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Selection of coating material for magnesium alloy using Fuzzy AHP-TOPSIS

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Abstract. Magnesium alloys are inherently negative electrochemical potential and are very reactive compared to other engineering metals. They are prone to galvanic corrosion and micro cracks. Various coating materials or Alternatives and the required criteria and sub-criteria for the selection of Alternatives for AZ31B magnesium alloy substrate are identified by means of literature review. Criteria weight and the rank of the alternatives are usually vague and hence uncertainty prevails. The best Alternative from several potential "Candidates", subject to several criteria and sub-criteria, needs to get decided. In such cases, multi criteria decision making (MCDM) techniques help in determining the MOST suitable coating material. This paper concentrates on the selection of coating material for the magnesium alloy substrate. The problem is subjective, uncertain and equivocal in nature. Hence in this study, fuzzy analytic hierarchy process (AHP) is applied to obtain the weights of criteria and technique for order performance by similarity to ideal solutions (TOPSIS) is utilised for ranking the Alternatives.

Keywords. Alternatives; fuzzy analytic hierarchy process (AHP); MCDM; technique for order performance by similarity to ideal solutions (TOPSIS).

1. Introduction

In solving a multi criteria decision making (MCDM) problem, the decision environment affects the decision outcome in which the criteria knowledge is known or uncertain. The decision-making environment can be classified into three types: certainty, uncertainty, and risk [1].

a. Certainty: In this environment, a decision maker (DM) is fully aware of the criteria which can be quantified by means of numbers.
b. Uncertainty: Uncertain environment means, the DM has only less knowledge about the criteria at the time of assignment.
c. Risk: From the historical data, the risk factors can be identified and the necessary steps can be taken.

Zimmerman [2] proposed that fuzzy sets can be used to model uncertainty. AZ31B Magnesium alloy suffers from corrosion attack in spite of its physical deposition treatment on various applications. Hence thermal coating method has been decided to adopt to reduce the intermetallic corrosion. To find the suitable coating material for the alloy, integrated fuzzy analytic hierarchy process–Technique for order performance by similarity to ideal solutions (AHP-TOPSIS) method is being employed.

1.1 *Fuzzy logic*

Unlike usual "True or False" procedure, "Degrees of Truth" is being adopted by fuzzy logic for finding solutions that are uncertain. Fuzzy logic is like crisp logic in many ways. While crisp sets take the values 0 or 1, Fuzzy sets accept input values that range between 0 and 1. Hence the membership function becomes μ_c:X → [0,1] [3]

1.2 *Fuzzy composition*

If we represent P as a fuzzy relation from X to Y and Q from Y to Z respectively, the configuration of P and Q is a Fuzzy relation that is described as

μ_{PoQ} (x_i, z_k) = max (min (μ_P (x_i, y_j), μ_Q (y_j, z and $_k$))).

The triangular function represented by x(a, b, c) has three parameters 'a' (min), 'b' (mid) and 'c' (max) and

*For correspondence

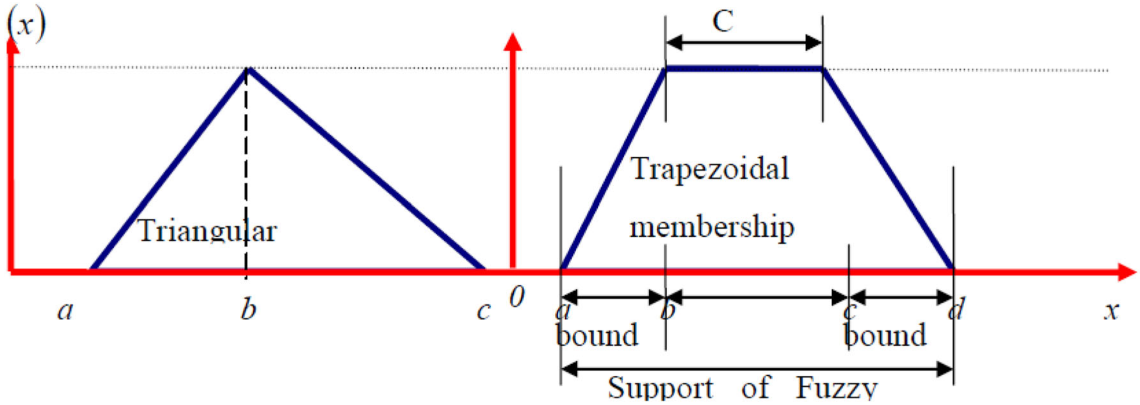

Figure 1. Example of a typical fuzzy membership and properties.

trapezoidal function represented by x(*a*, *b*, *c*, *d*) has four parameters and '*a*' (min), '*b*', '*c*' (essential) and '*d*' (max) that determine the triangular or trapezoidal shape. Figure 1 represents the triangle and trapezoidal functions.

The triangular and trapezoidal functions are described as shown in Eq. (1.1) and Eq. (1.2)

$$\begin{aligned} &0, x \le a \\ &(x-a)/(b-a), x \in (a,b) \\ &(c-x)/(c-b), x \in (b,c) \\ &0, x \ge c \end{aligned} \tag{1.1}$$

$$\begin{aligned} &0, x \le a \\ &(x-a)/(b-a), x \in (a,b) \\ &1, x \in (b,c) \\ &(d-x)/(d-c), x \in (c,d) \end{aligned} \tag{1.2}$$

1.3 *Linguistic variables and linguistic values*

Linguistic variables are those values that can be conveyed in the way of spoken language. Fuzzy sets always represent imprecise terms. Let L, M and H represent three fuzzy sets that have the member ship functions, μ_Z, μ_M, and μ_H respectively. They are referred as less, medium and high. Fuzzy logic is shown in figure 2 [4].

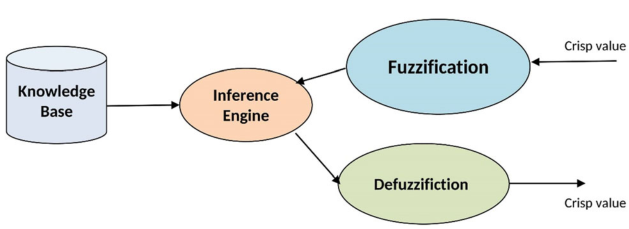

Figure 2. Working steps of Fuzzy Logic.

1.4 *α-Cuts for fuzzy sets*

Fuzzy sets can be decomposed into classical sets of weighted combination by applying the principle of identity of resolution. Alpha (α) cuts connects fuzzy sets and crisp sets. α-cut $^{\alpha}S = \{x/S(x) \ge \alpha\}$ and is inclusive of all the constituents of the universal set X whose membership grades in (S) is either **≥ α.**

2. Method

A critical limitation for the extensive application of magnesium alloys is their susceptibility to corrosion. Many processes like effective addition of alloying elements, control of microstructure through rapid solidification, various surface modification treatments, etc have been adopted to control the corrosion. Among these methods, thermal spraying process on the magnesium alloy substrate seems to enhance the corrosion resistance effectively. Hence for thermal spray process suitable coating material is to be identified for the AZ31B magnesium alloy substrate.

Since coating material selection problem belongs to MCDM category, an integrated Fuzzy AHP-TOPSIS is being employed for the solution procedure. TOPSIS can be used as an integrated tool with any other research techniques. It works best with fuzzy AHP as criteria weights are calculated by AHP technique and final ranks of alternatives are obtained by applying TOPSIS. The steps involved are shown in figure 3 [5].

The assumptions of the model development are given in section 2.1. The fuzzy judgment matrix is constructed in section 2.2 and the fuzzy performance matrix is obtained in section 2.3. Execution of defuzzification in section 2.4, is to develop the crisp performance by the concepts of α-cut method and β-risk index. TOPSIS method is applied to obtain the priority ranking order for each coating material alternative in section 2.5 [6].

