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# Application of MATLAB INMODELING and Optimization of Unconventional Finishing Process

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## ABSTRACT

Increasing demand of high accuracy and high efficiency machining of difficult-to-machine materials is making the application of abrasive finishing technologies increasingly important. Among those unconventional processes the magnetic abrasive finishing (MAF) and electric discharge machining (EDM)process are most importantly used in manufacturing industries. These processes can produce surfaces with surface finish in nanometerrange and dimensional accuracy up to 0.5 µm. In order to predict the effect of various machining parameters on material removal rate, tool wear rate and surface roughness value, it is important to model and optimise these machining parameters. In the present research work the process parameters of a MAF process are optimized using a very effective evolutionary algorithm termed as genetic algorithm (GA). Response Surface Methodology is applied for developing the models using the techniques of Design of Experiments and Central composite rotatable design was used to plan the experiments. The software used for design of experiments is Design Expert and that for implementing GA is MATLAB. The four input parameters under consideration are current to the electromagnetic coil (magnetic flux density),machining gap, grain size(mess no.) and number of cycles and two response variables are material removal(MR) and surface roughness value(ΔRa),tool wear rate(TWR).

**Keywords:** *Alloy steel, unconventional Finishing process, MAF,EDM Response Surface Methodology, Surface Roughness, Analysis of Variance(ANOVA), Genetic Algorithm, GA Toolbox, MATLAB,DESIGN EXPERT*

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## 1.INTRODUCTION

### 1.1Unconventional machining process

Finishing is final operation involved in the manufacturing of components and is most labour intensive, time consuming and least controllable area. The need of better finishing of complicated shapes made of advanced materials and high accuracy are the main factors responsible for using advanced abrasive fine finishing processes (Jain,2002).

### 1.2 Electric Discharge Machining

Electrical discharge machining (EDM) is one of the most extensively used nonconventional manufacturing processes used for hard materials which are very difficult to machine with conventional techniques. EDM is sometimes referred to as spark machining, spark eroding, burning, die sinking or wire erosion. This is a manufacturing process whereby a desired shape is obtained using electrical discharges (sparks). English chemist Joseph Priestly laid the foundation for EDM by discovering the erosive effect of electrical discharges or sparks in 1770. However EDM was discovered in 1943 by two Russian scientists B. R. Lazarenko and N. I. Lazarenkowhen they explored the destructive properties of electrical discharges for constructive purpose. They developed a controlled process for machining difficult-to-cut materials. They invented and applied resistance capacitance (RC) relaxation circuit in EDM that was widely used till 1950s and after that several developments and advancements were made by different researchers in the field of EDM. Electrical Discharge Machining (EDM) is a non-conventionalmachining process, where electrically conductive materials is machined by using precisely controlled sparks that occur between an electrode and a workpiece in the presence of a dielectric fluid.It uses thermoelectric energy sources for machining extremely low machinability materials; complicated intrinsic-extrinsicshaped jobs regardless of hardness have been its distinguishing characteristics.

