Grading of Spot Welding Electrode Material Properties Using AHP

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Abstract: An objective of this research is to rank the essential property required for spot welding material selection. Total ten attributes namely Electrical conductivity, Thermal conductivity, Rockwell Hardness, Wear resistance, Density, Cost, Melting point, Percentage Elongation, Yield Strength and Ultimate Tensile Strength were considered for the purpose of selection of the electrode Material. In order to select appropriate spot welding electrode, authors have studied various Copper alloys having equally good properties. The selection of essential properties was done using Analytical Hierarchy Process (AHP). Experimental work have been carried out on Cu-Cr-Zr material using universal tensile and found that the strength and hardness increases with alloying element, however percentage elongation decreases by 50 % as compared to pure Cu. While performing AHP, the authors found that electrical conductivity, wear resistance, thermal conductivity and Rockwell hardness proved to be the most crucial parameters. Wear of electrode material also affects on current density and performance characteristics of spot welding process and makes it more expensive. The ranking of the property thus provide an input to apply various Multi-Attribution Decision Making (MADM) techniques for selection of the appropriate material for spot welding application. This work is recommended to spot welding electrode manufacturers as well as end users in order to prioritize the properties for selection of spot welding electrode with longer life and good weld quality.

Keywords: Spot Welding Electrode, Copper Alloys, AHP.

1. INTRODUCTION

Copper is known for its high electrical conductivity and is also available at a low cost compared to other high conducting metals. However, pure Copper is having high consumption rates and also affects on current densities while spot welding. Appropriate selection of an electrode material plays an important role in achieving good weld strength and make cost effective welding [1, 3]. Present work aims at ranking of electrode properties which in turn used to select welding electrodes without compromising with the quality of welds [3]. Addition of alloying materials to Copper enhances its properties such as its hardness, thermal conductivity and wear resistance however affects on its Electrical Conductivity [2]. Copper inhibits one of the fairest electrical conductivity and hence its electrical conductivity has become measurement standard for rest of the copper alloys. This measurement standard is being designated as % IACS (International Association of Classification Societies) [2]. It is a relative standard where the electrical conductivity of other copper alloys are compared with the pure copper. It is taken as 100% IACS [2, 3]. The problem is that during spot welding pure copper wears easily which leads to increase in consumption of electrode material. Hence, it is important to find out a material which has significant electrical conductivity as compared to pure copper as well as good wear resistance [1, 3].

This research paper highlights about ranking of properties required for the selection of material for spot welding application. Ten properties namely Electrical conductivity, Thermal conductivity, Rockwell Hardness, Wear resistance, Density, Cost, Melting point, Percentage Elongation, Yield Strength and Ultimate Tensile Strength were considered. The selection of essential parameters was done using the technique of Analytical Hierarchy Process (AHP). AHP is a Multi Criteria Decision Making (MCDM) process which was developed by Thomas L Satty and has provided an effective methodology for selection of effective parameters from a set of parameters by pair-wise comparisons of attributes considered [4,32,33]. Saluja and Singh recently, use modified AHP to justify appropriate welding technique for seamless tube manufacturing [35]. Chavan and Patil used Taguchi method followed by combined TOSIS and AHP for optimization of machining parameters of spheroidal graphite [36].

2. LITERATURE REVIEW

Analytic Hierarchy Process (AHP) which is a Multi-Criteria Decision Making Approach, introduced by Thomas L. Saaty, provided an effective way of properly evaluating the opposite data, using a pair-wise comparison between the parameters considered [4]. Critical property selection using AHP and other MADM

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techniques were performed for various lubricant selection problems [5, 7, 9] and novel brake pad material selection problem [6, 8]. Various numerical and experimental studies on spot and resistance welding electrodes have been carried out so far [10-14]. The comparisons were done to obtain the weight-age of importance as a basis for decision-making. Following steps were undertaken to solve the problem. Investigations on microstructure, mechanical and electro-chemical properties of Cu based alloys for welding applications have been done [15-20]. Effect of alloying elements and rolling directions on structure, strength and electrical conductivity on Cu alloys were studied [21-25]. Several researchers have worked on AHP method as a multi-criteria decision making process [26-29], and conjunction of AHP with various subjective and objective multi-criteria decision making problems such as vector projection approach [30, 31]. Through this research work, authors have intended to apply AHP for ranking of spot welding electrode material property, which will made easier to select appropriate electrode.

