A DECISION SUPPORT SYSTEM FOR TOOL ELECTRODE SELECTION FOR ELECTRO DISCHARGE MACHINING PROCESS USING THE ANALYTIC HIERARCHY PROCESS

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ABSTRACT

The shape and accuracy of any part machined using the electro discharge machining process depends primarily on the shape and accuracy of the tool or the cutting electrode. Hence, the selection of tool electrodes in Electro Discharge Machining Process becomes an important task. Theoretically, any material that is a good conductor of electricity can be used as a tool with varying advantages. It is very difficult to find a single material that possesses all the desirable characteristics, and therefore the selection becomes a difficult task. The present paper proposes a methodology based on the Analytic Hierarchy Process (AHP) for selection of a Tool Electrode for the Electro Discharge Machining Process. Based on the AHP method, an Electrode Selection Index (ESI) is found for all the alternatives that are considered in the present study. This ESI helps to evaluate and rank any given number of alternative materials. The results of the present study suggest that Graphite and Copper are the best materials for fabricating a tool electrode in EDM process.

Keywords: Tool Electrodes, Analytic Hierarchy Process, Electrode Selection Index

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1. Introduction

In an Electro Discharge Machining (EDM) process the shape and accuracy of the machined part depends largely on the shape and accuracy of the tool electrode. No matter how accurate the machine is, the work produced by EDM process can never be more accurate than the electrode that machines the work. Also, the tool electrode is the means of providing electrical energy to the work material, and therefore should be good conductor of electricity. The heat that the tool receives must be dissipated away quickly in order to reduce surface temperature and tool wear. Hence, it is necessary that the tool electrode is made of highly thermal conductive material. It is also evident that the tool electrode should have high melting point to reduce its wear rate. It has been observed that during EDM process, both the work piece and tool electrode get eroded. Hence, the accuracy of the machined part depends on electrode wear. The amount of erosion suffered by the electrode as compared to that of work material is referred to as the wear ratio. The wear ratio depends on the physical and chemical properties of the electrode and work material as well as environmental conditions. Hence, the basic desirable characteristics of a tool electrode can be summarized as: (i) Electrical conductivity (ii) Thermal conductivity (iii) Melting temperature (iv) MRR (v) Wear Ratio (vi) Cost. (Pandey and Shan, 2003; Mishra, 2007).

A good amount of research work has been carried out in the past on materials selection [3-16]. The selection of an optimal material for an engineering design from among two or more alternative materials on the basis of two or more attributes is a multiple attribute decision-making problem. Various approaches have been proposed in the past to help address the issue of material selection. Liao (1996) presented a fuzzy multi criteria decision-making method for material selection. However, the method is complicated and requires a large amount of computation. Farag (1997) proposed a simple mathematics-based weighted properties method that can be used when several properties should be taken into consideration. Giachetti (1998) described a prototype material and manufacturing process selection system that integrates a formal multiple attribute decision model with a relational database. Ashby (2000) proposed multi-objective optimization in materials design and selection, using ‘utility’ functions. Ashby *et al.* (2004) provided a comprehensive review of the strategies or methods for materials selection. A framework to represent and deal with the relationships between design variables of both materials parameters and system-level parameters was proposed by Raj (2000) and Raj *et al.* (2000). Deng and Edwards (2007) presented an overview of recent research in materials identification and materials selection. Shanian and Savadogo (2006) had presented a material selection model using an MADM method known as ELECTRE. Chan and Tong (2006) proposed a multi criteria weighted average method using gray relational analysis to rank the materials. Rao (2006) presented a material selection model using graph theory and the matrix approach. A ‘material suitability index’ was proposed that evaluates and ranks the materials for a given engineering component. Kumar and Singh (2006) presented an intelligent system for selection of materials for progressive die components. Cheng *et al.* (2008) used the fuzzy AHP method for selection of technological forecasting methods for prediction of new materials development. Rao and Davim (2007) used the TOPSIS method for selection of materials for a given application. AHP method has also been applied for selection of phase change material using fuzzy concept (2011).

