Selection of Bituminous Binder using MCDM Approach as an Auxiliary Tool

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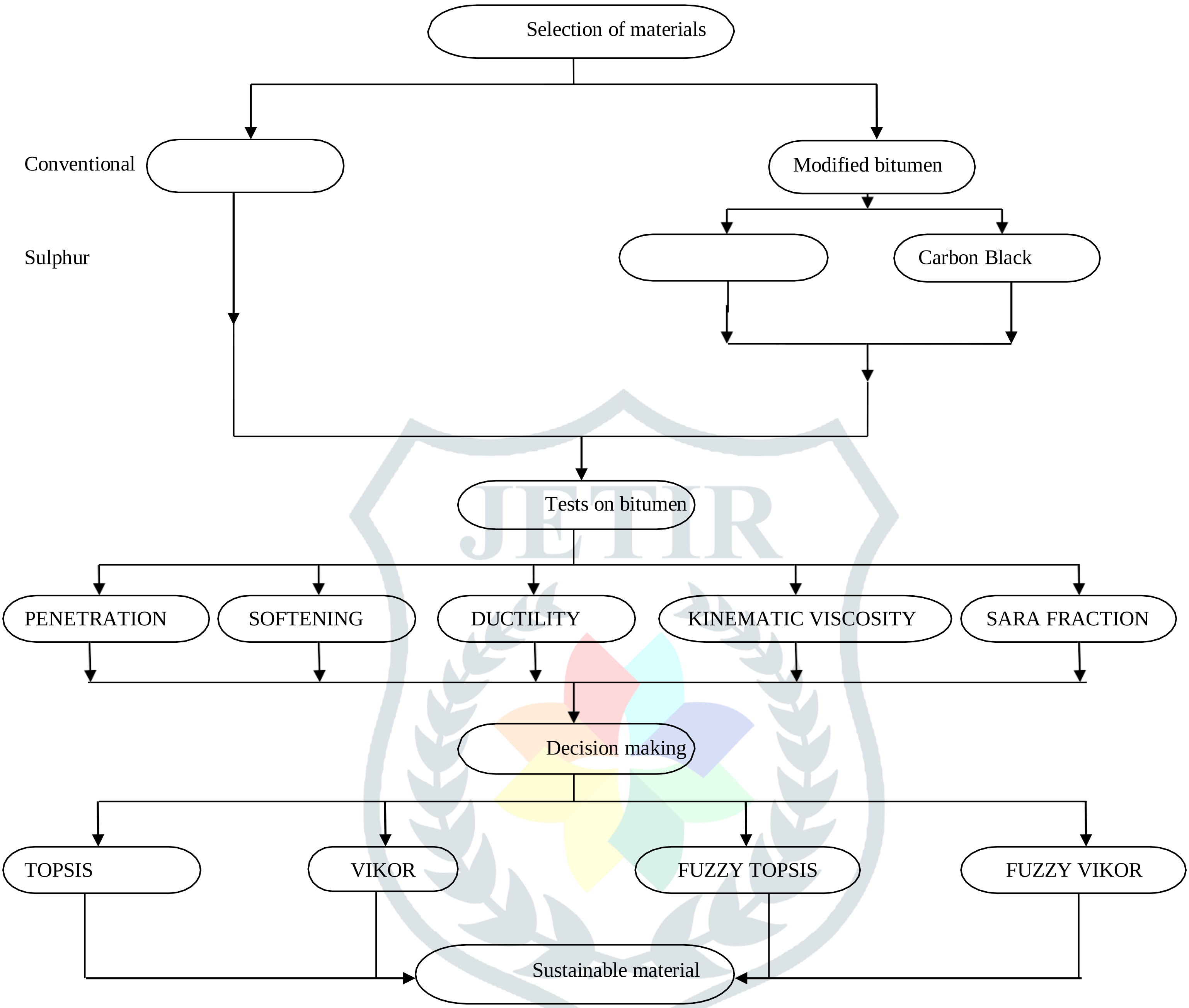
Abstract. Proper selection of materials for different uses is one of the most important tasks in the design of pavements. Material plays a significant role in pavement structure. Bitumen is brittle and tough in cool temperatures and soft in hot temperatures, to overcome these effects bitumen is modified by using different modifiers. This paper deals with the modification of asphalt grade VG40 with sulphur 4%, 8%, 12%, 16% and carbon black 10%, 20%, and 30%. Different experiments were carried out to determine the physical, chemical and rheological properties and to overcome the difficulty in selection of proper material with definite properties from a huge number of alternative by using four different MCDM (Multi-Criteria Decision Making) techniques i.e. TOPSIS (technique for order performance by similarity to ideal solution), VIKOR (VIsekriterijumskoKOmpromisnoRangiranje), FUZZY TOPSIS, FUZZY VIKOR. Criteria weighting was evaluated using compromised weighting method which is composed of AHP (analytic hierarchy process) and Entropy methods. The obtained results of each method were compared between these techniques. The results indicate that carbon10%, sulphur 8% and sulphur 4% are the best materials.
Keywords: Sulphur, Carbon black, MCDM, TOPSIS, VIKOR, FUZZY TOPSIS, FUZZYVIKOR.

