OPTIMIZATION OF PARAMETERS ON WEDM MACHINE ON H13 USING TAGUCHI & ANOVA TECHNIQUE

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Abstract: The selection of optimum process parameters plays a significant role to ensure quality of product. If more than one attribute comes into consideration it is very difficult to select the optimal setting which can achieve all quality requirements simultaneously. The present study response surface methodology is applied for optimization of process parameters for machining of hard material by WEDM. This study investigates the multi-response optimization of process WEDM for an optimal parametric combination to yield the tool wear and surface roughness. It deals with the effects of three input process parameters chosen on the machining of H13 (High speed steel) by using design of experiment. The main objectives of this work are to investigate the process parameters for surface roughness and tool wear by using Response Surface Methodology and to recommend the best machining parameters that contribute to the optimum surface roughness and tool wear value. By this method we can achieve more efficient metal removal rate reduction in tool wear and improve surface quality.

Keywords: H13, Taguchi, ANOVA, WEDM

I. I. INTRODUCTION

1.1 Background

The Electrical Discharge Machining (EDM) is an important non-conventional manufacturing method which is used for hard to cut conductive material and has been accepted worldwide as a standard process in the manufacture of forming tools to produce plastic mouldings, forming dies, die casting, since it does not require cutting tools and allows machining involving hard, brittle, thin and complex geometry.

The rapidly growing demand of better surface finish and greater accuracy especially in tool and die making industry has compelled the researchers to persistently investigate the complex inter relations that exist between the process parameters and desired performance measures of the WEDM process.

In wire cut EDM machine inputs impulse voltage between electrode wire and work piece through impulse source controlled by servo system to get a certain gap and realize impulse discharging in the working liquid between electrode wire and work piece. Numerous tiny holes appear due to erosion of impulse discharging and therefore get the needed shape of work piece (as show in figure 1.1).

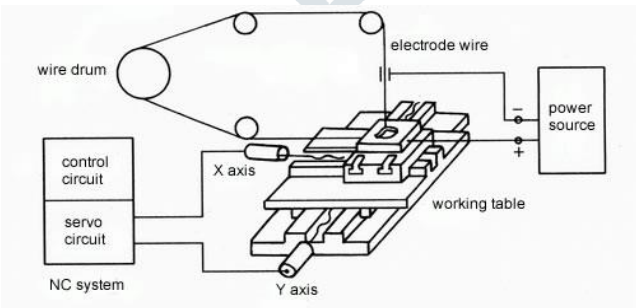


Fig. 1.1 Principle of WEDM

Electrode wire is connected to cathode of impulse power source and work piece is connected to anode of impulse power source. When work piece is approaching electrode wire in the insulating liquid and gap between them getting small to a certain value. Insulating liquid was broken through very shortly discharging channel forms and electrical discharging happens. And release huge high temperature instantaneously up to more than 10000 degree centigrade. The eroded work piece is cooling down swiftly in working liquid and flushed away as show in above fig. 1.2.

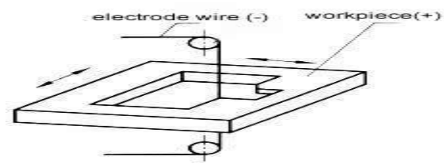


Fig. 1.2 Schematic diagram of Cutting operation on WEDM

In WEDM the wire is kept in tension using a mechanical tensioning device reducing the tendency of producing in accurate parts. During the WEDM process, the material is eroded ahead of the wire and there is no direct contact between the work piece and the wire, eliminating the Mechanical stresses during machining.

The material removal mechanism of WEDM is very similar to the conventional EDM Process involving the erosion effect is produced by the electrical discharge (sparks). In WEDM, material is eroded from the work piece by a series of discrete sparks occurring between the work piece and the wire separated by a stream of dielectric fluid, which is continuously fed to the machining zone.

The most important performance characteristics for WEDM process include material removal rate, Cutting speed, surface finish, discharge current; pulse time, pulse frequency, wire speed, wire tension and servo voltage are parameters which influence by this process.

1.2 Types of EDM machine

a) Sinker EDM

Sinker EDM is also called as cavity type EDM or volume EDM. It consists of an electrode and work piece submerged in an insulating liquid such as oil or other dielectric fluids. As the electrode approaches the work piece, dielectric breakdown occurs in the fluid, forming a plasma channel and a spark jumps.

b) Fast hole drilling EDM

The fast hole drilling EDM was designed for producing fast, accurate, small and deep holes. It is conceptually akin to Sinker EDM but the electrode is a rotating tube conveying a pressurized jet of dielectric fluid. It can make a hole an inch deep in about a minute and is a good way to machine holes in materials too hard for twist-drill machining. This EDM drilling type is used largely in the Aerospace industry, producing cooling holes into Aero blades and other components. It is also used to drill holes in industrial gas turbine blades, in moulds and in dies and in bearings.

