Aherwar, A., Pruncu, C., & Mia, M. (2021). Optimal design based on fabricated SiC/B4C/Porcelain filled aluminium alloy matrix composite using hybrid AHP/CRITIC-COPRAS approach. Silicon. https://doi.org/10.1007/s12633-020-00916-1

Abstract

In this present study, SiC, B_4C and waste porcelain reinforced AA7075 alloy composites are fabricated by adopting stir casting approach. Twelve formulations based on different weight percentages of reinforcers (3 wt.%, 4.5 wt.%, 6wt.% and 7.5 wt.%.) were manufactured and afterward analysed in terms of physical, mechanical, corrosion and tribological performances. The reinforcers of less than 53 µm size were consistently blended in molten AA7075 accompanied by stirring process. To identify the best suitable formulation the density, hardness, tensile strength, compressive strength, flexural strength, friction coefficient, wear and corrosion rate were fixed as selection criteria. The composite containing 7.5 wt.% B_4C (ASBP-8) exhibited the highest mechanical strength (Hardness=162 Hv; Tensile strength= 298 MPa; Compressive strength= 221 MPa; and Flexural strength= 267 MPa), whereas wear performance (at 40N load and 1300 m SD= 0.00261 grams; and at 5.026 m/sec SV and 1300m SD= 0.0231 grams) and coefficient of friction (at 40N load and 1300 m SD= 0.536 grams; and at 5.026 m/sec SV and 1300m SD= 0.47 grams) remain the lowest for 6 wt.% porcelain (ASBP-11) based composites. The density and corrosion rate remains lowest for the composite containing 7.5 wt.% porcelain (ASBP-12).Since no single composite(ASBP-1 to ASBP-12) could merely satisfy all the desired characteristics; to this end, this study applied a novel hybrid AHP/CRITIC-COPRAS method for the selection of optimal alternative material for automotive components. The weight of each material evaluated was determined by establishing a criterion of importance by applying inter-criteria correlation (CRITIC) and analytic hierarchy process (AHP) methods. The alternative ranking was evaluated using the complex proportional assessment (COPRAS) method. The evaluation indicated that the AA7075 containing 7.5wt.% porcelain (ASBP-12) composite possesses the best material solution to be used in automotive applications.

Keywords: AA7075 alloy; Silicon carbide (SiC); B_4C; Porcelain; Aluminum- matrix composites

LIST OF ABBREVIATIONS

AMCs : Aluminum matrix composites

ASBP : Al-SiC-B_4C-Porcelain

MCDM : Multi Criteria Decision Making

COPRAS : Complex Proportional Assessment

CRITIC : Criteria Importance through Inter-criteria Correlation

AHP : Analytic Hierarchy Process

GM : Geometric Mean

UTM : Universal Testing Machine

TOPSIS : Technique for Order of Preference by Similarity to Ideal Solution

VIKOR : VlseKriterijumska Optimizacija I Kaompromisno Resenje in Serbian

GRA : Grey relational analysis

MDL : Modified Digital Logic

PSI : Preference Selection Index

SAW : Simple Additive Weighting

ELECTRE : ELimination and Choice Expressing the REality

MOORA : Multi objective optimization from ratio analysis

CR : Consistency ratio

RI : Random Consistency Index

1. Introduction

With increased pressure from the environmental agencies and government, the movement towards a greener world has forced the industries to invent and use advanced materials for mass utilization, one being the automobile body parts and components. Over a century, the uses of conventional metal-alloys for manufacturing the parts of the automobile vehicles are now challenged with the requirement to reduce the weight but exhibit performance that is unprecedented. This opposing nature expectation forced material scientists to invent materials with special benefits i.e., benefits of multiple materials in a single material package i.e., composite material. Reportedly the light in weight nature, lower friction, and higher resistance to wear and fracture, improved electrical resistance etc. are some typical advantageous roles of composite material.