1 Introduction

The selection of material will show a momentouspart in the pavement design and in different layers of pavement structure. Materials used in the structure will give a good road surface. In the world around 80,000 materials are available. For selecting most appropriate material, a decision making must take in to account various factors. Generally, there are two steps for the selection of material one is to examine the product necessities and best materials among all are selected. By introducing MCDM (Multi-Criteria Decision Making) different units and differing attributes are the two problems for selection of materials. These can be tackled by employing MCDM techniques. Many MCDM methods such as AHP, TOPSIS, COPRAS, VIKOR, PROMETHEE, ANP, MOORA, WPN, SAW, EVAMIX, PSI, GTMA, ELECTRE, DEMATEL etc. from current years MCDM is using to solve the problems .

The main advantage of bitumen is its great versatility which has very high adhesive property,impermeable and durable and it is usedfor laying of roads. Though there are several modifiers available in the market, in this study sulphur powder and carbon black have been used as a modifier in bitumen. The authors had determined the improvement of bitumen properties by adding sulphur [1]. They described the mechanical and rheological properties of sulphur modified bitumen [2]. By the partial replacement of sulphur in bitumen mechanical properties were improved [3]. By adding more percentage of pyrolytic carbon black there is a influence on temperature [4]. The materials which are used increased temperature and anti-aging properties [5]. In this they determined the selection of best material among all the materials by using VIKOR method [6]. In this paper material selection was done by using the EXPROM2, TOPSIS and VI-KOR methods [7].

2. METHODOLOGY



3. Multi Criteria Decision making

3.1 Criteria weighting

By using compromised weighted method, the criteria weights can be obtained, In order to get more reasonable weight coefficients weights of the criteria are taken in to account by merging AHP and Entropy methods. The composite weight for the jth criteria is:

$$w_j = \frac{\beta_j \times \Upsilon_j}{\sum_{i=1}^{n} \beta_j \times \Upsilon_j} \quad (1)$$

j = 1,2,3…n

3.1.1 AHP method

By using multiple criteria, they developed subjective decision-making processes. In this method three principles are composed.

$$P = \begin{bmatrix} p_{1i} & \cdots & p_{1j} & \cdots & p_{1n} \\ p_{in} & \cdots & p_{ij} & \cdots & p_{in} \\ p_{1n} & \cdots & p_{nj} & \cdots & p_{nn} \end{bmatrix}, \quad p_{ii} = 1, \; p_{ij} = \frac{1}{p_{ji}}, \; p_{ji} \neq 0 \quad (2)$$

The consistency index (C.I.) and the consistency ratio (C.R.) are evaluated in order to confirm the consistency of subjective perception weights. The consistency index Is

$$C.I = \frac{(Y_{max} - n)}{(n-1)} \quad (3)$$

Here n is represented as number of criteria. For obtaining sustainable result the value of C.I must be less than 0.1. the consistency ratio can be computed as:

$$C.R. = \frac{C.I.}{R.I.} \quad (4)$$

Generally, R.I value differs for differentmatrixes sizes whereas for 6× 6 matrix the R.I. value is 1.25. In order to obtain the reliable result, the value of C.R must be under 0.1.

