Selecting a Material for an Electroplating Process Using AHP and VIKOR Multi Attribute Decision Making Method

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Abstract

In this era of Industrialization every company is trying to develop their manufacturing process better and better. Electroplating is one of the important processes in manufacturing company like automobile, ship, airspace, machinery, electronics, jewelry, defense, toy industries, etc. It is generally used to alter the characteristics of a surface to provide improved appearance, ability to withstand corrosive agents, resistance to abrasion, or other desired properties. In time of selecting metal for the electroplating process, it is necessary to compare their characteristics in a decisive way and should be taken into account other conflicting criteria that can influence the process. Multiple attribute decision making method can be used to solve this problem. In this paper, VIKOR method along with Analytical Hierarchy Process (AHP) is used as multiple attribute decision making method to select the appropriate metal for the electroplating process. AHP is used to calculate the weight of the criteria and by using these weights VIKOR is used to rank the alternatives. Finally the proposed model has been presented for the selection of appropriate electroplating material.

Keywords
Electroplating, Analytic Hierarchy Process Matrix, Multi Criteria Decision Making (MCDM), Plating Material.

1. Introduction

Electroplating is an important process in a manufacturing factory. Nowadays, Electroplating has wide application fields including thin or thick layer depositions, metals machining, energy production or organic synthesis without forgetting organic and heavy metals de-polluting. The electroplating industry is one of the major industries. There are two main areas of electroplating business. One provides heavy coatings of hard metal such as chromium to machine parts. The other provides light coatings to personal and domestic items, such as jewellery, ornaments, hobby items, motor vehicle parts and electronic components. The items may be new or second hand. A smaller and more specialized industry uses electroplating in the manufacture of electronic circuit boards. Electroplating products are widely used for many industries, such as automobile, ship, airspace, machinery, electronics, jewelry, defense, and toy industries. The core part of the electroplating process is the electrolytic cell (electroplating unit). In the electrolytic cell (electroplating unit) a current is passed through a bath containing electrolyte, the anode, and the cathode. In industrial production, pretreatment and post treatment steps are usually needed as well.

Electroplating process is a sensitive process in terms of selecting an electroplating metal. The selection depends on many criteria like type of process tank, breadth of electrode, length of electrode, distance between electrodes, electrolytic concentration, current value, voltage value, layer thickness, surface cleaning, corrosion resistance, dullness, roughness, environmental factor, adhesions, cohesion, hardness of plating, coefficient of friction, surface tension, deposition rate, deposition time, wear resistance, part geometry, part irregularity, friction of plating parts, heat resistance, color of plating, impurities impingement, etc. These parameters will decide the life, durability, capability, grad ability and operating economy of the electroplating. The primary objective is to control the wear or erosion so that the user adaptability of product does not exceed the certain level.

There are a number of reported studies concerning the selection of electroplating for manufacturing application. Most of them are based on the modification of the electroplating process like (Willey 2006). There have been many attempts in the past aimed at quality control of the different electroplating process for the performance characteristic attributes and for carrying out sensitivity analysis (Singh and Rao 2011). These include optimized surface pretreatment for copper electroplating (Kim and Kim 2001), etc. (Sombatsompop, Sukeemith et al. 2004) also designed the electroplating experiment apparatus for improvement of efficiency by cathode rotating (CR) and anode circumference rotating (ACR), simultaneously. (Janssen and Koene 2002) suggested the usefulness of different alternative electrodes for different applications and their effect on environment. (Zhang, Tan et al. 2001) have applied the Taguchi orthogonal array design approach for finding the optimum parameter which influences the lithography quality of SU-8photoresist. (Bayati, Shariat et al. 2005) designed an electroplating bath, for toxicity. In the paper Attribute based specification, comparison and selection of electroplating system using MADM approach, (Kumar and Agrawal 2009) used TOPSIS method to select the process metal.