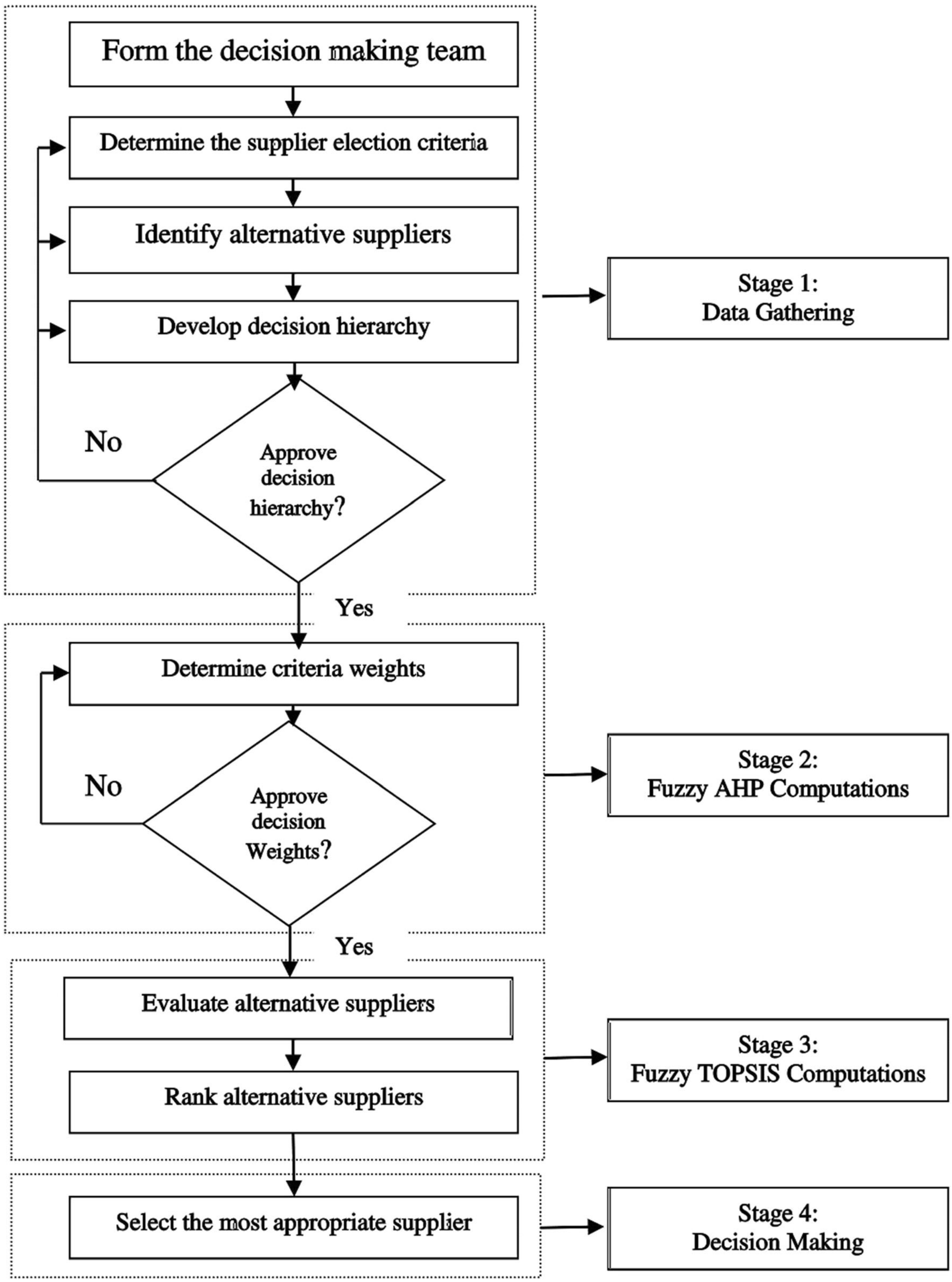

Figure 3. Steps in model development using Fuzzy AHP-TOPSIS integration.

2.1 *Assumptions*

This research work considers the scenario for selection of the suitable coating material from enlisted alternatives. The decision makers have to select the best material from several candidate alternatives that work under the same environmental conditions.

Table 1. Membership function of the triangular fuzzy number.

Fuzzy number	Membership function
$\tilde{1}$	(1, 1, 3)
$\tilde{n}$	(n-2, n, n + 2) for n = 3, 5, 7
$\tilde{9}$	(7, 9, 9)

In the proposed approach, the evaluation matrix and the weight vectors are defined using the triangular fuzzy numbers (TFN). This is useful in final pair wise comparison of criteria using the sub-criteria evaluation score generated primarily. Table 1 shows the TFN for the judgment matrix.

Five scales are detailed below. The membership function of the triangular fuzzy number$\tilde{n}$ is defined as

$$\mu_S(n) = \begin{cases} 1 & \text{If n belongs to S} \\ 0 & \text{If n does not belong to S} \end{cases} \quad (2.1)$$

While executing the fuzzy judgment matrix process, these triangular fuzzy numbers $\tilde{1}$, $\tilde{3}$, $\tilde{5}$, $\tilde{7}$, $\tilde{9}$ represent the following linguistic terms as tabulated in table 2.

2.2 *Formation of fuzzy judgment matrix*

The first step after assumptions that have been made is to determine fuzzy judgment matrix. The steps included are (a) MCDM problem formulation followed by hierarchical structure construction of the problem and (b) Alternative performance determination

2.2a *Construction of work break down structure* After defining all potential alternatives, required criteria and sub-criteria of the problem, a hierarchical structure has to be constructed. Bottom-Up evaluation criteria have been employed and firstly each potential candidate is measured by means of sub-criteria. Sub-score is assigned to each criterion. The following sections explain the calculation procedures [4].

2.2b *Evaluation of tangible sub-criteria* The Fuzzy ratio scales for each tangible sub-criterion is created as shown in table 3.

The following rules are considered:

Table 2. Lexical term and the fuzzy ratio scale.

Linguistic term	Fuzzy ratio scale
Poor	$\tilde{1}$
Satisfactory	$\tilde{3}$
Good	$\tilde{5}$
Very good	$\tilde{7}$
Excellent	$\tilde{9}$

Table 3. Fuzzy ratio scales for a positive tangible sub-criterion.

Scale	Sub-criterion
$\tilde{1}$	The interval value correspondence to 1
$\tilde{3}$	The interval value correspondence to 3
$\tilde{5}$	The interval value correspondence to 5
$\tilde{7}$	The interval value correspondence to 7
$\tilde{9}$	The interval value correspondence to 9

For a positive sub-criterion, a relatively large fuzzy number will be assigned to the relative high interval value.

If it is a negative sub-criterion, a relatively small fuzzy number will be assigned to the relative high Interim Value.

A fuzzy ratio scale represents a sub score ($\tilde{G}_{ijk}$). This means, the Alternative's (A_i) sub score with respect to each sub-criterion (c_{jk}).

2.2c *Evaluation of intangible sub-criteria* Intangible sub-criteria are difficult to calculate objectively. In order to get a consistent and precise outcome from the decision maker's subjective judgments, a group decision method has been proposed so that each decision maker (D_s) can grade individual alternative (A_i) on the same sub-criterion (c_{jk}). By following this procedure, an alternative can acquire several grades $\tilde{G}(_{ijks})$ as shown in table 4.

The above grades are composed in to synthetic sub-score ($\tilde{G}_{ijks}$) by Eqs. (2.2)–(2.6)

$$\tilde{G}_{ijks} = (L_{ijks}, M_{ijks}, U_{ijks}) \quad (2.2)$$

$$L_{ijk} = \min(L_{ijks}), s = 1, 2, \ldots, \quad (2.3)$$

$$M_{ijk} = \sum\nolimits_{s=1}^{t} Mijk \; s = 1, 2, \ldots\ldots, t \quad (2.4)$$

$$U_{ijk} = \max(U_{ijks}), s = 1, 2, \ldots, t \quad (2.5)$$

Table 4. Grades ($\tilde{G}_{ijks}$) of Alternative (Ai) as per DM (Ds) on sub-criterion (C_{jk}).

	Decision maker (D_s)			
Alternative	D_1	D_2	…	D_t
A_1	$\tilde{G}_{1jk1}$	$\tilde{G}_{1jk2}$	…	$\tilde{G}_{1jkt}$
A_2	$\tilde{G}_{2jk1}$	$\tilde{G}_{2jk2}$	…	$\tilde{G}_{2jkt}$
⋮	⋮	⋮	⋮	⋮
A_n	$\tilde{G}_{njk1}$	$\tilde{G}_{njk2}$	…	$\tilde{G}_{1njkt}$

where j = 1, 2,…, m k = 1, 2…, q s = 1, 2…,

Table 5. Sub-scores (G_{ijk}) of Alternative (A_i) with respect to the sub-criteria (c_{jk}).