3.1.2 Entropy method

It estimates the vulnerability in the data formulated utilizing probability theory. It demonstrates that a wide distribution which represents more vulnerability than that of a pointedly crested one.

$$\begin{matrix} A_1 & r_{11} & r_{12} \ldots & r_{1n} \\ A_2 & r_{2n} & r_{22} \ldots & r_{2n} \\ A_m & r_{mn} & r_{m2} \ldots & r_m \end{matrix} \quad (5)$$

Where r_{ij} is the performance value of i[th] alternative to the j[th]criteria and the determination of weights is done calculating normalized decision matrix R_{ij}.

$$R_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{m} r_{ij}^2}} \quad (6)$$

The value of entropy E_j of j[th] criteria can be derived as:

$$E_j = -h\sum_{i=1}^{m} \ln(R_{ij})$$

j = 1,2,3……, n (7)

Where $h = \frac{1}{\ln m}$ is a guarantee $0 \leq E_j \leq 1$ and m is the number of alternatives.

$$d_j = [1 - E_j] \quad (8)$$

Where d_j is degree of divergence (d_j)

Thus, the Entropy weight of j[th] criteria is defined as:

$$\beta_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \quad (9)$$

3.2. TOPSIS Method

By using TOPSIS method solution is obtained, which is nearest to ideal solution and farthest to the nadir ideal solution.

Step-1: The normalization of decision matrix is determined by

$$n_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}^2}}$$

j = 1,2,3,…………….n; i= 1,2,3,………..m (10)

Step-2: Calculation of weighted normalized data:

Weights are obtained by AHP process and weighted normalized data is obtained by the following equation:

$N_{ij} = n_{ij} * w_{ij}$

j =1,2,3,…………..n; i=1,2,3,……….m (11) Where, N_{ij}= weighted normalized matrix.

Step-3: Calculations of ideal and nadir solution.

In order to determine the ideal solution, the following equation is used:

$\{N_1^+ N_2^+, \ldots \ldots N_n^+\}$= {(Max N_{ij}| j€K), (Min N_{ij}| j€K)}(12)

i=1,2,3,…….m

Calculating nadir ideal solutions by using following equations:

$\{N_1^- N_2^-, \ldots \ldots N_n^-\}$= {(Min N_{ij}| j€K), (Max N_{ij}| j€K) |}(13)

i =1,2,3,…….m

Where, K = index set of beneficial criteria and K'= index set of non- beneficial criteria. **Step-4**: By using the following equation, the distance from ideal and nadir solutions are evaluated.

$S_i^+ = \{\sum_{j=1}^n (N_{ij} - N_j^+)^2\}^{0.5}$; (14)

j =1,2,3,………n; i=1,2,3,………m

$S_i^- = \{\sum_{j=1}^n (N_{ij} - N_j^-)^2\}^{0.5}$ (15)

j =1,2,3,…………ni=1,2,3,………m

Step-5: In this step the relative closeness to the ideal solutions is determined by using following equation:

$C_i = \frac{S_i^-}{S_i^+ + S_i^-}$; (16)

i=1,2,3,………m; 0 ≤ i ≤ 1

The highest value of Ci is given the best rank.

3.3 VIKOR Method

This method was introduced to implement within MCDM and explained as follows

Step-1 Determination of normalized decision matrix

$f_{ij} = \frac{I_{ij}}{\sqrt{\sum_{i=1}^m (I_{ij}^2)}}$ (17)

i = 1,2,3,…, m; j = 1,2,3,……, n

Step-2 The utility measure (p) can be evaluated by using following equations:

$p = \sum_{i=1}^n w_i [\frac{(f_{ij})\max - (f_{ij})}{(f_{ij})\max - (f_{ij})\min}]$ for beneficial attribute (18)

$p = \sum_{i=1}^n w_i [\frac{(f_{ij}) - (f_{ij})\min}{(f_{ij})\max - (f_{ij})\min}]$ for non-beneficial attribute (19)**Step-3** Evaluation of regret measure (Q) can be done by following equation

Q = maximum of $p = \sum_{i=1}^n w_i [\frac{(f_{ij})\max - (f_{ij})}{(f_{ij})\max - (f_{ij})\min}]$ i = 1,2, ,…, n (20)

For beneficial attribute

Q = maximum of $p = \sum_{i=1}^n w_i [\frac{(f_{ij}) - (f_{ij})\min}{(f_{ij})\max - (f_{ij})\min}]$ i = 1,2,…, n (21)

For non-beneficial attribute

Now the maximum and minimum values of P and Q are determined.

Step-4 Determination of R value by subsequent equations:

$R = v[\frac{p - (p)_{min}}{(p)_{max} - (p)_{min}}] + (1+v)[\frac{Q - (Q)_{min}}{(Q)_{max} - (Q)_{min}}]$ (22)

However, the value of (v) can be taken between 0-1. Generally, v value is considered as0.5.