In this paper two multi attribute decision making methods are used to select the plating material considering five attributes as example, but many attributes can be considered. Here AHP is used to calculate the consistency ratio of the comparison matrix and the weight of the criteria. Using this weight of the criteria VIKOR is used to rank the alternatives and select the best one.

2. Analytical Hierarchy Process (AHP)

Analytical Hierarchy Process (AHP) is a multi-criteria decision making process that is a structured technique for organizing and analyzing complex decisions. It uses a multi-level hierarchical structure of objectives, criteria, sub-criteria and alternatives. Based on the mathematics and psychology, it was developed in 1980 by Thomas L. Saaty and perhaps the most widely used method in the world and has been extensively studied and refined since then. It has attracted the interest of many researchers mainly due to the nice mathematical properties of the method and the fact that the required input data are rather easy to obtain. This method is popularly known as AHP. AHP is a tool that helps to find the suitable alternative when problem involves many decision alternatives.

3. Theoretical Background of AHP

The Analytical Hierarchy Process Implementation steps:
Step 1: Identify the goal/objective, available alternatives and important performance criteria.
Step 2: Identified criteria are then structured into a hierarchy descending from an overall objective to various criteria and sub-criteria in successive levels.
Step 3: AHP Matrix (Analytic Hierarchy Process Matrix) or Comparison Matrix is a Matrix in which the Rows and Columns have the same parameters. Assuming that there are n criteria at a given hierarchy, the procedure establishes an $n \times n$ pair-wise comparison matrix (Let "A"). This matrix reflects the decision maker's judgment of the relative importance of the different criteria. $a_{ij} = d$ indicates that i is d times more important than j and
$a_{ji} = k$ automatically implies that $a_{ij} = 1/k$.
Step 4: Sum of the element in a column, $y_k = \sum a_{ij}$ ………… (1)
where, i = 1,2, ….. n and j = 1,2, …… n
Geometric mean is calculated as, $b_k = [(a_{k1}).(a_{k2})\ldots\ldots(a_{kn})]^{1/n}$ ………… (2)
where, k = 1, 2, …… n
Normalized weights are calculated as, $X_k = bk/\sum bk$ ………… (3)
Consistency Index (C.I.) C.I.= $(\lambda max - n)/(n-1)$ ………… (4)
where, $\lambda_{max} = y_1x_1 + y_2x_2 + \ldots\ldots + y_kx_k.\ \ldots\ldots + y_nx_n = \sum y_kx_k$
= largest Eigen value of matrix of order n
Acceptability of alternative or attribute is measured in terms of Consistency Ratio (C.R.)
Consistency ratio (C.R.) = consistency index (C.I.) / randomly generated consistency index (R.I.)
Some Randomly Generated Consistency Index (R.I.) values (proposed by Saaty) are as follows:

n	1	2	3	4	5	6	7	8	9	10
R. I.	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

If C.R. < 10 % then the alternative or attribute is accepted. Otherwise, the alternative or attribute is rejected. The overall consistency may also be measured to justify the validity of selection.

4. VIKOR

Multi Criteria Decision Making (MCDM) methods is a branch of a general class of Operations Research models which deal with the process of making decisions in the presence of multiple objectives. This class is further divided into Multi Objective Decision Making (MODM) and Multi Attribute Decision Making (MADM) (Pohekar and Ramachandran 2004) (Pohekar and Ramachandran 2004). These methodologies share the common characteristics of conflict among criteria, incommensurable units, and difficulties in design/selection of alternatives(Huang, Poh et al. 1995).

VIKOR method as mentioned before has some advantages:

- VIKOR method is ranking alternatives by closeness to PIS and farness from NIS.
- The best alternative is preferred by maximizing utility group and minimizing regret group.

