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Optimization of Micro EDM Process Using Multi Objective Grasshopper Optimization Algorithm (MOGOA)

B.Sc. Engineering (Mechanical) Thesis

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CERTIFICATE OF RESEARCH

The thesis title **“Optimization of Micro EDM Process Using Multi Objective Grasshopper Optimization algorithm”** submitted by **Mohmmad Shadman Sakib** has been accepted as satisfactory in partial fulfillment of the requirement for the Degree of Bachelor of science in Mechanical Engineering on March 2021.

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Candidate's Declaration

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

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Abstract

The complex cross sectional micro-operation entails precise and stable micro machining processes. Localized electrochemical deposition in micro EDM operation is an inexpensive meticulous machining approach which can maneuver a variation of structures. The discharge energy of RC type pulse generator depends on capacitance and pulse voltage which have direct impact on Material Removal Rate (MRR), Relative Wear Ratio (RWR), Average Spark Gap (ASG) and Average Taper Angle (ATA). In this book, the optimal performance of MRR, RWR, ASG and ATA are optimized using Multi Objective Grasshopper Optimization Algorithm (MOGOA) on steel, copper, brass and aluminium are investigated. The desired condition of micro EDM operation is higher MRR and lower RWR, ASG and ATA in order to minimize the discharge energy of the machining process. The objective of the book is to find the optimal set of parameters that satisfies the multi conflicting optimizing parameters. The effect of the workpiece materials at different operating conditions are investigated to determine the effect of the optimizing parameters on the tool efficiency, workpiece efficiency and dimensional accuracy are studied. The optimization algorithm is evaluated with diverse optimization algorithms.

Keywords: **micro EDM, MOGOA, MRR, RWR, ASG, ATA**

CHAPTER 1
INTRODUCTION

The micro EDM process is a non-conventional fabrication machining process which is simple, inexpensive and precise used to fabricate on complex cross-sectional workpiece. The non-conventional fabrication process die sinking EDM, wire EDM, EDM grinding, rapid prototyping (RP) uses electrode for machining operation. [1] The EDM operation works on thermoelectric energy applied between workpiece and an electrode submerged in dielectric fluid medium. The researchers are developing EDM machine capable of operate on verities of cross sections. The EDM operation is very useful to fabricate on hard and brittle and conductive material as the electrodes capability of melting any conductive material. The EDM machined operation depends on thermal conductivity, melting point and electrical resistivity[2][3]. The EDM operation involves a series of electrical discharge between two electrodes. Localized Electro Chemical Deposition is a non-conventional machining process which is cost efficient and provides smooth performance. [4][5] The machining process on complex cross sectional area can be achieved using a non-conductive milled mask and the cathode is positioned at the z axis.

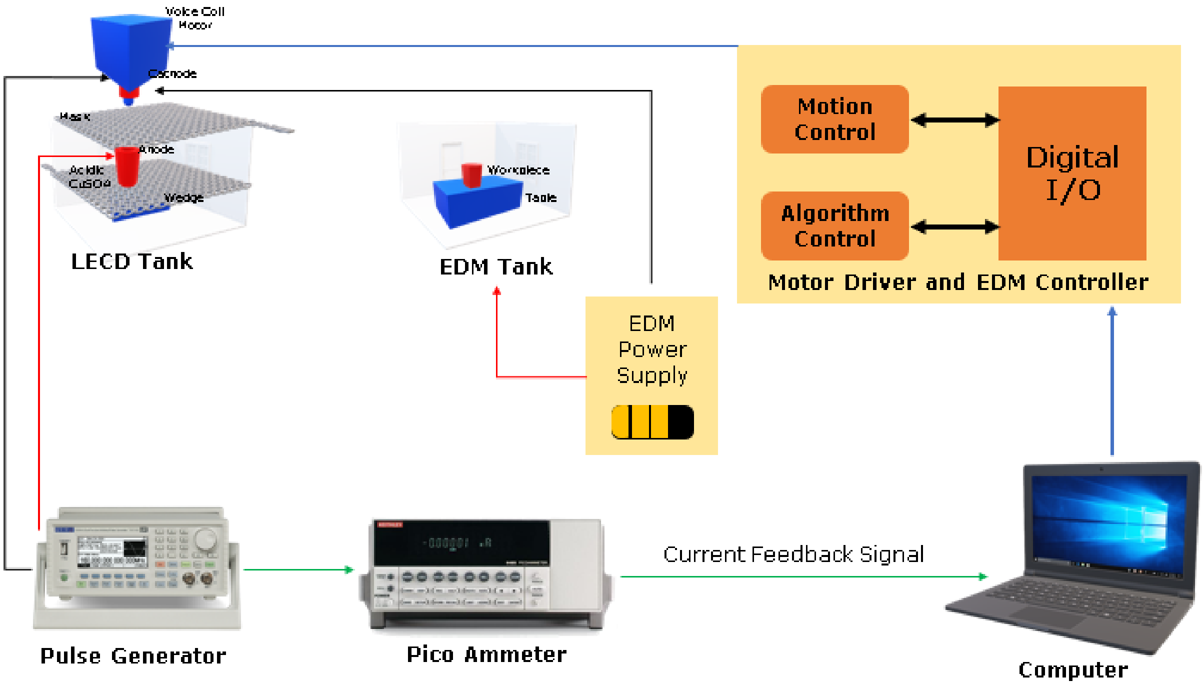


Figure 1.1: Schematic of LECD EDM combined process

The nature inspired grasshopper optimization algorithm imitated from the navigation mechanism of grasshopper. The similarity of the grasshopper across the nymph stage and the adult stage has inspired in the formulation of the optimization algorithm. The meta-heuristic algorithm provides better output in case of minimizing or maximizing functions. The objective of the meta-heuristic algorithm is to develop set of optimized values within the provided constrains highly recommended for real life complex dynamic problems. The algorithm investigates set of optimal solution iteratively until best fit value is obtained. [6] The industrial type real life hard optimization problems [7] requires iterative approach to determine the best set of optimal value from the optimization. Grasshopper Optimization algorithm was introduced by Saremi, Shahrzad Mirjalili, Seyedali Lewis and Andrew based on the swarming behavior of the grasshopper.[8] The fast and easy implementing capability has provided grasshopper optimization algorithm an advantageous edge over other metaheuristic algorithm.

In this book, multi objective optimization has been simulated on the experimental data of the electrodes made of steel, copper, brass and aluminium for fabricated LECD in micro EDM operation [9]. The impacting parameters on the micro EDM operation namely material removal rate, relative wear ratio, average spark gap and average tapper angle to obtain combination of optimal parameters.

CHAPTER 2
LITERATURE REVIEW

The high precision industrial level operation for non-conventional and contact free operational processes can be executed using Electro Discharge Machining (EDM) which is very essential for manufacturing industries, automotive industries and plays a vital role in communication and technology industries. The EDM process is suitable for hard and brittle conductive material machining operation. The electrical generated pulse can melt any conductive material which can be useful for micro machining operations. The criteria that determine EDM machining operations are thermal conductivity, electrical resistivity and melting point of the workpiece material. The electrodes are submerged in dielectric fluid medium commonly used as kerosene, deionized water etc.

2.1 Brief review on micro EDM operation

The EDM operation are the common contact free machining process mostly classified as dry EDM, wire EDM and micro EDM. [10][11][12][13] The wire EDM has been a priority in machining operation due to its capability to operate on complicated shapes and extremely complex geometry with high precision and reliability. [14][15][16]. The wired EDM operation is executed by using wiring as electrode. [17] The micro WEDM process includes machining operation of very small diameter to fabricate the work piece. The supply spool uses take up mechanism to draw the wire where dielectric medium is used for the operation. The circuit used in EDM operations are generally resistance capacitance relaxation circuit whereas in case of micro EDM operation RC type pulse circuit is used. In real operation pulse on-time circuit determines the current voltage level at prerequisite level. But in case of RC type pulse generator, predetermined level of current and voltage cannot be maintained. Dhanic et al. conducted micro machining single resistor pulse generator to determine the effect of micro EDM operation. The micro EDM operations are generally machined for work piece material less than 999 μ m [18][19] Das et al. incorporated spark erosion rate for micro EDM operation. [20] The EDM operation is suitable for nonconductive material having conductivity of minimum 0.1 Scm^{-1} which can be used for different metals and ceramics. [21] [22]. The researchers are interested in incorporating EDM operations in to the ceramic applications as is very precise and accurate as a non-conventional cutting technique.

2.2 Brief Review on optimization parameters of micro EDM operation

Puertas el. al. [23] investigated the impact of different controllable parameters e.g. intensity, pulse timing for machining performance criteria such as surface finishing and dimensional accuracy. It has been illustrated that repetitive set of experiments and developed regression model can be implicated to determine optimized parameters for performance of the EDM operation. Puri et al. [24] developed mathematical model to optimize input parameters for WEDM process for brass wire electrode for a typical die steel machining operation. T. A. El-Taweel [25] studied the correlation of machining condition in EDM operations of CK-45 steel and Al-Cu-Si-TiC composite and investigated the impact of peak current, dielectric flushing pressure and pulse time. The experiment was carried out in response machining process He concluded that peak current has highest impact on material removal rate and tool wear ratio. The arc gap between electrodes, pulse on-off time, discharge current plays a vital role in affecting the micro EDM operations. Iqbal et al. [26] conducted EDM milling operation on stainless steel AISI 306 and modelled controllable parameter of MRR, EWR and surface roughness for machining operation. For precise machining operation it is very important to select proper optimizing parameters for smooth operation. [25]. Sohani et al. [27] investigated the effect of response surface methodology (RSM) for studying the impact of different tool geometries and concluded that circular geometry provides the most precise machining.

2.3 Brief review on multi objective optimization algorithm

Multi objective optimization algorithm refers to finding optimum value satisfying optimal conditions for multi objectives. The multi objective optimization algorithms investigates simple mathematical model of dynamic problem within a defined range of values. Bhattacharyya et al. [28] investigated multi-dimensional electrode gap model to maximize material removal rate optimizing the feed rate of the flow and flow velocity of the electrolyte for variables. To solve multi objective machining optimization researchers have used graphical techniques which is proved to less accurate. El Dardery [29] proposed optimization model that investigates cost model to optimize the cost for ECM operations. The swarm search algorithm iterating on population based algorithm like artificial bee algorithm[30], krill herd algorithm[31], ant lion algorithm[32], particle swarm optimization algorithm [33] are the most bio inspired remarkable optimization algorithm.

CHAPTER 3
PROBLEM STATEMENT

In LECD operation, cathode deposits the electrode at its base and to maintain optimal gap of 0.5 mm between the electrodes, mask is placed on top of the cathode. The metal deposition process occurs instantaneously by pulse voltage application. The electrode with negative polarity has been chosen for micro-EDM operation to improve the material removal rate and reduce the electrode wear. MRR is defined as the amount of material removed per unit time. The material removal rate is directly related to discharge energy for the RC type pulse generator calculated from gap voltage $(V)$and capacitance(C). The value of MRR increases with increasing discharge energy.

$$Material\ Removal\ Rate\ (MRR) = \frac{Amount\ of\ material\ removed\ from\ workpiece}{Unit\ time} \qquad (1)$$

Relative wear ratio (RWR) is the ratio of the material removed and the workpiece material removed. As deduced in [9], RWR increases with rising gap voltage as the discharge energy rises. The value of RWR is comparatively high with moderate capacitance and gap voltage due to high machining time for a low MRR.

$$Relative\ wear\ ratio\ (RWR) = \frac{Amount\ of\ material\ removed\ from\ electrode}{Amount\ of\ material\ removed\ from\ workpiece} \qquad (2)$$

Average spark gap (ASG) is calculated from dimensional inaccuracy of the machined dimension (hole) from the actual dimension (mask). The ASG increases with increasing gap voltage and capacitance. The machined dimensions are represented by g_1,g_2, g_3 and g_4 and actual dimension is represented by a.

$$Average\ spark\ gap\ (ASG) = \frac{1}{2}\left(\frac{g_1 + g_2 + g_3 + g_4}{4} - a\right) \qquad (3)$$

Average tapper angle (ATA) is calculated from dimensional inaccuracy in terms of the average of top and bottom dimensions of the workpiece. The corner wear of the electrode result in increasing ATA with rising gap voltage and capacitance. The top diameter, bottom diameter and height of the workpiece is represented by d_{top},d_{bottom} and h respectively.

$$Average\ tapper\ angle\ (ATA) = \tan^{-1}\frac{d_{top} - d_{bottom}}{2 \times h} \qquad (4)$$

To obtain optimal performance of electrode for micro-EDM operation, high MRR and low RWR, ASG and ATA is anticipated in spite of all the parameter increases with rising discharge energy.

MOGOA approach is used to determine the optimal parameters of the electrodes considering the multi conflicting parameters. The discharge energy is required to be low with decreasing spark voltage and capacitance which eventually reduces the discharge energy

To represent relation between setting input parameters of gap voltage and capacitance, multiple linear regression model is implemented to determine the optimizing equations of MRR, RWR, ASG and ATA for workpiece material. The linear regression model used to represent the correlation between machining input parameters and output parameters for workpiece material made of steel, copper, brass and aluminum are

$$\begin{aligned} \ln MRR_{steel} = {} & -8.45582 + 0.002212C + 0.02122V - 8.52 \times 10^{-6}CV \\ & - 1.40 \times 10^{-6} \times C^2 - 0.00019 \times V^2 + 4.32 \times 10^{-10}C^2V \\ & + 4.39 \times 10^{-8}CV^2 + 3.35 \times 10^{-10}C^3 + 8.11 \times 10^{-7}V^3 \end{aligned} \tag{5}$$

$$\begin{aligned} \ln RWR_{steel} = {} & 3.38509 + 0.002267C - 0.00738V + 8.46 \times 10^{-6}CV \\ & + 3.10 \times 10^{-6}C^2 + 0.000052V^2 - 1.83 \times 10^{-9}C^2V \\ & - 1.89 \times 10^{-8}CV^2 + 9.51 \times 10^{-10}C^3 - 8.93 \times 10^{-8}V^3 \end{aligned} \tag{6}$$

$$\begin{aligned} \ln ASG_{steel} = {} & -0.99274 + 0.001466C + 0.050775V + 8.63 \times 10^{-6}CV \\ & - 6.34 \times 10^{-7}C^2 - 0.0054 \times V^2 - 3.08 \times 10^{-9}C^2V \\ & - 1.61 \times 10^{-8}CV^2 + 1.43 \times 10^{-10}C^3 + 2.10 \times 10^{-6}V^3 \end{aligned} \tag{7}$$

$$\begin{aligned} \ln ATA_{steel} = {} & 0.037026 + 0.000894C + 0.00166V - 4.02 \times 10^{-7}CV \\ & + 1.28 \times 10^{-7}C^2 + 0.000075V^2 - 1.27 \times 10^{-9}C^2V + 8.32 \ast 10^{-9}CV^2 \\ & - 7.73 \times 10^{-11}C^3 - 2.17 \times 10^{-7}V^3 \end{aligned} \tag{8}$$

The corresponding equation for determining the optimized operating condition for copper as a workpiece material are:

$$\begin{aligned} \ln MRR_{copper} = {} & -8.80099 + 0.001635C + 0.025277V + 9.69 \times 10^{-6}CV \\ & - 1.90 \times 10^{-6}C^2 - 0.000263V^2 - 3.96 \times 10^{-9}C^2V \\ & + 2.17 \times 10^{-9}CV^2 + 6.18 \times 10^{-10}C^3 + 1.16 \times 10^{-6}V^3 \end{aligned} \tag{9}$$

$$\begin{aligned}\ln RWR_{copper} = {} & 3.08398 + 0.001793C - 0.031593V + 0.000024CV \\ & - 3.06 \times 10^{-6}C^2 + 0.000267V^2 - 5.27 \times 10^{-9}C^2V \\ & - 7.33 \times 10^{-8}CV^2 + 9.70 \times 10^{-10}C^3 - 4.72 \times 10^{-7}V^3\end{aligned} \tag{10}$$

$$\begin{aligned}\ln ASG_{copper} = {} & -0.851933 + 0.002815C + 0.031424V + 5.28 \times 10^{-6}CV \\ & - 2.23 \times 10^{-6}C^2 - 0.000167V^2 - 1.18 \times 10^{-9}C^2V \\ & - 1.77 \times 10^{-8}CV^2 + 5.80 \times 10^{-10}C^3 + 3.87 \times 10^{-7}V^3\end{aligned} \tag{11}$$

$$\begin{aligned}\ln ATA_{copper} = {} & -0.056797 + 0.002504C + 0.007591V - 2.79 \times 10^{-6}CV \\ & - 1.55 \times 10^{-6}C^2 + 0.00003V^2 + 1.34 \times 10^{-9}C^2V - 1.12 \times 10^{-8}CV^2 \\ & + 3.19 \times 10^{-10}C^3 - 1.36 \times 10^{-7}V^3\end{aligned} \tag{12}$$

The corresponding equation for determining the optimized operating condition for brass as a workpiece material are:

$$\begin{aligned}\ln MRR_{brass} = {} & -8.48826 + 0.001671C + 0.030347V - 9.95 \times 10^{-7}CV \\ & - 1.50 \times 10^{-6}C^2 - 0.000186V^2 - 6.09 \times 10^{-9}C^2V \\ & + 8.96 \times 10^{-8}CV^2 + 5.50 \times 10^{-10}C^3 + 6.91 \times 10^{-7}V^3\end{aligned} \tag{13}$$

$$\begin{aligned}\ln RWR_{brass} = {} & 1.65811 + 0.001686C + 0.012156V + 0.000017CV \\ & - 3.26 \times 10^{-6}C^2 - 0.000206V^2 - 4.12 \times 10^{-9}C^2V \\ & - 3.48 \times 10^{-8}CV^2 + 1.10 \times 10^{-9}C^3 + 1.03 \times 10^{-6}V^3\end{aligned} \tag{14}$$

$$\begin{aligned}\ln ASG_{brass} = {} & -3.74984 + 0.005176C + 0.073354V - 0.000052CV \\ & + 7.39 \times 10^{-8}C^2 - 0.000246V^2 + 1.12 \times 10^{-8}C^2V \\ & + 6.70 \times 10^{-8}CV^2 - 5.06 \times 10^{-10}C^3 + 2.68 \times 10^{-7}V^3\end{aligned} \tag{15}$$

$$\begin{aligned}\ln ATA_{brass} = {} & -4.70698 + 0.002206C + 0.115021 \times V - 0.00000037CV \\ & + 1.75 \times 10^{-6}C^2 - 0.000643V^2 + 4.59 \times 10^{-9}C^2V \\ & + 7.79 \times 10^{-8}CV^2 - 7.51 \times 10^{-10}C^3 + 1.18 \times 10^{-6}V^3\end{aligned} \tag{16}$$

The corresponding equation for determining the optimized operating condition for aluminium as a workpiece material are:

$$\begin{aligned}\ln MRR_{aluminium} \\ = -8.56073 + 0.002039C + 0.009454V - 0.009454V \\ - 2.88\times10^{-6}CV - 1.45\times10^{-6}C^2 + 0.000027V^2 - 5.36\times10^{-9}C^2V \\ + 8.18\times10^{-8}CV^2 + 4.84\times10^{-10}C^3 - 2.65\times10^{-8}V^3\end{aligned} \tag{17}$$

$$\begin{aligned}\ln RWR_{aluminium} \\ = 0.49168 + 0.001081C + 0.053237V + 0.000017CV \\ - 2.14\times10^{-6}C^2 - 0.000586V^2 - 1.29\times10^{-9}C^2V \\ - 6.01\times10^{-8}CV^2 + 6.52\times10^{-10}C^3 + 2.23\times10^{-6}V^3\end{aligned} \tag{18}$$

$$\begin{aligned}\ln ASG_{aluminium} \\ = -0.963552 + 0.00324C + 0.015896V - 0.000019CV \\ - 1.01\times10^{-6}C^2 + 0.000169V^2 + 2.76\times10^{-9}C^2V \\ + 3.75\times10^{-8}CV^2 + 1.22\times10^{-10}C^3 - 9.66\times10^{-7}V^3\end{aligned} \tag{19}$$

$$\begin{aligned}\ln ATA_{aluminium} \\ = -0.705539 + 0.000783C + 0.0225V + 3.61\times10^{-6}CV \\ + 3.22\times10^{-8}C^2 + 0.000043V^2 - 2.24\times10^{-9}C^2V \\ - 1.57\times10^{-9}CV^2 - 3.62\times10^{-11}C^3 - 5.82\times10^{-7}V^3\end{aligned} \tag{20}$$

Chapter 4
OPTIMIZATION APPROACH

In this section firstly the grasshopper optimization algorithm (GOA) is introduced. The multi-objective optimization algorithm (MOGOA) is presented in the following section in order to optimize the multi conflicting criteria.

4.1 Grasshopper Optimization Algorithm

Among the prominent stochastic optimization algorithm nature inspired metaheuristic population-based algorithm are the most befitting while solving real world problems. The metaheuristic algorithm has shown better result in solving optimization problem compared to heuristic algorithms due to the diverse characteristics of the problem [34] The Grasshopper Optimization Algorithm (GOA) is regarded as of the well-liked global optimization algorithm. The inspiration of the algorithm is based on the life cycle of grasshopper [8]. The social behavior of grasshopper movement as swarm across the nymph and adult stage has motivated to formulate metaheuristic genetic algorithm. The adaptive exploration and exploitation capability of GOA has proven to be fitting in terms of converging speed of the algorithm. The grasshoppers tend to move suddenly during exploration stage whereas the grasshoppers tend to locally during the exploitation stage inspiring from the food seeking characteristics of grasshopper. The unique characteristics of social behavior inspired the construction of search space prevailing in the larval phase consists of slow movement and small steps and adult phase of the grasshopper considers swift and distant movement depending on the maturity of the swarm to solve real application-based optimization problems.

The mathematical model to demonstrate the swarming nature of grasshopper in order to identify the position of i^{th} grasshopper represented by X_i is given,

$$X_i = S_i + G_i + A_i \tag{21}$$

where, S_i, G_i, A_i represents the social interaction, impact of force of gravity and wind advection quantity for the grasshopper respectively. The component that emanated from grasshopper itself is the social interaction which is modeled as:

$$S_i = \sum_{\substack{j=1 \\ j\neq 1}}^{N} s\left(d_y\right)\hat{d}_y \tag{22}$$

where $\hat{d}_{ij} = \frac{x_j - x_i}{d_{ij}}$ represents a unit vector in between i^{th} grasshopper and j^{th} grasshopper. The distance between i^{th} and j^{th} grasshopper is represented by d_y. The strength of social forces represented by s is modeled as below:

$$s(r) = f e^{\frac{-r}{l}} - e^{-r} \tag{23}$$

where f represents attraction intensity and l represents the scale of attraction length. The social interaction behavior between grasshopper can be interpreted as attraction and repulsion. As introduced in [8], the distance between two grasshoppers are considered between 0 and 15. The repulsion between grasshoppers occur at an interval $[0, 2.079]$. When the distance between two grasshopper goes beyond 2.079, there is no effect of attraction and repulsion in terms of social interaction on the grasshopper. This situation is termed as comfort zone. The grasshopper segregates the s function into two parts: attraction and repulsion region and the comfort zone. The distance for the s function is higher than 10 and the value of the function is very close to zero. The social interaction function cannot operate within operation space with large distance between grasshopper.

$$G_i = -g\hat{e}_g \tag{24}$$

Where $\hat{e}_g$represents a unit vector directing towards the center of the earth and g represents gravitational constant.

$$A = u\hat{e}_w \tag{25}$$

Where $\hat{e}_w$ represents a unit vector toward the wind direction and u represents drift constant.

To solve the optimization problem, this model cannot be implemented directly due to the tendency of the grasshopper to converge towards the comfort zone quickly in spite of swarm system converging toward the target position. The modified grasshopper position from equation 21 to solve optimization problems are:

$$x_{i+1}^{d} = c\left(\sum_{\substack{j=1 \\ j\neq 1}}^{N} c\frac{ub_d - ib_d}{2} s\left(\left|x_j^d - x_i^d\right|\right)\frac{x_{j-x_i}}{d_{ij}}\right) + \hat{T}_d \tag{25}$$

where u_{bd} is upper boundary in the d^{th} dimension, l_{bd} is lower boundary in the d^{th} dimension, and $\hat{T}_d$ is the best solution found so far and c is a reduction coefficient to reduce size of comfort zone, repulsion region and attraction region. The count of iteration proportional to the comfort zone is diminished by the c parameter.

