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Multi-Criteria Decision-Making Technique for Optimal Material Selection of AA7075/SiC Composite Foam using COPRAS Technique

Nitish Kumar Singh[1,2]*, S. Balaguru[2], Ram Krishna Rathore[3], Avinash Kumar Namdeo[1,4], Amit Kaimkuriya[2]

[1]*Department of Mechanical Engineering, Lingaya's Vidyapeeth, Faridabad - 121001, Haryana, India; hknitish@gmail.com*

[2]*School of Mechanical Engineering, VIT Bhopal University, Sehore - 466144, Madhya Pradesh, India*

[3]*Department of Mechanical Engineering, RCET, Bhilai - 492099, Chhattisgarh, India*

[4]*iNurture Education Solutions Pvt. Ltd., Bengaluru - 560052, Karnataka, India*

Abstract

Aluminium foams have been manufactured and discovered to have a variety of uses in automotive and structural applications. However, due to their varied characteristics, it is difficult to choose an appropriate material. In this context, the selection of material for good properties is a challenging task. This study attempted to identify materials from various combinations employing the Multiple Attribute Decision Making (MADM) technique based on their mechanical and physical properties. Complex Proportional Assessment (COPRAS) is a Multi-Criteria Decision Making (MCDM) technique employed for evaluating the ranking order of the aluminium composite foam's formulations based on performance measures. The composite foam with 2.5 wt.% of Calcium carbonate as foaming agent demonstrated the best combination of mechanical properties.

Keywords: *AA7075/SiC, Aluminium Composite Foam, CaCO3, COPRAS, Foaming Agent, MCDM*

1.0 Introduction

Aluminium foams offer exceptional mechanical, electrical, and corrosion resistance. As a result, they constitute the main constituent in the majority of current industrial applications, particularly in the automotive, aerospace, marine, and other analogous sectors[1-3]. These days, attention is being drawn to particle-reinforced metal matrix composite foam, which has superior physical and mechanical properties and is used in a variety of applications[4-6]. For a favourable outcome and improved performance of aluminium metal matrix composite foam, proper consideration of the reinforcing phase and manufacturing technique/parameters is required[7-9]. The design professional finds it difficult to choose a material for a certain application when there are several possibilities available. As a result, Multi Criteria Decision Making (MCDM) techniques may be used in combination with other quantitative decision-making abilities. In order to understand and use these methods in their research, several material scientists and researchers have tried adopting these methodologies from earlier literature. Sharma *et al.*,[10] presented a comprehensive description of several Multi-Criteria Decision Making (MCDM) strategies. Several quantitative approaches for identifying the most appropriate material were thoroughly explained and material ranking-based tools

**Author for correspondence*

like TOPSIS, VIKOR, COPRAS, and PROMETHEE for ranking based on properties of AA8081 reinforced with various weight percentages of Si_3N_4. Chauhan *et al.,*[11] provided the combined effect of VIKOR-TOPSIS for the selection of magnetic materials. Singh *et al.*,[12] optimize the process parameter of the welding process. Assigning weights to criteria is a crucial step that must be computed in most MCDM models since it strongly influences the result. In the literature, a number of weighting techniques have been suggested[13]. Entropy, standard deviation, and the mean weighting technique are frequently used in weighing procedures[14]. In this research standard deviation method was used to calculate the weight of different characteristics. Many scientists are working on closed-cell aluminium foam however, there is still a lack of study on Al composite foaming processes, restricting our understanding of the elements and characteristics that influence the generation of foams of consistent quality. Material selection for the production of composite foam plays an important role in the mechanical characteristics of the composite foam, which have a remarkable influence on its microstructure, compressive deformation, and energy absorption. Therefore, in this research, Multi attributes decision making COPRAS technique was implemented for the material selection of foam based on the effect of the foaming agent on the physical properties (density, porosity), compressive deformation mechanism (yield strength, plateau strength, and energy absorption capacity), and bending properties (flexural strength and bending stiffness).