The procedure of VIKOR for ranking alternatives can be described as the following steps:
Step 5: Determine the best and worst values
For all criterion functions determine the best f_i* and the worst f_j^- values (j= 1, 2 ….n). If we assume the j th function represents a benefit, then f_i*= max f_{ij} (or setting an aspired level) and f_j^- = min f_{ij} (or setting a tolerable level). Alternatively, if we assume the j th function represents a cost/risk, then f_i*= min f_{ij} (or setting an aspired level) and f_j^- = max f_{ij} (or setting a tolerable level).

$$f_i^* = \left[(\max_j f_{ij} | i \epsilon I_1), \min_j f_{ij} | i \epsilon I_2) \right]$$

$$f_i^- = \left[(\min_j f_{ij} | i \epsilon I_1), \max_j f_{ij} | i \epsilon I_2) \right] \quad \cdots\cdots\cdots\cdots (5)$$

I_1 is a benefit type indicator set, I_2 is a cost type indicator set.

Step 6: Compute the distance of alternatives to ideal solution
Calculate the values of Si and Ri, j = 1, 2, ⋯, J, Si is the optimal solution of schemes' comprehensive evaluation, Ri is most inferior solution of schemes' Comprehensive evaluation.

$$S_i = \sum_{j=1}^{n} w_j \, (f_j^* - f_{ij})/(f_j^* - f_j^-)$$

$$R_i = max_j[w_j(f_j^* - f_{ij})/(f_j^* - f_j^-)] \quad \cdots\cdots\cdots\cdots (6)$$

In the function, wi are weights of each indicator, meaning the relative importance among the indicators.
Step 7: Calculate Q_i:
The value of Q_i (i=1, 2… m) can be calculated by the following equation

$$Q_i = v\left[\frac{S_i - S^*}{S^- - S^*}\right] + (1-v)\left[\frac{R_i - R^*}{R^- - R^*}\right] \quad \cdots\cdots\cdots\cdots (7)$$

$$where, S^* = \min_j S_j, S^- = \max_j S_j, R^* = \min_j R_j, R^- = \max_j R_j,$$

v represents the weights of "the majority of criteria" strategy or the largest group's utility value, here we define the value v = 0.5.
Step 8: Rank the alternatives.
Sorting by the values S, R and Q in decreased order rank all the alternatives. The results are three ranking lists.
Step 9: Propose as a compromise solution the alternative ($A^{(1)}$) which is the best ranked by the measure Q (minimum), if the following two conditions are satisfied:
a. Acceptable advantage $Q(A^{(2)}) - Q(A^{(1)}) \geq DQ, where\ DQ = \frac{1}{J-1}\ and\ A^{(2)}$ is the alternative with second position in the ranking list by Q;
b. Acceptable stability in decision making. The alternative (A^1) must also be the best ranked by S or/and R. This compromise solution is stable within a decision making process, which could be the strategy of maximum group utility (when 5 . 0 > v is needed), or "by consensus" (5 . 0 ≈ v), or with veto (5 . 0 < v).
If one of the conditions is not satisfied, then a set of compromise solutions is proposed which consists of:
c. Alternative (A^1) and (A^2) if only condition (b) is not satisfied, or
d. Alternatives $A^{(1)}, A^{(2)}, \ldots\ldots, A^{(m)}$ if the condition (a) is not satisfied. (A^M) is determined by the relation $Q(A^{(M)}) - Q(A^{(1)}) < DQ$ for maximum n (the positions of these alternatives are "in closeness").

The compromise solution is determined by the compromise-ranking method; the obtained compromise solution could be accepted by the decision makers because it provides maximum group utility of the majority (represented by min S, Eq. (7)), and minimum individual regret of the opponent (represented by min Q, Eq. (8)). The VIKOR algorithm determines the weight stability intervals for the obtained compromise solution with the input weights given by the experts.

5. Case Study

In this thesis, the selection of electroplating system for ornamental purpose is taken from the case study conducted by Kumar and Agrawal (2009). Decision matrix is given in Table 1 which includes both quantitative and qualitative attributes.

