



Decision Making Methodology for Heat Sink Material Selection Using a Compromise Ranking and Outranking Method under Fuzzy Environment

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ABSTRACT

This paper proposes judicious selection of heat sink materials by extensive evaluation under consideration of numerous alternative materials and evaluation criteria. This enhances the reliability and life of modern electronic devices. Thermal management of electronic devices relies on stabilizing the component temperature at an acceptable level. A hierarchical decision making framework structure based on novel hybrid fuzzy set theory combined with multi-criteria decision-making (MCDM) model is formed. A fuzzy analytic hierarchical process (FAHP) is more realistic to use linguistic terms to describe the expectation value, perception value and important weight of evaluation criteria. This study comprises six alternatives and seven criteria such as thermal conductivity, density, specific heat, melting point, latent heat of fusion, thermal expansion and cost. The results obtained from FAHP-TOPSIS and FAHP- VIKOR is compared with each other. These results help the designer to choose the apt heat sink material for designing and developing electronic packages.

Indexing terms/Keywords

Multi criteria decision making, Heat sink, Thermal management system, Electronic devices, Fuzzy set theory.

1. INTRODUCTION

Electronic manufacturing industries are facing problems in thermal management of electronic equipment due to the increase in heat dissipation. The heat must be dissipated to prevent the deterioration of performance, improving the long term consistency and safety of the components. In attempt to enhance the performance of thermal management, numerous study and investigation have been conducted and various methods have been proposed to reduce the thermal impact on the performance of the electronic device. Virtually all of the heat generated in the electronic device is removed by the heat sink. The manufacturing industries are constantly striving to find low cost, lighter and more thermal conductive material to make efficient heat sinks. The heat sink material selection involves a systematic approach for seeking the best match between the design requirements and the materials attributes. The material selection problems with non-commensurable and conflicting criteria can be resolved by MCDM methods, since they are used for solving conflicting ideas with multiple criteria. The MCDM combined with fuzzy set theory has been used to interpret the linguistic information in accordance with the subjective evaluation and represent the uncertainty in human perceptions involved in heat sink material selection problem in electronic manufacturing industry. The aim of this article is to deal with the selection of suitable heat sink material for thermal management of electronics cooling applications in manufacturing industry.

2. LITERATURE REVIEW

In this section, the significance of heat sink material in thermal management system, evolution of material and MCDM are reviewed.

2.1 Literature review on Heat sink

Micro-channel heat sinks constitute an innovative cooling technology for the removal of a large amount of heat from a small area [1]. Any material can act as a heat sink by increasing its temperature whilst storing thermal energy as sensible heat. However, technical constraints often determine maximum temperatures or mass due to functional and safety requirements limit the amount of sensible heat that can be stored [2]. Research in the field of heat transfer enhancement is still ongoing. Forced convection cooling may become a necessary part of the thermal management of future handheld devices to accommodate increased power dissipation levels [3]; it is one of the most decisive methods of transferring heat from electronic products because it is low-cost, easily implemented, and highly efficient. A common method of increasing heat transfer from an electronic component is to attach a heat sink to it. The heat that is generated by the electronic component is conducted to the heat sink, from which it is transferred out of the system by convection. A proper tuning of heat sink configuration is an effective way to improve the convective air stream over the heat sink surface and subsequently produce significant improvement in heat sink thermal performance [4]. The use of active thermal methods such as miniature centrifugal fans proved to be inefficient due to space, noise levels, high maintenance and additional power consumption [3]. A number of factors used for cooling methodology includes: space, operating environment, heat dissipated, cost of materials and maintenance required [5]. Chen [6] has investigated the heat dissipation performance of the pin-fin heat sinks under uncertainties. Among the various types of cooling systems that have been developed, the plate-fin heat sink is the most widely used because of its simple design and ease of fabrication [7]. Fiedler [8] investigated the energy storage capacity and transient thermal behavior of compact heat sinks enclosed in aluminum cases. Heat sinks contained different cores that improve thermal conduction and/or energy storage capacity.



