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Material Selection of Gear using Grey TOPSIS and COPRAS-G Method

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Abstract—*Material selection is a lengthy and expensive process for specific engineering purpose. For any engineering application, always more than one material is suitable. Final selection is a compromise that brings some advantage as well as disadvantages. Numerous types of materials are now a day's available to enhance the quality and efficiency of Gear. Picking the dominant one with reference to a Gear is a difficult problem. Various MCDM techniques are now-a-days presented to estimate and rank the offered substitute for a specified engineering application. This paper considers a list of 10 materials of Gear whose performance are estimated based on four selection criteria. The Grey-TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method is then applied to solve this problem statement. Decision matrix has grey data in the Table due to vagueness in the mechanical properties values. The result is then validated by (COPRAS-G) Grey Complex proportional assessment method. Pyrowear emerge out as the best choice for connecting rod material, while Leaded tin bronze is the least preferred choice.*

Keywords*: Gear, MCDM, Grey, TOPSIS, COPRAS, Material selection.*

1. INTRODUCTION

Now-a-days, many conventional materials are being swapped by some innovative materials to encounter the call of weight cut and increase the related properties. Due to competitive environment in the market, manufacturers has to bear superior quality, better efficiency and lower cost developed technology to scribble up components so as to increase their vigorous capability. Selection parameters of materials has complex relationship between them and it make the task of evaluations and assortment of material for a specified use is a difficult one[1].Material selection in engineering design is critical phenomenon. It is well established inconsistent issue because material selection requires knowledge about all the properties namely physical, chemical, mechanical, electrical, magnetic and manufacturing. It also requires the knowledge about the material cost, shape of product, effect of environment, performance characteristic, considering the design and other intricate associations among various selection criteria swaying the entire selection process. To sustenance the material choice decision-making problems, there are several existing method where the anticipations from the materials are generally known

2. LITERATURE REVIEW

Both material and geometric parameters are required for the optimal design of Gears[2].An important difference between the above given factors is that the geometrical factors are often varied freely. On the other hand material properties are related to each other. Jee and Kang [3]. Solve the selection flywheel material by applying technique for order preference by similarity to ideal solution (TOPSIS) method taking into consideration several technical requirements simultaneously. To evaluate the weight of criteria, shannon entropy approach is used. For selection of polymeric-based composite materials, Sapuan developed a knowledge-based system [4]. To choose effective materials, however, it is recommended that individual material properties be grouped into a set of performance indices to reflect particular design goals [5]. The fact is that the individual material properties may interact differently in each application. To rank the finest bargained gear materials considering criteria balances, preference knowledge, data suspicions and incompleteness Milani and Shanian applied ELECTRE III method[6].Chan and Tong [7] offered an combined technique of building an order duo of materials and end-of-life product tactic for material choice using grey relational analysis methodology. Shanian and Savadogo [8] solve a extremely delicate module selection problem involving mutually conflicting design objectives using Electre IS and Electre IV and compared it. Prasenjit Chatterjee and Shankar Chakraborty [9] verifies the offer accessibility and precision of Copras and Aras methods while solving a intricate gear material choice problem. The decision maker has not to aware about the decision making process, yet they can simply apply these methods to assess the substitutes and picked the utmost appropriate material.

3. MATHEMATICAL MODEL

Universal set is denoted by X. X has a grey set G which is defined by its two mappings.

$$G = \begin{cases} \overline{\mu}_G(x): x \to [0,1] \\ \underline{\mu}_G(x): x \to [0,1] \end{cases} \quad (1)$$

Where

$$\overline{\mu}_G(x) \geq \underline{\mu_G}, x \in X, X \in R \quad (2)$$

If only the lower limit of x can be possibly estimated, x is defined as lower limit grey number and if only the upper limit of x can be estimated, x is defined as upper limit grey number. If the lower and upper limits of x can be estimated, x is defined as interval grey number.

