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Selection of Flywheel Material using Multicriteria Decision Making Fuzzy Topsis

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Abstract

Flywheel is used to store rotational energy and subjected to more stress and strain. The selection of material have a vital role in the fabrication of flywheel. In this paper we are using Multi Criteria Decision-Making Fuzzy Topsis tool for selecting the material for flywheel. As per the literature review best suitable 5 materials (Carbon steel 1065, Alloy steel AISI 4340, Maraging steel 18ni, Alloy steel AISI E9310 and Stainless steel) are taken into consideration for selection and with the help of decision makers 5 material properties (Density, hardness, young's modulus, bulk modulus and poison's ratio) are chosen for analysis. Weightages are provided by 3 decision makers and averaged for analysis. As per the analysis maraging steel 18ni chosen for the fabrication of flywheel and the least material will be carbon steel 1065. In future more suitable materials and properties will be chosen for analysis which will provide more accurate results and the same method can be applied for selection of materials for other applications.

Keywords: Flywheel, Fuzzy Topsis, MCDM

1. Introduction

A fuzzy number is a quantity whose value is imprecise[1]. Any fuzzy number can be defined as a function whose domain is a specified set. In many situations, fuzzy numbers depict the physical world more realistically than any single valued numbers[2]. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is one of the well-known methods in Multiple Attribute Decision-Making (MADM). TOPSIS in a fuzzy environment is where the vagueness and subjectivity are handled with linguistic terms and parameterized by triangular fuzzy numbers[3]. A fuzzy multi-criteria decision analysis method based on the concepts of ideal and anti-ideal points used in mathematical model of linguistic variable. A flywheel is a rotating mechanical device that is used to store rotational energy[4]. Flywheels have a significant moment of inertia and thus resist changes in rotational speed. The amount of energy stored in a flywheel is proportional to the square of its rotational speed. Energy is transferred to a flywheel by applying torque to it, thereby increasing its rotational speed, and hence its stored energy. Conversely, a flywheel releases stored energy by applying torque to a mechanical load, thereby decreasing its rotational speed. The technique for order preference by similarity to ideal solution proposed is one of the well-known methods for classical MCDM[5]. The underlying logic of TOPSIS is to define the ideal solution and negative ideal solution[6]. The positive ideal solution is composed of all best criteria values attainable, and the negative ideal solution is composed of all worst criteria values attainable. This technique can also obtain the gap between the ideal alternative and each alternative, and the ranking order of alternatives, so it can be used widely in many fields. Fuzzy TOPSIS is used to aggregate the ratings and generate an overall performance score for measuring each alternative.

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Table 1. Materials and properties

Sl.no.	Materials	Properties				
		Density	Hardness	Young's modulus	Bulk Modulus	Poisson's ratio
1.	Carbon steel 1065	7.85 g/cm^3	187	210GPa	140 GPa	0.27 - 0.30
2.	Alloy steel AISI 4340	7.85 g/cm^3	217	196GPa	140GPa	0.27 – 0.30
3.	Maraging steel 18NI	8.1 g/cm^3	290	210GPa	160GPa	0.30
4.	Alloy steel AISI E9310	7.85 g/cm^3	241	190GPa	140GPa	0.27 – 0.30
5.	Stainless steel	7.75 g/cm^3	219	190GPa	134GPa	0.26 – 0.27

2. Methodology Adopted

Decide the criteria (properties) for selecting the alternative (materials intended to be used for engineering purpose). The criteria or attributes may be cost, yield strength, density etc. Choose a set of materials alternatives. Measure the performance of each alternative with respect to attributes. Determine weights of importance of the attributes using variance method. Find the weighted normalized decision matrix. Determine the ideal and negative-ideal solution. Calculate the separation measures using n dimensional Euclidean distance. The separation of each alternative from the ideal solution and negative ideal solution is given. Find the relative closeness to the ideal solution. The relative closeness of the alternative a_i with respect to A^* should be find out. Finally as per the result rank materials in the Preference Order.

Table 2. Criteria and alternatives

Criteria	Description	Alternative	Description
C1	Density	A1	Carbon steel 1065
C2	Hardness	A2	Alloy steel AISI 4340
C3	Young's modulus	A3	Maraging steel 18ni
C4	Bulk modulus	A4	Alloy steel AISI E9310
C5	Poisson's ratio	A5	Stainless steel

3. Materials Selection and Properties

For the fabrication of flywheel as per the priority five top most material was chosen as per the literature review, the materials are Carbon steel 1065[7], Alloy steel AISI 4340[8], Maraging steel 18ni[9], Alloy steel AISI E9310[10] and Stainless steel[11]. As per the decision makers, the following properties were chosen, they are Density, hardness, young's modulus, bulk modulus and poison's ratio. The Table 1 shows the properties of all the materials which were chosen for fabricating the flywheel. The Table 2 shows the criteria and alternatives chosen.

