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# Selection of Spot Welding Electrode Material by Preference Ranking Organization Method for Enrichment Evaluation, VIKOR and WASPAS Methods

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## Abstract

Selection of electrode material for spot welding operation is a complex task due to compromising properties such as electrical conductivity and the strength of material, although limited materials possess them collectively. This research aims to rank eight discrete classes of Cr-Zr, Cu-Be, Cu-Cd, Cu-Cr-Zr, Cu-Ti and Cu-W spot welding electrode materials based on PROMETHEE, VIKOR and WASPAS methods. Preliminary screening of essential attributes was performed using Analytical Hierarchy Process (AHP). It was observed that Cu-Cr-Zr is ranked as the best candidate material by all three MADM methods. However, the selection is based on availability, manufacturability, environment protection rules and cost. This paper suggested an approach for electrode manufacturers and end users to select reliable spot welding electrode material to achieve high weld quality.

**Keywords:** Cu alloys, welding Electrode, PROMETHEE, VIKOR, WASPAS.

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## Introduction

In resistance spot welding, heat and pressure are applied to produce coalescence. The heat is produced between the workpiece interfaces by the electrical resistance and pressure is applied externally to form weld nuggets. The strength of the welded joint depends on the amount of heat generated, current density, interface resistance and holding time. The current density depends on the electrode tip dimensions, which may alter due to high heat and pressure. Pure copper has high electrical conductivity; however, due to its ductility, the electrode tip gets deformed under high pressure and affects current densities, causing high consumption rate while spot welding. Hence, strength, hardness, wear resistance and thermal conductivity are equally important properties to electrical conductivity while selecting electrode materials. Addition of alloying materials such as Cr, Zr, Ni, Be, Si, Al to Cu improves its hardness, thermal conductivity and wear resistance. Due to the availability of newly developed alloy materials, selecting appropriate electrode material becomes a complex task.

Analytic hierarchy process (AHP) is an effective method of correctly assessing the conflicting data by a pairwise judgment between the attributes under consideration.[1-4]

Attempts have been made to rank spot welding electrode material properties using AHP and found that high electrical conductivity, thermal conductivity and wear resistance are most predominant properties amongst all ten attributes under consideration.[3] AHP were performed for various applications such as critical property assessment novel brake pad material selection[5,6] and grade classification of bio-lubricants.[7,8] Several researchers have worked on AHP in conjunction with various subjective and objective multi-criteria decision making methods.[9] Various other multi-attribute decision making approaches have been used for material selection such as VIKOR, TOPSIS, PROMETHEE, MADM, compromise ranking methods, ELECTRE etc.[10,11]

MADM is mathematics-based optimization for the selection of appropriate materials. From the available number of methods, simple additive weighting (SAW), weighted aggregates sum product assessment (WASPAS), VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR), Technique for Order of Preference by Similarity to

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**Table 1:** Alternate material and their chemical composition

| *Elements (%)* | *Material Designation with Chemical Composition* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *C17500* | *C16200* | *C18150* | *C17510* | *C17200* | *C17540* | *75W-25Cu* | *C1990* |
| Al | -- | -- | -- | -- | -- | -- | -- | -- |
| Be | 0.7 | -- | -- | 0.6 | 1.8 | 0.7 | -- | -- |
| Cd | -- | 1.2 | -- | -- | -- | -- | -- | -- |
| CO | 2.7 | -- | -- | -- | 0.2 | 1.3 | -- | -- |
| Cr | -- | -- | 1.5 | -- | -- | -- | -- | -- |
| Cu | 96.1 | 98.7 | 98.3 | 97.2 | 97.6 | 96.3 | 25.0 | 97.1 |
| Fe | 0.10 | 0.02 | -- | -- | -- | 0.2 | -- | -- |
| Ni | 0.2 | -- | -- | 2.2 | 0.2 | 1.3 | -- | -- |
| Si | 0.2 | -- | -- | -- | 0.2 | 0.2 | -- | -- |
| Ti | -- | -- | -- | -- | -- | -- | -- | 2.9 |
| W | -- | -- | -- | -- | -- | -- | 75.0 | -- |
| Zr | -- | -- | 0.2 | -- | -- | -- | -- | -- |

