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Materials Selection Method Combined with Different MADM Methods

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Abstract: Materials selection is a multiple attribute decision making (MADM) problem. A lot of MADM methods are applicable to materials selection, and it may produce considerable differences between the results of materials selection. But it is unknown which MADM method is better. So it is desirable to decide reasonable final result of materials selection in consideration of the individual results from different MADM methods. In this paper, materials selection method combined with different MADM methods is proposed. The method is based on final ranks of alternative materials, where the final ranks are determined from the ranks of the alternative materials using different MADM methods. This method is applied to select optimal magnesium alloy material for automobile wheels. This method may be widely used to select optimal material in engineering practice.

Keywords: Materials selection, MADM, final rank index, final rank, membership degree, magnesium alloy.

1 Introduction

Materials selection is a multiple attribute decision making (MADM) problem that materials designers and engineers have to select optimal material to achieve a good properties from two or more alternative materials on the basis of two or more attributes [Khorshidi and Hassani (2013); Zafarani, Hassani and Bagherpour (2014); Çalıskan (2013)]. A lot of MADM methods have been reported in the literature. These methods include simple additive weighted (SAW) method, weighted product method (WPM), elimination and et choice translating reality (ELECTRE) method, analytic hierarchy process (AHP), technique for order preference by similarity to ideal solution (TOPSIS) method, VIse Kriterijumska Optimizacija Kompromisno Resenje (VIKOR) method, preference selection index (PSI) method, preference ranking organization method for enrichment evaluations (PROMETHEE), grey relational analysis (GRA), etc.

These MADM methods have been widely used in materials selection problems.

AL-Oqla et al. [AL-Oqla, Sapuan, Ishak et al. (2015)] applied AHP method and TOPSIS method to select appropriate reinforcement condition for natural fiber composites. Asodariya et al. [Asodariya, Patel, Babariya et al. (2018)] used the AHP method, entropy method, COPRAS and TOPSIS to optimize the design of flywheel regarding to the manufacturing

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aspects. The AHP and entropy methods were used to select appropriate subjective and objective weight criterion respectively while the COPRAS and TOPSIS were applied for the selection procedure for the optimal alternative among the several materials for flywheel. Finally, definitive response from MADM was used for non-classical algorithm namely as genetic algorithm (GA) presents for weight optimization of flywheel design with respect to specified set of constraints. Bai et al. [Bai, Hua, Elwert et al. (2018)] proposed a multi-criteria evaluation system that enables decision-makers to quantitatively analyze the comprehensive effectiveness of application of cutting fluid in their granite production lines. The decision algorithm was designed based on the integration of two distinctive MADM techniques: AHP approach was used to determine the weights of each indicator, and the TOPSIS technique was applied to obtain the prioritization of alternative cutting fluids. Çalıskan [Çalıskan (2013)] applied three MADM methods (EXPROM2, TOPSIS and VIKOR) to select optimal boron based tribological coating material with high wear resistance and adhesion to substrate. Çalıskan et al. [Çalıskan, Kursuncu, Kurbanoglu et al. (2013)] applied decision models including EXPROM2, TOPSIS and VIKOR methods to select best material for the tool holder used in hard milling. Deshmukh et al. [Deshmukh and Angira (2019)] utilized three material selection methodologies to select the most promising material for switching structure of RF-MEMS shunt capacitive switches. The Ashby, TOPSIS and VIKOR methods were used to select the best material. The material was selected such that RF-MEMS capacitive switches had low pull-in voltage, low RF loss, high thermal conductivity and maximum displacement of the beam. For this purpose, the concerned material indices were as follows: low value of Young's modulus, low electrical resistivity, high thermal conductivity and high fracture strength. Elevli et al. [Elevli and Ozturk (2019)] applied multi-criteria decision making (MCDM) approach to assess and evaluate the heavy metals (Cr, Mn, Co, Ni, Cu, Zn, As, Cd, Pb and Hg) pollution in Dilovasi region (one of the largest industrial area in Turkey). The heavy metal contents of 10 different locations were evaluated and these locations were ranked according to their metal contents by using PROMETHEE-GAIA method. PROMETHEE method was used to rank the locations according to their heavy metal content and GAIA (Geometrical Analysis for Interactive Aid) method was used to analyze and show the relations between alternatives (locations) and criteria (heavy metals). Patel et al. [Patel, Patel and Maniya (2018)] applied PSI method for selection of optimal process parameters of fused deposition modeling (FDM) for polylactic acid material. Karande et al. [Karande, Gauri and Chakraborty (2013)] proposed utility concept and desirability function approaches to solve four material selection problems; gear material selection for high speed and high stress applications, material selection for load wagon walls, material selection problem for high speed naval craft and insulation material for computer cables. Khorshidi et al. [Khorshidi and Hassani (2013)] applied TOPSIS and PSI methods to select Al-SiC powder metallurgy composite with a desirable combination of strength and workability. Khorshidi et al. [Khorshidi, Hassani, Rauof et al. (2013)] applied TOPSIS and fuzzy TOPSIS method to select optimal refinement condition to achieve maximum tensile properties of Al-15%Mg2Si composite. Kumar et al. [Kumar and Suman (2014)] applied some MADM methods (SAW, WPM, AHP, Multiplicative AHP, TOPSIS, Modified TOPSIS) to select magnesium alloy material used in automotive wheel applications. Mansor et al. [Mansor, Sapuan, Zainudin et al. (2013)] applied AHP method to select most suitable natural fiber to be hybridized with glass fiber