2.2 Literature review on integrated MCDM methods

The compromise ranking and outranking methods are computationally easy to implement and sounds logical, as it helps the decision maker to choose the best industrial robot from a finite set of alternate robots [2]. Fuzzy sets extend deterministic multi-criteria decision-making methods to deal with uncertainty and imprecision in decision-making [9]. Opricovic and Tzeng [10] have compared the two MCDM methods, VIKOR and TOPSIS by focusing on modeling aggregating function and normalization, in order to reveal and compare the procedural basis of these two MCDM methods. Dagdeviren et al. [11] proposed the systematic evaluation model for the weapon selection process in defense industries to select an optimal weapon among a set of available alternatives with integrated AHP and TOPSIS method under fuzzy environment. Sun [12] has proposed a model to evaluate the performance of global top four notebook computer ODM companies. This study integrated two MCDM methods namely AHP and TOPSIS under fuzzy environment. Chu et al., [13] proposed three MCDM methods, simple average weight TOPSIS and VIKOR to establish objective and measurable patterns to obtain anticipated achievements of knowledge communities through a group-decision comparison. They discovered that TOPSIS and VIKOR methods can be used to highlight innovative idea, academic analysis, and practical appliance value. Sen Liu [14] proposes a multi-attribute group decision-making based scientific decision tool to help firms to judge which cloud computing vendor is more suitable for their need by considering more comprehensive influence factors. Rao [15] applied the improved compromise ranking method to select the apt material for engineering applications. Ang and Tien-Chang [16] proposed a fuzzy MCDM approach to selecting the best-suited tool steel material for specific manufacturing applications such as die design, and jig and fixture design. Material selection is one of the most important activities in the design process.

2.3 Research gap

Based on literature review, several researchers have been done in integrated MCDM methods for numerous applications. But the usage of these integrated MCDM in the selection of heat sink is found inadequate. This article focuses on the development and application of MCDM in heat sink material selection and design challenges providing designer with broader and more versatile tool to optimize device cost, performance and reliability. One of the most challenging problems in real life manufacturing environment is faced in the selection of heat sink material for electronic cooling application. Due to the impressive increase of the power dissipation many engineers do not consider heat sink material to be a feasible solution for the far future of thermal management. Selection of heat sink material involves complex decision variables. This method solves problem in a fuzzy environment since both criteria and weights are vague in nature. Furthermore, vagueness also exists in determining how each criterion impacts the attributes for evaluation. In order to deal with vagueness and uncertainty associated with decision making problem, fuzzy based methods are being used in the present study.

3. Methodology

The following briefly describes several MCDM methods, including fuzzy analytical hierarchy process (FAHP) with VIKOR and TOPSIS.

3.1. FAHP method

In AHP method proposed by Saaty [17], the decision problem is structured hierarchically at different levels with each level consisting of a finite number of elements [18]. Laarhoven and Pedrycz [19] applied fuzzy logic principle. The procedural steps involved in FAHP method are listed below:

Step 1: With the FAHP, the complex MCDM problems are fragmented and arranged in a hierarchical structure similar to a family tree with at least three levels: overall goal of the problem at the top, multi criteria that define criteria in the middle and decision criteria at the bottom.

Step 2: The pair-wise comparison matrix A is fuzzified using the triangular fuzzy number (TFN) $M = (l, m, u)$, where l and u represent lower and upper bound range, respectively, that might exist in the preferences expressed by the decision-maker. The membership functions of the TFN i.e. M_1, M_3, M_5, M_7 , and M_9 are used to represent the assessment from equally preferred (M_1), moderately preferred (M_3), strongly preferred (M_5), very strongly preferred (M_7), and extremely preferred (M_9). This project uses a TFN to express the membership functions of the aforementioned expression values on five scales used for FAHP listed in Table 1.

Table 1: Membership function of Fuzzy numbers

Linguistic scale for importance	Fuzzy number	TFN (L,M,U)	Reciprocal of TFN (1/U,1/M,1/L)
Just equal		(1,1,1)	(1,1,1)
Equal importance	M_1	(1,1,3)	(0.33,1,1)
Weak importance of one over another	M_3	(1,3,5)	(0.2,0.33,1)
Essential or strong importance	M_5	(3,5,7)	(0.14,0.2,0.33)
Very strong importance	M_7	(5,7,9)	(0.11,0.14,0.2)
Extremely preferred	M_9	(7,9,9)	(0.11,0.11,0.14)



Intermediate value between two adjacent judgments	M_2, M_4, M_6, M_8		
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Let $C = \{C_j, j = 1, 2, \dots, n\}$ be a set of criteria. The result of the pair-wise comparison on “n” criteria can be summarized in an $(n \times n)$ evaluation matrix A in which every element $a_{ij} (i, j = 1, 2, \dots, n)$ is the quotient of weights of the criteria, as shown:

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix}, a_{ii} = 1, a_{ji} = \frac{1}{a_{ij}}, a_{ij} \neq 0. \quad (1)$$

