EXPERIMENTAL INVESTIGATION AND OPTIMIZATION OF GEOMETRICAL AND DIMENSIONAL ERRORS ON WEDM USING GENETIC ALGORITHM

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Abstract : Aluminium based alloys usages in aeronautical applications are machined by using WEDM to obtain complex profiles with good accuracy and minimum taperness. However, selection of cutting parameters for higher efficiency in WEDM is still not fully solved. In the present investigation, Sequence of experiments are developed to research the process parameters effect of Aluminium-6061 such as Pulse-on Time (TON), Wire Feed Rate(WFR), Pulse-off Time(TOFF) and Servo Voltage (SV) on MRR, Wire wear rate, Taperness (Geometric error) and Dimensional Deviation (dimensional error). Trial runs on Al-6061 are conducted by design of the experiments using taguchi methodology and a regression equation is developed for evaluating the relationship between input and output parameters. Genetic algorithm optimization technique is applied to yield global optimum results of process variables. Finally, comparison was done across experimental results and predicted the values of confidence level as 98%.

***Index Terms* - Aluminium Alloy, WEDM, Taguchi method, Genetic Algorithm.**

I. INTRODUCTION

Wire EDM can machine anything that is electrically conductive regardless of the hardness. The wire does not touch the workpiece, so there is no physical pressure imparted on the workpiece compared to grinding wheels and milling cutters. The amount of clamping pressure required to hold small, thin and fragile parts is minimal, preventing damage or distortion to the workpiece. The accuracy, surface finish and time required to complete a job is extremely predictable, making it much easier to quote; WEDM leaves a totally random pattern on the surface as compared to tooling marks left by milling cutters and grinding wheels. The WEDM process leaves no residual burrs on the workpiece, which reduces or eliminates the need for subsequent finishing operations. . New materials with high hardness and toughness, such as die and tool steels, are being developed which are difficult to be machined by conventional manufacturing techniques such as milling, drilling and turning. Hence, WEDM is widely used to machine these.

II. LITERATURE SURVEY

IbrahemMaher, LiewHui [1] has optimized the process parameters with consideration of multiple performance characteristics including MRR and Surface Roughness Using Taguchi technique in WEDM on AlSi 1050 carbon steel.

Praveen Kr.Saini [2] has investigate the effect of the wire discharge machining processes parameters on MRR of Titanium alloy using taguchi approach. L_{36} mixed orthogonal array has been selected for experimentation under different variables like dielectric conductivity, pulse width, time between pulses, maximum feed rate, short pulse time, wire feed rate and injection pressure. The predicted optimal setting of process parameters for MRR has been obtained and analyzed by using Taguchi Method.

Vikas [3] has optimized the process parameters namely Pulse on time, pulse off time, Discharge current & voltage over the Surface Roughness (SR) Using Taguchi technique in WEDM on EN41 material.

P.Balasubramanian [4] has optimized the process parameters namely peak current, Pulse on time, pulse off time, dielectric pressure & tool diameter over the Metal Remove Rate, Tool wear Rate & Surface Roughness using Response Surface Methodology(RSM) in WEDM on EN8 & D3 steel material.

Shivkantjilkar [5] optimized the process parameters namely spark on time, spark off time, input current & wire feed rate over the Surface Roughness (SR) using ANOVA in WEDM on Aluminium and Mild steel.

J.B.Saedon [6] has optimized the process parameters namely Surface Roughness (SR), MRR, over Noise(S/N) ratio plots Using Grey Relational Analysis in WEDM on Titanium alloy.

Amiteshtzoswamy [7]has optimized the process parameters namely Pulse on time, pulse off time, peak current over the MRR, Surface Roughness (SR) and surface topography Using Taguchi technique in WEDM on Nimonic-80A alloy.

Anuragjoshi [8] has optimized the process parameters namely Pulse on time, pulse off time, Discharge current & voltage over the Surface Roughness (SR) Using Taguchi technique in WEDM on EN31 material.

Probirsaha [9] has optimize the process parameter namely Multi-response of WEDM using Neuro Gentic Technique for optimal input machining Titanium carbide(TIC) reinforced manganese steel.