reinforced polymer composites for the design of a passenger vehicle center lever parking brake component. Peng et al. [Peng and Xiao (2013)] applied PROMETHEE method combined with analytic network process (ANP) to select best material for a journal bearing. Srinivasan et al. [Srinivasan, Chand, Kannan et al. (2018)] used Taguchi method, GRA and TOPSIS to optimize the welding parameters of gas tungsten arc welding of 15CDV6 steel. Experiments based on Taguchi's L9 orthogonal array were carried out. The input parameters such as current, voltage, travel speed were considered for joining 15CDV6 plates of thickness 3.7 mm. Aftermath, the welds were subjected to post weld heat treatment. The performance characteristics such as bead width, reinforcement, tensile strength, hardness and depth of penetration of the welds were also measured. GRA and TOPSIS were used for identifying the optimized input parameters. Teraiya et al. [Teraiya, Jariwala, Patel et al. (2018)] investigated the applicability and the impact of some primary MADM technique for the material selection of the connecting rod. The objective weighting criteria (Entropy) and subjective weighting criteria (AHP) were applied with some primary MADM techniques like TOPSIS, COPRAS, MOORA, VIKOR and ARAS to find the definite response across the various connecting rod materials. Zafarani et al. [Zafarani, Hassani and Bagherpour (2014)] applied AHP method to select Al-SiC composite with best combination of strength and workability.

A lot of MADM methods have been applied to select optimal material, but it is unknown which method is better. And reasonable method to select optimal material in consideration of the results from different MADM methods is not proposed in the literature.

In this paper, method to select optimal material in consideration of the results from different MADM methods is proposed and applied to select optimal magnesium alloy for automobile wheels. In subsection 3.1, method to select optimal material by MADM method is described. In subsection 3.2, some popular MADM methods, which is used in this paper, are listed. In subsection 3.3, a method is proposed to select optimal material using final ranks of the alternative materials based on the individual results from different MADM methods. In section 4, some popular MADM methods are applied to select optimal magnesium alloy for automobile wheels. The performance scores and ranks of the alternative magnesium alloys using some MADM methods are calculated and compared, and optimal magnesium alloy is selected using the final ranks of the alternative magnesium alloys.

