Mechanics and Mechanical Engineering
Vol. 21, No. 1 (2017) 37–55

Optimization Kerf Width and Surface Roughness in Wirecut Electrical Discharge Machining Using Brass Wire

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Received (21 November 2016)
Revised (6 December 2016)
Accepted (11 December 2016)

Wire Electric Discharge Machining (WEDM) is one of the important non–traditional machining process used for machining difficult to machine materials like composites and inter–metallic materials, Intricate profiles. In the present work, the study has been made to optimize the process parameters during machining of Hastelloy -C-276 by wire–cut electrical discharge machining (WEDM). This paper presents an effective approach to optimize process parameters for Wire electric discharge machining (WEDM) is extensively used in tool and die industries. Precision and intricate machining are the strengths. While machining, time and surface quality still remains as major challenges. The input parameters are pulse on time (Ton), pulse off time (Toff), wire feed rate and current and voltage were changed during the process. The optimization of analysis is performed by using Genetic Algorithm (GA) method L–27 orthogonal array.

Keywords: kerf, Wire Electric Discharge Machining, optimization.

1. Introduction

1.1. *Introduction of Wire–cut EDM*

There is always a demand for alloy materials having high strength, impact resistance, hardness, toughness. Nevertheless, such materials are difficult to be machined bytraditionalmethods. Hence, non-traditional machining methods including ultrasonic machining, electrical discharge machiningand electrochemical machiningetc. are used to machine such materials. Wire–cut electrical discharge machining (WEDM) technology has grown tremendously since it was applied more than 45 years ago. In 1974, D.H. Dulebohnapplied the optical–line follower system to automatically control the shape of the components to be machinedby the

WEDM process. By its popularity rapidly increased, as the process and its capabilities wereunderstood by the industry. When computer numerical control (CNC) system was initiated into WEDM, which brought about a major evolution of the machining process.

In WEDM process, a thin wire as an electrode transforms electrical energy to thermal energy for cutting materials. A thin wire electrode is made of brass or molybdenum having diameter of 0.05-0.30 mm, which iscapable of achieving very small corner radii.During the process, the material is eroded ahead of the wire and there is no direct contact between the work piece and the wire. The most important measures in WEDM are MRR, surface finish, Kerf width, pulse duration, wire feed and voltage are the machining parameters which affects the performance measure.

1.1.1. *Principle of Wire-cut EDM*

In wire EDM, the conductive materials are machined with a series of electric sparks that are produced between the tool (cathode) and work material (anode). High frequency of current is discharged from the wire to the work piece with a very small spark gap through an insulated dielectric fluid. Heat generated due to sparking results in the melting of work piece and wire material and a constant gap between tooland work pieceis maintained with help of a computer controlled, positioning system. This system used to cut through complicated contours especially in difficult to machine materials.

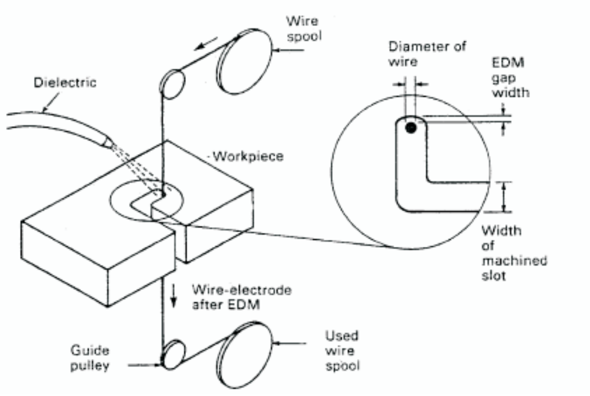

Figure 1 Basic Principle of Wire EDM

1.1.2. *Process of Wire–cut EDM*

Wire EDM machining is an electro–thermal production process in which a thin metal wire in conjunction with deionized water allows the wire to cut the metal by the use of heat from electrical sparks. Due to the inherent properties of the process, wire EDM can easily machine complex parts and precision components out of hard conductive materials. Wire EDM machine works by creating an electrical discharge between wire or electrode and the workpiece. As the spark jumps across the gap, material is removed from both the workpiece and the electrode.

