Optimization of Thermal Barrier Coating Material for IC Engine

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Abstract- **Conservation of energy and improvement of efficiency has always been the major area of concern for the automobile engineering. During the combustion stroke on an IC engine, a lot of heat is generated inside the combustion chamber, nearly thirty three percent of heat is absorbed by the cylinder walls, valves, piston, and etc. thirty three percent goes to the surrounding buy exhaust gases, the rest thirty four percent is used for the shaft work. By this study we aim to minimize the emission to the surrounding from the combustion chamber. The transfer of heat can be minimized by applying Thermal barrier coating on the various components of I.C. engine. A TBC is a ceramic material usually consisting of duplex structure the top coat and the bond coat. After studying various journals, we have found some TBC material candidate which could be used in our experiment. To find the optimal material, the method called as Simple Additive Weighted (SAW) method is used which is a non-traditional optimizing method under the category of Multiple Attribute Decision Making method.**

Index Terms- **Simple Additive Weighted Method, Multiple Attribute Decision Making, Thermal Barrier Coatings, Alumina, Weight, non-traditional methods.**

1. INTRODUCTION

Selection of material is a key factor for any industry. To solve this complex and important problem we must go for an analytical method rather than other initiative decisions. We had shortlisted a list of materials and their corresponding properties of utmost use. The demands of the properties of ideal material were different. Some should be high and some should be low. Now the question arises – Which material is best suited? There are many traditional optimizing methods like Linear Programming (LPP), Simplex method, Assignment method. But these cannot be applied because the variables were more than the requirement of the method. Simplex can be employed but the set of equations and its degree would be very high which would take years to calculate the solution.

This is where the non-traditional optimizing methods come into the scenario. Here we have used Multiple Attribute Decision Making (MADM) method. Various methods come under this category like SAW/WSM, WPM, AHP, TOPSIS, and PEOMETHBE. We have used Simple Additive Weighting (SAW) method; one of the simplest methods of MADM.

This paper considers a real application of material selection with using one of the decision making model. It is called SAW method. This paper has applied six criteria on eight alternatives that they are positively required for selecting one of the best materials of TBC (Thermal Barrier Material) and rank them.

2. METHODOLOGY

Simple Additive Weighting (SAW) is mostly used multi attribute decision making method. It is also known as weighted linear combination method. This method is based on weighted average. A score is calculated for each alternative by multiplying the given value of each attribute with the weights of relative importance. And then the rank of the sum of scores of the attributes of each alternatives gives us the best among the given. Process of SAW consists of the following steps:

Step I:

1) Construct a pair-wise matrix (n*n) of the attributes with respect to the Saaty's 1-9 scale[2] as shown in table 1. It is used to compare each criterion with the other one by one.

Table 1: Saaty's 1-9 scale

	Numeric Rating	Reciprocal

Extreme importance	9	1/9
Very strong to extremely	8	1/8
Very strong importance	7	1/7
Strongly to very strong	6	1/6
Strong importance	5	1/5
Moderately to strong	4	1/4
Moderate importance	3	1/3
Equally to moderately	2	1/2
Equal importance	1	1

2) For each comparison of attributes, decide which of the two attribute is more important, then assign the score to it. The less important attribute has score reciprocal of the more important attribute score.Compute the same for each comparison individually.
3) Weighted sum matrix is obtained by multiplying the pair-wise comparison matrix.
4) Now dividing all the elements of the weighted sum matrix by their individual priority score.
5) Calculate the average of this particular value to obtain α_{max}.
6) Find the Consistency Index (CI):

$CI = \frac{\alpha max-1}{n-1}$, where n is the matrix size.

7) Calculate the Consistency Ratio (CR):

$CR = \frac{CI}{RI}$, where RI is the Random Consistency

8) If the CR does not exceed 0.01, it is acceptable.

