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Implementation of VIKOR Method for Selection of Magnesium Alloy to Suit Automotive Applications

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Abstract

Because of its lower density and plenty of availability, Magnesium alloy is a good choice material in automobile and aerospace industry. There are more and more materials available in the market to serve the common sake. Material selection plays an important role in the process of designing any physical product. A better methodology is required to help the organizations for selecting the best material. Multi Criterion Decision Making (MCDM) methods provide a ranking of the available alternatives thereby, decision of critical thinking become easier. A branch of MCDM methods named Vlse Kriterijumska Optimizacija I Kompromisno Resenje in Serbian (VIKOR) is used in the present work. The work presents the selection of a Magnesium alloy material, where eight materials and ten properties are considered to identify the best material. The influence of weightage factors by three different methods was also discussed.

Keywords: *Magnesium Alloy, MCDM methods, Material Selection, VIKOR, Entropy Method*

1. Introduction

India is one of the largest automotive industries in the world and one of the fastest growing countries. Now all automakers are concentrating on India for the promising growth in the sector and also the competition in this industry is very high. Hence the development of the product needs to be started from conceptual design with low cost, high performance and quality [1]. It is clear that reducing the mass of automobiles is a critical technology objective for vehicle performance, carbon dioxide (CO_2) emissions, and fuel economy. Vehicle mass-reduction technology offers the potential to reduce the mass of vehicles without compromising other vehicle attributes, like acceleration, size, cargo capacity, or structural integrity [2].

Power train components contribute a considerable portion of vehicle weight. There are several possibilities for resolving this problem, which include the use of alternative fuel sources, power train enhancements, aerodynamic improvements *etc*. However, lightweight construction seems to be the best cost effective solution for significant decrease of fuel consumption and CO_2 emissions. So there is a large scope for reducing the mass of wheel. Weight reduction of vehicles is a key step to reducing fuel consumption, so the industry is actively looking at replacing steel with lighter materials [3].

The abundance of Magnesium on the earth is considered to be 4th highest following iron, oxygen and silicon. The density of magnesium is approximately two thirds of that of aluminum, one quarter of zinc, and one fifth of steel. Accordingly, magnesium casting production has experienced an annual growth of between 10 and 20% over the past decades and is expected to continue at this rate [4].

Obtaining a solution, simultaneously satisfying all criteria is difficult task in any multi-criteria analysis [5]. Instead, a compromise solution can provide acceptable answers [6].

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The Compromise Ranking method, also known as the VIKOR method ranks alternatives and determines the solution named compromise that is the closest to the ideal. Even this work considers a less number of alternatives for simplicity, but this model can be used in evaluating more number of alternatives. The main task is to compare the properties of alternative materials and selecting the best one out of it.

Jee and Kang [11] applied TOPSIS method for material selection problem for flywheel by considering several technical requirements and also used entropy approach to evaluate the weight of the material selection attributes. Athawale and Chakraborty [12] solved a flywheel and a sailing boat material selection problem using Vlse Kriterijumska Optimizacija Kompromisno Resenje (VIKOR) and ELECTRE II methods, and relative ranking performances were compared.

The rest of the paper is organized as follows: The following section presents a brief description of the problem considered. Section 3 outlines the VIKOR method used in detail along with procedural steps. The application of the method is addressed in Section 4. Finally, conclusions are provided in Section 5.

2. Problem Formulation

Mg alloys have been increasingly used in the automotive and space industry in recent years due to their lightweight. Recent studies show that, magnesium passes aluminum in the cost perspective also. So selection process, among various magnesium alloys is relatively necessary and also the selection of criteria/weights for the assessment and evaluation is also clearly specified.

A survey has been made on different Mg alloys in automotive industries [8, 14, 15, 16, 17] and its properties among which 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 and tabulated below[10,18].

The details of the various attributes considered for the selection are given below in Table 1.