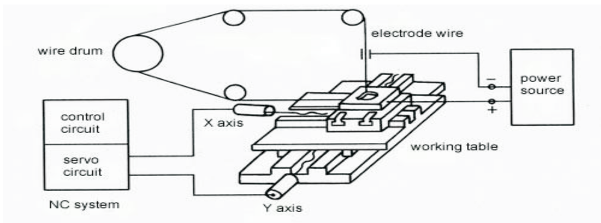

Figure 2 Wire-cut EDM Process

To stop the spark process from shorting out, a non–conductive fluid or dielectric is also applied. The waste material is removed by the dielectric and process continues. The materials can cut through wire EDM are Aluminum, Stainless Steel, Copper, Brass, Titanium, Bronze and Super Alloys.
Neeraj Sharma et al [1] find out on Wire electric discharge machining (WEDM) is a thermo–electric spark erosion non–traditional type manufacturing process. The applications of WEDM have been found in aerospace and die manufacturing industries, where precise dimensions were the prime objective. This process is applied in case of processing difficult to machine material. Brass wire is used as an electrode and High strength low alloy (HSLA) steel as a work–piece during experimentation. Vishal Parashar, et al [2] find out on this paper, statistical and regression analysis of kerf width using design of experiments is proposed for WEDM operations. Each experiment has been performed under different cutting conditions of gap voltage, pulse ON time, and pulse OFF time, wire feed and dielectric flushing pressure. Dhruv H. Gajjar et al [3] find out on this paper, Wire Electrical Discharge Machining (WEDM) is one of the latest non–traditional machining processes, based on thermoelectric energy between the work piece and wire. A suitable selection of tool can reduce the cost of machining. The performance of WEDM is find out on the basis of Material Removal Rate (MRR), KERF Width and Surface Roughness (SR).
S. Sivanaga Malleswara Rao et al [4] on Wire Electro Discharge Machining (WEDM) has become one of the most popular processes for producing precise geometries in hard materials, such as those used in the tooling industry. With the demands on the minimization of surface roughness, decrease of the producible geometric dimensions and improvement of the machining accuracy, Micro–Wire–EDM with a wire diameter of 80 μm – 250 μm has been a key technology for micro–machining. R. Pandithurai et al [5] he said on this paper of Wire Electro Discharge machining (WEDM) is one of the important non–traditional machining processes which are used for machining difficult to machine materials like composites and inter–metallic materials. Shandilya et al [6] received on this work is focused on optimization ofprocess parameters during wire electric discharge machining (WEDM) of metal matrix composites (MMCs). Responsesurface methodology (RSM) and genetic algorithm

(GA) integrated with each other to optimize the process parameters. Four WEDM parameters namely servo voltage, pulse–on time, pulse–off time and wire feed rate were varied to study their effect on the quality of cut in SiCp/6061 Al MMC using surface roughness as response parameter.

R. Ravi Kumar et al [7]find out on this work is aimed to optimize the parameters of (WEDM) process by considering the effect of input parameters viz. Time On, Time Off, Wire Speed & Wire Feed. Experiments have been conducted with these parameters in three different levels data related to process responses viz. Metal removal rate, surface roughness (Ra) have been measured for each of the experimental run. These data have been utilized to fit a quadratic mathematical model (RSM) for each of the responses, which can be represented as a function of the process parameters. Mir Asif Iquebal [8] received on genetic Algorithm (GA) is a calculus free optimization technique based on principles of natural selection for reproduction and various evolutionary operations such as crossover, and mutation. S. S. Mahapatra et.al [9] find out on wire electric discharge machining (WEDM) is a special form of traditional electrical discharge machining in which the electrode is a continuously moving conducting wire. The mechanism of metal removal in WEDM involves the complex erosion effect from electric spark generated by a pulsating direct current power supply.

Sonu Dhiman et al [10] he said on Wire electrical discharge machining (WEDM) is a non–conventional machining process which is widely used in machining of conductive materials The applications of WEDM are in automobiles, aero–space, medical instruments, tool and die industries. in the present study analysis of effect of various control factors like Ton, Toff, Sv, Ip, Wf, Wt on checking the cutting rate of S7 steel is studied by using wire cut EDM and one factor time approach. Amitesh Goswami et al [11] received on Wire Electrical Discharge machining (WEDM) is very complex process due to the presence of large number of process variables involved. WEDM is used for machining of hard material parts that are extremely difficult to machine by conventionalmachining process. L. Li et al [12] received on Super alloys such as Inconel 718 are widely used in turbo machinery industry due to their outstanding mechanical properties. Inconelalloys are very difficult to machine using conventional mechanical processes like broaching, milling or grinding.

