safety to the passengers by dissipating some failure effects into plastic deformation. The young's modulus is a material property representing the stiffness of a material. This property remains constant for isotropic material and varies for an anisotropic material. To get a more reliable result of material selection, most of the researchers have used more than one MCDM approach[7,8]. Many researchers have used the TOPSIS and MOORA methodology in various material selection problems as discussed in the literature part. Integrated TOPSIS MOORA methodology has been used for the new product selection[9]. For the first time, both these approaches have been applied simultaneously for the material selection of crankcase cover in the automobile industry. The first objective of the study is to find out the best material for the two-wheeler crankcase cover in the automobile industry. The second objective is to compare and validate the results by other MCDM approaches such as MOORA, reference point approach, and PROMETHEE with greater accuracy.

The material selection problem is considered an MCDM problem and it is solved by considering all multiple conflicting criteria[10]. Milani *et al.*[11] has applied the MCDM approach for material selection of plastic gear with the life cycle assessment. Gupta[12] has used the MADM approach for the material selection problem of thin-film solar cells. Bhowmik *et al.*[13] has adopted the TOPSIS technique for energy-efficient material selection and used sensitivity analysis for validating the results. Jajimoggala *et al.*[14] has utilized an MCDM approach for the material selection of impellers using the TOPSIS technique. Okokpujie *et al.*[15] has utilized the AHP and TOPSIS technique for wind turbine blade material selection. Aly *et al.*[16] has proposed an integrated fuzzy geometric mean method TOPSIS model for material selection and design concept. Kelemenis *et al.*[17] has adopted the TOPSIS technique for personnel selection and enhanced the organization's performance. Tiwary *et al.*[18] has utilized the fuzzy TOPSIS for the parameter selection of the micro-EDM process.

Mousavi-Nasab *et al.*[8] has adopted MCDM approaches such as DEA (Data Envelopment Analysis), TOPSIS, and COPRAS for material selection problems. Zanakis[19] has analyzed the performance using a simulation comparison of ELECTRE, TOPSIS Multiplicative Exponential Weighting, Simple Additive Weighting, and AHP. Dagdeviren[5] has selected the best equipment among many alternatives using the AHP and PROMETHEE and this proper selection has increased productivity, flexibility, precision, and product quality.

Anoj kumar *et al.*[20] has adopted the comparative MCDM analysis approach for material selection of pipes in the sugar industry. Shanian *et al.*[3] has applied the TOPSIS technique for material selection of metallic bipolar plates. Dursun *et al.*[16] has employed a fuzzy COPRAS method for material selection for the detergent manufacturers. Ashby *et al.*[21] has described that there is a material selection option is between 40,000 to 80,000 and almost 1000 ways to process them which have shown that the material selection problems are complex and challenging. They have also shown the selection strategies for materials and processes. Chatterjee *et al.*[22] has used the COPRAS and ARAS (additive ratio assessment) techniques for gear material selection. Chatterjee *et al.*[23] has also applied the four MCDM techniques together for gear material selection problems. These Four MCDM techniques are extended PROMETHEE II, COPRAS, ORESTE (Organization, Rangement Et Syn- these De Donnes Relationnelles), and operational competitiveness rating analysis (OCRA) methods. Athawale *et al.*[24] has solved the material selection problems using the utility additive (UTA) method. UTA method is one type of MCDM tool used for solving the various complex material selection problems. Chakraborty *et al.*[25] has applied the three MCDM approaches such as TOPSIS, VIKOR, and PROMETHEE for five material selection problems. They have also shown that the choices of the final selection depend on the criteria weights. Maity *et al.*[26] used the fuzzy TOPSIS for material selection of grinding wheel abrasive. Ilangkumaran *et al.*[27] has adopted the hybrid MCDM approach for material selection of automobile bumpers. They have applied the Fuzzy AHP, PROMETHEE I, and PROMETHEE II for ranking of the materials. Chakraborty[28] has considered the MOORA methodology for robot selection, flexible manufacturing system selection, CNC machine selection, and manufacturing process selection in the manufacturing environment.