2.1. Problem Definition

In metal joining processes where two dissimilar metal sheets are to be welded, Spot Welding is usually implied for getting reliable welds. During Spot Welding , a spot is formed where heat gets concentrated which fuses the two metals, thus , forming a nugget or weld [1, 3]. This process is affected by various tribological and non-tribological properties such as

Wear Resistance

It is the Wear Rate of electrode happening at the time of resistance spot welding which is calculated as material loss of electrode in (mm^3) per unit time (hrs). It occurs due to the formation of Heat Affected Zone (HAZ) near to the Fusion Zone where weld has to be done. Gradually if higher current is passed through the electrodes, HAZ encounters with electrode cap resulting in increasing electrode wear. However, the reciprocal of wear rate is Wear Resistance. More wear resistance contributes positively towards life of electrode [3].

Electrical Conductivity

It is simply the ease of the material to pass electric charge or heat through it. Since in the process of RSW higher electrical conductivity is required which plays a major role in the wear characteristics of electrode material [1].

Thermal Conductivity

It is rate at which heat is transferred via conduction through a unit cross section of the material. Increased thermal conductivity allows for faster rate of heat transfer in phase of material. In this process, we require higher thermal conductivity as for the formation of weld at the Fusion Zone.

Rockwell Hardness

It is based on the Scales of Hardness (A, B, C) which relies on the indentation hardness of material. In the Rockwell test the depth of penetration by the Tungsten-Carbide or Diamond indenter decides the hardness value of the material.

Yield Strength

When a material is stressed by certain amount which is less than materials yield strength where it will only undergo elastic strain (no plastic deformation). The level of stress which shows the yield point is Yield Strength of the material.

Ultimate Tensile Strength

It is maximum stress that a material can withstand (before the point where it will fracture). It is important property of materials to determine their mechanical performance.

Density

It is calculated as mass per unit volume which can be further be defined as how much stuff (mass) can be placed in a controlled volume. Rather, it's the comparison between volume and mass.

Elongation

It is measure of deformation of the material before it breaks while it is subjected to tensile load. It is important in manufacturing at the time of operations like bending and shaping.

Melting Point

It is temperature at which the phase change of material occurs i.e. solid to liquid at a atmospheric pressure. In the process of RSW (Resistance Spot Welding) higher Melting point is required as at the time of actual use of electrode temperature may reach beyond the melting temperature of the electrode material resulting in wear of electrode. Various properties affecting weld strength, welding current and weld nugget quality related to electrode material are shown in Fig. (**1**). Due to large number of properties involved, selection of appropriate material is become more complex. Hence, the first task is to find out important properties from Fig. (**1**) by using Pair-wise comparison.

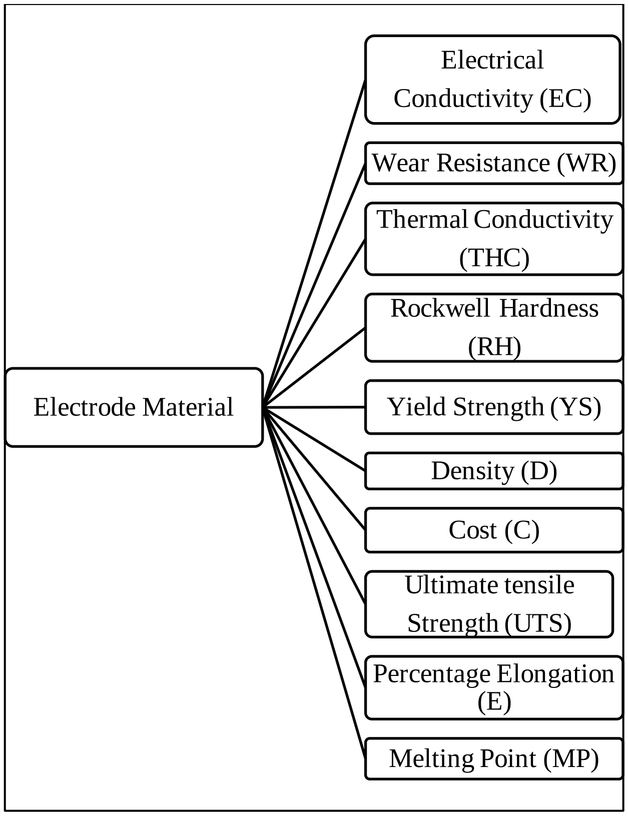

Figure 1: Electrode Material Properties.