A_i	C_1		C_2			C_m		
	C_{11}	C_{12}	C_{21}	C_{22}	$\dots$	C_{m1}	$\dots$	C_{mq}
A_1	$\tilde{G}_{111}$	$\tilde{G}_{112}$	$\tilde{G}_{121}$	$\tilde{G}_{122}$	$\cdots$	$\tilde{G}_{1m1}$	$\cdots$	$\tilde{G}_{1mq}$
A_2	$\tilde{G}_{211}$	$\tilde{G}_{212}$	$\tilde{G}_{221}$	$\tilde{G}_{222}$	$\cdots$	$\tilde{G}_{2m1}$	$\cdots$	$\tilde{G}_{2mq}$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
A_n	G_{n11}	G_{n12}	G_{n21}	G_{n22}	$\cdots$	G_{nm1}	$\cdots$	G_{nmq}

$$\tilde{G}(_{ijk}) = \left(L_{ijk}, M_{ijk}, U_{ijk}\right) \tag{2.6}$$

2.2d. *Attaining the fuzzy evaluation matrix* The sub-scores ($\tilde{G}_{ijk}$) of every potential candidate (A_i) related to sub-criteria (c_{jk}) can be seen in table 5.

To obtain the scores $\tilde{G}_{ijk}$ of each alternative related to each criterion, Eq. (2.7) is used.

$$\tilde{G}_{ij} = \sum\nolimits_{k-1}^{q} \tilde{G}_{ijk}, \quad i = 1,2,\ldots,n \quad j = 1,2,\ldots,m \quad k = 1,2,\ldots,q \tag{2.7}$$

From Eq. (2.7), a decision matrix like Eq. (2.8) can be formed.

$$A = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \ldots & C_m \end{array} \\ \begin{pmatrix} \tilde{G}_{11} & \tilde{G}_{12} & \ldots & \tilde{G}_{1m} \\ \tilde{G}_{21} & \tilde{G}_{22} & \ldots & \tilde{G}_{2m} \\ \vdots & \vdots & & \vdots \\ \tilde{G}_{n1} & \tilde{G}_{n2} & \ldots & \tilde{G}_{nm} \end{pmatrix} \end{array} \tag{2.8}$$

Weight vector is to be calculated by means of normalization method. All the criteria (C_j) in Eq. (2.8) get normalized through Eq. (2.9). A fuzzy judgment/evaluation Matrix (A) is obtained in Eq. (2.10) following the normalization

$$\tilde{a}_{ij} = \frac{\tilde{G}_{ij}}{\sqrt{\sum_{i=1}^{n}\left(\tilde{G}_{ij}\right)^2}}, \quad j = 1,2,\ldots,m \tag{2.9}$$

$$A = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \ldots & C_m \end{array} \\ \begin{bmatrix} \tilde{a}_{11} & \tilde{a}_{12} & \ldots & \tilde{a}_{1m} \\ \tilde{a}_{21} & \tilde{a}_{22} & \ldots & \tilde{a}_{2m} \\ \vdots & \vdots & & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & & \tilde{a}_{nm} \end{bmatrix} \end{array} \tag{2.10}$$

where $\tilde{a}_{ij}$ represents the evaluation score of Alternatives (A_i) related to criteria (Cj).

2.3 *Obtaining fuzzy performance matrix*

The collective accomplishment of each coating material with respect to each criterion is formulated in the form of fuzzy performance matrix. It is attained by the multiplication of the fuzzy judgment matrix with its respective fuzzy weight vector. Hence there arises the need for the determination of fuzzy weight vector.

2.3a *Obtaining the fuzzy weight vector* In order to represent the relative importance among criteria, weight vector is to be defined. A pair wise comparison is required to obtain the weight vector.

Satty's scale (table 6) 1–9 was used in table 5 by each decision maker (D_s) to carry out pair wise comparison for all criteria as Eq. (2.11i) and Eq. (2.11ii).

Table 6. Saaty's scale.

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	Any activity is favoured very strongly over another, its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption
1.1–1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities.

$$D = \begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_n \end{array} \begin{array}{c} \begin{array}{ccc} C_1 & C_2 \cdots & C_m \end{array} \\ \left[\begin{array}{ccc} \tilde{b}_{11} & \tilde{b}_{12} \cdots & \tilde{b}_{1m} \\ \tilde{b}_{21} & \tilde{b}_{22} \cdots & \tilde{b}_{2m} \\ \vdots & \vdots & \vdots \\ \tilde{b}_{m1} & \tilde{b}_{m2} & \tilde{b}_{mn} \end{array} \right] \end{array} \tag{2.11i}$$

$$\begin{aligned} \mathbf{b_{jes}} &= \mathbf{b}_{jes}^{-1} \quad \boldsymbol{if\ j \neq e} \\ \mathbf{b_{jes}} &= \mathbf{1} \quad \boldsymbol{if\ j = e} \end{aligned} \tag{2.11ii}$$

where

$$j = 1, 2, \ldots m \quad e = 1, 2, \ldots m$$

where score (b_{jes}) denotes the measurement of relative importance between each criterion by the decision maker D_s.

Thus a comprehensive pair wise comparison matrix (D) is obtained by combining the grades (b_{jes}) of all decision makers. The Eqs. (2.12)–(2.15) represent the combination:

$$U_{je} = \max(U_{jes}), \quad s = 1, 2, \ldots t \quad j = 1, 2, \ldots m \quad e = 1, 2, \ldots m \tag{2.12}$$

$$\mathrm{L_{je}} = \min(\mathrm{b}_{jes}), \quad \mathrm{s} = 1, 2, \ldots \mathrm{t} \quad \mathrm{j} = 1, 2, \ldots \mathrm{m} \quad \mathrm{e} = 1, 2, \ldots \mathrm{m} \tag{2.13}$$

$$M_{je} = \frac{\sum_{s=1}^{t} b_{jes}}{s}, \quad s = 1, 2, \ldots, t \quad j = 1, 2, \ldots, m \quad e = 1, 2, \ldots, m \tag{2.14}$$

$$\tilde{b_{je}} = \left(L_{je}, M_{je}, U_{je}\right), j = 1, 2, \ldots m, \quad e = 1, 2, \ldots m \tag{2.15}$$

where a comprehensive score (b_{je}) denotes the comparative importance among criteria which is represented in triangular fuzzy numbers.

$$\tilde{w_j} = \frac{\sum_{e=1}^{m} \tilde{b_{je}}}{\sum_{j=1}^{m} \sum_{e=1}^{m} \tilde{b_{je}}}, \quad j = 1, 2, \ldots, m \quad e = 1, 2, \ldots, m \tag{2.16}$$

Each criterion has its own importance. The following equation is used to calculate relative weight corresponding to each criterion.

$$D_s = \begin{array}{c} C_1 \\ C_2 \\ \vdots \\ C_m \end{array} \overset{\begin{array}{cccc} C_1 & C_2 & \cdots & C_m \end{array}}{\begin{bmatrix} b_{11s} & b_{12s} & \cdots & b_{1ms} \\ b_{21s} & b_{22s} & \cdots & b_{2ms} \\ \vdots & \vdots & & \vdots \\ b_{m1s} & b_{m2s} & \cdots & b_{mms} \end{bmatrix}} \quad s = 1,2,\ldots t \tag{2.17}$$

The weights of each criterion are solved sequentially by Eq. (2.17) and thereby one obtains a collective fuzzy weight vector (W) as in Eq. (2.18).

$$W = \tilde{W}_1, \tilde{W}_2 \ldots \ldots \ldots, \tilde{W}_m \tag{2.18}$$

2.3b *Synthesization of fuzzy weight vector* The overall evaluation scores of each alternative (A_i) related to each criterion (C_j) are found out in fuzzy judgment matrix. This has been formulated without considering the relative weight between each criterion. The final fuzzy judgment matrix (H) is obtained by multiplying each criterion weight ($\tilde{W}_j$) with the corresponding criterion (C_j). It is shown in Eq. (2.19).

interval performance cut, α, by considering the risk factors also.