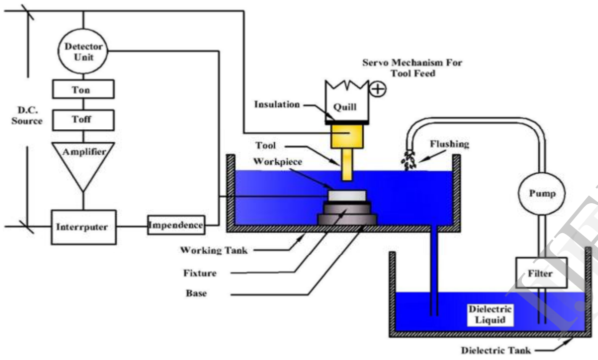


**Figure 1.1**: Layout of Electric Discharge Machining

## 1.3 Magnetic Abrasive Finishing (MAF)

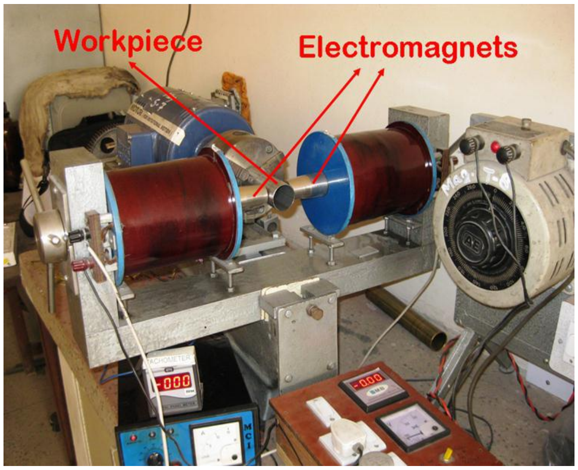


**Figure1.2:Cylindrical work piece machining on magnetic abrasive finishing machine[1]**

MAF is an unconventional finishing process in which the cutting force is primarily controlled by the magnetic field. It reduces the possibility of microcracks on the surface of the workpiece, specially in hard brittle material, due to low forces acting on abrasive particles (Jain, 2002). This process is capable of producing surface roughness in the nanometer range on flat surfaces as well as internal and external cylindrical surfaces (Jain et al., 2001). The MAF process offers many advantages, such as self-sharpening, self-adaptability, controllability and the finishing tools require neither compensation nor dressing (Chang et al., 2002). In MAF, the workpiece is kept between the two poles of a magnet. The working gap between the workpiece and the magnet is filled with magnetic abrasive particles, composed of ferromagnetic particles and abrasive powder. Bonded or unbounded Magnetic abrasive particles can be used. In this process, usually ferromagnetic particles are sintered with fine abrasive particles (Al2O3, SiC, CBN, or diamond) and such particles are called ferromagnetic abrasive particles (Shinmura et al., 1986, 1990; Chang et al., 2002; Jain, 2009).

### Common magnetic materials

- Iron and its oxides
- Cobalt
- Nickel
- Steel and Stainless Steel

### Common Abrasive Materials

- Synthetic Diamond
- Cubic Boron Nitride CBN
- Aluminium Oxide Al2O3
- Silicon Carbide SiC

### Common Magnetic Abrasive Materials

- White Alumina + Iron
- Diamond + Iron
- Tungsten Carbide + Cobalt

# 2.EXPERIMENTATION

## 2.1 Experimental setup

A schematic diagram of the plane MAF apparatus is shown in Figure 2.1. The flat-faced electromagnet has been designed such that the centre part of the magnet acts as a north pole and outer case as south pole. The reason of doing so that it concentrates magnetic force at the Centre of the magnet. The gap between the flat workpiece and the magnetic poles is known as working gap or machining gap and is filled with unbound magnetic abrasive particles. The iron particles are magnetized by the induced magnetic flux (by passing a current to the coil) and are coupled magnetically. These particles are concentrated in the machining gap. The finishing setup is attached to the main spindle of the machine through a holder. The current supplied to the coil of electromagnet is given by a device consisting of brass slip rings and electric carbon brushes.

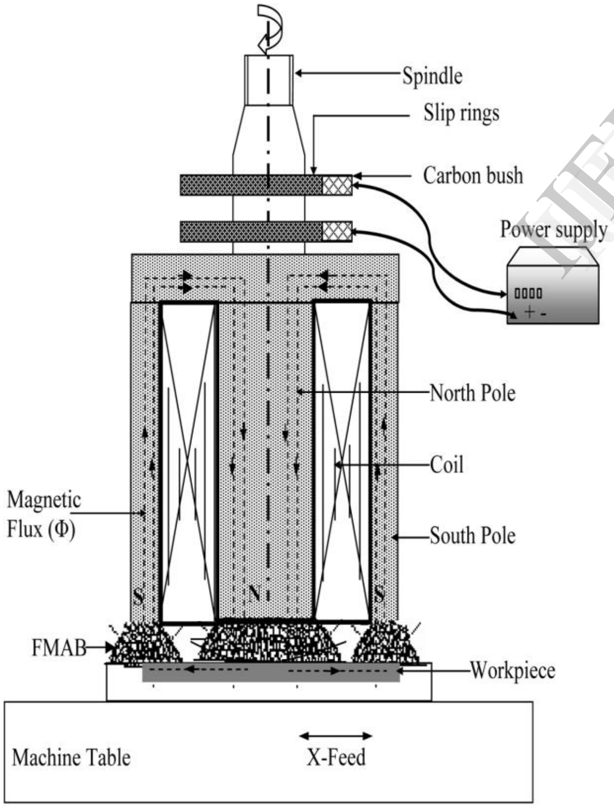


**Figure 2.1: Schematic diagram of plane magnetic abrasive finishing setup. (Source D.K.Singh et. al.)**

During the design of the setup, the parameters that have been considered are magnetic flux density (current), machining gap, and composition of ferromagnetic abrasive particles (ratio of iron particles and SiC abrasive particles in the gap).