Indeed, composite material came, and established its usability in key engineering sectors like automobile and aircraft industries, small-to-big structure etc. That said, lately, researches are carried out to find an appropriate material or to select the combination of materials to simultaneously ensure satisfactory multiple performance attributes. The two-phase composite material with weak matrix and strong reinforcement, a range of materials is possible to synthesize, and a large variation of composition is attainable. However, to have the right combination of materials and right composition of the ingredients is cumbersome and requires practicing of advanced mathematical techniques to propose such solution.

The aluminium metal matrix composite is renowned for its suitability in automotive parts [1] like pistons, high speed rotating shafts, brake and engine parts, piston rings and connecting rods etc. As reinforcer, the addition of SiC, TiO, B_4C, Al_2O_3, C (graphite) etc. is widely noted. Beside this list, the waste porcelain (P) has been tried and found effective owing to its good thermal and mechanical properties. Some researchers investigated the microstructural, mechanical performances, tribological, thermal, corrosion etc. for different composites materials in which some of them provided promising results while others were very limited in performances. Kumar et al.[2] has reported a review of the mechanical and tribological aspects of the AMC reinforced with varieties of elements. They have focused on the hardness, tensile strength, wear of the material, influential factors to cause performance improvement, behaviour under certain conditions like load, sliding distance, contact area etc. In a new dimension of review, Suthar and Patel [3] have reviewed the machining of AMC with the noting of its application and processing issues. Hariprasad et al. [4] investigated the hybrid composite with Al alloy as matrix incorporating B_4C, Al_2O_3 as reinforcement to obtain superior wear resistant materials. Increasing weight percentage of the reinforced elements caused an improvement of the wear resistance of the material.

In line with above work, we have investigated the potential of addition of three different reinforcements i.e., SiC, B_4C and waste porcelain (having different physical/mechanical/thermal properties) within various weight percentages into AA7075 alloy matrix then evaluated their performances (mechanical strength, friction and wear resistance and corrosion potential). The overall test matrix can enable multiple solution as candidate materials. To indicate the best option, it is of paramount importance to embed a criterion which leads to an appropriate solution. Multi criteria decision making (MCDM) was considered in this research as a robust tool and fast decision maker.

Several studies were implemented successfully by various researchers. They have investigated the ranking of optimization of composite materials by the evaluation of different option and leading to most appropriate one. The most criteria used was Fuzzy-TOPSIS, VIKOR, AHP,

GRA, DL, MDL, PSI, T-SAW, COPRAS ELECTRE, MOORA-fuzzy [5-14]. Dewangan et al.[10] applied Fuzzy-TOPSIS based MCDM approach for the optimization of parametric contribution of EDM process parameters on surface integrity and dimensional accuracy of tool material. Ahmed et al. [15] employed the fuzzy-AHP approach for the selection of regional aircraft for the Canadian airlines system wherein MCDM were considered. Rao [16] used graph theory combined with matrix method (GTMA) to select the best option when manufacturing process were optimized. Rajan and Narasimhan [17] presented a technique for material selection of rocket motors by applying weighted performance index values. Shanian and Savadogo [18] applied the ELECTRE (ELimination and Choice Expressing the REality) strategy to indicate an appropriate material used in manufacturing of thermal conductor component. Chatterjee et al. [19] solved the robot selection problems using two criteria VIKOR and ELECTRE II MCDM methods, and the results were compared. Karande and Chakraborty [20] used MOORA (multi objective optimization from ratio analysis) criterion to obtain an appropriate material for their problems. Hambali et al.,[21] identified the best automotive bumper material by using AHP (analytic hierarchy process) method. Yadav et al. [22] used an improved hybrid TOPSIS-PSI strategy to detect an appropriate material for marine application. Kumar et al.,[23] indicated an improved hybrid AHP-SAW strategy to detect an appropriate brake friction composite formulation. Maniya and Bhatt [6] evaluated three dissimilar materials applying PSI (preference selection index)strategy and validated the final ranking through using GTMA and TOPSIS method. Further, Ishizaka et al. [24] applied GAHPO (Groups Analytic Hierarchy Process Ordering) approach for selecting a novel production facilities. Satapathy et al. [25] applied ranking and balancing approach for design and selection of optimal composite for friction material.