2.4a *Calculation of the Interval performance matrix* α-cut method is applied to obtain the interval performance matrix ($^{H}_{\alpha}$). Each fuzzy performance score ($\tilde{h}_{ij}$) is agglomerated with α-cut to constitute an interval $\left[h^{\alpha}_{ijl}, h^{\alpha}_{ijr}\right]$ respectively. The values of $\left[h^{\alpha}_{ijl}, h^{\alpha}_{ijr}\right]$ can be found out by Eqs. (2.20) and (2.21), respectively.

$$h^{\alpha}_{ijl} = L_{ij} + \alpha(M_{ij} - L_{ij}) \tag{2.20}$$

$$h^{\alpha}_{ijr} = U_{ij} - \alpha(U_{ij} - M_{ij}) \tag{2.21}$$

$$H = \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \overset{\begin{array}{cccc} C_1 & C_2 & \cdots & C_m \end{array}}{\begin{bmatrix} \tilde{w}_1 \otimes \tilde{a}_{11} & \tilde{w}_1 \otimes \tilde{a}_{12} & \cdots & \tilde{w}_m \otimes \tilde{a}_{1m} \\ \tilde{w}_1 \otimes \tilde{a}_{21} & \tilde{w}_2 \otimes \tilde{a}_{22} & \cdots & \tilde{w}_m \otimes \tilde{a}_{2m} \\ \vdots & \vdots & & \vdots \\ \tilde{w}_1 \otimes \tilde{a}_{n1} & \tilde{w}_2 \otimes \tilde{a}_{n2} & \cdots & \tilde{w}_m \otimes \tilde{a}_{nm} \end{bmatrix}} \tag{2.19}$$

where $\tilde{h}_{ij}$ denotes the Fuzzy performance score of alternative (A_i) with respect to criterion (C_j) using fuzzy triangular numbers (L_{ij}, U_{ij}, M_{ij}).

2.4 *Formulation of crisp performance matrix*

Crisp performance matrix is obtained by the execution of defuzzification. This is done by the determination of

where $[h^{\alpha}_{ijl}, h^{\alpha}_{ijr}]$ denote the respective left and right points of the Triangle range.

The overall interval performance matrix (H^{α}) can be obtained from Eq. (2.22), shown below. The α value represents the Degree of Confidence of the Experts.

$$H^{\alpha} = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_m \end{array} \\ \begin{bmatrix} [h^{\alpha}_{11l}, h^{\alpha}_{11r}] & [h^{\alpha}_{12l}, h^{\alpha}_{12r}] & \cdots & [h^{\alpha}_{1ml}, h^{\alpha}_{11l}] \\ [h^{\alpha}_{21l}, h^{\alpha}_{21r}] & [h^{\alpha}_{22l}, h^{\alpha}_{22r}] & \cdots & [h^{\alpha}_{2ml}, h^{\alpha}_{2mr}] \\ \vdots & \vdots & & \vdots \\ [h^{\alpha}_{n1l}, h^{\alpha}_{n1r}] & [h^{\alpha}_{n2l}, h^{\alpha}_{n2r}] & \cdots & [h^{\alpha}_{nml}, h^{\alpha}_{nmr}] \end{bmatrix} \end{array} \tag{2.22}$$

Larger the α value, stronger the degree of confidence of the decision maker. Continuous increase in α value shows that there will be a narrow progress in the interval between h^{α}_{ijl} and h^{α}_{ijr}.

Hence it is clear that the evaluation of the decision is always approximate to the most probable value M_{ij} of the triangular fuzzy numbers (L_{ij}, U_{ij}, M_{ij}) [7].

2.4b *Risk index and defuzzification* Decision making process is always accompanied by the risk issues. Hence experts also consider a risk index (β) in dealing with the problem. Defuzzification is executed by compounding the Risk Factor in order to obtain the crisp numbers [8].The overall crisp performance matrix (H^{α}_{β}) can be obtained from Eq. 2.24 through Eq. 2.23.

$$h^{\alpha}_{ij\beta} = \boldsymbol{\beta} h^{\alpha}_{ijr} + (1 - \boldsymbol{\beta}) h^{\alpha}_{ijr}, \quad 0 \le \alpha \le 1; 0 \le \beta \le 1 \tag{2.23}$$

2.5 *Ranking the alternatives using TOPSIS [9]*

Hwang and Yoon [10] framed the MCDM technique, namely, TOPSIS. This structure has been used to finalise the ranking order of the selected coating materials. This approach was employed as its logic is rational and understandable, involves straight computations, permits the pursuit of best potential candidate or alternative for each identified criterion expressed in an analytical form.

TOPSIS is to define two sets of solutions, viz, the most and the least Ideal solution [11]. The positive ideal solution maximises the criteria that are beneficial and minimises those criteria that seem non-beneficial. The negative ideal solution maximises non-beneficial criteria and minimises the beneficial criteria. We have to find the Optimal Alternative which is closest to the solution that is BEST and farthest from the solution that are LEAST. A "*Relative Similarity To The Ideal Solution*" has been considered in TOPSIS to select the BEST potential candidate in order to avoid the similarity between the defined solutions. The TOPSIS model is calculated as follows.

$$H^{\alpha}_{\beta} = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_m \end{array} \\ \begin{bmatrix} h^{\alpha}_{11\beta} & h^{\alpha}_{12\beta} & \cdots & h^{\alpha}_{1m\beta} \\ h^{\alpha}_{12\beta} & h^{\alpha}_{22\beta} & \cdots & h^{\alpha}_{2m\beta} \\ \vdots & \vdots & & \vdots \\ h^{\alpha}_{n1\beta} & h^{\alpha}_{n2\beta} & \cdots & h^{\alpha}_{nm\beta} \end{bmatrix} \end{array} \tag{2.24}$$

where H^{α}_{β} denotes the crisp performance score in which every alternative (A_i) corresponds to all criteria (C_j) under degree of confidence (α) and risk index (β).

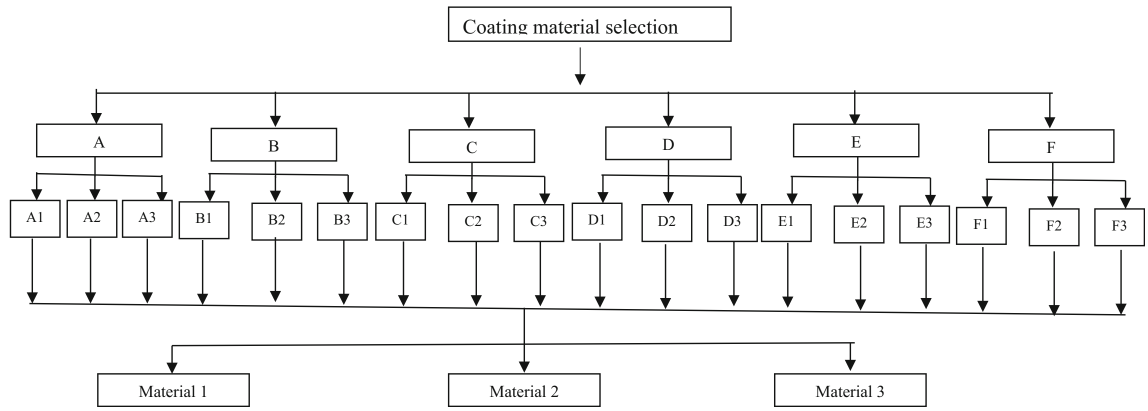

Figure 4. Work break down structure.

(a) Develop a decision matrix (D) for Alternative

$$D = \begin{bmatrix} X_{11} & X_{12} & \dots & X_{1n} \\ X_{21} & X_{22} & \cdots & X_{2n} \\ \vdots & \vdots & \dots & \vdots \\ X_{i1} & X_{i2} & \cdots & X_{in} \\ \vdots & \vdots & \vdots & \vdots \\ X_{m1} & X_{m2} & \cdots & X_{mn} \end{bmatrix} \tag{2.25}$$

where A_i represents the possible alternatives, i = 1, . . ., m;

X_j denotes the criteria corresponding to the performance of alternatives, j = 1,…, n;

and X_{ij} is a crisp value which indicates the performance rating of each alternative A_i with respect to each criterion X_j.

(b) Normalisation of decision matrix

Obtain the normalised decision matrix R (= $[r_{ij}]$) calculated as

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{j=1}^{n} X_{ij}^2}}, \quad j = 1,\ldots,n;\ i = 1,\ldots,m \tag{2.26}$$

where Xij is the performance of alternate i to criterion j.