**Table 2:** Attributes for the selected materials

| | *EC (S/m)* | *THC (W/m.K)* | *RH (B Scale)* | *YS(N/m$^2$)* | *D (kg/m$^3$)* | *C (Rs)* | *WR* |
|---|---|---|---|---|---|---|---|
| C17500 | 40 | 120 | 90 | 450 | 8.75 | 4000 | 0.86 |
| C16200 | 90 | 200 | 70 | 475 | 8.89 | 1200 | 0.50 |
| C18150 | 74 | 190 | 85 | 425 | 8.89 | 0700 | 0.68 |
| C17510 | 50 | 140 | 95 | 495 | 8.89 | 0750 | 1.00 |
| C17200 | 22 | 075 | 85 | 650 | 8.25 | 4000 | 0.13 |
| C17540 | 40 | 135 | 90 | 390 | 8.81 | 5000 | 0.86 |
| C16200 | 40 | 100 | 95 | 670 | 14.3 | 7000 | 1.00 |
| C1990 | 50 | 045 | 98 | 800 | 08.70 | 10000 | 1.00 |

Ideal Solution (TOPSIS), Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) are being used for decision making.

Mardani *et al.,* reviewed almost 176 research papers published during 2004 to 2015 in various application areas where VIKOR and Fuzzy VIKOR was widely used for selection problems.[12]

PROMETHEE, WASPAS and MOORA are mathematically simple, highly accurate, having less computational time and most effective decision making methods.[13-15]

Chakraborty *et al.*, solved several manufacturing associated decision making problems, like selection of process parameters for arc welding, forging, electro-discharge micro-machining face milling, machinability of different materials, cutting fluids for different operations, selection of industrial robot etc. using WASPAS and PROMETHEE methods and concluded that these are most effective MCDM technique for quantitative as well as qualitative selection problems.[16-18]

The primary step for every MADM technique is to carry out AHP to determine beneficial and non-Beneficial factors and to determine objective weights in some MADM techniques. For the performance of AHP for MADM techniques, seven parameters from which electrical conductivity, wear resistance, thermal conductivity, Rockwell hardness, and yield strength are beneficial, whereas density and cost are non-beneficial factors.

## Problem Modelling

In order to make decision on complex problems in case of multiple alternatives and conflicting criteria multi-attribute decision making (MADM) techniques are applied. The selection of appropriate spot welding electrode material becomes more complex due to the involvement of large number of properties as well available alternate materials. Pure Cu is having excellent thermal and electrical conductivity; however, its operational life is very low. Essential properties considered for the selection of candidate materials for the spot welding electrode materials are electrical conductivity (EC), thermal conductivity (THC), Rockwell hardness (RH), yield strength (YS), density (D), cost (C), wear resistance (WR) are considered to be essential properties for electrode material. Eight discrete classes of Cr-Zr, Cu-Be, Cu-Cd, Cu-Cr-Zr, Cu-Ti and Cu-W spot welding electrode commercial alloys are selected having high-conductivity and high-strength suitable for spot welding electrode material. Compositions of the commercial alloys are listed in Table 1.

## Material Ranking using Preference Ranking Organization Method for Enrichment Evaluation

PROMETHEE (Preference ranking organization method for enrichment evaluation) method is a resourceful decision-making method. The following steps are involved in the conduction of the PROMETHEE method to compare the candidate materials based on the considered properties are as follows:

### Determining the Criteria

An important attributes were considered based on results obtained through AHP analysis are electrical conductivity (EC) in, thermal conductivity (THC), Rockwell hardness (RH), yield strength (YS), density (D), cost (C), wear resistance (WR).[3]

The values of the attributes for the selected materials were collected from open literature and depicted in Table 2.[3,19-22]

### Determining the Weight of $W_j$ of the Criteria

Let $x_{ij}$ be performance score of $i^{th}$ alternative of $j^{th}$ parameter

$$\begin{array}{ll} & \text{Parameters}\rightarrow \\ & \begin{array}{ccccccc} EC & THC & RH(B) & YS & D & C & WR \end{array} \\ \text{Alternatives}\downarrow \begin{array}{r} C17500 \\ C16200 \\ C18150 \\ C17510 \\ C17200 \\ C17540 \\ 75W-25Cu \\ C1990 \end{array} & \begin{bmatrix} 40 & 120 & 90 & 450 & 8.75 & 4000 & 0.863 \\ 90 & 198 & 70 & 474 & 8.89 & 1200 & 0.5 \\ 74 & 187 & 82 & 425 & 8.89 & 700 & 0.681 \\ 48 & 120 & 90 & 483 & 8.75 & 800 & 0.863 \\ 22 & 75 & 85 & 648 & 8.25 & 4000 & 0.136 \\ 40 & 135 & 90 & 390 & 8.81 & 5000 & 0.863 \\ 48 & 110 & 94 & 670 & 14.3 & 4000 & 1 \\ 74 & 54 & 101 & 900 & 8.7 & 6000 & 1 \end{bmatrix} \end{array}$$