Step 1: Initialization the parameters of algorithm;

Step 2: Random population generation;

Step 3: Merit calculation of each grasshopper;

Step 4: Target Identification;

Step 5: Repeat Steps 6 to 12;

Step 6: Repeat steps 7 to 11;

Step 7: $C = C_{msx} - I\ \frac{C_{max} - C_{min}}{L}$

Step 8: Update C;

Step 9: Set the new grasshopper as target comparing the merit

Step 10: Consider the stop condition;

Step 11: End

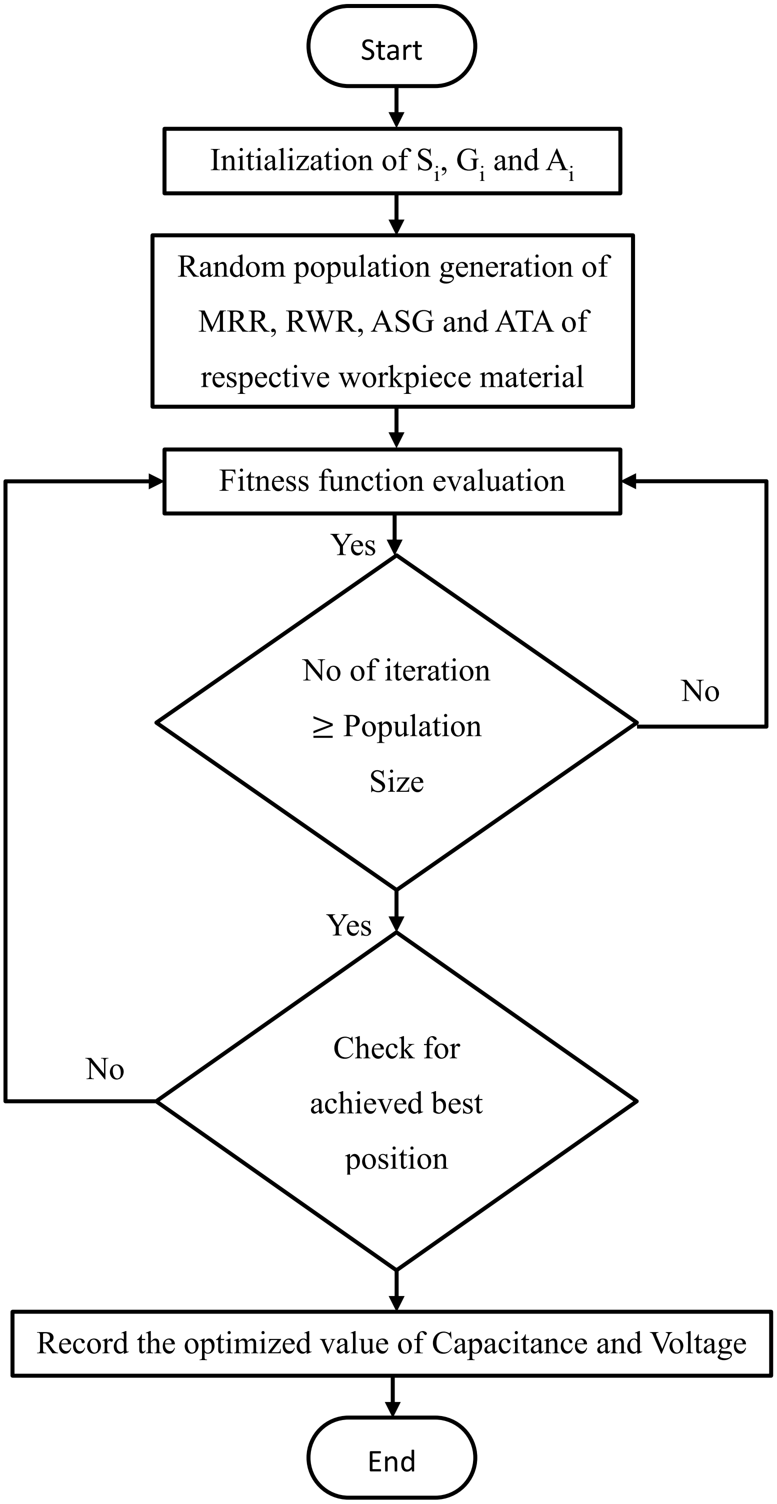


Figure 4.1: Flow Chart of MOGOA algorithm for optimization

4.2 Multi-objective Grasshopper Optimization Algorithm

To solve multi-objective optimization algorithm-based problems two objective has to be satisfied: approximation of true Pareto optimal solution and ensure the diversity of the optimal solution across the search space simultaneously. To ensure assessment of the multi-objective optimization objectives it is necessary for posteriori method as the optimization is followed by decision making. In case of multi-objective optimization problems more than one solution prevails. In order to transform the GOA into MOGOA, modelling the algorithm such that the modified method of updating the target so that the search agent converge towards the propitious regions in the search space. To compare the optimal solutions in MOGOA, Pareto optimal dominance is exploited and the best pareto optimal solutions are reserved in the archive. The target has to be selected from the stored best pareto optimal solution. To update the target position for enhancing the distribution solution, keeping a fixed distance the number of neighboring solutions of every solution is calculated. The crowdedness in the space of the pareto optimal front are determined by the number of neighboring solutions in terms of metrics.

4.3 MOGOA for optimized electrode material

In this paper, MOGOA is developed to compute the optimal performance of different electrode materials for micro-EDM operation. The solution storing switches to be extended is represented by each grasshopper. The process of initial population generation is similar to every evolutionary algorithm. The objective deploying MOGOA is to optimize MRR, ASG, ATA and RWR of micro-EDM process. Non dominated sorting method is implemented for population generation indexing and GOA approach is used to obtain the optimal solutions. In the next step, the optimal solutions are compared and continuously updated for every iteration and store the optimal solutions in the archive.

The bound of the input parameter for optimization are:

$$100 \leq C \leq 2200$$

$$60 \leq V \leq 140$$

Table 4.1: Simulation Parameter for two objective optimizations

Iteration	10
Objective	2
Grasshopper Number	500
Archive Size	50
Minimum Number (c_{min})	0.00004
Maximum Number (c_{max})	1

Table 4.2: Simulation Parameter for four objective optimizations

Iteration	10
Objective	4
Grasshopper Number	500
Archive Size	100
Minimum Number (c_{min})	0.00004
Maximum Number (c_{max})	1

Chapter 5
SIMULATION RESULTS AND MAJOR FINDINGS

In this book, the simulation is carried out to obtain optimized value of gap voltage and capacitance for minimizing the discharge energy. The impact of MRR on discharge energy is directly opposite to the impact of RWR, ASG and ATA. This book carries out simulation to optimize two objectives consecutively to obtain set of optimized value. The archive size for the simulation is 50 where 10 iterations are carried out iteratively to obtain the best set of pareto optimal front for respective cases.

5.1 Case I (a): Two objective optimization of parameters of steel

The optimization simulation is carried out to determine the optimal value of capacitance and gap voltage represented by keeping MRR, RWR, ASG and ATA selecting two objectives repeatedly for steel as electrode.

5.1.1 Effect of optimizing MRR against RWR, ASG and ATA respectively

The variation of optimized material removal rate against the conflicting criteria are obtained by optimized pareto optimal front prepared by executing the simulation parameter.

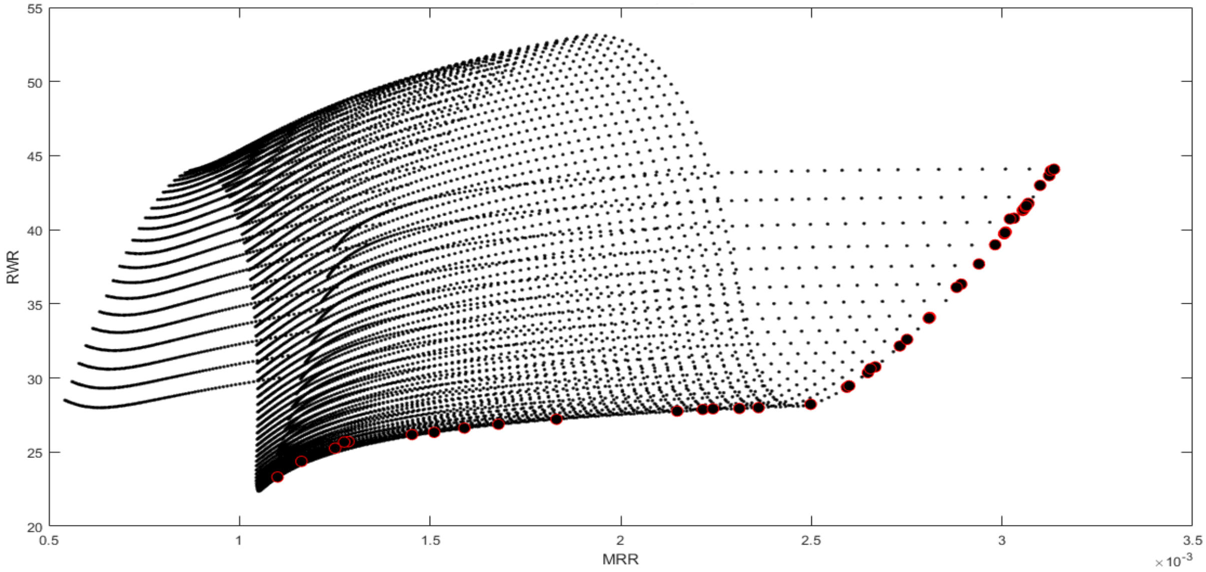


Figure 5.1: Pareto Front considering only RWR and MRR of steel

The non dominated front represented in Figure 5.1 by red circled are the optimized front of the optimizing parameter MRR and RWR. The search space for MRR ranges from 0.0005 to 0.00032 and the search space for RWR ranges from 23 to 53. The optimized MRR can be achieved within a range of 0.0011 to 0.003061. The least RWR that can be achieved within optimizing space is 23.3144.

The optimized value of capacitance and voltage and corresponding value of MRR and RWR are provided in the following table:

Table 5.2: Optimized MRR and RWR of steel

Optimized Capacitance	**Optimized Voltage**	**Optimized MRR**	**Optimized RWR**	**Optimized Capacitance**	**Optimized Voltage**	**Optimized MRR**	**Optimized RWR**
1697.30	120.54	0.001679	26.87467	2012.01	140.00	0.002751	32.60087
1783.80	82.66	0.001163	24.37004	2195.13	140.00	0.003124	43.64681
1817.23	96.37	0.001286	25.70245	2047.32	140.00	0.002808	34.0243
1582.18	97.84	0.001275	25.67458	2198.83	139.94	0.003128	43.98778
1718.29	137.34	0.002311	27.94179	2048.73	140.00	0.00281	34.08687
1744.04	138.02	0.002361	27.99316	2161.10	139.90	0.003031	40.77974
1737.17	72.06	0.0011	23.3144	2048.07	140.00	0.002809	34.05742
1613.89	95.48	0.001251	25.25839	2089.75	139.95	0.002881	36.11167
1756.34	109.33	0.001453	26.1789	2187.86	139.94	0.0031	42.99378
1706.07	134.07	0.002148	27.75904	2047.67	140.00	0.002809	34.03972
1764.54	134.89	0.002215	27.87524	2173.65	140.00	0.003069	41.78276
1725.47	125.53	0.001831	27.21174	2170.92	140.00	0.003062	41.55989
1767.94	135.41	0.002242	27.91723	2116.74	140.00	0.002939	37.69018
1714.51	112.95	0.001511	26.32909	2160.45	139.79	0.003021	40.72864
1695.61	116.88	0.00159	26.61538	2168.85	140.00	0.003057	41.39279
1888.59	140.00	0.002593	29.37123	2168.02	140.00	0.003055	41.32573
1894.29	140.00	0.002599	29.47055	2167.69	140.00	0.003054	41.29955
2170.60	140.00	0.003061	41.53373	2199.86	140.00	0.003136	44.08395
1999.46	140.00	0.002732	32.15574	2168.68	140.00	0.003057	41.37883
1952.68	140.00	0.002668	30.74676	2148.71	140.00	0.00301	39.84954
1937.29	140.00	0.002648	30.3619	2170.77	140.00	0.003062	41.5478
2146.97	140.00	0.003006	39.72334	2147.96	140.00	0.003008	39.79457
1781.53	140.00	0.002498	28.22046	2171.65	140.00	0.003064	41.61961

1948.04	139.90	0.002655	30.62326	2136.50	140.00	0.002982	38.98512
2093.71	140.00	0.002893	36.33162	2116.74	140.00	0.002939	37.69011

The search space for MRR ranges from 0.0006 to 0.00033 and the search space for ASG ranges from 2 to 17. The optimized MRR can be achieved within a range of 0.000544 to 0.002709. The least ASG that can be achieved within optimizing space is 16. 0917.The optimized parameter for optimizing ASG and ATA of steel:

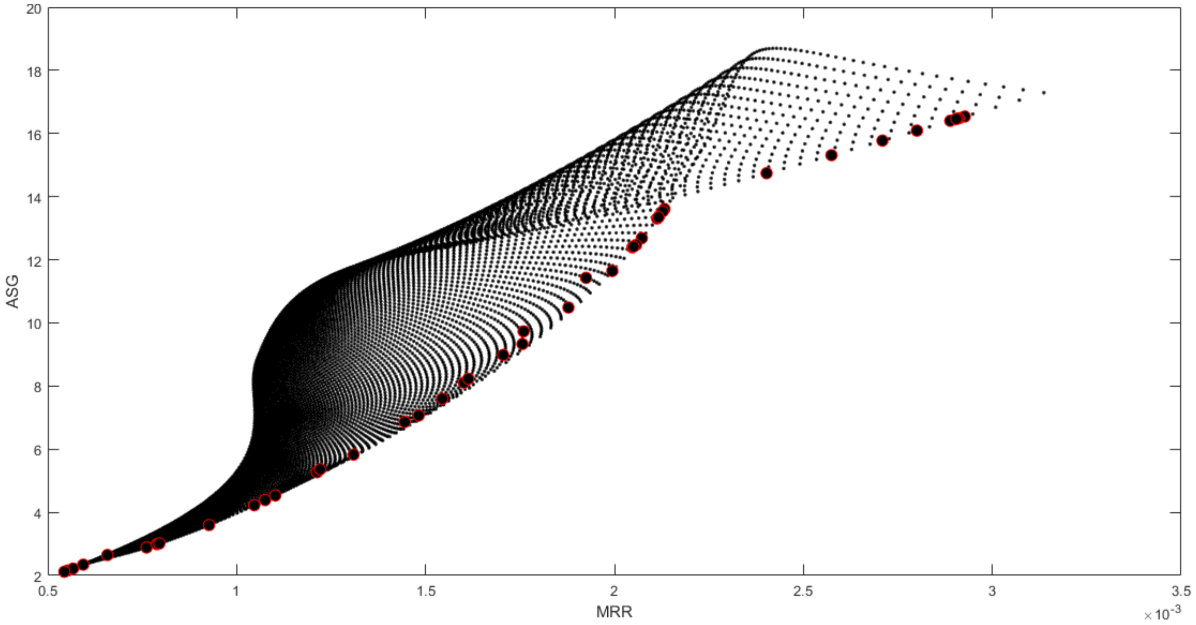


Figure 5.2: Pareto Front considering only ASG and MRR of steel

Table 5.2: Optimized MRR and RWR of steel

Optimized Capacitance	**Optimized Voltage**	**Optimized MRR**	**Optimized ASG**	**Optimized Capacitance**	**Optimized Voltage**	**Optimized MRR**	**Optimized ASG**
622.96	138.56	0.001878	10.48666	645.90	133.94	0.001759	9.732351
105.79	61.23	0.000552	2.158252	744.82	136.43	0.001925	11.42717
299.37	127.80	0.001213	5.27017	407.29	134.07	0.001482	7.06674
325.71	126.10	0.001221	5.361272	144.23	135.42	0.001102	4.53368
553.69	137.26	0.001756	9.332104	460.53	133.70	0.001544	7.599847
2200.00	134.06	0.002709	15.77415	519.03	133.57	0.001613	8.230668
418.65	131.69	0.001445	6.861805	2200.00	136.95	0.002903	16.45372
302.28	133.06	0.001309	5.827161	2200.00	137.28	0.002927	16.53864

2200.00	135.47	0.002801	16.0917	2200.00	137.00	0.002907	16.46556
2200.00	128.60	0.002403	14.74241	2200.00	137.06	0.002911	16.48107
2200.00	137.08	0.002912	16.48545	2200.00	137.04	0.002909	16.47551
2200.00	131.81	0.002574	15.31303	2200.00	136.98	0.002905	16.4607
684.02	140.00	0.001994	11.6452	2200.00	136.75	0.002889	16.40266
Optimized Capacitance	**Optimized Voltage**	**Optimized MRR**	**Optimized ASG**	**Optimized Capacitance**	**Optimized Voltage**	**Optimized MRR**	**Optimized ASG**
100.00	127.78	0.000927	3.597026	2200.00	137.05	0.00291	16.47813
229.36	61.03	0.000658	2.648281	2200.00	136.97	0.002905	16.45951
127.96	60.00	0.000567	2.218177	766.35	140.00	0.002072	12.68579
100.00	60.33	0.000544	2.118942	823.81	139.98	0.002118	13.38052
154.44	61.04	0.000594	2.343491	842.25	140.00	0.002132	13.60617
100.00	109.27	0.000761	2.885768	749.02	140.00	0.002057	12.46984
100.00	113.13	0.000789	2.988506	836.27	140.00	0.002128	13.53533
100.00	113.97	0.000795	3.013374	749.00	139.83	0.00205	12.41671
505.16	133.75	0.001601	8.106308	749.00	139.75	0.002047	12.39284
556.85	135.36	0.001705	8.9869	749.00	139.83	0.002051	12.41843
134.93	132.83	0.001047	4.225322	818.21	139.96	0.002113	13.30824
116.29	136.64	0.001075	4.388704	820.68	140.00	0.002116	13.34918

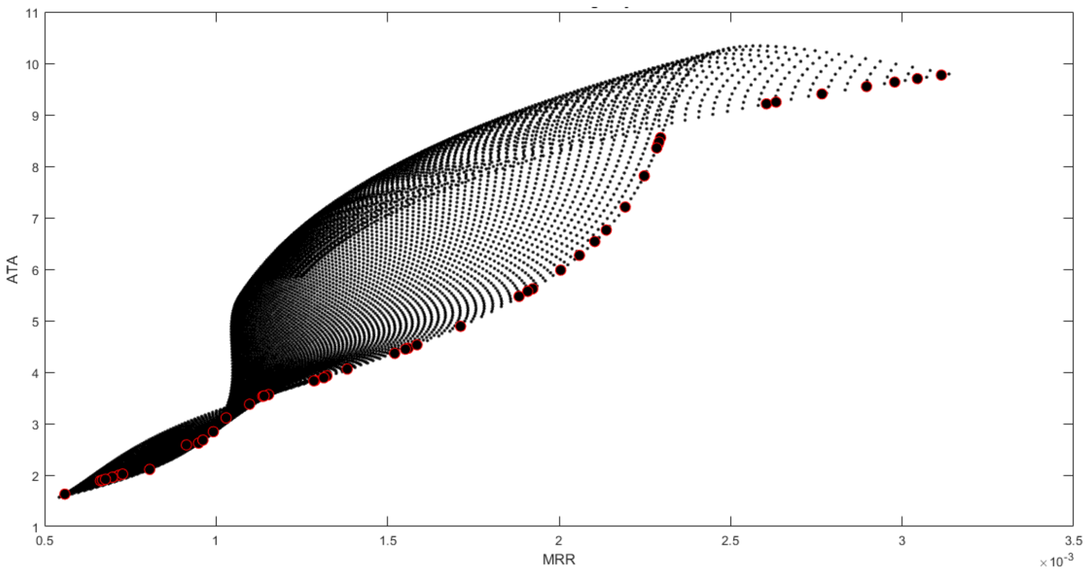


Figure 5.3: Pareto Front considering only ATA and MRR of steel

The figure 5.3 represents the pareto optimal front considering ATA and MRR for steel. The search space for MRR ranges from 0.0005 to 0.00032 and the search space for RWR ranges from 23 to 53. The optimized MRR can be achieved within a range of 0.000559 to 0.003044. The least ATA that can be achieved within optimizing space is 1.629641.

Table 5.3: Optimized MRR and ATA of steel

Optimized Capacitance	**Optimized Voltage**	**Optimized MRR**	**Optimized ATA**	**Optimized Capacitance**	**Optimized Voltage**	**Optimized MRR**	**Optimized ATA**
346.52	115.03	0.001098	3.375747	619.20	140.00	0.001923	5.619408
2200.00	132.33	0.002604	9.211985	694.04	140.00	0.002005	5.981873
938.15	140.00	0.002193	7.208214	1169.90	140.00	0.002285	8.355092
849.77	140.00	0.002138	6.760041	201.29	140.00	0.001285	3.829676
1058.28	140.00	0.002248	7.81236	283.82	137.97	0.001382	4.059946
100.00	64.48	0.000559	1.629641	337.88	140.00	0.001521	4.364284
595.12	67.73	0.000949	2.620228	358.93	139.88	0.001552	4.445839
597.00	70.07	0.000962	2.679538	117.90	140.00	0.001136	3.52947
813.76	66.12	0.001029	3.110934	128.09	139.92	0.001153	3.562212
2200.00	136.85	0.002896	9.549256	589.68	139.87	0.001883	5.471423

2200.00	132.81	0.002632	9.246881	120.06	140.00	0.00114	3.537018
2200.00	134.95	0.002766	9.405364	610.48	139.88	0.001909	5.570523
2200.00	137.98	0.002978	9.635248	252.99	137.59	0.001323	3.926591
2200.00	139.73	0.003114	9.770933	462.16	139.91	0.001713	4.890236
2200.00	138.84	0.003044	9.702295	377.66	140.00	0.001586	4.529786
709.57	65.73	0.000992	2.841775	217.57	140.00	0.001314	3.890601
416.64	83.19	0.000914	2.585945	219.77	72.98	0.000699	1.96198
426.20	60.00	0.000806	2.110011	251.12	72.92	0.000727	2.017685
1212.68	140.00	0.002296	8.555143	239.81	72.88	0.000716	1.996379
1186.50	140.00	0.002289	8.433337	179.77	72.91	0.000663	1.890231
1194.51	140.00	0.002291	8.470808	252.61	72.83	0.000727	2.018872
806.10	139.97	0.002104	6.5376	194.53	72.94	0.000676	1.916417
362.93	139.92	0.00156	4.464119	186.20	72.89	0.000669	1.90116
752.27	139.98	0.002059	6.268822	218.63	72.90	0.000698	1.958411
202.79	140.00	0.001288	3.835257	195.94	72.90	0.000678	1.918306

5.2.2 Effect of optimizing RWR against ASG and ATA

The variation of optimized relative wear ratio against the conflicting criteria are obtained by optimized pareto optimal front prepared by executing the simulation parameter.

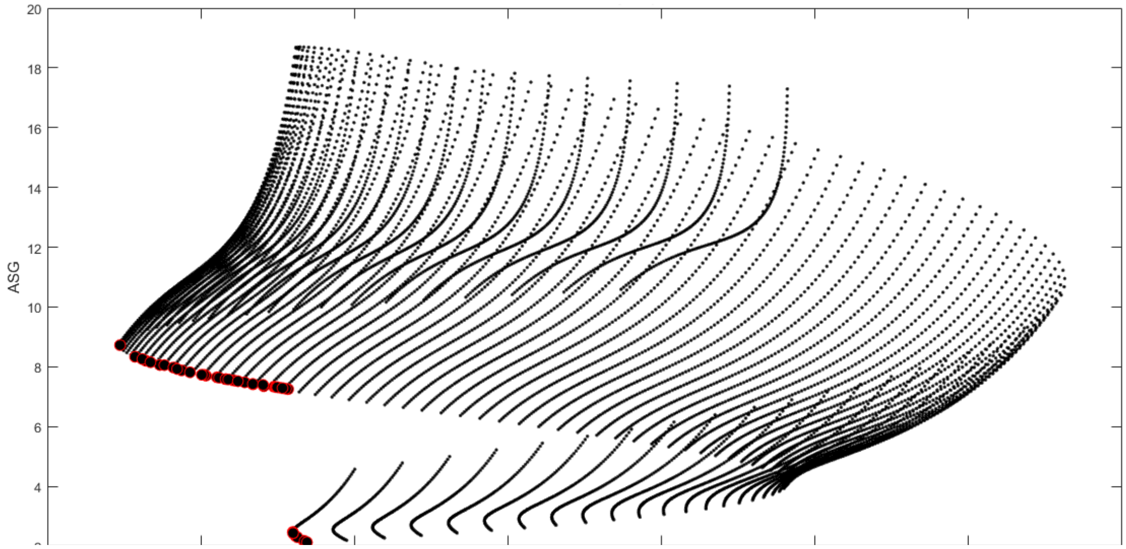


Figure 5.4: Pareto Front considering only ASG and RWR for steel

The figure 5.4 represents the pareto optimal front considering ASG and RWR for steel where the search space for RWR ranges from 23 to 53 and the search space for ASG ranges from 2 to 19. The optimized RWR can be achieved within a range of 22.3679 to 28.42068. The least ATA that can be achieved within optimizing space is 1.629641.