Low alloyed Cu based alloys such as Cu-Cr, Cu-Zr, Cu-Ti are being widely used as a spot welding electrode due to their high thermal and electrical conductivity. In order to study operational life of spot welding electrodes the properties of different classes of copper-based alloys recommended by manufacturers are summarised Table **1**. for the purpose of compareson.

3. EXPERIMENTAL EVALUATION OF PROPERTIES

In order to verify the data collected from open literature, the tensile test was conducted using universal tensile testing machine on Cu-Cr-Zr alloy and the results are depicted in Figure **2**. Computerised universal test equipment from FIE Pvt. Ltd. was used to conduct test with a load range from 4 to 200 N with an accuracy of ± 0.1%. A specimen with circular cross section was prepared as per ASTM standard. A gauge length of 50.8 mm was machined at the centre with shoulder to avoid sharp change in cross section. The results are recorded in stress verses strain graph. An elastic limit, Young's Modulus, percentage elongation and Ultimate tensile strength (UTS) were recorded. The UTS and percentage elongation was found 426 N/mm^2 and 18.60% respectively. The ultimate tensile strength of newly developed alloy is almost double than the pure copper and percentage elongation reduced by more than 35 %. This is due to addition of Zirconium, which is support for long life. The hardness was also increased by 50% due to addition of Zr in pure Cu. The evaluation of properties is in line with the literature. Hence, data is collected from other source material for further understanding.

Table 1: Properties Spot Welding Electrodes

Principal Elements	Hardness Rockwell	Electrical Conductivity % IACS	Ultimate Tensile Strength, N/mm^2	Elongation %
Cu-Zr	70B	90	429	18
Cu-Cr	70B	80	345	20
	83B	85	517	15
Cu-Ni-Si-Cr	94B	48	688	10
	90B	48	586	13
Cu-Ni-Be	100B	48	658	10
Cu-Be	38C	20	758	2
	38C	23	1172	4
Cu-Al	92B	13	586	15
Pure Cu	30B	95	172	50
	40B	100	276	35
Cu-Cr-Zr	80 B	87	426	18.60

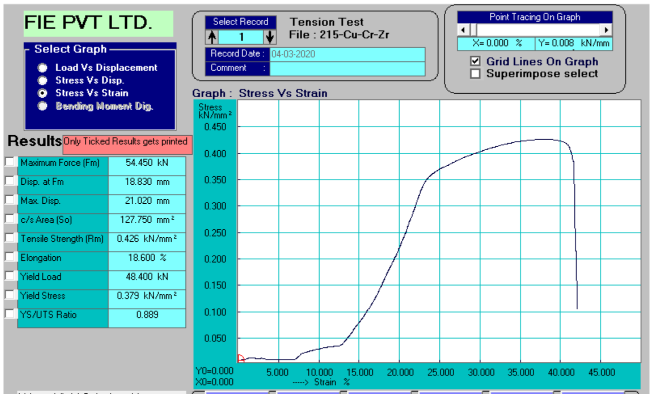

Figure 2: Tensile strength of Cu-Cr-Zr alloy.

4. CRITICAL PROPERTIES ASSESSMENT BY AHP

Analytic Hierarchy Process (AHP) is a multi-criteria decision approach, introduced by Saaty [4, 32, 33] which uses a pair-wise comparison between the parameters. AHP is proved to be useful for modeling and analysis of various types of managerial level decision-making state of affairs in many fields of engineering. The pair-wise comparisons are used to obtain weight age of significance as basis of decision criteria. Comparisons must fall in an permissible range of consistency, to prove the feasibility of the decision. It covenants with the problem of selecting a substitute from a set of candidate alternative (or) attributes.

Saaty [33] has developed AHP which allows decision makers to develop a hierarchical structure for the factors which are explicit in the given problem and to provide the decision about the relative importance of each of these factors specify a preference for each decision alternative with respect to each factors, providing a prioritized ranking order of preference for decision alternatives.

AHP consists of three stages:

i. Determination of the self- importance of attributes.

ii. Determination of the relative importance of each of the alternative with respect to each attribute.

iii. Determination of overall priority weight of each of these alternatives.