The basic operation laws of grey numbers $\otimes X_2 = (\bar{x}_2, \underline{x}_2)$ and $\otimes X_2 = (\bar{x}_2, \underline{x}_2)$ are expressed as follows:

Addition: $\otimes X_1 + \otimes X_2 = [\underline{X_1} + \underline{X_2}, \overline{X_1} + \overline{X_2}]$ (3) (3)

Subtraction: $\otimes X_1 - \otimes X_2 = [\underline{X_1} - \underline{X_2}, \overline{X_1} - \overline{X_2}]$ (4) (4)

Multiplicatin $\otimes X_1 \times \otimes X_2 = \begin{bmatrix} \min\left(\underline{X_1}\underline{X_2}, \underline{X_1}\overline{X_2}, \overline{X_1}\underline{X_2}, \overline{X_1}\overline{X_2}\right), \\ \max\left(\underline{X_1}\underline{X_2}, \underline{X_1}\overline{X_2}, \overline{X_1}\underline{X_2}, \overline{X_1}\overline{X_2}\right) \end{bmatrix}$ (5)

Division: $\otimes X_1 / \otimes X_2 = \left[\underline{X_1}, \overline{X_1}\right] \times \left[\frac{1}{\underline{X_2}}, \frac{1}{\overline{X_2}}\right]$ (6)

3.2 GTOPSIS (Grey Technique of Order Preference by Similarity to Ideal Solution)

Step 1: To select the set of the most important attributes which describes the alternatives.
Step 2: To Construct the decision-making matrix $\otimes X$. Grey number matrix $\otimes X$ can be defined as:

$$\otimes X = \begin{bmatrix} \otimes x11 & \otimes x12 & \cdots & \cdots & \otimes x1n \\ \otimes x21 & \otimes x22 & \cdots & \cdots & \otimes x2n \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \otimes xm1 & \otimes xm2 & \cdots & \cdots & \otimes xmn \end{bmatrix} \quad (7)$$

Where $\otimes X_{ij}$ denotes the grey evaluations of the i-th alternative with respect to the j-th attribute.

Step 3: Calculate the normalized grey decision matrices. The normalized values of maximizing characteristics are calculated as:

$$\otimes x_{ij,b} = \frac{\otimes x_{ij}}{\max_i(b_{ij})} = \left(\frac{w_{ij}}{\max_i(b_{ij})}, \frac{b_{ij}}{\max_i(b_{ij})}\right) \quad (8)$$

Where w_{ij} and b_{ij} are lower and upper values of characteristics, respectively.

The normalized values of minimizing characteristics are calculated as:

$$\otimes x_{ij,w} = 1 - \frac{\otimes x_{ij}}{\max_i(b_{ij})} = \left(1 - \frac{w_{ij}}{\max_i(b_{ij})}, 1 - \frac{b_{ij}}{\max_i(b_{ij})}\right) \quad (9)$$

Step 4: To Determine weights of the criteria q_j.

Step 5: To construct the grey weighted normalized decision-making matrix.

Step 6: For each decision-maker, determine the positive and negative ideal alternatives. The positive ideal alternative A^+, and the negative ideal alternative A^-.

$$A^+ = \left\{\left(\max_i b_{ij} / j \in J\right), \left(\min_i w_{ij} / j \in J\right) / i \in n\right\} \quad (10)$$

$$= \left[x_1^+, x_2^+, \ldots\ldots\ldots, x_m^+\right]$$

$$A^- = \left\{\left(\min_i w_{ij} / j \in J\right), \left(\max_i b_{ij} / j \in J'\right) / i \in n\right\} \quad (11)$$

$$= \left[x_1^-, x_2^-, \ldots\ldots\ldots, x_m^-\right]$$

Step 7:Calculate the separation measure from the positive and negative ideal alternatives, d_i^+ and d_i^-, for the group.

$$d_i^+ = \sqrt{\frac{1}{2}\sum_{j=1}^{m} q_j \{(x_j^+ - w_{ij})^2 + (x_j^+ - b_{ij})^2\}} \quad (12)$$

$$d_i^- = \sqrt{\frac{1}{2}\sum_{j=1}^{m} q_j \{(x_j^- - w_{ij})^2 + (x_j^- - b_{ij})^2\}} \quad (13)$$