## 2.2 Work piece composition

Alloy steel is considered as work piece for the experimental work.

**Table 2.1: Workpiece Material composition (Alloy Steel)**

| Alloying elements | percentage |
|---|---|
| C | 0.35-0.45 |
| Mn 0.45-0.60 | |
| Si | 1.31-1.81 |
| Cr | 0.20-0.30 |
| Ni | 0.10-0.30 |
| Iron | Rest |

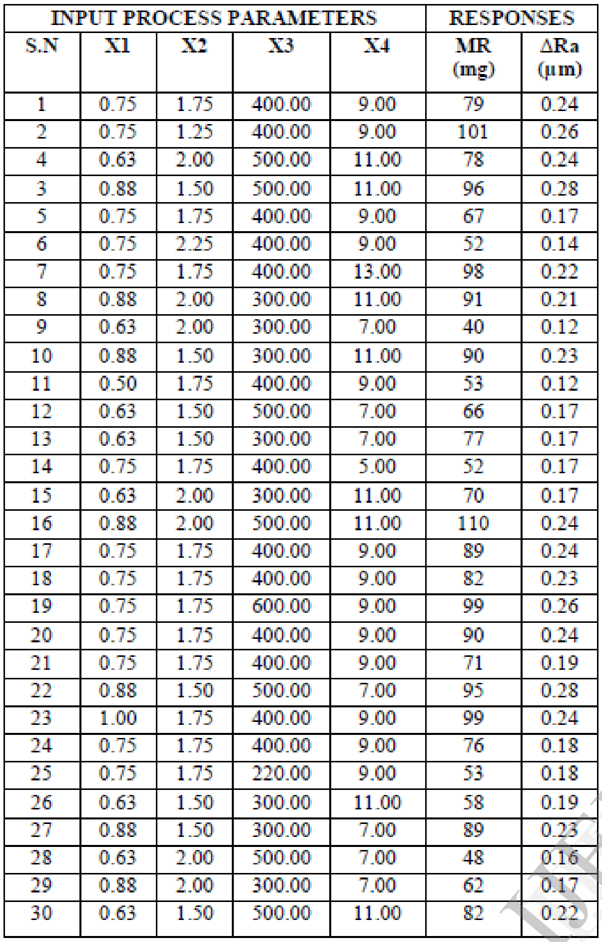
## 2.3 Experimental design

The various levels of machining parameters are selected based on the previous studies. The considered machining parameters and their coded levels are represented in table 2.2 Experiments have been planned using statistical technique to get useful inferences by performing minimum number of experiments. Design Expert software was used for designing of experiments.

**Table 2.2: Machining Parameters and Their Corresponding Variation Levels.**

| **Parameters(unit)** | **levels** | | | | |
|---|---|---|---|---|---|
| | **-2** | **-1** | **0** | **1** | **2** |
| current (amp) | 0.5 | 0.63 | 0.75 | 0.88 | 1.0 |
| Machining gap (mm) | 1.25 | 1.50 | 1.75 | 2.00 | 2.25 |
| Grain size(mesh no) | 220 | 300 | 400 | 500 | 600 |
| Number of cycles | 5 | 7 | 9 | 11 | 13 |