The past studies have shown that most of the researchers have successfully applied the MCDM approach to solving the material selection problem. After reviewing the existing literature, it has been found a material selection of crankcase cover in the automobile industry is an untouched area of research. This is our motivation to find out the best material for

Fig. 2 — Material Selection criteria of TOPSIS.

$$x_{ij}^* = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad ...(2)$$

Step 3 - Calculate the weighted decision matrix d_{ij} using Eq. 3.

$$d_{ij} = w_j \times x_{ij}^* \quad ...(3)$$

Step 4 - Find the Positive Ideal Solution A^+ and Negative Ideal Solution A^-

$$A^+ = \{d_1^+, d_2^+ ...., d_n^+\}, \text{where}: d_j^+ \quad ...(4)$$

$$= \{(\max i \ (d_{ij}) \ if \ j \in K); (\min i \ (d_{ij}) \ if \ j \in K')\}$$

$$A^- = \{d_1^-, d_2^- ...., d_n^-\}, \text{where}: d_j^- \quad ...(5)$$

$$= \{(\min i \ (d_{ij}) \ if \ j \in K); (\max i \ (d_{ij}) \ if \ j \in K')\}$$

where, K and K' are beneficial and the non-beneficial based attributes in Eqs 4-5[35].

Step 5 - Calculate the separation distances $(S^+ \& S^-)$ of each alternative from ideal and non-ideal solutions using Eqs 6-7.

$$S^+ = \sqrt{\sum_{j=1}^{n} (d_j^+ - d_{ij})^2} \quad ...(6)$$

$$S^- = \sqrt{\sum_{j=1}^{n} (d_j^- - d_{ij})^2} \quad ...(7)$$

Step 6 - Measure the relative closeness C_i values using the Eq. 8.

$$C_i = \frac{S_i^-}{S_i^+ + S_i^-}, \ 0 \le C_i \le 1 \quad ...(8)$$

Step 7 - Based on the relative closeness values, a ranking of alternatives is obtained.

2.2 MOORA methodology

MOORA methodology is a multi-objective optimization technique which is preferred than other MCDM approach because of its fast computational time. MOORA methodology consists of two components. The first one is the ration system developed in 2004 by Brauers and the other reference point approach developed in 2006 by Brauers and Zavadskas. This technique is used in solving the various complex decision-making problems[33,34]. This technique can optimize the two or more conflicting criteria at the same time e.g. minimize cost and maximize profit[24]. The methodology of MOORA is as follows:

Step 1 - Find the decision matrix X in which x_{ij} shows performance index of i_{th} alternative w.r.t j_{th} attribute, i = 1, 2, …, m and j = 1, 2, …, n using Eq. 1.

Step 2 - Find normalized decision matrix x_{ij}^* using Eq. 2.

Step 3 - The overall performance score of each alternative y_i^* is calculated by adding all beneficial criteria and subtracting the non-beneficial criteria as given in Eq. 9.

$$y_i^* = \sum_{j=1}^{q} x_{ij}^* - \sum_{j=q+1}^{n} x_{ij}^* \quad ...(9)$$

Here, q and (n-q) are the number of beneficial and non-beneficial criteria respectively. Equation 10 can be used for giving weights to the different criteria[4,28].

$$y_i^* = \sum_{j=1}^{q} w_j x_{ij}^* - \sum_{j=q+1}^{n} w_j x_{ij}^* \quad ...(10)$$

Step 4 - The ranking of alternatives is obtained using y_i^* values from equations 9-10.

The above four steps show the calculation of the ration system part of the MOORA method. The reference point part is shown in steps 5 and 6.