Step 3: The mathematical process is used to normalize and find the relative weights of each matrix. The relative weights are given by the right Eigen vector (W) corresponding to the largest Eigen value (λ_{max}), as

$$A \cdot W = \lambda_{max} W \quad (2)$$

It should be noted that the quality of output of FAHP is strictly related to the consistence of the pair-wise comparison judgments. The consistency is defined by the relation between the entries of $A: a_{ij} \times a_{jk} = a_{ik}$. The consistency index (CI) is

$$CI = (\lambda_{max} - n) / (n - 1) \quad (3)$$

Step 4: The pair-wise comparison is normalized and priority vector is computed to weigh the elements of the matrix. The values in this vector sum to 1. The consistency of the subjective input in the pair-wise comparison matrix can be determined by calculating a consistency ratio (CR). In general, a CR having a value less than 0.1 is considered to be good [17]. The CR for each square matrix is obtained from dividing CI values by the random consistency index (RCI) values.

$$CR = CI / RCI \quad (4)$$

The RCI which is obtained from a large number of simulations runs and varies depending on the order of the matrix. Table 2 lists the values of the RCI for matrices of order 1 - 10 obtained by approximating random indices using a sample size of 500. The acceptable CR range varies according to the size of the matrix, that is, 0.05 for a 3x3 matrix, 0.08 for a 4x4 matrix and 0.1 for all larger matrices having $n \geq 5$. If the value of CR is equal to or less than that value, it implies that the evaluation within the matrix is acceptable or indicates a good level of consistency in the comparative judgments represented in that matrix. In contrast, if the value of CR is more than the accepted value, it indicates that inconsistency of judgments within that matrix has occurred and the evaluation process should therefore be reviewed, reconsidered, and improved.

Table 2: Random Consistency Index (RCI)

No	1	2	3	4	5	6	7	8	9	10
RCI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

3.2. TOPSIS method

The TOPSIS was first developed by Hwang and Yoon [20]. It is a relatively simple, fast and a systematic procedure [21]. The procedure of TOPSIS method is as follows:

- Step 1: *Normalization of the evaluation matrix*: The process is used to transform different scales and units among various criteria into common measurable units to allow comparisons across the criteria. Assume f_{ij} to be of the evaluation matrix R of alternative j under evaluation criterion i then an element r_{ij} of the normalized evaluation matrix R can be calculated by many normalization methods to achieve this objective.

$$r_{ij} = \frac{f_{ij}}{\sqrt{\sum_{j=1}^n f_{ij}^2}} \quad j=1, 2, 3, \dots, j, \quad i=1, 2, 3, \dots, n. \quad (5)$$

- Step 2: *Construction of the weighted normalized decision matrix*: The weighted normalized decision matrix can be calculated by multiplying the normalized evaluation matrix r_{ij} with its associated weight w_i to obtain the result

$$V_{ij} = w_i \cdot r_{ij} \quad j=1, 2, \dots, j, \quad i=1, 2, 3, \dots, n. \quad (6)$$

Where w_i is given by $\sum_{i=1}^n w_i = 1$



- Step 3: *Determination of the positive-and negative- ideal solutions*: The positive-ideal solution A^+ indicates the most preferable alternative and the negative-ideal solution A^- indicate the least preferable alternative.

$$A^+ = \{v_1^+, \dots, v_i^+, \dots, v_n^+\} = \{(max_j v_{ij} | i \in I^+), (min_j v_{ij} | i \in I^-)\} \quad (7)$$

$$A^- = \{v_1^-, \dots, v_i^-, \dots, v_n^-\} = \{(min_j v_{ij} | i \in I^+), (max_j v_{ij} | i \in I^-)\} \quad (8)$$

- Step 4: *Calculation of the separation measure*: The separation from the positive- and negative-ideal solutions for each alternative can be measured by the n -criteria Euclidean distance.

$$D_j^+ = \sqrt{\sum_{i=1}^n (v_{ij} - v_i^+)^2} \quad j=1, 2, 3, \dots, j. \quad (9)$$

$$D_j^- = \sqrt{\sum_{i=1}^n (v_{ij} - v_i^-)^2} \quad j=1, 2, 3, \dots, j \quad (10)$$

- Step 5: *Calculation of the relative closeness to the ideal solution*: The relative closeness of the i^{th} alternative with respect to ideal solution A^+ is defined as follows:

$$CC_j^+ = \frac{D_j^-}{(D_j^+ + D_j^-)} \quad j = 1, 2, 3, \dots, j. \quad (11)$$

- Step 6: *Ranking the priority*: A set of alternatives then can be preference ranked according to the descending order of CC_j^+ .