Despite this volume of research on material selection, there is still a need for a simple, systematic, and logical scientific method or mathematical tool to guide user organizations in making a proper material selection decision with respect to tool electrode material selection in electro discharge machining process. From purely technical considerations, it is possible to specify a specific material as the most efficient tool electrode material providing high MRR with least tool wear. However, the cost of such an electrode under most conditions is very high. Hence, it becomes a very difficult task to select a material based on any specific characteristics. It is necessary to make the proper choice regarding material since the tool electrode cost represents more than 50% of total machining cost. The selection of the best tool material primarily aims to achieve better material utilization. However, the tool electrode with least tool wear may not be the best selection; indeed the tool fabrication may become more complex which could offset the savings due to material economy. Whatever the chosen procedure for obtaining the best alternative, it is desirable to make an optimum choice among the available materials. Ideally, it is essential to choose the factors that are relevant to the particular problem at hand, and determine the relative importance of one factor over another. The actual identification of evaluating factors may involve discussions with the experts working in the areas of production and tool design. Very few published studies are available that address the selection of tool material especially for electro discharge machining process.

The objective of a tool electrode selection procedure is to identify the influencing factors and obtain the most appropriate combination of the factors in conjunction with the real requirement of the EDM process. Thus, efforts need to be extended to determine factors which influence tool electrode selection for EDM process, using a logical approach, to ensure the selection of a proper tool electrode to strengthen the existing selection procedure. This objective is considered in this paper using analytic hierarchy process (AHP). AHP is a logical approach, and is proved to be useful for modeling and analyzing various types of decision making situations in many fields of science and technology (Saaty, 1980; Saaty, 2000). AHP deals with the problem of choosing an alternative from a set of candidate alternatives which are characterized in terms of some factors. The selection of a right tool electrode for the EDM process amongst the available tool electrodes is clearly a decision making situation and hence in the present work the application of AHP, in selecting the right tool electrode, is considered.

2. Analytic Hierarchy Process

Saaty (1980, 2000) has evolved the AHP which enables decision makers to represent the interaction of multiple factors in complex situations. The process requires the decision makers to develop a hierarchical structure for the factors which are explicit in the given problem, to provide judgments about the relative importance of each of these factors, and specify a preference for each decision alternative with respect to each factor. It provides a prioritized ranking order indicating the overall preference for each of the decision alternatives.

An AHP hierarchy can have as many levels as needed to fully characterize a particular decision situation. A number of functional characteristics make AHP a useful methodology. These include the ability to handle decision situations involving subjective judgments, multiple decision makers, and the ability to provide measures of consistency of preference (Triantaphyllou, 2000). Designed to reflect the way people actually think, AHP continues to be the most highly regarded and widely used decision-making method. An advantage of the AHP over other multi criteria decision making methods is that AHP is designed to incorporate tangible as well as non-tangible factors especially where the subjective judgments of different individuals constitute an important part of the decision process. The main procedure of AHP using geometric mean method has been explained by Rao (2000). The procedure is explained briefly as follows:

Step 1: Determine the objective and the evaluation attributes. Develop a hierarchical structure with a goal or objective at the top level, the attributes at the second level and the alternatives at the third level.

Step 2: Find out the relative importance of different factors with respect to the goal or objective:

1) Construct a pair-wise comparison matrix using a scale of relative importance. The judgments are entered using the fundamental scale of the AHP (Liao, 1996; Farag, 1997) as given in Table 1. Assuming N factors, the pair-wise comparison of factor i with factor j yields a square matrix $A1_{N\times N}$ where a_{ij} denotes the relative importance of factor i with respect to factor j. In the matrix, $a_{ij} = 1$ when $i = j$ and $a_{ji} = 1/a_{ij}$