The relative significance of each criterion is calculated as follows:

$$\sum_{j=1}^{k} wj = 1$$

### Normalizing the Decision Matrix

First we classify the given criteria into beneficial and non-beneficial criteria. The property whose maximum possible value would prove favorable would be termed as beneficial. Electrical conductivity, thermal conductivity, Rockwell hardness, wear resistance, density,

Melting point, percentage elongation, yield strength and ultimate tensile strength are beneficial criteria as higher their values the superior it will be. We require the cost to be as low as possible; hence it is a non-beneficial criteria.

For beneficial criteria;

$$R_y = \frac{[x_y - \mathrm{Min}\,(x_y)]}{[\mathrm{Max}\,(x_y) - \mathrm{Min}\,(x_y)]}$$

For non-beneficial criteria;

$$Ry = \frac{[\mathrm{Max}\,(x_y) - x_y]}{[\mathrm{Max}\,(x_y) - \mathrm{Min}\,(x_y)]}$$

Where $x_{ij}$ is evaluation values provided by decision makers i=1,......,n, and number of criteria j=1,.....m.

The normalized decision matrix for PROMETHEE method is as shown in Table 3.

### Determining the Deviation by Pairwise Comparison

In this method, we will deal with the preference of one alternative over another and how each alternative will differ from the other based on each criterion.

$d_j(a,b)=g_j(a)-g_j(b)$

Dj (a,b) denotes the difference between the evaluation of a and b on each criterion.

### Defining the Preference Function

The preference function is used to determine how much an alternative is preferred to another alternative and it translates the difference in evaluations of the two alternatives into a preference degree.

$$P_j(a,b) = F_j[d_j(a,b)]$$

A numerical scale ranging between 0 and 1 holds these preferences. A smaller numerical value represents indifference of preference value between the two alternatives, whereas one shows a greater preference.

### Determining the Multi-criteria preference index

The overall preference index Π(a,b) represents the intensity of the preference a over b and it is calculated as follows:

$$\Pi(a,b)=\sum_{j=1}^{k} P(a,b)w_j$$

**Table 3:** The normalized the decision matrix for PROMETHEE

| *Alternatives* | *EC* | *THC* | *RH (B SCALE)* | *YS* | *D* | *C* | *WR* |
|---|---|---|---|---|---|---|---|
| C17500 | 0.2647 | 0.4838 | 0.7142 | 0.1463 | 0.0826 | 0.6451 | 0.8414 |
| C16200 | 1.0000 | 1.0000 | 0.0000 | 0.2073 | 0.1057 | 0.9462 | 0.4212 |
| C18150 | 0.7647 | 0.9354 | 0.5357 | 0.0853 | 0.1057 | 1.0000 | 0.6307 |
| C17510 | 0.4117 | 0.6129 | 0.8928 | 0.2560 | 0.1057 | 0.9946 | 1.0000 |
| C17200 | 0.0000 | 0.1935 | 0.5357 | 0.6341 | 0.0000 | 0.6451 | 0.0000 |
| C17540 | 0.2647 | 0.5806 | 0.7142 | 0.0000 | 0.0925 | 0.5376 | 0.8414 |
| 75W-25Cu | 0.2647 | 0.3548 | 0.8928 | 0.6829 | 1.0000 | 0.3225 | 1.0000 |
| C1990 | 0.4117 | 0.0000 | 1.0000 | 1.0000 | 0.0743 | 0.0000 | 1.0000 |

Where Π(a,b) is the overall preference intensity of a over b with respect to all of the criteria, $w_j$ is the weight of criterion , and P(a,b) is the preferred function with respect to criterion j . (a,b)=0 implies a weak preference over b, whereas (a,b)=1 implies a strong preference over b. The multi-criteria preference indices are as shown in Table 4.