**TABLE 2.3: Table for Design of Experiments and Responses**



| INPUT PROCESS PARAMETERS | | | | | RESPONSES | |
|---|---|---|---|---|---|---|
| S.N | X1 | X2 | X3 | X4 | MR (mg) | ΔRa (µm) |
| 1 | 0.75 | 1.75 | 400.00 | 9.00 | 79 | 0.24 |
| 2 | 0.75 | 1.25 | 400.00 | 9.00 | 101 | 0.26 |
| 4 | 0.63 | 2.00 | 500.00 | 11.00 | 78 | 0.24 |
| 3 | 0.88 | 1.50 | 500.00 | 11.00 | 96 | 0.28 |
| 5 | 0.75 | 1.75 | 400.00 | 9.00 | 67 | 0.17 |
| 6 | 0.75 | 2.25 | 400.00 | 9.00 | 52 | 0.14 |
| 7 | 0.75 | 1.75 | 400.00 | 13.00 | 98 | 0.22 |
| 8 | 0.88 | 2.00 | 300.00 | 11.00 | 91 | 0.21 |
| 9 | 0.63 | 2.00 | 300.00 | 7.00 | 40 | 0.12 |
| 10 | 0.88 | 1.50 | 300.00 | 11.00 | 90 | 0.23 |
| 11 | 0.50 | 1.75 | 400.00 | 9.00 | 53 | 0.12 |
| 12 | 0.63 | 1.50 | 500.00 | 7.00 | 66 | 0.17 |
| 13 | 0.63 | 1.50 | 300.00 | 7.00 | 77 | 0.17 |
| 14 | 0.75 | 1.75 | 400.00 | 5.00 | 52 | 0.17 |
| 15 | 0.63 | 2.00 | 300.00 | 11.00 | 70 | 0.17 |
| 16 | 0.88 | 2.00 | 500.00 | 11.00 | 110 | 0.24 |
| 17 | 0.75 | 1.75 | 400.00 | 9.00 | 89 | 0.24 |
| 18 | 0.75 | 1.75 | 400.00 | 9.00 | 82 | 0.23 |
| 19 | 0.75 | 1.75 | 600.00 | 9.00 | 99 | 0.26 |
| 20 | 0.75 | 1.75 | 400.00 | 9.00 | 90 | 0.24 |
| 21 | 0.75 | 1.75 | 400.00 | 9.00 | 71 | 0.19 |
| 22 | 0.88 | 1.50 | 500.00 | 7.00 | 95 | 0.28 |
| 23 | 1.00 | 1.75 | 400.00 | 9.00 | 99 | 0.24 |
| 24 | 0.75 | 1.75 | 400.00 | 9.00 | 76 | 0.18 |
| 25 | 0.75 | 1.75 | 220.00 | 9.00 | 53 | 0.18 |
| 26 | 0.63 | 1.50 | 300.00 | 11.00 | 58 | 0.19 |
| 27 | 0.88 | 1.50 | 300.00 | 7.00 | 89 | 0.23 |
| 28 | 0.63 | 2.00 | 500.00 | 7.00 | 48 | 0.16 |
| 29 | 0.88 | 2.00 | 300.00 | 7.00 | 62 | 0.17 |
| 30 | 0.63 | 1.50 | 500.00 | 11.00 | 82 | 0.22 |

Where X1 X2 X3 X4 are in actual levels values of current, machining gap, grain size and no of cycles. ,whose coded values are in table 2.2.

## 3.MODELLING OF PROCESS PARAMETERS

In the present work response surface methodology is used to model the process.A central composite design is adopted to develop model.

The statistical software (design expert) has been employed to analyse the experimental findings (Table2.3), and the following regression models have been evolved:

Equation for material removal is given by-

$$\begin{aligned} MR &= 79.47 + 22.80\,X1 - 15.35X2 + 12.18X3 \\ &+ 19.23X4 - 3.00X12 \; - 2.49X22 - 2.52X32 \\ &- \; 3.99X42 + 1.87X1X2 + 1.05X1X3 \\ &+ 4.31X1X4 + 3.34X2X3 + 33.49X2X4 \\ &+ 11.86X3X4 \qquad (2) \end{aligned}$$

And equation for surface roughness is given by-

$$\begin{aligned} \Delta Ra &= 0.21 + 0.055X1 - 0.040X2 + 0.038X3 \\ &+0.032X4 - 0.029X12 - 0.008963X22 \\ &+0.009668X32 - 0.014X42 - 0.033X1X2 \\ &+0.006102X1X3 - 0.031X1X4 + 0.011X2X3 \\ &+0.034X2X4{+}0.013X3X4 \qquad (3) \end{aligned}$$

### 3.1 Analysis of variance (ANOVA) of regression

Analysis of variance (ANOVA) is a procedure for assigning sample variance to different sources and deciding whether the variation arises within or among different population groups. Samples are described in terms of variation around group means and variation of group means around an overall mean. If variations within groups are small relative to variations between groups, a difference in group means may be inferred. Hypothesis Tests are used to quantify decisions. ANOVA table for MR and Ra is shown in table 3.2 and table 3.3 respectively.