Table 1. The Information Sorted for the Selection of Magnesium Alloy

S.No	Material	Density (g/cm^3)	Thermal Conductivity (W/m K)	UTS (Mpa)	YTS (Mpa)	Fatigue Strength (Mpa)	Impact (J)	Hardness (BHN)	% Elongation in 50 mm	Specific Heat (J/g-°C)	Coeff . of Thermal Expansion (µm/m -C)
1	AZ91	1.81	72.7	230	150	97	2.7	63	3	0.8	26
2	AM60	1.79	62	241	131	80	2.8	65	13	1	26
3	AM50	1.77	65	228	124	75	2.5	60	15	1.02	26
4	AZ31	1.771	96	260	200	90	4.3	49	15	1	26
5	ZE41	1.84	113	205	140	63	1.4	62	3.5	1	26
6	EZ33	1.8	99.5	200	140	40	0.68	50	3.1	1.04	26.4
7	ZE63	1.87	109	295	190	79	2.3	75	7	0.96	27
8	ZC63	1.87	122	240	125	93	1.25	60	4.5	1	26

The decision making is complicated because each material is possesses its own characteristics and also the materials mentioned here are most commonly used materials.

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AM50 posse's superior density value than other materials, while considering yield strength AZ31 preferable. When fatigue Strength is the main criterion AZ 91 is a good choice. EZ 33 almost matches AZ91 in % elongation and density is low for EZ33 when with AZ91. ZE63 possesses good UTS and ZC63 in terms of thermal conductivity. Similarly, every material is having its own positives and negatives. Hence the Decision maker has to compare all the materials in view of each aspect and has to judge the best one. So the proposed approach is trying to find the best candidate, satisfying the requirements.

3. Compromise Ranking Method (VIKOR):

The foundation for compromise solution was established by Yu and Zeleny and later advocated by Opricovic and Tzeng. The VIKOR method was introduced as an applicable technique to implement within MCDM [4]. It focuses on ranking and selecting from a set of alternatives in the presence of conflicting criteria. The compromise solution is a feasible solution that is the closest to the ideal solution, and a compromise means an agreement established by mutual concession. The compromise solution method which is also known as the VIKOR method can be the base for negotiations, involving the decision maker's preference on criteria weights. The multiple attribute merit for compromise ranking was developed from the L_p-metric used in the compromise programming method [13].

The main procedure of the VIKOR method [4, 5, and 7] is described below:

Step 1: The first step is to determine the objective, and to identify the pertinent evaluation attributes. Also determine the best $(m_{ij})_{max}$ and the worst, $(m_{ij})_{min}$, values of all attributes.

$$E_i = \sum_{j=1}^{M} w_j \left[m_{ij_{max}} - m_{ij} \right] / \left[m_{ij_{max}} - m_{ij_{min}} \right] \quad (1)$$

Step 2: Calculate the values of E_i and F_i.

$$F_i = Max^m \left\{ \sum_{j=1}^{M} w_j \left[m_{ij_{max}} - m_{ij} \right] / \left[m_{ij_{max}} - m_{ij_{min}} \right] j = 1, 2, 3 \ldots.. M \right\} \quad (2)$$

Step 3: Calculate the value ofP_i.

$$P_i = v\left(\left(E_i - E_{i\,min}\right) / \left(E_{i\,max} - E_{i\,min}\right)\right) + (1 - v)\left(\left(F_i - F_{i\,max}\right) / \left(F_{i\,max} - F_{i\,min}\right)\right) \quad (3)$$

Where E_{i-max} is the maximum value of E_i, and E_{i-min} the minimum value of E_i, F_{i-max} is the maximum value of F_i, and F_{i-min} is the minimum value of F_i.

Step 4: Arrange the alternatives ascending order, according to the values of P_i. Similarly, arrange the alternatives according to the values of E_i and F_i separately. Thus, three ranking lists can be obtained.

***Step* 5:** Propose as a compromise solution the alternative (p') which is ranked the best by the minimum Q if the following two conditions are satisfied:

C1. "Acceptable advantage": $Q(p'') - Q(p') \geq DQ$, where p'' is the alternative with second position in the ranking list by Q, $DQ = 1/(m - 1)$ and m is the number of alternatives.

C2. "Acceptable stability in decision making": Alternative p' must also be the best ranked by E or/and F. This compromise solution is stable within a decision making process, which could be: "voting by majority rule" (when $v > 0.5$ is needed), or "by consensus" ($v \approx 0.5$), or "with vote" ($v < 0.5$). Here, v is the weight of the decision making strategy "the majority of criteria" (or "the maximum group utility"). $v = 0.5$ is used in this paper. If one of the conditions is not satisfied, then a set of compromise solutions is proposed.