1.3 Applications of WEDM

a) The WEDM machining is mainly used to process various punch dies, plastic mould, Powder metallurgy mould etc. It can also cut various sample plates, magnetic steels, Silicon steel sheets, semi-conductive material or precious metal. Furthermore, it is able to do tiny machining, abnormal shaped groove or machining of standard defect of sample parts which is widely used in precious machine tools, light industry, Army industry and so on.

b) WEDM is also widely used to machine various moulds such as punch dies, powder metallurgy mold and plastic mold. WEDM can cut terrace die, punch plate etc.

c) Special material which is not easy to processed by various conventional or traditional machines like Lathes, Boring machines, Milling machines and Grinding machines. Thus, such special gears, forming of cutting tools and various shaped holes can be easily done in all non-conventional or non-traditional machines.

1.2 History of WEDM

The erosive effect of electrical discharges was first noted in 1770 by English physicist.
Two Russian scientists B. R. Lazarenko and N. I. Lazarenko were tasked in 1943 to investigate ways of preventing the erosion of tungsten electrical contacts due to sparking. They failed in this task but found that the erosion was more precisely controlled if the electrodes were immersed in a dielectric fluid. This led them to invent an EDM machine used for working difficult-to-machine materials such as tungsten simultaneously, but independently. An American team of Harold Stark, Victor Harding and Jack Beaver, developed an EDM machine for removing broken drills and taps from aluminium castings.

The wire-cut type of machine arose in the 1960s for the purpose of making tools (dies) from hardened steel. The tool electrode in wire EDM is simply a wire. The first commercially available NC machine built as a wire-cut EDM machine was manufactured in the USSR in 1967. Machines that could optically follow lines on a master drawing were developed by David H. Dulebohn's group in the 1960's at Andrew Engineering Company. A wire-cut EDM machine using the CNC drawing plotter and optical line follower techniques was produced in 1974.

1.4 Properties and specification of H13 (High speed steel)

H13 (High speed steel) has high hot tensile strength, hot wear resistance and toughness properties. Good thermal conductivity and insensitiveness to hot cracking. H13 material is a type of grade which offers a good resistance to softening i.e. up to 600ºC, combined with good stability in hardening and high toughness, making it suitable not only for hot die applications but also for plastic moulds. It has many applications for making hot punches and dies for blanking, bending, swaging and forging, hot extrusion dies for aluminium cores, ejector pins, inserts and nozzles for aluminium, tin and lead die casting.

H13 High speed Steel is a versatile chromium-molybdenum hot work steel that is widely used in hot work and cold work tooling applications. The hot hardness (hot strength) of H13 resists thermal fatigue cracking which occurs as a result of cyclic heating and cooling cycles in hot work tooling applications.

Table 1.1 Chemical Composition of H13 Material

Elements	Weight in %
Carbon	0.32-0.45
Chromium	4.75-5.50
Molybdenum	1.10-1.75
Vanadium	0.80-1.20
Iron	Balance
Silicon	0.80-1.25
Sulphur	0.30 max
Phosphorus	0.30 max
Manganese	0.25-0.50

1.4 Objectives

a. To find the MRR (Material Removal Rate) value from the performed experiment on WEDM machine.

b. To find the surface roughness value after testing the roughness.

1.4 Proposed work

a. Literature Review.

b. Study of various parameters.

c. Study of various materials.

d. Study of operating principle of various non-conventional machines.

e. Study of operating principle of WEDM (Wire Electrode Discharge Machine).

f. Taking various parameters and calculating the MRR (Material Removal Rate) value.

g. After pocketing of the material, check the surface roughness value from surface roughness testing.

II. LITERATURE SURVEY

Literature survey discussed in this chapter mainly focuses on the various parameters to be taken by using Taguchi and ANOVA Technique and the experimental study of the WEDM (Wire Electrode Machine).