**Table3.2:Analysis of variance(ANOVA) of regression for ΔRa**

| Sourcedofss | f | p | percentage | | |
|---|---|---|---|---|---|
| Regression | 14 | 0.0482 | 6.42 | 0.0003 | 84.9 |
| Residual error | 16 | 0.0086 | --15.1 | | |
| Total30 | 0.0568 | - | - 100 | | |

**Table3.3:Analysis of variance(ANOVA) of regression for MR**

| Sourcedofss | f | p | percentage | | |
|---|---|---|---|---|---|
| Regression | 14 | 8758.70 | 6.59 | 0.0002 | 82.6 |
| Residual error | 16 | 1519.10- | - | 17.6 | |
| Total30 | 10277.80 | - | -100 | | |

***significance at 95% confidence interval.***

F value for Ra is found to be 6.59 which is greater than standard f value(2.35),means our data is highly correlated and p value is almost found to be zero.

The analysis of variance (ANOVA, Table 4 and5) indicates that the variance ratio (F) is more than the standard value of F (¼2.35) at 95% confidence interval (a ¼ 0.05) for both the responses. Their P values come out to be zero .These statistical terms i.e., variance ratio (F) and P value are used tomeasure the significance of the regression under investigation. On the basis of these F and P values, it can be concluded that there is a good correlation between the predicted and the experimental values. Therefore, the regression Equation 2 for ΔRa and Equation 3 for material removal (MR) can be used to predict the responses of the MAF process.

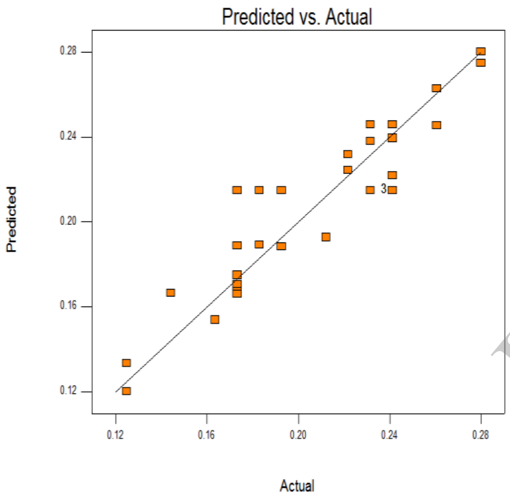


**Fig 3.1 plot of actual vs predicted value for ΔRa**

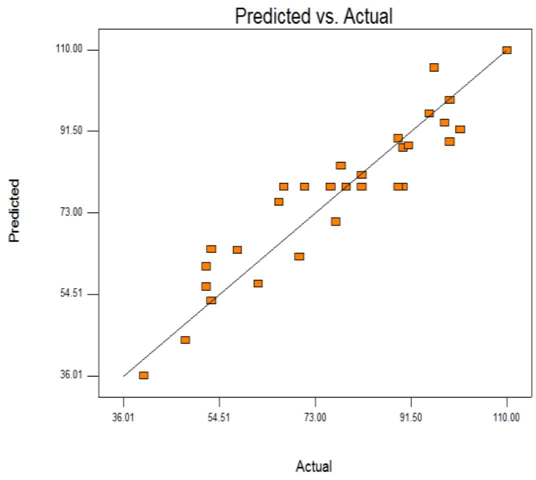


**Fig 3.2 plot of actual vs predicted value for mr**

Figure 3.1,3.2 shows the graphs between actual and predicted value.it clearly indicates a straight line which means our model responses mr and ΔRa are very close to the actual values.

### 3.2 Percentage contribution of factors

Table3.4for percentage contribution of factors in responses is also presented based on the result of anova. It clearly indicates the contribution of different factors in reduction in surface roughness value and amount of material removed.

Table3.4:Percentage Contribution Of Factors

| **Factors** | **MR (mg)** | **ΔRa (μm)** |
|---|---|---|
| Current (Magnetic flux density) X1 | 30.63% | 33.33% |
| Machining gap X2 | 14.01% | 17.66% |
| Grain mesh number X3 | 9.69% | 17.38% |
| Number of cycles X4 | 21.99% | 11.40% |
| Error | 23.68% | 20.23% |
| Total | 100 | 100 |

Error obtained is due to the negligence of higher order terms in the analysis of variance of regression. From the above table it can be concluded that material removal and reduction in surface roughness is affected mostly by current to the electromagnet.