Table 1: Decision matrix (Kumar & Agrawal, 2009)

	Alternatives	Cost	Adhesion	Aesthetic	Thickness(μm)	Hardness(HV)
1.	Silver	Medium(2)	Good(4)	Good(4)	20	350
2.	Gold	High(1)	Average(3)	Excellent(5)	25	250
3.	Lead	Low(3)	Poor(1)	Average(3)	30	150
4.	Rhodium	Medium(2)	Average(3)	Fair(2)	20	400
5.	Nickel	Low(3)	Fair(2)	Poor(1)	30	550
6.	Chromium	Low(3)	Excellent(5)	Poor(1)	35	600
7.	Platinum	High(1)	Good(4)	Good(4)	30	580

To give the weight of the attribute five decision makers (DS) were considered and the average of that value is taken in new decision matrix. In table 2 all the considered alternatives are given a numeric value with respect to 'cost' criterion by the decision makers (DS).

Table 2: Decision from decision makers (DS) for Cost

	DS 1	DS 2	DS 3	DS 4	DS 5	AVG
Silver	2	1	2	2	2	1.8
Gold	3	2	3	3	3	2.8
Lead	1	1	2	1	1	1.2
Rhodium	2	2	1	1	2	1.6
Nickel	1	1	1	2	2	1.4
Chromium	1	1	2	1	1	1.2
Platinum	3	3	3	3	3	3.0

After considering the number given by the five decision makers (DS) for the cost, adhesion and aesthetic the new decision matrix is formed.

Table 3: New decision matrix

	Hardness	Thickness	Aesthetic	Adhesion	Cost
Silver	350	20	3.2	3.6	1.8
Gold	250	25	4.6	2.8	2.8
Lead	150	30	2.6	1.4	1.2
Rhodium	400	20	2.2	2.6	1.6
Nickel	550	30	1.4	1.6	1.4
Chromium	600	35	1.2	4.6	1.2
Platinum	580	30	4.4	4.4	3.0

Table 4: Pair-wise comparison matrix of attribute and determine their weight using AHP:

	Hardness	Thickness	Aesthetic	Adhesion	Cost	Weight
Hardness	1	3	2	2	1/4	0.198
Thickness	1/3	1	1/2	¼	1/5	0.060
Aesthetic	½	2	1	½	¼	0.100
Adhesion	½	4	2	1	1/3	0.166
Cost	4	5	4	3	1	0.475

Alternatives (n) = 5
Consistency Index (C.I.) = 0.05
Randomly Generated Consistency Index (R.I.) = 1.12
Consistency Ratio (C.R.) =

$$\frac{\text{Consistency Index}}{\text{Randomly Generated Consistency Index}}$$

$$= \frac{0.05}{1.12} = 0.045$$

Consistency Ratio (C.R.) is less than 10% so the comparison is acceptable.

6. VIKOR

In this part to illustrate the VIKOR method and how to apply it on electroplating material selection an example is concerned. The weights of criteria are calculated by AHP have used in this method, these are as follow:
From AHP weight of the criteria:
W = (0.198, 0.06, 0.10, 0.166, 0.475)
For solving this problem, at first, the best and the worst values of all the criteria are identified. Now, the values of f_i+and f_i- are calculated using Eqn. (5) as given in Table 5. Table 6 shows the s_i and R_i values (for v = 0.5), and table 7 gives value of Q and a relative ranking of alternatives.