J. Simao et al [10] developed the surface modification using EDM, details are given of operations involving powder metallurgy (PM) tool electrodes and the use of powders suspended in the dielectric fluid, typically aluminum, nickel, titanium, etc.

P. Narender Singh et al. [11] discussed the evolution of effect of the EDM current (*C*), Pulse ON-time (*P*) and flushing pressure (*F*) on MRR, TWR, taper (*T*), ROC, and surface roughness (SR) on machining Al-MMC with 10% SiCp . ELEKTRAPULS spark erosion machine was used for the purpose and jet flushing of the dielectric fluid, kerosene, was employed. ANOVA was performed and the optimal levels for maximizing the responses were established. Scanning electron microscope (SEM) analysis was done to study the surface characteristics.

III. EXPERIMENTAL SETUP

All experimental runs were carried out on a CNC Wire cut EDM with the following specifications.

Table 1: Specifications of CNC WEDM

Description	WEDM
Controlling of Machine	CNC
Types of Material cutting	MS, SS, Al, Brass, Titanium, GI
Supply voltage	3x40v-50Hz
Maximum cutting size	10^{I}x43^{I} (3000mmX13000 mm)
Hole making possibility compare with thickness	1:1
Accuracy (+/-)	0.6-1 mm
Cutting speed	0.4m/min
Maximum work sheet weight	Up to 12 ton
Distance between orifice and material	0.010" to 0.02"
Z axis travelling	200 mm

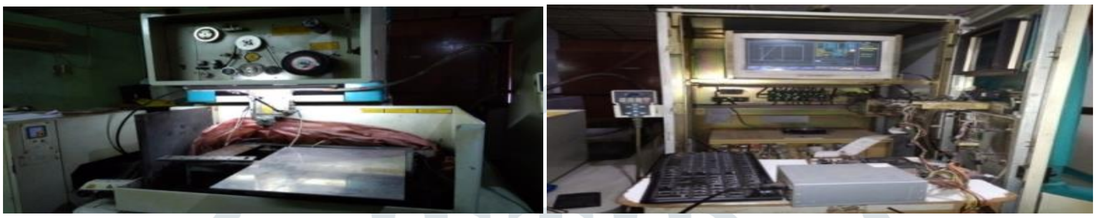

Fig. 1: CNC Wire Cut Electrical Discharge Machining

All experiments were accomplished on a WEDM system and steps that are carried in the cutting operation are as follows:

1. The work piece was mounted and clamped on the work table.
2. A reference point on the work piece was set for setting work co-ordinate system (WCS).The programming was done with the reference to the WCS. The reference point was defined by the ground edges of the work piece.
3. The WEDM system which is used for this research had a Wire with a diameter of 0.25mmit is made up of Copper which is having high tension.

The input parameters like Pulse on time (T_{ON}), Pulse off Time (T_{OFF}), Servo Control and Wire Feed (WF) are given to the CNC machine in the input panel

Table 2:Work piece material Chemical composition (wt.%)

Element	Aluminium	Si	Iron	Cu	Mn	Cr	Zn	Ti
Percentage (%)	95.8-98.6	0.4-0.8	0.7-Max	0.15-0.40	0.8-1..2	0.04-0.35	0.25- Max	0.15-Max

IV. EXPERIMENTAL PARAMETERS

The discussions related to the measurement of Wire cut EDM experimental processes parameters eg. MRR (mm/min), Dimensional deviation (mm), Taperness (radians) and Wire wear rate (mm) are presented in the following subsections.

4.1 Metal Removal Rate (MRR):

MRR is the rate at which the material is removed the work piece. The MRR is defined as the ratio of the difference in weight of the work piece before and after machining to the machining time. Metal Removal Rate (MRR) is the rate at which the material is removed from the work piece. The MRR is defined as the ratio of the amount of metal removed from the work piece in mm^3 to time taken for machining in min.

$$\text{MRR}=\frac{\text{Amount of metal removed from the workpiece (W) in } mm^3}{\text{time taken for machining (t) in min}}$$

Where, $W = V_a - v$

V_a = volume of machined specimen on the work piece.

v = volume of cut piece from the specimen.