(c) Obtaining weighted normalized matrix

This matrix can be obtained by multiplying each column of R with its associated weight wj, that has already been calculated by AHP.

Hence, the weighted normalized decision matrix V becomes

$$V = \begin{bmatrix} V_{11} & V_{12} & \dots & V_{1j} & \cdots & V_{1n} \\ V_{21} & V_{22} & \cdots & V_{2j} & \cdots & V_{2n} \\ \vdots & \vdots & \dots & \vdots & \vdots & \vdots \\ V_{i1} & V_{i2} & \cdots & V_{ij} & \cdots & V_{in} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ V_{m1} & V_{m2} & \cdots & V_{mj} & \cdots & V_{mn} \end{bmatrix} = \begin{bmatrix} w_1r_{11} & w_2r_{12} & \dots & w_jr_{1j} & \cdots & w_nr_{1n} \\ w_1r_{21} & w_2r_{22} & \cdots & w_jr_{2j} & \cdots & w_nr_{2n} \\ \vdots & \vdots & \dots & \vdots & \vdots & \vdots \\ w_1r_{i1} & w_2r_{i2} & \cdots & w_jr_{ij} & \cdots & w_nr_{in} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ w_1r_{m1} & w_2r_{m2} & \cdots & w_jr_{mj} & \cdots & w_nr_{mn} \end{bmatrix} \tag{2.27}$$

(d) Determination of the most and least ideal solutions

The following equation can be used to obtain the positive and negative ideal solutions

$$\begin{aligned} A^* &= \{(\max V_{ij}|j \in J), (\min V_{ij}|j \in J'), i = 1,2,\ldots,m\} \\ A^- &= \{(\min V_{ij}|j \in J), (\max V_{ij}|j \in J'), i = 1,2,\ldots,m\} \end{aligned} \tag{2.28}$$

where

$$j = \{j = 1,2,\ldots,n|j \text{ belongs to Benefit Criteria}\}$$
$$j' = \{j = 1,2,\ldots,n|j \text{ belongs to Non - Benefit Criteria}\}$$

(e) Determination of distance between the positive and negative ideal solutions for each defined coating material

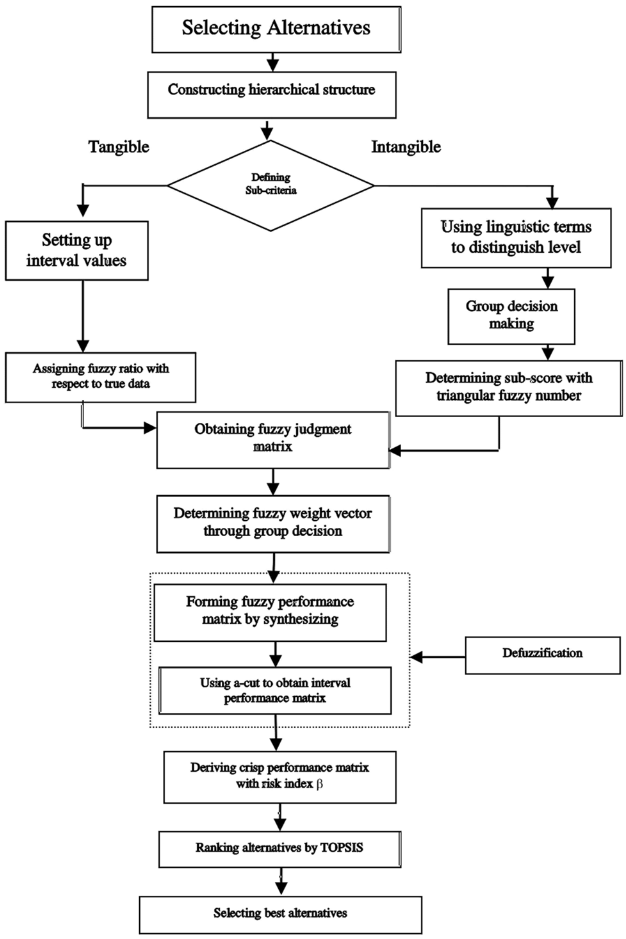

Figure 5. Schematic diagram for the combination of fuzzy AHP and TOPSIS of the proposed model.

$$S_i^* = \sqrt{\sum\nolimits_{=1}^{n} \left(V_{ij} - V_{j*}\right)2} \quad i = 1, 2, \ldots m \qquad (2.29)$$

$$S_i^- = \sqrt{\sum\nolimits_{=1}^{n} \left(V_{ij} - V_{j-}\right)2} \quad i = 1, 2, \ldots m \qquad (2.30)$$

(f) Estimation of the relative closeness to the PIS and NIS

$$C_i^* = \frac{S\,i-}{S\,i* + S\,i-} \quad i = 1, 2, \ldots, m, \qquad (2.31)$$

Where $0 \leq C_i^* \leq 1$ that is, an alternative I is closer to A* as C_i* approaches to 1.

(g) Prioritize or rank the Alternatives

The potential coating materials are ranked with respect to the relative closeness values obtained.

3. Case study

The proposed methodology is applied to any manufacturing industry where the thermal coating technique on magnesium alloy is being employed. The problem is to select the

Table 7. The selection criteria.

Coating material selection criteria	Industrial relevance in material selection	Reference used
Quantitative	Importance of the measurable parameters like hardness, elastic modulus etc are considered	Georgios Athanasopoulos *et al* (2013), Dong-hyunJee. *et al* (2000)
Qualitative	The properties that can be expressed as a linguistic term rather than the crisp numbers	Georgios Athanasopoulos *et al* (2013),Dong-hyunJee. *et al* (2000)
Cost	The economical aspects related to the availability accessibility etc are studied	Rubayetkarim *et al* (2016), L.A.Dobrzanski *et al* (2016)
Quality	The coating material-substrate adherence properties are considered	Rubayetkarim *et al* (2016), L.A.Dobrzanski *et al* (2016)
Coating structure	The material structure of the coating material	p.Kulu and t.pihl *et al* (2001)
Risk factors	The various risk factors are identified prior to the selection	Felix T.S. chan *et al* (2007)

Table 8. The selection sub-criteria.

Coating material selection criteria	Relevance and explanation in material selection	Reference used
Density	The selected coating material should have low density and weight in order to reduce the payload	Georgios Athanasopoulos *et al* (2013) Dong-hyunJee *et al* (2000)
Thermal conductivity	Low thermal conductivity is required for the coating material	Georgios Athanasopoulos *et al* (2013),Dong-hyunJee *et al* (2000)
Thermal expansion coefficient	The coating material with a coefficient of thermal expansion which is higher than that of the substrate to be selected	H.Holleck *et al* (1986)
Hardness	Maximum value of Hardness is advisable	Georgios Athanasopoulos *et al* (2013), Dong-hyunJee *et al* (2000), Aditya chauhan *et al* (2013), Kulu and Pihl (2001), Halilkaliscan (2013) *et al*
Young's modulus	The value of modulus of elasticity should be minimum	Georgios Athanasopoulos *et al* (2013), Dong-hyunJee. *et al* (2000), Aditya Chauhan *et al* (2013), Halilkaliscan (2013) *et al*
Critical load	At normal load, neither fatigue pits nor cracks could be found easily. But as the load increases, chances that the coatings may get either failed or worn through. Hence calculation of crucial load of the substrate is essential.	Georgios Athanasopoulos *et al* (2013)
Yield stress	Stress affects adhesive/and or cohesive properties. It also causes delamination and cracking.	Georgios Athanasopoulos *et al* (2013) Dong-hyunJee . *et al* (2000)
Melting temperature	The coating material should have high melting point to withstand high operating temperatures without melting away	Georgios Athanasopoulos *et al* (2013) Dong-hyunJee. *et al* (2000)
H/E ratio	Lower the ratio, lesser the wear rate.	Halilkaliscan (2013) *et al*, Aditya chauhan *et al* (2013)
H^3/E^2 ratio	Lower the ratio, lesser the wear rate.	Halilkaliscan (2013) *et al*, Aditya chauhan *et al* (2013)
Wear resistance	Minimum wear resistance	Georgios Athanasopoulos *et al* (2013), Halilkaliscan (2013) *et al*,
Coefficient of friction	Minimum coefficient of friction is preferred	Halilkaliscan (2013) *et al*,
Radiation sensitivity	Individual sample testing to be done for the prediction of the radiation sensitivity of the materials	Georgios Athanasopoulos *et al* (2013) Dong-hyunJee. *et al* (2000)
Harden ability	It is the measure of potential of the material or the rate of reduction in hardness after quenching from high temperature	Georgios Athanasopoulos *et al* (2013) Dong-hyunJee. *et al* (2000)