Table 5: Decision matrix

	Hardness	Thickness	Aesthetic	Adhesion	Cost	Sj	Rj
Silver	350	20	3.2	3.6	1.8	0.96	0.6
Gold	250	25	4.6	2.8	2.8	1.07	0.42
Lead	150	30	2.6	1.4	1.2	0.62	0.2
Rhodium	400	20	2.2	2.6	1.6	0.97	0.6
Nickel	550	30	1.4	1.6	1.4	0.52	0.2
Chromium	600	35	1.2	4.6	1.2	0.10	0.1
Platinum	580	30	4.4	4.4	3	0.70	0.475

Determine f_i+ and f_i- :

	Max	Max	Max	Max	Min
f_i+	600	35	4.6	4.6	1.2
f_i-	150	20	1.2	1.4	3
W	0.198	0.06	0.10	0.166	0.475

Table 6: s_i and R_i scores

	s_i	R_i	
Silver	0.96	0.60	
Gold	1.07	0.42	
Lead	0.62	0.20	
Rhodium	0.97	0.60	
Nickel	0.52	0.20	
Chromium	0.10	0.10	
Platinum	0.70	0.475	
S*	0.10	R*	0.10
S-	1.07	R-	0.60

After calculating the value of Q_i the alternatives are ranked according to the lowest value using the condition given in the step 9.

Table 7: Q scores and ranks of the Banks

	Q_i	Ranking
Silver	0.943	6
Gold	0.820	5
Lead	0.368	2
Rhodium	0.948	7
Nickel	0.716	4
Chromium	0	1
Platinum	0.684	3

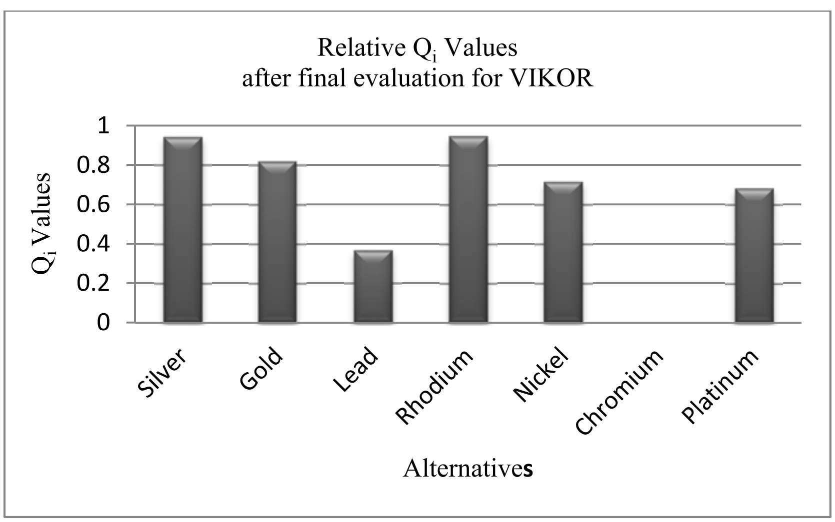

Figure 1: Relative Q_i Values after final evaluation for VIKOR

7. Results and Analysis

The selection of a material for a given application has become a challenging and difficult task, in particular in the selection of materials for an electroplating process. Decision maker must consider several conflicting objectives, technological, environmental, economic, etc. The VIKOR Method has a very useful applicability in materials selection; in those particular cases where in there are a lot of variables to consider.

In this paper, we have shown how the VIKOR method, which introduces the multi-criteria ranking index based on the particular measure of "closeness" to the "ideal" solution, can be used in the selection of an electroplating metal. Combining the VIKOR method with AHP for weighting the importance of the different criteria, allows the decision maker to systematically assign the value of relative importance to the attributes based on their preferences.

After the evaluation Chromium has the highest rate among seven materials which are considered in this study. The main list of materials can be seen in the table 7 with respect to Q. The VIKOR method is sensitive to criteria's weights (w_i). So the researches using VIKOR may test the result with alternative weights. Also the weight v has an important role in identifying the ranking. Further researches may compare results with setting this value between 0 and 1. The VIKOR method can also be used another sectors as a ranking methods and VIKOR method may compare with other MCDM Methods.

Acknowledgements

This research study is completed under fully cooperation and resources of Department of Industrial and Production Engineering, Bangladesh University of Engineering and Technology (BUET). The authors express thanks and profound indebt for the kind cooperation and valuable suggestions to complete the thesis work.

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Biography

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