### Determining the Negative, Positive Outranking and Net Flow

In PROMETHEE method two flow measures can be determined for each alternative. There are a positive flow which expresses how alternative *'a'* is outranking all the others and negative flow which expresses how alternative all the others outrank a. Higher value of $\Phi^+(a)$ and lower value of $\Phi^-(a)$ is the preferred alternative.

The positive outranking flow is given as follows;

$$\phi^+(a) = \frac{1}{n-1}\sum_{z\in A}\pi(a,x)$$

The negative outranking flow is given as follows;

$$\phi^-(a) = \frac{1}{n-1}\sum_{z\in A}\pi(x,a)$$

The net flow by using the following equation.

$$\phi(a) = \phi^+(a) - \phi^-(a) = \frac{1}{n-1}\sum_{j=1}^{k}\sum_{z\in A}[P_j(a,x) - P_j(x,a)]w_j$$

The positive outranking, negative outranking flow and net flow is given in Table 5.

Net flow Φ(a) is achieved by comparing the positive outranking flow and negative outranking flow. Thus, a higher value of Φ(a) represents a higher rank and the most preferred alternative. Based on the PROMETHEE method, C18150 and C17510 are the best suitable alternatives.

## Material Ranking using VIKOR

The VIKOR is a multi-attribute decision-making method. VIKOR is an abbreviation for Serbian: VIseKriterijumska Optimizacija I Kompromisno Resenje meaning Multi-criteria Optimization and Compromise Solution. Serafim Opricovic originally developed it to solve decision problems with desired properties that conflicted each other and the criteria of various units. VIKOR is based on the theory that compromise is acceptable for conflict resolution.VIKOR ranks alternatives and determines the solution that is the closest to the ideal.

Let $x_{ij}$ be the performance score of $i^{th}$ alternative of $j^{th}$ parameter

$$\begin{array}{cc} & \text{Parameters}\rightarrow \\ & \begin{array}{ccccccc} EC & THC & RH & YS & D & Cost & WR \end{array} \\ \text{Alternatives}\downarrow \begin{array}{c} C17500 \\ C16200 \\ C18150 \\ C17510 \\ C17200 \\ C17540 \\ 75W-25Cu \\ C1990 \end{array} & \begin{bmatrix} 40 & 120 & 90 & 450 & 8.75 & 4000 & 0.863 \\ 90 & 200 & 70 & 475 & 8.89 & 1200 & 0.5 \\ 74 & 190 & 85 & 425 & 8.89 & 700 & 0.681 \\ 48 & 140 & 95 & 495 & 8.89 & 750 & 1 \\ 22 & 75 & 85 & 650 & 8.25 & 4000 & 0.136 \\ 40 & 135 & 90 & 390 & 8.81 & 5000 & 0.863 \\ 40 & 100 & 95 & 670 & 14.3 & 7000 & 1 \\ 50 & 45 & 98 & 800 & 8.7 & 10000 & 1 \end{bmatrix} \end{array}$$

The steps involved in the conduction of VIKOR method are as follows:

### Finding the Best and Worst Value of Each Parameter

The best value of alternatives in beneficial criteria is the maximum value of the parameters. The worst parameter of beneficial criteria is the least value of the parameter across the alternatives.

The best value of non-beneficial criteria is the least of the parameters across the alternatives. The worst alternative of the non-beneficial criteria is the greatest value across the electrode candidates. The best and worst values of parameters are as follows;

$$\begin{array}{cc} & \begin{array}{ccccccc} EC & THC & RH & YS & D & Cost & WR \end{array} \\ \begin{array}{c} Best \\ Worst \end{array} & \begin{bmatrix} 90 & 200 & 98 & 800 & 14.3 & 700 & 1 \\ 22 & 45 & 70 & 390 & 8.25 & 10000 & 0.136 \end{bmatrix} \end{array}$$

### Computing the Unity Measure (Si)

The unity measure is similar to normalization, *i.e.,* scaling all the criteria values on the same scale so they can be compared.

$$Si = \sum_{j=1}^{m}[(W_j * (Xi^+ - Xij)/(Xi^+ - Xi^-)]$$

$$\begin{array}{cc} & S_i \\ \begin{array}{c} C17500 \\ C16200 \\ C18150 \\ C17510 \\ C17200 \\ C17540 \\ 75W-25Cu \\ C1990 \end{array} & \begin{bmatrix} 0.473993 \\ 0.35003 \\ 0.317162 \\ 0.323275 \\ 0.858172 \\ 0.466834 \\ 0.384874 \\ 0.41117 \end{bmatrix} \end{array}$$