4. Results and Discussions

From the basic data, the normalized values of both beneficial and non beneficial attributes are calculated and are tabulated in Table 2.

Table 2. Normalized Data of Final Selection

S.No	Material	Density (g/cm^3)	Thermal Conductivity (W/m K)	UTS (Mpa)	YTS (Mpa)	Fatigue Strength (Mpa)	Impact (J)	Hardness (BHN)	% Elongation in 50 mm	Specific Heat (J/g-°C)	Coeff . of Thermal Expansion (μm/m -C)
1	AZ91	0.9779	0.5959	0.7797	0.7500	1.0000	0.6279	0.8400	1.0000	1.0000	1.0000
2	AM60	0.9888	0.5082	0.8169	0.6550	0.8247	0.6512	0.8667	0.2308	0.8000	1.0000
3	AM50	1.0000	0.5328	0.7729	0.6200	0.7732	0.5814	0.8000	0.2000	0.7843	1.0000
4	AZ31	1.0000	0.7869	0.8814	1.0000	0.9278	1.0000	0.6533	0.2000	0.8000	1.0000
5	ZE41	0.9620	0.9262	0.6949	0.7000	0.6495	0.3256	0.8267	0.8571	0.8000	1.0000
6	EZ33	0.9833	0.8156	0.6780	0.7000	0.4124	0.1581	0.6667	0.9677	0.7692	0.9848
7	ZE63	0.9465	0.8934	1.0000	0.9500	0.8144	0.5349	1.0000	0.4286	0.8333	0.9630
8	ZC63	0.9465	1.0000	0.7119	0.6250	0.9588	0.2907	0.8000	0.6667	0.8000	1.0000

Attributes with equal importance (Equal weightage factors) - Mean Weight Method

This section discusses, consideration of all the properties with equal importance, so that the decision maker will look on each individual property with the same importance. There are ten attributes such that the weightage factor for each attribute is 1/10 = 0.1 and is given in Table 3.

Table 3. The Weights Given to each Attribute

Density	Thermal Conductivity	UTS	YTS	Fatigue Strength	Impact	Hardness	% Elongation in 50 mm	Specific Heat	Coeff. of Thermal Expansion
0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Using the above weights, apply the VIKOR method of compromise ranking to each alternate as explained in Section 3. Then the corresponding performance scores obtained are tabulated below in Table 4.

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Table 4. VIKOR Method Performance Scores

Alternate	Performance score obtained by using		
	E_i	F_i	P_i
1	0.3467	0.0822	0
2	0.5440	0.1	0.7930
3	0.6032	0.1	0.8809
4	0.3768	0.1	0.5446
5	0.5359	0.0947	0.6334
6	0.6834	0.1	1
7	0.4217	0.1	0.6113
8	0.5330	0.1	0.7765

On arranging the values from Table 4 in ascending order, the selection of the best alternate can be easily identified.The ranking selection can be chosen based on P_i, E_i and F_i also. From the Table 5, it can be clearly identified that the alternate 1 is the best choice among the other. Hence AZ91 is the best material choice with equal weightage of properties.

Table 5. Ascending Order of Performance Scores for Final Selection of Ranking

Arranging the performance scores in ascending order by using		
E_i	F_i	P_i
0.3467	0.0822	0
0.3768	0.0947	0.5446
0.4217	0.1	0.6113
0.5330	0.1	0.6334
0.5359	0.1	0.7765
0.5440	0.1	0.7930
0.6032	0.1	0.8809
0.6834	0.1	1

Attributes with unequal importance (different weightage factors) - Random Weightage Method

It is not always preferable to give equal importance to all the attributes. Weighting factors are given to indicate the relative importance or impact of that item in the group. The purpose of assigning weighting factors is helpful in measuring an accurate overall performance rating.