According to VIKOR method, the minimum value of r is considered as the best alternative.

3.4 FUZZY TOPSIS

This method is relayed on principle that alternative must be possessing shortest distance to positive ideal solution [which indulge in maximum benefit and minimum cost].

MCDM problem with 'm' alternative [conventional, S-4%, S-8%,S-12%, S-16%, C.B-10%, C.B-20%, C.B- 30%] should be assessed by applying n criteria [penetration, softening, ductility, kinematic viscosity and sara fraction] can be expressed by decision matrix.

$$X = \begin{matrix} x_{11,} & x_{12,\ldots} & x_{1n,} \\ . & . & . \\ x_{m,} & x_{m2} & x_{mn} \end{matrix}$$

Weights of the criteria c_j to the decision is denoted by $W_j = [w_1, w_2, w_n]$

Step-1 Assignment of rating to alternatives and selected criteria

In this method, decision group of '3' members are involved. Decision makers provide rating for all alternatives and weights for criteria as based on logistic values given by Fuzzy Topsis method.

Step-2 Computing aggregate fuzzy ratings for alternatives and weights of criteria. Aggregates fuzzy ratings weights for criteria and alternatives are described below:

$w_j = [w_{j1}, w_{j2}, w_{j3}]$ for criteria c_j are calculated as
$w_{j1} = \min[w^k_{ij}]$; $w_{j2} = \frac{1}{k}\sum_{k=1}^{k} [w^k_{j2}]$; $w_{j3} = \max[w^k_{j3}]$ (24)

Step-3 Computation of normalized fuzzy decision matrix R = $[r_{ij}]$

Where $r_{ij} = [\frac{a_{ij}}{c^*_j}, \frac{b_{ij}}{c^*_j}, \frac{c_{ij}}{c^*_j}]$ and $c^*_j = \max[c_{ij}]$ for beneficial criteria

$r_{ij} = [\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}]$ and $a_j^- = \min[a_{ij}]$ for non-beneficial criteria

Step-4 Derivation of weighted normalized fuzzy matrix ($\tilde{v}_{ij}$)
Where $\tilde{v}_{ij} = \tilde{r}_{ij} \times w_j$ (25)

Step-5 Computation of fuzzy negative ideal solution $A^-(FNIS)$ and fuzzy positive ideal solution $A^+(FPIS)$:
$A^+ = (\tilde{v}^*_1, \tilde{v}^*_2, \tilde{v}^*_3)$ where $\tilde{v}^*_j = \max[v_{ij3}]$ (26)
$A^- = (\tilde{v}^-_1, \tilde{v}^-_2, \tilde{v}^-_3)$ where $\tilde{v}^-_j = \max[v_{iji}]$ (27)

Step-6 Determination of distance to FPIS and FNIS from each alternative

$d^*_i = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}^*_j)$ (28)
$d^-_i = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}^-_j)$ (29)

Step-7 Evaluation of closeness co-efficient (CC_i) for each alternative

$$CC_i = \frac{d^-_i}{d_i^+ + d_i^-} \quad (31)$$

FUZZY VIKOR

VIKOR is an effective MCDM technique used for selection of materials.

Since, the number of criteria alternate, and decision makers is very high. Fuzzy environment is selected to make it easier.

Application steps

Step-1 Input data collection

This method selects the feasible solution which is very close to ideal solution. Corresponding linguistic terms are taken as explained in fuzzy vikor method

Step-2 Aggregation

Aggregation of each alternatives and criteria weights fuzzy ratios are calculated using below equation [8].

$$Y_{ij} = \{Y_{ij1}, Y_{ij2}, Y_{ij3}, Y_{ij4}\}$$

Where $Y_{ij1} = \min\{Y_{ijL}\}$, $Y_{ij2} = \frac{1}{L} \in Y_{ij2}$, $Y_{ij3} = \frac{1}{L} \in Y_{ij3}$, $Y_{ij4} = \min\{Y_{ij4}\}$

Step-3 Normalization

To achieve common scale of values, normalization is adopted. Normalization is used to remove dimensions of criterions.