3.3. VIKOR method

The VIKOR method was developed for multi-criteria optimization of complex problems. This method focuses on ranking and selecting from a set of alternatives and determines the compromise solution obtained with the initial weights for a problem with conflicting criteria. Assuming that each alternative is computed according to each criterion function, the compromise ranking is performed by comparing the measure of closeness to the ideal alternative. The various alternatives are denoted as A_1, A_2, \dots, A_m . For alternative A_j , the rating of the i^{th} aspect is denoted by f_{ij} , that is, f_{ij} is the value of i^{th} criterion function for the alternative a_j ; n is the number of criteria. Development of VIKOR is started with the following form of L_p - metric:

$$L_p = \left\{ \sum_{i=1}^n [w_i (f_i^* - f_{ij}) / (f_i^* - f_i^-)]^p \right\}^{1/p} \quad 1 \leq p \leq \infty, j = 1, 2, \dots, j \quad (12)$$

In VIKOR method $L_{1,j}$ (as S_j) and $L_{\infty,j}$ (as R_j) are used to formulate ranking measure. The results are obtained by $\min_j S_j$ is with the maximum group utility ("majority" rule), and the answer obtained by $\min R_j$ is with a minimum individual regret of the "opponent". The compromise ranking algorithm of VIKOR encompasses the following steps:

- Step 1: The purpose of normalizing the performance metrics is to unify the unit of matrix entries. The determination of normalized values of alternatives x_{ij} is the numerical score of alternative j on criterion i . The corresponding normalized value f_{ij} is defined as follows:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^n x_{ij}^2}}, \quad i = 1, 2, \dots, m; \quad j = 1, 2, \dots, n; \quad (13)$$

- Step 2: Determine the best f_i^* and the worst f_i^- values for each criterion functions, $i = 1, 2, \dots, m$

$$f_i^* = \max_j f_{ij}, \quad f_i^- = \min_j f_{ij}. \quad (14)$$

- Step 3: The utility measure and the regret measure for each maintenance alternative are given as:

$$S_j = \frac{\sum_{i=1}^n w_i (f_i^- - f_{ij})}{f_i^- - f_i^*} \quad (15)$$

$$R_j = \left[\frac{w_i (f_i^- - f_{ij})}{f_i^- - f_i^*} \right] \quad (16)$$

Where S_j and R_j represent the utility measure and the regret measure, respectively and w_j the weight of the j^{th} criterion.

- Step 4: Calculate the VIKOR index

$$Q_j = \frac{v(S_j - S^*)}{S^- - S^*} + \frac{(1-v)(R_j - R^*)}{R^- - R^*} \quad (17)$$

Where, $S^* = \min_j S_j$, $S^- = \max_j S_j$, $R^* = \min_j R_j$, $R^- = \max_j R_j$ and v is introduced as weight of the strategy of "the majority of criteria" (or "the maximum group utility"), here $v = 0.5$.

- Step 5: Rank the order of preference.

The alternate with the smallest VIKOR value is determined to be the best solution. Proposed a compromise solution with an alternative ' A^* ', which is ranked the best by the measuring Q (minimum) if the following two conditions are satisfied:

- C1. Acceptable advantage:

$$Q(A'') - Q(A') \geq DQ \quad (18)$$

Where A'' is the alternative with second position in the ranking list by Q ; $DQ = 1/(m - 1)$, and m the number of alternatives.

- C2. Acceptable stability in decision-making:

Alternative A' must be the best ranked by S or R or both. This compromise solution is stable within a decision-making process, which could be "voting by majority rule" (when $v > 0.5$ is needed), or "by consensus" $v \approx 0.5$, or "with veto" ($v < 0.5$). Here, v is the weight of the decision-making strategy "the majority of criteria" (or "the maximum group utility"). If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of the following:

- Alternatives A' and A'' if only condition C2 is not satisfied, or
- Alternatives $A', A'', \dots, A^{(M)}$ if condition C1 is not satisfied; $A^{(M)}$ is determined by the relation $Q(A^{(M)}) - Q(A) < DQ$ for maximum M (the positions of these alternatives are "in closeness").

