SELECTION OF BRAKE FRICTION MATERIALS USING COMPROMISE RANKING METHOD

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Abstract: Selection of proper formulation is one of the most challenging tasks in the design and development of brake friction materials. Wrong selection often leads to premature component or product failure during working. This paper develops an evaluation approach based on 'Vlse Kriterijumska Optimizacija Kompromisno Resenje'(VIKOR), a compromise ranking method strengthened with analytic hierarchy process (AHP) to choose an optimal friction formulation according to several performance defining criteria which are probably conflicting. Friction materials formulation based on the variation in nanoclay and multiwalled carbon nanotubes (MWCNT) are fabricated and characterize for tribological performance on a Krauss type friction tester and the test results were considered as criteria for performance optimization. The VIKOR result shows that the formulation of 2 wt.-% MWCNT exhibits the optimal properties.

Keywords: Brake friction materials, multi-criteria decision-making, MWCNT, Nanoclay

Introduction: The most important safety feature of an automobile is its braking system. The ability of brakes is to provide safe and repeatable stopping, which is related to safety of automobiles and human. Friction material has been considered as the key component which determines the tribological performance of the braking system. Friction materials are multi-ingredient composites generally containing a phenolic resin as binder in which fibres, fillers property modifiers are distributed to fulfill the diverse and conflicting performance requirements such as high and stable coefficient of friction, resistance to fading, wear, squeal, judder along with good recovery, noise propensity [1],[2]. The development and performance evaluation of new formulations are an intricate task because of their compositional variations that comprises different materials. The complication in performance evaluation arises more as the same composition the friction materials yield different results with different manufacturing conditions [3]. The selection of an optimal material for any application from many alternative materials on the basis of different criteria is a Multiple Criteria Decision-Making (MCDM) problem. In the past, several researchers used different MCDM approaches to various areas such as engineering, science, management etc. [4]-[8]. Among them, Vise Kriterijumska Optimizacija Kompromisno Resenje (VIKOR) and Analytical Hierarchy Process (AHP) are two popular ones. VIKOR is a quite simple ranking method used to rank a finite set of alternatives [9]. AHP used to determine the weights of a set of performance defining criteria's (PDCs) and widely applied for the selection of friction material formulation [10]-[13]. How-ever, nothing has been reported on VIKOR method for the assessment of friction materials. The target of this paper is to find most desirable friction formulation by VIKOR method which is strengthened by AHP for the estimation of weights.

Materials and Methods Fabrication of composites: Friction composite materials based on straight phenolic resin of Novolac type, Kevlar pulp, Lapinus fibre, barites, graphite, nanoclay and multiwalled carbon nanotubes amounting to 100% by weight were fabricated. The compositional variations and the designation of the composites are given in Table 1. Detail of the processing conditions for composite fabrication is briefly reported in our earlier publications [15], [16].

Table 1: Details of friction material designation and composition

	Friction material designation			
Composition (wt.-%)	F_{NL}	F_{NT}	F_{NC}	F_{NCT}
PF Resin	15	15	15	15
$BaSO_4$	50	50	50	50
Kevlar Fibre	10	10	10	10
Lapinus Fibre	20	20	20	20
MWCNT	0	2	0	1
Nanoclay	0	0	2	1
Graphite	5	3	3	3

Tribo-performance evaluation methodology: In order to evaluate the tribological characteristics standard regulatory test PVW-3212 conforming to Economic Commission for Europe (ECE) regulation has been adopted and run on a Krauss type friction tester. The details of the machine and the protocol behind PVW-3212 standard reported elsewhere [14]-[16].

Compromise ranking method:'VIKOR' also known as compromise ranking method was mainly established by Zeleny [17]. The various steps for the

VIKOR methods are listed as follows:
Step-I: The alternatives and various PDCs are identified and a relative decision matrix is constructed. If the number of alternative is M and the number of performance defining criterion are N, then the decision matrix having an order of M × N is represented as:

$$D_{M\times N} = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1N} \\ x_{21} & x_{22} & \dots & x_{2N} \\ \vdots & \vdots & \dots & \vdots \\ x_{M1} & x_{M2} & \dots & x_{MN} \end{bmatrix} \quad (1)$$

Where, an element x_{ij} (for i=1, 2... M; j = 1, 2... N), of the decision matrix $D_{M\times N}$ represents the actual value of the i[th] alternative in term of j[th] PDC.
Step II: After the development of decision matrix, values of benefit $(x_{ij})_{\max}$ and cost $(x_{ij})_{\min}$ criterion is obtained as:

$$(x_{ij})_{\max} = {}^{\max}_{i} x_{ij} = \max\left[x_{ij},\, i = 1, 2 \ldots M\right]$$
$$(x_{ij})_{\min} = {}^{\min}_{i} x_{ij} = \min\left[x_{ij},\, i = 1, 2 \ldots M\right] \quad (2)$$

Step III: The weight (w_j) of the PDC which is calculated by AHP method reported elsewhere [11], [12].
Step IV: The values of utility measure (E_i) and regret measure (F_i) are calculated as:

$$E_i = \sum_{j=1}^{N} \frac{w_j\left[(x_{ij})_{\max} - x_{ij}\right]}{\left[(x_{ij})_{\max} - (x_{ij})_{\min}\right]},\ if\ \ j\ is\ benefit\ criteria$$
$$E_i = \sum_{j=1}^{N} \frac{w_j\left[x_{ij} - (x_{ij})_{\min}\right]}{\left[(x_{ij})_{\max} - (x_{ij})_{\min}\right]},\ if\ \ j\ is\ cost\ criteria, \text{for } j = 1, 2\ldots N \quad (3)$$

$$F_i = Max^x\ of\ \left\{\frac{w_j\left[(x_{ij})_{\max} - x_{ij}\right]}{\left[(x_{ij})_{\max} - (x_{ij})_{\min}\right]}\right\}, \text{for } j = 1, 2\ldots N \quad (4)$$