In this normalization method,

I. The benefit criteria are divided by highest value of entire decision matrix

$$N_{ij} = \{\frac{Y_{ij1}}{Y^+_{ij4}}, \frac{Y_{ij2}}{Y^+_{ij4}}, \frac{Y_{ij3}}{Y^+_{ij4}}, \frac{Y_{ij4}}{Y^+_{ij4}}\} \; C_i \in B \quad (32)$$

C_i denotes i^{th} criterion

II. The non-benefit criteria are divided by least value of decision matrix

$$N_{ij} = \{\frac{Y_{ij1}}{Y^-_{ij1}}, \frac{Y_{ij2}}{Y^-_{ij1}}, \frac{Y_{ij3}}{Y^-_{ij1}}, \frac{Y_{ij4}}{Y^-_{ij1}}\} \; C_j \in NB \quad (33)$$

C_j denotes i^{th} criterion

Step-4 Defuzzification

To get crisp values (F_{ij}), the fuzzy weight criterions and importance of criterions with respect to material ratings are defuzzified using below equation

$$\text{Defuzzy}(Y_{ij}) = \frac{\int \mu(Y)\,Y\,dy}{\int \mu(Y)\,dy} = \frac{-Y_{ij1}Y_{ij2} + Y_{ij3}Y_{ij4} + \frac{1}{3}(Y_{ij4}-Y_{ij3})^2 - \frac{1}{3}(Y_{ij2}-Y_{ij1})^2}{-Y_{ij1} - Y_{ij2} + Y_{ij3} + Y_{ij4}} \quad (34)$$

The worst value (F^-_j) and the best value (F^*_j) for criterion crisp value are selected.

Step 5 calculation of utility and regret Utility is calculated using the below equation

$$S_j = \sum_{i=1}^{n} \frac{W_i(F^*_j - F_{ij})}{(F^*_j - F^-_j)} \quad (35)$$

Regret is calculated using the equation

$$R_j = \max \frac{W_i(F^*_j - F_{ij})}{(F^*_j - F^-_j)} \quad (36)$$

Step-6 Calculation of VIKOR indices

$$Q_j = \frac{\surd(S_j - S^*)}{S^- - S^*} + \frac{(1-\surd)(R_j - R^*)}{R^- - R^*} \quad (37)$$

Where Q_j, represents j^{th} alternative VIKOR value, j = 1,2,3,……n

√ is introduced as weight for the strategy, 1-√ is weight of concurring individual regret. S^- represents max value of individual regret ,S^* represents min value of individual S_j, R^* represents min value of individual R_j and R^- represents max value of individual R_j

Step-7 Choosing the sustainable alternative

Alternative having the least VIKOR value is endowed to be the best solution.

4. Results and Discussions

The physical properties of the bitumen modified with sulphur and black carbon are elaborated in the subsequent paragraphs

4.1 Penetration

Penetration values of all the modified binders are observed as below.

TABLE 2 Penetration Values

Materials	Conventional	Sulphur 4%	Sulphur 8%	Sulphur 12%	Sulphur 16%	Carbon black 10%	Carbon black 20%	Carbon black 30%
Penetration	53	51.6	43.6	39.3	23.6	49.6	58.5	51.5

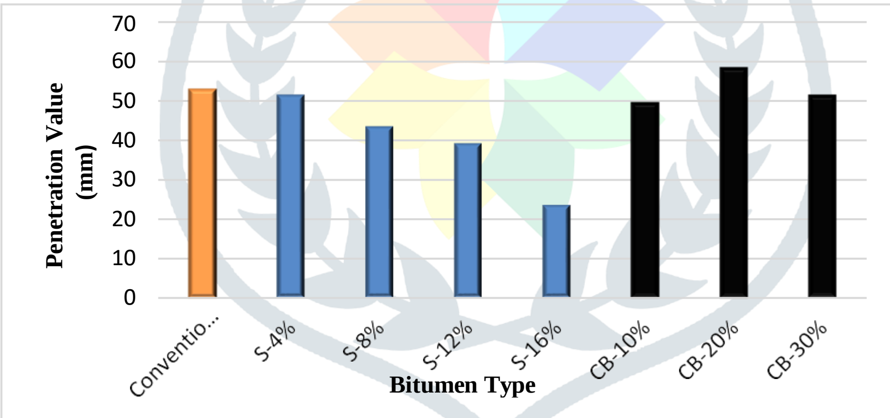


Fig. 1 varying penetration values

From the above graph it is observed that penetration value is more for carbon black 20% and less for sulphur 16%.