Table 8 continued

Coating material selection criteria	Relevance and explanation in material selection	Reference used
Workability	The workability of the material to be selected from the alternatives should be higher	Georgios Athanasopoulos *et al* (2013) Dong-hyunJee. *et al* (2000)
Appearance	Good quality aesthetic appearance is preferred	Georgios Athanasopoulos *et al* (2013)
Oxidation resistance	Very high oxidation resistance is required for the material to be selected for coating	Georgios Athanasopoulos *et al* (2013) Dong-hyunJee. *et al* (2000), M. SalehiDoolabi (2017) *et al*
Oxidation rate constant	The low rate of oxidation is preferred in the best coating material for thermodynamically stable oxide formers with slow growth rates	NitishVashishtha (2016) *et al*
Impact resistance	Very high impact resistance is required for the material to be selected for coating	p.Kulu and t.pihl (2007) *et al*
Material cost	Most cost effective material to be selected from the alternative selected for coating.	L.A.Dobrzanski *et al* (2016)
Manufacturing cost	The manufacturing cost of the coating material should be economical.	L.A.Dobrzanski *et al* (2016)
Availability	The alternatives that are identified should ensure the availability at the right time at right quantity and quality	MehmetSevkli (2010)
Accessibility	The means to access the selected coated material in an economical and easy manner is very important	MehmetSevkli (2010)
Toxicity	The coating material should be less toxic in nature.	Dong-hyunJee . *et al* (2000)
Adhesion to substrate	The coating material to be selected should have the best adhesiveness to the identified substrate.	Halilkaliscan (2013) *et al*
Bond strength	The quality and durability of bonded joints, coated systems depend on various factors and hence effective quantitative tests to determine the bonding strength are required	Halilkaliscan (2013) *et al*
Durability	Adhesion, abrasion, accelerated light aging, stain resistance etc to be considered for the testing of the durability and the appropriate selection to be made	Maria Oksa.(2011) *et al* (2011)

Table 8 continued

Coating material selection criteria	Relevance and explanation in material selection	Reference used
Brittleness	Although brittle coatings are tolerant to wear and external concentrated loads, they can be subjected to occasional severe stress concentration. Hence testing is essential to select the appropriate materials.	L.A.Dobrzanskiet, al (2016)
Compatibility of the material	There should be chemical, process, mechanical compatibilities between coating material and substrate	Georgios Athanasopoulos *et al* (2013)
Possibility of surface treatment	The coating should support the surface treatment procedures for further modifications	Georgios Athanasopoulos *et al* (2013) Dong-hyunJee. *et al* (2000)
Framed structure	The optimal structure which guarantees high wear resistance.	p.Kulu and t.pihl (2001)
Matrix structure	A structure with a Hard Phase Content $<$ 50% to be preferred in the case of a direct impact	p.Kulu and t.pihl (2001)
Mixed structure	Double cemented matrix structure	p.Kulu and t.pihl (2001)
Aging tendency	Temperature aging increases the stiffness of the substrate. Temperature dependence of the aged materials become less significant than that of the virgin materials	Georgios Athanasopoulos *et al* (2013) Dong-hyunJee. *et al* (2000)
Porosity	Coating hardness and particle temperature should be controlled to reduce the porosity.	Georgios Athanasopoulos *et al* (2013) Dong-hyunJee. *et al* (2000), p.Kulu and t.pihl (2001), vasileios katrasidis (2017) *et al*
Geographical location	Geographical factors should be considered to avoid the risk.	Felix T.S. chan (2007) *et al*
Political stability and Foreign policy	The Foreign policies and the prevailing political conditions and related social factors will affect the coating material procurement.	Felix T.S. chan (2007) *et al*
Exchange rate and Economic position	Money value and the financial position also plays a role in the coating material selection.	Felix T.S. chan (2007) *et al*

Table 9. The sub scores of all candidates with respect to all sub-criteria.

Coating assortment criteria	Coating selection sub-criteria	Evaluation score						
		316 SS	Al2O3-TiO2	Zn/Al-Mn composite	Si_3N_4	NiCrBSi	CoNiCrAlY	Ni-Zn-Cu-P/ Ni-P duplex
Quantitative (QUN)	Density (D)	1	3	1	7	5	5	7
	Thermal conductivity (TC)	3	7	3	9	3	7	9
	Thermal expansion coefficient (TEC)	1	3	5	7	7	3	1
	Hardness (H)	3	7	3	3	9	7	3
	Young's modulus (E)	5	5	3	3	7	3	5
	Elastic recovery (ER)	3	9	9	5	3	7	3
	Critical Load (L)	3	3	3	5	3	5	3
	Yield stress (YS)	3	9	9	3	5	9	9
	Melting temperature (MT)	3	3	3	9	5	3	3
	H/E ratio	3	5	3	9	3	9	9
	H^3/E^2 ratio	7	3	7	5	9	3	3
Qualitative (QUL)	Wear resistance (WR)	5	9	5	3	9	5	3
	Coefficient of friction (COF)	1	9	9	3	5	3	7
	Radiation sensitivity (RS)	3	3	3	9	3	9	5
	Workability (W)	7	5	3	9	7	5	7
	Appearance (AP)	5	3	7	5	3	9	5
	Oxidation resistance (OR)	5	9	5	3	5	5	9
	Oxidation rate constant (ORC)	9	5	7	7	5	5	7
	Impact resistance (IR)	1	9	5	3	3	7	9
	Possibility of surface treatment (ST)	3	5	9	5	7	3	1
Cost (CST)	Material (MTL)	5	5	7	5	9	7	3
	Manufacturing (MN)	3	7	9	3	7	3	5
	Availability (A)	3	3	1	7	3	7	3
	Accessibility (AC)	1	7	3	9	3	5	3
Quality (Q)	Toxicity (T)	3	5	7	5	5	9	9
	Adhesion to substrate (AS)	1	7	9	3	5	3	3
	Bond strength (BS)	3	3	1	7	3	9	9
	Durability (D)	1	7	3	9	9	3	3
	Brittleness (B)	5	3	5	7	9	5	3
	Compatibility of the material (COM)	5	7	3	3	5	3	7
Coating Structure (CS)	Matrix (M)	3	5	3	3	3	9	5
	Framed (F)	1	9	9	5	7	5	7
	Mixed (MX)	3	5	7	5	3	9	5
	Aging tendency (AT)	3	7	9	3	5	5	9
	Porosity (P)	3	3	1	7	5	5	7
Risk Factors (RF)	Geographical location (GL)	1	7	3	9	3	7	9
	Political stability & foreign policy (PF)	3	3	5	7	7	3	1
	Exchange rate & economic position (EP)	1	7	3	3	9	7	3

Table 10. Rating of each coating material with respect to all criteria.

Coating selection sub-criteria	Evaluation score						
	316SS	Al2O3-TiO2	Zn/Al-Mn Composite	Si_3N_4	NiCrBSi	CoNiCrAlY	Ni-Zn-Cu-P/Ni-P duplex
Quantitative (QUN)	(17,35,57)	(35,57,75)	(24,49,67)	(43,65,81)	(37,59,77)	(39,61,79)	(35,55,71)
Qualitative (QUL)	(25,39,55)	(39,57,67)	(35,53,67)	(29,47,61)	(29,47,63)	(33,51,65)	(37,53,67)
Cost (CST)	(6,12,20)	(14,22,30)	(14,20,26)	(16,24,30)	(14,22,28)	(14,22,30)	(6,14,22)
Quality (Q)	(10,18,30)	(20,32,44)	(18,28,38)	(22,34,44)	(24,36,44)	(20,32,40)	(22,34,42)
Coating structure (CS)	(5,13,23)	(19,29,37)	(21,29,35)	(13,23,33)	(23,33,41)	(23,33,39)	(23,33,41)
Risk factors (RF)	(3,5,11)	(11,17,23)	(5,11,17)	(13,19,23)	(13,19,23)	(11,17,23)	(9,13,17)

Table 11. The fuzzy judgment scores of each coating material relating to each criterion.