2 Materials

Wheel is a most important component in an automobile. It support and bear the entire load and suffers not only with the vertical force but also the irregular and sudden forces resulting from braking, road bumps , car's ride, cornering, and all shocks in the process of moving on an uneven road. Due to high speed rotation, its quality has a huge impact on wheel stability, handling and their characteristics [Kumar and Suman (2014)]. The selection of alloying elements of Magnesium depends on the functional requirement, availability of alloying element, manufacturing capabilities, cost and customer requirement. The problem involves identification of different magnesium alloy materials that are used in the manufacturing of alloy wheels and to select the best among them. A survey was made on Mg alloys and properties on the web. Similar properties of all alloys are tabulated in Tab. 1. Eight Magnesium alloys with ten important properties (Density -Physical Property, UTS, YTS, FS,

Impact, Hardness, % Elongation-Mechanical Properties, Thermal Conductivity, Specific heat, CTE-Thermal Properties) are considered. The decision maker has to compare all the materials regarding each aspect and has to judge the best one, and this is difficult decision making problem. So different MADM methods are applied to select optimal magnesium alloy material in this section.

Table 1: Magnesium alloy materials and its properties [Kumar and Suman (2014)]

Properties	Magnesium alloy materials							
	AZ91	AM60	AM50	AZ31	ZE41	EZ33	ZE63	ZC63
Density (g/cm^3)	1.81	1.79	1.77	1.771	1.84	1.8	1.87	1.87
Thermal conductivity (W/mK)	72.7	62	65	96	113	99.5	109	122
UTS (MPa)	230	241	228	260	205	200	295	240
YTS (MPa)	150	131	124	200	140	140	190	125
Fatigue strength (MPa)	97	80	75	90	63	40	79	93
Impact (J)	2.7	2.8	2.5	4.3	1.4	0.68	2.3	1.25
Hardness (BHN)	63	65	60	49	62	50	75	60
% Elongation in 50 mm	3	13	15	15	3.5	3.1	7	4.5
Specific heat (J/g-°C)	0.8	1	1.02	1	1	1.04	0.96	1
Coeff. of thermal expansion (μm/m-C)	26	26	26	26	26	26.4	27	26

Among these ten properties, density, % elongation in 50 mm, specific heat and coefficient of thermal expansion are cost attributes, and others are benefit attributes.

3 Methods

3.1 Method to select optimal material by MADM method

Let $A=\{A_1,A_2,...,A_n\}$ ($n\geq 2$) be a discrete set of n alternative materials, and $U=\{u_1,u_2,...,u_p\}$ be a finite set of p attributes $\{u_j\,;\, j=1,2,\ldots,p\}$. Suppose every alternative material is evaluated with respect to the p attributes, whose values constitute a decision matrix denoted by $X=(x_{ij})_{n\times p}$, where x_{ij} is the measurement value of *j-th* attribute for *i-th* alternative material.

The main steps of materials selection using MADM method are presented as below:

Step 1: Constitute normalized decision matrix $Z=(z_{ij})_{n\times p}$ from the decision matrix $X=(x_{ij})_{n\times p}$.

Step 2: Constitute weighted normalized decision matrix $V=(v_{ij})_{n\times p}$.

The element v_{ij} of the weighted normalized decision matrix is calculated as follow:

$$v_{ij} = w_j \times z_{ij};\ i=1, 2,\ldots, n, j=1, 2,\ldots, p, \quad (1)$$

where $w_j>0$ represents the weight of *j-th* attribute ($w_1+\ldots+w_p=1$).

The attribute weights are usually determined by different methods such as AHP method, entropy weighting method, etc.

Step 3: Calculate the performance scores (synthetic evaluation values) V_i (i=1, 2,…, n) of each alternative material using MADM method.

Step 4: Rank the alternative materials in the descending order based on the values of V_1, V_2,…, and V_n, and select an alternative material with maximum V_i as optimal material.