4.2 Softening

Softening values of all the modified binders are observed as below.

TABLE 3 Softening Values

Materials	Conventional	Sulphur 4%	Sulphur 8%	Sulphur 12%	Sulphur 16%	Carbon black	Carbon black	Carbon black

						10%	20%	30%
Softening	54	57.5	56.5	58.5	68.5	54	56	56

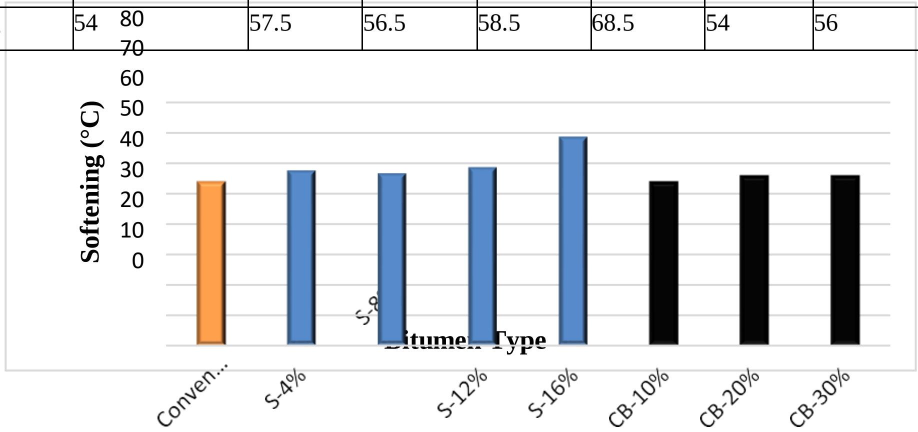


Fig. 2 Varying Softening point values

From the above graph it is observed that softening value is increased when carbon black 30% is added to conventional.

4.3 Ductility

Ductility values of all the modified binders are observed as below.

TABLE 4 Ductility Values

Materials	Conventional	Sulphur 4%	Sulphur 8%	Sulphur 12%	Sulphur 16%	Carbon black 10%	Carbon black 20%	Carbon black 30%
Ductility	44	46	46	24.56	10.3	61	16	14

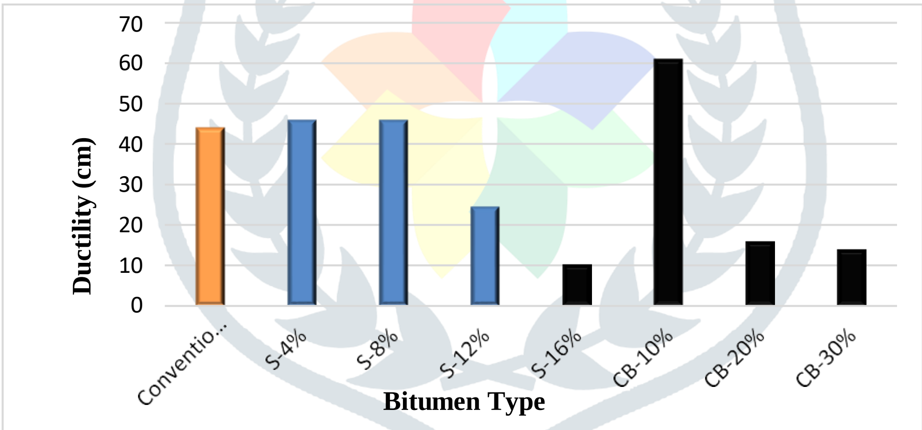


Fig. 3 Varying Ductility Values

From the graph it is observed that, when carbon black 10% added to conventional bitumen ductility value has increased.

4.4 Kinematic Viscosity

Kinematic Viscosity values of all the modified binders are observed as below.