## 4.OPTIMISATION WITH GA

### 4.1 Genetic algorithm

The EA holds a population of individuals (chromosomes), which evolve my means of selection and other operators like crossover and mutation. Every individual in the population gets an evaluation of its adaptation (fitness) to the environment. In the terms of optimization this means, that the function that is maximized or minimized is evaluated for every individual. The selection chooses the best gene combinations (individuals), which through crossover and mutation should drive to better solutions in the next population.

## 4.2 Basic steps of GA

- Generate initial population
- Calculation of the values of the function that we want to minimize of maximize.
- Check for termination of the algorithm
- Selection
- Crossover
- Mutation
- New generation

## 4.3 Fitness function

The fitness function is any function, which you want to optimize. For standard optimization algorithms, it is known as the objective function. GAs follows the 'survival-of-the-fittest' principle of nature to make a search process.

GAs are naturally suitable for solving maximization problems. All minimization problems are usually transformed into maximization problems by suitable transformations.

### *Fitness function for MR*

function y = objective(x)

$$y(1) = -((307.80428) + (89.19921 \ast x(1)) - (172.1285$$

$$\ast x(2)) - (0.097110 \ast x(3)) - (29.64022 \ast x(4)$$

$$-\left(48.02137 \ast (x(1)^2)\right) - \left(9.96576 \ast (x(2)^2)\right)$$

$$-\left(0.0000698313 \ast (x(3)^2)\right) - \left(0.24947 \ast (x(4)^2)\right)$$

$$+\left(14.96249 \ast x(1) \ast x(2)\right) + \left(0.022038 \ast x(1) \ast x(3)\right)$$

$$+\left(4.31306 \ast x(1) \ast x(4)\right) + \left(0.035112 \ast x(2) \ast x(3)\right)$$

$$+(16.74442 \ast x(2) \ast x(4)) + (0.015611 \ast x(3) \ast x(4)));$$

### *Fitness function for ∆Ra*

function ra =shukla(x)

$$ra(1) = ((-0.46892) + (1.60717 \ast x(1)) + (0.043693$$

$$\ast x(2)) - (0.00046892 \ast x(3)) + (0.010948 \ast x(4))$$

$$-\left(0.46689 \ast (x(1)^2)\right)$$

$$-\left(0.035851 \ast (x(2)^2)\right)$$

$$+ (0.00000026781 \ast (x(3){}^\wedge 2))$$

$$- (0.000872671 \ast (x(4){}^\wedge 2))$$

$$- (0.26191 \ast x(1) \ast x(2))$$

$$+ (0.000128469$$

$$\ast x(1) \ast x(3)) - (0.031227 \ast x(1) \ast x(4)) + (0.000114900$$

$$\ast x(2) \ast x(3)) + (0.016755 \ast x(2) \ast x(4)) + (0.000016887$$

$$\ast x(3) \ast x(4)));$$

These functions acts as the fitness functions for our problem. variation of factors for both the functions are as follows-

$0.5<x1<1.0$

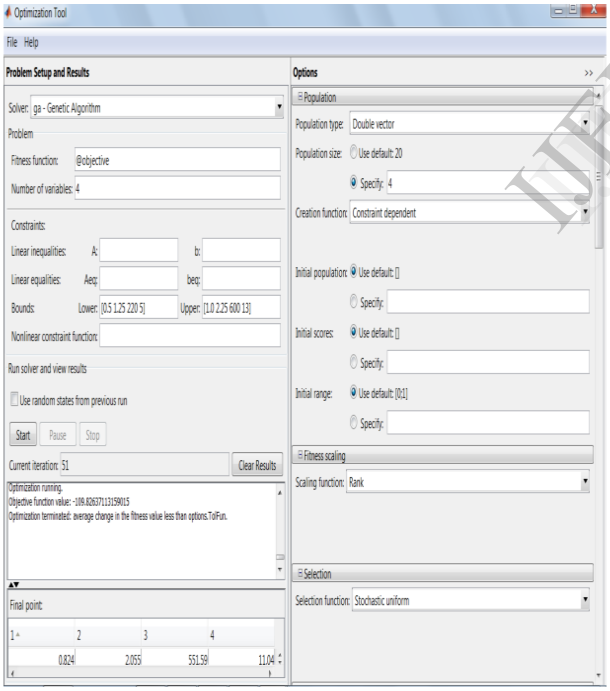
$1.25<x2<2.25$

$220<x3<600$ and

$5<x4<13$

The above two fitness functions are used in ga toolbox in matlab.this toolbox can be easily accessed by simply typing gatool in matlab command window.