Here we get MRR in terms of mm^3/min. To find out the MRR in terms of gm/min, the value should be multiplied with the density of the material chosen.

4.2 Dimensional Deviation (DD)

$$\text{Dimensional Deviation} = \frac{\text{Actual dimention+Measured dimention}}{2} X100$$

4.3 Wire Wear Rate (WWR)

Wire wear rate=(Wire diameter before cut-Wire diameter after cut)

4.4 Taperness

$$\text{Hole taper (rad)}=\frac{Hole\ Entrance\ Diameter - Hole\ Exit\ Diameter}{2X\ Thickness\ of\ the\ Workpiece}$$

V. EXPERIMENTATION

5.1 Experimental Design

Design of Experiments (DOE) was selected for carrying out experiments and conducted as per DOE. After obtaining experimental results, analysis for processes responses were carried using Minitab 17 software. Genetic Algorithm has been carried out for experimental data for obtaining optimum processes parameter in each response and finally optimal setting for minimum Dimensional deviation, Wire wear rate, Taperness and Maximum MRR was done to obtain individually.

For this research work, four processes variables: each at four levels with equal spacing has been decided as per literature survey and trial experiments. It is important to have four minimum levels of processes variables to reflect the accurate behaviour of processes responses, which are given in the table.

Table 3: Number of Processes Parameters and their levels

Parameters	Symbols	Notation	Units	Levels			
				1	2	3	4
Pulse on Time	T_{ON}	A	Machine units	103	105	107	109
Pulse off Time	T_{OFF}	B	Machine units	56	58	60	62
Wire Feed	WF	C	Mm/rev	2	4	6	8
Control of Servo	COS	C	%	40	60	80	100

As per Taguchi technique, the processes parameters of 4 level designs have three degree of freedom (DOF) which gives a total of 12 DOF for three processes variables. The selected OA must have higher DOFs than that of the experiment so, the nearest available OA is L_{16} having 13Dofs is selected and detailed coded factors of the same are given in table.

DOF for a Control Factor = 1+Number of Parameters (Number of stages-1)

$$(DOF)_{Taguchi} = 1+ 4(4-1) = 1+ 4*3 = 1+12 = 13.$$

Hence at least 16 experiments to be conducted, OA L16 experimental runs are sufficient.

Table 4: Taguchi's L_{16} OA in terms of coding factors.

S.No.	Pulse on	Pulse off	Wire Feed	Control of
1	103	60	2	40
2	103	58	4	60
3	103	56	6	80
4	103	54	8	100
5	105	60	4	80
6	105	58	2	100
7	105	56	8	40
8	105	54	6	60
9	107	60	6	100
10	107	58	8	80
11	107	56	2	60
12	107	54	4	40
13	109	60	8	60
14	109	58	6	40
15	109	56	4	100
16	109	54	2	80

Here we get MRR in terms of mm^3/min. To find out the MRR in terms of gm/min, the value should be multiplied with the density of the material chosen.

Now to convert the value of MRR in terms of gm/min, we have to multiply the MRR-mm^3/Min each value with density of material i.e., 0.0027 gm/mm^3.

∴We get for Specimen-1 MRR = 4.762931226 x 0.0027 = 0.012859914 gm/min.