To further improve the literature and provide a robust tool for material selection we have systematically investigated the benefits of COPRAS (complex proportional assessment) with CRITIC-AHP hybrid approaches to find the best candidate material which can solve the problem of automobile industry, decreasing the lightweight of cars which leads to lower energy consumption. This is because many researchers have implemented the weight criterions either by using the objective weight methods or the subjective weight methods for calculating the final rank of the alternatives, but the accuracy of their results were reduced. Apart from this, to our best knowledge, no literature study is available to reveal the final ranking of material/composite (AMCs) selection problem by considering the combined weights integrated by objective and subjective weights. CRITIC and AHP methods allow obtaining the weights of criterions (importance of material properties) in specific MCDM. The combination of these two methods of alternative ranking is possible by using COPRAS method. To prove the validity of this method, here we have manufactured different series of aluminium-matrix composites (AMCs) by liquid stir caste route with various weight percentages of reinforcers (SiC/B4C/Porcelain). Their performances were measured through experiments and ranking of each AMCs was performed using proposed AHP/CRITIC-COPRAS hybrid approach. Figure 1 shows the adopted methodology in this paper.

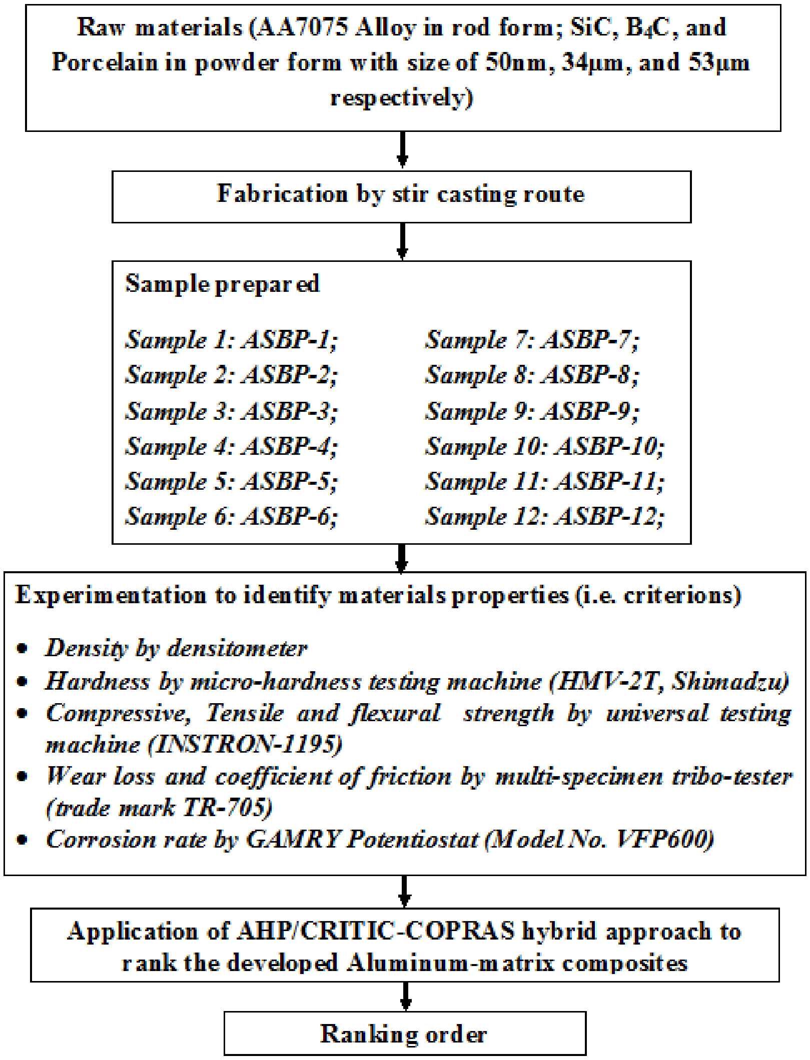


Figure 1: The steps taken in the methodology

2. Experimental work

2.1 Fabrication Details

Aluminium (AA-7075) with a density of 2.8g/cm^3 (provided by Nextgen steel and alloys, Mumbai, India) was used as a matrix material having composition of 5.3% Zn, 1.43% Cu, 0.11% Mn, 2.43% Mg, 0.43% Fe, and 0.22%Cr and the rest of 90.08% Al. Mesh sizes of B_4C(Theoretical density; 2.52 g/cm^3), SiC (Theoretical density; 3.21 g/cm^3) reinforcements are