Step 8: To Calculate the relative closeness c_i^+ to the positive ideal alternative for the group. The collection of relative closeness for the i[th] alternative with respect to the positive ideal alternative for the group can be expressed as:

$$ci^+ = \frac{di^+}{di^+ + di^-} \quad (14)$$

Where $0 \leq c_i^+ \leq 1$, the larger the index value is, the better the evaluation of alternative will be.

Step 9: Rank the liking imperative. A set of alternatives now can be ranked by the sliding order of the value of c_i^+.

3.3 G COPRAS (Complex proportional assessment)

Step 1: For describing the alternative, select the most important criteria.

Step 2: Decision matrix developed by expressing the criteria values in intervals.

$$\otimes X = \begin{bmatrix} \otimes x11 & \otimes x12 & \cdots & \cdots & \otimes x1n \\ \otimes x21 & \otimes x22 & \cdots & \cdots & \otimes x2n \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \otimes xm1 & \otimes xm2 & \cdots & \cdots & \otimes xmn \end{bmatrix} \quad (15)$$

Where $\otimes x_{ij}$ denotes the grey evaluations of the i-th alternative with respect to the j-th attribute. he value of xij is determined by $\otimes x_{ij}$ (lower limit) and $\otimes b_{ij}$ (upper limit).

Step 3: Normalize the decision matrix, $\otimes X$ using the following equations. Eq.(16) is used for x_{ij} values, whereas, Eq.(17)is applied for b_{ij} values.

$$\otimes \overline{X} = [\bar{x}_{ij}]_{m\times n} = \frac{2x_{ij}}{[\sum_{j=1}^{n} x_{ij} + \sum_{j=1}^{n} b_{ij}]} \quad (16)$$

$$\otimes \overline{X} = [\bar{b}_{ij}]_{m\times n} = \frac{2b_{ij}}{[\sum_{j=1}^{n} x_{ij} + \sum_{j=1}^{n} b_{ij}]} \quad (17)$$

Step 4: Shannon Entropy method used to calculate the criteria weight..

Step 5: Determine the weighted normalized decision matrix, $\otimes \overline{\overline{X}}$ using the following equations:

$$\otimes \overline{\overline{X}} = [\overline{\overline{x_{ij}}}]_{m\times n} = \overline{x_{ij}} \times w_j \quad (18)$$

$$\otimes \overline{\overline{X}} = [\overline{\overline{b_{ij}}}]_{m\times n} = \overline{b_{ij}} \times w_j \quad (19)$$

(i=1,2,3…..m; j=1,2,3….n)

where w_j is the weight of jth criterion.

Step 6: For beneficial criteria and non-beneficial criteria Weighted mean normalized sums for all the alternatives is calculated.

$$P_i = \frac{1}{2}\sum_{j=1}^{k} (\overline{\overline{x_{ij}}} + \overline{\overline{b_{ij}}}) \quad (20)$$

$$R_i = \frac{1}{2}\sum_{j=k+1}^{n} (\overline{\overline{x_{ij}}} + \overline{\overline{b_{ij}}}) \quad (21)$$

Where P_i and R_i are the weighted mean normalized sums for the beneficial and non-beneficial criteria respectively for ith alternative, and k is the number of beneficial criteria.

Step 7: Determine the minimum value of R_i.

$$R_{min} = \min R_i \quad (i=1,2,3\ldots..,m) \quad (22)$$

Step 8: Priorities of the candidate alternatives are calculated based on Q_i values. Candidate having greater value of Q_i has upper priority in the alternative. The degree of agreement attained by that substitute shown by the relative significance of an alternative. The highest relative significance value (Q_{max}) for the alternative is the best choice among the feasible candidates.