same procedure is applied for all specimens

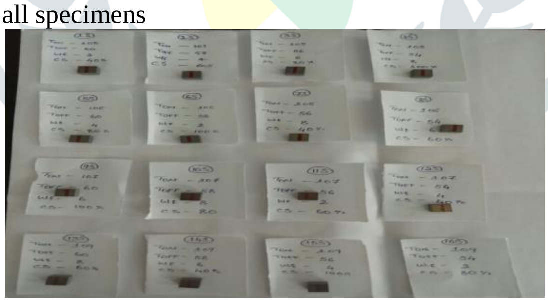

Fig. 2: Al-6061 WEDM Machined Work pieces with square geometry

Table 5: Calculations of Metal Removal Rate for Square pieces

S.No	V_a- mm^3	v- mm^3	W- mm^3	TIME T-	Mrr-	Density-	MRR-
1	416.61	368.2642	48.3458	10.15043	4.762931226	0.0027	0.012859914
2	408.56	368.0389	40.5211	9.3503	4.333668438	0.0027	0.011700905
3	410.16	368.8728	41.2872	8.818	4.682150147	0.0027	0.012641805
4	411.77	369.025	42.745	8.1004	5.276899906	0.0027	0.01424763
5	417.42	368.188	49.232	7.6846	6.406579393	0.0027	0.017297764
6	418.23	368.7967	49.4333	7.1679	6.896482931	0.0027	0.018620504
7	415.8	368.5684	47.2316	6.6342	7.119411534	0.0027	0.019222411
8	414.19	368.9489	45.2411	6.3516	7.122787959	0.0027	0.019231527
9	414.99	366.8204	48.1696	10.3838	4.638918315	0.0027	0.012525079
10	413.38	366.5927	46.7873	10.4001	4.498735589	0.0027	0.012146586
11	414.99	366.5169	48.4731	10.3507	4.683074575	0.0027	0.012644301
12	419.04	365.6069	53.4331	10.351	5.162119602	0.0027	0.013937723
13	421.48	366.59	54.89	10.317	5.320345062	0.0027	0.014364932
14	419.04	365.6069	53.4331	10.4166	5.12961043	0.0027	0.013849948

15	415.8	367.6559	48.1441	10.3681	4.643483377	0.0027	0.012537405
16	414.99	366.2893	48.7007	10.4	4.682759615	0.0027	0.012643451


Fig. 3: Measurement of DD & WWR by using Digital Vernier.

5.2 Regression Equation

Regression equation is used to optimize the output parameters by using the formulae individually. The regression equation is used to calculate the best grade for all the individual parameters. It is used to get the best output value for all parameters by substituting the obtained values in the regression equations from MiniTab-18 Software.

Linear Regression Equation for Square geometry machined hole:

ln(MRR)=-71.9+16.32ln(TN)-1.79ln(TF)+0.1688ln(WF)-0.265ln(CS)
ln(WWR)=-10.3-0.85ln(TN)+2.33ln(TF)+0.165ln(WF)-0.136ln(CS)
ln(DD)=-8.045+1.332ln(TN)+0.002ln(TF)-0.0053ln(WF)-0.0058ln(CS)
ln(Taperness)=47.4-16.4ln(TN)+7.55ln(TF)-0.360ln(WF)-1.402ln(CS)

In real time application the regression equation considered is Non-linear, therefore Non- Linear Regression Equation for Square geometry machined hole are as follows.

MRR= $e^{(-71.9)} TN^{16.32} TF^{1.79} WF^{0.1688}$
WWR= $e^{-10.3} TN^{-0.85} TF^{2.33} WF^{0.165}$
DD= $e^{-8.045} TN^{1.332} TF^{0.002} WF^{-0.0053} CS^{-0.0058}$
Taperness= $e^{47.4} TN^{-16.4} TF^{7.55} WF^{-0.36} CS^{-1.402}$

Proposed GA: GA based optimization for machine assignment in CMS is explained as follows.

Step: 1 Representation

The length of a chromosome represents the number of machines considered in the problem. The geneS in the chromosome indicates the machine number and the position number indicates the machine present in that position. The position of any machine represents its location.

Example: 2 4 1 3 5 8 9 7 6

$$\begin{bmatrix} 241 \\ 358 \\ 976 \end{bmatrix}$$

Here the length of the chromosome is 9, which indicates that the number of machines considered in the problem is 9. The genes in the chromosome take the values 1 to 9 which indicates the machine number. Position of machine 2 is 1, 4 is 2 and so on.

Step: 2 Initialization

Randomly generated population of 40 chromosomes is used as initial population. Each chromosome is converted in to a 3x3 matrix and the objective value is calculated using the objective function equation.