4.1. Pair-wise Comparison of Attributes

The Analytic Hierarchy Process is a technique to make ranking of a finite number of criteria. While developing the hierarchical structure, the overall objective of the decision is placed at the top level of the hierarchy and the criteria, sub-criteria, if any, and the decision alternatives on each descending level [34].

Human perceptions may be different while solving a problem and hence collective decision should be made by comparing one attribute with another to know the relative importance in between the two parameters. Based on this, Satty [4] devised a table of Fundamental Scale of Importance (Table **2**) to give appropriate weight-age to the concerned attribute accordingly.

Table 2: Relative Importance

Intensity Level	Definition
1	Equal Importance
2	Weak Importance
3	Moderately Important
4	Above Moderate
5	Strongly Important
6	Above Strong
7	Very strong or demonstrated importance
8	Very, Very strong
9	Extreme importance

While assuming the factor the pair-wise comparison of factors i with factor j yields a decision matrix [A1] N × N where, r_{ij} Comparative importance of factor i with respect to factor j.

In the matrix r_{ij} = 1 when row number is equal to column number i.e. when i=j and $r_{ji} = 1/r_{ij}$ which shows the relativity of importance of one parameter over another.

A1=

	YS	THC	WR	EC	RH	D	C	UTS	E	MP
YS	1	0.5	0.25	0.2	0.333	1	2	2	3	3
THC	2	1	0.5	0.333	2	3	3	5	7	8
WR	4	2	1	1	2	5	6	9	9	9
EC	5	3	1	1	3	6	6	9	9	9
RH	3	0.5	0.5	0.333	1	2	3	3	5	6
D	1	0.333	0.2	0.167	0.5	1	2	2	3	4
C	0.5	0.333	0.167	0.167	0.333	0.5	1	2	3	3
UTS	0.5	0.2	0.111	0.111	0.333	0.5	0.5	1	1	2
E	0.333	0.143	0.111	0.111	0.2	0.333	0.333	1	1	1
MP	0.333	0.125	0.111	0.111	0.167	0.25	0.333	0.500	1	1

4.2. Formulation of Relative Normalize Matrix

For the formulation of relative normalized matrix, the geometric mean of every row has to be found. The Geometric Mean is given by the formula below:-

$$GMi = \sqrt[N]{\sum_{j=1}^{N} \text{rij}} \quad (1)$$

GM_i =

	YS	THC	WR	EC	RH	D	C	UTS	E	MP	Gmi
YS	1	0.5	0.25	0.2	0.333	1	2	2	3	3	0.887
THC	2	1	0.5	0.333	2	3	3	5	7	8	2.102
WR	4	2	1	1	2	5	6	9	9	9	3.584
EC	5	3	1	1	3	6	6	9	9	9	4.048
RH	3	0.5	0.5	0.333	1	2	3	3	5	6	1.633
D	1	0.333	0.2	0.167	0.5	1	2	2	3	4	0.876
C	0.5	0.333	0.167	0.167	0.333	0.5	1	2	3	3	0.652
UTS	0.5	0.2	0.111	0.111	0.333	0.5	0.5	1	1	2	0.428
E	0.333	0.143	0.111	0.111	0.2	0.333	0.333	1	1	1	0.325
MP	0.333	0.125	0.111	0.111	0.167	0.25	0.333	0.500	1.000	1.000	0.285

For calculation of the weighted matrix,

$$A2 = GMi \,/\, \sum_{i=1}^{N} GMi \quad (2)$$

A2= [0.0598 0.1418 0.2418 0.2731 0.1102 0.0591 0.0439 0.0288 0.0219 0.0192]^T

4.3. Calculations of A_3 and A_4 Matrix

$$A3 = A1 \times A2 \quad (3)$$

$$A4 = \frac{A3}{A2} \quad (4)$$

After calculation the matrices A3 and A4 are obtained as

$$A3=\begin{bmatrix}0.611\\1.455\\2.448\\2.819\\1.135\\0.604\\0.455\\0.293\\0.224\\0.198\end{bmatrix} \quad A4=\begin{bmatrix}10.212\\10.260\\10.123\\10.322\\10.295\\10.211\\10.331\\10.151\\10.215\\10.301\end{bmatrix}$$