Sr. No.	Name	Methodology	Results & Conclusion
1.	Varun Singh, S. K. Sharma	They had used Taguchi & ANOVA Technique on H13 material on EDM machine. Taguchi's L16 mixed orthogonal array has been used for planning & designing the experiment.	They had considered three parameters i.e. Pulse-on time (µs), Gap Voltage (volts) & Pulse Current (Ampere). They had set four levels i.e. L1, L2, L3 & L4. They have observed two values i.e. Material Removal Rate(mm^3/min) & Surface Roughness(Ra)
2.	João Ribeiro, Hernâni Lopes, Luis Queijo and Daniel Figueiredo	They had used Taguchi & ANOVA Technique on steel 1.2738 on Face Milling machine. Taguchi's L9 mixed orthogonal array has been used for planning & designing the experiment.	They had considered three cutting parameters i.e. Cutting speed (m/min), Feed rate (mm/tooth) & Radial depth of cut (mm) with three levels. They had calculated Surface Roughness & S/N ratio values.
3.	Gyanendra Singh, Ajitanshu Mishra & Dilbag Singh	They had used Taguchi method. Surface Response & Grey Relational Analysis Technique is also used	Surface Roughness of the Material & Material Removal Rate of the material.
4.	Rahim Jafari, Müge Kahya, Samad Nadimi Bavil Oliaei, Hakki Őzgür Űnver & Tuba Okutucu Őzyurt.	They had used Taguchi & ANOVA Technique on µ-WEDM machine on Micro-channel heat sink. Taguchi's L25 mixed orthogonal array has been used for planning & designing the experiment.	They had considered six process parameters i.e. T-on; T-off; V (V); SF (mm/min); C (pF) & WS (m/min) with setting five levels. They had calculated Surface Roughness values by four parameters i.e. Ra; Rz; Rv & Sm all in (µm).
5.	Tushar Saini, Khushdeep Goyal & Deepak Bhandari	They had used Taguchi & ANOVA Technique on WEDM machine on 16MnCr5. Taguchi's L18 mixed orthogonal array has been used for planning & designing the experiment.	The response parameters i.e. surface roughness & material removal rate were optimized by varying types of electrodes, pulse on time (T-on), pulse off time (T-off) & peak current (Ip)

2.2 Problem Statement

1. As we all know that there are many materials like D2, D3, En8, En47 and H13 etc. which have different properties according to the different types of materials. So, these types of material are not possible to be machined in conventional or traditional machines in various taper angle, depth of cut, feed rate and other such parameters.
2. So, such materials also have to be machined properly and perfectly. Thus it has to be machined in various non-conventional or non-traditional machines like WEDM, EDM, Chemical Machining (CM), Photochemical Machining (PCM), Electron Beam Machining (EBM) and Ultrasonic Machining (USM) etc.
3. These can be executed using Taguchi method and ANOVA technique and by setting various input and output parameters. Input parameters such as Voltage Gap (Volts), Wire Feed (m/min), Pulse ON-Time (µs) and Pulse OFF-Time (µs). Output parameters are Time (min), Material Removal Rate (MRR) (mm^3/min) and Surface Roughness value (Ra) (µm).

III. Methodology

The Taguchi approach is based in statistical analysis of tests that can economically satisfy the product or process for a defined optimal design. One advantage of this method is that multiple factors are considered at once, including noise factors. Taguchi method when combined with other statistical tools, like analysis of variance (ANOVA), principal component analysis (PCA) or grey relational analysis, transforms into a powerful tool for optimization of the machining parameters. Some authors have studied the turning machining process associated with Taguchi method to optimise the most common controllable parameters, such as: cutting speed, feed rate and depth of cut. The main goal is to reduce the surface roughness, through the application of Taguchi method based on the highest signal-to-noise ratio for surface roughness. Other studies have focused in the milling process, being one of the most used metallic chips removal processes in industry. As in turning process, the main controllable factors are the feed rate; depth of cut and cutting speed (or spindle speed) and, for the most of this works, the authors used three levels for each factor through the use of Taguchi L16 array. In many studies of milling optimization using Taguchi method referenced in the bibliography, the surface roughness measurements are performed on the surface perpendicular to tool axis, usually horizontal or on both surfaces, perpendicular and parallel to tool axis, and is computed the average value. However, the contour operation is very common in metallic machining and is important to control the lateral surface roughness which can be measured in parallel direction of toll axis. In this work the authors analysed the influence of each machining parameters in the surface roughness on parallel direction of tool axis for the end milling operation. The main goal is the determination of the optimal combination of milling parameters to obtain the lower surface roughness value.