Table 1
Relative importance of factors

Relative importance (a_{ij})	**Description**
1	Equal importance of *i* and *j*
3	Moderate importance of *i* over *j*
5	Strong importance of *i* over *j*
7	Very strong importance of *i* over *j*
9	Absolute importance of *i* over *j*
2, 4, 6, 8	Intermediate values

2) Find the relative normalized weight (w_j) of each attribute by (i) calculating the geometric mean of the *i*th row, and (ii) normalizing the geometric means of rows in the comparison matrix. This can be represented as:

$$GM_i = \left[\prod_{j=1}^{N} a_{ij}\right]^{1/N}$$

and

$$W_i = \frac{GM_i}{\sum_{j=1}^{N} GM_i}$$

3) Calculate matrix A3 and A4 such that $A3 = A1 \times A2$ and $A4 = A3/A2$ where $A2 = [W_1, W_2, W_i, ...W_N]^T$

4) Find the maximum Eigenvalue $\lambda_{\max}$ which is the average of matrix $A4$.

5) Calculate Consistency Index, $CI = \dfrac{\lambda_{\max} - n}{n-1}$

   The smaller the value of CI, the smaller the deviation from the consistency.

6) Obtain the random index (RI) for the number of factors used in decision making. Table 2 helps the users determine the RI value. (Liao, 1996; Farag, 1997; Ashby, 2000).

7) Calculate the Consistency Ratio, $CR = CI/RI$. Usually, a CR of 0.1 or less is considered as acceptable as it reflects an informed judgment which could be attributed to the knowledge of the analyst about the problem under study.

Table 2
Random Index (RI) values

Attributes	**RI**
3	0.52
4	0.89
5	1.11
6	1.25
7	1.35
8	1.4
9	1.45
10	1.49

Step 3: The next step is to compare the candidate alternatives pair-wise with respect to how much better each is at (more dominant) satisfying each of the factors. This is simply ascertaining how well each candidate alternative serves each factor. If there are M numbers of candidate alternatives, then there will be N number of $M \times M$ matrices of judgments since there are N factors. Construct pair-wise comparison matrices using a scale of relative importance. The judgments are entered using the fundamental scale of the AHP (Liao, 1996; Farag, 1997). The steps are same as that suggested under Step 2.

Step 4: The next step is to obtain the composite weights for the alternatives by multiplying the relative normalized weight (Wi) of each factor (obtained in Step 2) with its corresponding normalized weight value for each alternative (obtained in Step 3) and making summation over all the factors for each alternative.

3. Tool electrode selection using AHP

The authors propose using AHP to work on Tool wear monitoring in the Electro discharge machining process. Various electrodes materials are available, and it is a difficult task to select any one or few from the choices. Hence, AHP is applied to rank these tool electrode materials and based on the Electrode Selection Index (ESI) so obtained materials are selected to fabricate electrodes for experimentation. The materials considered are Electrolyte Copper (*Cu*), Copper Tungsten (*CuW*), Tungsten (*W*), Brass (*B*), Stainless Steel (*SS*), Aluminum (*Al*) and Graphite (*G*). Six selection factors are identified that are relevant to the present case: Cost (*C*), Material Removal Rate (*MRR*), Tool Wear (*TW*), Electrical Resistivity (*ER*), Thermal Conductivity (*TC*) and Melting Temperature (*MT*). Table 3 presents the estimated quantitative values of *ER*, *TC*, *MT* and qualitative values of *C, MRR, TW*.