2. Material and Method

2.1 Selection of Workpiece

The raw material utilized in this investigation was aluminium AA7075 alloy (the composition of AA70705 is illustrated in Table 1), with zinc as the primary alloying element and magnesium as the secondary alloying element. In comparison to aluminium and other series, AA7075 has superior mechanical strength and corrosion resistance, as well as excellent fatigue strength, creep resistance, and formability, as mentioned in our prior research[15,16].

2.2 COPRAS Method

Making better, more effective decisions on the materials requires taking into account a variety of criteria and structuring the components of complicated problems logically. MCDM is a decision-making tool that helps researchers to select the materials based on their performance criteria for optimal performance. From the available MCDM technique, the Complex Proportional Assessment (COPRAS) technique is a mathematical procedure used to solve problems with finite alternatives and competing criteria[17]. The COPRAS utilizes a sequential ranking and evaluating technique for the alternatives based on their relevance and utility level[18]. In the present study, the COPRAS decision making tool is used to identify the optimal composition and ranking among all of the produced composite foams. In the present study, the COPRAS decision making tool is used to identify the optimal composition and ranking among all of the produced composite foams in our previous study. Density, % porosity, hardness, flexure strength, bending stiffness were taken from our previous study[16] and plateau strength, compressive strength and energy absorption capacity were evaluated by using standard methodology.

The decision matrix (X_{ij}) was created using alternatives and criteria, where m and n are the number of choices and criteria, respectively. The matrix uses the structure shown below.

$$X_{ij} = \begin{matrix} X_{11} & X_{12} & X_1n \\ \cdots & \cdots & \cdot\cdot \\ X_{31} & X_{22} & X_1n \end{matrix} \tag{1}$$

After which standard deviation objective weighting method was employed for evaluating each criteria's weight (w_j) using Equation (2). Based on the weight of responses the Performance Defining Criteria (PDC) was decided for all responses which is shown in Table 3.

Table 1. Chemical composition of AA7075

Element	C K	Mg K	Al K	Si K	Ca K	Fe K	Cu K	Zn K
Weight %	2.1	3.81	86.18	0.75	0.06	0.82	0.76	5.52

$$W_j = \frac{c_j}{\sum_{k=1}^{m} c_j} \quad (2)$$

Where, $W_j \geq 0$ and $\sum_{k=1}^{m} c_j = 1$

The matrix was then normalized in order to remove the dimension of the values from the original matrix. The mathematical formula is provided by Equation (3).

$$\mathrm{R} = \left[r_{ij}\right]_{mn} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad (3)$$

The weighting of the normalized matrix came next, which included multiplying the allocated weights for each criterion by each of the values for each column. Computing the weighted normalized matrix using Equation (4) and tabulated in Table 4.

$$D = \left[y_{ij}\right]_{m\times n} = x_{ij} \times w_j \quad (4)$$

the total of P_j and R_j of attribute values for higher the better and lower the better qualities, respectively by using Equations (6) and (7) and tabulated in Table 5.

$$P_J = \sum_{i=1}^{k} \hat{y}_{+ij} \quad (5)$$

$$R_J = \sum_{i=1}^{k} y_{ij}^{\Lambda} \quad (6)$$

After that, the relative weight of each alternative was calculated by using Equation (7) and tabulated in Table 6.

Table 2. Aluminium matrix (AA7075) composite foam composition

Sample Nos.	Sample Names	Wt. % of foaming agent ($CaCO_3$)
1	ACFs -1	2
2	ACFs -2	2.5
3	ACFs -3	3

Table 3. Performance Defining Criteria (PDCs) for the evaluation/ranking of AA7075/SiC composite foam

S.N	Performance Defining Criteria (PDC)		Impact on PDC
	Response	Designation	
1	Density (g/cc)	PDC-1	Lower the better
2	% Porosity	PDC-2	Higher the better
3	Energy absorption (E_{ab}) (MJ/m^3)	PDC-3	Higher the better
4	Hardness (HRB)	PDC-4	Higher the better
5	Compressive strength (σ_c) (MPa)	PDC-5	Higher the better
6	Flexural strength (FS) (MPa)	PDC-6	Higher the better
7	Stiffness (KN/mm)	PDC-7	Higher the better
8	plateau strength (σ_{pl}) (MPa)	PDC-8	Higher the better