3.4. Fuzzy set theory

A fuzzy set is a class of objects with grades of membership. It is characterized by a membership function that assigns a grade of membership ranging between 0 and 1 for each object of the class. It can solve real-world problems by providing a wider frame than classic set theory. Zadeh [22] proposed the fuzzy set theory for scientific environment and later it was made available to other fields as well. In our daily life, there are different decision-making problems of diverse intensity, and if the fuzziness of human decision-making is not taken into account, the results can be misleading. Fuzzy decision-making turned out to be a rational approach in handling decision-making that takes into account of human subjectivity. Bellman and Zadeh [23] described the decision making methods in fuzzy environments. The use of fuzzy set theory allows the decision-makers to incorporate uncertain information into decision models [24]. The fuzzy set theory resembles human reasoning with the use of approximate information and certainty to generate decisions and it's a better approach to convert linguistic variables to fuzzy numbers under ambiguous assessments. The fuzzy set theory, which is incorporated with AHP, allows us to have a more accurate description of the decision-making process.

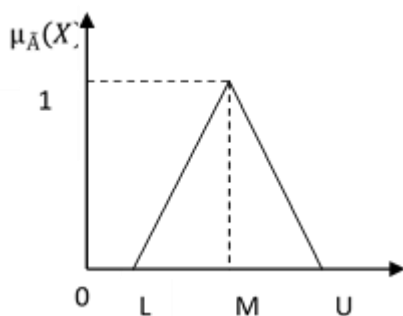


Fig 1: Triangular fuzzy numbers

The uncertain comparison ratios are expressed as fuzzy numbers. It is possible to use different fuzzy numbers according to the situation. In general, triangular and trapezoidal fuzzy numbers are used. In common practice, the triangular form of the membership function is used most often [25,26]. The reason for using a TFN is to be intuitively easy for the decision-makers to use and calculate. In addition, modeling using TFN has proved to be an effective way for formulating decision problems where the information available is subjective and imprecise [27,28]. The evaluation criterion in the judgment matrix and weight vector is represented by TFNs. A fuzzy number is a special fuzzy set $F = \{ (x, \mu_F(x), x \in R) \}$ where x takes its value on the real line $R_1: -\infty < x < +\infty$ and $\mu_F(x)$ is a continuous mapping from R_1 to the close interval $[0, 1]$. A TFN can be denoted as $M = (l, m, \text{ and } u)$ and can be represented as follows:

$$\mu_A(x) = \begin{cases} 0, & x < l, \\ \frac{(x-l)}{(m-l)}, & l \leq x \leq m, \\ \frac{(u-x)}{(u-m)}, & m \leq x \leq u, \\ 0, & x > u \end{cases} \quad (19)$$

According to the nature of TFN, it can be defined as a triplet (l, m, u) . The TFN can be represented as follows:

$\tilde{A} = (L, M, U)$ where L and U represent the fuzzy probability between the lower and upper boundaries of evaluation. The TFN is shown in Figure. 1.

The two fuzzy numbers $\tilde{A}_1 = (L_1, M_1, U_1)$ and $\tilde{A}_2 = (L_2, M_2, U_2)$ are assumed.

$$\tilde{A}_1 \oplus \tilde{A}_2 = (L_1, M_1, U_1) \oplus (L_2, M_2, U_2) = (L_1 + L_2, M_1 + M_2, U_1 + U_2) \quad (20)$$

$$\tilde{A}_1 \otimes \tilde{A}_2 = (L_1, M_1, U_1) \otimes (L_2, M_2, U_2) = (L_1 L_2, M_1 M_2, U_1 U_2) \quad (21)$$



$$\check{A}_1 - \check{A}_2 = (L_1, M_1, U_1) - (L_2, M_2, U_2) = (L_1 - L_2, M_1 - M_2, U_1 - U_2) \quad (22)$$

$$\check{A}_1 \div \check{A}_2 = (L_1, M_1, U_1) \div (L_2, M_2, U_2) = (L_1/L_2, M_1/M_2, U_1/U_2) \quad (23)$$

$$OP; ZZA. \check{A}_1^{-1} = (L_1, M_1, U_1)^{-1} = (1/L_1, 1/M_1, 1/U_1) \quad (24)$$

4. Proposed Methodology

The Fuzzy AHP is used to determine the preference weights of evaluation. Compromise Ranking and Outranking Method is used to improve the gaps between alternatives and conflicting criteria to evaluate the apt material for cooling application.

4.1 Criteria for selecting an optimum material

The following criteria are used for selecting heat sink materials.

- *Thermal conductivity*: It helps in sorting out the best material for manufacturing heat sink. It's a bulk property that describes the ability of a material to transfer heat and it plays a significant role in the cooling of electronics equipment.
- *Density*: The substance is the relationship between the mass of the substance and how much volume it takes up.
- *Specific heat capacity*: The material is the heat required to raise unit mass of substance by one degree of temperature.
- *Melting point*: Melting point of a solid is the temperature at which it changes state from solid to liquid at atmospheric pressure. Fusion or solidification is the heat absorbed when a substance changes its phase from liquid to solid.
- *Thermal Expansion*: It is the tendency of matter to change in shape, area, and volume in response to a change in temperature through heat transfer.
- *Cost*: imprecise cost

4.2. FAHP computations

The decision hierarchy diagram is established using identified evaluation criteria and the alternate materials are shown in Figure 2.