Table 3
Attribute data for different alternatives

	C	*MRR*	*TW*	*ER*	*TC*	*MT*
Cu	High	Very High	Average	1.7	385	1083
CuW	Very High	Low	Very Low	6.2	150	3410
W	Very High	Low	Very Low	5.7	163	3370
B	High	High	High	5.4	136	966
SS	Average	Average	Low	72	16	1400
Al	Average	Low	High	5.9	210	660
G	Average	High	Average	6000	24	3650

Cols: C= Cost; *MRR* = Material Removal Rate (volume/time); *TW* = Tool Wear; *ER* = Electrical Resistivity (x 10^{-6} ohm. cm); *TC* = Thermal Conductivity (W/mK); *MT* = Melting Temperature (^{o}C).
Rows: Cu = Copper; *CuW* = Copper Tungsten; *W* = Tungsten; *B* = Brass; *SS* = Stainless Steel; *Al* = Aluminum; *G* = Graphite

Now, various steps of the proposed procedure are carried out to obtain an Electrode Selection Index (ESI) as mentioned below:

3.1 Calculation and consistency check of relative normalized weights

Step 1: The objective is to select the best material to fabricate a tool electrode from amongst a number of available materials. Various selection factors are identified and these are: Cost (*C*), Material Removal Rate (*MRR*), Tool Wear (*TW*), Electrical Resistivity (*ER*), Thermal Conductivity (*TC*) and Melting Temperature (*MT*). The objective, selection factors, and the decision alternatives (i.e. tool electrode materials) are arranged in a hierarchy as shown in Fig. 1.

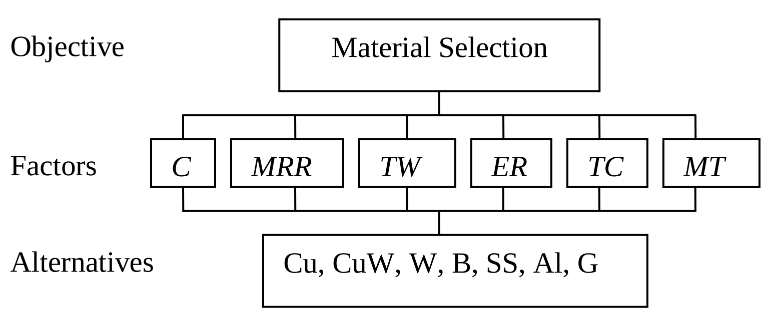

Figure 1 Decomposition of tool electrode material problem into a hierarchy

To make comparative judgments, the relative importance of all possible pairs of factors with respect to the overall objective of selecting the right material for fabricating tool electrodes, is decided by consensus judgment for each pair, and their judgments are arranged into a matrix. The questions to ask when comparing two factors are: which is more important and how much more important is it with respect to the overall objective? The matrix, $A1_{6\times 6}$, of pair-wise comparison judgments on the factors is shown below. The judgments are entered using the fundamental scale of the AHP as described in Table 1.

$$A1_{6\times6} = \begin{array}{c} \begin{array}{cccccc} C & MRR & TW & ER & TC & MT \end{array} \\ \begin{bmatrix} 1 & 3 & 3 & 5 & 5 & 5 \\ 1/3 & 1 & 1/2 & 2 & 3 & 2 \\ 1/3 & 2 & 1 & 3 & 3 & 3 \\ 1/5 & 1/2 & 1/3 & 1 & 2 & 1 \\ 1/5 & 1/3 & 1/3 & 1/2 & 1 & 1/2 \\ 1/5 & 1/2 & 1/3 & 1 & 2 & 1 \end{bmatrix} \end{array} \begin{array}{c} \\ C \\ MRR \\ TW \\ ER \\ TC \\ MT \end{array}$$

TW is moderately more important than *MT*. Decreasing *TW* is comparatively moderately more important than increasing *MT*. In order to reduce the total cost, the value of *TW* should be decreased. So, a relative importance value of 3 is assigned to *TW* over *MT* (i.e. $a_{35} = 3$) and a relative importance value of 1/3 is assigned to *MT* over *TW*. (i.e. $a_{53} = 1/3$). *MT* and *ER* are considered equally important and a relative importance of 1 is assigned to *MT* over *ER* (i.e. $a_{46} = 1$) and relative importance of 1/1 is assigned to *ER* over *MT* (i.e. $a_{64} = 1$). Similarly, the relative importance among other factors can be explained. It may be added that these values can be decided by the user/experts depending on the requirements. These values are to be arrived at judiciously after careful analysis. The assigned values in this paper are specifically applicable to the problem under discussion.