Step 5 - Determine the Tche by cheff Min–Max metric[34].

$$\min_i \{ \max_j |s_j - x_{ij}^*| \} \quad ...(11)$$

s_j is the j_{th} coordinate of the reference point which shows those alternatives having the most desirable performances concerning j_{th} criterion. For determining s_j , Eq. 12 can be used. Equation 13 can be used in the case of assigning weights to alternatives.

$$s_j \begin{cases} \max_i x_{ij}^* \\ \min_i x_{ij}^* \end{cases} \quad ...(12)$$

$\max x_{ij}^*$ represents beneficial criteria & $\min x_{ij}^*$ represents non-beneficial criteria.

$$\min_i \{ \max_j |w_j s_j - w_j x_{ij}^*| \} \quad ...(13)$$

Step 6 - Finally, the selection of alternatives is done using the minimum deviation value from reference point[24].

2.3 PROMETHEE Methodology

PROMETHEE is an MCDM method developed by Brans *et al.*[35,36]. PROMETHEE methodology is classified into two types PROMETHEE I and PROMETHEE II. PROMETHEE I is used for obtaining the partial ranking of alternatives whereas PROMETHEE II provides the full ranking of alternatives.

The aggregated preference index of 'a' over 'b' is represented by $\pi(a,b)$ for each alternative a, belonging to the set A of alternatives. The leaving flow $\varphi^+(a)$ and the entering flow $\varphi^-(a)$ show the positive and negative dominancy of alternative 'a' on all another alternative.

The methodology of PROMETHEE II is described as follows.

Step 1 - Normalize the evaluation matrix or decision matrix (R_{ij})

$$R_{ij} = \frac{[x_{ij} - \min(x_{ij})]}{[\max(x_{ij}) - \min(x_{ij})]} \quad ...(14)$$

$$R_{ij} = \frac{[\max(x_{ij}) - x_{ij}]}{[\max(x_{ij}) - \min(x_{ij})]} \quad ...(15)$$

Where, i=1, 2, …, m; j=1, 2,…, n. Equations 14-15 are applicable for beneficial and non-beneficial criteria respectively.

Step 2 - Calculate the evaluative differences of i^{th} alternative concerning other alternatives

Step 3 - Calculate the preference function $P_j(s,t)$ using equations 16-17.

$$P_j(s,t) = 0 \quad \text{if } R_{sj} \le R_{tj} \quad ...(16)$$

$$P_j(s,t) = (R_{sj} - R_{tj}) \quad \text{if } R_{sj} > R_{tj} \quad ...(17)$$

Step 4 - Determine the aggregated preference function $\pi(s,t)$

$$\pi(s,t) = \left[\frac{\sum_{j=1}^{n} W_j P_j(s,t)}{\sum_{j=1}^{n} W_j} \right] \quad ...(18)$$

Step 5 - Calculate the leaving and the entering outranking flows

Leaving flow for s^{th} alternative

$$\varphi^+ = \frac{1}{m-1} \sum_{t=1}^{m} \pi(s,t) \qquad (s \ne t) \quad ...(19)$$

Entering flow for s^{th} alternative

$$\varphi^{-} = \frac{1}{m-1}\sum_{t=1}^{m} \pi(t,s) \qquad (s \neq t) \qquad ...(20)$$

where, m is the number of alternatives in equations 19-20.

Step 6 - Calculate the net outranking flow $\varphi(s)$ for each alternative

$$\varphi(s) = \varphi^{+}(s) - \varphi^{-}(s) \qquad ...(21)$$

Step 7 - Determine the ranking of alternatives based on the net outranking flow value $\varphi(a)$.

2.4 Application of TOPSIS-PROMETHEE-MOORA model

In this study, seven attributes are considered and these attributes are of different types, among these six attributes belong to the category of beneficial criteria and there is only one non-beneficial criterion. The beneficial criteria are Brinell hardness (C_1), yield strength (C_2), % elongation (C_3), tensile strength (C_4), young's modulus (C_5), and fatigue strength (C_6) whereas the material cost (C_7) is the non-beneficial criteria. This study aims to maximize the beneficial criteria and minimize the non-beneficial criteria. The conflicting criteria are optimized using the Integrated TOPSIS MOORA approach. The Specification parameter values of various Aluminum Alloys as collected from the literature review are shown in Table 1. This entire numerical value used in Table 1 is converted to an approximate score out of 10 as shown in Table 2.