In Step 2, the attribute weights using the entropy weighting method are as follow:

$$w_j = \left|1 - e_j\right| \Big/ \sum_{j=1}^{p} \left|1 - e_j\right|, j=1, 2,\ldots, p, \tag{2}$$

where

$$e_j = -\frac{1}{\ln n} \sum_{i=1}^{n} \left[p_{ij} \ln p_{ij}\right], j=1, 2,\ldots, p, \tag{3}$$

$$p_{ij} = x_{ij} \Big/ \sum_{i=1}^{n} x_{ij} \; ; i=1, 2,\ldots, n, j=1, 2,\ldots, p. \tag{4}$$

3.2 Some popular MADM methods

In this paper, some popular MADM methods are used to select optimal magnesium alloy. The MADM methods are listed as follow:

- SAW (Simple Additive Weighted method) [Athawale and Chakraborty (2011); Kumar and Suman (2014)]
- TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) [AL-Oqla, Sapuan, Ishak et al. (2015); Asodariya, Patel, Babariya et al. (2018); Athawale and Chakraborty (2011); Bai, Hua, Elwert et al. (2018); Çalıskan (2013); Çalıskan, Kursuncu, Kurbanoglu et al. (2013); Deshmukh and Angira (2019); Khorshidi and Hassani (2013); Khorshidi, Hassani, Rauof et al. (2013); Kumar and Suman (2014); Teraiya, Jariwala, Patel et al. (2018); Wood (2016); Yue (2011); Zhao, Liu and Yu (2011)]
- GRA (Grey Relational Analysis) [Athawale and Chakraborty (2011); Sahu and Pal (2015); Srinivasan, Chand, Kannan et al. (2018); Zhao, Liu and Yu (2011)]
- PSI (Preference Selection Index) method [Athawale and Chakraborty (2011); Khorshidi and Hassani (2013); Patel, Patel and Maniya (2018)]
- WPM (Weighted Product Method) [Athawale and Chakraborty (2011); Kumar and Suman (2014)]
- PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluations) [Athawale and Chakraborty (2011); Elevli and Ozturk (2019); Peng and Xiao (2013)]

The normalization of the decision matrix is performed using the vector normalization method in case of TOPSIS method, the linear-ratio-based normalization method in case of

SAW, PSI and WPM methods, and the linear max–min normalization method in case of GRA and PROMETHEE methods.

The vector normalization method is as follows [Çalıskan (2013); Jahan and Edwards (2015); Khorshidi and Hassani (2013)]:

$$r_{ij} = x_{ij} \Big/ \sqrt{\sum_{i=1}^{n} x_{ij}^2} \,. \tag{5}$$

The linear-ratio-based normalization method is as follows [Athawale and Chakraborty (2011); Kumar and Suman (2014); Podviezko and Podvezko (2015)]:

$$r_{ij} = x_{ij} \big/ x_{j\max} \,;\, j \in J^+ \,, \tag{6}$$

$$r_{ij} = x_{j\min} \big/ x_{ij} \,;\, j \in J^- \,, \tag{7}$$

The linear max–min normalization method is as follows [Athawale and Chakraborty (2011); Jahan and Edwards (2015); Peng and Xiao (2013)]:

$$z_{ij} = (x_{ij} - x_{j\min}) \big/ (x_{j\max} - x_{j\min}) \,;\, j \in J^+ \,, \tag{8}$$

$$z_{ij} = (x_{j\max} - x_{ij}) \,/ (x_{j\max} - x_{j\min}) \,;\, j \in J^- \,, \tag{9}$$

where J^+ is the index set of the benefit attributes (where higher values are desirable) and J^- is the index set of the cost attributes (where lower values are desirable).

3.3 Method to select optimal material using final ranks of alternative materials based on individual results from different MADM methods

Let V_{mi} be the performance score of i-th alternative material using m-th MADM method (m=1,2,...,M, i=1,2,...,n), where M is the number of MADM methods and n is the number of the alternative materials.

Step 1: Constitute the performance score matrix $V=(V_{mi})_{M\times n}$.

Step 2: Constitute the rank matrix $R=(r_{mi})_{M\times n}$ from the performance score matrix $V=(V_{mi})_{M\times n}$, where r_{mi} is the rank of performance score of i-th alternative material using m-th MADM method (m=1,2,...,M, i=1,2,...,n).