The next step is to find out the relative normalized weight (Wi) of each factor by calculating the geometric mean of the ith row and normalizing the geometric means of rows in the comparison matrix.

$$GM_1 = (1\times3\times3\times5\times5\times5)^{1/6} = 3.225$$

$$GM_2 = \left(1/3\times1\times 1/2\times2\times3\times2\right)^{1/6} = 1.1225$$

$$GM_3 = \left(1/3\times2\times1\times3\times3\times3\right)^{1/6} = 1.6189$$

$$GM_4 = \left(\tfrac{1}{5} \times \tfrac{1}{2} \times \tfrac{1}{3} \times 1 \times 2 \times 1 \right)^{1/6} = 0.6368$$

$$GM_5 = \left(\tfrac{1}{5} \times \tfrac{1}{3} \times \tfrac{1}{3} \times \tfrac{1}{2} \times 1 \times \tfrac{1}{2} \right)^{1/6} = 0.4208$$

$$GM_6 = \left(\tfrac{1}{5} \times \tfrac{1}{2} \times \tfrac{1}{3} \times 1 \times 2 \times 1 \right)^{1/6} = 0.6368$$

Now,

$$W_i = \frac{GM_i}{\sum_{i=1}^{5} GM_i}$$

gives W1 = 0.421, W2 = 0.1465, W3 = 0.2113, W4 = 0.0831, W5 = 0.0549, W6 = 0.0831

These relative normalized weights are written in matrix form as follows:

$$A2_{6\times1} = \begin{bmatrix} 0.421 \\ 0.1465 \\ 0.2113 \\ 0.0831 \\ 0.0549 \\ 0.0831 \end{bmatrix}$$

Matrix $A3_{6\times1}$ is calculated as $A3_{6\times1} = A1_{6\times6} \times A2_{6\times1}$.

$$A3_{6\times1} = \begin{bmatrix} 2.5999 \\ 0.8896 \\ 1.3079 \\ 0.5039 \\ 0.3415 \\ 0.5039 \end{bmatrix}$$

Matrix $A4_{6\times1}$ is calculated as $A4_{6\times1} = \dfrac{A3_{6\times1}}{A2_{6\times1}}$.

$$A4_{6\times1} = \begin{bmatrix} 6.1755 \\ 6.0724 \\ 6.1898 \\ 6.0638 \\ 6.2204 \\ 6.0638 \end{bmatrix}$$

Now, the maximum Eigenvalue $\lambda_{\max}$ which the average of matrix *A4* is determined as shown below:

$$\lambda_{\max} = \sum_{i=1}^{6} \left[\frac{\left(A4_{6\times1}\right)_i}{6} \right]$$

$$= \left[\frac{6.1755 + 6.0724 + 6.1898 + 6.0638 + 6.2204 + 6.0638}{6} \right]$$

$$= 6.131$$

Now, Consistency Index (CI) is calculated as shown below:

$$CI = \frac{\left(\lambda_{\max} - M\right)}{\left(M - 1\right)} = \frac{\left(6.131 - 6\right)}{\left(6 - 1\right)} = 0.0262$$

The value of Random Index (RI) for 6 factors is taken from Table 2 which is 1.25 in the current case.

The Consistency Ratio (CR) is calculated as

$$CR = CI/RI = 0.0262/1.25 = 0.02096$$

This value is less than the allowed CR of 0.1 and hence the value is acceptable. Thus, there is a good consistency in the judgments made in the current example.

3.2 Normalization of attribute data of different alternatives

MRR, *TC* and *MT* are beneficial factors and higher values of these factors are desirable. *C*, *TW* and *ER* are non-beneficial factors and lower values of these factors are desirable. *C*, *MRR* and *TW* are assigned qualitative values. These qualitative values are assigned values as mentioned in Table 4.