50nm and 34µm (Procured from Savita Scientifics Product, Jaipur, India) and mesh size of waste porcelain (Theoretical density; 2.4 g/cm^3) is 53µm.Figure 2 shows the micrographs of B_4C, Porcelain, and SiC. Table 1 shows the sample code of different types of sample; these samples are used for investigation. Twelve different formulations using Al, SiC, B_4C, and porcelain were manufactured using mechanical stir casting process. In reference [26] was reported the conversion process of porcelain powder from scrap of porcelain insulator. The actual setup to fabricate the AMCs using the stir casting method is shown in Figure3.The sequences of activities performed for fabrication are listed below:

a) The graphite crucible is preheated (about 200°C) first to prevent oxidation of base material (i.e. aluminium alloy AA7075) and its easy melting.

b) Thereafter pieces of base material are put inside the graphite crucible. Further, crucible is heated till 820°C±20°C. This melts the base material.

c) The reinforcements (i.e., SiC, B_4C, and Porcelain) are added to the molten base alloy slowly and mechanical stirrer at 300 rpm is used to mix the ingredients at least for 12 minutes. To ensure proper wettability between ingredients 1wt.% magnesium powder is added to the mixture. Thus, homogeneity in the mixture is ensured.

d) Aluminium matrix-composites (AMCs) were prepared for 3wt.%, 4.5wt.%, 6wt.% and 7.5wt.% of SiC, B_4C, and Porcelain ceramics separately.

e) After successful addition of reinforcements, the alloy melt was poured into the mold (made of rectangular graphite) for solidification. The mold is kept in the room for 20 minutes to achieve proper curing.

f) When the room temperature of casting is obtained, the specimen samples are prepared as per characterization or testing methods with the help of diamond cutter. Figure 4 presents the flow chart which were followed to synthesize the aluminium-matrix composites.

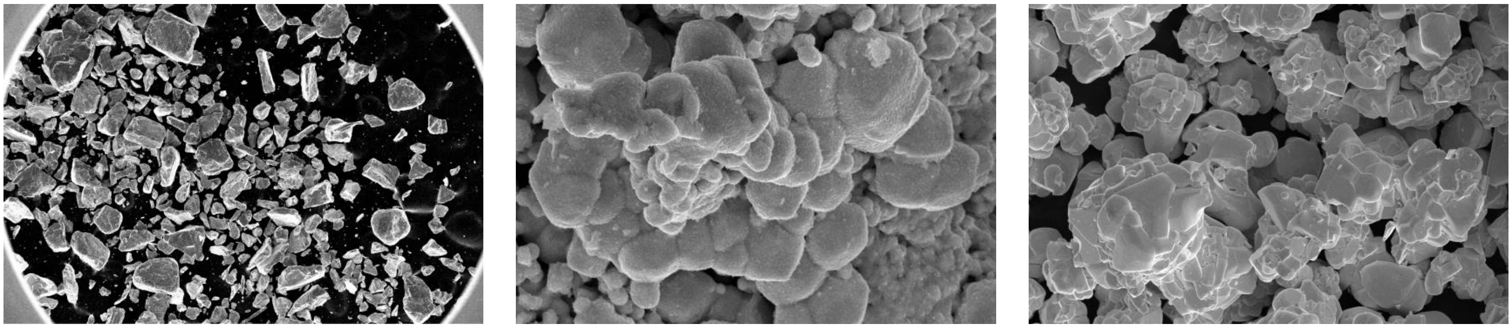

(a) **(b)** **(c)**

Figure2: FESEM micrograph of (a) SiC powder, (b) B_4C powder, and (c) Porcelain powder