The optimization parameters for ASG and RWR are:

Table 5.4: Optimized RWR and ASG of steel

Optimized Capacitance	**Optimized Voltage**	**Optimized RWR**	**Optimized ASG**	**Optimized Capacitance**	**Optimized Voltage**	**Optimized RWR**	**Optimized ASG**
1677.42	60.12	22.3679	8.724961	1281.47	60.39	27.38354	7.332778
1436.77	60.00	24.37345	7.87917	1456.14	60.28	24.10762	7.97517
1565.93	60.00	22.85881	8.33433	1513.73	60.00	23.35721	8.152957
1528.34	60.00	23.20172	8.204029	1447.17	60.12	24.22599	7.92776
1311.20	60.00	26.69367	7.412463	1342.46	60.15	26.05543	7.544962
100.00	72.81	28.10226	2.326806	1339.78	60.15	26.1093	7.534874
100.00	61.80	28.42068	2.147036	1369.83	60.16	25.52526	7.648497
100.00	63.62	28.35218	2.180452	1324.24	60.18	26.43068	7.478329
100.00	73.34	28.0923	2.334443	1311.76	60.13	26.69144	7.426272
1294.97	60.00	27.04878	7.350118	1366.30	60.15	25.59109	7.63444
100.00	70.94	28.14084	2.299548	1396.65	60.00	25.02911	7.732935
100.00	62.91	28.37818	2.167582	1354.94	60.10	25.80489	7.587077
100.00	60.96	28.45425	2.131181	1350.75	60.16	25.89118	7.57668
100.00	83.97	27.99417	2.473386	1335.14	60.17	26.20457	7.518583
100.00	81.47	28.00085	2.441951	1297.49	60.40	27.02355	7.395506
100.00	83.84	27.99428	2.471708	1276.18	60.40	27.50524	7.312595
100.00	80.69	28.00497	2.432035	1268.89	60.39	27.67436	7.28364
100.00	81.13	28.0025	2.437706	1279.21	60.37	27.43362	7.322215
1487.88	60.00	23.66207	8.061922	1261.72	60.36	27.84049	7.252496
1388.99	60.00	25.16362	7.704737	1277.96	60.40	27.46429	7.319446
1451.71	60.26	24.16997	7.957491	1271.88	60.40	27.60511	7.295859
1392.69	60.16	25.1099	7.732889	1264.74	60.37	27.76996	7.265479

1478.03	60.32	23.81157	8.057447	1272.13	60.40	27.59889	7.296471
1540.27	60.15	23.09438	8.259793	1277.14	60.40	27.48328	7.316596
1419.46	60.00	24.64606	7.816394	1269.60	60.40	27.65781	7.286583

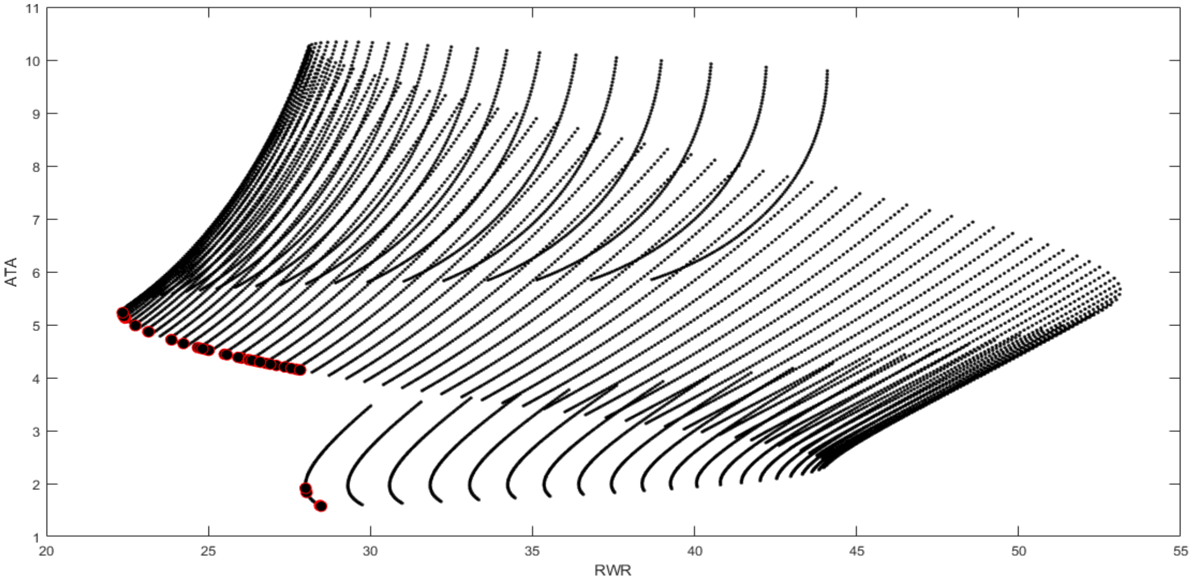


Figure 5.5: Pareto Front only considering ATA and RWR for steel

The figure 5.5 represents the pareto optimal front considering ASG and RWR for steel where the search space for RWR ranges from 23 to 53 and the search space for ASG ranges from 2 to 19. The optimized RWR can be achieved within a range of 22.4344 to 28.45288. The least ATA that can be achieved within optimizing space is 1.572842.

Table 5.5: Optimized RWR and ATA of steel

Optimized Capacitance	**Optimized Voltage**	**Optimized RWR**	**Optimized ATA**	**Optimized Capacitance**	**Optimized Voltage**	**Optimized RWR**	**Optimized ATA**
1292.79	60.00	27.09735	4.231689	1686.93	60.00	22.35559	5.228079
100.00	61.30	28.44043	1.585847	1401.70	60.00	24.94194	4.526467
100.00	77.48	28.0321	1.833938	1302.94	60.00	26.87282	4.259444
100.00	81.82	27.99931	1.911618	1319.36	60.00	26.51967	4.304218
100.00	60.99	28.45288	1.581741	1370.40	60.00	25.50261	4.442524
100.00	60.32	28.48074	1.572842	1343.17	60.00	26.02963	4.368948
1263.41	60.00	27.77243	4.151233	1411.60	60.00	24.77508	4.552871
1473.41	60.11	23.85714	4.718447	1409.90	60.00	24.80334	4.548328

1281.50	60.05	27.35623	4.202266	1417.53	60.00	24.67748	4.568578
1640.68	60.00	22.4344	5.125094	1313.97	60.00	26.63425	4.289525
1266.64	60.00	27.69643	4.160085	1319.62	60.00	26.51417	4.304959
1272.49	60.00	27.55969	4.176137	1307.10	60.00	26.78224	4.270788
1472.28	60.01	23.86475	4.712418	1413.59	60.00	24.74211	4.558127
1534.01	60.01	23.14511	4.869531	1397.79	60.00	25.00932	4.516034
1446.19	60.01	24.23208	4.644339	1366.86	60.00	25.56899	4.433007
1580.61	60.00	22.74783	4.983856	1322.77	60.00	26.44775	4.31352
1648.35	60.01	22.41145	5.142635	1348.55	60.00	25.92272	4.383514
1679.24	60.01	22.35863	5.211444	1332.82	60.00	26.2394	4.34084
1653.55	60.01	22.39803	5.154418	1320.62	60.00	26.493	4.307655
1648.19	60.01	22.41195	5.142314	1317.05	60.00	26.56856	4.29794
1667.10	60.00	22.37149	5.184665	1301.33	60.00	26.90818	4.255032
1306.39	60.00	26.79764	4.268848	1331.45	60.00	26.26752	4.337119
1655.70	60.00	22.39281	5.159162	1327.67	60.00	26.34551	4.326857
1532.54	60.01	23.15965	4.865875	1315.75	60.00	26.59629	4.294418
1260.81	60.00	27.83384	4.144116	1408.88	60.00	24.82037	4.545588

5.2 Case I (b): Two objective optimization of parameters of copper

The optimization simulation is carried out to determine the optimal value of capacitance and gap voltage represented by keeping MRR, RWR, ASG and ATA selecting two objectives repeatedly for steel as electrode.

5.2.1 Effect of optimizing MRR against RWR, ASG and ATA respectively

The variation of optimized material removal rate against the conflicting criteria are obtained by optimized pareto optimal front prepared by executing the simulation parameter.

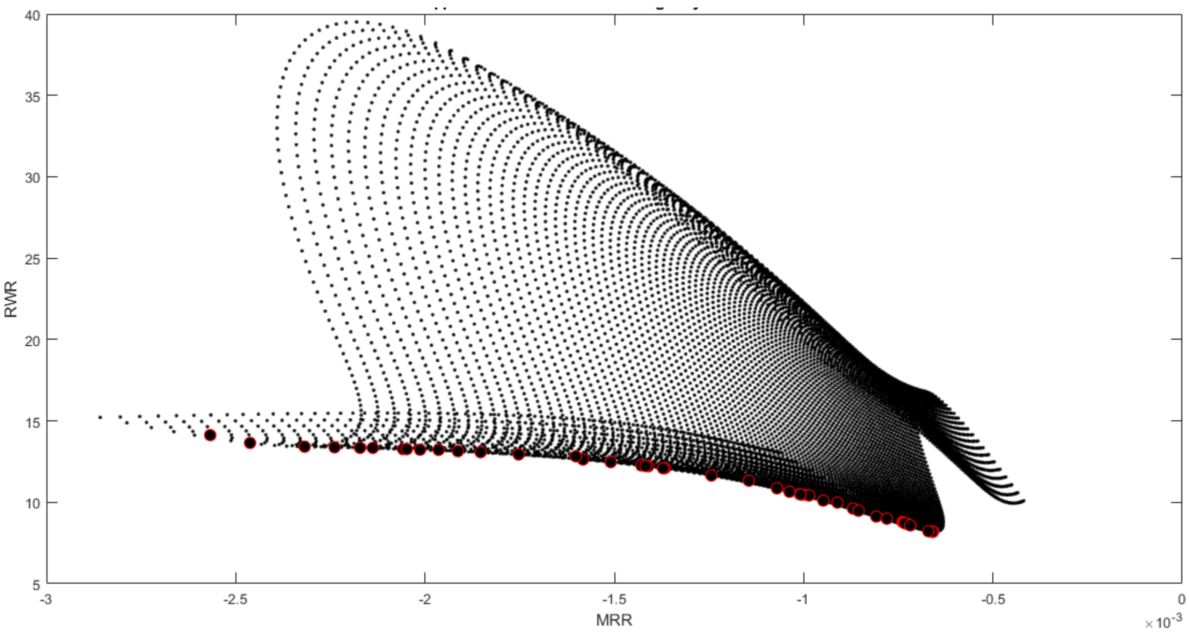


Figure 5.6: Pareto Front considering RWR and MRR for copper

The non dominated front represented in Figure 5.6 by red circled are the optimized front of the optimizing parameter MRR and RWR. The search space for MRR ranges from 0.00032 to 0.0056 and the search space for RWR ranges from 23 to 53. The optimized MRR can be achieved within a range of 0.000669 to 0.002318. The least RWR that can be achieved within optimizing space is 23.3144.

Table 5.5: Optimized MRR and RWR of brass

Optimized Capacitance	**Optimized Voltage**	**Optimized MRR**	**Optimized RWR**	**Optimized Capacitance**	**Optimized Voltage**	**Optimized MRR**	**Optimized RWR**
1883.90	109.23	0.001244	11.64504	1882.92	115.44	0.001367	12.08632
1799.70	83.30	0.00087	9.610632	1905.45	114.93	0.001371	12.0877
1928.91	119.98	0.001509	12.46552	1930.71	115.82	0.00141	12.21349
1910.15	123.20	0.001583	12.62762	1932.03	116.57	0.001429	12.26461
1923.21	132.36	0.001913	13.13536	1920.40	116.49	0.001417	12.22582
1766.98	88.58	0.000911	9.981433	1778.29	60.04	0.000669	8.215752
1865.15	73.03	0.000808	9.123745	1760.45	60.00	0.000663	8.194389
1966.73	138.24	0.002239	13.37834	1925.97	60.00	0.000738	8.778752
1841.28	89.39	0.000948	10.10634	1741.34	60.00	0.000658	8.183832
1814.76	81.11	0.000855	9.483338	1908.58	60.00	0.000728	8.669543
1844.09	99.52	0.00107	10.85582	1926.23	60.00	0.000739	8.780516
1965.35	139.71	0.002318	13.41716	1892.04	60.00	0.000718	8.57737
1911.35	66.40	0.00078	8.991762	1914.60	60.00	0.000731	8.70587
1905.89	128.58	0.001753	12.94084	1750.32	60.00	0.000661	8.187509
1840.57	125.38	0.001602	12.8204	1922.45	60.00	0.000736	8.75562
2049.01	139.94	0.002462	13.64631	1917.34	60.00	0.000733	8.722929
1972.14	98.49	0.001145	11.3249	1892.96	60.00	0.000719	8.582231
1935.69	135.35	0.002058	13.26669	1782.38	60.02	0.00067	8.220167
1977.09	136.70	0.002172	13.34749	1839.69	94.35	0.001003	10.46211
2114.84	139.34	0.002567	14.1261	1853.98	94.35	0.00101	10.49088
1932.01	134.46	0.002013	13.23	1843.73	94.36	0.001005	10.47027
1911.33	131.14	0.001853	13.07751	1901.44	94.33	0.001037	10.64355
1987.15	135.75	0.002138	13.34149	1806.12	94.36	0.000988	10.42585
1907.12	133.89	0.001964	13.21896	1798.96	94.35	0.000986	10.4228
1976.62	134.13	0.002048	13.26591	1850.35	94.35	0.001008	10.48313

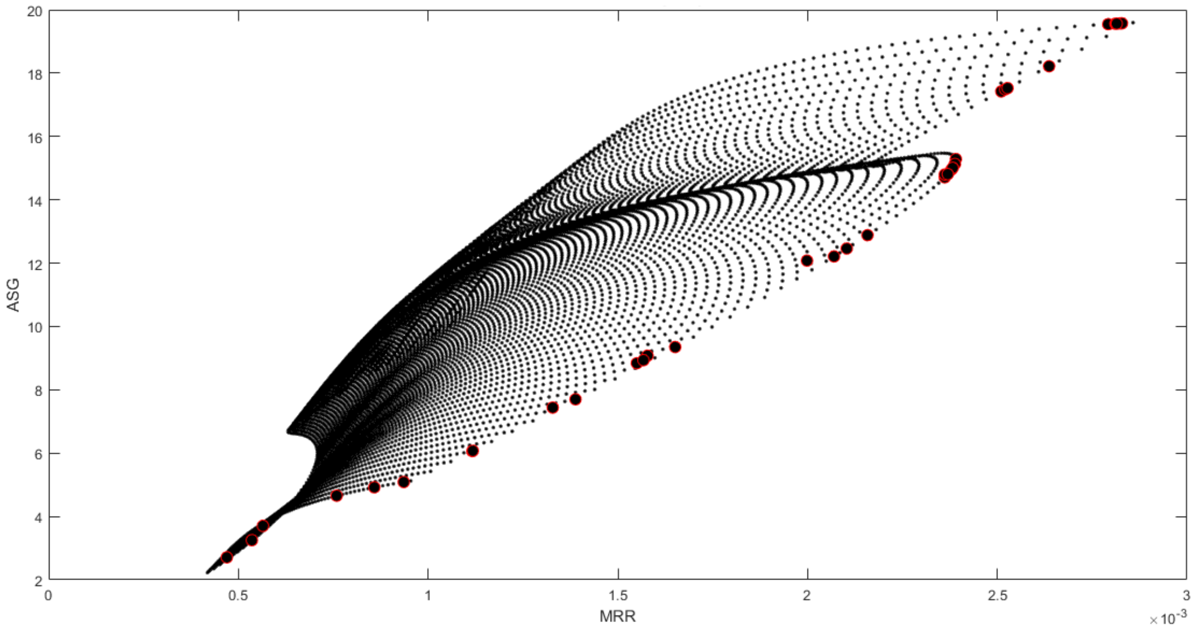


Figure 5.7: Pareto Front considering only ASG and MRR

The non dominated front represented in Figure 5.7 by red circled are the optimized front of the optimizing parameter MRR and ASG. The search space for MRR ranges from 0.0004 to 0.0026 and the search space for ASG ranges from 2 to 19. The optimized MRR can be achieved within a range of 0.00078 to 0.002567. The least ASG that can be achieved within optimizing space is 8.183832.

Table 5.5: Optimized MRR and ASG of brass

Optimized Capacitance	Optimized Voltage	Optimized MRR	Optimized ASG	Optimized Capacitance	Optimized Voltage	Optimized MRR	Optimized ASG
1883.90	109.23	0.001244	11.64504	1882.92	115.44	0.001367	12.08632
1799.70	83.30	0.00087	9.610632	1905.45	114.93	0.001371	12.0877
1928.91	119.98	0.001509	12.46552	1930.71	115.82	0.00141	12.21349
1910.15	123.20	0.001583	12.62762	1932.03	116.57	0.001429	12.26461
1923.21	132.36	0.001913	13.13536	1920.40	116.49	0.001417	12.22582
1766.98	88.58	0.000911	9.981433	1778.29	60.04	0.000669	8.215752
1865.15	73.03	0.000808	9.123745	1760.45	60.00	0.000663	8.194389
1966.73	138.24	0.002239	13.37834	1925.97	60.00	0.000738	8.778752
1841.28	89.39	0.000948	10.10634	1741.34	60.00	0.000658	8.183832
1814.76	81.11	0.000855	9.483338	1908.58	60.00	0.000728	8.669543

1844.09	99.52	0.00107	10.85582	1926.23	60.00	0.000739	8.780516
Optimized Capacitance	**Optimized Voltage**	**Optimized MRR**	**Optimized ASG**	**Optimized Capacitance**	**Optimized Voltage**	**Optimized MRR**	**Optimized ASG**
1965.35	139.71	0.002318	13.41716	1892.04	60.00	0.000718	8.57737
1911.35	66.40	0.00078	8.991762	1914.60	60.00	0.000731	8.70587
1905.89	128.58	0.001753	12.94084	1750.32	60.00	0.000661	8.187509
1840.57	125.38	0.001602	12.8204	1922.45	60.00	0.000736	8.75562
2049.01	139.94	0.002462	13.64631	1917.34	60.00	0.000733	8.722929
1972.14	98.49	0.001145	11.3249	1892.96	60.00	0.000719	8.582231
1935.69	135.35	0.002058	13.26669	1782.38	60.02	0.00067	8.220167
1977.09	136.70	0.002172	13.34749	1839.69	94.35	0.001003	10.46211
2114.84	139.34	0.002567	14.1261	1853.98	94.35	0.00101	10.49088
1932.01	134.46	0.002013	13.23	1843.73	94.36	0.001005	10.47027
1911.33	131.14	0.001853	13.07751	1901.44	94.33	0.001037	10.64355
1987.15	135.75	0.002138	13.34149	1806.12	94.36	0.000988	10.42585
1907.12	133.89	0.001964	13.21896	1798.96	94.35	0.000986	10.4228

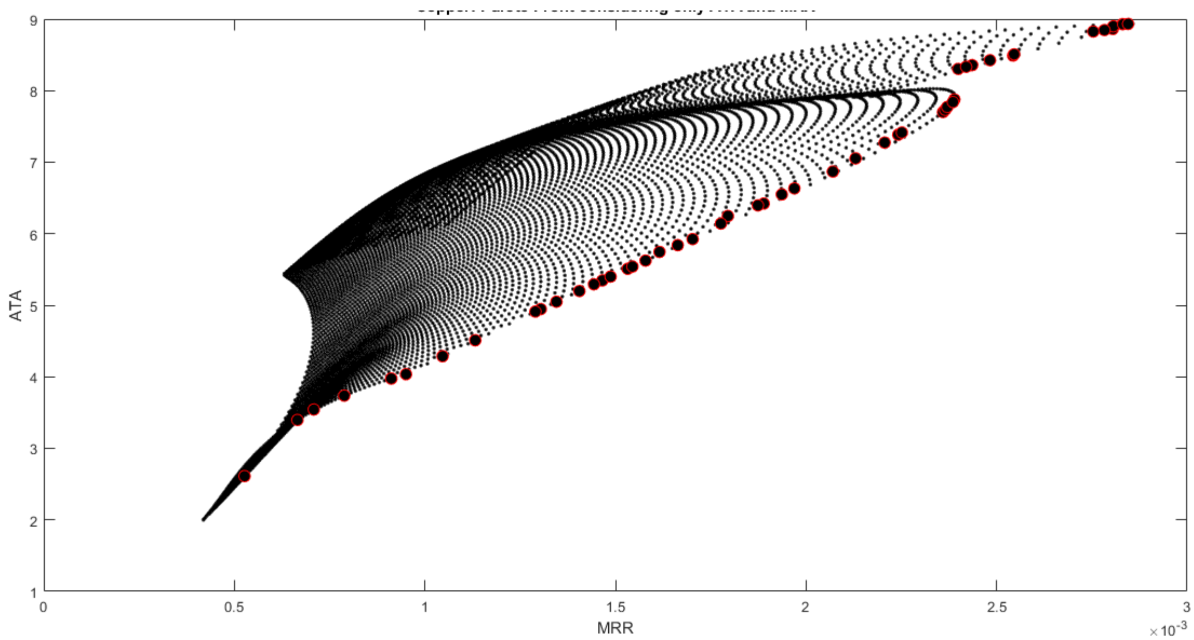


Figure 5.8: Pareto Front considering only ATA and MRR for copper

The non dominated front represented in Figure 5.8 by red circled are the optimized front of the optimizing parameter MRR and ATA. The search space for MRR ranges from 0.0004 to 0.0026.

The optimized MRR can be achieved within a range of 0.00066 to 0.00283. The least ATA that can be achieved within optimizing space is 2.611539.

Table 5.5: Optimized MRR and ATA of brass

Optimized Capacitance	**Optimized Voltage**	**Optimized MRR**	**Optimized ATA**	**Optimized Capacitance**	**Optimized Voltage**	**Optimized MRR**	**Optimized ATA**
195.72	69.70	0.000527	2.611539	2177.65	139.53	0.002754	8.826878
171.05	140.00	0.001132	4.510623	2200.00	139.61	0.002832	8.930007
254.14	140.00	0.001345	5.049638	2042.62	139.69	0.002436	8.356952
238.09	140.00	0.001304	4.946816	2066.92	139.70	0.002483	8.425453
110.55	121.01	0.000709	3.54276	2022.32	139.67	0.002399	8.304297
2184.14	140.00	0.002805	8.861797	2181.44	139.80	0.002783	8.847145
494.34	139.47	0.001889	6.422082	2200.00	139.81	0.002845	8.932636
2087.01	140.00	0.002543	8.490904	2033.73	139.70	0.00242	8.333527
137.13	140.00	0.001046	4.287357	538.39	139.39	0.001969	6.633349
2200.00	139.59	0.00283	8.929711	490.38	139.31	0.001874	6.396378
100.00	118.13	0.000666	3.396033	398.37	140.00	0.001702	5.92499
847.05	140.00	0.002359	7.700848	635.61	139.46	0.00213	7.052908
2193.86	139.53	0.002806	8.900158	520.80	139.39	0.001936	6.549444
346.87	140.00	0.001579	5.62422	696.89	139.44	0.002206	7.274208
100.00	137.76	0.000912	3.975133	731.28	139.43	0.002242	7.384429
863.05	139.97	0.002365	7.73264	466.48	138.60	0.001795	6.248495
950.12	140.00	0.002389	7.876649	741.38	139.43	0.002251	7.414969
100.00	139.80	0.00095	4.036531	440.86	139.46	0.001777	6.14232
884.87	139.93	0.00237	7.772426	370.62	139.44	0.001616	5.745408
924.71	140.00	0.002385	7.840582	327.89	140.00	0.001532	5.509749
384.55	139.83	0.001663	5.839998	301.49	140.00	0.001466	5.347514
232.60	140.00	0.00129	4.911501	310.09	139.99	0.001487	5.400503
588.68	139.68	0.00207	6.869011	277.72	139.99	0.001405	5.198882
100.00	129.76	0.000788	3.736333	292.71	140.00	0.001444	5.292973

5.2.2 Effect of optimizing RWR against ASG and ATA

The variation of optimized material removal rate against the conflicting criteria are obtained by optimized pareto optimal front prepared by executing the simulation parameter.

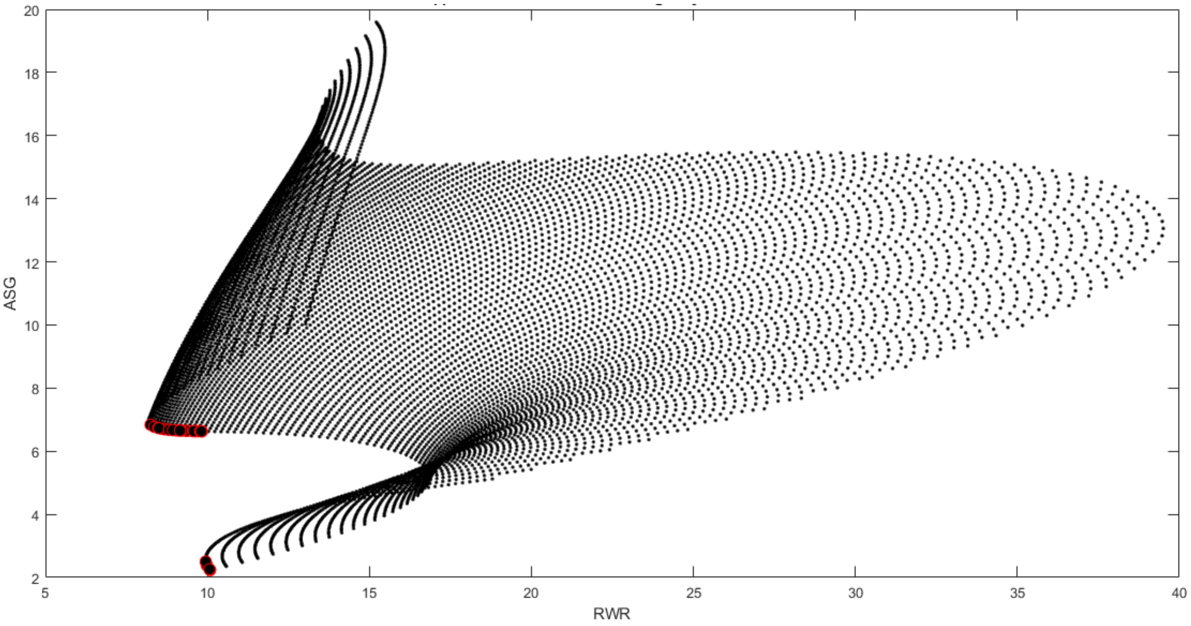


Figure 5.9: Pareto Front considering only ASG and RWR for copper

The non dominated front represented in Figure 5.9 by red circled are the optimized front of the optimizing parameter RWR and ASG. The search space for RWR ranges from 6 to 38. The optimized RWR can be achieved within a range of 8.247014 to 10.0844. The least ASG that can be achieved within optimizing space is 6.837194.