Nihat Tosun et al [13]received on this paper, an investigation on the effect and optimization of machining parameters on the kerf (cutting width) and material-removal rate (MRR) in wire electrical discharge machining (WEDM) operations. The experimental studies were conducted under varyingpulse duration, open circuit voltage, wire speed and dielectric flushing pressure. Rodge M. K. et al [14] he says that advanced manufacturing processes play animportant role in production of complicated profiles on such difficult–to–machinecomponents. Inconel 625 is one of the recent materials developed to have highstrength, toughness and corrosion resistant. The high degree of accuracy, fine surfacequality and good productivity made wire electrical discharge machining (WEDM) avaluable tool in today's manufacturing scenario. [15] Sreenivasa Rao M. et al [14] received on Nimonic-263 is a nickel–chromium–cobalt–molybdenumalloy specially meant for use in high temperature and high strength applications. This material is mainly used in gas turbine-hot section components. Machining of these high strengthmaterials is a challenging task now a day. Wire cut electricaldischarge machining is one of the advanced machining processes and can be used to machine any material, which can electrically conduct, irrespective of its hardness. The optimal values from RSM have been compared against that of DE technique. The results from DEalgorithm were found to be more accurate than that of RSM results. It was also found that pulse on time and peak current aredominating the WEDM process as compared to other process parameters.

2. Experimental setup

Major Components
A Wire EDM system consist of four major components:

1. Computerized Numerical Control (CNC).

   It controls the movement of tool while cutting the work piece by using programs. Think of this as "The Brains".

2. Power supply.

   It provides energy to the spark. Think of this as "The Muscle".

3. Mechanical section.

   Worktable, work stand, taper unit, and wire drive mechanism. Think of this as "The Body".

4. Dielectric system.

   The water reservoir where filtration, condition of the water and temperature are provided and maintained.Think of this as "The Nourishment".

2.1. *Computerized Numerical Control*

CNC machining is a process used in the manufacturing sector that involves in the use of computers to control machine tools. Tools that can be controlled in manner include lathes, mills, routers and grinders. CNC stands for computer numerical control. Under CNC machining, machine tool's function throughout numerical control. A computer program is customized for an object and the machines are programmed with CNC machine language. The essential controls all features like feed rate, coordination, location and speeds with CNC machining, the computer can control exact positioning and velocity. CNC machining is used in machining both metal and plastic components.Initially a CAD drawing is created and then a code is created that the CNC will understand. The program is loaded and finally an operator runs a test of a program to ensure there are no problems. This trial is referred to as "cutting air" and it is an important step because any mistake with speed and tool position could result in a scraped part or a damaged machine.

2.2. *Work table*

The Wire–cut EDM machine tool comprises of a main work table (X-Y) on which the work Piece is clamped; an auxiliary table (U–V) with wire drive mechanism. The main table moves along X and Y axis and it is driven by the D.C servo motor. The travelling wire is continuously fed from wire feed spool and collected on take up spool which moves though the work piece and is supported under tension between a pair of wire guides located at the opposite sides of the work piece. The lower wire guide is stationary whereas the upper wire guide, supported by the U–V table, can be displaced transversely along U and V axis with respect to lower wire guide. The upper wire guide can also be positioned vertically along Z axis by moving the quill. In order to produce taper machining, the wire electrode has to be tilted. This is achieved by displacing the upper wire guide (along U-V axis) with respect to the lower wire guide. The desired taper angle is achieved by simultaneous control of the movement of X–Y table and U–V table along their respective predetermined paths stored in the controller. The path information of X–Y table and U–V table is given to the controller in terms of linear and Circular elements via NC program.

2.3. *Tool material*

Brass is an alloy of Copper and Zinc, the proportions of zinc and copper can be varied to create a range of brasses with varying properties. Brass is a substitutional alloy, it is used for decoration for its bright gold-like appearance and softer than most other metals. It has a muted yellow color which is somewhat similar to gold. It is relatively resistant to tarnishing and is often used in decoration and used in coins. In antiquity, polished brass was often used as mirror.

Figure 3 Brass Wire

Density	8.53 g/cm
Thermal Expansion	0.0000199 / C
Specific Gravity	8.53
Electrical Resistance	6.16 .ohm-cm
Specific Heat	0.09 Cal/g/C
Modulus of Elasticity	11200 kg/sq.mm
Modulus of Rigidity	4200 kg/sq.mm
Melting Range	915 – 955C

2.4. *Work piece material*

Hastelloy C–276 is a combination of Nickel–Molybdenum–Chromium alloy with an additional of tungsten designed to have excellent corrosion resistance in a wide range of several environments. The high Nickel and Molybdenum contents make the nickel steel alloy especially resistant to pitting and crevice corrosion reducing environments while chromium conveys resistant to oxidizing media.The low carbon content minimizes carbides precipitation during welding to maintain corrosion resistance in as welded structure. Which is used in chemical processing, population control, pulp and paper production, industrial and municipal waste treatment and recovery of sour natural gas.