Example: 241358976

Step: 3 Fitness function calculation

Since the objective of this problem is minimization of the following fitness equation, used to calculate the fitness function (Deb 2002).

$$F(x) = 1/(1+f(x))$$

Where, f (x) is the objective function value of each chromosome.

Step: 4 Selection and reproduction

In this process, the probability of selecting the string from initial population is using the relation (Deb2002) and the cumulative probability is also found out. The Roulette wheel selection is used for reproduction by generating random numbers.

Step: 5 Crossover

The single point hybrid technique is utilized for traverse process with a traverse likelihood of 0.4. The hybrid point is haphazardly chosen. After the hybrid procedure, the machine number is checked. In the event that any machine number is rehashed, supplant that machine numbers with another machine number, which is not in the chromosome.

Example:

Parent 1: 241358976
Parent 2: 134579862
Crossover point: 4 (Randomly selected)
After crossover: Child 1: 241379862
Child 2: 134558976

After crossover machine number 2 is repeated in child 1. So machine number 2 is replaced with 5, which is not in the chromosome. Similarly in child 2, machine number 5 is replaced with 2.

Final chromosomes: 1: 241379865
2: 134258976

Step: 6 Mutations

Mutation is done with a mutation probability of 0.04 using Swapping operation. The mutation location is selected randomly.

Example: 2 4 1 3 5 8 9 7 6

Mutation location: 3, 7 (Randomly selected)

After mutation : 249358176

Step: 7 Start the next generations

Step: 8 Terminate after the given number of generations are carried out. The proposed GA is programmed in Mat Lab and run on a PC with Pentium IV CPU.

5.3 Finding of Weights:

In Genetic Algorithm Technique weights are measured based on entropy analysis method.

Table 6: Process Responses for square geometry pieces

S.No	Criteria	**Taperness-** radians	**MRR-** gm/min	**WWR-** mm	**DD-** mm
1.	C1	0.051	0.012121597	0.006	0.15225
2.	C2	0.047	0.012740491	0.007	0.151
3.	C3	0.055	0.013007152	0.008	0.14925
4.	C4	0.002	0.012699966	0.004	0.149
5.	C5	0.008	0.013601366	0.007	0.1555
6.	C6	0.016	0.011515385	0.004	0.1515
7.	C7	0.002	0.025043936	0.007	0.156
8.	C8	0.009	0.025070756	0.005	0.15425
9.	C9	0.002	0.028649171	0.005	0.15975
10.	C10	0.003	0.02747019	0.008	0.15875
11.	C11	0.001	0.030116653	0.004	0.15975
12.	C12	0.026	0.029075054	0.004	0.15975
13.	C13	0.031	0.032355355	0.006	0.164
14.	C14	0.02	0.030963484	0.007	0.157
15.	C15	0.002	0.027080692	0.005	0.15975
16.	C16	0.009	0.029634741	0.006	0.16625
Sum		0.284	0.361145988	0.093	2.50375
Count		16			

Table 7: Normalized pay of matrix

S.No	Criteria	Control of Servo	Pulse on Time	Pulse off Time	Wire Feed
1.	C1	0.179577465	0.033564258	0.064516129	0.0608088
2.	C2	0.165492958	0.035277952	0.075268817	0.0603095
3.	C3	0.193661972	0.036016327	0.086021505	0.0596106
4.	C4	0.007042254	0.035165742	0.043010753	0.0595107
5.	C5	0.028169014	0.037661682	0.075268817	0.0621068
6.	C6	0.056338028	0.031885678	0.043010753	0.0605092
7.	C7	0.007042254	0.069345741	0.075268817	0.0623065
8.	C8	0.031690141	0.069420005	0.053763441	0.0616076
9.	C9	0.007042254	0.079328504	0.053763441	0.0638043
10.	C10	0.01056338	0.076063948	0.086021505	0.0634049
11.	C11	0.003521127	0.083391907	0.043010753	0.0638043
12.	C12	0.091549296	0.080507758	0.043010753	0.0638043
13.	C13	0.10915493	0.089590793	0.064516129	0.0655017
14.	C14	0.070422535	0.085736752	0.075268817	0.0627059
15.	C15	0.007042254	0.074985442	0.053763441	0.0638043
16.	C16	0.031690141	0.08205751	0.064516129	0.0664004
Sum		1	1	1	1