The optimized values from the simulation are:

Table 5.9: Optimized RWR and ASG of copper

Optimized Capacitance	**Optimized Voltage**	**Optimized RWR**	**Optimized ASG**	**Optimized Capacitance**	**Optimized Voltage**	**Optimized RWR**	**Optimized ATA**
100.00	60.25	10.0844	2.23492	1392.30	60.00	9.533373	6.638541
100.00	60.41	10.07937	2.240674	1391.10	60.00	9.542426	6.63827
100.00	64.20	9.988645	2.375442	1466.63	60.00	9.026078	6.66153
100.00	65.03	9.975316	2.405315	1380.63	60.00	9.622677	6.636002
100.00	67.76	9.947958	2.503429	1414.35	60.00	9.371649	6.643993
100.00	60.96	10.0632	2.259978	1369.72	60.00	9.708466	6.633845

1538.29	60.00	8.642581	6.701248	1461.82	60.00	9.055581	6.659626
Optimized Capacitance	**Optimized Voltage**	**Optimized RWR**	**Optimized ASG**	**Optimized Capacitance**	**Optimized Voltage**	**Optimized RWR**	**Optimized ATA**
1507.45	60.00	8.794469	6.681467	1378.57	60.00	9.638682	6.635558
1451.30	60.00	9.1218	6.655583	1420.55	60.00	9.327831	6.6457
1661.03	60.01	8.247014	6.837194	1354.64	60.00	9.830584	6.63094
1612.68	60.01	8.361981	6.772058	1377.50	60.00	9.647083	6.635351
1576.48	60.02	8.483734	6.734638	1357.06	60.00	9.810692	6.631382
1566.68	60.02	8.521903	6.726257	1366.70	60.00	9.732568	6.633203
1554.38	60.00	8.571565	6.713886	1374.27	60.00	9.672397	6.63469
1561.35	60.02	8.543477	6.721823	1420.09	60.00	9.331079	6.645583
1528.23	60.00	8.689903	6.694297	1440.25	60.00	9.193672	6.651741
1438.90	60.00	9.20263	6.651295	1386.20	60.00	9.579726	6.637204
1571.60	60.02	8.502317	6.730042	1358.13	60.00	9.801997	6.631585
1451.79	60.00	9.118626	6.655764	1360.50	60.00	9.782639	6.63203
1361.74	60.00	9.772604	6.632234	1361.04	60.00	9.778222	6.632122
1381.39	60.00	9.616766	6.636148	1481.52	60.00	8.937663	6.668162
1503.11	60.00	8.817441	6.679033	1437.61	60.00	9.211282	6.650944
1378.02	60.00	9.643027	6.635483	1354.47	60.00	9.831982	6.630909
1367.36	60.00	9.727245	6.633321	1446.43	60.00	9.15318	6.65388

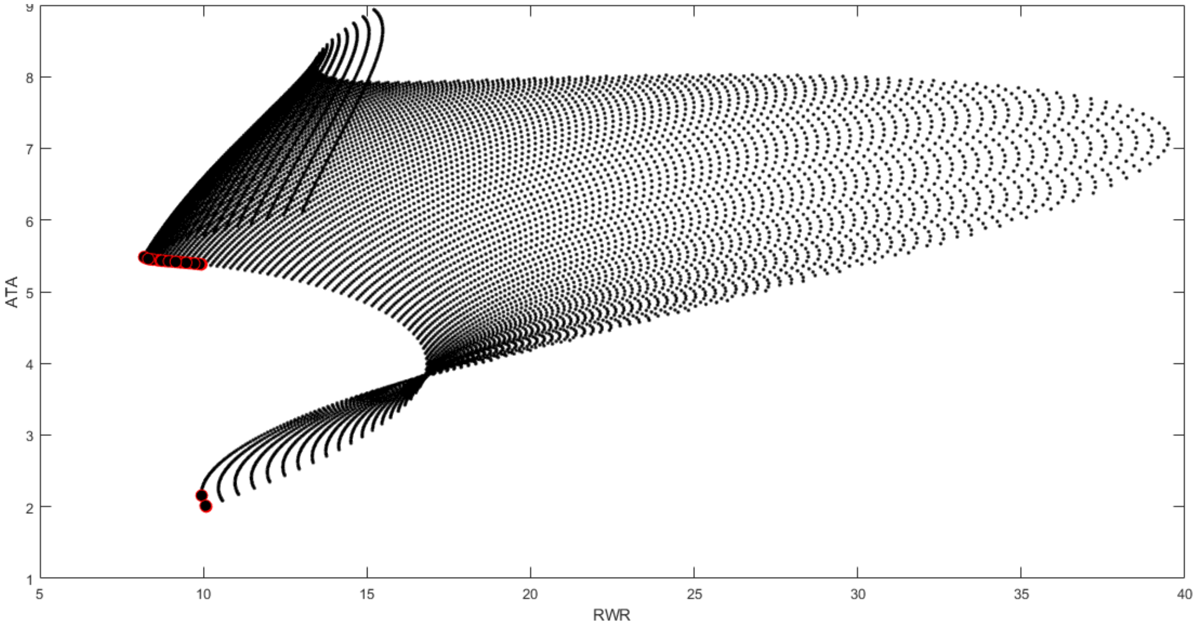


Figure 5.10: Pareto Front considering only RWR and ATA

The non dominated front represented in Figure 5.10 by red circled are the optimized front of the optimizing parameter RWR and ATA. The search space for RWR ranges from 6 to 38. The optimized RWR can be achieved within a range of 8.18936 to 10.08542. The least ASG that can be achieved within optimizing space is 2.155649.

Table 5.10: Optimized RWR and ASG of copper

Optimized Capacitance	Optimized Voltage	Optimized RWR	Optimized ASG	Optimized Capacitance	Optimized Voltage	Optimized RWR	Optimized ATA
100.00	68.08	9.94636	2.155649	1480.26	60.00	8.945145	5.424576
1494.332	60.00	8.865153	5.427616	1446.86	60.02	9.151327	5.416939
1499.839	60.00	8.835048	5.42884	1387.76	60.01	9.568398	5.399715
100	60.22	10.08542	2.002799	1439.14	60.01	9.201526	5.41465
100	68.15	9.946067	2.156999	1343.93	60.01	9.920638	5.383904
1512.442	60.00	8.768524	5.431602	1405.90	60.01	9.433287	5.405481
1545.209	60.00	8.611269	5.438662	1374.03	60.01	9.675082	5.39518
1544.598	60.00	8.613989	5.438531	1366.36	60.01	9.736052	5.39246
1606.528	60.00	8.379838	5.452475	1443.93	60.01	9.170253	5.416078
100	60.80	10.06777	2.013713	1442.35	60.01	9.180624	5.415677

1635.721	60.00	8.299609	5.459893	1434.73	60.01	9.231273	5.413644
1676.572	60.00	8.221379	5.47185	1410.76	60.01	9.397982	5.406866
1582.799	60.04	8.461679	5.448426	1355.60	60.01	9.823498	5.388467
1709.342	60.02	8.189396	5.483774	1350.21	60.01	9.868078	5.386395
1391.912	60.00	9.536273	5.400699	1381.18	60.01	9.619144	5.397636
1516.641	60.01	8.747513	5.432779	1352.71	60.01	9.847296	5.387366
1421.905	60.01	9.319069	5.410099	1426.22	60.01	9.289178	5.411336
1630.59	60.01	8.312614	5.458775	1347.45	60.01	9.891078	5.38533
1527.985	60.02	8.692404	5.435819	1402.90	60.01	9.455285	5.404633
1519.804	60.01	8.731728	5.433534	1445.56	60.01	9.159663	5.416522
1341.921	60.00	9.936811	5.382652	1380.77	60.01	9.622298	5.397488
1425.591	60.01	9.293497	5.411137	1348.59	60.01	9.881572	5.385757
1421.337	60.00	9.322542	5.409645	1368.25	60.01	9.720924	5.393144
1630.142	60.00	8.31364	5.458579	1400.76	60.01	9.470948	5.40391

5.3 Case I (c): Two objective optimization of parameters of brass

The optimization simulation is carried out to determine the optimal value of capacitance and gap voltage represented by keeping MRR, RWR, ASG and ATA selecting two objectives repeatedly for steel as electrode.

5.3.1 Effect of optimizing MRR against RWR, ASG and ATA respectively

The variation of optimized material removal rate against the conflicting criteria are obtained by optimized pareto optimal front prepared by executing the simulation parameter.

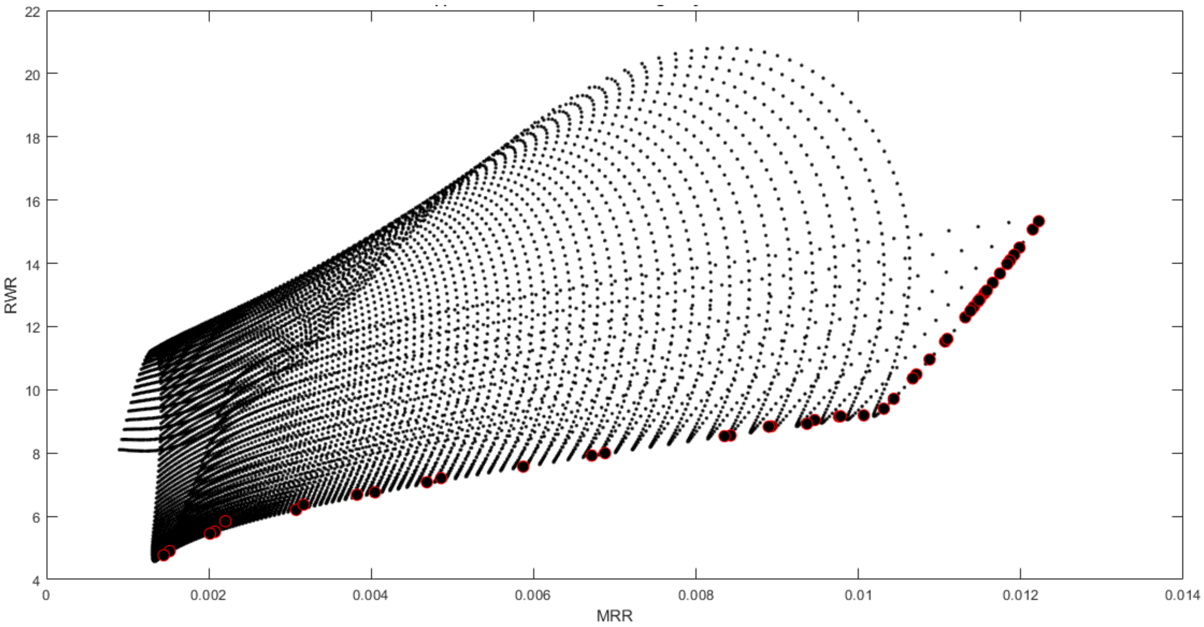


Figure 5.11: Pareto Front considering RWR and MRR for brass

The non dominated front represented in Figure 5.10 by red circled are the optimized front of the optimizing parameter MRR and RWR. The search space for MRR ranges from 0.0014 to 0.013. The optimized MRR can be achieved within a range of 0.001144 to 0.010713. The least RWR that can be achieved within optimizing space is 4.896504.

Table 5.11: Optimized MRR and RWR of brass

Optimized Capacitance	**Optimized Voltage**	**Optimized MRR**	**Optimized RWR**	**Optimized Capacitance**	**Optimized Voltage**	**Optimized MRR**	**Optimized RWR**
1727.52	67.30	0.001517	4.896504	1639.51	138.14	0.009462	9.043852
1653.55	103.33	0.003076	6.202113	1640.30	136.66	0.008926	8.844038
1786.05	119.38	0.004859	7.206407	1679.52	137.92	0.009366	8.924524
1604.60	111.30	0.003826	6.681167	1668.36	139.70	0.010066	9.191352
1632.91	118.22	0.004686	7.076803	1639.40	136.57	0.008895	8.834695
1783.71	104.22	0.003168	6.367532	1638.37	138.91	0.00976	9.155312
1671.41	65.07	0.001444	4.765217	1747.12	135.21	0.008425	8.555589
1752.89	129.10	0.006715	7.921352	1638.59	138.96	0.00978	9.162054
1633.19	113.34	0.004046	6.755639	1754.70	134.97	0.008351	8.534433
2054.33	140.00	0.011067	11.52863	2162.09	140.00	0.011871	14.11223
1847.24	140.00	0.010312	9.402259	2102.67	140.00	0.011383	12.51058
1667.49	129.77	0.006879	7.998271	2173.98	140.00	0.011983	14.49632
1676.60	125.25	0.005872	7.568741	2167.07	140.00	0.011917	14.2704
1972.99	140.00	0.010668	10.35949	2114.43	140.00	0.011471	12.78972
1983.91	140.00	0.010713	10.4868	2137.40	140.00	0.011655	13.38664
2147.71	140.00	0.011742	13.67837	2108.17	140.00	0.011425	12.63927
1691.78	85.82	0.002075	5.506195	2106.99	140.00	0.011414	12.61088
1820.88	87.52	0.002203	5.841637	2161.21	140.00	0.011863	14.08499
1673.12	84.39	0.002014	5.448361	2117.76	140.00	0.011497	12.87197
1973.36	140.00	0.01067	10.36362	2101.96	140.00	0.011377	12.49404
1902.06	140.00	0.010434	9.714837	2190.42	140.00	0.012147	15.06835
2019.23	140.00	0.010876	10.95862	2197.56	140.00	0.012221	15.33219
2092.98	140.00	0.011315	12.29355	2157.82	140.00	0.011832	13.98008
2124.84	140.00	0.011552	13.05163	2128.21	140.00	0.011579	13.13921

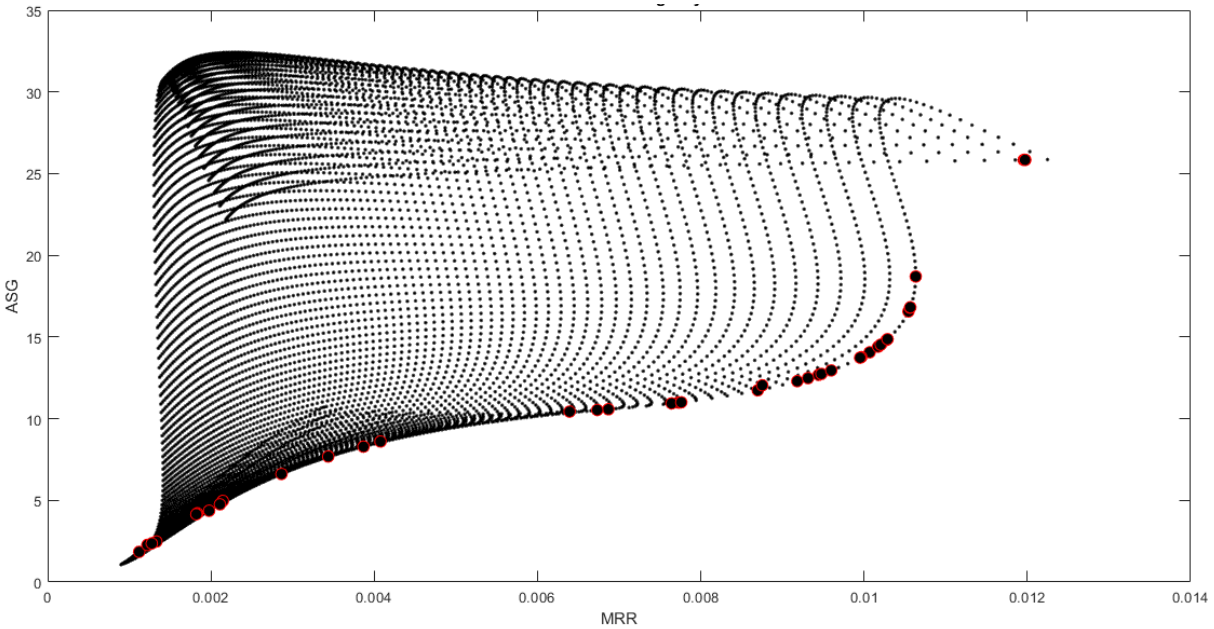


Table 5.12: Pareto Front considering only ASG and MRR for brass

The non dominated front represented in Figure 5.10 by red circled are the optimized front of the optimizing parameter MRR and ASG. The search space for MRR ranges from 0.0014 to 0.013. The optimized MRR can be achieved within a range of 0.001045 to 0.011265. The least ASG that can be achieved within optimizing space is 1.392358.

Table 5.12: Optimized MRR and ASG of brass

Optimized Capacitance	**Optimized Voltage**	**Optimized MRR**	**Optimized RWR**	**Optimized Capacitance**	**Optimized Voltage**	**Optimized MRR**	**Optimized RWR**
198.31	60.69	0.001045	1.392358	532.02	113.49	0.003915	8.810884
443.53	113.41	0.003599	7.994255	499.57	113.67	0.003824	8.515543
390.49	138.91	0.006212	10.33001	491.36	113.43	0.003775	8.41355
429.43	140.00	0.006804	10.55534	513.98	113.46	0.003854	8.629999
100.00	84.75	0.00132	2.71286	534.95	140.00	0.007845	11.05463
242.84	96.49	0.002015	4.615056	894.18	140.00	0.01021	14.54757
2200.00	136.56	0.01068	25.74641	496.15	140.00	0.007476	10.84314
1085.36	140.00	0.010607	17.50392	614.76	139.98	0.008546	11.59133
1117.13	140.00	0.010625	18.05993	531.55	140.00	0.007815	11.03506
549.70	140.00	0.007983	11.14394	698.22	139.98	0.00918	12.29908
1066.98	140.00	0.010591	17.18982	717.56	140.00	0.009316	12.48487

446.43	140.00	0.006978	10.61941	892.02	140.00	0.010202	14.51835
1097.33	140.00	0.010615	17.71146	891.60	140.00	0.010201	14.51268
469.71	140.00	0.007214	10.71747	889.36	140.00	0.010193	14.48255
1108.09	140.00	0.010621	17.90008	900.07	140.00	0.010231	14.62778
2200.00	139.93	0.012214	25.85679	682.15	140.00	0.00907	12.15162
2200.00	137.31	0.011	25.7705	670.22	139.99	0.008983	12.04543
2200.00	136.85	0.010802	25.75569	576.61	140.00	0.008225	11.31828
2200.00	137.21	0.010957	25.76733	599.74	140.00	0.008425	11.48056
2200.00	137.92	0.011265	25.78996	676.49	140.00	0.009029	12.10083
2200.00	139.67	0.012081	25.84772	591.76	140.00	0.008356	11.42331
340.05	113.45	0.003177	7.243819	675.20	139.99	0.009019	12.08937
359.60	113.41	0.003258	7.365945	678.80	140.00	0.009046	12.12152
520.96	113.40	0.003872	8.691903	585.01	140.00	0.008298	11.37593

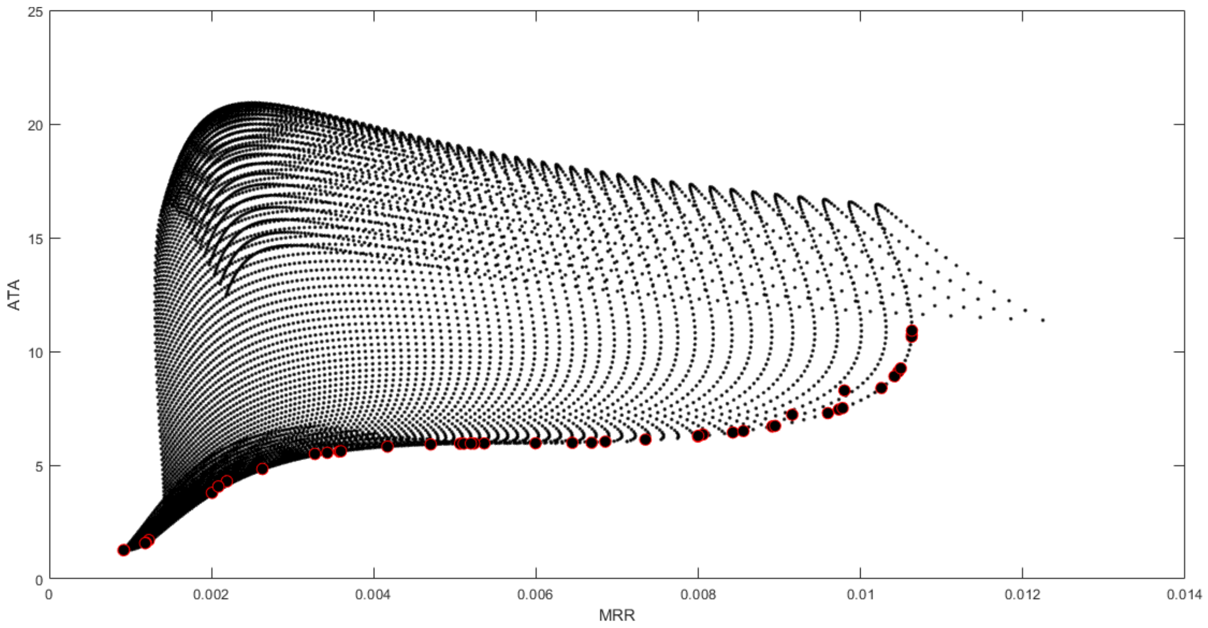


Figure 5.13: Pareto Front considering only ATA and MRR for brass

Table 5.13: Optimized MRR and ATA of brass

Optimized Capacitance	**Optimized Voltage**	**Optimized MRR**	**Optimized ATA**	**Optimized Capacitance**	**Optimized Voltage**	**Optimized MRR**	**Optimized ATA**
298.39	96.86	0.002189	4.289479	451.00	139.12	0.006854	6.034265
481.34	82.72	0.002006	3.782843	664.96	140.00	0.008945	6.725487
985.31	140.00	0.010466	9.112154	1151.17	140.00	0.010633	10.91498
369.71	124.08	0.004169	5.813791	558.27	139.74	0.007998	6.289526
352.89	130.31	0.004702	5.912785	762.82	140.00	0.009597	7.286664
551.03	140.00	0.007995	6.261857	795.77	140.00	0.009779	7.509293
359.31	135.23	0.005362	5.957755	408.01	139.24	0.006447	5.981409
964.13	140.00	0.010418	8.906824	355.10	133.23	0.005065	5.944408
304.26	93.72	0.002085	4.060507	359.28	133.29	0.005108	5.946368
360.97	102.56	0.002628	4.832601	374.91	133.27	0.005235	5.95446
999.76	140.00	0.010495	9.255872	370.61	133.26	0.005198	5.951632
660.54	140.00	0.008912	6.703676	100.00	61.21	0.000918	1.268379
417.95	140.00	0.006685	5.985593	100.00	61.06	0.000915	1.259537
907.76	140.00	0.010257	8.39146	103.47	61.17	0.000922	1.269018
599.86	140.00	0.008426	6.435432	286.49	64.19	0.001227	1.703654
615.36	140.00	0.008555	6.498449	286.56	62.46	0.001191	1.588415
1133.99	140.00	0.01063	10.71457	100.00	61.19	0.000917	1.267395
1127.97	140.00	0.010629	10.64491	284.18	62.24	0.001183	1.569856
573.71	139.42	0.008056	6.348004	100.00	61.20	0.000917	1.267682
359.82	133.28	0.005111	5.946438	349.90	116.45	0.003427	5.542892
746.68	138.88	0.009158	7.21865	382.64	116.41	0.003578	5.600842
889.11	138.87	0.0098	8.281903	382.64	116.38	0.003575	5.599627
368.61	138.94	0.005994	5.963345	382.64	116.39	0.003576	5.600024
787.07	140.00	0.009733	7.4489	382.64	116.63	0.003595	5.608932

5.3.2 Effect of optimizing RWR against ASG and ATA

The variation of optimized material removal rate against the conflicting criteria are obtained by optimized pareto optimal front prepared by executing the simulation parameter.