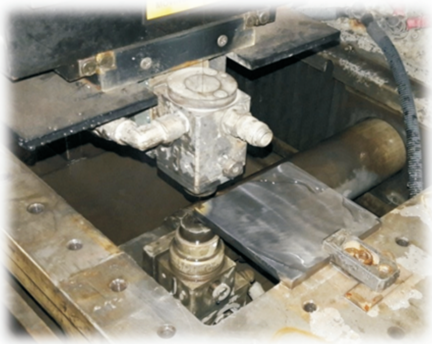

Figure 4 Work piece material after clamped

2.5. *Dielectric material (deionized water)*

Wire–cut EDM uses deionized water as the dielectric compared to other processes kerosene is used. The dielectric system includes the water reservoir, filtration system and water chiller unit and deionization system. Deionization is a water filtering process whereby total dissolved solids are removed from water through ion exchange. The process of deionization uses two resins that are opposite in charges which are cationic (-ve) and anionic (+ve). Cationic resins attract the positive charged ions (Ca^{++}, Mg^{++}, Na^{++}, etc.) and release an equivalent amount of hydrogen (H^{+}) ions.

Main functions of dielectric fluid,

(a) It helps in initiating discharge acting as a conducting medium when ionized, and conveys the spark.

(b) Eroded metal is carried away along with it.

(c) It acts as a coolant while quenching the sparks.

(d) It helps in cooling the work piece and tool electrode.

Flushing is an important function in Wire-cut electrical discharge machining operation. It is the process of introducing clean filtered dielectric fluid into the spark gap. There are various types of flushing methods used to remove the metal particles efficiently.The interfacing of machine tool with pump filter unit is done by connecting the two hoses coming from flow meters to the distributor block. By adjusting the knob of the flow meters pressure of water coming out of the flushing assemblies can be adjusted. For high-speed cutting, flushing at high pressure is selected. The pressure / flow selection is also programmable. To carry on the cutting at lower speed or while taking the second cut on the job already usually low flushing pressure is selected. Flushing pressure fluid flowing from the upper & lower flushing pressure is approximately 12 kg/cm^2.During the cutting process the chips from the material that is being eroded, gradually changes the water conductivity level.

Figure 5 Flushing of work piece material

3. Selection of parameters

In order to identify the process parameters that may affect the machining characteristics of WEDM machined parts.

3.1. *Pulse on time*

The pulse on time is referred as Ton and it represents the duration of time in micro seconds, μs, for which the current is flowing in each cycle. During this time the voltage, VP, is applied across the electrodes. The Ton setting time range of the machine tool which is applied in steps of 1 unit. The single pulse discharge energy increases with increasing Ton period, resulting in higher cutting rate.

3.2. *Pulse off time*

The pulse off time is referred as Toff and it represents the duration of time in micro seconds, μs, between the two simultaneous sparks. The voltage is absent during this part of the cycle. The Toff setting time range of the machine tool is applied in steps of 1 unit. As a result, the cutting rate also increases. Using very low values of Toff period, however, may cause wire breakage which in turn reduces the cutting efficiency. As and when the discharge conditions become unstable, one can increase the Toff period.

3.3. *Peak current*

The peak current is represented by IP and it is the maximum value of the current passing through the electrodes for the given pulse. The IP setting current range available on the present WEDM machine is 10–230 ampere which is applied in steps of 10 ampere. Increase in the IP value will increase the pulse discharge energy which in turn can improve the cutting rate further.

3.4. *Wire feed*

Wire feed is the rate at which the wire-electrode travels along the wire guide path and is fed continuously for sparking. The wire feed range available on the present WEDM machine is 1–15 m/min in steps of 1m/min. It is always desirable to set the wire feed to maximum. This will result in less wire breakage, better machining stability and slightly more cutting speed.

3.5. *Wire tension*

Wire tension determines how much the wire is to be stretched between upper and lower wire guides. This is a gram-equivalent load with which the continuously fed wire is kept under tension so that it remains straight between the wire guides. More the thickness 32 of job more is the tension required. Improper setting of tension may result in the job inaccuracies as well as wire breakage. The wire tension range available on the machine is 1-15 units.