**Table 4:** The multi-criteria preference indices

| *Alternatives* | *C17500* | *C16200* | *C18150* | *C17510* | *C17200* | *C17540* | *75W-25Cu* | *C1990* |
|---|---|---|---|---|---|---|---|---|
| C17500 | 0.0000 | 0.1802 | 0.0742 | 0.0000 | 0.3416 | 0.0135 | 0.0325 | 0.0975 |
| C16200 | 0.2922 | 0.0000 | 0.0807 | 0.2155 | 0.5089 | 0.2914 | 0.3197 | 0.3460 |
| C18150 | 0.2176 | 0.1119 | 0.0000 | 0.1423 | 0.4886 | 0.2131 | 0.2487 | 0.2750 |
| C17510 | 0.1398 | 0.2433 | 0.1388 | 0.0000 | 0.4748 | 0.1389 | 0.1063 | 0.1326 |
| C17200 | 0.0292 | 0.0845 | 0.0329 | 0.0226 | 0.0000 | 0.0427 | 0.0141 | 0.0558 |
| C17540 | 0.0143 | 0.1802 | 0.0706 | 0.0000 | 0.3559 | 0.0000 | 0.0415 | 0.1071 |
| 75W-25Cu | 0.1443 | 0.3195 | 0.2172 | 0.0783 | 0.4383 | 0.1525 | 0.0000 | 0.1191 |
| C1990 | 0.1611 | 0.2976 | 0.1952 | 0.0564 | 0.4318 | 0.1699 | 0.0709 | 0.0000 |

**Table 5:** Positive outranking, negative outranking flow and net flow

| | *Positive flow* | *Negative flow* | *Net flow* |
|---|---|---|---|
| C17500 | 0.1056 | 0.1426 | -0.0370 |
| C16200 | 0.2935 | 0.2025 | 0.0910 |
| C18150 | 0.2425 | 0.1157 | 0.1267 |
| C17510 | 0.1964 | 0.0736 | 0.1227 |
| C17200 | 0.0403 | 0.4343 | -0.3940 |
| C17540 | 0.1099 | 0.1460 | -0.0360 |
| 75W-25Cu | 0.2099 | 0.1191 | 0.0907 |
| C1990 | 0.1976 | 0.1619 | 0.0356 |

## Finding the Individual Regret ($R_i$)

The Individual Regret ($R_j$) is calculated as follows;

$$R_i = \mathrm{Max}\ [(W_j * (X_i^+ - X_{ij}) / (X_i^+ - X_{ij})]$$

$$\begin{array}{r} C17500 \\ C16200 \\ C18150 \\ C17510 \\ C17200 \\ C17540 \\ 75W-25Cu \\ C1990 \end{array} \begin{bmatrix} 0.223305 \\ 0.175749 \\ 0.112128 \\ 0.178644 \\ 0.303694 \\ 0.223305 \\ 0.223305 \\ 0.178978 \end{bmatrix}$$

## Finding $S^*$, $R^*$, $S^-$ and $R^-$

$S^*$ and $R^*$ are the best (i.e. the minimal values) of Si and $R_i$

$S^-$ and $R^-$ are the worst (i.e. the maximum values) of Si and $R_i$

$S^* = 0.334662$ $R^* = 0.09739$

$S^- = 0.841451$ $R^- = 0.3$

## Calculating $Q_i$

The $Q_i$ is calculated using the following equation;

$$Q_i = [\mu * (S_i - S^*) / (S^- - S^*)] + [(1 - \mu)(R_i - R^*) / (R^- - R^*)]$$

$$\begin{array}{r} \\ C17500 \\ C16200 \\ C18150 \\ C17510 \\ C17200 \\ C17540 \\ 75W-25Cu \\ C1990 \end{array} \begin{array}{c} Q_i \\ \begin{bmatrix} 0.435121 \\ 0.196432 \\ 0 \\ 0.17926 \\ 1 \\ 0.428504 \\ 0.352757 \\ 0.261365 \end{bmatrix} \end{array}$$