Table 6. The Weights given to each Attribute

Density	Thermal Conductivity	UTS	YTS	Fatigue Strength	Impact	Hardness	% Elongation in 50 mm	Specific Heat	Coeff. of Thermal Expansion
0.2	0.0666	0.1	0.1	0.1	0.1	0.1	0.1	0.0666	0.0666

The performance scores tabulated below is obtained by applying VIKOR method as explained in Section 3 for the variable weights mentioned in above table.

Table 7. VIKOR Method Performance Scores with un Equal Weights

Alternate	Performance score obtained by using		
	E_i	F_i	P_i
1	0.3293	0.0800	0.0373
2	0.5029	0.0908	0.3075
3	0.5410	0.1	0.4056
4	0.3356	0.1	0.0833
5	0.5732	0.14	0.6228
6	0.6543	0.1	0.5833
7	0.4589	0.2	0.6934
8	0.6052	0.2	0.9230

The selection of the best alternate can be easily identified by arranging the performance scores in ascending order.

Table 8. Ascending Order of Performance Scores for Final Selection of Ranking

Arranging the performance scores in ascending order by using		
E_i	F_i	P_i
0.3293	0.0800	0.0373
0.3356	0.0908	0.0833
0.4589	0.1	0.3075
0.5029	0.1	0.4056
0.5410	0.1	0.5833
0.5732	0.14	0.6228
0.6052	0.2	0.6934
0.6543	0.2	0.9230

From the Table 8, it is identified that the AZ91 which is alternate 1 is the best choice among the other materials with different weightage factor to the attributes *i.e.*, properties. While comparing the ranking, weights influenced the order of preference.

Entropy based weighting method

Entropy method was highly reliable for information measurement and to provide high accuracy in determination of weight of the feature.

Classical MCDM methods require the determination of alternatives rating and criteria weights are made which depend on decision makers' (DM) judgments/preferences. However, in practice, alternative ratings and criteria weights could not be assessed precisely, which may come from various sources, including (1) unquantifiable information, (2) incomplete information, (3) unobtainable information, and (4) partial ignorance [4].

To ensure that the evaluation result will be affected by the weighting approaches, subjective weighting and objective weighting methods are both utilized in the comparison. The use of subjective weighting is based on decision maker's expertise and judgment, nevertheless the objective weighting is based on mathematical computation. The approach with objective weighting is particularly applicable for situations where reliable subjective weights cannot be obtained [11-13].

Entropy is a well known method in obtaining the weights for an MADM problem especially when obtaining a suitable weight based on the preferences and DM experiments are not possible.

In order to determine objective weights by the entropy measure, the decision matrix needs to be normalized for each criterion C_j (j= 1,2,..., n) to obtain the projection value of each criterion $P\ ij$:

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$$P_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad (4)$$

The raw data are normalized to eliminate anomalies with different measurement units and scales. This process transforms different scales and units among various criteria into common measurable units to allow for comparisons of different criteria.After normalized the decision matrix, we can calculate the entropy values e_j as

$$e_j = -k \sum_{j=1}^{n} p_{ij} \ln p_{ij} \quad (5)$$

k is a constant, let k=$(\ln(m))^{-1}$

The degree of divergence d_i of the intrinsic information of each criterion C_j (j= *1, 2... n*) may be calculated as

$$d_j = 1 - e_j \quad (6)$$

The value d_j *represents* the inherent contrast intensity of C_j. The higher the d_j is, the more important the criterion c_j is for the problem. The objective weight for each criterion can be obtained.

$$W_j = \frac{d_j}{\sum_{k=1}^{n} d_k} \quad (7)$$

The weights by using entropy method are calculated by above procedure

Table 9. The Weights given to each Attribute

Density	Thermal Conductivity	UTS	YTS	Fatigue Strength	Impact	Hardness	% Elongation in 50 mm	Specific Heat	Coeff. of Thermal Expansion
0.0005	0.0690	0.0194	0.0391	0.0691	0.2838	0.0203	0.4919	0.0067	0.0002

The performance scores tabulated below is obtained by applying VIKOR method as explained in section 3 for the weights obtained by entropy method mentioned in above table.