3.6. *Flushing pressure*

Flushing Pressure is for selection of flushing input pressure of the dielectric. High input pressure of water dielectric is necessary for cutting with higher values of pulse power and also while cutting the work piece of more thickness. Low input pressure is used for thin work piece and in trim cuts.

4. Measurement of experimental parameters

The discussions related to the measurement of WEDM experimental parameters e.g. cutting rate, surface roughness, gap current and dimensional accuracy, are presented in the following subsections.

4.1. *Cutting rate*

For WEDM, cutting rate is a desirable characteristic and it should be as high as possible to give least machine cycle time leading to increased productivity. In the present study cutting rate is a measure of job cutting which is digitally displayed on the screen of the machine and is given quantitatively in mm/min.

4.2. *Gap current*

In WEDM machining the specimen is mounted on the machine and during the process of cutting a small amount of gap is maintained between the job and the electrode wire. To initiate the cutting a pulse of current is given by the pulse generator and the current passes through the material being cut which is measured and named as gap current. The gap current is read on an ammeter, which is an integral part of the machine, in amperes.

4.3. *Surface roughness*

Roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion. Roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface.

4.4. *Response variables*

4.4.1. *Surface roughness*

Surface roughness values of finished work pieces were measured by Mitutoyo Surface Roughness Tester SJ – 201 by. It is an instrument that works by gently dragging a mechanical stylus across a Surface. Surface Roughness Tester acquires data by moving the sample beneath the diamond tipped stylus. Vertical movements of the stylus are sensed by an LVDT, digitalized, and stored in the instruments memory. Surface Roughness Standard ISO was used for measurement. The temperature of environment was 32 ± 1^{o}C. In this present study we have taken Ra for measuring Surface Roughness.

4.4.2. *Kerf width*

It is measured in millimeters (mm). It is the measure of the amount of the material that is wasted during machining and determines the dimensional accuracy of the finishing part. For present experiments kerf width has been measured using Nikon profile projector model 6C.

4.4.3. *Method adopted in optimization*

Genetic algorithm
Genetic algorithm (GA) is a search and optimization method which works by mimicking the evolutionary principles and chromosomal processing in naturalgenetics.GA begins its search with a random set of solutions usually coded in binary strings. Every solution is assigned a fitness which is directly related to the objective function of the search and optimization problem. The genetic algorithm is an evolutionary algorithm that uses genetic operators to obtain optimal solutions without any assumptions about the search space. Genetic algorithms need design space to be converted into genetic space. So, Genetic algorithms work with a coding of variables. The advantage of working with a coding of variable space is that coding discretizes the search space even though the function may be continuous. Each chromosome can represent a feasible solution containing a sequence/string of binary or real numbers known as genes.

5. Results and discussion

In the present study, GA is used as an optimization technique for solving a bound–constrained optimization problem. The regression models developed by RSM have been used as objective function and the upper and lower bounds of parameters

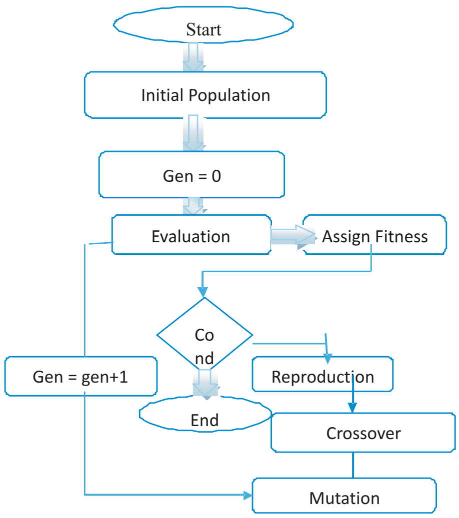

Figure 6 Flow chart of genetic algorithm

are identified by conducting experiments. The problem can be formulated as given below. The main aim is to minimize the surface roughness value. The analysis of variance is the statistical treatment most commonly applied to the results of the experiment to determine the percent contribution of each factors. Study of ANOVA table for a given analysis helps to determine which of the factors need control and which do not. Once the optimum condition is determined, it is usually good practice to run a confirmation experiment. In case of fractional factorial only some of the tests of full factorial are conducted.The analysis of the partial experiment must include an analysis of confidence that can be placed in the results. So analysis of variance is used to provide a measure of confidence.