## Sorting the Matrix of $Q_i$ in Ascending Order

The top most material is ranked 1, the next alternative is ranked 2, so on and so forth. Rank based on $Q_i$

$$\begin{array}{r} Q_i \\ C17500 \\ C16200 \\ C18150 \\ C17510 \\ C17200 \\ C17540 \\ 75W-25Cu \\ C1990 \end{array} \begin{array}{c} Q_i\ Rank \\ \begin{bmatrix} 7 \\ 3 \\ 1 \\ 2 \\ 8 \\ 6 \\ 5 \\ 4 \end{bmatrix} \end{array}$$

## Checking for the Acceptable Advantage Condition C1

Condition C1:- Q(A(2) – Q(A(1)) >= DQ

QA(2)= $Q_i$ value of Second ranked Alternative

QA(1)= $Q_i$ value of First ranked Alternative

$$DQ = \frac{1}{n-1}$$

Where, n= No. of Alternatives

The calculated value of DQ is 0.1428.

Q(A(2)) =0.16451 Q(A(1))= 0

Q(A(2) – Q(A(1)) =0.16451 > 0.1428

Hence Condition C1 is satisfied.

## Check for Acceptable Stability In Decision-making Condition C2

Condition 2: The Alternative with best rank according to the Ranking of $Q_i$ should also be the best ranked by Si and $R_i$

Best Alternative by $Q_i$ = C18150. [least $Q_i$ value =0]

Best Alternative by Si = C18150. [least Si value =0.337]

Best Alternative by $Q_i$ = C18150. [least $R_i$ value =0.097]

Hence, it is observe that the alternative with the best rank in $Q_i$ is also ranked the best by Si and $R_i$. Hence, the Condition C2 is satisfied. Thus, the ranking obtained by sorting the values of $Q_i$ using the VIKOR method found that C18150 and C16200 are the most suitable spot welding materials.

# Material Ranking using Waspas (Weighted Aggregated Sum Product Assessment) Method

WASPAS stands for Weighted Aggregated Sum Product Assessment. The MADM method was developed by Zavdskas in 2012. It is a combination of two MADM methods *i.e.* WSM (Weighted Sum Method) and WPM (Weighted Product Method).

The steps used in the WASPAS method are as follows:

## Creation of a Decision Matrix

Let $X_{ij}$ be the value for i[th] Alternative and j[th] property. The decision matrix hence obtained is as follows:

$$\begin{array}{cr} \text{Parameters}\rightarrow & \\ & C17500 \\ & C16200 \\ & C18150 \\ \text{Alternatives}\downarrow & C17510 \\ & C17200 \\ & C17540 \\ & 75W-25Cu \\ & C1990 \end{array} \begin{array}{c} \begin{array}{ccccccc} EC & THC & RH & YS & D & C & WR \end{array} \\ \begin{bmatrix} 40 & 120 & 90 & 450 & 8.75 & 4000 & 0.863 \\ 90 & 200 & 70 & 475 & 8.89 & 1200 & 0.5 \\ 74 & 190 & 85 & 425 & 8.89 & 700 & 0.681 \\ 48 & 140 & 95 & 495 & 8.89 & 750 & 1 \\ 22 & 75 & 85 & 650 & 8.25 & 4000 & 0.136 \\ 40 & 135 & 90 & 390 & 8.81 & 5000 & 0.863 \\ 40 & 100 & 95 & 670 & 14.3 & 7000 & 1 \\ 50 & 45 & 98 & 800 & 8.7 & 10000 & 1 \end{bmatrix} \end{array}$$

## Normalizing the Decision Matrix

In order to compare the various properties of various alternatives, we normalize the decision matrix. In order to formulate the decision matrix, we have to find the maximum value of each parameter.

$$X_{\max j} = \mathrm{Max}(X_{i=0}^{i=8})$$

$$X_{\mathrm{Best}\ j} = [90 \quad 200 \quad 98 \quad 800 \quad 14.3 \quad 700 \quad 1]$$

For beneficial criteria following equation is used;

$$\overline{X_{ij}} = \frac{X_{ij}}{X_{\max j}}$$

For non-beneficial criteria following equation is used;

$$\overline{X_{ij}} = \frac{X_{minj}}{X_{ij}}$$

The normalized matrix obtained is as follows;