Step 3: Calculate the values of the rank state variables $\delta_{ik}^{(m)}$; m=1,2,...,M, i=1,2,...,n, k=1,2,...,n from the rank matrix $R=(r_{mi})_{M\times n}$, where

$$\delta_{ik}^{(m)} = \begin{cases} 1 \,;\, r_{mi} = k \\ 0 \,;\, r_{mi} \neq k \end{cases} \quad (m=1,2,...,M,\ i=1,2,...,n,\ k=1,2,...,n). \tag{10}$$

Step 4: Constitute rank frequency number matrix $F=(f_{ik})_{n\times n}$, where f_{ik} is the rank frequency number that the rank of i-th alternative material is k-th place by different MADM methods, and f_{ik} is as follows:

$$f_{ik} = \sum_{m=1}^{M} \delta_{ik}^{(m)} \quad (i=1,2,...,n,\ k=1,2,...,n). \tag{11}$$

Step 5: Constitute membership degree matrix $\Phi=(\varphi_{ik})_{n\times n}$, where φ_{ik} is the membership degree that the rank of i-th alternative material belongs to k-th place by different MADM methods, and φ_{ik} is as follows:

$$\varphi_{ik} = f_{ik}/M \ (i=1,2,...,n,\ k=1,2,...,n). \tag{12}$$

The i-th row $(\varphi_{i1}, \varphi_{i2},..., \varphi_{in})$ of the membership degree matrix $\Phi=(\varphi_{ik})_{n\times n}$ represent the degree that the rank of i-th alternative material belongs to n places, where

$$0\le\varphi_{ik}\le 1 \text{ and } \sum_{k=1}^{n}\varphi_{ik} = 1. \tag{13}$$

Step 6: Calculate final rank index I_i of i-th alternative material (i=1,2,...,n), where I_i is calculated as follows:

$$I_i = \sum_{k=1}^{N} k\cdot\varphi_{ki}\ . \tag{14}$$

Step 7: Determine final ranks $r_{01}, r_{02},\ldots, r_{0n}$ of the alternative materials in the ascending order based on the values of $I_1, I_2,\ldots, I_n$.

Step 8: Select an alternative material with first place of the final ranks (with minimum final rank index) as optimal material.

We developed the MATLAB program to calculate the performance scores, ranks, final rank indices and final ranks of the alternative materials using above-mentioned method.

4 Results and discussions

This section deals with the problem to select optimal magnesium alloy material for automotive wheels by different MADM methods.

The attribute weights were determined using entropy weighting method. The attribute weight vector determined using entropy method is as follows:

$\boldsymbol{w}$= (0.000539, 0.069137, 0.017334, 0.039164, 0.069232, 0.284360, 0.020390, 0.492920, 0.006721, 0.000205).

In order to select optimal magnesium alloy material, different MADM methods were applied. The performance scores of the alternative materials using different MADM methods are listed in Tab. 2.

Table 2: Performance scores of the alternative materials using different MADM methods

MADM methods	Alternative materials							
	AZ91	AM60	AM50	AZ31	ZE41	EZ33	ZE63	ZC63
SAW	0.849	0.455	0.414	0.575	0.687	0.666	0.563	0.608
TOPSIS	0.781	0.327	0.243	0.402	0.643	0.596	0.596	0.607
GRA	0.078	0.044	0.040	0.060	0.068	0.067	0.059	0.066
PSI	0.862	0.797	0.772	0.877	0.794	0.728	0.892	0.825
WPM	0.829	0.395	0.354	0.437	0.634	0.524	0.537	0.559
PROMETHEE	0.285	-0.227	-0.363	-0.097	0.132	0.023	0.126	0.121

The ranks of the performance scores of the alternative materials using different MADM methods are listed in Tab. 3.

Tabs. 2 and 3 show that the performance scores and ranks of the alternative materials differ according to the MADM methods. For example, AZ91 can be selected as optimal magnesium alloy by SAW, TOPSIS, GRA and PROMETHEE, and AZ31 can be selected as optimal magnesium alloy by PSI and VIKOR. So we can't decide optimal magnesium alloy in such status.