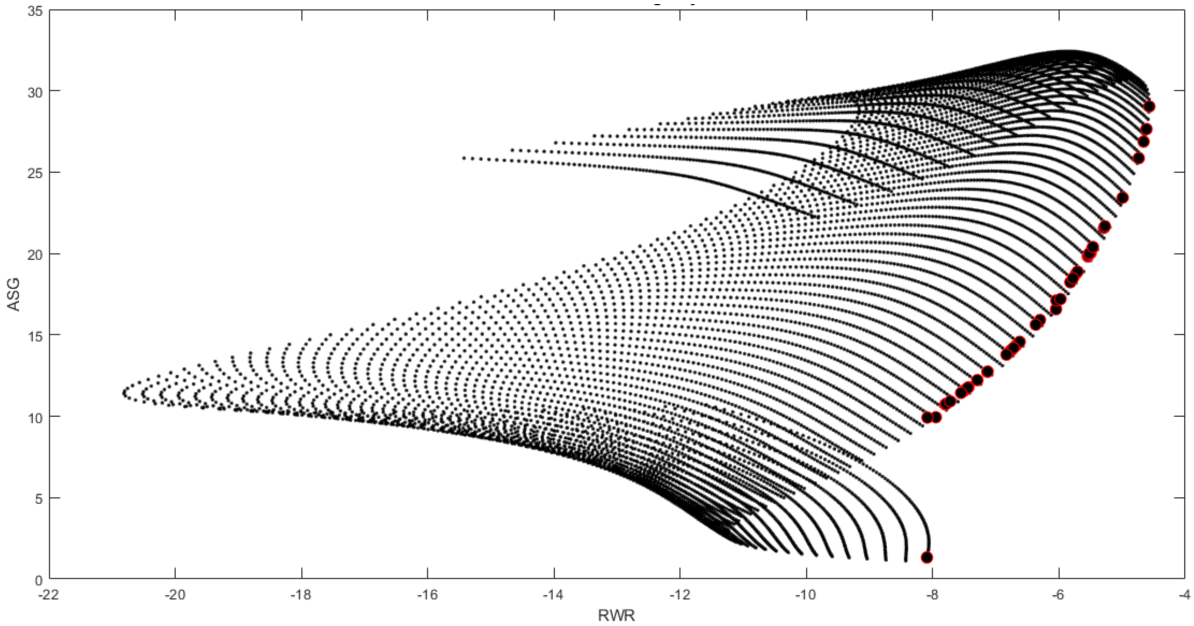


Figure 5.14: Pareto Front considering only ASG and RWR for brass

The non dominated front represented in Figure 5.14 by red circled are the optimized front of the optimizing parameter RWR and ASG. The search space for RWR ranges from 2 to 22. The optimized RWR can be achieved within a range of 0.0010466 to 0.010495. The least ASG that can be achieved within optimizing space is 1.268379.

Table 5.14: Optimized RWR and ASG of brass

Optimized Capacitance	Optimized Voltage	Optimized RWR	Optimized ASG	Optimized Capacitance	Optimized Voltage	Optimized RWR	Optimized ASG
298.39	96.86	0.002189	4.289479	451.00	139.12	0.006854	6.034265
481.34	82.72	0.002006	3.782843	664.96	140.00	0.008945	6.725487
985.31	140.00	0.010466	9.112154	1151.17	140.00	0.010633	10.91498
369.71	124.08	0.004169	5.813791	558.27	139.74	0.007998	6.289526
352.89	130.31	0.004702	5.912785	762.82	140.00	0.009597	7.286664
551.03	140.00	0.007995	6.261857	795.77	140.00	0.009779	7.509293
359.31	135.23	0.005362	5.957755	408.01	139.24	0.006447	5.981409

964.13	140.00	0.010418	8.906824	355.10	133.23	0.005065	5.944408
304.26	93.72	0.002085	4.060507	359.28	133.29	0.005108	5.946368
360.97	102.56	0.002628	4.832601	374.91	133.27	0.005235	5.95446
999.76	140.00	0.010495	9.255872	370.61	133.26	0.005198	5.951632
660.54	140.00	0.008912	6.703676	100.00	61.21	0.000918	1.268379
417.95	140.00	0.006685	5.985593	100.00	61.06	0.000915	1.259537
907.76	140.00	0.010257	8.39146	103.47	61.17	0.000922	1.269018
599.86	140.00	0.008426	6.435432	286.49	64.19	0.001227	1.703654
615.36	140.00	0.008555	6.498449	286.56	62.46	0.001191	1.588415
1133.99	140.00	0.01063	10.71457	100.00	61.19	0.000917	1.267395
1127.97	140.00	0.010629	10.64491	284.18	62.24	0.001183	1.569856
573.71	139.42	0.008056	6.348004	100.00	61.20	0.000917	1.267682
359.82	133.28	0.005111	5.946438	349.90	116.45	0.003427	5.542892
746.68	138.88	0.009158	7.21865	382.64	116.41	0.003578	5.600842
889.11	138.87	0.0098	8.281903	382.64	116.38	0.003575	5.599627
368.61	138.94	0.005994	5.963345	382.64	116.39	0.003576	5.600024
787.07	140.00	0.009733	7.4489	382.64	116.63	0.003595	5.608932

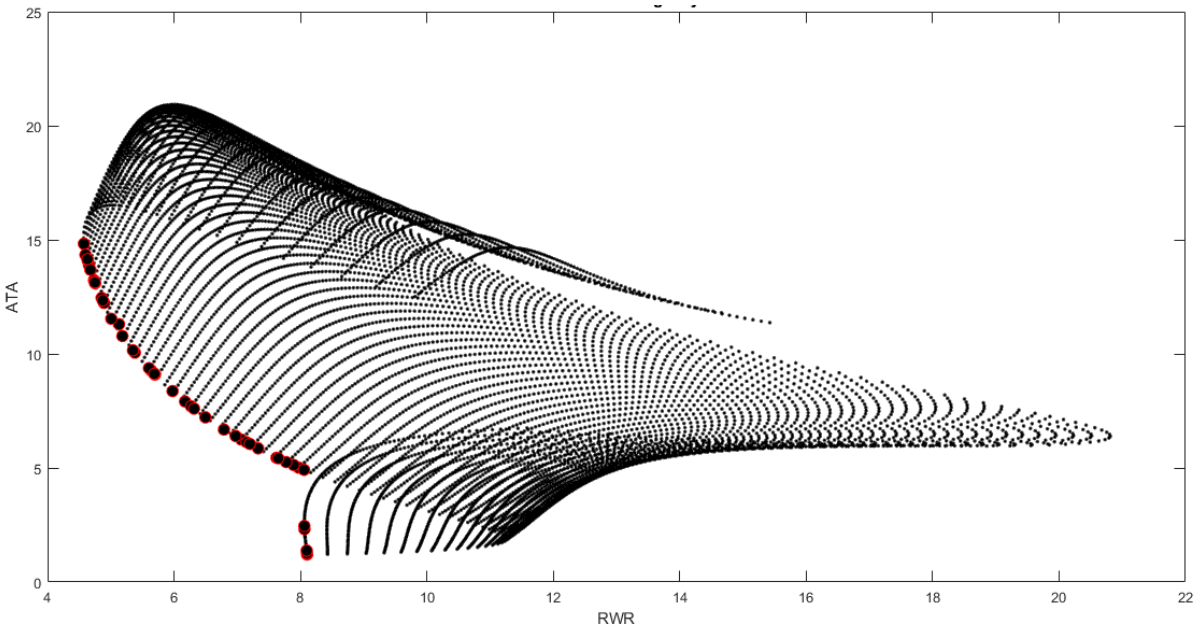


Figure 5.15: Pareto Front considering only ATA and RWR for brass

The non dominated front represented in Figure 5.15 by red circled are the optimized front of the optimizing parameter ATA and RWR. The search space for RWR ranges from 4.2 to 21. The optimized RWR can be achieved within a range of 0.0010466 to 0.010495. The least ATA that can be achieved within optimizing space is 1.268379.

Table 5.15: Optimized RWR and ATA of brass

Optimized Capacitance	**Optimized Voltage**	**Optimized RWR**	**Optimized ATA**	**Optimized Capacitance**	**Optimized Voltage**	**Optimized RWR**	**Optimized ATA**
100.00	75.96	8.063357	2.321072	1275.75	60.09	5.681779	9.145841
1628.67	60.00	4.574886	14.82589	1182.20	60.10	6.270541	7.702497
1009.57	60.00	7.621766	5.446229	1272.63	60.09	5.699626	9.095882
1332.16	60.00	5.380378	10.05655	1175.33	60.08	6.317556	7.599756
969.64	60.00	7.973027	5.014559	1066.08	60.08	7.149261	6.126485
960.23	60.00	8.057176	4.917428	1006.78	60.06	7.649355	5.424216
1593.72	60.00	4.599555	14.34465	1283.20	60.09	5.640189	9.267657
1375.27	60.00	5.183032	10.7844	1226.56	60.09	5.976671	8.368466
960.39	60.00	8.055701	4.919112	1087.64	60.09	6.975021	6.398784
1110.66	60.00	6.789451	6.684721	1289.75	60.09	5.604074	9.374097
1149.71	60.00	6.496076	7.218221	1060.08	60.09	7.198767	6.053062
100.00	77.61	8.061554	2.457578	1274.55	60.10	5.689432	9.130038
100.00	60.19	8.104442	1.208499	1456.82	60.27	4.893385	12.23679
100.00	60.96	8.103037	1.253435	1571.94	60.27	4.635792	14.09561
100.00	62.98	8.09843	1.376564	1573.26	60.27	4.633966	14.11484
100.00	62.99	8.098407	1.37714	1558.08	60.27	4.655837	13.88416
1338.12	60.00	5.351527	10.15648	1469.58	60.27	4.854949	12.45202
1516.49	60.27	4.734641	13.22754	1571.58	60.27	4.63615	14.08934
1395.63	60.73	5.13016	11.3003	1545.36	60.27	4.677214	13.68803
979.14	60.09	7.893841	5.127694	1512.23	60.27	4.744182	13.15846
1044.22	60.08	7.330604	5.860414	1576.03	60.27	4.630331	14.1562
1076.34	60.04	7.063265	6.247215	1510.49	60.27	4.748176	13.13011
1419.68	60.00	5.007337	11.54114	1463.37	60.27	4.873364	12.34754
992.11	60.03	7.775628	5.257512	1508.60	60.27	4.752565	13.09919

5.4 Case I (d): Two objective optimization of parameters of aluminium

The optimization simulation is carried out to determine the optimal value of capacitance and gap voltage represented by keeping MRR, RWR, ASG and ATA selecting two objectives repeatedly for aluminium as electrode.

5.4.1 Effect of optimizing MRR against RWR, ASG and ATA respectively

The variation of optimized material removal rate against the conflicting criteria are obtained by optimized pareto optimal front prepared by executing the simulation parameter.

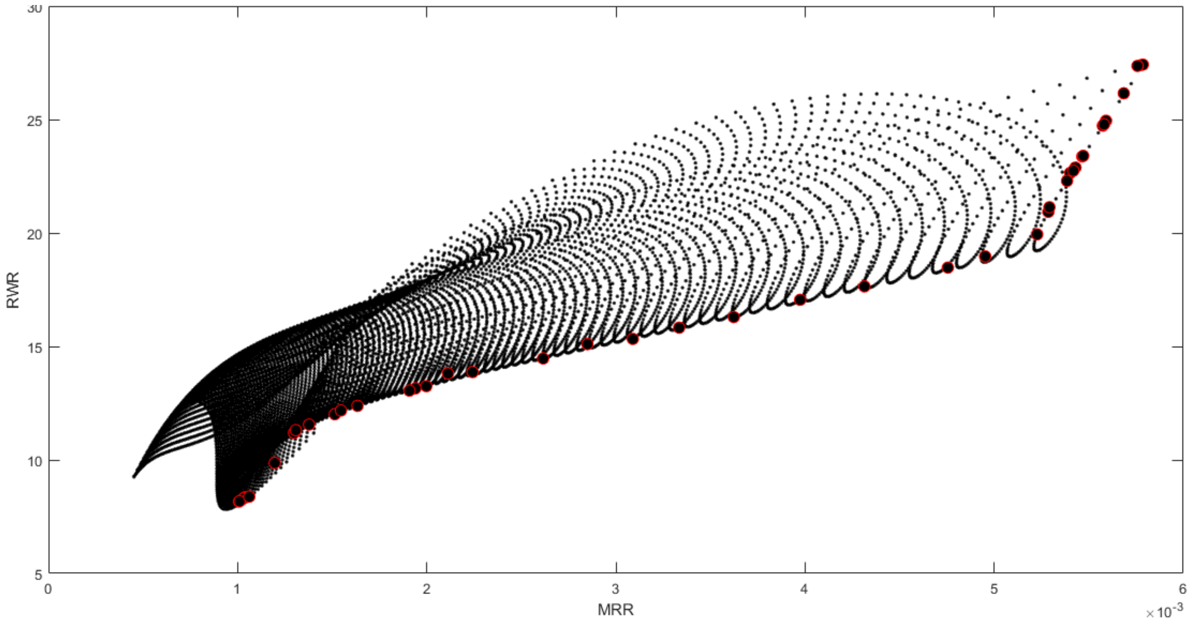


Figure 5.16: Pareto Front considering only RWR and MRR for aluminium

The non dominated front represented in Figure 5.16 by red circled are the optimized front of the optimizing parameter RWR and MRR. The search space for MRR ranges from .0002 to 0.005. The optimized MRR can be achieved within a range of 0.00101 to 0.005786. The least ATA that can be achieved within optimizing space is 1.20849.

Table 5.16: Optimized MRR and RWR of aluminium

Optimized Capacitance	**Optimized Voltage**	**Optimized MRR**	**Optimized RWR**	**Optimized Capacitance**	**Optimized Voltage**	**Optimized MRR**	**Optimized RWR**
1624.17	85.64	0.001299	11.18974	1950.62	140.00	0.005287	20.92905
1637.07	123.15	0.00309	15.33218	2030.20	140.00	0.005385	22.2966

2055.31	63.08	0.001196	9.867383	2200.00	139.96	0.005786	27.42043
Optimized Capacitance	**Optimized Voltage**	**Optimized MRR**	**Optimized RWR**	**Optimized Capacitance**	**Optimized Voltage**	**Optimized MRR**	**Optimized RWR**
1617.63	106.50	0.001998	13.24819	2057.25	139.99	0.005429	22.88544
1779.92	85.07	0.001307	11.31159	2200.00	139.82	0.005759	27.36506
1859.95	60.89	0.001016	8.21463	2125.76	139.99	0.005574	24.73051
1696.45	125.92	0.003335	15.82798	2167.96	139.97	0.005685	26.15528
1727.39	134.29	0.004314	17.64468	2051.11	139.99	0.005418	22.74461
1781.05	138.51	0.004952	18.96942	1862.02	140.00	0.005227	19.94267
1790.30	108.92	0.002112	13.81135	2132.58	139.99	0.005591	24.94512
1734.77	131.72	0.003974	17.05626	1965.98	139.95	0.005292	21.13569
1753.99	120.52	0.00285	15.10025	2200.00	139.82	0.005758	27.36335
1726.15	111.44	0.002242	13.86935	2077.56	139.98	0.005466	23.37335
1636.49	128.53	0.003623	16.29482	2127.45	140.00	0.005581	24.78789
1741.77	137.28	0.004755	18.47468	2078.40	140.00	0.005471	23.4013
1600.12	117.05	0.002615	14.47079	1861.78	140.00	0.005227	19.9406
1589.90	88.91	0.001378	11.55736	1861.67	140.00	0.005227	19.93972
1633.49	93.85	0.001514	12.01127	1895.57	60.89	0.001039	8.349598
1601.20	97.51	0.001634	12.38139	1858.05	60.87	0.001015	8.205077
1720.95	94.84	0.001546	12.17831	1845.24	60.87	0.001008	8.164775
1572.64	105.09	0.00194	13.15114	1890.62	60.87	0.001035	8.325054
1635.49	104.62	0.001909	13.05253	1845.22	60.87	0.001008	8.164677
2200.00	139.95	0.005785	27.41788	1849.66	60.87	0.00101	8.178128
2047.58	139.93	0.005402	22.64585	1935.11	60.00	0.001062	8.382728

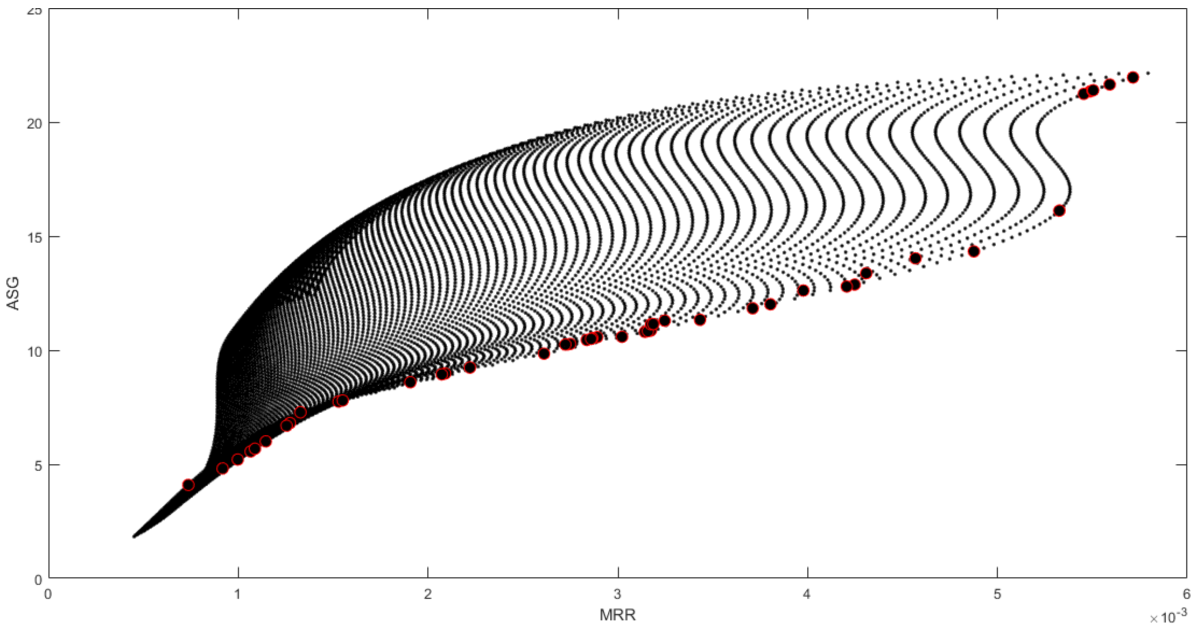


Figure 5.17: Pareto Front considering only ASG and MRR for aluminium

The non dominated front represented in Figure 5.17 by red circled are the optimized front of the optimizing parameter RWR and MRR. The search space for MRR ranges from .0002 to 0.005. The optimized MRR can be achieved within a range of 0.001528 to 0.003162. The least ASG that can be achieved within optimizing space is 1.20849.

Table 5.17: Optimized MRR and ASG of aluminium

Optimized Capacitance	**Optimized Voltage**	**Optimized MRR**	**Optimized RWR**	**Optimized Capacitance**	**Optimized Voltage**	**Optimized MRR**	**Optimized RWR**
429.85	140.00	0.003162	10.84061	402.52	140.00	0.003022	10.58901
808.58	138.42	0.004568	14.02734	244.32	137.13	0.00209	8.977036
660.89	140.00	0.004248	12.87771	100.00	139.70	0.001528	7.74652
341.65	92.21	0.001066	5.561131	474.45	137.24	0.003175	11.13632
100.00	131.51	0.001328	7.281404	475.26	137.35	0.003187	11.14892
507.73	92.08	0.001272	6.808254	378.06	137.43	0.002736	10.25243
400.25	92.24	0.001146	6.003339	380.32	137.46	0.002748	10.27482
349.29	92.84	0.001088	5.683643	203.73	137.17	0.001907	8.595637
296.02	92.03	0.000998	5.207981	271.37	137.26	0.002221	9.239273

100.00	94.84	0.000737	4.096603	105.99	139.55	0.00155	7.795627
Optimized Capacitance	**Optimized Voltage**	**Optimized MRR**	**Optimized RWR**	**Optimized Capacitance**	**Optimized Voltage**	**Optimized MRR**	**Optimized RWR**
242.20	91.95	0.000918	4.815129	378.90	137.16	0.002723	10.24687
493.55	92.00	0.001255	6.689618	413.81	137.20	0.002891	10.57473
483.89	139.97	0.003433	11.33193	409.32	137.14	0.002866	10.53001
426.04	140.00	0.003143	10.80564	492.78	137.10	0.003247	11.2972
432.06	140.00	0.003173	10.86093	399.58	137.40	0.002836	10.4519
322.86	140.00	0.002611	9.847769	240.46	137.15	0.002073	8.94116
560.09	140.00	0.003804	12.01207	404.51	137.39	0.002859	10.49741
726.59	138.38	0.004308	13.37413	2175.30	140.00	0.005714	21.95651
650.73	140.00	0.004206	12.79234	2086.97	140.00	0.005488	21.34537
843.69	140.00	0.004876	14.33087	2088.48	140.00	0.005491	21.35528
429.10	140.00	0.003158	10.83374	2070.45	140.00	0.005455	21.23847
1105.78	140.00	0.005326	16.12119	2131.55	140.00	0.005591	21.64503
1104.92	140.00	0.005326	16.11583	2175.31	140.00	0.005714	21.95656
540.29	140.00	0.00371	11.8375	2092.62	140.00	0.0055	21.38245

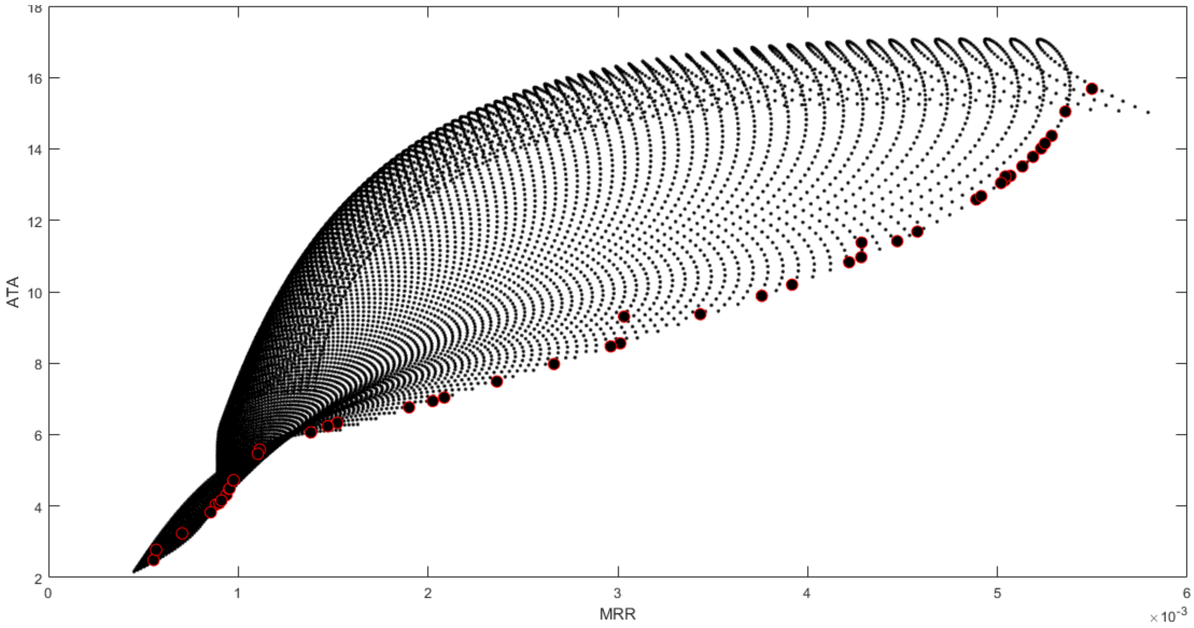


Figure 5.18: Pareto Front considering only ATA and MRR for aluminium

The non dominated front represented in Figure 5.18 by red circled are the optimized front of the optimizing parameter ATA and MRR. The search space for MRR ranges from .0002 to 0.005. The optimized MRR can be achieved within a range of 0.001528 to 0.003162. The least ASG that can be achieved within optimizing space is 1.20849.

Table 5.18: Optimized MRR and ATA of aluminium

Optimized Capacitance	**Optimized Voltage**	**Optimized MRR**	**Optimized RWR**	**Optimized Capacitance**	**Optimized Voltage**	**Optimized MRR**	**Optimized RWR**
212.44	61.47	0.000554	2.489205	694.12	69.10	0.000955	4.49406
669.36	140.00	0.004282	10.96954	509.41	68.80	0.000855	3.82539
218.60	140.00	0.002086	7.038122	599.77	69.06	0.000911	4.155345
274.24	140.00	0.002363	7.487473	762.46	68.86	0.000974	4.718482
206.12	140.00	0.002025	6.939312	162.43	68.84	0.000567	2.773943
910.39	140.00	0.00504	13.12668	759.74	69.01	0.000976	4.724391
584.76	140.00	0.003918	10.19811	1034.60	139.98	0.00525	14.15502
494.11	139.38	0.003434	9.37162	717.63	138.43	0.004284	11.37831
653.81	140.00	0.004218	10.82753	848.33	140.00	0.004888	12.58526
1061.95	140.00	0.005286	14.36931	987.89	140.00	0.005187	13.77871
550.42	140.00	0.003758	9.886641	747.92	140.00	0.004578	11.68495
503.30	133.61	0.003033	9.305511	924.72	139.98	0.005068	13.24916
1016.79	140.00	0.00523	14.01339	922.81	139.83	0.005042	13.23011
400.71	140.00	0.003013	8.556431	955.58	140.00	0.005131	13.51058
391.00	140.00	0.002963	8.472311	1153.86	140.00	0.005357	15.04602
184.17	139.46	0.0019	6.763857	900.90	140.00	0.005019	13.04485
333.04	140.00	0.002663	7.976833	859.18	139.98	0.004914	12.68051
2107.10	139.82	0.005498	15.68491	718.39	140.00	0.004472	11.41664
767.65	76.76	0.001113	5.582331	100.23	133.87	0.001383	6.063171
298.96	69.92	0.000705	3.235115	136.87	133.84	0.001522	6.328998
441.31	74.30	0.000882	4.0381	124.02	133.86	0.001473	6.235224
741.38	76.71	0.001103	5.46464	123.76	133.85	0.001472	6.233031
515.51	74.30	0.000938	4.313229	100.00	133.87	0.001382	6.061474
561.35	69.78	0.000901	4.084694	100.00	133.87	0.001382	6.061464

5.4.2 Effect of optimizing RWR against ASG and ATA

The variation of optimized material removal rate against the conflicting criteria are obtained by optimized pareto optimal front prepared by executing the simulation parameter.