Table 8 : PHI Publication Logarithmic values for Process Parameters

S.No	Criteria	Control of Servo)	Pulse on Time	Pulse off Time	Wire Feed
1.	C1	-1.71715	-3.39429	-2.74084	-2.80002
2.	C2	-1.79883	-3.3445	-2.58669	-2.80827
3.	C3	-1.64164	-3.32378	-2.45316	-2.81992
4.	C4	-4.95583	-3.34768	-3.14631	-2.8216
5.	C5	-3.56953	-3.27911	-2.58669	-2.7789
6.	C6	-2.87639	-3.4456	-3.14631	-2.80496
7.	C7	-4.95583	-2.66865	-2.58669	-2.77569
8.	C8	-3.45175	-2.66758	-2.92316	-2.78697
9.	C9	-4.95583	-2.53416	-2.92316	-2.75193

10.	C10	-4.55036	-2.57618	-2.45316	-2.75821
11.	C11	-5.64897	-2.4842	-3.14631	-2.75193
12.	C12	-2.39088	-2.5194	-3.14631	-2.75193
13.	C13	-2.21499	-2.4125	-2.74084	-2.72568
14.	C14	-2.65324	-2.45647	-2.58669	-2.7693
15.	C15	-4.95583	-2.59046	-2.92316	-2.75193
16.	C16	-3.45175	-2.50033	-2.74084	-2.71205

Table 9: Product of Control of servo and Logarithmic values

S.No	Criteria	Control of Servo	Pulse on Time	Pulse off Time	Wire Feed
1.	C1	-0.30836	-0.11393	-0.17683	-0.17027
2.	C2	-0.29769	-0.11799	-0.1947	-0.16937
3.	C3	-0.31792	-0.11971	-0.21102	-0.1681
4.	C4	-0.0349	-0.11772	-0.13532	-0.16792
5.	C5	-0.10055	-0.1235	-0.1947	-0.17259
6.	C6	-0.16205	-0.10987	-0.13532	-0.16973
7.	C7	-0.0349	-0.18506	-0.1947	-0.17294
8.	C8	-0.10939	-0.18518	-0.15716	-0.1717
9.	C9	-0.0349	-0.20103	-0.15716	-0.17559
10.	C10	-0.04807	-0.19595	-0.21102	-0.17488
11.	C11	-0.01989	-0.20716	-0.13532	-0.17559
12.	C12	-0.21888	-0.20283	-0.13532	-0.17559
13.	C13	-0.24178	-0.21614	-0.17683	-0.17854
14.	C14	-0.18685	-0.21061	-0.1947	-0.17365
15.	C15	-0.0349	-0.19425	-0.15716	-0.17559
16.	C16	-0.10939	-0.20517	-0.17683	-0.18008
Sum		-2.26042	-2.7061	-2.7441	-2.7721

Table 10: Product of Control of servo and Logarithmic values for square geometry

S.No	Processes Response	Entropy Value	1-Entropy value	Weights of Criteria
1.	Taperness	0.81527325	0.18472675	0.842880625
2.	MRR	0.976018842	0.023981158	0.109422447
3.	WWR	0.989724691	0.010275309	0.046884702
4.	DD	0.999821991	0.000178009	0.000812227

VI. OPTIMIZATION USING GENETIC ALGORITHM

Soft computing technique genetic algorithm (GA) technique is used to estimate processes parameters that lead to a minimum value of machining performance. Experimental data and regression modelling are used to estimate the optimal process parameters values that have to be within the range of minima and maxima of processes parameter values of experimental design. Estimated the optimal process parameters reading to the minimum value of machining performance and predicted results in between experimental and actual values.