TABLE 5 Kinematic Viscosity Values

Materials	Conventional	Sulphur 4%	Sulphur 8%	Sulphur 12%	Sulphur 16%	Carbon black 10%	Carbon black 20%	Carbon black 30%
Kinematic Viscosity	475.02	808.01	952.38	1074.63	1371.52	709.03	863.07	1033.05

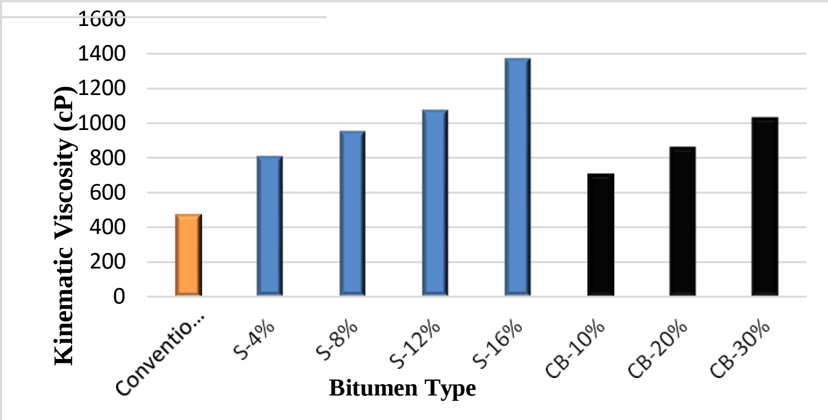


Fig. 4 Varying Kinematic Viscosity values

From the above graph, highest kinematic viscosity value is observed when sulphur 16% is added to conventional bitumen.

4.5 Sara Fraction

Sara Fraction of all the modified binders are observed as below.

TABLE 6Sara Fraction Values

Materials	Conventional	Sulphur 4%	Sulphur 8%	Sulphur 12%	Sulphur 16%	Carbon black 10%	Carbon black 20%	Carbon black 30%
Sara fraction	23	26	29	32.5	35	24	28.5	33

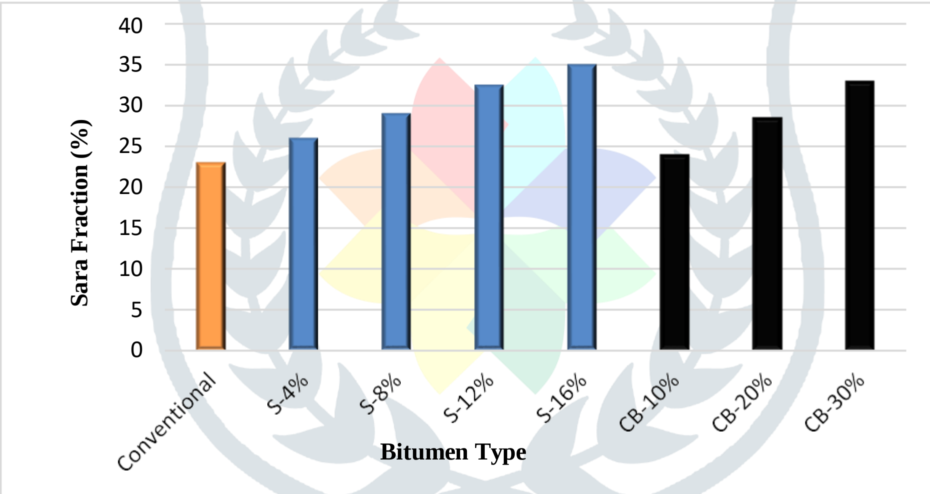


Fig. 5 Varying Sara Fraction values

The above graph shows that the sara fraction value is within the limits when sulphur 16% is added to conventional bitumen.

Criteria weighting

The pair wise comparisons are used to obtain the criteria weights (*aj*).The C.R values of AHP and entropy methods are 0.094< 0.1and 0.091 < 0.1, and from these values it shows that the results which obtained are dependable.

The recycled aggregate was partially replaced with natural aggregate at different proportions from 10% to 50% at interval of 10%. Optimum recycled aggregate was arrived and is used in preparation of Plastic cell filled concrete.

Table-7 Weighing for criteria's by AHP, Entropy and compromised weighting methods

Criteria weights	Penetration	Softening	Ductility	Kinematic viscosity	Sara fraction
β_j	0.1276	0.2984	0.2067	0.1823	0.1846
Υ_j	0.1289	0.0149	0.6177	0.1728	0.0654
w_j	0.085	0.0229	0.6649	0.1641	0.0625

TOPSIS method

By applying TOPSIS Eq.(10), it is used to normalize the matrix and it is multiplied by compromised weights.

Ideal solution is determined from Eq.(12) and nadir ideal solutions is determined from Eq (13). The distances between the ideal solutions to nadir ideal solutions and relative closeness to ideal solution (C_i) are estimated using Eqs. (14)-(16) and obtained results are shown in table 8.