Table 10. VIKOR Method Performance Scores with Weights by Entropy Method

Performance score obtained by using			
Alternate	E_i	F_i	P_i
1	0.2307	0.1254	0
2	0.6771	0.4099	0.7831
3	0.7958	0.4919	1
4	0.5634	0.4919	0.7943
5	0.3648	0.2273	0.2576
6	0.4596	0.2838	0.4185
7	0.3679	0.164	0.1739
8	0.3792	0.2391	0.2865

The selection of the best alternate can be easily identified by arranging the performance scores in ascending order.

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Table 11. Ascending Order of Performance Scores for Final Selection of Ranking

Arranging the performance scores in ascending order by using		
E_i	F_i	P_i
0.2307	0.1254	0
0.3648	0.164	0.1739
0.3679	0.2273	0.2576
0.3792	0.2391	0.2865
0.4596	0.2838	0.4185
0.5634	0.4099	0.7831
0.6771	0.4919	0.7943
0.7958	0.4919	1

From the Table 11, it is identified that the AZ91 which is alternate 1 is the best choice among the other materials with different weightage factor to the attributes i.e. properties. While comparing the ranking, weights influenced the order of preference. Table 12 shows that the first material AZ91 is a good choice magnesium alloy satisfying the conditions proposed.

Table 12. Ranking Comparison with Different Weight Factors

Ranking Based on P_i	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	Rank 6	Rank 7	Rank 8
With Equal weights	1	4	7	5	8	2	3	6
With un equal weights	1	4	2	3	6	5	7	8
Weights with entropy method	1	7	5	8	6	2	4	3

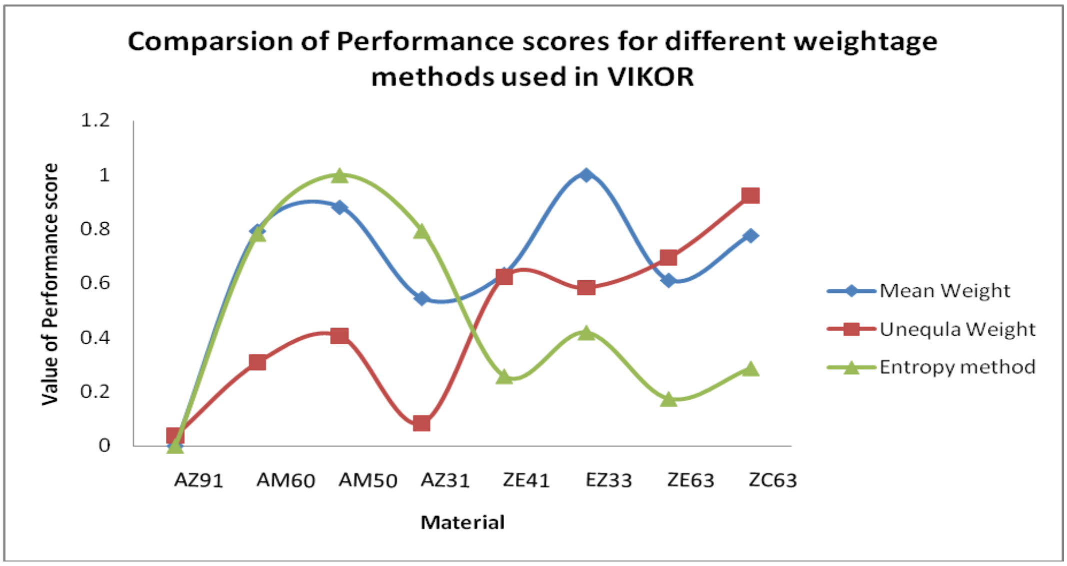

Figure 1. Comparison of Performance Scores for Different Weightage Methods used in VIKOR

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From the above figure it is evident that the first material *i.e.*, AZ91 is having best performance score in all weightage methods employed and a good choice among the materials compared for automotive applications.

5. Conclusions

This paper presented the successful implementation of VIKOR method for choosing the best material among various alloys of Magnesium used for automotive applications. These methods provided simple and powerful ranking criteria to proposed materials. For the same problem proposed, weights influenced the selection. The material ranked high among the others is AZ91. The proposed method can be extended not only to material selection but also to any organization / Industry so on by varying different attributes and selection criteria in various fields. Fine tuning of weightage to individuals, creating more fuzziness in the problem can be implemented in the future.

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