5.1. *Prediction equations*

$$\begin{aligned}\text{Surface roughness} &= -0.96189 + 0.0025111x(1) + 0.078119x(2) \\ &\quad +0.023313x(3) + 0.10892x(4) + 0.6019x(5) \\ \text{Kerf width} &= 0.18315 - 0.00529936x(1) + 0.00346924x(2) \\ &\quad +0.00134616x(3)\end{aligned} \tag{1}$$

The technique does not directly analyze the data, but rather determines the variability (variance) of the data. Analysis provides the variance of controllable and noise factors. By understanding the source and magnitude of variance, robust

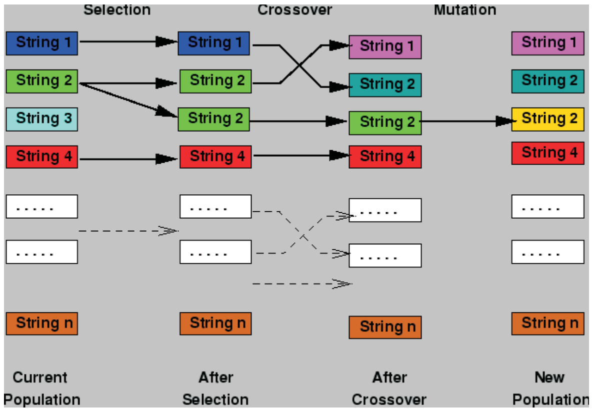

Table 1 Experimental data

S. No.	Ton [μs]	Toff [μs]	Wire Feed [m/min]	Cur. [A]	Volt. [V]	Machine Speed [mm/min]	Time [min.sec]	Ra [μm]	Kerf Width [mm]
1	8	4	2	2.1	45	2.5	07.00.66	1.98	0.290
2	8	4	4	1.9	55	1.9	08.50.37	2.01	0.293
3	8	4	6	1.5	65	1.5	11.02.33	1.82	0.288
4	8	6	4	2.0	45	2.1	07.48.79	2.50	0.283
5	8	6	6	1.8	55	1.6	10.03.06	1.75	0.280
6	8	6	2	1.5	65	1.4	11.51.81	2.72	0.290
7	8	8	6	1.9	45	2.0	08.55.89	2.23	0.294
8	8	8	2	1.9	55	1.7	10.15.14	1.88	0.297
9	8	8	4	1.5	65	1.3	13.36.07	1.95	0.295
10	6	4	2	1.9	45	2.2	07.30.32	2.02	0.304
11	6	4	4	1.9	55	1.7	09.22.62	1.84	0.282
12	6	4	6	1.5	65	1.4	12.56.78	1.88	0.314
13	6	6	4	1.9	45	1.8	08.57.47	1.67	0.310
14	6	6	6	1.2	55	1.5	11.17.74	1.64	0.316
15	6	6	2	1.1	65	1.2	13.45.59	1.71	0.301
16	6	8	6	1.8	45	1.6	10.36.19	1.80	0.310
17	6	8	2	1.5	55	1.4	11.51.80	2.18	0.247
18	6	8	4	1.1	65	1.1	10.07.51	2.03	0.291
19	4	4	2	1.9	45	1.9	08.30.90	1.80	0.289
20	4	4	4	1.5	55	1.6	10.31.68	1.64	0.294
21	4	4	6	1.1	65	1.2	13.25.48	1.69	0.297
22	4	6	4	1.5	45	1.8	09.35.50	1.85	0.320
23	4	6	6	1.5	55	1.4	11.52.45	2.03	0.289
24	4	6	2	1.1	65	1.1	14.33.50	1.99	0.290
25	4	8	6	1.5	45	1.6	10.53.66	1.86	0.292
26	4	8	2	1.1	55	1.3	13.11.50	1.83	0.293
27	4	8	4	1.1	65	1.1	16.24.46	1.84	0.355

operating conditions can be predicted.The basic GA operations: One generation is broken down into a selection phase and recombination phase. Strings are assigned into adjacent slots during selection.

5.2. *Natural selection*

In nature, the individual that has better survival traits will survive for a longer period of time. This in turn provides it a better chance to produce offspring with its genetic material. Therefore, after a long period of time, the entire population will consist of lots of genes from the superior individuals and less from the inferior individuals. In a sense, the fittest survived and the unfit died out. This force of nature is called natural selection.The existence of competition among individuals of a species was recognized certainly before Darwin. The mistake made by the older theorists (like Lamarck) was that the environment had an effect on an individual. That is, the environment will force an individual to adapt to it. The molecular explanation of evolution proves that this is biologically impossible. The species does not adapt to the environment, rather, only the fittest survive.