| S.N | CURRENT (amp) | MACH. GAP (mm) | GRAIN SIZE (Mesh no.) | No. Of Cycle | MR (mg) |
|---|---|---|---|---|---|
| 1 | 0.50 | 1.25 | 220 | 5 | 84.5233 |
| 2 | 0.911 | 1.391 | 324.731 | 10.555 | 93.1472 |
| 3 | 0.692 | 1.25 | 220 | 5 | 99.3082 |
| 4 | .999 | 1.787 | 385.298 | 10.807 | 106.6533 |
| 5 | .824 | 2.055 | 551.59 | 11.04 | 109.8263 |
| 6 | .865 | 1.25 | 510.798 | 7.808 | 107.0072 |
| 7 | .932 | 1.25 | 461.009 | 7.602 | 110.6545 |
| 8 | .688 | 1.507 | 591.371 | 10.132 | 91.6999 |
| 9 | .677 | 2.232 | 462.717 | 12.983 | 108.3185 |
| 10 | .972 | 1.25 | 531.048 | 5.364 | 113.0458 |



Solver: ga - Genetic Algorithm

Problem

Fitness function: @objective

Number of variables: 4

Constraints:

Linear inequalities: A: b:

Linear equalities: Aeq: beq:

Bounds: Lower: [0.5 1.25 220 5] Upper: [1.0 2.25 600 13]

Nonlinear constraint function:

Run solver and view results

☐ Use random states from previous run

Current iteration: 51

```
Optimization running.
Objective function value: -109.82637113159015
Optimization terminated: average change in the fitness value less than options.TolFun.
```

| 1 | 2 | 3 | 4 |
|---|---|---|---|
| 0.824 | 2.055 | 551.59 | 11.04 |

Population

Population type: Double vector

Population size: ○ Use default: 20 ● Specify: 4

Creation function: Constraint dependent

Initial population: ● Use default: [] ○ Specify:

Initial scores: ● Use default: [] ○ Specify:

Initial range: ● Use default: [0;1] ○ Specify:

Fitness scaling

Scaling function: Rank

Selection

Selection function: Stochastic uniform

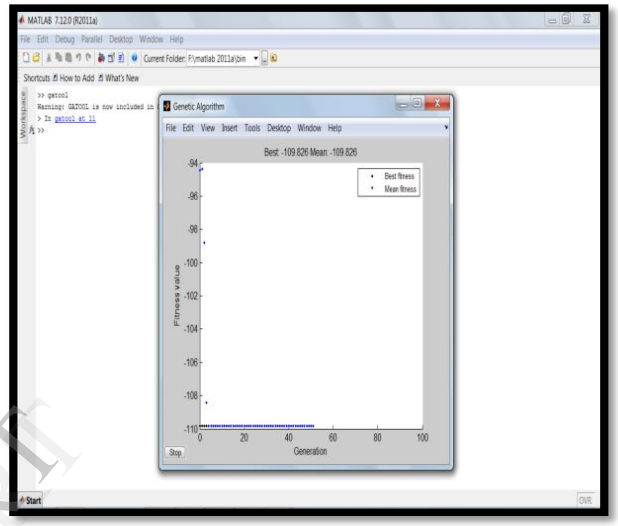
**Fig 4.1:Snapshot of GA toolbox(matlab 2011a)**

# 5.RESULTS AND DISCUSSION

## 5.1 Result for MR

**TABLE 5.1 Result From Genetic Algorithm for MR**

Based upon the result obtained from data the final optimized value of MR is found to be 109.8263 mg.



```
>> gatool
Warning: GATOOL is now included in
> In gatool at 11
>>
```