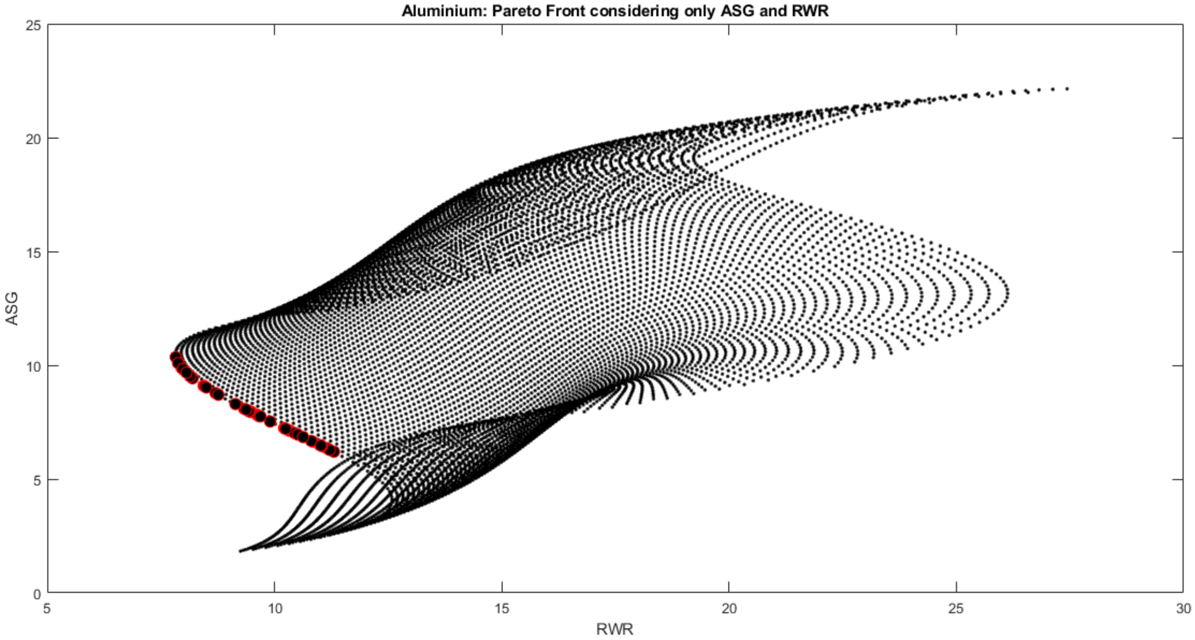


Figure 5.19: Pareto Front considering only ASG and RWR for aluminium

The non dominated front represented in Figure 5.19 by red circled are the optimized front of the optimizing parameter ASG and RWR. The search space for RWR ranges from 6 to 27. The optimized MRR can be achieved within a range of 7.827208 to 11.30823. The least ASG that can be achieved within optimizing space is 6.450537.

Table 5.19: Optimized RWR and ASG of aluminium

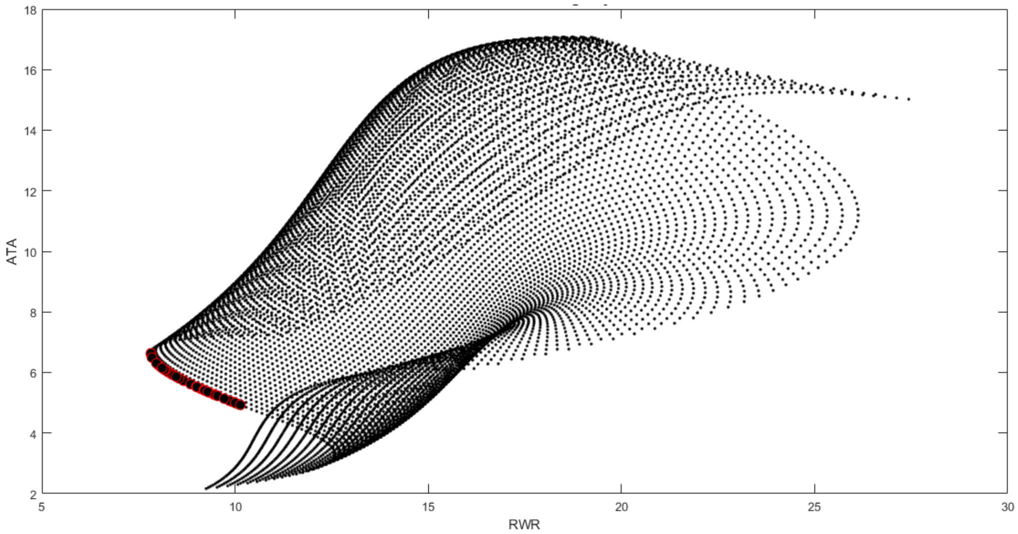
Optimized Capacitance	Optimized Voltage	Optimized RWR	Optimized ASG	Optimized Capacitance	Optimized Voltage	Optimized RWR	Optimized ASG
958.82	60.00	11.03643	6.450537	1176.12	60.00	9.660346	7.760424
1674.58	60.00	7.827208	10.35692	1173.31	60.08	9.690064	7.751569
1570.25	60.00	7.958981	9.872865	1401.26	60.05	8.49772	9.025097
1614.68	60.04	7.888436	10.08658	1354.43	60.06	8.704244	8.774217
1616.95	60.00	7.879561	10.09351	1214.65	60.02	9.434702	7.986369
1480.36	60.00	8.196924	9.429779	1225.87	60.06	9.375834	8.054763
1497.63	60.00	8.143036	9.516764	1341.81	60.06	8.763773	8.705578

917.21	60.09	11.30823	6.202496	959.47	60.01	11.03435	6.455685
Optimized Capacitance	**Optimized Voltage**	**Optimized RWR**	**Optimized ASG**	**Optimized Capacitance**	**Optimized Voltage**	**Optimized RWR**	**Optimized ASG**
942.41	60.08	11.15173	6.356767	990.75	60.01	10.83604	6.647545
930.65	60.02	11.21426	6.278808	965.18	60.01	10.99841	6.490771
1231.21	60.00	9.336496	8.08001	1088.10	60.01	10.21142	7.238814
1184.29	60.08	9.624608	7.816285	963.19	60.01	11.01092	6.478505
1414.96	60.05	8.441902	9.097374	1077.19	60.01	10.28112	7.173145
1206.29	60.08	9.493823	7.944262	1085.52	60.01	10.22782	7.223336
1136.61	60.00	9.903007	7.527382	1051.87	60.01	10.44336	7.019938
1268.08	60.06	9.140621	8.295847	961.71	60.01	11.02027	6.469398
1213.99	60.04	9.442012	7.984724	1084.23	60.01	10.23612	7.215554
1551.53	60.05	8.007622	9.787678	958.35	60.01	11.04136	6.448779
1208.55	60.00	9.467395	7.949346	1086.10	60.01	10.22419	7.226803
1068.74	60.00	10.33312	7.120906	1040.98	60.01	10.51376	6.953988
1411.05	60.05	8.457909	9.077006	994.95	60.01	10.80921	6.673217
1562.49	60.05	7.983457	9.840766	959.61	60.01	11.03346	6.456512
1410.33	60.06	8.461146	9.073396	961.52	60.01	11.02144	6.468287
1076.10	60.00	10.28592	7.165344	1023.06	60.01	10.62884	6.844888

The non dominated front represented in Figure 5.20 by red circled are the optimized front of the optimizing parameter ATA and RWR. The search space for RWR ranges from 7 to 28. The optimized RWR can be achieved within a range of 7.827208 to 11.30823. The least ASG that can be achieved within optimizing space is 6.450537.

Table 5.20: Optimized RWR and ASG of aluminium

Figure 5.20: Pareto Front considering only ATA and RWR for aluminium



Optimized Capacitance	Optimized Voltage	Optimized RWR	Optimized ASG	Optimized Capacitance	Optimized Voltage	Optimized RWR	Optimized ASG
958.82	60.00	11.03643	6.450537	1176.12	60.00	9.660346	7.760424

1674.58	60.00	7.827208	10.35692	1173.31	60.08	9.690064	7.751569
1570.25	60.00	7.958981	9.872865	1401.26	60.05	8.49772	9.025097
1614.68	60.04	7.888436	10.08658	1354.43	60.06	8.704244	8.774217
1616.95	60.00	7.879561	10.09351	1214.65	60.02	9.434702	7.986369
1480.36	60.00	8.196924	9.429779	1225.87	60.06	9.375834	8.054763
1497.63	60.00	8.143036	9.516764	1341.81	60.06	8.763773	8.705578
917.21	60.09	11.30823	6.202496	959.47	60.01	11.03435	6.455685
942.41	60.08	11.15173	6.356767	990.75	60.01	10.83604	6.647545
930.65	60.02	11.21426	6.278808	965.18	60.01	10.99841	6.490771
1231.21	60.00	9.336496	8.08001	1088.10	60.01	10.21142	7.238814
1184.29	60.08	9.624608	7.816285	963.19	60.01	11.01092	6.478505
1414.96	60.05	8.441902	9.097374	1077.19	60.01	10.28112	7.173145
1206.29	60.08	9.493823	7.944262	1085.52	60.01	10.22782	7.223336
1136.61	60.00	9.903007	7.527382	1051.87	60.01	10.44336	7.019938
1268.08	60.06	9.140621	8.295847	961.71	60.01	11.02027	6.469398
1213.99	60.04	9.442012	7.984724	1084.23	60.01	10.23612	7.215554
1551.53	60.05	8.007622	9.787678	958.35	60.01	11.04136	6.448779
1208.55	60.00	9.467395	7.949346	1086.10	60.01	10.22419	7.226803
1068.74	60.00	10.33312	7.120906	1040.98	60.01	10.51376	6.953988
1411.05	60.05	8.457909	9.077006	994.95	60.01	10.80921	6.673217
1562.49	60.05	7.983457	9.840766	959.61	60.01	11.03346	6.456512
1410.33	60.06	8.461146	9.073396	961.52	60.01	11.02144	6.468287
1076.10	60.00	10.28592	7.165344	1023.06	60.01	10.62884	6.844888

5.5 Case II (a): Multi objective optimization of parameters for steel

The optimization simulation is carried out to determine the optimal value of capacitance and gap voltage represented by keeping MRR, RWR, ASG and ATA selecting two objectives repeatedly for steel as electrode. The variation of different optimizing parameters is observed in this book.

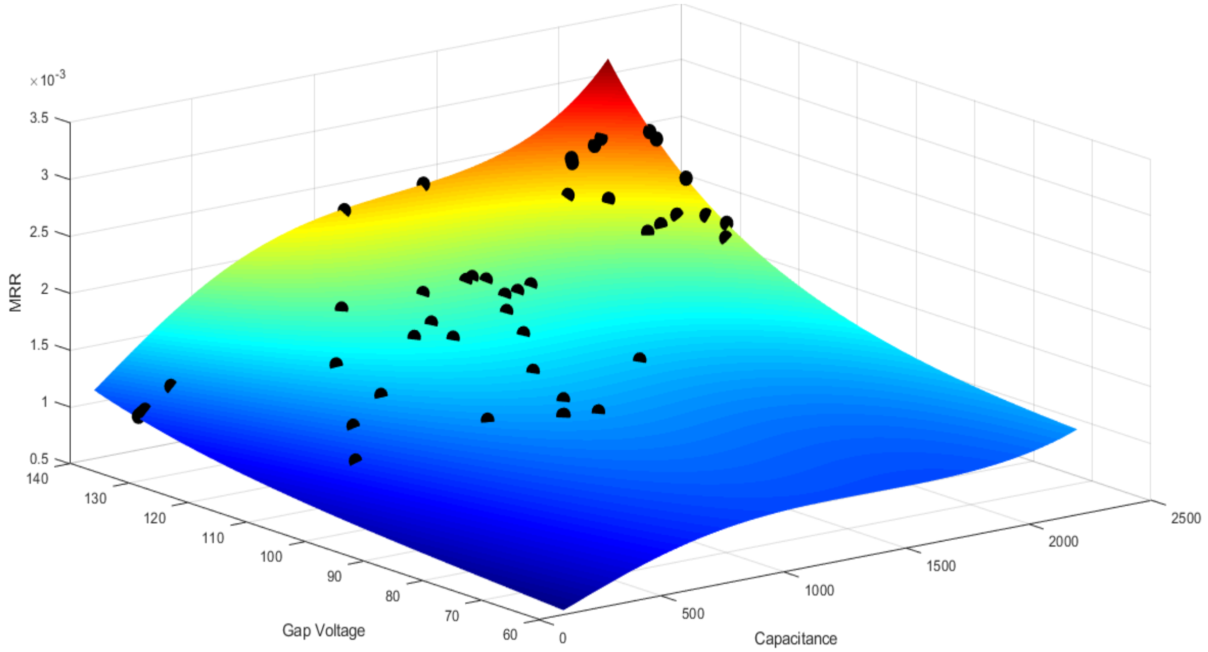


Figure 5.21: Variation of MRR for steel with capacitance and voltage

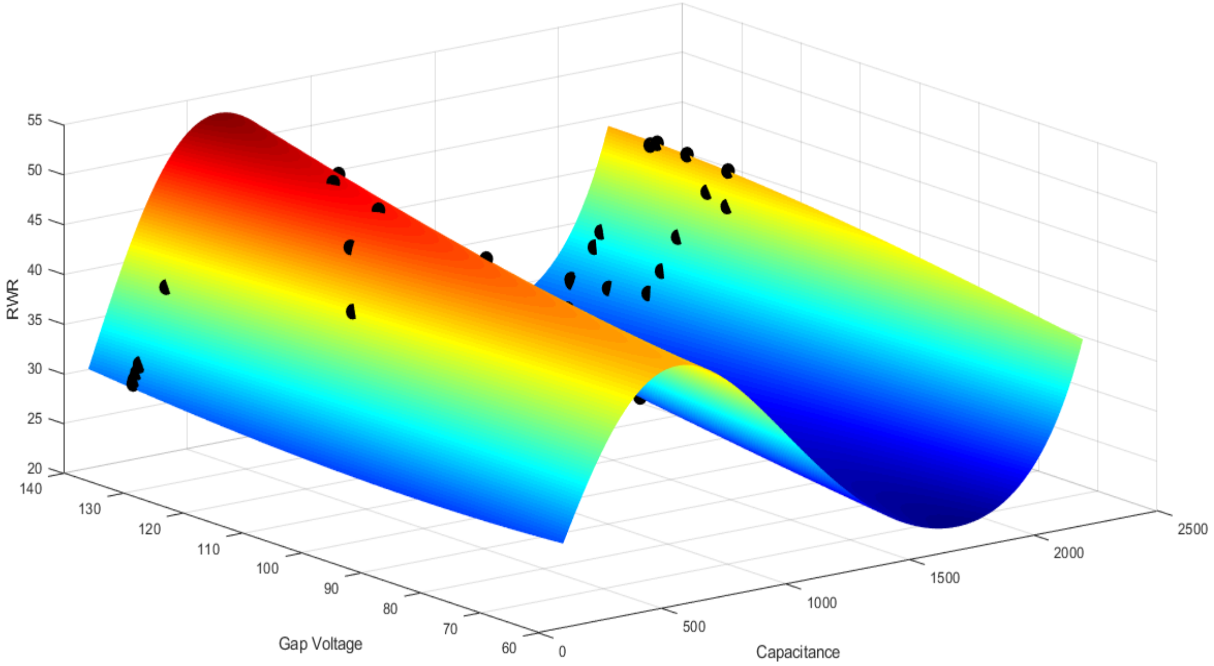


Figure 5.22: Variation of RWR for steel with capacitance and voltage

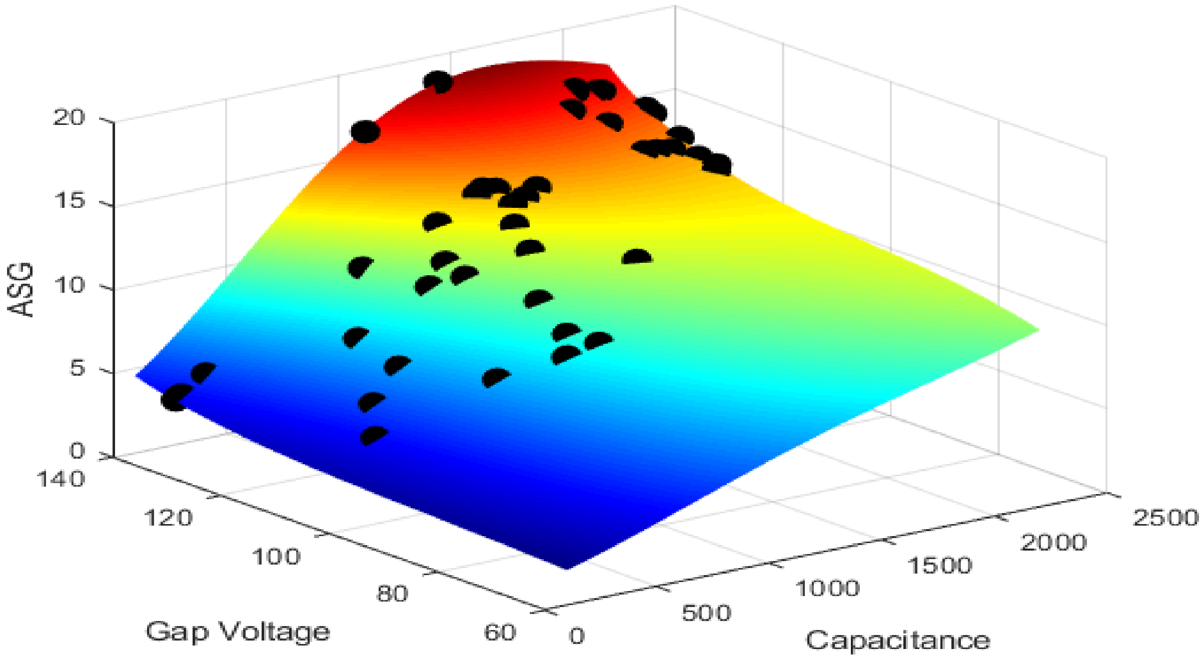


Figure 5.22: Variation of RWR for steel with capacitance and voltage

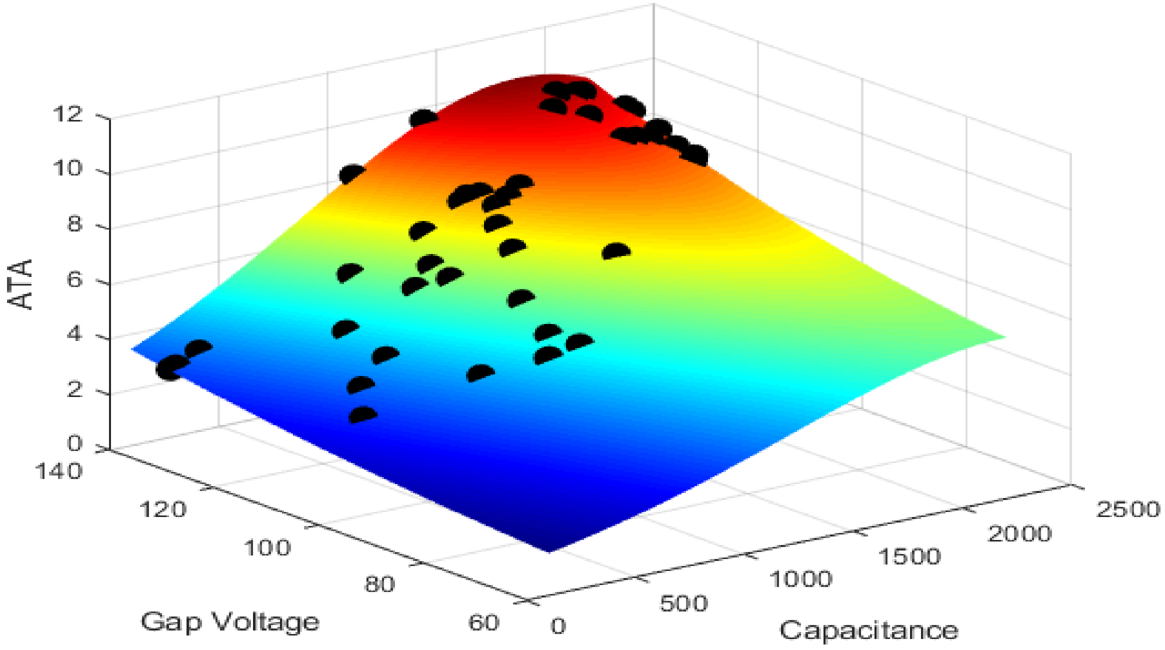


Figure 5.14: Variation of ATA for steel with capacitance and voltage

The optimizing parameters MRR, RWR, ASG and ATA increases with the increasing capacitance and voltage. The optimized discharge energy value can be achieved within a range of MRR from

0.000982 to 0.00262. The RWR, ASG and ATA value for maximizing MRR can be achieved up to 27.18888, 3.963198 and 2.99267 respectively.

The optimized capacitance and voltage to achieve optimized MRR, RWR, ASG and ATA are:

Table 5.21: Optimized MRR, RWR, ASG and ATA of steel

Combination Parameter	**Optimized Capacitance**	**Optimized Voltage**	**Optimized MRR**	**Optimized RWR**	**Optimized RWR**	**Optimized ASG**
1	2171.76	122.11	0.002075	41.16623	13.88524	8.566058
2	1969.83	130.31	0.002161	30.83502	15.50363	9.455356
3	1867.75	132.97	0.002193	28.71837	16.27126	9.700201
4	1503.50	105.56	0.00137	27.18888	11.49571	6.93114
5	918.48	119.59	0.001575	44.42226	9.938692	5.716151
6	2105.68	124.33	0.002068	36.52298	14.25521	8.841875
7	1023.53	121.06	0.001631	41.2826	10.94314	6.248125
8	1117.28	139.78	0.002259	40.62716	16.34602	8.083957
9	2045.23	124.55	0.002005	33.35779	14.35962	8.938809
10	820.37	127.88	0.001723	48.42205	10.38639	5.806916
11	1306.08	120.01	0.001632	32.50662	12.48212	7.305455
12	1263.33	115.36	0.001534	33.1403	11.59714	6.812612
13	2165.50	118.49	0.001941	40.47991	13.50099	8.340052
14	624.08	120.60	0.001439	50.0246	7.550987	4.581302
15	616.49	112.65	0.001311	48.88649	6.782346	4.178984
16	1027.15	117.49	0.001558	40.67577	10.46234	6.031342
17	2200.00	119.79	0.002034	43.60798	13.60224	8.353933
18	1445.42	140.00	0.002349	31.16474	18.35244	9.516854
19	1994.12	124.65	0.001959	31.34169	14.42717	8.990284
20	2039.78	135.62	0.002515	33.56862	16.62769	9.823385
21	2069.12	135.73	0.002565	34.92933	16.57116	9.78335
22	2200.00	131.74	0.00257	44.00324	15.2997	9.169298
23	1949.03	135.64	0.002402	30.4859	16.85747	9.920293

Combination Parameter	**Optimized Capacitance**	**Optimized Voltage**	**Optimized MRR**	**Optimized RWR**	**Optimized RWR**	**Optimized ASG**
24	1954.88	136.01	0.002429	30.65567	16.95046	9.949096
25	2200.00	126.71	0.002312	43.87188	14.44931	8.812923
26	2195.93	132.74	0.00262	43.64051	15.50899	9.253933
27	1057.32	99.96	0.001305	37.45791	8.959218	5.135229
28	972.16	96.50	0.001261	39.66319	8.214346	4.671382
29	1114.47	107.51	0.001401	36.60244	9.911805	5.757133
30	1092.51	95.45	0.001261	35.84136	8.848937	5.027649
31	758.06	100.40	0.001244	45.749	7.045841	4.126192
32	976.64	96.49	0.001261	39.52564	8.241252	4.686218
33	330.51	105.07	0.000984	41.63485	4.231804	2.99267
34	449.01	110.41	0.001149	46.44143	5.320189	3.525653
35	1421.50	122.96	0.001708	30.13738	13.47622	7.941471
36	1294.10	126.46	0.001798	33.50803	13.62012	7.757449
37	1109.72	126.07	0.001769	39.10027	12.43381	6.965237
38	1362.18	125.83	0.001784	31.71154	13.80491	7.964661
39	1489.66	123.53	0.001728	28.9547	13.8091	8.205711
40	1325.93	126.71	0.001808	32.69488	13.83042	7.900951
41	1366.03	122.81	0.001702	31.32334	13.23117	7.737903
42	131.96	132.68	0.00104	31.81965	4.187978	3.320462
43	238.21	132.66	0.001205	39.01809	5.154283	3.677988
44	111.72	132.69	0.001008	30.38228	4.015745	3.255837
45	120.54	132.68	0.001022	31.00918	4.089838	3.283657
46	131.78	132.60	0.001038	31.80191	4.180411	3.317273
47	129.86	132.61	0.001035	31.66656	4.164765	3.311465
48	105.59	132.67	0.000998	29.9441	3.963198	3.235964
49	111.10	132.71	0.001007	30.33901	4.012069	3.254559
50	109.95	132.70	0.001005	30.25707	4.002135	3.2508

5.6 Case II (b): Multi objective optimization of parameters for copper

The optimization simulation is carried out to determine the optimal value of capacitance and gap voltage represented by keeping MRR, RWR, ASG and ATA selecting two objectives repeatedly for copper as electrode. The variation of different optimizing parameters is observed in this book.