5.3. *Simulated evolution*

To simulate the process of natural selection in a computer, we need to define the following: A representation of an individual at each point during the search process we maintain a "generation" of "individuals." Each individual is a data structure representing the "genetic structure" of a possible solution or hypothesis. Like a chromosome, the genetic structure of an individual is described using a fixed, finite alphabet. In GAs, the alphabet 0, 1 is usually used. This string is interpreted as a solution to the problem we are trying to solve.

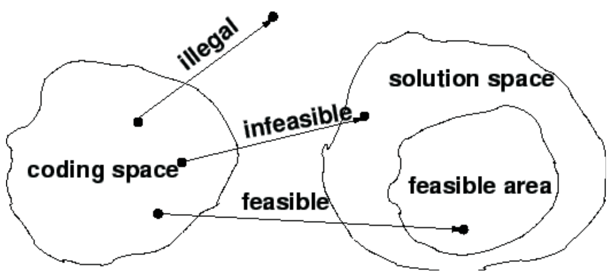

Figure 7 Coding in GA

5.4. *Coding*

It is important to mention here that the coding of the variables is not absolutely necessary. There exist some studies where GAs are directly used on the variables themselves, but here these exceptions are ignored and the working principles of a simple genetic algorithm is discussed.

Binary–coded strings having's and's are mostly used. The length of the string is usually determined according to the desired solution accuracy. For example, if four bits are used to code each variable in a two–variable optimization problem, the strings and would represent the points respectively, because the sub–strings and have the minimum and the maximum decoded values. Any other eight bit string can be found to represent a point in the search space according to a fixed mapping rule. Usually, the following linear mapping rule is used:

$$x_i = x_i^l + \frac{x_i^u + x_i^l}{2^\beta - 1} \sum_{j=0}^{\beta} \gamma_j 2^j \tag{2}$$

In the above equation, the variable is coded with sub–string of length. The decoded value of a binary sub–string is calculated as where and the string is represented as:

$$(s_{\beta-1}\, s_{\beta-2}\, \ldots\, s_2\, s_1\, s_0) \tag{3}$$

5.5. *GA operators*

The operation of GAs begins with a population of a random strings representing design or decision variables. The population is then operated by three main operators; reproduction, crossover and mutation to create a new population of points. GAs can be viewed as trying to maximize the fitness function, by evaluating several solution vectors. The purpose of these operators is to create new solution vectors by selection, combination or alteration of the current solution vectors that have shown to be good temporary solutions.The new population is further evaluated and tested till termination. If the termination criterion is not met, the population is iteratively operated by the above three operators and evaluated. This procedure is continued until the termination criterion is met. One cycle of these operations and the subsequent evaluation procedure is known as a generation in GAs terminology. The operators are described in the following steps.