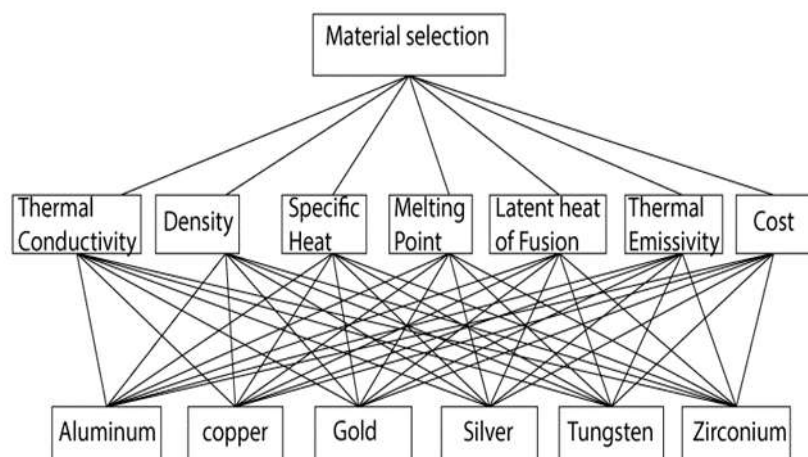


Fig 2: Decision hierarchy of Heat Sink material selection

There are three levels in the decision hierarchy structure of the heat sink material selection process. The selection of optimal available material at the first level, the criteria are at the second level and discover the alternate materials are at the third level of the hierarchy. The weights of the criteria are computed using FAHP method. The relative weights are determined using pair wise comparison of the criteria. Using satty's scale each criterion is compared with other criteria. The fuzzy comparison judgments of the seven criteria with respect to overall objective are shown in Table 3. The geometric mean of the values obtained from the evaluations is computed. A consensus is arrived at on a final pair-wise comparison matrix formed. On the basis of this final comparison matrix, the weights of the criteria are calculated. Then CI and CR are calculated to check whether the importance given to the criteria in the pair-wise comparison matrix is correct. The weights are approved by a decision-making team towards the completion of this phase. The obtained relative weights, CI, and CR of criteria are given in Table 4.



Table 3: Pairwise comparison matrix of criteria

	Thermal Conductivity Btu / (hr-ft-F)	Density (lbs/in)	Specific Heat (Btu/lb/F)	Melting Point (F)	Latent Heat of Fusion (Btu/lb)	Thermal Expansion (in/in/F $\times 10^{-6}$)	Cost / kg
Thermal Conductivity	1,1,1	5,7,9	5,7,9	5,7,9	3,5,7	1,3,5	0.2,0.33,1
Density	0.2,0.14,0.11	1,1,3	0.2,0.33,1	1,3,5	0.2,0.33,1	0.14,0.2,0.33	0.11,0.11,0.14
Specific Heat	0.2,0.14,0.11	5,3,1	1,1,3	1,3,5	0.2,0.33,1	0.14,0.2,0.33	0.11,0.11,0.14
Melting Point	0.2,0.14,0.2	1,0.33,0.2	1,0.33,0.2	1,1,3	0.2,0.33,1	0.11,0.14,0.2	0.11,0.11,0.14
Latent Heat of Fusion	0.33,0.12,0.14	5,3,1	5,3,1	5,3,1	1,1,3	0.2,0.33,1	0.11,0.14,0.2
Thermal Expansion	1,0.33,0.2	7,5,3	7,5,3	9,7,5	5,3,1	1,1,3	0.14,0.2,0.33
Cost	5,3,1	9,9,7	9,9,7	9,9,7	9,7,5	7,5,3	1,1,3

Table 4: Results obtained with FAHP

Criteria	Weights	λ_{max} , CI, RCI	CR
Thermal Conductivity	0.253	$\lambda_{max} = 7.577$ CI = 0.096 RCI = 1.35	0.071
Density	0.038		
Specific Heat	0.046		
Melting Point	0.027		
Latent Heat of Fusion	0.071		
Thermal Expansion	0.149		
Cost	0.416		

4.3. TOPSIS computations

In TOPSIS method normalized values obtained using Eq. 5 is given in Table 5. The data are obtained based on many experiments with the use of trial and error methods. The normalized data are given in Table 6. The FAHP criteria weights are considered to compute the weighted normalized decision matrix using Eq. 6 and the data is given in Table 6. The positive- and negative-ideal solutions are calculated using Eq. 7 and 8 and are given in Table 7. The separation measures of each alternative are computed using Eq. 9 and 10. And these are given in Table 8. The calculation of the relative closeness to the ideal solution is carried out using Eq. 11 and given in Table 8. Finally, according to the relative closeness to the ideal solution value, the ranks are preferred to the materials and the obtained results are given in Table 8.