3. 2 Taguchi method for design of experiments and experimental details

3.2.1 Taguchi method

Genichi Taguchi (Tokamachi, Japan, 1924–2012) was a statistician and an engineer. He developed a methodology to improve the quality of manufactured goods by using a fractional-factorial approach whenever there are several factors involved and is accomplished with the aid of orthogonal arrays. Taguchi has made influential contribution to industry. The key elements of his quality philosophy include the following aspects:

• The philosophy of off-line quality control, robust design of products and processes;

• Taguchi loss function;

• Innovations in the statistical design of experimental tests.

The Taguchi method involves reducing the variation in a process through robust design of experiments. The main objective of this method is to produce high quality product at low cost to the manufacturer. The key idea behind this method is the quality of a product required by the society is same how related to the loss caused during its life cycle. A high quality product will cause less loss to the society. The loss can be measured in different parameters like time or noise. In general, if the product result is not as the consumer expects, the loss is big since the quality is far from the user expectations. So, this is not desirable for the industry, neither for the society. Taking into account the quality needed, Taguchi included in his method some loss functions that recognize the customer's desire to have products that are more consistent and meets the producer's desire to make them low-cost. Taguchi's philosophy says that quality should be designed into a product, not inspected into it. This is achieved through a system design, parameter design and tolerance design. If a producer decides to choose the quality "inspected into" a product, it means the product is produced at random quality levels and those are too far from the user desired levels. Quality is more easily achieved by the reduction of deviation from a target, through the minimization of the influence of uncontrollable factors. This means one should have a high signal-to-noise ratio (S/N).

3.3 Experimental Set Up

The WEDM experiments were conducted by using Brass as the tool electrode. The diameter of Brass is 0.25 mm. The material selected for WEDM machining process is H13 (High Carbon Steel) material. Whose length is 250 mm, width is 100 mm and thickness is 16 mm (before machining process). Sizing of the material was done on Hydraulic Hacksaw Cutter to get the specified dimension of work piece. After that Grinding process took pl ace and then machining takes place on WEDM machine. After grinding of the work piece the thickness of work piece becomes 15.50 mm. Then 16 holes were drilled of 5 mm diameter each and then 16 square pockets were done on WEDM machine, each of 20×20 mm.

3.3.1 Design of work piece

In first step we designed the model of work piece using Creo Parametric software. In which we did the sample 2D sketch whose dimensions are 250*100*16 (All dimensions are in mm). Thus, with the help of all the dimensions had drawn the square and the small 16 pockets of 20*20 (All dimensions of pockets are in mm) is done after extruding the work piece and by giving the command of material removal throughout the plate. The below figure 4.3.1 shows the design model of work piece.

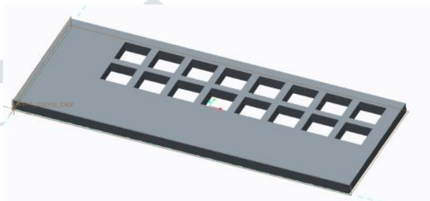


Figure. 3.3.1 CAD model

3.3.2 Sizing of work piece

The work piece is to be sized perfectly according to our required specification. This is done with the help of Hydraulic Hacksaw cutter machine. The above figure 4.3.2 shows the perfectly sized work piece which is to be required for further machining process.

Figure 3.3.2 Sizing of work piece

3.3.3 Grinding of work piece

The grinding process is done in order to acquire the good surface finish, good surface quality and removing rust we did the grinding operation. The grinding machine consists of a bed with a fixture to guide and hold the work piece and a power-driven grinding wheel spinning at the required speed. The speed is determined by the wheel's diameter .The grinding head can travel across a fixed work piece or the work piece can be moved while the grind head stays in a fixed position. Its specifications are:-

Figure 3.3.3 Grinding of work piece

Table size: 1500*600mm; Longitudinal transverse: 1500mm; Wight carrying capacity of table: 1000kg; Spindle speed: 1400rpm; Wheel dia.: 350*50*127mm & Wheel material: Asbestos

The above figure 3.3.3 shows the grinding process of the work piece. After the grinding of the work piece, the thickness of the work piece becomes 15.5 mm.

3.3.4 Drilling of work piece

The below figure 4.3.4 shows the drilling operation on work piece. For simply operations of inserting the wire into work piece for pocketing we drilled the 16 holes on drilling machine into the work piece. The diameter of each hole is 5mm.