Table 4
Conversion of qualitative to quantitative value of factors

Qualitative Measure	**Assigned Value**
Very Low	0.1
Low	0.3
Average	0.5
High	0.7
Very High	0.9

Hence, Table 5 is obtained that has all the attributes in quantitative form.

Table 5
Attribute Data in quantitative form

	C	*MRR*	*TW*	*ER*	*TC*	*MT*
Cu	0.7	0.9	0.5	1.7	385	1083
CuW	0.9	0.3	0.1	6.2	150	3410
W	0.9	0.3	0.1	5.7	163	3370
B	0.7	0.7	0.7	5.4	136	966
SS	0.5	0.5	0.3	72	16	1400
Al	0.5	0.3	0.7	5.9	210	660
G	0.5	0.7	0.5	6000	24	3650

Normalization of beneficial attributes is done by assigning the value '1' to the highest value, and then the rest of the normalized values are obtained by dividing the respective values in Table 5 by the highest value. Similarly, for non-beneficial attributes, the lowest value is assigned '1' and then the rest of the normalized values are obtained by dividing the least value by respective values in Table 5. Hence, a normalized table is obtained as given in Table 6.

Table 6
Normalized Attribute data

	C	*MRR*	*TW*	*ER*	*TC*	*MT*
Cu	0.7143	1.0	0.2	1	1	0.2967
CuW	0.5555	0.3333	1	0.2742	0.3896	0.9343
W	0.5555	0.3333	1	0.2982	0.4234	0.9233
B	0.7143	0.7777	0.1429	0.3148	0.3532	0.2647
SS	1.0	0.5555	0.3333	0.0236	0.0416	0.3836
Al	1.0	0.3333	0.1429	0.2881	0.5455	0.1808
G	1.0	0.7777	0.2	0.0003	0.0623	1

3.3 Calculation of electrode selection index (ESI)

The overall performance scores, termed Electrode Selection Index (*ESI*) in the current case, for all the alternatives have to be calculated. This score is obtained by multiplying the relative normalized weight (w_j) of each attribute (obtained in section 3.1) with its corresponding normalized weight value for each alternative (as obtained in Table 6) and summing over the attributes for each alternative. The alternative with the highest value of *ESI* is considered as the best alternative.

$$ESI = \sum_{j=1}^{M}\left[w_j \times \left(m_{ij} \right)_{normal} \right]$$

For the alternative 1 i.e. Cu, *ESI* is calculated as follows:

$$\begin{aligned} ESI_{Cu} &= [(0.421 \times 0.7143) + (0.1465 \times 1) + (0.2113 \times 0.2) \\ &\quad + (0.0831 \times 1) + (0.0549 \times 1) + (0.0831 \times 0.2967)] \\ &= 0.6521 \end{aligned}$$

Similarly, *ESI* for all alternatives are calculated as shown in Table 7. They are ranked in descending order.

Table 7
ESI and rank of all alternatives

Alternative	***ESI***	**Rank**
Cu	0.6521	II
CuW	0.6155	IV
W	0.6187	III
B	0.5124	VII
SS	0.6089	V
Al	0.5689	VI
G	0.6637	I

The highest *ESI* is noted for Graphite followed by Copper, Tungsten, Copper Tungsten, Stainless Steel, Aluminum and Brass. Hence, it is concluded that Graphite is the best material for fabricating tool electrode followed by Copper, Tungsten, Copper Tungsten, Stainless Steel, Aluminum and Brass.

4. Conclusion

A logical procedure based on the Analytic Hierarchy Process (AHP) has been suggested that helps in the selection of a suitable material from amongst a large number of available materials for fabricating tool electrodes for electro discharge machining process. The methodology is capable of taking into account various desirable characteristics of the material and it strengthens the existing procedure by proposing a logical and rational method of material evaluation and selection for tool electrode fabrication. For all the alternatives, an Electrode Selection Index (*ESI*) is evaluated and ranked in descending order. This resulted in the selection of Graphite as the best material for tool electrode fabrication.

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