Table 4. Experimental Data

	Density[16]	Porosity[16]	E_{ab}	Hardness[16]	σ_c	FS[16]	Stiffness [16]	σ_{pl}
ACFs-1	1.15	59.43	0.91	61.29	24	240.23	21.53	18.2
ACFs-2	0.95	66.12	3.98	47.06	21.8	219.3	18.8	11.2
ACFs-3	0.88	68.68	5.63	37.5	21.35	214.23	19.04	19.23
Weight	0.1437	0.1433	0.1387	1.0385	0.1115	0.11	0.1089	0.1054

Table 5. Normalized matrix of the AA7075/SiC/ composite foams

Attributes Alternatives	Density	Porosity	E_{ab}	Hardness	σ_c	FS	Stiffness	σ_{pl}
ACFs -1	0.0555	0.0438	0.0120	0.4364	0.03985108	0.039221	0.039492	0.039446
ACFs -2	0.0458	0.0488	0.0525	0.3351	0.03619806	0.035804	0.034484	0.024274
ACFs -3	0.0424	0.0507	0.0742	0.2670	0.03545086	0.034976	0.034924	0.041678

Table 6. Ranking table with P_j, $R_{j,}$ Q_j and N_j

Alternatives	Larger the better Pj	Smaller the better Rj	1/RJ	Qj	Nj	Ranking
ACFs -1	0.6503	0.0555	18.0327	0.6111	0.313744	2
ACFs -2	0.5671	0.0458	21.8291	0.6166	0.324503	1
ACFs -3	0.5389	0.0424	23.5655	0.5923	0.311753	3

$$Q_j = P_j + \frac{\sum_{i-1}^{n} R_j}{R_l \sum_{i=1}^{n} k_j} \tag{7}$$

The quantitative utility N_j for the j^{th} option was calculated as the last step using Equation (8) and tabulated in Table 6:

$$N_j = \frac{Q_j}{Q_{max}} \times 100\% \tag{8}$$

here Q_{max} is the maximum relative significance. By calculating the direct significance of the alternatives, the selection process could be determined.

3.0 Result and Discussion

COPRAS multiple criterion decision-making methodology was used to determine the best combination of AA7075/7 wt. % SiC composite foams ACFs -1, ACFs -2, and ACFs -3 with 2, 2.5, and 3 wt. % foaming agents based on their mechanical and physical properties. Table 3 emphasizes performance-based composite foam decision-making factors. According to performance characteristics, the decision matrix is summarized in Table 4. By employing Equation (8) the decision matrix's attributed values were transformed in the common scale of 0-1, and the evaluated normalized decision matrix is showcased in Table 5. Table 5 contains the evaluated normalized decision matrix by using Equation (8), which was transformed to the common scale of 0-1 based on the decision matrix's attributed values. The standard deviation objective weighting approach was used to assess the weighted normalized matrix. Table 6 illustrates that ACFs -2 performed the best with an Nj value of 0.324503 to attain rank -1, followed by ACFs -1 with rank -2 (0.313744), and ACFs -3 with rank -3 (0.311753).

4.0 Conclusion

In this research work, the Performance Determining Criteria (PDC) measures like density, porosity, energy absorption, hardness, compressive strength, flexural strength, bending stiffness, and plateau strength of AA7075/SiC composite foam are analyzed using the COPRAS technique. The relative weight (of all properties was evaluated by using the standard deviation technique and it was found that density > % porosity > E_{ab} > Hardness > σ_c > FS > σ_{pl}. Based on physical and mechanical qualities, the COPRAS is used to determine the optimum option from the produced aluminium composite foam. The ranking order as per the COPRAS approach is ACFs-2 > ACFs-1 > ACFs-3. The results demonstrate that composite foam with 2.5 wt.% $CaCO_3$ foaming agent provided the best combination of physical and mechanical properties when compared to other produced composites foam. It is also demonstrated that the MCDM technique can be used as a powerful tool to obtain an optimal process parameter during the stir casting techniques of metal foam. In addition, dynamic testing under different strain rates has been offered for future studies.

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