Table 5: Material Properties

Criteria Material	Thermal Conductivity Btu / (hr-ft-F)	Density (lbs/in)	Specific Heat (Btu/lb/F)	Melting Point (F)	Latent Heat of Fusion (Btu/lb)	Thermal Expansion (in/in/F $\times 10^{-6}$)	Cost / kg
Aluminum	136	0.098	0.24	1220	169	13.1	118
Copper	231	0.322	0.095	1976	91.1	9.8	413
Gold	183	0.698	0.032	1945	29	7.9	266560
Silver	247.87	0.379	0.057	1760	38	10.8	45380
Tungsten	100.53	0.697	0.04	6170	79	2.5	2576
Zirconium	145	0.234	0.067	3350	108	3.2	9039



Table 6: Normalized decision matrix (ND) And Weighted normalized decision matrix (WN)

C M	Thermal Conductivity		Density		Specific Heat		Melting Point		Latent Heat Fusion		Thermal Expansion		Cost / kg	
	ND	WN	ND	WN	ND	WN	ND	WN	ND	WN	ND	WN	WN	ND
Al	0.30	0.07	0.08	0.00	0.86	0.04	0.15	0.01	0.70	0.05	0.60	0.09	0.01	0.01
Cu	0.51	0.13	0.28	0.01	0.34	0.01	0.25	0.01	0.38	0.02	0.45	0.06	0.15	0.06
Au	0.41	0.10	0.61	0.02	0.11	0.01	0.24	0.01	0.12	0.08	0.36	0.05	0.98	0.98
Ag	0.55	0.14	0.33	0.01	0.20	0.01	0.22	0.01	0.15	0.01	0.50	0.07	0.16	0.97
W	0.22	0.05	0.61	0.02	0.14	0.01	0.78	0.02	0.33	0.03	0.11	0.01	0.95	0.39
Zr	0.32	0.08	0.20	0.00	0.24	0.01	0.42	0.01	0.45	0.03	0.14	0.02	0.34	0.38

4.4. VIKOR computations

The VIKOR methodology is also used for selecting heat sink materials. The normalized decision matrix is calculated same as TOPSIS methodology; the resulting normalized decision matrix is shown in Table 6. The best and worst values of the each criterion are calculated by using Eq. 14 and the obtained values are given in Table 7. The values of utility measure and regret measure are calculated using the Eq. 15 and 16 are given in Table 8. Finally, the VIKOR index value is calculated using an Eqn. 17 and are given in Table 8. On the basis of VIKOR index value the ranks are assigned to the materials and the obtained results are presented in Table 8.

Table 7: Positive ideal solution (A*) and Negative ideal solution (A-) of TOPSIS and best value and worst value for VIKOR

Criteria	TOPSIS		VIKOR	
	Positive ideal solution A*	Negative ideal solution A-	f_i	f_i
Thermal Conductivity	0.141	0.057	0.557	0.225
Density	0.003	0.023	0.086	0.615
Specific Heat	0.040	0.005	0.864	0.115
Melting Point	0.021	0.004	0.786	0.155
Latent Heat of Fusion	0.050	0.008	0.707	0.121
Thermal Expansion	0.017	0.090	0.116	0.608
Cost / kg	0.018	0.409	0.044	0.985