The value of RI is taken from the table:

Table 2: Values of RI

Size of matrix	Random consistency
1	0
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

Step II:

Obtain a decision matrix (m*n). Calculate the normalized decision matrix for positive criteria (maximize)

$n_{ij} = r_{ij} / r_j^*$, i = 1,… m and j = 1,… n

And for negative criteria (minimize)

$n_{ij} = r_j^{min} / r_{ij}$, i = 1,… m and j = 1,… n

Calculate each alternative, A_i by the formula:

$A_i = \Sigma\, w_j\, x_{ij}$

Where x_{ij} is the score of the i^{th} alternative with respect to the j^{th} criteria, w_j is the weighted criteria.

3. CALCULATION

By using six criteria given below we want to sort eight materials which can be used for coating the piston. These criteria have been mentioned in table 3 as follows:

Table 3: Criteria name

Criteria	Explanation
C1	Young's Modules
C2	Thermal diffusivity
C3	Thermal conductivity
C4	Heat capacity
C5	Poisson's number
C6	Density

The weights of the criteria can be calculated by using comparison matrix. Data was gathered by the research paper which criterion has more weightage than other criteria. It has been shown in table by using scale values of 1 – 3.

Table 4: Specifying the scale values

Intensity of importance	Definition
1	Equal importance
2	Strong importance
3	Extreme importance

The comparison matrix shown in table indicating that relative importance of the criterion in the columns compared to the criterions in the rows.

Table 5: Comparison Matrix

Criteria	C1	C2	C3	C4	C5	C6
C1	1.00	0.50	0.33	0.33	0.50	0.50
C2	2.00	1.00	0.50	0.50	1.00	0.50
C3	3.00	2.00	1.00	1.00	0.50	2.00
C4	3.00	2.00	1.00	1.00	2.00	1.00
C5	2.00	1.00	2.00	0.50	1.00	3.00
C6	2.00	2.00	0.50	1.00	0.33	1.00

Weights of criteria by comparison matrix:

1) Apply $(X)^{1/6}$ to each single cell of comparison matrix.
2) Product of each row.
3) Take the summation of product column obtained.
4) Weight, $W = \frac{product\ of\ each\ row}{summation\ of product\ coloumn}$

Criteria	C1	C2	C3	C4	C5	C6	*	Weights
C1	1.00	0.8908	0.8312	0.8312	0.8908	0.8908	0.4883	0.07603
C2	1.1224	1.00	0.8908	0.8908	1.00	0.8908	0.7933	0.123522
C3	1.2009	1.1224	1.00	1.00	0.8908	1.1224	1.3476	0.209831
C4	1.2009	1.1224	1.00	1.00	1.1224	1.00	1.5128	0.2354
C5	1.1224	1	1.1224	0.8908	1.00	1.2009	1.3476	0.2098
C6	1.1224	1.1224	0.8908	1.00	0.8312	1.00	0.9327	0.1452
Total							6.4223	1.00

Test of consistency:

If the calculated rate of consistency is less than 0.1 then it indicated that it is sufficiently consistent. The following steps will show how the test of consistency will be done:

Step 1: To calculate weights

In order to calculate weighted sum vector (WSM)

1.00	0.50	0.33	0.33	0.50	0.50		0.07603		0.4621
2.00	1.00	0.50	0.50	1.00	0.50		0.123522		0.7805
3.00	2.00	1.00	1.00	0.50	2.00	×	0.209831	=	1.3155
3.00	2.00	1.00	1.00	2.00	1.00		0.2354		1.4851
2.00	1.00	2.00	0.50	1.00	3.00		0.2098		1.4582
2.00	2.00	0.50	1.00	0.33	1.00		0.1452		0.9537

From this we get the consistency vector. Round off this CV up to four decimal points. In following division each corresponding cell must be divided by each other cell. For example, the value of 6.0802 has been extracted from 0.4621 divided by 0.07603 and so on.