4. Results and Discussion

The relative importance weights of five criteria are described using linguistic variables such as low, medium, high etc[12]…Criteria/attribute values and the relative weights are usually characterized by fuzzy numbers[13].

The ratings (criteria values) are also characterized by linguistic variables such as poor, fair, good etc[14]. The importance weight of each criterion can be obtained by either directly assign or indirectly using pair wise comparisons[15]. Here it is suggested that the decision maker's use the linguistic variables (shown in Table 3.)

Table 3. Linguistic variables for criteria and ratings

Criteria			rating		
Linguistic variable	Denotation	Fuzzy number	Linguistic variable	Denotation	Fuzzy number
Very low	VL	(0, 0, 0.1)	Very poor	VP	(0, 0, 1)
Low	L	(0, 0.1, 0.3)	Poor	P	(0, 1, 3)
Medium low	ML	(0.1, 0.3, 0.5)	Medium poor	MP	(1, 3, 5)
Medium	M	(0.3, 0.5, 0.7)	Fair	F	(3, 5, 7)
Medium high	MH	(0.5, 0.7, 0.9)	Medium good	MG	(5, 7, 9)
High	H	(0.7, 0.9 1)	Good	G	(7, 9, 10)
Very high	VH	(0.9, 1, 1)	Very good	VG	(9, 10, 10)

to evaluate the importance of the criteria and ratings of alternative with respect to various criteria[16].

$$w_{ij} = 1/K(w_j^1 + w_j^2 + \ldots + w_j^k)$$
$$x_{ij} = 1/K(x_{ij}^1 + x_{ij}^2 + \ldots + x_{ij}^k)$$

Where,

w_j^k – The importance weight of the k^{th} decision maker.

x_{ij}^k – The rating of the k^{th} decision maker.

+ - It indicates the fuzzy arithmetic summation foundation.

Table 4 and 5 shows Decision maker's opinions on weights of the five criteria and ratings of each alternative wrt criteria.

Table 4. Decision maker's opinions on weights of the five criteria

Criterion	DM1	DM2	DM3	Aggregated fuzzy numbers
C_1	H	H	VH	(0.7, 0.93, 1)
C_2	H	H	H	(0.7, 0.9, 1)
C_3	VH	H	H	(0.7, 0.87, 0.97)
C_4	MH	H	MH	(0.57, 0.77, 0.93)
C_5	M	M	MH	(0.37, 0.57, 0.77)

Table 5. Decision maker's opinions on ratings of each alternative wrt criteria

	DMs				
Alternatives	C_1	C_2	C_3	C_4	C_5
A_1	MG	F	F	MG	G
A_2	MG	F	F	MG	G
A_3	VG	F	MG	MG	VG
A_4	MG	MG	F	MG	VG
A_5	MG	G	F	MG	VG

4.1 Construct the Fuzzy Decision Matrix

This problem which can be concisely expressed in matrix format

$$\begin{array}{c} C_1X_{11} \\ C_2X_{21} \\ D = \\ C_MX_{n1} \end{array} \begin{pmatrix} A_1 & A_{2\ldots\ldots} & A_N \\ X_{12} & \cdots & X_{1n} \\ X_{22} & \cdots & X_{2n} \\ X_{n2} & \cdots & X_{nn} \end{pmatrix}$$

Table 6 shows the final fuzzy decision matrix.

4.2 Construct the Normalized Fuzzy Decision Matrix

The normalized fuzzy decision matrix denoted R is shown as following formula.

$R = \{r_{ij}\}_{m*n,}$

Table 6. Fuzzy decision matrix

(5, 7, 9)	(5, 7, 9)	(9, 10, 10)	(5, 7, 9)	(5, 7, 9)
(3, 5, 7)	(3, 5, 7)	(3, 5, 7)	(5, 7, 9)	(7, 9, 10)
(3, 5, 7)	(3, 5, 7)	(5, 7, 9)	(3, 5, 7)	(3, 5, 7)
(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)
(7,9, 10)	(7,9, 10)	(9,10,10)	(9,10,10)	(9,10,10)

Table 7 shows the final normalized fuzzy decision matrix.