The relative significance (Q_i) of ith alternative is obtained as below:

$$Q_i = P_i + \frac{R_{min} \sum_{i=1}^{m} R_i}{R_i \sum_{i=1}^{m} (R_{min} / R_i)} \quad (23)$$

Step 9: Determine the maximum relative significance value.

$$Q_{max} = \max Q_i \quad (i=1,2,3\ldots,m) \quad (24)$$

Step 10: The quantitative utility (U_i) for ith alternative is calculated. The utility value of a substitute is openly connected with its relative significance value (Q_i).By comparing the priorities of all the alternative, the ranking of the candidate options is determined with the best one and is expressed as follows:

$$U_i = [\frac{Q_i}{Q_{max}}] \times 100\ \% \quad (25)$$

4. ILLUSTRATIVE EXAMPLE

This example deals with the selection of most appropriate material for Gear transmitting the power. Material with high temper resistance are preferred for selection. This problem consider four criteria namely Density, Young's Modulus, Tensile Yield strength, Poisson ratio, while selecting the most suitable material. And 10 alternative namely Plain carbon steel (AISI/SAE 1045) (A_1), Among the four criteria density, Young's modulus, Tensile yield strength are beneficial attribute where higher values are desirable; on the other hand Poisson ratio is considered as non-beneficial attribute where lower values is desirable

Table 1: Initial decision Matrix for Gear Material

Alt.	Density	Young's Modulus	Tensile Yield Strength	Poisson's ratio
A1	7830	210	310	0.29
A2	7850	200	310	0.29
A3	7850	210	470	0.29
A4	7860	207	655	0.29
A5	7080	158	862	0.25
A6	7800	190	965	0.30
A7	7700	117	820	0.34
A8	8280	117	460	0.34
A9	8800	117	140	0.34
A10	7450	110	205	0.31

4.1 Grey TOPSIS Method Calculations

The problem statement calculated using Grey TOPSIS Method give Pyrowear 53 as the best alternative for Gear. The decision matrix, as shown in Table 1 is normalized using Eq. (2),which is shown in Table 2.Shannon Entropy method used for determining the criteria weight, the criteria weight are determined as WD=0.0081,WY=0.182, WT=0.788, WP=0.0244. The positive-ideal and negative-ideal solutions have been obtained from the following equations and shown in Table 2. Separations between each alternative and their relative closeness are evaluated from Eq. and shown in Table 3.According to the result of Table 3relative closeness are evaluated from Eq. and shown in Table3 .According to the result of Table 3, Pyrowear 53 (UNS K71040) is the best selected material for gear, while leaded tin bronze (UNS C92500) is the worst alternative

Table 2: normalized decision matrix with positive and negative ideal values

Materia l	**Density**		**Young's Modulus**		**Tensile Yield Strength**		**Poisson's ratio**	
	min	max	min	max	min	max	min	max
A1	0.59	0.89	0.67	1.00	0.21	0.32	0.43	0.15
A2	0.59	0.89	0.63	0.95	0.21	0.32	0.43	0.15
A3	0.59	0.89	0.67	1.00	0.32	0.49	0.43	0.15
A4	0.60	0.89	0.66	0.99	0.45	0.68	0.43	0.15
A5	0.54	0.80	0.50	0.75	0.60	0.89	0.51	0.26
A6	0.59	0.89	0.60	0.90	0.67	1.00	0.41	0.12
A7	0.58	0.88	0.37	0.56	0.57	0.85	0.33	0.00
A8	0.63	0.94	0.37	0.56	0.32	0.48	0.33	0.00
A9	0.67	1.00	0.37	0.56	0.10	0.15	0.33	0.00
A10	0.56	0.85	0.35	0.52	0.14	0.21	0.39	0.09
A^+	1.00		1.00		1.00		0.51	
A^-	0.54		0.35		0.1		0.00	