5.6. *Surface roughness optimized in GA*

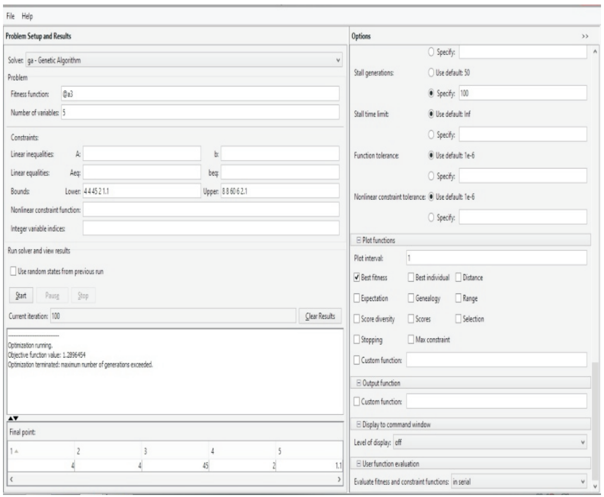

Figure 8 D.O.E software analysis

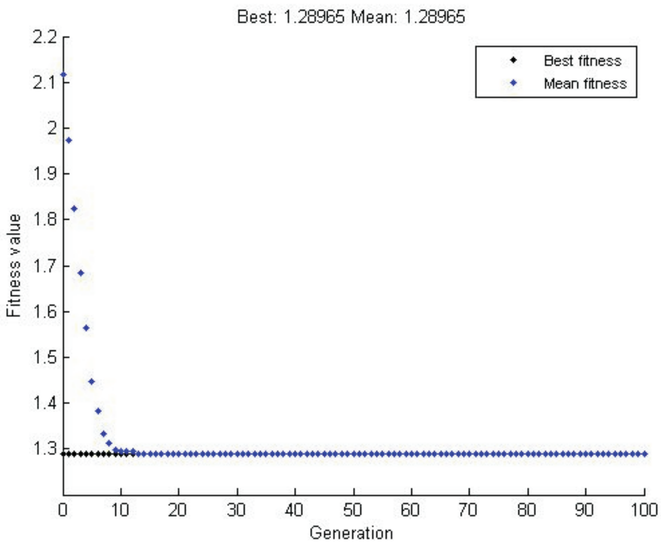

Figure 9 Optimized desirability Graph: 1

Table 2 Machining time optimized in GA

Parameter	Optimized output value
Pulse ON time [μs]	4
Pulse off time [μs]	4
Voltage [V]	45
Current [A]	2
Machine speed (mm/min)	1.1
No. of Iteration	100
Surface roughness [μm]	1.28965
Population size	100
Cross over probability	0.8
Mutation probability	0.2
Total iterations	100

5.7. *Kerf width optimized in GA*

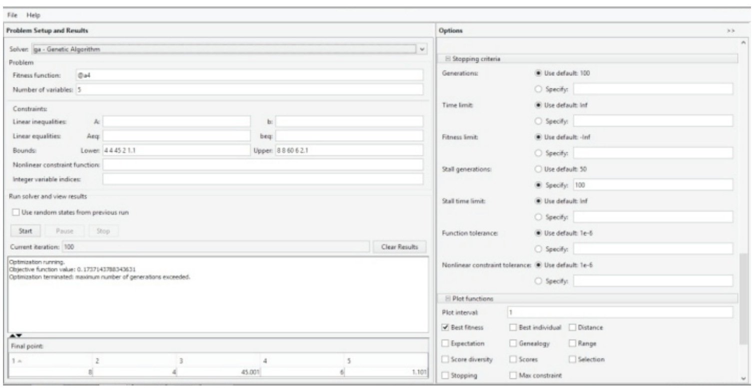

Figure 10 D.O.E. software analysis

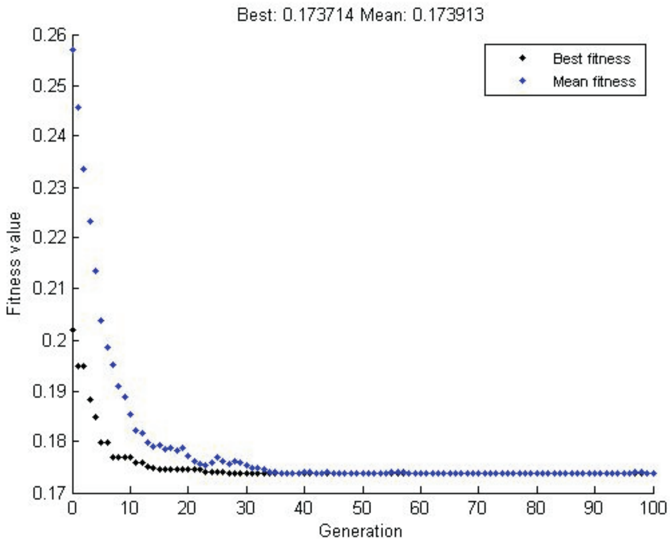

Figure 11 Optimized desirability Graph: 1

Table 3 Machining time optimized in GA

Parameter	Optimized output value
Pulse ON time [μs]	8
Pulse off time [μs]	4
Voltage [Volts]	45
Current [Amps]	6
Machine speed [mm/min]	1.1
No. of Iteration	100
Kerf width [mm]	0.173714
Population size	100
Cross over probability	0.8
Mutation probability	0.2
Total iterations	100

6. Conclusion

This experimental work reveals the following conclusions on Wire EDM operations on Hastelloy C–276 work piece material. Main objective of this work is to develop the empirical model using GA. The genetic algorithm methodology is one of the best technique to identify the effects of machining parameter on Wire EDM process.The voltage and pulse off time are have the significant effect on machining time, the higher level of current produce lower machining time.The voltage, Current, Pulse on time and pulse off time are have significant effect on surface roughness. The higher level of current, voltage, pulse on time and pulse off time are produce poor surface finish.

The genetic algorithm models were developed based on design of experiment with current, voltage, pulse on time and pulse off time as an input and machining time and surface roughness were response.The genetic algorithm model has smaller deviation from experimental data. This confirms that the developed model can be used to predict the machining time, surface roughness value in effective manner.

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