4.3 Construct the Weighted Normalized Fuzzy Decision Matrix

The weighted normalized fuzzy decision matrix (V) is computed by multiplying the weights (w_j) of evaluation criteria with the normalized fuzzy decision matrix (r_{ij}) as,

$V = (v_{ij})_{m*n}$, $i = 1,2,\ldots,m$; $j = 1,2,\ldots,n$;

$V_{ij} = r_{ij}(.)w_j$

Where,

w_j is the relative weight of the jth criterion or attribute

4.4 The Weighted Normalized Fuzzy Decision Matrix (V) by using Equation (6)

Table 8 shows the final weighted normalized fuzzy decision matrix.

$$\tilde{V} = \begin{bmatrix} \tilde{V}_{11} & \tilde{V}_{12} & \tilde{V}_{13} & \cdots & \tilde{V}_{1n} \\ \tilde{V}_{21} & \tilde{V}_{22} & \tilde{V}_{23} & \cdots & \tilde{V}_{2n} \\ \tilde{V}_{31} & \tilde{V}_{32} & \tilde{V}_{33} & \cdots & \tilde{V}_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \tilde{V}_{m1} & \tilde{V}_{m2} & \tilde{V}_{m3} & \cdots & \tilde{V}_{m2} \end{bmatrix}$$

We can define the Fuzzy Positive-Ideal Solution (FPIS, A^+) and Fuzzy Negative Ideal Solution (FNIS, A^-) as:

$A^* = \{v_1^*,\ldots,v_m^*\} = \{(\max v_{ij}|j\ I'),(\min v_{ij}|j$ and

$A^- = \{v_1^-,\ldots,v_m^-\} = \{(\min v_{ij}|j\ I'), (\max v_{ij}|j\ I'')\}$

To find the relative closeness to the ideal solution. The

Table 7. Normalized fuzzy decision matrix (R)

(0.5,0.7,0.9)	(0.5,0.7,0.9)	(0.9,1,1)	(0.5,0.7,0.9)	(0.5,0.7,0.9)
(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0.5,0.7,0.9)	(0.7,0.9,1)
(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0.5,0.7,0.9)	(0.3,0.5,0.7)	(0.3,0.5,0.7)
(0.5,0.7,0.9)	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(0.5,0.7,0.9)
(0.7,0.9,1)	(0.7,0.9,1)	(0.9,1,1)	(0.9,1,1)	(0.9,1,1)

Table 8. Weighted normalized fuzzy decision matrix

(0.38,0.65,0.9)	(0.38,0.65,0.9)	(0.63,0.87,0.97)	(0.38,0.65,0.9)	(0.38,0.65,0.9)
(0.21,0.45,0.7)	(0.21,0.45,0.7)	(0.21,0.45,0.7)	(0.35,0.63,0.9)	(0.49,0.81,1)
(0.21,0.43,0.68)	(0.21,0.43,0.68)	(0.35,0.61,0.87)	(0.21,0.43,0.68)	(0.21,0.43,0.68)
(0.28,0.54,0.84)	(0.28,0.54,0.84)	(0.28,0.54,0.84)	(0.28,0.54,0.84)	(0.28,0.54,0.84)
(0.26,0.51,0.77)	(0.26,0.51,0.77)	(0.33,0.57,0.77)	(0.33,0.57,0.77)	(0.33,0.57,0.77)

relative closeness of the alternative a_i with respect to A^* is defined as: $C_i^* = D_i^- / (D_i^* + D_i^-)$, i=1...,n.

Table 9. Relative closest co efficient of alternatives with rank

Alternatives	$C_i^* = D_i^- / (D_i^* + D_i^-)$	Rank
A_1	0.53	5
A_2	0.54	4
A_3	0.66	1
A_4	0.61	3
A_5	0.65	2

Table 9 shows the final rank of alternatives (materials). As per the ranking Maraging 350(A_3) Steel is selected as the best material for making of an engine flywheel.

5. Conclusion

Here we apply fuzzy TOPSIS method in MCDM for selection of alternate material for making engine flywheels. By applying this TOPSIS method for various types of materials and finally we got Maraging 350 Steel as best among all other materials. The materials are listed as per the ranking. The fuzzy TOPSIS method can be applied for any selection of materials in manufacturing sector. Further studies can be extended by selecting more number of materials and properties.

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