1. An automatic search for the non-linear connection between the inputs and outputs.
2. Fast and simple optimizing technique.
3. Estimate the potential minimum value of the machining performance with the recommended optimal processes parameters.
4. In the GA based optimization module, the predicted equation of the regression model would define the optimization objective function. The minimum and maximum processes parameter values of experimental design would define the optimization limitation constraints. Based on some criteria the minimum predicted performance value at the optimal solution was estimated.

$GA=Ra_{=}C\ V^{q}P^{r}h^{s}d^{r}\ m^{u}$------ Non-linear

$Ln\ Ra= lnC+qlnv+rlnp+slnh+rln\ d+ u\ ln\ m$----- LinEar

GA is Multi-objective optimization tool. GA must be iterated many times in order to produce a usable result for a non-trial problem.

Table 11: Optimal solution obtained by GA parameter combination

S.No	Parameters	Setting value / Function type
1	Population Size	100
2	Scaling Function	Rank
3	Selection Function	Rollete wheel
4	Cross over function	Heuristic
5	Cross over rate	0.8
6	Mutation function	Adaptive feasible

Regression Equation

Regression equations along with weights are considered as input to run Genetic Algorithm module.

Square Fitness function:

$$Y= (((0.109*(5.946025*10^{-32}*X^{16.32}*Y^{1.79}*Z^{0.1688}*r^{-0.265}))+(0.001*(3.2070*10^{-4}*X^{1.332} *Y^{0.002} *Z^{-0.0053} *r^{-0.0058}))^{-1})+(0.843*(3.8508*10^{20}*X^{-16.4}*Y^{7.55}*Z^{-0.360}*r^{-1.402}))^{-1}+ (0.047*(3.3633*10^{-5}*X^{-0.85}*Y^{2.33}*Z^{0.165}*r^{-0.136}))^{-1}$$

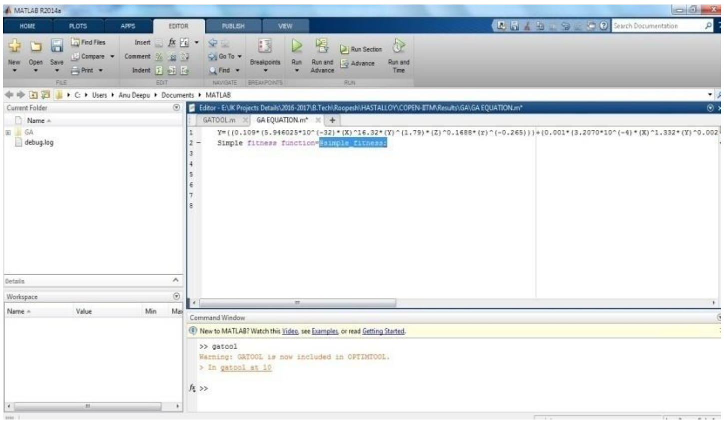

Fig. 4: Regression equation for square geometry placed in Mat lab script

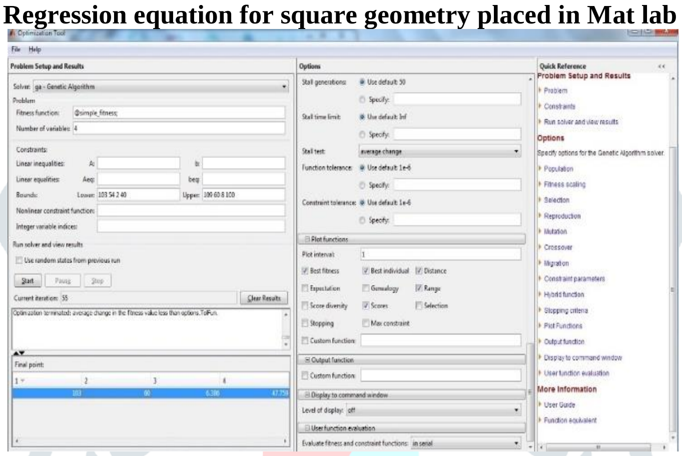

Fig. 5: Assign Fitness function and bounds in GA Tool

Optimal Process Parameters

Table 12: Optimal processes parameter obtained by Genetic Algorithm Tool

S.No	Geometry	T_{ON} µs	T_{OFF} µs	WFR mm/min	COS %	Iterations
1.	Square	103	59.99999993	6.45106078	92.5257256	85