Figure 3.3.4 Drilling operation on work piece

The specification of Grinding machine and pockets are:-

Supply voltage: 415 volt; Phase: 3; Frequency: 50 Hz; Drill diameter: 5 mm & Drilled hole diameter: 5 mm

4.3.5 Pocketing operation on work piece

After drilling the work piece is to be clamped in WEDM machine for pocketing operation on the work piece as shown in figure 4.3.5. In WEDM a thin single-strand metal wire, usually brass is feed through the work piece. The wire which is constantly fed from a spool is held between upper and lower guides. The guides move in the X-Y plane and sometimes the upper guide can also move independently giving rise to transitioning shapes (circle on the bottom square at the top). This gives the Wire EDM the ability to be programmed to cut very intricate and delicate shapes.

The wire-cut uses water as its dielectric with the water's resistivity and other electrical properties carefully controlled by filters and de-ionizer units. Wire EDM machining works by creating an electrical discharge between the wire or the electrode and the work piece. As the spark jumps across the gap, material is then removed from the work piece and the electrode. Due to the inherent properties of the process, Wire EDM can easily machine complex parts and precision components out of hard conductive materials.

To stop the sparking process from shorting out, a non-conductive fluid or dielectric is also used in the process. The waste material is removed by the dielectric and the process continues.

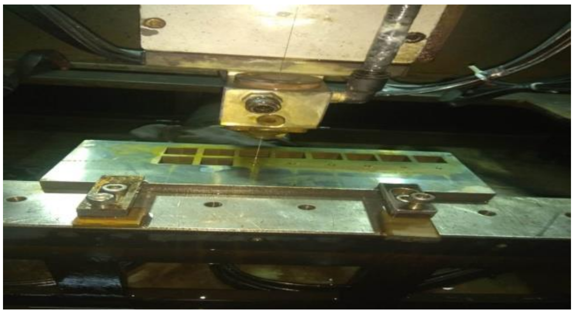


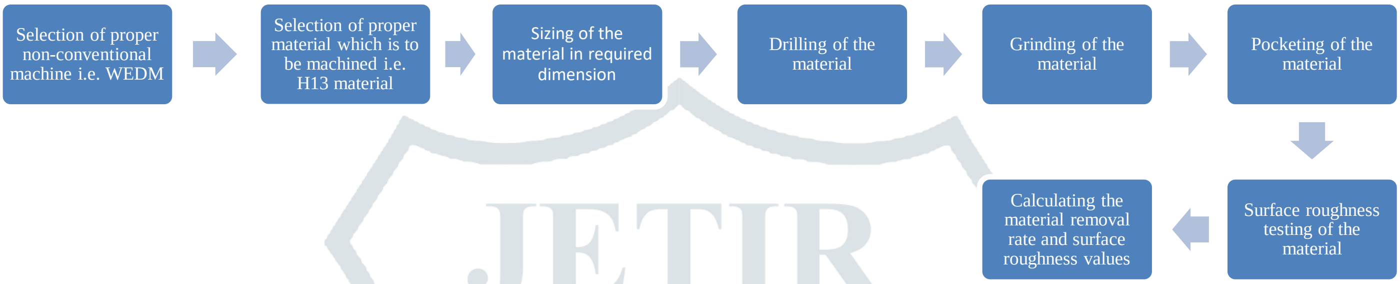
Figure 3.3.5 Pocketing operation on work piece

The specifications of WEDM are:-

Wire diameter: 0.25 mm; Wire used: Brass coated; Water pressure max.: 15 kg/sq.cm Cutting speed: 45 m/min.; Dielectric fluid used: Water & Motor speed: 2100 rpm

3.4 Experimental process

The material used for this study is H13 material. The experimental runs have been conducted on WEDM using L16 orthogonal array of Taguchi methods with four factors and four levels each. The selected input variables and their levels have been given in Table 2. An L16 orthogonal array design for performing experiments is shown in Table 3. Experimental runs have been carried out on WEDM of H13 as per parametric combinations shown in Table 3. The corresponding output response i.e. MRR is measured and shown in Table 3.



3.5 Block diagram of the work

3.4 Process parameter and their levels

Process Parameters	Units	Levels			
		Level-1	Level-2	Level-3	Level-4
Voltage gap (A)	Volts	17	18	19	20
Wire feed (B)	mm/min	3	4	5	6
Pulse on-time (C)	µs	118	121	122	123
Pulse off-time (D)	µs	55	54	51	50

IV. Results and Analysis

The experimental data of surface roughness given in the Table 3 has been used to analyze, model and optimize the WEDM operation to maximize the MRR of H13 tool steel material with the use of statistical analysis of variance and Taguchi methodology.