Coating selection criteria	Evaluation score						
	316SS	Al2O3-TiO2	Zn/Al-Mn composite	Si_3N_4	NiCrBSi	CoNiCrAlY	Ni-Zn-Cu-P/Ni-P duplex
Quantitative (QUN)	(0.09,0.24,0.64)	(0.18,0.4,0.84)	(0.12,0.36,0.75)	(0.22,0.47,0.9)	(0.19,0.44,0.86)	(0.20,0.47,0.88)	(0.18,0.45, 0.79)
Qualitative (QUL)	(0.15,0.3,0.63)	(0.23,0.43,0.77)	(0.21,0.40,0.77)	(0.17,0.36,0.70)	(0.17,0.36,0.73)	(0.2,0.39,0.75)	(0.22,0.4,0.77)
Cost (CST)	(0.08,0.23,0.6)	(0.2,0.42,0.9)	(0.2,0.38,.8)	(0.23,0.46,0.9)	(0.2,.42,0.84)	(0.2,0.42,0.9)	(0.08,0.27,0.66)
Quality (Q)	(0.09,0.22,0.57)	(0.19,0.39,0.84)	(0.17,0.34,0.72)	(0.21,0.41,0.84)	(0.22,0.44,0.84)	(0.19,0.39.0.76)	(0.21,0.41,0.8)
Coating structure (CS)	(0.05,0.18,0.49)	(0.21,0.41,0.78)	(0.23,.41,0.74)	(0.14,0.32,0.7)	(0.25,0.46,0.87)	(0.25,0.46,0.83)	(0.24,0.44,0.81)
Risk factors (RF)	(0.06,0.12,0.42)	(0.21,0.42,0.87)	(0.1,0.27,0.64)	(0.25,0.47,0.87)	(0.25,0.47,0.87)	(0.21,0.42,0.87)	(0.17,0.32,0.64)

Table 12. Four pair wise comparison matrix.

DM 1						
	QUN	QUL	CST	Q	CS	RF
QUN	**1**	1/4	1/3	1/2	1/2	1/5
QUL	**4**	**1**	**1/3**	1/4	1/2	1/4
CST	**3**	**3**	**1**	1/4	1/2	1/3
Q	**2**	**4**	**4**	1	1/5	1/2
CS	**2**	**2**	**2**	5	1	1/4
RF	**5**	**4**	**3**	2	4	1

best coating material among the alternatives identified from literature review and field survey. Minimum porosity, optimal hardness, and optimal structure are the rules to be followed (Kulu 2009) in selection of coating. The process parameters like unmelted particles, roughness, bond strength and inclusion also play a part in the selection. Similarly, the other criteria and sub-criteria that are essential for the best alternative selection are determined. Then the Fuzzy AHP –TOPSIS Integration procedures are adopted in the problem as shown in figure 4 [12].

3.1 *Problem definition*

In view of the studies conducted regarding the properties of AZ31B magnesium alloy which has been coated by means of thermal spray technique, especially high velocity oxy fuel process, the following gaps were identified: [13].

- Micro cracks in the splat intersection with the substrate can occur.
- Poor bonding combination of the applied surface layer to the substrate material.
- Appearance of porosity.
- Distortion of the work piece due to thermal effect.
- Corrosion attack of Mg–Al alloys occurs at α-Mg matrix/ intermetallic interfaces.
- Galvanic corrosion between the substrate and coating is a serious problem.
- Twinning process in microstructure enhances the corrosion. Hence a detailed study of the role of twins is required.
- Structural defects present in the coated surface can accelerate corrosion rate.
  Hence to fill all the aforementioned gaps, a suitable coating material is to be identified for the magnesium alloy.

3.2 *Applying methodology or strategy for the case study [14–16]*

Step 1 Obtaining the fuzzy judgement matrix.

Table 13. Four pair wise comparison matrix.

DM 1I	QUN	QUL	CST	Q	CS	RF
QUN	1	1/5	1/2	1/4	1/3	1/6
QUL	**5**	**1**	**1/4**	1/5	1/2	1/5
CST	**2**	**4**	**1**	1/6	1/2	1/3
Q	**4**	**5**	**6**	1	1/2	1/2
CS	**3**	**2**	**2**	2	1	1/6
RF	**6**	**5**	**3**	2	6	1

Table 14. Four pair wise comparison matrix.

DM 1II	QUN	QUL	CST	Q	CS	RF
QUN	1	1/3	1/2	1/4	1/5	1/6
QUL	**3**	**1**	**1/6**	1/3	1/4	1/5
CST	**2**	**6**	**1**	1/4	1/2	1/3
Q	**4**	**3**	**4**	1	1/6	1/2
CS	**5**	**4**	**2**	6	1	1/4
RF	**6**	**5**	**3**	2	4	1

Table 15. Four pair wise comparison matrix.

DM 1V	QUN	QUL	CST	Q	CS	RF
QUN	1	1/4	1/2	1/5	1/3	1/6
QUL	**4**	**1**	**1/5**	1/3	1/2	1/4
CST	**2**	**5**	**1**	1/4	1/2	1/5
Q	**5**	**3**	**4**	1	1/5	1/2
CS	**3**	**2**	**2**	5	1	1/2
RF	**6**	**4**	**5**	2	2	1

An expert survey was conducted by distributing questionnaire to various industries and based on their collective opinion, criteria and sub-criteria were determined. Thus, 6 criteria and 39 sub-criteria were identified. Criteria are as follows: quantitative (Qut), qualitative (Qul), cost (C), quality (Q), coating structure (CS), and risk factors (R) [17–19].

Sub-criteria selected are: density, thermal conductivity, thermal expansion coefficient, hardness, modulus of elasticity, elastic recovery, ultimate or critical load, yield stress, melting temperature, H/E ratio, H^3/E^2 ratio, material cost, manufacturing cost, availability, accessibility, wear resistance, coefficient of friction, radiation sensitivity, hardenability, workability, appearance, oxidation resistance, oxidation rate constant, impact resistance. toxicity, adhesion to substrate, bond strength, durability, brittleness, compatibility of the materials, possibility of surface treatment, framed structure, matrix nature, mixed, aging tendency, porosity, geographic allocation, political stability and foreign policy, exchange rate and economic position.

Figure 5 shows the hierarchical structure with various criteria and sub-criteria required for evaluating the best coating material.

The explanation of the criteria and the sub-criteria along with the literature is tabulated in table 7 and 8.

Calculation of Fuzzy Judgment Score with respect to each criterion is tabulated in table 9, 10 and 11 respectively.

Table 17. Criteria weights.

Quantitative (QUN)	(0.025, 0.039, 0.06)
Qualitative (QUL)	(0.058, 0.094, 0.146)
Cost (CST)	(0.083, 0.134, 0.219)
Qualitative (QUL)	(0.058, 0.094, 0.146)
Quality (Q)	(0.129, 0.210, 0.356)
Cost (CST)	(0.083, 0.134, 0.219)
Coating Structure (CS)	(0.111, 0.207, 0.365)
Quality (Q)	(0.129, 0.210, 0.356)
Risk Factors (RF)	(0.205, 0.316, 0.494)
Coating Structure (CS)	(0.111, 0.207, 0.365)

4. Results

4.1 *Computation of weight vector*

Fuzzy AHP is used to evaluate the fuzzy weight with the help of pair wise comparison technique. It appears to be difficult to avoid the decision –makers' substantial judgment or assessment. Hence, AHP is employed to solve this situation by a group decision-making technique which is get converted into the fuzzy form. The computations are tabulated in table 12, 13, 14, 15, 16 and 17 respectively [20].

Table 16. Comprehensive Pair Wise Comparison Score

Criteria	QUN	QUL	CST	Q	CS	RF
QUN	(1,1,1)	(0.2,0.26,0.33)	(0.33,0.46,0.5)	(0.2,0.3,0.5)	(0.2,0.34,0.5)	(0.17,0.18,0.2)
QUL	(3,4,5)	(1,1,1)	(0.17,0.24,0.33)	(0.2,0.28,0.33)	(0.25,0.44,0.5)	(0.2,0.23,0.25)
CST	(2,2.25,3)	(3,4.5,6)	(1,1,1)	(0.17,0.23,0.25)	(0.5,0.5,0.5)	(0.2,0.3,0.33)
Q	(2,3.75,5)	(3,3.75,5)	(4,4.5,6)	(1,1,1)	(0.17,0.27,0.5)	(0.5,0.5,0.5)
CS	(2,3.25,5)	(2,2.5,4)	(2,2,2)	(2,4.5,6)	(1,1,1)	(0.17,0.29,0.5)
RF	(5,5.75,6)	(4,4.5,5)	(3,3.5,5)	(2,2,2)	(2,4,6)	(1,1,1)

Table 18. Fuzzy performance score of each coating material related to each criterion.