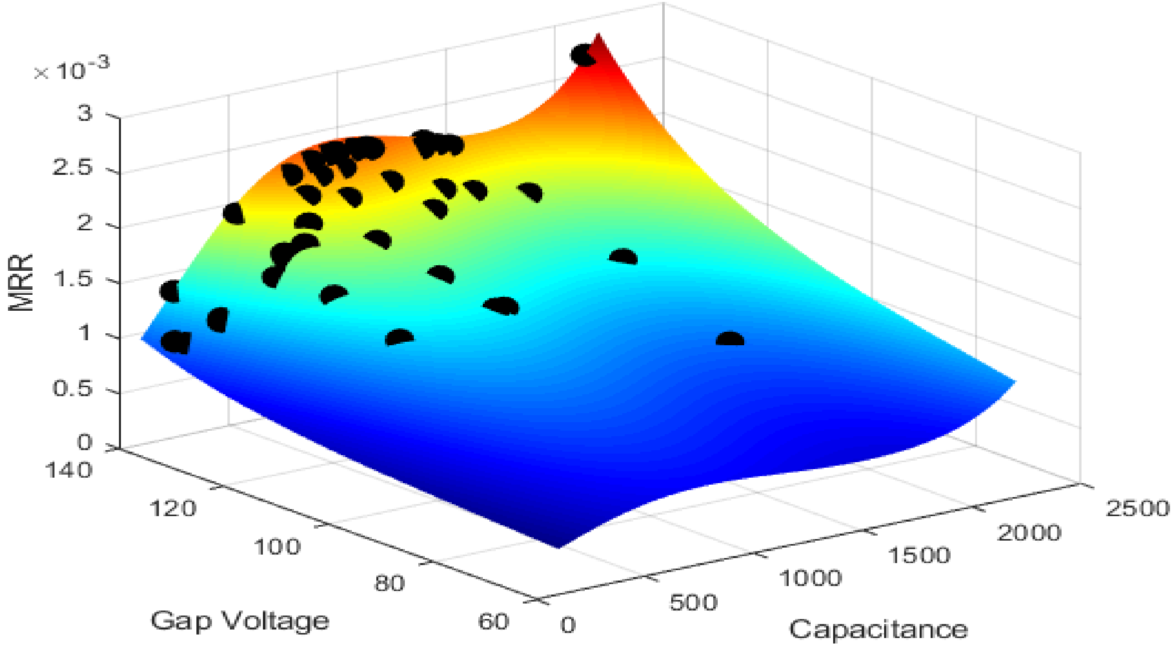


Figure 3.25: Variation of MRR for copper with capacitance and voltage

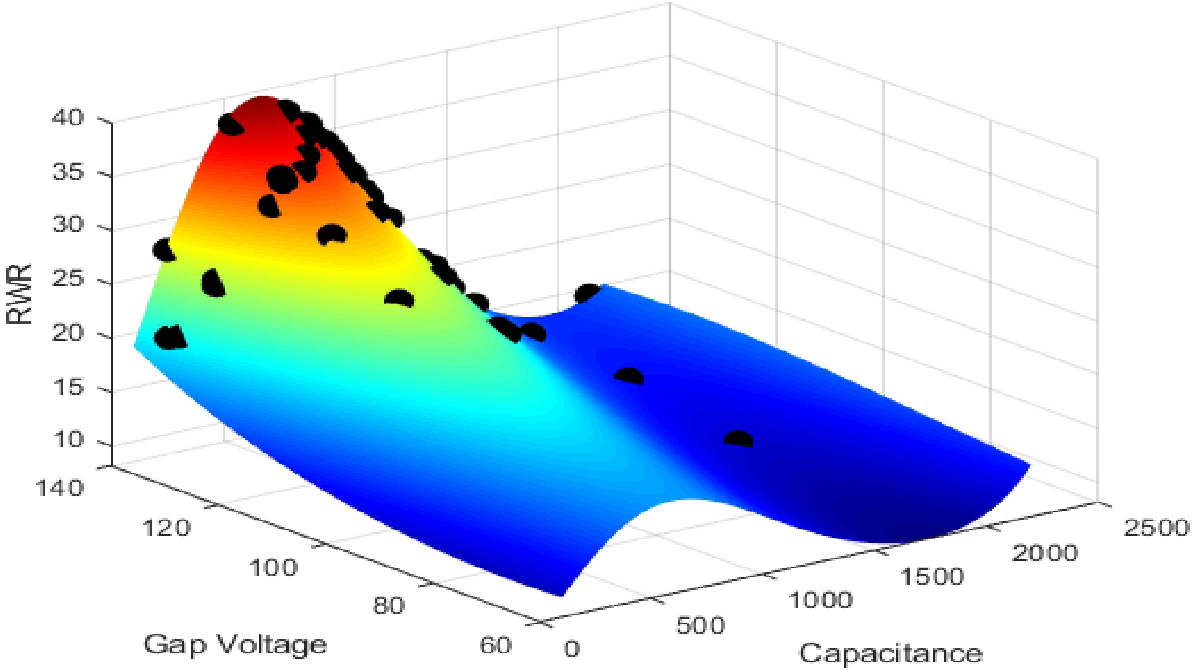


Figure 5.22: Variation of RWR for copper with capacitance and voltage

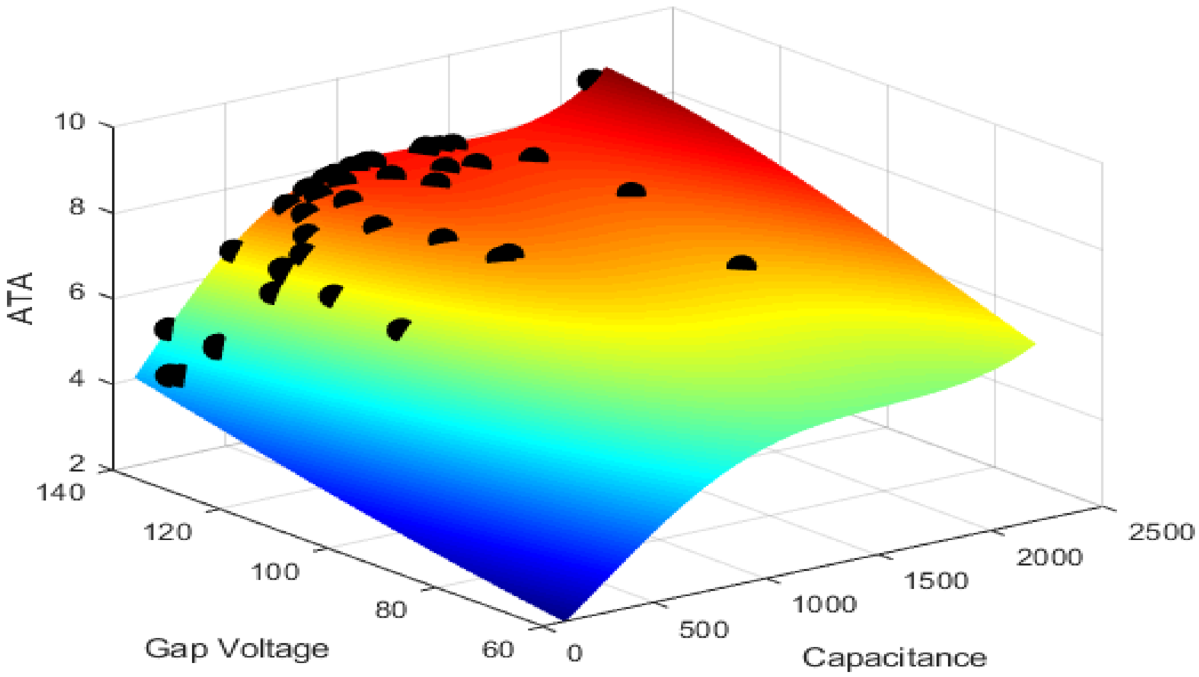


Figure 5.26: Variation of ASG for copper with capacitance and voltage

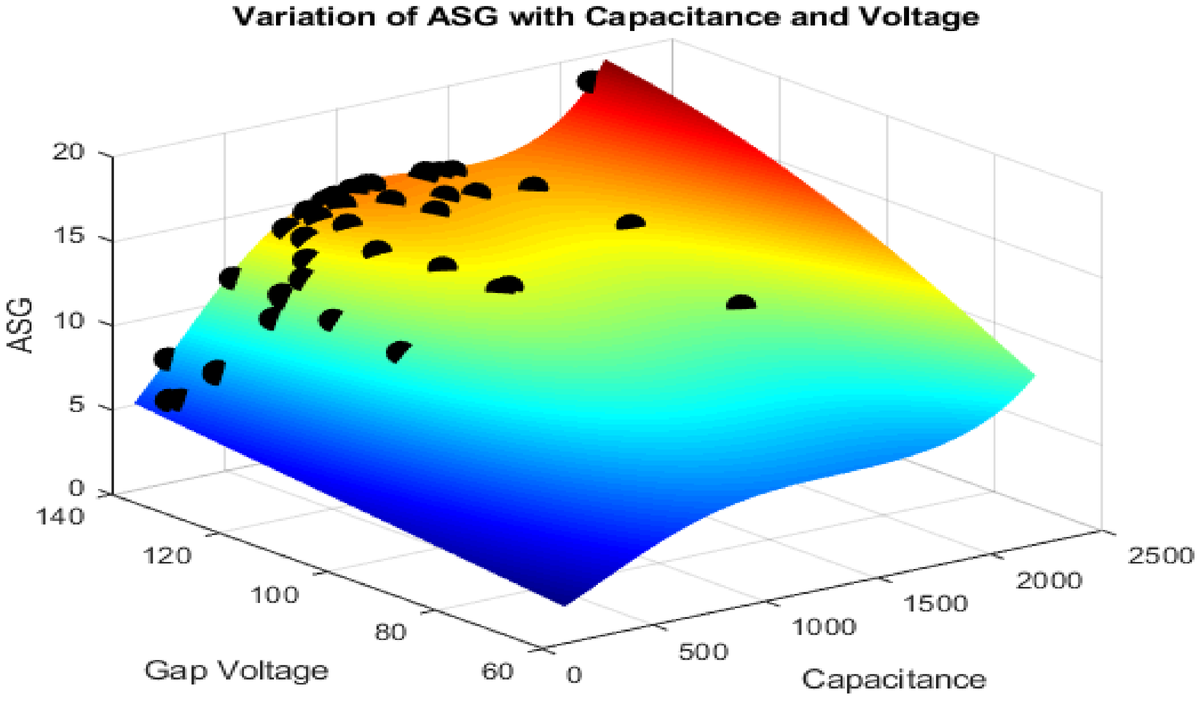

Variation of ASG with Capacitance and Voltage

Figure 5.27: Variation of ATA for copper with capacitance and voltage

The optimizing parameters MRR, RWR, ASG and ATA increases with the increasing capacitance and voltage. The optimized discharge energy value can be achieved within a range of MRR from 0.000986 to 0.002673. The RWR, ASG and ATA value for maximizing MRR can be achieved up to 10.57773, 11.30303 and 6.794753 respectively.

Table 5.22: Optimized MRR, RWR, ASG and ATA of copper

Combination Parameter	**Optimized Capacitance**	**Optimized Voltage**	**Optimized MRR**	**Optimized RWR**	**Optimized RWR**	**Optimized ASG**
1	1746.06	95.81	0.000986	10.57773	11.30303	6.794753
2	1771.44	117.36	0.001356	12.39092	13.53977	7.483361
3	972.05	119.04	0.001511	25.21979	13.08539	7.232508
4	1449.30	132.68	0.00185	17.99807	14.55136	7.81822
5	693.31	132.57	0.001876	35.19605	12.78311	7.026791
6	1318.76	133.05	0.001916	20.97432	14.71277	7.855017
7	1107.09	134.30	0.002054	27.15144	14.89888	7.859247
8	2139.75	140.00	0.002673	14.37729	18.44229	8.676465
9	844.72	136.81	0.002177	35.39376	14.35128	7.596904
10	949.56	136.82	0.002204	32.7757	14.83806	7.78406
11	753.76	135.44	0.002054	36.21959	13.58429	7.319644
12	1094.24	138.62	0.00229	29.11478	15.31533	7.967826
13	574.60	122.75	0.001438	30.09866	10.66991	6.19398
14	1386.52	139.51	0.002218	20.72298	15.20624	7.977725
15	248.59	139.81	0.001325	27.11522	7.337346	5.008051
16	865.82	126.73	0.001745	30.24224	13.45249	7.306503
17	889.52	133.22	0.002014	32.64294	14.22746	7.573355
18	277.83	131.67	0.001184	25.2743	7.331286	4.917914
19	552.33	130.93	0.001652	33.66487	11.10631	6.396426
20	150.46	135.51	0.000986	20.19987	5.657004	4.234933
21	484.18	130.06	0.001524	31.95413	10.1674	6.03417
22	557.88	131.55	0.001681	34.06024	11.22646	6.444476

Combination Parameter	**Optimized Capacitance**	**Optimized Voltage**	**Optimized MRR**	**Optimized RWR**	**Optimized RWR**	**Optimized ASG**
23	632.88	130.74	0.001745	34.27801	12.01062	6.73596
24	1203.38	130.01	0.00183	23.12229	14.49787	7.774627
25	165.07	134.04	0.000991	20.5115	5.802122	4.282982
26	274.59	131.80	0.00118	25.17349	7.29062	4.902286
27	1671.12	131.29	0.001758	14.43922	14.44393	7.770528
28	281.42	132.06	0.0012	25.58598	7.405756	4.953011
29	523.45	139.15	0.00193	37.69129	11.42412	6.553995
30	1493.99	138.95	0.002142	18.16852	15.03252	7.930925
31	1121.19	138.54	0.002278	28.22529	15.32403	7.977504
32	744.20	138.45	0.0022	38.00489	13.79884	7.391338
33	1043.60	138.50	0.002295	30.68084	15.24266	7.932689
34	1350.87	138.54	0.002179	21.42693	15.16947	7.970164
35	1037.65	138.66	0.002305	30.93506	15.24876	7.932325
36	1358.17	138.67	0.002183	21.26601	15.17132	7.970564
37	1106.54	138.41	0.002275	28.64434	15.30356	7.968254
38	1106.81	138.71	0.002292	28.74746	15.33347	7.97608
39	1436.78	139.09	0.002172	19.43082	15.10582	7.952276
40	1083.82	111.40	0.00131	20.72467	12.50454	7.100976
41	1082.08	111.40	0.001311	20.75943	12.50259	7.099351
42	603.69	111.41	0.001222	25.97543	9.976289	5.888461
43	1045.66	111.40	0.001318	21.45776	12.44403	7.058799
44	963.26	138.61	0.002306	33.20028	15.06344	7.854247
45	838.55	138.61	0.002273	36.46658	14.49461	7.63978
46	963.11	138.60	0.002306	33.2031	15.0627	7.853986
47	950.96	138.60	0.002305	33.55971	15.02268	7.838033
48	839.50	138.61	0.002274	36.44608	14.5004	7.641882
49	921.02	138.62	0.002302	34.41769	14.91215	7.794851
50	847.71	138.60	0.002277	36.26222	14.5487	7.659497

5.7 Case II (c): Multi objective optimization of parameters for brass

The optimization simulation is carried out to determine the optimal value of capacitance and gap voltage represented by keeping MRR, RWR, ASG and ATA selecting two objectives repeatedly for brass as electrode. The variation of different optimizing parameters is observed in this book.

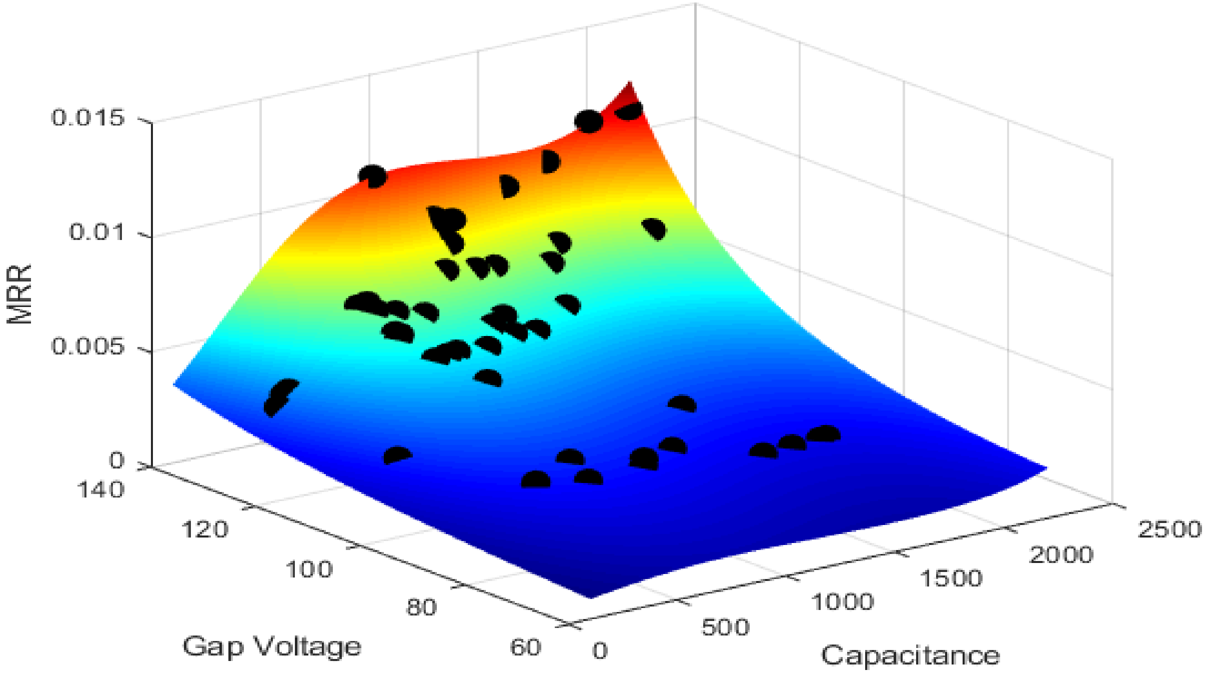


Figure 5.28: Variation of MRR for brass with capacitance and voltage

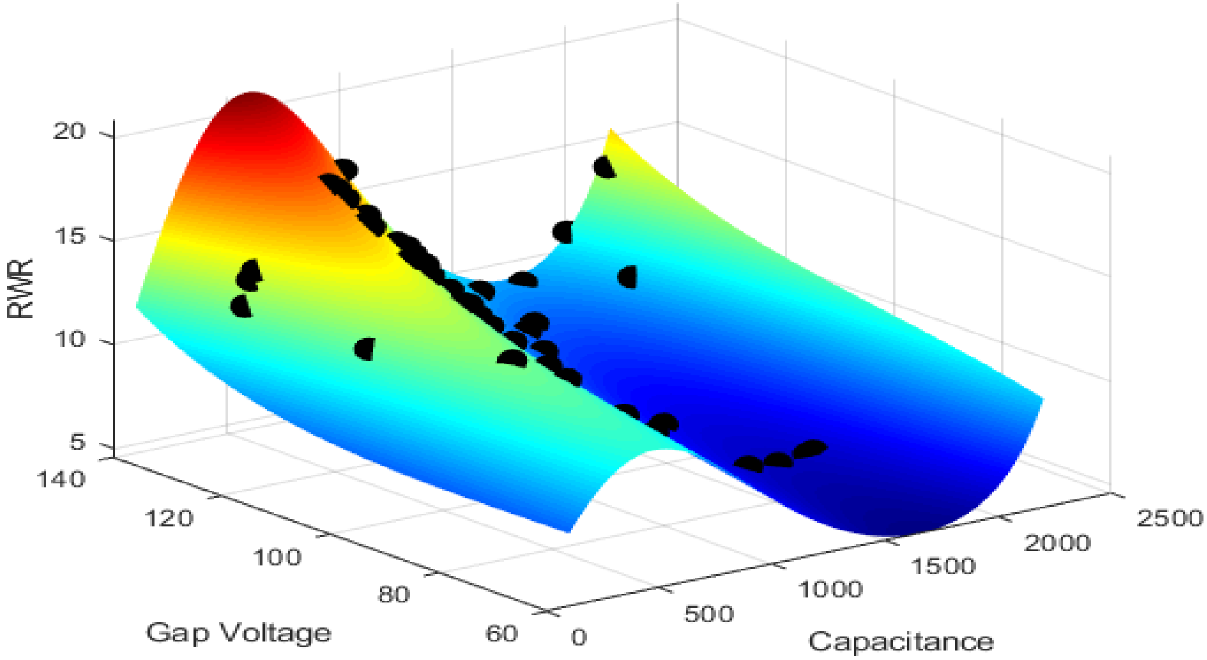


Figure 5.29: Variation RWR for brass with capacitance and voltage

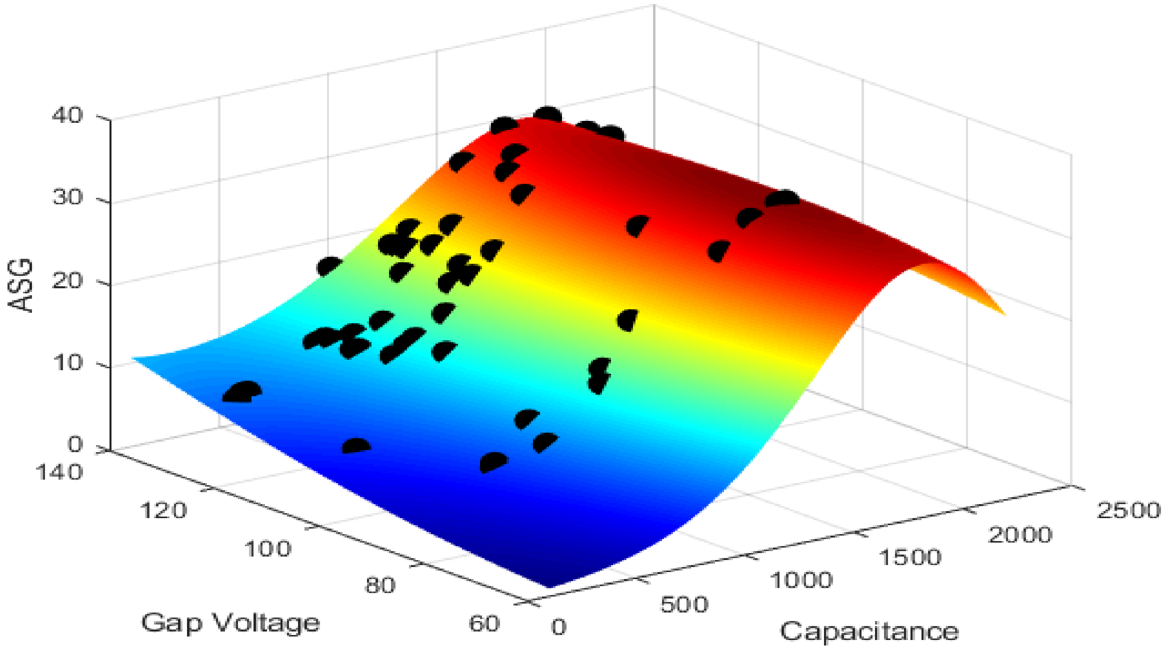


Figure 5.30: Variation of ASG for brass with capacitance and voltage

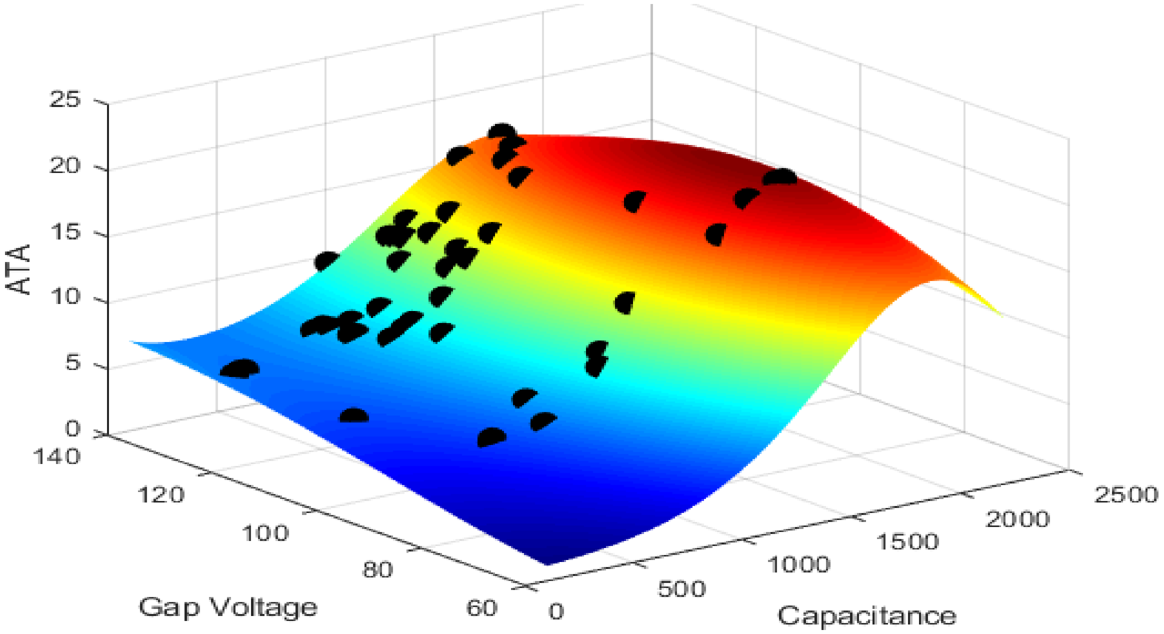


Figure 5.31: Variation of ATA for brass with capacitance and voltage

The optimizing parameters MRR, RWR, ASG and ATA increases with the increasing capacitance and voltage. The optimized discharge energy value can be achieved within a range of MRR from 0.001377 to 0.008927. The RWR, ASG and ATA value for maximizing MRR can be achieved up to 5.73762, 4.041709 and 15.03267 respectively.