3 Results and Discussion

Steps 1 and 2 are common in TOPSIS and MOORA methodology which give the same value of decision matrix and normalized decision matrix as given in Tables 1 and 2 respectively. In this study, equal weightage is given to all the criteria. Thus, the weighted normalized decision matrix for crankcase cover material selection is the same as the normalized decision matrix. For the calculation of ranking of the alternatives using the TOPSIS technique, separation distances of alternatives $(S^{+} \& S^{-})$ from the positive ideal and negative ideal solution is calculated using equations 6-7. Based on these separation distance values, the relative closeness of each alternative to the ideal solution C_i is determined using Eq. 8. The final ranking using the TOPSIS methodology ($A_3 > A_2 > A_4 > A_1 > A_5 >$ A6) is obtained using the decreasing order of these C_i values. For the calculation of ranking of alternatives using the MOORA methodology, the first $\sum_{j=1}^{q} x_{ij}^{*}$ value is obtained by adding weighted normalized values of six beneficial criteria which are brinell hardness, yield strength, % elongation, ultimate tensile strength, young's modulus, and fatigue strength.

Similarly, $\sum_{j=q+1}^{n} x_{ij}^{*}$ represents the material cost which is a non-beneficial criterion in this study. The final ranking of the crankcase cover (A3 > A5 > A2 > A4> A1 > A6) is decided by the overall performance score which is represented by y_i^{*}. Since the number of

Table 1 — Specification parameter of various aluminum alloys

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
A_1	75	172	2.5	303	71	138	1490.52
A_2	80	159	3.5	317	71	138	1478.20
A_3	80	159	3.5	324	71	138	1355.02
A_4	75	152	3.5	310	71	145	1478.20
A_5	120	248	<1	317	81	138	1724.57
A_6	80	145	2.5	296	71	131	1847.75

Table 2 — Decision and weighted normalized decision matrix using TOPSIS-MOORA

	C1	C2	C3	C4	C5	C6	C7
A1	6.00	6.88	6.25	9.18	8.66	9.20	7.84
A2	6.40	6.36	8.75	9.61	8.66	9.20	7.78
A3	6.40	6.36	8.75	9.82	8.66	9.20	7.13
A4	6.00	6.08	8.75	9.39	8.66	9.67	7.78
A5	9.60	9.92	2.00	9.61	9.88	9.20	9.08
A6	6.40	5.80	6.25	8.97	8.66	8.73	9.73
A_1	0.35	0.40	0.35	0.40	0.40	0.41	0.39
A_2	0.38	0.37	0.49	0.42	0.40	0.41	0.38
A_3	0.38	0.37	0.49	0.42	0.40	0.41	0.35
A_4	0.35	0.35	0.49	0.41	0.40	0.43	0.38
A_5	0.57	0.57	0.11	0.42	0.45	0.41	0.45
A_6	0.38	0.34	0.35	0.39	0.40	0.39	0.48

Table 3 — Normalized decision matrix using PROMETHEE

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
A_1	0.000	0.262	0.615	0.250	0.000	0.500	0.725
A_2	0.111	0.136	1.000	0.750	0.000	0.500	0.750
A_3	0.111	0.136	1.000	1.000	0.000	0.500	1.000
A_4	0.000	0.068	1.000	0.500	0.000	1.000	0.750
A_5	1.000	1.000	0.000	0.750	1.000	0.500	0.250
A_6	0.111	0.000	0.615	0.000	0.000	0.000	0.000

Table 4 — Ranking of alternatives using reference point approach

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	P_i	Rank
A_1	0.213	0.176	0.141	0.028	0.056	0.021	0.035	0.213	2
A_2	0.189	0.206	0.000	0.009	0.056	0.021	0.032	0.206	1
A_3	0.189	0.206	0.000	0.000	0.056	0.021	0.000	0.206	1
A_4	0.213	0.222	0.000	0.019	0.056	0.000	0.032	0.222	3
A_5	0.000	0.000	0.382	0.009	0.000	0.021	0.096	0.382	5
A_6	0.189	0.239	0.141	0.037	0.056	0.042	0.128	0.239	4