Step V: Value of VIKOR index (P_i) is calculated as:

$$P_i = \nu\left(\frac{(E_i - E_i^-)}{(E_i^+ - E_i^-)}\right) + (1-\nu)\left(\frac{(F_i - F_i^-)}{(F_i^+ - F_i^-)}\right) \quad (5)$$

Where, $E_i^+ = {}^{\max}_{i} E_i = \max\left[E_i,\, i = 1, 2 \ldots M\right]$

$E_i^- = {}^{\min}_{i} E_i = \min\left[E_i,\, i = 1, 2 \ldots M\right]$

$F_i^+ = {}^{\max}_{i} F_i = \max\left[F_i,\, i = 1, 2 \ldots M\right]$

$F_i^- = {}^{\min}_{i} F_i = \min\left[F_i,\, i = 1, 2 \ldots M\right]$

ν is introduced as weight for the maximum value of utility and $(1-\nu)$ is the weight of the individual regret and normally its value of ν is taken as 0.5.
Step VI: According to the value of VIKOR index (P_i) alternatives are arranged in the ascending order and the best alternative is the one having the minimum value of P_i.

Ranking of the alternatives: The experimental data of four alternatives against six PDCs as per evaluated on Krauss machine is listed in Table 2. The description of various PDCs for analysis purpose is listed in Table 3. The decision matrix from Eq. 1 is used for the VIKOR analysis. The values of utility measure (E_i), regret measure (F_i) and VIKOR index (P_i) is calculated by using Eq. 3-5 and the alternative with lower P_i value is chosen as the best alternative. The results are shown in Table 5 and depicted in Fig. 1.

Table 2: Experimental data of the PDCs as evaluated on a Krauss testing machine.

Composite designation	PDC-1 (μ_P)	PDC-2 (wear)	PDC-3 (μ_F)	PDC-4 (μ_R)	PDC-5 (DTR)	PDC-6 (μ_{max}-μ_{min})
F_{NL}	0.351	2.61	0.167	0.447	502	0.339
F_{NT}	0.313	2.25	0.184	0.446	457	0.337
F_{NC}	0.289	1.07	0.152	0.378	459	0.305
F_{NCT}	0.301	1.3	0.158	0.402	484	0.318
$(x_{ij})_{\max}$	0.351	2.61	0.184	0.447	502	0.339
$(x_{ij})_{\min}$	0.289	1.07	0.152	0.378	457	0.305
Weight, w_j	0.259	0.259	0.155	0.136	0.113	0.078

Table 3: Description of the different performance defining attributes.

Different PDCs	Implications of PDCs	Description of the individual PDCs
Friction Performance (μ_P)	PDC-1 Beneficial criteria	It is the average friction coefficient of cold, fade and recovery cycles.
Wear (gm)	PDC-2 Cost criteria	It is the progressive loss of the material from the surface during working.
Fade Performance (μ_F)	PDC-3 Beneficial criteria	It is the minimum coefficient of friction for the fade cycles taken after 270°C.
Recovery Performance (μ_R)	PDC-4 Beneficial criteria	It is the maximum coefficient of friction for the recovery cycle taken after 100°C.
Disc temperature rise (DTR) °C	PDC-5 Cost criteria	It is the maximum disc temperature rise during braking.
Friction Fluctuation (μ_{max}-μ_{min})	PDC-6 Cost criteria	It is the difference between the maximum and minimum coefficient of friction.

Table 4: E_i, F_i, P_i values and ranking of the alternatives.

Alternatives	E_i	F_i	P_i	Ranking
F_{NL}	0.447	0.259	0.6570	3
F_{NT}	0.399	0.198	0.0000	1
F_{NC}	0.553	0.259	0.9995	4
F_{NCT}	0.517	0.209	0.4721	2

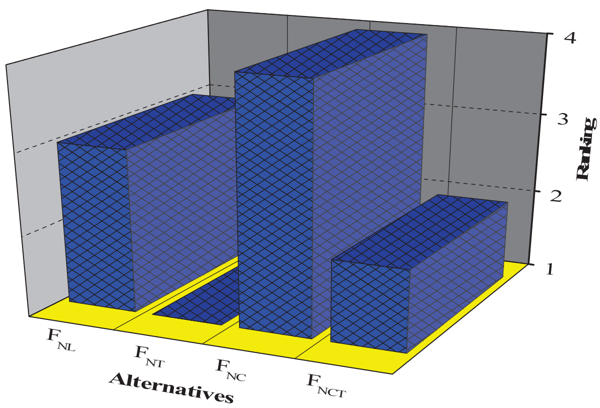

Figure 1. Ranking of the alternatives.

Conclusions: The selection of optimal friction material formulation on tribological properties of lapinus/Kevlar fibers reinforced and nanofilled phenolic composites was carried out in this work. The tribological results obtained from Krauss type tester were considered as criterions in the performance assessment of friction materials. The AHP method, introduced to calculate the weight for each criterion. Compromised ranking (VIKOR) method strengthened with AHP is used to rank the alternatives; the order of alternatives could be obtained as F_{NT}>F_{NCT}>F_{NL}>F_{NC}. The alternative F_{NT} of 2 wt.-% MWCNT exhibits the optimal properties. The study shows that VIKOR method should be helpful in the optimal friction formulation selection without performing long and costly experiments.

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