0.4621		0.07603		6.0802
0.7805		0.123522	=	6.3198
1.3155	÷	0.209831		6.2702
1.485		0.2354		6.3084
1.4582		0.2098		6.9504
0.9537		0.1452		6.5681

$$\alpha_{max} = \frac{6.0802 + 6.3198 + 6.2702 + 6.3084 + 6.9504 + 6.5681}{6}$$

=6.4161

Amount of Consistency Index (CI):

$C.I = \frac{\alpha max - n}{n-1}$ n= No. of criteria

$= \frac{6.4161 - 6}{6-1}$ = 0.08322

Consistency rate $C.R = \frac{\text{Consistency Index(C.I)}}{\text{Random Index (RI)}}$

$= \frac{0.08322}{1.24}$ = 0.06711

Our consistency ratio is less than 0.10; therefore the scale values assumed earlier are correct. Our data collected regarding the materials and their properties is given below:

Alternative	Explanation
P1	3YSZ
P2	Mullite
P3	Al_2O_3
P4	NiCrAl
P5	MgPSZ
P6	YPSZ
P7	$CaZrO_3$
P8	$MgZrO_3$

	C1	C2	C3	C4	C5	C6
P1	21	11.5	2.12	640	0.29	5711
P2	30	5.2	3.3	950	0.25	2800
P3	30	9.6	1.8	775	0.26	3696
P4	90	10.3	3.88	764	0.27	7870
P5	46	10	1.8	650	0.23	5600
P6	11.29	10.9	1.4	620	0.25	5650
P7	87	11.5	14.6	698	0.21	4680
P8	86	8.01	15.3	650	0.20	5600
Obj.	max	max	min	max	min	min
Weight	0.07627	0.1234	0.2097	0.2394	0.2097	0.14541

Step 2: Normalization of Matrix

For positive criteria (maximize)

$n_{ij} = r_{ij} / r_j^*$, i = 1 to 8 and j = 1 to 6

And for negative criteria (minimize)

$n_{ij} = r_j^{min} / r_{ij}$, i = 1 to 8 and j = 1 to 6

	C1	C2	C3	C4	C5	C6
P1	0.233	1	0.6603	0.6736	0.8	0.4902
P2	0.344	0.460	0.4242	1	0.8	1
P3	0.344	0.834	0.78	0.8157	0.7692	0.7575
P4	1	0.895	0.3608	0.8042	0.7407	0.3557
P5	0.511	0.8695	0.78	0.6842	0.8695	0.5
P6	0.125	0.9478	1	0.6526	0.8	0.495
P7	0.967	1	0.0959	0.7347	0.9523	0.585
P8	0.956	06954	0.0915	0.6842	1	0.5

Step 3: Multiply attributes‘value with its respective weight.

The simple additive weighting method evaluates each alternative, Ai. By the following formula:

$A_i = \Sigma\, w_j\, x_{ij},$

where x_{ij} is the score of the i^{th} alternative with respect to the j^{th} criteria, w_j is the weighted criteria.

i=1 to 6 and j = 1 to 8.

The final matrix is as follows:

	C1	C2	C3	C4	C5	C6
P1	0.017	0.1234	0.1384	0.158	0.167	0.071
P2	0.026	0.0568	0.889	0.235	0.167	0.145
P3	0.262	0.1030	0.1635	0.192	0.161	0.110
P4	0.076	0.1106	0.0765	0.189	0.155	0.051
P5	0.038	0.1073	0.635	0.161	0.182	0.072
P6	0.009	0.1170	0.2097	0.153	0.167	0.720
P7	0.073	0.1234	0.0201	0.17	0.199	0.085
P8	0.729	0.086	0.0191	0.161	0.209	0.072

The summation of the attributes with their rank is as follows:

Alternative	Summation	Rank
P1	0.6769	5th
P2	0.07201	4th
P3	0.9937	1st
P4	0.6587	7th
P5	0.7257	3rd
P6	0.7295	2nd
P7	0.6749	6th
P8	0.6220	8th

Thus the best suited material obtained is P3, i.e.; Alumina

4.CONCLUSIONS

In this study, methodology for material selection is presented. Using this methodology best suited material obtained is P3, i.e.; Alumina. Evaluation of the materials on the basis of the criteria only will be sufficient for the future applications of the model and implementation of this evaluation via simple software will speed up the process. The limitation of this article is some criteria could have a qualitative structure or have an uncertain structure which cannot be measured precisely

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