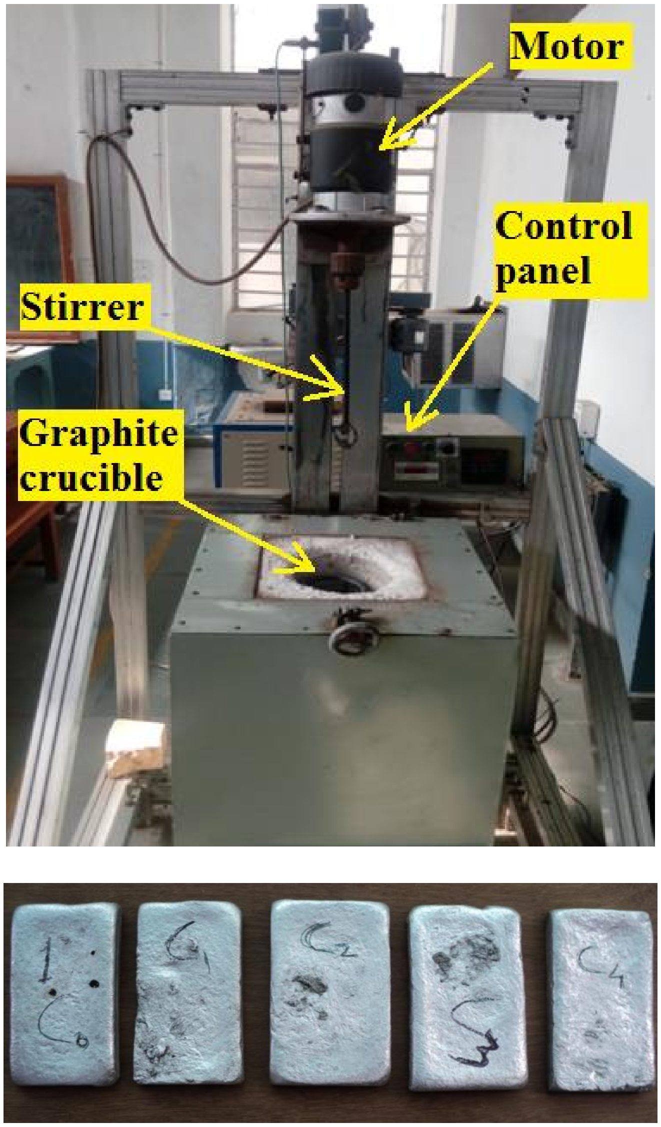


Figure3: Actual setup to fabricate the AMCs using the stir casting method and five images of casted samples