Table 5 — Ranking of the alternatives using TOPSIS-MOORA-PROMETHEE method

	S^+	S^-	C_i	TOPSIS Ranking	$\sum_{j=1}^{q} x_{ij}^*$	$\sum_{j=q+1}^{n} x_{ij}^*$	y_i^*	MOORA Ranking	$\varphi^+(s)$	$\varphi^-(s)$	$\varphi(s)$	PROMETHEE Ranking
A_1	0.319	0.267	0.455	4	2.311	0.387	1.924	5	0.615	1.410	0.795	5
A_2	0.288	0.398	0.580	2	2.464	0.384	2.080	3	1.094	0.776	0.318	4
A_3	0.286	0.408	0.588	1	2.473	0.352	2.121	1	1.594	0.676	0.918	2
A_4	0.315	0.397	0.558	3	2.436	0.384	2.052	4	1.372	0.969	0.403	3
A_5	0.394	0.329	0.455	5	2.534	0.448	2.086	2	3.263	1.441	1.822	1
A_6	0.368	0.242	0.397	6	2.242	0.480	1.762	6	0.167	2.834	2.666	6

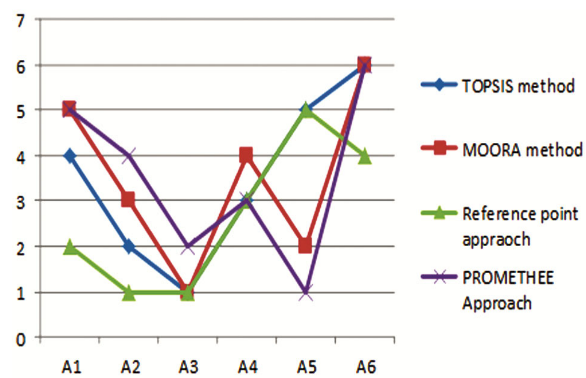

Fig. 3 — Rankings of the alternatives for material selection.

beneficial criteria is more than the number of non-beneficial criteria, so the overall performance score becomes positive. The final ranking of crankcase cover using the reference point method is ($A_3 = A_2 > A_1 > A_4 > A_6 > A_5$).

PROMETHEE approach shows the final ranking $A_5 > A_3 > A_4 > A_2 > A_1 > A_6$. All the above approaches except PROMETHEE represents the aluminum alloy A380 (A_3) is the best material for crankcase cover. Figure 3 shows the final ranking of alternatives using the TOPSIS, MOORA, reference point approach, and PROMETHEE. The final ranking of alternatives obtained using these approaches are shown in Tables 4 and 5.

4 Conclusion

In this study, a comparative analysis of MCDM approaches such as TOPSIS-PROMETHEE-MOORA methods has done for material selection of a two-wheeler crankcase cover in the automobile industry. Results of TOPSIS methodology have concluded that the aluminum alloy A380 (A3) is the best material for the two-wheeler crankcase cover in the automobile industry. This result has compared and validated by the multi-objective optimization by ration analysis (MOORA) and reference point approach with greater accuracy. MOORA approach is very simple and easy to implement as compared to the other MCDM approaches. MOORA approach has not given accurate results when large numbers of qualitative attributes are present. Limitations of this type of study are uncertainty in the decision-making process arises due to uncertainties in the input data and it is also difficult to show the performance of most alternatives by single numerical data. TOPSIS technique has not considered the correlation of the attributes. The proposed integrated model is a simple, easy to implement, and efficient tool for decision-makers. This novel TOPSIS-PROMETHEE-MOORA method can also be utilized for other material selection problems in the automobile industry. The results obtained in this study are valuable for all automobile industries and research organizations. This study can be further extended by applying other remaining MCDM approaches.

References

1 Aly M F, Attia H A, & Mohammed A M, *Int J Innov Res Sci Eng Technol*, 2 (2013) 6464.
2 Anojkumar L, Ilangkumaran M, & Sasirekha V, *Expert Syst Appl*, 41 (2014) 2964.
3 Ashby M F, Cebon D, & Salvo L, *Mater Des*, 25 (2004) 51.