4.4. Calculating Eigen Value

$$\text{Eigen Value} = \lambda_{max} = \frac{1}{N}\sum_{i=1}^{N} Values\ of\ Matrix\ A4 \quad (5)$$

$$\lambda_{max} = 10.242 \quad (6)$$

4.5. Calculation of Consistency Index

$$CI = \frac{\lambda_{max}-1}{N-1} \quad (7)$$

$$CI = 0.027 \quad (8)$$

Consistency Ratio is calculated by dividing the Consistency Index for the set of judgments by the index for the corresponding random matrix. *Saaty* [32,33] suggests that if that ratio exceeds 0.1 the set of judgments may be untrustworthy.

4.6. Selection of Random Index Value (RI)

Based on the number of parameters involved Satty devised a tabulated form for selection of Random Index Values. They are as follows (Table **3**).

Table 3: Random Index Value

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

4.7. Calculation of Consistency Ratio

The Consistency Ratio is a parameter to check whether the applied weights are consistent or not. If the consistency ratio exceeds more than 0.1 the given weighted system is considered as inconsistent and one needs to redraw the decision matrix. The Consistency Ratio is the ratio of Consistency Index to the Random Index. Mathematically,

$$CR = CI/RI \quad (9)$$

$$CR = 0.01805 \quad (10)$$

The CR is 0.01805 which implies the given weighted matrix is consistent. Also it shows that there's a good consistency in selection of weights while preparing the matrix. The table below shows ranking of all the properties according to their relative worth. Table **4** shows the ranking of the parameters and Fig. (**3**) shows the graph for statistical comparative study in between the parameters to determine its criticality.

Table 4: Ranking of Parameters

Critical Parameters		Relative Worth
EC	Electrical Conductivity	0.273
WR	Wear Resistance	0.242
THC	Thermal Conductivity	0.142
RH	Rockwell Hardness	0.110
YS	Yield Strength	0.060
D	Density	0.059
C	Cost	0.044
UTS	Ultimate Tensile Strength	0.029
E	Percentage Elongation	0.022
MP	Meting Point	0.019

From Fig. (**3**) it is evident that Electrical conductivity is the most crucial parameter along with Wear Resistance. Thermal Conductivity and Rockwell

Hardness shares good importance , whereas, Density , Yield-Strength and Cost shares moderate importance. Other properties like Melting Point, Elongation and Ultimate Tensile Strength is found to be of the least importance.

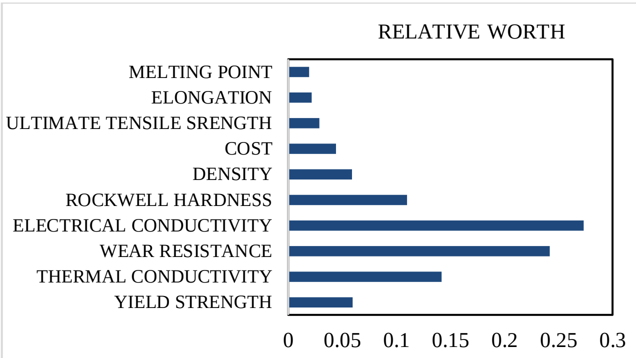

Figure 3: Relative Worth.

5. CONCLUSIONS

The Analytical Hierarchy Process (AHP) is a quite simpler technique for evaluation of essential property based on pair-wise comparisons. In this research paper, the authors placed a total of ten properties for the selection of copper alloy material for the spot welding application. Experimental work have been carried out on Cu-Cr-Zr material, the UTS and percentage elongation was found 426 N/mm^{2}and 18.60% respectively. It was found that the strength and hardness increases by 35 % and 50 % respectively and percentage elongation decreases by 50 % as compared to pure Cu. Further analysis of properties was done through AHP. After performing AHP and through relative worth it was found that electrical conductivity ranked as first with relative worth 0.273 followed by wear resistance 0.242 are more critical and contributes for a selection of better electrode material. Melting point and Percentage elongation with relative worth 0.022 and 0.019 respectively are hardly significant while selecting spot welding electrode. Other significant properties were thermal conductivity, yield strength, density and cost respectively. This work can be recommended to find an appropriate electrode material by considering these properties using other Multi-Attribute Decision Making (MADM) Processes such as WASPAS, VIKOR, PROMETHEE, and TOPSIS.

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