Table 8 Values of s^+, s^-, and c_i.

i *i*

Samples	Si+	Si-	Ci	RANK
1	0.1222666	0.2133795	0.6357277	4
2	0.102591	0.226877	0.688616	3
3	0.099247	0.227946	0.696671	2
4	0.23154	0.098211	0.297833	5
5	0.320813	0.059416	0.156263	6
6	0.043985	0.321164	0.879544	1
7	0.287235	0.043502	0.13153	7
8	0.298637	0.041773	0.122714	8

[The samples represent 1-Conventional, 2-Sulphur 4%, 3-Sulphur 8%, 4-Sulphur 12%, 5-Sulphur 16%, 6-Black carbon 10%, 7-Black carbon 20%, 8-Black carbon 30%]. VIKOR method

The least and highest values of all criteria is obtained from calculated decision matrix. The values of S_i, $R_i and Q_i$ is calculated using Eqs. **(18)–(19)** and are shown in table 9. Material with least $Q_i$value is awarded the best rank.

Table 9 Values of Si, Ri, and Qi.

Samples	Di+	Di-	CCi	RANK
1	14.7838	10.9196	0.4248	4
2	14.5346	12.1586	0.4555	3
3	14.9351	15.7166	0.5127	2
4	15.5690	11.3212	0.4210	5
5	18.8850	11.8575	0.3857	6
6	8.5614	16.7836	0.6622	1
7	18.0799	7.8689	0.3032	7
8	21.3834	9.1231	0.2991	8

FUZZY TOPSIS

The values of distances are derived by using eq. (28) and (29), and closeness coefficient is evaluated by using eq. (31) and values with highest CCi value is given the highest rank as explained by fuzzy topsis technique and is shown in Table 10.

Table 10 Values of Di+, Di-, CCi

Samples	Di+	Di-	CCi	RANK
1	14.7838	10.9196	0.4248	4
2	14.5346	12.1586	0.4555	3
3	14.9351	15.7166	0.5127	2
4	15.5690	11.3212	0.4210	5
5	18.8850	11.8575	0.3857	6
6	8.5614	16.7836	0.6622	1
7	18.0799	7.8689	0.3032	7
8	21.3834	9.1231	0.2991	8

FUZZY VIKOR

In this method utility, regret are calculated using equations (35) &(36) and VIKOR indices with values of Q=0.2, 0.3, 0.4 is being calculated by using equation (37) . Values with least Q values is given best rank as described in fuzzy vikor Technique. **Table 11 Values of Si, Ri and Q**

Samples	Si	Ri	Q(V=0.2)	Q(V=0.3)	Q(V=0.4)	Rank
1	1.8250	0.8270	0.1257	0.1209	0.1161	4
2	1.6280	0.7700	0.0819	0.0741	0.0663	3
3	1.7000	0.6240	0.0094	0.0138	0.0181	2
4	3.9210	2.1200	0.9557	0.9372	0.9186	6
5	2.3687	0.8270	0.1630	0.1769	0.1908	5
6	1.5710	0.6230	0.0000	0.0000	0.0000	1
7	4.4810	2.1300	0.9995	0.9995	0.9996	8
8	4.2210	2.1250	0.9789	0.9704	0.9619	7

Best alternative

In this paper different techniques are used to determine the best alternative out of all the materials. Alternative with highest rank is chosen as best material.

Table 12 Rankings and alternatives

SAMPLES	TOPSIS	VIKOR	FUZZY TOPSIS	FUZZY VIKOR
1	4	4	4	4
2	3	3	3	3
3	2	2	2	2
4	5	5	5	6
5	6	6	6	5
6	1	1	1	1
7	7	7	7	8
8	8	8	8	7

Conclusions

In this paper bitumen is modified by sulphur and carbon black with different percentages and selection of best material is carried out by using four different techniques MCDM, VIKOR, TOPSIS, FUZZY TOPSIS, FUZZY VIKOR in ranking order. It is concluded that carbon black used as modifier in bitumen has influence on temperature, physical and chemical properties. By considering all different four techniques the best material percentages were carbon black 10%, sulphur 8% and 4%. The worst material was carbon black 30%. By adding more percentage of carbon black in bitumen the physical and chemical properties are affecting and there is a significant change in temperature. Therefore by comparing all the four MCDM techniques, it shows that the ranks of the selected materials are almost similar, hence the obtained results are more accurate.

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