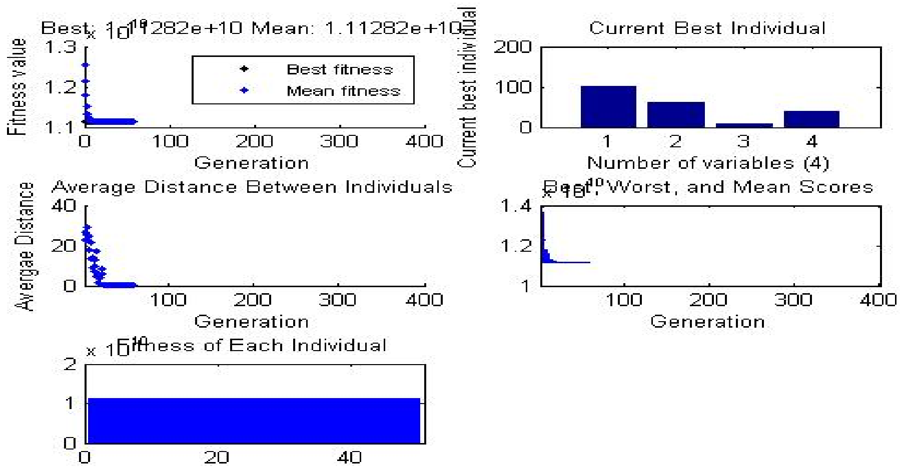

Fig.6: Fitness function graph for Square geometry Machining

Fig.7: Finally machined square work-pieces for identification of error

Table 13: Optimum parameter control level for Square Geometry

S.No	Geometry	Processes Response	Experimental	Optimal Value	% of Error
1.	Square	MRR (gm/min)	0.07657	0.07589	0.8960
2.		Wire Wear Rate (mm)	0.006798	0.0068536379	0.9653
3.		Dim. Deviation (mm)	0.14678	0.14964	1.9484
4.		Taperness- (radians)	0.008851432	0.00885364	1.0992

$$\text{Experimental Error}=\frac{\text{Actual-Experimental}}{\text{Actual}}\times 100$$

From the confirmation experiments, the error percentage of process responses from the predicted responses is less than 2%.

VII. CONCLUSIONS

In this work Wire cut Electrical Discharge Machining is used for machining of Al6061. Square geometry were carried out to investigate the effects of process parameters (i.e., Pulse on Time, Pulse off time, Wire feed rate and Control of speed) on the quality of machined work-pieces such as Metal Removal Rate (MRR), Dimensional Deviation (DD), Wire Wear Rate (WWR) and Taperness. Conclusions are drawn based on Genetic Algorithm Technique.

1. Four factors four level factorial design matrixes were effectively used for the development of mathematical models regression equations.
2. The Control of Servo (COS) has major effect on the chosen output responses compared to the other four Input Processes parameters and has 92.5257256% for square hole. Control of speed show its effect on Taperness and Dimensional deviation, which should be maintained at optimum range.
3. Effect of Pulse on Time (T_{ON}) is a most significant factor on Metal Removal rate. Pulse on Time generates a lot of high discharge energy and spark.
4. The effect of Pulse off Time (T_{OFF}) is a most significant factor on Metal Removal rate. During Pulse off Time not machining will happen because of no spark. Such that Pulse off Time has to reduce to improve Metal removal rate.
5. The Wire Feed Rate (WFR) shows its effect on Wire wear rate. By reducing the wire feed rate and increasing the Pulse on Time wire wear rate increases.
6. It was found that optimized processes parameters for square geometry is COS-92.5257%, T_{ON}-103, T_{OFF}-59.99999,WFR-6.4510 for attaining the better quality in wire cut electrical discharge machining processes for AL-6061.

The accuracy of the developed mathematical models was tested by conformity tests with the experiments and the optimal results show that the accuracy of all the models was around 98%.

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