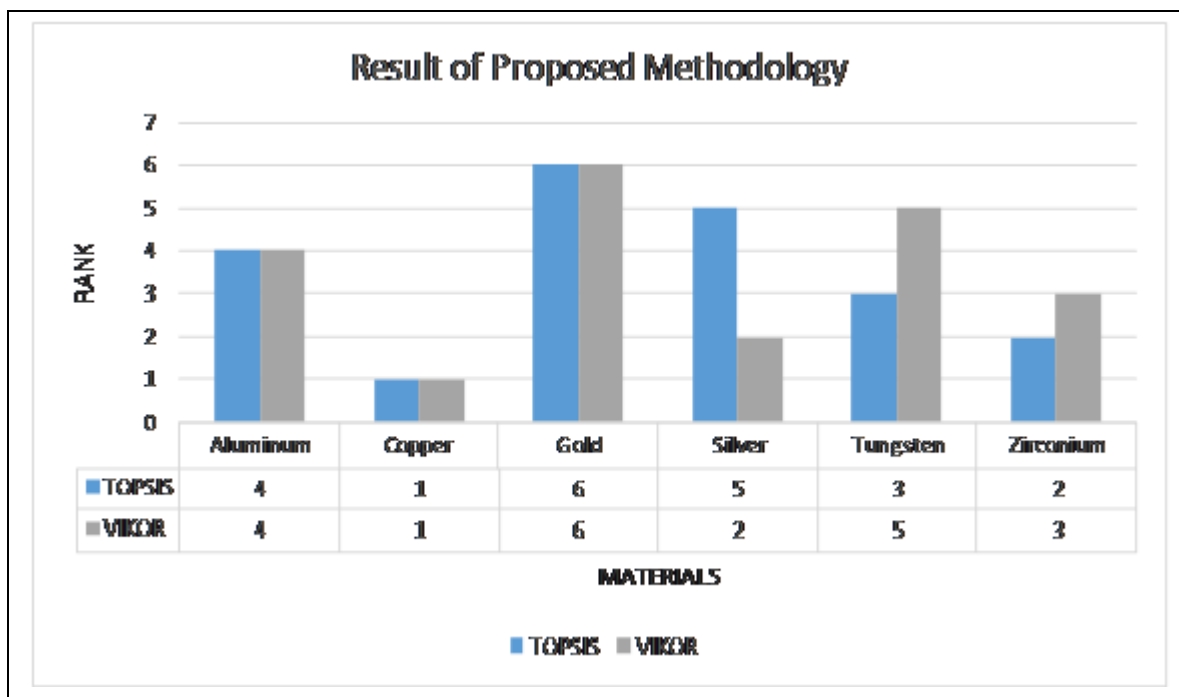
Table 8: TOPSIS AND VIKOR Computation

Alternatives	TOPSIS				VIKOR			
	Dj*	Dj-	CC _j *	Rank	S _i	R _i	Q _i	Rank
Aluminum	0.098	0.414	0.807	4	0.368	0.192	0.260	4
Copper	0.063	0.417	0.867	1	0.240	0.102	0	1
Gold	0.417	0.059	0.124	6	0.781	0.415	1	6
Silver	0.104	0.350	0.770	5	0.335	0.116	0.110	2
Tungsten	0.096	0.413	0.810	3	0.384	0.253	0.373	5
Zirconium	0.070	0.403	0.852	2	0.293	0.176	0.167	3

5. Results and Discussion

The results of the proposed methodology are given in Table 9. The results of the TOPSIS and VIKOR methodologies for selecting the suitable heat sink material for electronic manufacturing industry are described next. The ranking order from TOPSIS is based on closeness coefficient (Copper = 0.867 > Zirconium = 0.852 > Tungsten = 0.810 > Aluminum = 0.807 > Silver = 0.770 > Gold = 0.124). The ranking order of materials obtained from VIKOR is based on VIKOR index (Copper = 0 > Silver = 0.110 > Zirconium = 0.167 > Aluminum = 0.260 > Tungsten = 0.373 > Gold = 1). In VIKOR the aggregate functions are always closest to ideal values. In TOPSIS, the closeness coefficients of materials are nearly closest to ideal solution.

Table 9: Result of Proposed Methodologies



The comparative analysis of these methods shows that VIKOR method had less number of comparisons and valuations. The VIKOR method focuses on ranking and selecting from a set of alternatives in the presence of conflicting criteria. The VIKOR stood out to be the best in reducing computation time and providing desirable result, which was due to elegant method and ease of elegant method and computational easiness. The comparative results show usefulness of VIKOR in providing valuable assistance for material selection.

6. Conclusions

Material selection is becoming more and more important because of the failure rates of electronic equipment proliferate exponentially with an increase in temperature. In the present study shows that the fuzzy based multi criteria decision making methodology makes copper material as an appropriate option for manufacturing heat sink materials for electronic cooling applications. The fetched theoretical results proves that the material is much appropriate for manufacturing industry as it is easily available, low cost and high thermal conductivity for particular applications. The results obtained from other integrated techniques will help the designer better understand the criteria involved in the heat sink material selection process. The concepts of fuzzy set theory and hierarchical decision making framework structure analysis are used to develop a weighted suitability decision matrix to evaluate the weighted suitability of different alternatives versus various criteria.

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