$\overline{X_{ij}} =$

| | EC | THC | RH | YS | D | Cost | WR |
|---|---|---|---|---|---|---|---|
| C17500 | 0.444444 | 0.6 | 0.91836 | 0.5625 | 0.61188 | 0.175 | 0.863 |
| C16200 | 1 | 1 | 0.71428 | 0.59375 | 0.62167 | 0.5833 | 0.5 |
| C18150 | 0.82222 | 0.95 | 0.86734 | 0.53125 | 0.62167 | 1 | 0.681 |
| C17510 | 0.55556 | 0.7 | 0.969388 | 0.61875 | 0.62167 | 0.9333 | 1 |
| C17200 | 0.24444 | 0.375 | 0.86734 | 0.8125 | 0.5769 | 0.175 | 0.136 |
| C17540 | 0.44444 | 0.675 | 0.91836 | 0.4875 | 0.616084 | 0.14 | 0.863 |
| 75W – 25Cu | 0.44444 | 0.5 | 0.96938 | 0.8375 | 1 | 0.1 | 1 |
| C1990 | 0.55556 | 0.225 | 1 | 1 | 0.60839 | 0.07 | 1 |

## Calculating the Normalized Weighted Matrix

We multiply the parameters with weights to obtain normalized weighted matrix.

Wj = [0.30369 0.17897 0.10652 0.05143 0.02854 0.02712 0.30369]

$$\bar{X}_{Wij} = \mathrm{Wj} * [\,\overline{X_{ij}}_{j=1}^{j=8}\,]$$

The normalized weighted matrix obtained is as follows;

| | EC | THC | RH | YS | D | Cost | WR |
|---|---|---|---|---|---|---|---|
| C17500 | 0.134975 | 0.107387 | 0.097827 | 0.028934 | 0.017466 | 0.004747 | 0.262088 |
| C16200 | 0.33694 | 0.178978 | 0.076088 | 0.030542 | 0.017745 | 0.015824 | 0.151847 |
| C18150 | 0.249704 | 0.170029 | 0.092393 | 0.027327 | 0.017745 | 0.027126 | 0.206816 |
| C17510 | 0.168719 | 0.125285 | 0.103262 | 0.031828 | 0.017745 | 0.025318 | 0.303694 |
| C17200 | 0.074236 | 0.067117 | 0.092393 | 0.041794 | 0.016468 | 0.004747 | 0.041302 |
| C17540 | 0.134975 | 0.12081 | 0.097827 | 0.025076 | 0.017586 | 0.003798 | 0.262088 |
| 75W – 25Cu | 0.134975 | 0.089489 | 0.103262 | 0.04308 | 0.028544 | 0.002713 | 0.303694 |
| C1990 | 0.168719 | 0.04027 | 0.106523 | 0.051439 | 0.017366 | 0.001899 | 0.303694 |

## Calculating the Performance Score According to Weighted Sum Method

We now add all the elements of an alternative from the Weighted Normalized matrix to obtain the performance score of each Alternative.

$$A_{si} = \sum_{J=1}^{J=8} \bar{X}_{Wij}$$

The performance score according to weighted sum method is as follows;

| | |
|---|---|
| C17500 | 0.653425 |
| C16200 | 0.774719 |
| C18150 | 0.791141 |
| C17510 | 0.775852 |
| C17200 | 0.338057 |
| C17540 | 0.662161 |
| 75W – 25Cu | 0.705758 |
| C1990 | 0.689911 |

## Calculating the Weighted Normalized Matrix for Weighted Product Method

To obtain Performance score according to Weighted Product method, we obtain the Weighted Normalized Matrix for Weighted Product Method.

The Weighted Normalized Matrix for WPM is given by

$$\bar{X}_{Wij} = [(\overline{X_{ij}}^{W_j})_{j=1}^{j=8}]$$

| | EC | THC | RH | YS | D | Cost | WR |
|---|---|---|---|---|---|---|---|
| C17500 | 0.781707 | 0.912628 | 0.99097 | 0.970838 | 0.986077 | 0.95382 | 0.95624 |
| C16200 | 1 | 1 | 0.964793 | 0.973541 | 0.986524 | 0.985485 | 0.810175 |
| C18150 | 0.942286 | 0.990862 | 0.984954 | 0.967987 | 0.986524 | 1 | 0.889872 |
| C17510 | 0.836518 | 0.938158 | 0.996694 | 0.975609 | 0.986524 | 0.99813 | 1 |
| C17200 | 0.651919 | 0.838998 | 0.984954 | 0.989376 | 0.984422 | 0.95382 | 0.545583 |
| C17540 | 0.781707 | 0.932071 | 0.99097 | 0.963718 | 0.986269 | 0.948064 | 0.95624 |
| 75W – 25Cu | 0.781707 | 0.883328 | 0.996694 | 0.99092 | 1 | 0.93945 | 1 |
| C1990 | 0.836518 | 0.765693 | 1 | 1 | 0.985915 | 0.930404 | 1 |