Table 23: Optimized MRR, RWR, ASG and ATA for brass

Combination Parameter	**Optimized Capacitance**	**Optimized Voltage**	**Optimized MRR**	**Optimized RWR**	**Optimized RWR**	**Optimized ASG**
1	975.28	132.41	0.00804	14.76816	15.8344	9.396258
2	922.18	136.32	0.009071	16.5185	14.96987	8.691372
3	1435.05	130.38	0.007233	9.08288	25.10952	15.40294
4	2160.22	138.57	0.011187	13.82927	26.71913	12.29891
5	713.96	119.28	0.005063	15.04728	11.43619	7.242837
6	658.95	135.36	0.007711	19.06417	11.74936	6.795453
7	1404.09	126.21	0.006292	8.810582	24.81336	15.4254
8	1794.94	133.54	0.007932	8.443986	29.92767	17.30085
9	1676.67	131.72	0.007385	8.188821	29.07701	17.40898
10	845.44	140.00	0.010017	18.76269	13.91189	7.876814
11	1109.50	121.74	0.005724	11.13213	18.48723	11.49967
12	809.61	111.13	0.004223	13.09064	12.29725	7.945571
13	1004.65	127.46	0.006866	13.34888	16.37115	9.933147
14	421.57	106.38	0.003031	13.36086	7.02165	5.242282
15	907.09	102.73	0.003454	11.24894	13.47572	8.748057
16	1613.89	117.32	0.004565	7.048143	29.57213	18.75282
17	1451.45	138.59	0.009811	10.14822	24.62193	14.67218
18	2200.00	137.40	0.011038	15.00286	25.77333	11.57392
19	1149.16	140.00	0.010633	14.01146	18.63649	10.89146
20	1654.63	140.00	0.010194	9.267035	27.88316	16.19921
21	2101.34	140.00	0.011375	12.48045	27.84775	13.2846
22	806.84	140.00	0.009836	19.27868	13.44425	7.587907
23	1422.29	140.00	0.010412	10.6437	23.91091	14.18324
24	2200.00	139.77	0.012132	15.38574	25.85124	11.38663

Combination Parameter	**Optimized Capacitance**	**Optimized Voltage**	**Optimized MRR**	**Optimized RWR**	**Optimized RWR**	**Optimized ASG**
25	509.98	137.92	0.007166	19.81887	10.77084	6.170507
26	1057.64	138.03	0.009851	14.91413	17.10878	9.984415
27	1054.55	138.01	0.00984	14.9563	17.05657	9.951735
28	789.02	138.13	0.009157	18.86013	13.2112	7.526687
29	764.74	136.55	0.008585	18.61873	12.89692	7.407017
30	842.64	137.71	0.009259	18.05082	13.86567	7.945268
31	396.60	138.07	0.006134	18.60214	10.26919	5.977423
32	226.10	137.92	0.004424	14.83521	10.02038	6.138065
33	349.57	136.82	0.005491	17.41953	10.00667	5.962299
34	158.09	137.99	0.003777	12.94503	10.13948	6.387912
35	223.00	137.94	0.004396	14.75717	10.02582	6.147058
36	273.29	137.70	0.004863	15.99133	9.989319	6.031465
37	394.89	138.01	0.006107	18.55622	10.25777	5.976393
38	185.17	137.98	0.004033	13.7197	10.07956	6.273788
39	570.49	134.25	0.0069	18.89147	10.92788	6.406103
40	424.15	138.03	0.006395	18.99731	10.36506	6.003879
41	248.46	90.44	0.001832	10.56227	3.988835	3.692261
42	212.79	90.43	0.00174	10.03344	3.787609	3.642088
43	223.62	90.47	0.001769	10.20003	3.851021	3.658954
44	299.54	90.53	0.001959	11.23093	4.315882	3.797185
45	161.43	90.44	0.001604	9.196777	3.530196	3.600356
46	299.50	90.37	0.001954	11.22504	4.298971	3.784429
47	1356.98	119.48	0.005108	8.46387	24.20164	15.31184
48	1447.56	119.07	0.004948	7.828655	26.26987	16.66417
49	921.02	138.62	0.002302	34.41769	14.91215	7.794851
50	847.71	138.60	0.002277	36.26222	14.5487	7.659497

5.8 Case II (d): Multi objective optimization of parameters for aluminium

The optimization simulation is carried out to determine the optimal value of capacitance and gap voltage represented by keeping MRR, RWR, ASG and ATA selecting two objectives repeatedly for aluminium as electrode.

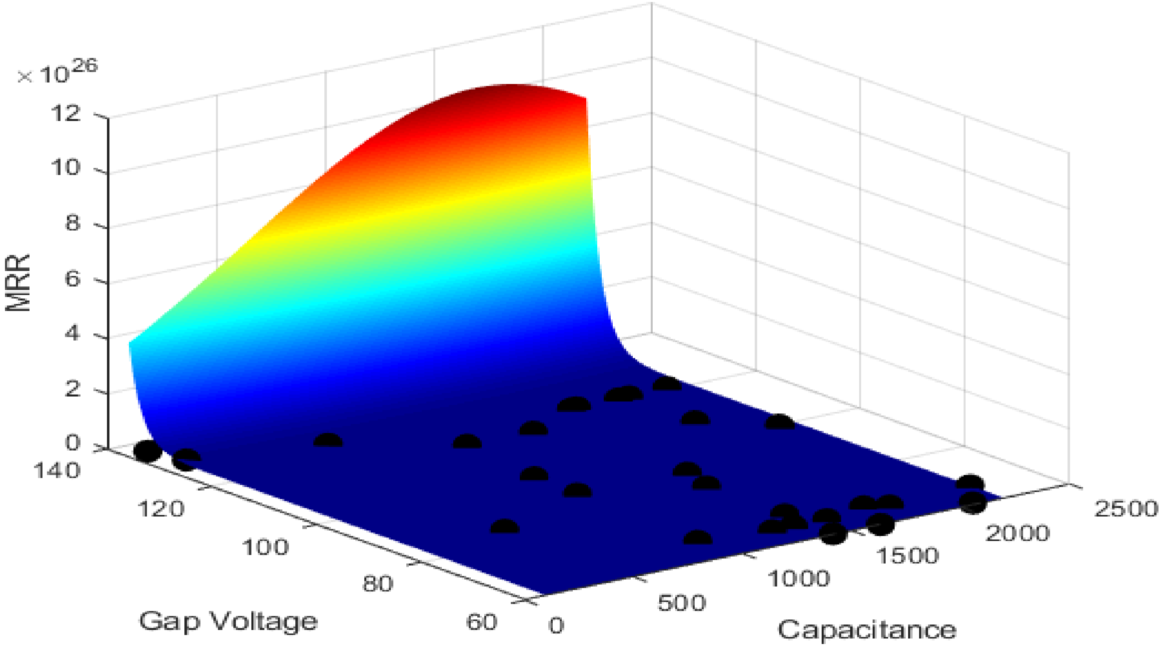


Figure 5.32: Variation of MRR for brass with capacitance and voltage

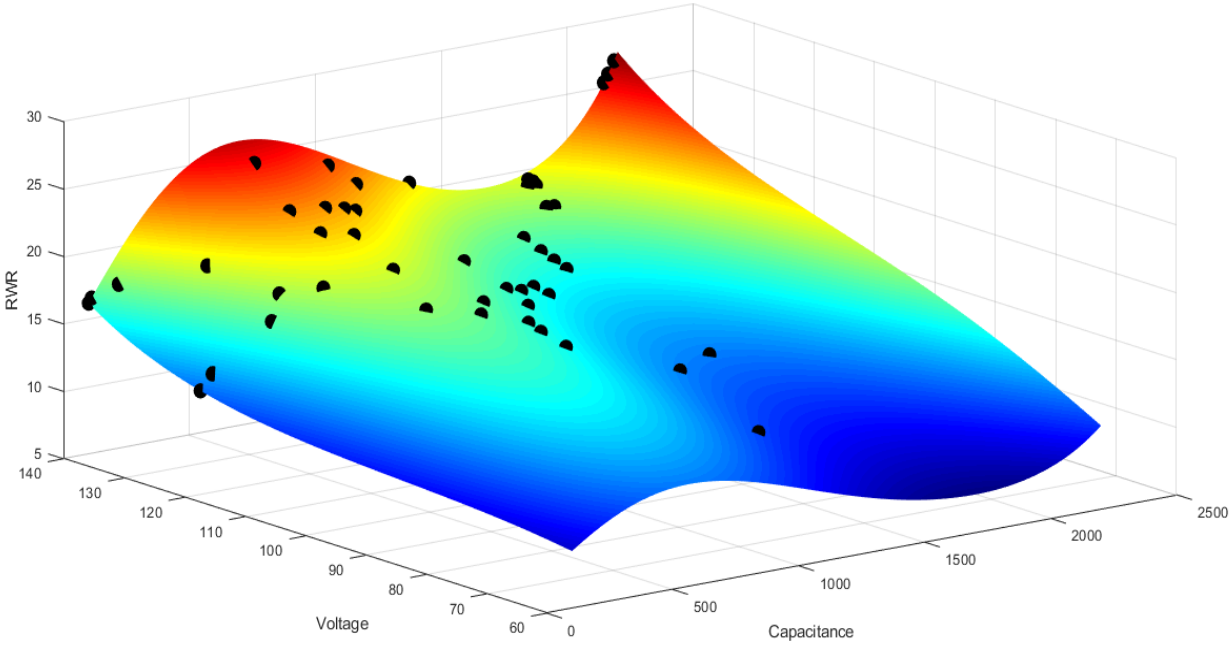


Figure 5.33: Variation of RWR for aluminium with capacitance and voltage

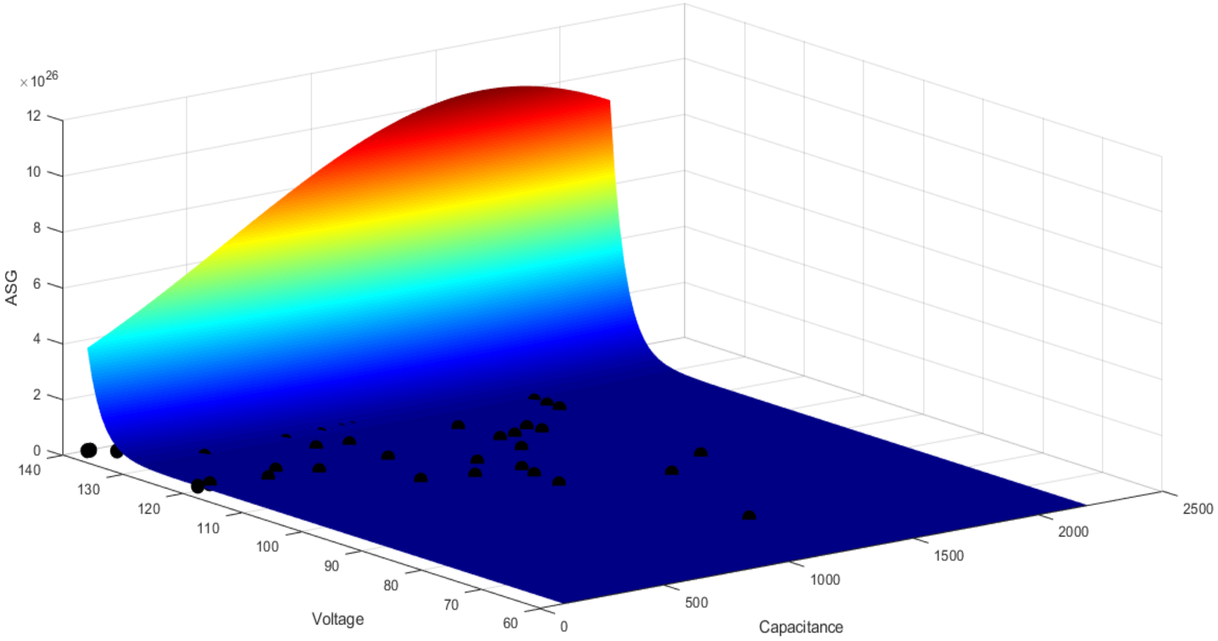


Figure 5.34: Variation of ASG for aluminium with capacitance and voltage

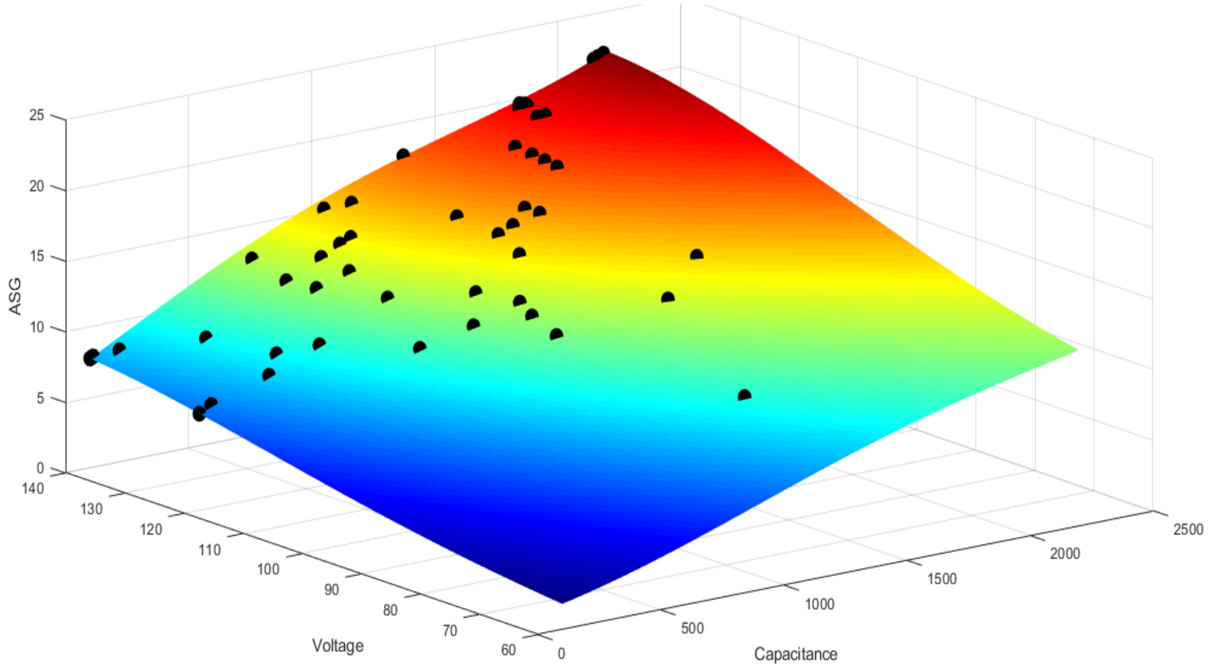


Figure 5.35: Variation of ATA for aluminium with capacitance and voltage

The optimizing parameters MRR, RWR, ASG and ATA increases with the increasing capacitance and voltage. The optimized discharge energy value can be achieved within a range of MRR from 0.000896 to 0.005495. The RWR, ASG and ATA value for maximizing MRR can be achieved up to 7.861442, 10.16064 and 6.461826 respectively.

Table 24: Optimized MRR, RWR, ASG and ATA of aluminium

Combination Parameter	**Optimized Capacitance**	**Optimized Voltage**	**Optimized MRR**	**Optimized RWR**	**Optimized RWR**	**Optimized ASG**
1	998.02	91.60	0.001528	14.78838	10.44167	8.66211
2	500.74	84.78	0.001108	15.12879	5.940093	5.217758
3	676.47	125.90	0.003007	20.87989	12.17092	10.40331
4	719.57	136.05	0.004027	24.27212	13.22832	11.32726
5	1363.65	115.27	0.002578	15.06383	15.93888	14.33512
6	1068.49	115.65	0.002663	17.09777	14.16975	12.53619
7	1431.91	70.02	0.001016	9.810998	10.25381	7.324118
8	1483.22	90.82	0.001439	11.98449	13.23655	10.91517
9	1428.96	84.87	0.001292	11.57877	12.13147	9.683599
10	628.68	140.00	0.004112	26.01048	12.60564	10.59823
11	947.08	138.31	0.004867	24.07645	15.04877	13.40163
12	403.04	140.00	0.003025	23.67124	10.5938	8.576661
13	856.29	140.00	0.004909	25.56311	14.42493	12.6554
14	482.94	140.00	0.00343	24.85739	11.32429	9.280399
15	2200.00	138.27	0.00547	26.77857	22.0896	15.10644
16	2129.94	100.17	0.00197	17.05494	17.34561	13.16456
17	100.00	136.36	0.001442	15.09979	7.580235	6.099966
18	2125.73	99.77	0.00195	16.90421	17.26722	13.11943
19	1914.23	107.27	0.00207	14.4824	17.46612	14.49217
20	1922.98	120.35	0.002878	16.22032	19.14841	16.00429
21	1005.24	100.17	0.001835	15.60193	11.6846	9.959953
22	140.80	130.69	0.001454	14.80142	7.601581	6.283576

Combination Parameter	Optimized Capacitance	Optimized Voltage	Optimized MRR	Optimized RWR	Optimized RWR	Optimized ASG
23	1419.62	60.25	0.000896	8.45439	9.141623	5.933222
24	1631.44	60.00	0.00092	7.861442	10.16064	6.461826
25	2069.46	60.63	0.0012	9.525076	12.00079	7.270595
26	2200.00	66.58	0.001431	12.78243	13.06045	8.13346
27	1526.39	136.47	0.004707	18.47479	18.35693	16.83099
28	2200.00	138.41	0.005495	26.82804	22.09429	15.1006
29	1133.63	140.00	0.005346	22.96851	16.29151	14.90309
30	2200.00	138.14	0.005447	26.73113	22.08496	15.11197
31	1638.69	139.35	0.005124	19.03131	18.92995	17.05455
32	1047.29	136.88	0.004795	22.56461	15.69526	14.17507
33	966.44	135.97	0.004575	22.94286	15.11686	13.48696
34	1409.59	138.68	0.005119	19.85519	17.80753	16.47229
35	969.80	67.40	0.000986	12.12952	7.254488	5.322187
36	1366.23	65.62	0.000957	9.482713	9.41216	6.482653
37	1514.67	65.45	0.000959	8.899898	10.15969	6.913545
38	1722.97	67.08	0.001013	8.896315	11.29263	7.691534
39	1804.09	65.50	0.001026	8.789075	11.46199	7.621235
40	1269.72	65.62	0.000959	9.978392	8.878127	6.164919
41	1685.57	120.45	0.002851	14.93807	18.08142	16.07491
42	1877.41	120.35	0.002857	15.78458	18.93779	16.07657
43	1660.25	120.35	0.002848	14.90535	17.95665	16.02584
44	1681.20	120.42	0.002849	14.9296	18.05891	16.06598
45	2106.23	120.68	0.003085	19.36846	20.09054	15.44212
46	566.34	135.85	0.003458	23.75954	11.89985	9.938806
47	582.83	135.86	0.003524	23.86535	12.04647	10.08681
48	575.99	135.85	0.003496	23.82165	11.98553	10.0252
49	465.71	135.85	0.003035	22.78709	10.98656	9.046514
50	490.50	135.85	0.003143	23.08203	11.21449	9.264374

5.9 Comparison with different optimization algorithm

The MRR, RWR, ASG and ATA has been optimized in this paper for workpiece materials like steel, copper, brass and aluminium. The equations of the optimizing parameters used in the optimization algorithm has been simulated in different optimization algorithm to demonstrate the optimization capability of MOGOA algorithm. The optimization algorithm is compared with other metaheuristic algorithms like Multi Objective Particle Swarm Optimization algorithm (MOPSO) and Non dominated Sorting Whale optimization algorithm and it has been found that MOGOA have outperformed the mentioned optimization algorithm.

Table 25: Comparison with other multi objective algorithms

		MOGOA	MOPSP	NSWOA
Steel	Maximum MRR	0.00262	0.00204	0.002016
	Minimum RWR	27.18888	28.2545	27.2461
	Minimum ASG	3.963198	3.95421	3.9997
	Minimum ATA	2.99267	2.99645	3.00012
Copper	Maximum MRR	0.002673	0.00297	0.0019
	Minimum RWR	10.57773	11.5001	10.5282
	Minimum ASG	11.30303	11.3334	13.5287
	Minimum ATA	6.794753	6.7999	7.4268
Brass	Maximum MRR	0.008927	0.00765	0.006654
	Minimum RWR	5.73762	5.4547	6.4527
	Minimum ASG	4.041709	5.1247	4.05415
	Minimum ATA	15.03267	16.9436	16.4822
Alumimium	Maximum MRR	0.005495	0.005161	0.004521
	Minimum RWR	7.861442	7.86606	8.5246
	Minimum ASG	10.16064	10.0014	11.0421
	Minimum ATA	6.461826	6.7241	6.9857

5.10 Effect of tool efficiency, workpiece efficiency and dimensional accuracy

The optimizing parameters involves iterative multi objective optimization of the MRR, RWR, ASG and ATA of the workpiece material. The MRR contributes to tool efficiency as it involves as the ratio of material removed from the workpiece. The relative wear ratio contributes to the workpiece efficiency of the electrode. The ASG and ATA contributes to the dimensional accuracy and precision. The multi objective optimization algorithms provides a set of optimizing parameters and the non-dominated output parameters are the recommended values to choose within a set of values.

Table 28: Effect of dimensional accuracy on optimal values

Workpiece Material	Capacitance	Voltage	MRR
Steel	2039.783	135.6249	0.002515
	2069.122	135.7254	0.002565
Copper	2139.751	140	0.002673
	963.2554	138.6072	0.002306
Brass	918.7393	918.7393	918.7393
	106.6194	106.6194	106.6194
Aluminium	1428.957	84.8699	0.001292
	628.6839	140	0.004112

Table29: Effect of tool efficiency on optimal values

Workpiece Material	Capacitance	Voltage	RWR
Steel	1445.416	140	31.16474
	1994.118	124.6526	31.34169
Copper	1746.064	95.80816	10.57773
	1771.436	117.3613	12.39092
Brass	1415.193	77.60517	5.73762
	1869.29	80.1222	5.811253
Aluminium	1631.441	60	6.461826
	1419.619	60.25455	5.933222

Table 30: Effect of workpiece efficiency on optimal values

Workpiece Material	Capacitance	Voltage	ASG	ATA
Steel	2171.764	122.1129	13.88524	8.566058
	105.5883	132.6715	3.963198	3.235964
Copper	150.4649	135.5098	5.657004	4.234933
	165.0727	134.0379	5.802122	4.282982
Brass	2167.943	113.3909	0.066745	14.37771
	2184.495	109.9597	0.07149	14.22017
Aluminium	500.744	84.78232	5.940093	5.217758
	969.8024	67.40496	7.254488	5.322187

Chapter 6

CONCLUSION AND FUTURE WORK

The MOGOA algorithm has been simulated on optimization of MRR, RWR, ASG and ATA in order to optimize discharge energy for localized electrodes in micro EDM operations. The discharge energy of RC type pulse generator depends on capacitance and pulse voltage which have direct impact on Material Removal Rate (MRR), Relative Wear Ratio (RWR), Average Spark Gap (ASG) and Average Taper Angle (ATA). In this book, the optimal performance of MRR, RWR, ASG and ATA are optimized using Multi Objective Grasshopper Optimization Algorithm (MOGOA) on steel, copper, brass and aluminium are investigated. The desired condition of micro EDM operation is higher MRR and lower RWR, ASG and ATA in order to minimize the discharge energy of the machining process. The effect of tool efficiency, workpiece efficiency and dimensional accuracy on optimal sets of values has been studied.

The future work involves further investigation of the effect of variation of optimal parameters in computing the machining behavior of micro EDM operation. The scope of research involves study of the optimal parameters on the machining process for different cross-sectional geometries.

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