Table 3: Ranking

Material	**d^+**	**d^-**	**C^+**	**Rank**
A1	**0.66163**	**0.27394**	**0.29281**	**7**
A2	**0.66330**	**0.26053**	**0.28201**	**8**
A3	**0.54437**	**0.36087**	**0.39865**	**5**
A4	**0.41524**	**0.48042**	**0.53639**	**4**
A5	**0.31908**	**0.60472**	**0.65460**	**2**
A6	**0.24837**	**0.69678**	**0.73722**	**1**
A7	**0.37241**	**0.56383**	**0.60223**	**3**
A8	**0.58883**	**0.28988**	**0.32989**	**6**
A9	**0.81522**	**0.09538**	**0.10474**	**10**
A10	**0.77215**	**0.10667**	**0.12138**	**9**

4.2 Grey COPRAS method Calculations

The problem statement calculated using Grey TOPSIS Method give Pyrowear 53 as the best alternative for Gear. The decision matrix, as shown in Table 1 is normalized using Eq. (2),which is shown in Table 2.Shannon Entropy method used for determining the criteria weight, the criteria weight are determined as WD=0.0081,WY=0.182, WT=0.788, WP=0.0244. The positive-ideal and negative-ideal solutions have been obtained from the following equations and shown in Table 2. Separations between each alternative and their relative closeness are evaluated from Eq. and shown in Table 3. According to the result of Table 3, Pyrowear 53 (UNS K71040) is the best selected material for gear, while leaded tin bronze (UNS C92500) is the worst alternativeis shown in Table 4 and 5.the worst material according to Grey COPRAS is Aluminum Bronze (UNS C95400).

Table 5: normalized decision matrix

Material/Alternative	**Density**		**Young's Modulus**		**Tensile Yield Strength**		**Poisson's ratio**	
	Min	max	min	max	min	max	min	max
A1	0.0006	0.0010	0.0187	0.0280	0.0376	0.0564	0.0017	0.0026
A2	0.0006	0.0010	0.0178	0.0267	0.0376	0.0564	0.0017	0.0026
A3	0.0006	0.0010	0.0187	0.0280	0.0570	0.0855	0.0017	0.0026
A4	0.0006	0.0010	0.0184	0.0276	0.0794	0.1191	0.0017	0.0026
A5	0.0006	0.0009	0.0141	0.0211	0.1045	0.1568	0.0015	0.0022
A6	0.0006	0.0010	0.0169	0.0254	0.1170	0.1755	0.0018	0.0027
A7	0.0006	0.0010	0.0104	0.0156	0.0994	0.1491	0.0020	0.0030
A8	0.0007	0.0010	0.0104	0.0156	0.0558	0.0837	0.0020	0.0030

A9	0.0007	0.0011	0.0104	0.0156	0.0170	0.0255	0.0020	0.0030
A10	0.0006	0.0009	0.0098	0.0147	0.0249	0.0373	0.0018	0.0027

Table 6: Pi, Ri , Qi, Ui Values

Material	Pi	Ri	Qi	Ui	Rank
A1	0.0711	0.0021	0.0713	79.066	6
A2	0.0700	0.0021	0.0702	77.884	7
A3	0.0954	0.0021	0.0956	85.027	4
A4	0.1231	0.0021	0.1233	91.515	3
A5	0.1489	0.0018	0.1492	94.479	2
A6	0.1682	0.0022	0.1684	100.000	1
A7	0.1381	0.0025	0.1382	82.955	5
A8	0.0836	0.0025	0.0837	71.173	8
A9	0.0351	0.0025	0.0353	60.712	9
A10	0.0441	0.0023	0.0443	60.481	10

5. CONCLUSION

The illustrative example shows the applicability, ability and exactness of both the Grey TOPSIS and Grey COPRAS Method, while solving intricate material choice problems. The best material chosen for Gear is Pyrowear alloy 53 (UNS K71040).It is a carburizing steel possessing good temperature resistance and high case hot hardness while maintaining high core impact strength and fracture toughness. Due to metal to metal contact between the gear during the power transmission, it creates high temperature due to rubbing action. So,the material with high temper resistance like Pyrowear is suitable for Gear construction.

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