## Calculating the Performance Score Weighted Product Method

We multiply the elements of an alternative from the weighted normalized matrix with each other.

$$Ap_i = \prod_{j=1}^{j=8} \bar{X}_{Wij}$$

The performance score for each alternative according to the weighted product method obtained is as follows;

| | |
|---|---|
| C17500 | 0.617289 |
| C16200 | 0.739818 |
| C18150 | 0.781478 |
| C17510 | 0.751421 |
| C17200 | 0.273049 |
| C17540 | 0.622161 |
| 75W – 25Cu | 0.640678 |
| C1990 | 0.587545 |

## Calculating the Joint Generalized Criterion of WASPAS *(Qi)*

In order to combine the results of WSM and WPM, we introduce a term known as Joint generalized Criterion of WASPAS *($Q_i$)*.

$$Q_i = [(\lambda * As_i) + (1-\lambda) * Ap_i]_{i=1}^{i=8}$$

Where, λ is the weightage given to WSM and accordingly weightage of (1-**l**) will be given to WPM.

| | $Q_i$ |
|---|---|
| C17500 | 0.635357 |
| C16200 | 0.757268 |
| C18150 | 0.786309 |
| C17510 | 0.76363 |
| C17200 | 0.305553 |
| C17540 | 0.642161 |
| 75W – 25Cu | 0.673218 |
| C1990 | 0.638728 |

The above matrix represents the performance score of each alternative given by a combination of WSM and WPM. The above matrix when sorted in descending order and ranked will give the rank of the alternatives.

The ranking based on the WASPAS method is as follows;

| | $Q_i$ |
|---|---|
| C17500 | 0.635357 |
| C16200 | 0.757268 |
| C18150 | 0.786309 |
| C17510 | 0.76363 |
| C17200 | 0.305553 |
| C17540 | 0.642161 |
| 75W – 25Cu | 0.673218 |
| C1990 | 0.638728 |

Hence the alternative ranked best by WASPAS is C18150 (Copper Chromium Zirconium).

# Comparative Rankings by the Vikor, Promethee and Waspas Methods

The ranking obtained by all three methods need to be compared with each other to obtain the best-ranked candidate material. The comparative rankings by the VIKOR, PROMETHEE and WASPAS methods are as shown in Table 6.

**Table 6:** Comparative rankings by the VIKOR, PROMETHEE and WASPAS methods

| *Material* | *VIKOR Ranking* | *PROMETHEE Ranking* | *WASPAS Ranking* |
|---|---|---|---|
| C16200 | 2 | 3 | 2 |
| C18150 | 1 | 1 | 1 |
| C17510 | 3 | 2 | 3 |
| 75W-25 Cu | 5 | 4 | 4 |
| C1990 | 4 | 5 | 5 |
| C17500 | 7 | 7 | 7 |
| C17540 | 6 | 6 | 6 |
| C17200 | 8 | 8 | 8 |

It is observed that C18150 (Copper, Chromium, Zirconium) is ranked as the best candidate material by all the three MADM methods, followed by C16200 (Cadmium, Copper).

## Conclusion

In this paper, an attempt to suggest suitable alternate materials for spot welding electrode using VIKOR, PROMETHEE and WASPAS multi-attribute decision making techniques is done. Pure Cu has excellent thermal and electrical conductivity; however, its operational life is very low. The critical properties such as electrical conductivity, wear resistance, hardness, thermal conductivity, yield strength, cost and density were selected as attributes for comparison of materials. Eight discrete classes of Cr-Zr, Cu-Be, Cu-Cd, Cu-Cr-Zr, Cu-Ti and Cu-W spot welding electrode materials were considered for selection purposes. It is observed that C18150 (Cu-Cr-Zr) is ranked as the best candidate material by VIKOR, PROMETHEE and WASPAS multi-attribute decision making methods. Further investigations on the thermal, electrical and tribo-mechanical properties of C18150 (Cu-Cr-Zr) at in-situ conditions need to be evaluated for its durability to achieve better weld quality.

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