**Fig5.1: Fitness curve for MR**

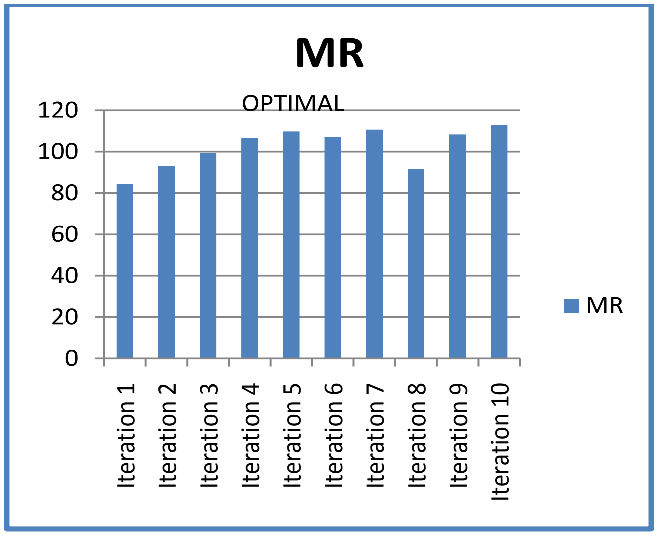


**Fig5.2: Iterations vs MR**

## 5.2 Result for ΔRa

**TABLE 5.2: Result From Genetic Algorithm for ΔRa**

| S.N | CURRENT (amp) | MACH .GAP (mm) | GRAIN SIZE (Mesh no.) | No. Of Cycle | ΔRa (µm) |
|---|---|---|---|---|---|
| 1 | 0.634 | 1.291 | 220 | 5 | 0.1655 |
| 2 | 0.880 | 1.962 | 330.791 | 11.962 | 0.2029 |
| 3 | 0.811 | 1.832 | 230.399 | 12.307 | 0.1932 |
| 4 | 0.511 | 1.908 | 327.37 | 9.476 | 0.1258 |
| 5 | 1.000 | 1.804 | 289.305 | 12.957 | 0.1905 |
| 6 | 0.569 | 2.083 | 417.661 | 7.689 | 0.1192 |
| 7 | 0.882 | 1.872 | 285.913 | 8.388 | 0.1939 |
| 8 | 0.574 | 1.647 | 471.117 | 6.449 | 0.1371 |
| 9 | 0.691 | 1.808 | 372.037 | 5.293 | 0.1389 |
| 10 | 0.566 | 2.209 | 558.993 | 8.164 | 0.1554 |

Based upon the result obtained from data the final optimized value of ΔRa is found to be 0.2029 µm.

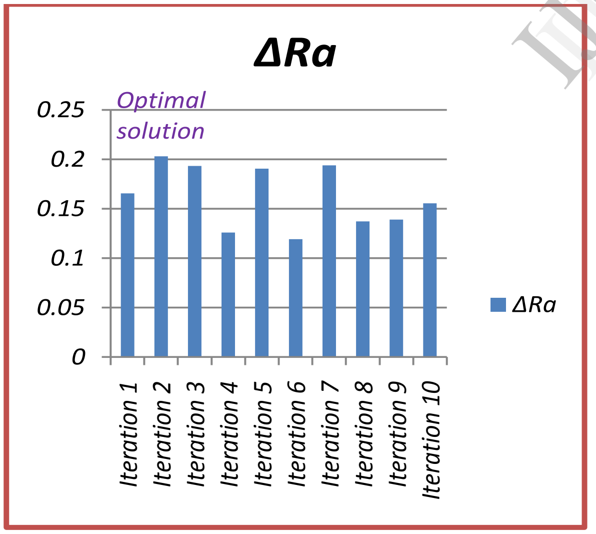


**Fig 5.3:Iteration vs ΔRa**

Based upon the result obtained from data the final optimized value of Ra is found to be 0.2058 µm and that for MR is 109.8263 mg. Corresponding values for parameters are shown in their respective rows. Some of the readings are found to be out of range so they are neglected. Current and machining gap are the most influencing parameters .These largely affect surface roughness value and material removal.

## 6.CONCLUSIONS

By completing the above work it can be conclude that response of any unconventional finishing process can be controlled by controlling process parameter variables. Table 5.1 and 5.2 shows the various optimized solutions of the problem for MR and ΔRa respectively for mafprocess.For optimising responses genetic algorithm is used.The result obtained by GA are very accurate.

Also the same methodology can be applied on any of the unconventional processes such as electric discharge machining(EDM),ECM etc.

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