Coating Selection Criteria	Quantitative (QUN)			Qualitative (QUL)			Cost (CST)			Quality (Q)			Coating structure (CS)			Risk factors (RF)		
316 SS	0.002	0.009	0.038	0.009	0.028	0.093	0.007	0.031	0.131	0.012	0.046	0.203	0.006	0.036	0.165	0.012	0.039	0.206
Al2O3-TiO2	0.005	0.016	0.050	0.013	0.041	0.113	0.016	0.056	0.197	0.024	0.082	0.297	0.022	0.080	0.266	0.042	0.134	0.431
Zn/Al-Mn Composite	0.003	0.014	0.045	0.012	0.038	0.113	0.016	0.051	0.171	0.022	0.071	0.257	0.024	0.080	0.252	0.019	0.87	0.318
Si3N4	0.006	0.018	0.054	0.009	0.034	0.103	0.019	0.061	0.197	0.026	0.087	0.297	0.015	0.063	0.237	0.050	0.150	0.431
NiCrBSi	0.005	0.017	0.051	0.009	0.034	0.106	0.016	0.056	0.184	0.029	0.092	0.297	0.027	0.091	0.295	0.050	0.150	0.431
CoNiCrAlY	0.005	0.018	0.053	0.011	0.036	0.110	0.016	0.056	0.197	0.024	0..082	0.270	0.027	0.091	0.280	0.042	0.134	0.431
Ni-Zn-Cu-P/Ni-P duplex	0.005	0.017	0.047	0.013	0.038	0.113	0.007	0.036	0.144	0.026	0..087	0.284	0.027	0.091	0.295	0.035	0.102	0.318

Table 19. The collective interval performance rate of α-CUT coating material with respect to each criterion.

	Performance score													
Coating assortment criteria	316 SS		Al2O3-TiO2		Zn/Al-Mn composite		Si_3N_4		NiCrBSi		CoNiCrAlY		Ni-Zn-Cu-P/Ni-P duplex	
Quantitative (QUN)	0.008	0.014	0.014	0.021	0.012	0.019	0.016	0.024	0.015	0.022	0.016	0.024	0.015	0.022
Qualitative (QUL)	0.025	0.038	0.037	0.052	0.034	0.049	0.030	0.044	0.030	0.045	0.033	0.047	0.034	0.049
Cost (CST)	0.027	0.046	0.050	0.077	0.046	0.069	0.055	0.081	0.050	0.075	0.050	0.077	0.031	0.052
Quality (Q)	0.041	0.069	0.073	0.114	0.064	0.099	0.078	0.118	0.082	0.045	0.073	0.110	0.078	0.116
Coating structure (CS)	0.031	0.055	0.071	0.108	0.071	0.105	0.056	0.089	0.081	0.121	0.081	0.119	0.081	0.121
Risk factors (RF)	0.035	0.064	0.120	0.178	0.077	0.121	0.135	0.192	0.135	0.192	0.120	0.178	0.092	0.135

Table 20. Comprehensive crisp performance matrix.

	Performance score						
Coating assortment criteria	316SS	Al2O3-TiO2	Zn/Al-Mn Composite	Si3N4	NiCrBSi	CoNiCrAlY	Ni-Zn-Cu-P/Ni-P duplex
Quantitative (QUN)	0.013	0.019	0.017	0.022	0.021	0.022	0.021
Qualitative (QUL)	0.035	0.049	0.046	0.041	0.042	0.045	0.046
Cost (CST)	0.042	0.072	0.064	0.076	0.070	0.072	0.048
Quality (Q)	0.064	0.106	0.092	0.110	0.052	0.103	0.109
Coating structure (CS)	0.050	0.100	0.099	0.083	0.113	0.112	0.113
Risk factors (RF)	0.059	0.167	0.112	0.180	0.180	0.167	0.126

Table 21. Separation measurement and ranking of each coating material.

Coating material	$s_{i,0.2}^{0.85+}$	$s_{i,0.2}^{0.85-}$	Final performance score	Ranking
316SS	0.077	0.127	0.621	**1**
Al2O3-TiO2	0.112	0.076	0.405	**7**
Zn/Al-Mn Composite	0.062	0.094	0.603	**4**
Si3N4	0.044	0.068	0.604	**3**
NiCrBSi	0.065	0.064	0.498	**5**
CoNiCrAlY	0.112	0.082	0.422	**6**
Ni-Zn-Cu-P/Ni-P duplex	0.068	0.105	0.607	**2**

4.2 *Determining the fuzzy performance matrix*

Fuzzy judgement score of each coating material is combined with the weight vector to develop the fuzzy performance score of the respective candidate related to each criterion. The matrix is tabulated in table 18.

4.3 *Decision of interval performance matrix*

The degree of confidence (**α**) of the decision maker and the risk factors are considered. Defuzzification is being carried out. The decision makers have decided to take α value as 0.85. The decision matrix is tabulated in table 19.

4.4 *Obtaining the crisp performance matrix (H_β^α)*

Risk index (β) is applicable here for the defuzzification process. The decision makers have unanimously decided to keep β = 0.2. Table 20 shows the tabulated matrix.

4.5 *Deciding the favourable and detrimental ideal solutions*

Here the TOPSIS technique is being employed for ranking the coating material alternatives. The positive ideal solution (PIS) ($h_{j\beta}^{\alpha+}$) is being considered as the most favourable crisp performance score and the negative ideal solution (NIS) ($h_{j\beta}^{\alpha-}$) is being treated as the least favourable crisp performance score. (Eq. (2.28) calculates both PIS and NIS).

4.6 *Calculation of the separation weigh up of each Alternative from the ideal solutions calculated*

The distance between the positive ideal solution and negative ideal solution can be found out from Eqs (2.29) and (2.30), respectively.

4.7 *Solution of the net performance indicator for each Alternative*

This involves the calculation of "Closeness of Relation" to the ideal solutions for all the coating material alternatives using Eq. (2.31).

4.8 *Prioritization of potential candidates*

Ranking of the seven alternatives has been carried out and the BEST alternative suitable for the substrate was identified and recommended for further processes.

Table 21 shows the final ranking of the selected alternatives using the ideal solution method.

5. Discussion

In this work, MCDM technique has been used to find the best coating material. But studies have shown that the selection of suitable alternative can also be done by using ANOVA by identifying the nonsignificant terms in the coating hardness and Young's modulus models. Predictive modeling approach in conjunction with global optimization procedure can be used to find the optimum combination of coating parameters. The predictions of the response surface methodology models can be compared with the experimental data [21]. Multiobjective optimization of coating criteria can be obtained by means of multiobjective genetic algorithm solver [22]. 316SS coating performed well in some field tests in petroleum plants [23]. A significant increase in wear resistance of coatings is found. It forms a protective passive layer for the base material [24]. This work can be employed with slight modifications using the mathematical models combined with the proposed model.

6. Conclusion

The attribute weights were obtained by Fuzzy AHP and the coating materials were evaluated with TOPSIS. The Fuzzy AHP–TOPSIS combination was made for robust and consistent results. The technique increases the accuracy of decision-making process and saves time to obtain consistent judgement matrices. Advantages of this technique are: material choice established during early-stage of the product development, avoiding later costs and delays, generate idea through a systematic search of materials, apply a repeatable process for validating the results. From the combination, it has been found that 316 SS exhibits better corrosion resistance than the other selected alternatives. The coating will be having low porosity and oxide contents with good hardness. The mean coefficient of thermal expansion of the as-sprayed 316 SS coating will be less. 316 SS coating provides better mechanical support than bare AZ31B substrate. Above all, 316 SS coating material is highly economical and can be used in aggressive environments. In future other multi-criteria methods can be used to select coating material.

List of Symbols

A_i Alternatives
C_j Criteria
α Degree of confidence
β Risk index

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