MRR = Wire feed*Wire diameter* Thickness of work piece

= Wf*Dw*H

= Wf*0.25*15.50

Constant value:-

Cutting speed (Cs) = 45%; Wire tension (Wt) = 8 N

Water pressure (Wp) = 15 kg/cm^2

Fig. 4.1 Surface Roughness Testing

4.1.1 L_{16} Orthogonal array of Taguchi method

Sr. No.	Input (I/P) Parameters			
	Voltage Gap (Volts)	**Wire Feed (m/min)**	**Pulse ON-Time (µs)**	**Pulse OFF-Time (µs)**
1.	17	3	118	55
2.	17	4	121	54
3.	17	5	122	53
4.	17	6	123	50
5.	18	3	121	53
6.	18	4	118	50
7.	18	5	123	55
8.	18	6	122	54
9.	19	3	122	50
10.	19	4	123	53
11.	19	5	118	54
12.	19	6	121	55
13.	20	3	123	54
14.	20	4	122	55
15.	20	5	121	50
16.	20	6	118	53

4.1.2 L_{16} Orthogonal array of Taguchi method

Sr. No.	Output (O/P) Parameters					
	Time (min)	Material Removal Rate MRR = Wf*H*Dw (mm³/min)	Surface Roughness value (Ra) (μm)			
			Ra1	Ra2	Ra3	Avg. Ra
1.	40	11.625	2.596	2.774	2.587	2.652
2.	33	15.50	2.785	2.827	2.308	2.64
3.	34	19.375	2.890	2.405	2.775	2.69
4.	30	23.25	3.030	2.898	2.896	2.941
5.	30	11.625	2.457	2.617	2.655	2.576
6.	35	15.5	2.447	2.383	2.668	2.499
7.	35	19.375	2.732	2.672	2.910	2.771
8.	40	23.25	2.395	2.418	2.609	2.474
9.	45	11.625	2.633	2.791	2.492	2.638
10.	30	15.5	2.712	2.710	2.894	2.772
11.	40	19.375	2.238	2.514	2.278	2.343
12.	35	23.25	2.769	2.562	2.502	2.611
13.	35	11.625	2.529	2.834	2.550	2.637
14.	30	15.5	2.627	2.521	2.588	2.578
15.	45	19.375	2.551	3.030	3.205	2.928
16.	40	23.25	2.654	2.599	2.635	2.629

As per experiment value the maximum material removal rate (MRR) = 23.25

For the optimum parameter

Wire feed = 6mm/min; Servo voltage = 17 ; Pulse ON-Time (P_{on}) = 118 ; Pulse OFF-Time (P_{off}) = 50 & Time (t) = 30 min

As per experiment value the minimum for surface roughness (Ra) = 2.343 μm

Wire feed = 5mm/min; Servo voltage = 19; Pulse ON-Time (P_{on}) = 118 ; Pulse OFF-Time (P_{off}) = 54 & Time (t) = 40 min

4.2 Future Scope

1) Enough scope still exists. In order to control the process more reliably and more precisely, the relationships between process parameters and surface roughness, MRR. delimitation need to be established.

2) In future it will widely used in electrics, precious machine tools, light industry, army industry and so on.

3) Different mathematical model can be generated to optimized the process parameters.

4.3 Total Cost Of Project

Sr. No	Particulars	App. Cost
1	Material	750
2	Machining	2900
3	Certification	1000
4	Testing	3,000
5	Others	2600
	Total Cost	10250

V. Conclusion

The experiments were conducted on a WEDM machine for the machining of AISI H13 steel. The tool used for the machining operation is a carbide coated tool. In this study, the effect of independent variables speed, feed, depth of cut and cutting condition and their interactions were studied in detail on two dependant variables, namely, surface roughness and tool wear. The response surface roughness and optimized using response surface methodology. During the present investigations, experiments were carried out using response surface design.

We have already seen the effect of process parameters on the surface roughness and tool wear using surface plot. We observed that surface roughness is increased with increase in feed and depth of cut while it is decreased when spindle speed is increased. Similarly tool wear is observed minimum when spindle speed is less for a particular run.

The MRR value = 23.25 mm^3/min.

Wire feed = 6 mm/ min; Servo voltage = 17 ; Pulse ON-Time (P_{on}) = 118 ; Pulse OFF-Time (P_{off}) = 50 & Time (t) = 30 min

The surface roughness value (Ra) = 2.343 µm

Wire feed= 5 mm/ min; Servo voltage = 19; Pulse ON-Time (P_{on}) = 118; Pulse OFF-Time (P_{off}) = 54 & Time (t) = 40 min

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