4 Athawale V M, Kumar R, & Chakraborty S, *Int J Adv Manuf Technol*, 57 (2011) 11.
5 Bhowmik C, Gangwar S, & Bhowmik S, *Stud Comput Intell,* 761 (2018) 59-79.
6 Brans J P, & Vincke P , *Manage Sci*, 31 (1985) 647.
7 Brans J P, Vincke P, & Mareschal B, *Eur J Oper Res*, 24 (1986) 228.
8 Brauers W K, Optimization Methods for a Stakeholder Society (Kluwer Academic, Boston) 2004th Edn, ISBN-13: 978-1402076817
9 Brauers W K M, & Zavadskas E K, *Control Cybern*, 35 (2006) 445.
10 Chakraborty S, *Int J Adv Manuf Technol*, 54 (2011) 1155.
11 Chakraborty S, & Chatterjee P, *Decis Sci Lett*, 2 (2013) 135.
12 Chatterjee P, *Int J Mater Sci Eng*, 1 (2013) 104.
13 Chatterjee P, & Chakraborty S, *Mater Des*, 35 (2012) 384.
14 Chawla S, Agrawal S, & Singari R M, *Lecture Notes in Mechanical Engineering,* (Springer, Singapore), ISBN: 978-981-13-6468-6, 2019, p.755-765.
15 Dagdeviren M, *J Intell Manuf*, 19 (2008) 397.
16 Dursun M, & Arslan O, *Symmetry (Basel)*, 10 (2018) 1.
17 Edwards K L, *Mater Des*, 26 (2005) 469.
18 Gupta N, *Mater Des*, 32 (2011)1667.
19 Ilangkumaran M, Avenash A, Balakrishnan V, Kumar B, & Raja M B, *Int J Ind Syst Eng*, 14 (2013) 20.
20 Ipek M, Selvi I H, Findik F, & Torkul O, *Mater Des*, 47 (2013) 331.
21 Jahan A, Bahraminasab M, & Edwards K L, *Mater Des*, 35 (2012) 647.
22 Jahan A, Ismail M Y, Sapuan S M, & Mustapha F, *Mater Des*, 31 (2010) 696.
23 Jajimoggala S, & Karri R R, *Int J Appl Decis Sci*, 6 (2013) 144.
24 Karande P, & Chakraborty S, *Mater Des*, 37 (2012) 317.
25 Kelemenis A, & Askounis D, *Expert Syst Appl*, 37 (2010) 4999.
26 Liu H, Liu L, & Wu J, *Mater Des*, 52 (2013) 158.
27 Maity S R, & Chakraborty S, *Mater Manuf Process*, 28 (2013) 408.
28 Milani A S, Eskicioglu C, Robles K, & Bujun K, *eXPRESS Polym Lett*, 5 (2011) 1062.
29 Mousavi-nasab S H, & Sotoudeh-anvai A, *Mater Des*, 121 (2017) 237.
30 Okokpujie I P, Okonkwo U C, Bolu C A, Ohunakin O S, Agboola M G, & Atayero A A, *Heliyon*. 6 (2020) 1.
31 Rai D, Jha G K, Chatterjee P, & Chakraborty S, *Univers J Mater Sci*, 1 (2013) 69.
32 Rao R V, & Patel B K, *Mater Des*, 31 (2010) 4738.
33 Shanian A, & Savadogo O, *J Power Sources*, 159 (2006) 1095.
34 Tiwary A P, Pradhan B B, & Bhattacharyya B, *Adv Manuf*, 2 (2014) 251.
35 Wang L, Chu J, & Wu J, *Int J Prod Econ*, 107 (2007) 151.
36 Yurdakul M, & Tansel Y, *J Mater Process Technol*, 209 (2009) 310.
37 Zanakis S H, Solomon A, Wishart N, & Dublish S, *Eur J Oper Res*, 107 (1998) 507.