Table 3: Ranks of each alternative material using different MADM methods

MADM methods	Alternative materials							
	AZ91	AM60	AM50	AZ31	ZE41	EZ33	ZE63	ZC63
SAW	1	7	8	5	2	3	6	4
TOPSIS	1	7	8	6	2	5	4	3
GRA	1	7	8	5	2	3	6	4
PSI	3	5	7	2	6	8	1	4
WPM	1	7	8	6	2	5	4	3
PROMETHEE	1	7	8	6	2	5	3	4

Therefore, it is necessary to decide final selection result of optimal magnesium alloy in consideration of the individual results from different MADM methods.

The rank frequency numbers of each alternative material using different MADM methods are listed in Tab. 4.

The membership degrees of each alternative material using different MADM methods are listed in Tab. 5.

Table 4: Rank frequency numbers of each alternative material

Alternative materials	Ranks							
	1	2	3	4	5	6	7	8
AZ91	5	0	1	0	0	0	0	0
AM60	0	0	0	0	1	0	5	0
AM50	0	0	0	0	0	0	1	5
AZ31	0	1	0	0	2	3	0	0
ZE41	0	5	0	0	0	1	0	0
EZ33	0	0	2	0	3	0	0	1
ZE63	1	0	1	2	0	2	0	0
ZC63	0	0	2	4	0	0	0	0

Tab. 5 shows that AZ91 has the highest membership degree (0.833) at the first rank, AM60 has the highest membership degree (0.833) at the seventh rank, and so on. In Tab. 5, bold typed numbers are the highest membership degrees on each alternative material.

The final rank indices and final ranks of each alternative material are listed in Tab. 6.

Tab. 6 shows that the final rank of AZ91 is 1, and therefore AZ91 is selected as optimal magnesium alloy, the next is ZE41 and so on.

Table 5: Membership degrees of each alternative material

Alternative materials	Ranks 1	2	3	4	5	6	7	8
AZ91	**0.833**	0.000	0.167	0.000	0.000	0.000	0.000	0.000
AM60	0.000	0.000	0.000	0.000	0.167	0.000	**0.833**	0.000
AM50	0.000	0.000	0.000	0.000	0.000	0.000	0.167	**0.833**
AZ31	0.000	0.167	0.000	0.000	0.333	**0.500**	0.000	0.000
ZE41	0.000	**0.833**	0.000	0.000	0.000	0.167	0.000	0.000
EZ33	0.000	0.000	0.333	0.000	**0.500**	0.000	0.000	0.167
ZE63	0.167	0.000	0.167	**0.333**	0.000	**0.333**	0.000	0.000
ZC63	0.000	0.000	0.333	**0.667**	0.000	0.000	0.000	0.000

Table 6: Final rank indices and final ranks of each alternative material

	Alternative materials							
	AZ91	AM60	AM50	AZ31	ZE41	EZ33	ZE63	ZC63
Final rank index	1.333	6.667	7.833	5.000	2.667	4.833	4.000	3.667
Final rank	1	7	8	6	2	5	4	3

5 Conclusions

In this paper, materials selection method combined with different MADM methods was proposed and applied to select optimal magnesium alloy for automobile wheels.

Conclusively, following conclusions were drawn:

First, the performance scores, ranks of the alternative materials and the result of materials selection may differ according to the MADM method in materials selection using different MADM methods, so we have to decide reasonable final result of materials selection in consideration of the individual results from different MADM methods.

Secondly, method to select optimal material using final ranks of the alternative materials may be reasonable method in consideration of the individual results from different MADM methods.

The proposed method may be widely applied to select an optimal material using different MADM methods.

On the other hand, the normalization method of decision matrix and attribute weights may produce considerable differences in the results of materials selection.

Therefore, future work needs to study about a decision making method to determine reasonable final result of materials selection in consideration of the individual results of materials selection using different MADM methods with different normalization methods.

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