of orthogonal arrays, linear graphs and triangular tables developed by Taguchi, in the design of 2K factorials and fractional factorial experiments. In this paper a connection between the linear graph method and graph theory is investigated. The use of orthogonal arrays, linear graphs, and triangular tables in the design of experiments is explained using an example.



5. RESULTS & DISCUSSIONS

TAGUCHI METHOD:

Taguchi method is a scientifically disciplined mechanism for evaluating and implementing improvements in products, processes, materials, equipment, and facilities. These improvements are aimed at improving the desired characteristics and simultaneously reducing the number of defects by studying the key variables controlling the process and optimizing the procedures or design to yield the best results.

The method is applicable over a wide range of engineering fields that include processes that manufacture raw materials, sub systems, products for professional and consumer markets. In fact, the method can be applied to any process be it engineering fabrication, computer-aided-design, banking and service sectors etc. Taguchi method is useful for 'tuning' a given process for 'best' results.

Taguchi proposed a standard 8-step procedure for applying his method for optimizing any process,

8-STEPS IN TAGUCHI METHOD:

Step-1 : identify the main function, side effects, and failure mode
Step-2 : identify the noise factors, testing conditions, and quality characteristics
Step-3 : identify the objective function to be optimized
Step-4 : identify the control factors and their levels
Step-5 : select the orthogonal array matrix experiment
Step-6 : conduct the matrix experiment
Step-7 : analyze the data, predict the optimum levels and performance
Step-8 : perform the verification experiment and plan the future action

8.2 Experimental Plan and details

In this study, three machining parameters were selected as control factors, and each parameter was designed to have three levels, denoted 1, 2, and 3 (Table 5.1). The trial configuration was by a L'9 cluster in light of Taguchi technique, while utilizing the Taguchi orthogonal exhibit would especially lessen the quantity of investigations. An arrangement of tests outlined utilizing the Taguchi strategy was directed to explore the connection between the procedure parameters and reaction factor. Minitab 16 programming is utilized to streamlining and graphical examination of acquired information.

Table 5.1: Turning Parameters and Levels

Symbol	Turning Parameters	Level 1	Level 2	Level 3
V	Cutting Speed (m/min)	150	188	226
F	Feed Rate	0.1	0.2	0.3
D	Depth of Cut (mm)	0.5	1.0	1.5

Table 5.2: Chemical composition of Medium Carbon Steel (AISI 1045)

Element	Percentage
Carbon	(0.43 – 0.50)%
Silicon	(0.2 – 0.3)%
Magnesium	(0.60 – 0.90)%
Phosphorus	(0.05)% max
Sulphur	(0.005)% max

$$MRR = \frac{Wi - Wf}{\rho st} mm^3/sec$$

Where, Wi = Initial weight of work piece in gm Wf = Final weight of work piece in gm t = Machining time in seconds ρs= Density of mild steel = (7.8 x 10^{-3} gm/mm³).

Experimentation and Calculation.

Response Table for MRR

Level	Cutting Speed	Feed Rate	Depth of Cut
1	2.270	1.167	2.133
2	1.997	1.920	2.080
3	1.900	3.080	1.953
Delta	0.370	1.913	0.180
Rank	2	1	3

Where, V-Variable, CS-Cutting Speed, F-Feed Rate, D-Depth Of Cut, SR-Surface Roughness, E-Error, T-Total, DF-Degree of Freedom, SS-Sum of Squares, MS-Mean of Squares, F-a statistical parameter, P-Percentage, C-Contribution. Here ***&** represents most significant and significant parameters and * as less significant.

Determination of Optimum Condition

Both the response and S/N ratio are used to derive the optimum conditions. The S/N ratio is always highest at the optimum condition. The graphs are used to determine the optimum process parameters combination. The optimum combination is therefore V5-F2-D3.

: Optimal Values of Machining and Response Parameters

CP	OV	OL	POV	EOV	OR
CS	188	V2	MRR=465.3	MRR=485.3	465.08 <MRR> 485.3
F	0.1	F1			
D	1.5	D3	RA =1.007	RA=1.04	1.007 <Ra> 1.04

CONCLUSION

In this study, the Taguchi method was applied for the multiple performance characteristics of turning operations. Therefore, the optimization of the complicated multiple performance characteristics of the processes can be greatly simplified using the Taguchi method. It is also shown that the performance characteristics of the turning operations, such as the material removal rate and the surface roughness are greatly enhanced by using this method.

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