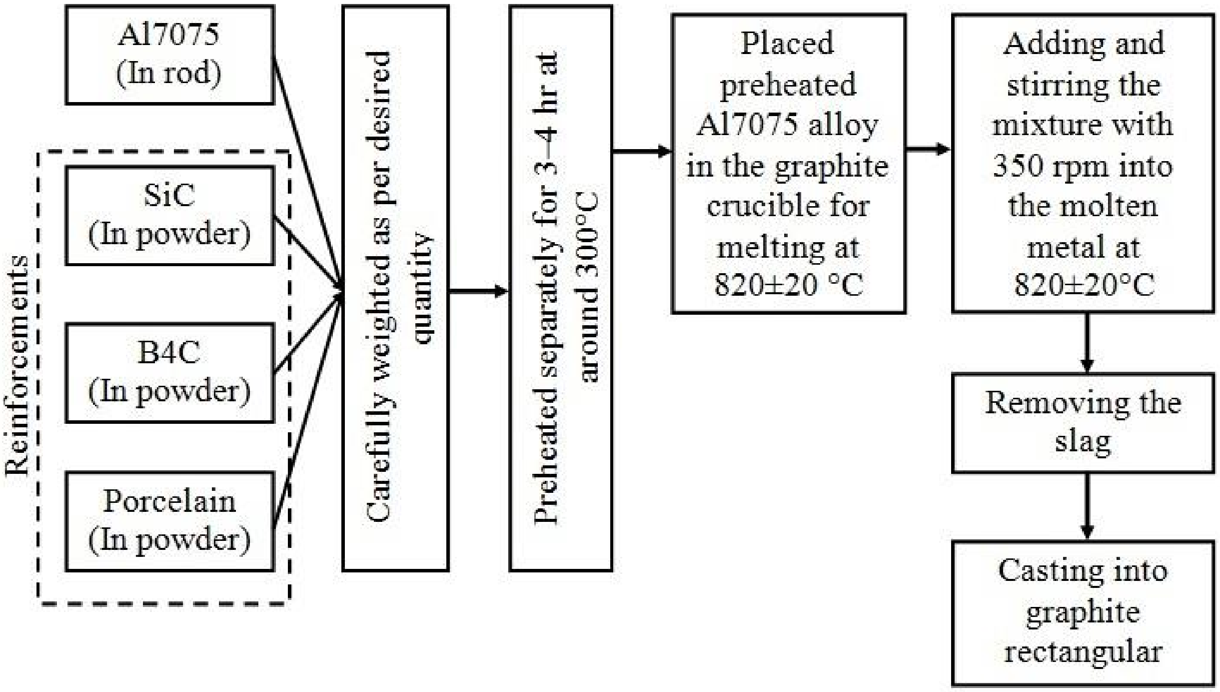


Figure 4: Synthesizing aluminium metal composites (AMCs)

Table 1: Grading of ASBP (Al-SiC-B_4C-Porcelain) composite specimens

Sample code	Composition (wt.%)			
	AA7075	SiC	B_4C	Porcelain
ASBP-1	Bal	3	0	0
ASBP-2	Bal	4.5	0	0
ASBP-3	Bal	6	0	0
ASBP-4	Bal	7.5	0	0
ASBP-5	Bal	0	3	0
ASBP-6	Bal	0	4.5	0
ASBP-7	Bal	0	6	0
ASBP -8	Bal	0	7.5	0
ASBP-9	Bal	0	0	3
ASBP-10	Bal	0	0	4.5
ASBP-11	Bal	0	0	6
ASBP-12	Bal	0	0	7.5

2.2 Evaluation of physical and mechanical strength

Density is a physical property of the material. The theoretical density of fabricated composites is estimated by the relation suggested by Agarwal et al. [27], and the form of experimental density can be determined by using a densitometer. The micro hardness (Vickers) measurement was conducted by using (HMV-2T, Shimadzu) hardness tester to detect the hardness behaviour of test samples as per the ASTM E-92 [28] standard. To determine the tensile test, compressive strength, and flexural strength (INSTRON 1195) UTM machine was used (Strain rate: 2mm/min) as per ASTM E8-99 [29], ASTM E9-09 [30], and ASTM-E290 [31] standard respectively. Five sample experiments was carried out for each mechanical characterization, and the average value was considered as the final property.

2.3 Dry sliding wear test

A multi-specimen tribo-tester (trade mark TR-705) which allows to simulate the sliding wear test (Manufactured by DUCOM) were used to analyse the wear characteristics of the test samples as per ASTM G99 [32] standard. This was performed in dry sliding behaviour of fabricated composite. The length, width and height of test specimen were 10mm×10mm×15mm.The machine parts are of disc type and made of hardened steel alloy with a surface roughness (Ra) of 1.6μm. The specimen was kept stationary over the rotating disc operated by a DC motor, and the average load was applied using a lever mechanism set up. To determine the applied load which acts over the sample, the LVDT was attached to the lever mechanism. The specimens were weighted under a precious electronic balance to a precision value of ±0.001 mg. The comparison between the initial and final weight of these samples represents mass loss under the dry sliding mechanism. The operating test parameters [33-35] for experimentation are illustrated in Table 2.

2.4 Evaluation of Electrochemical corrosion test

Corrosion tests were carried out by using a setup of three electrode glass cell by affixing GAMRY Potentiostat (Model No. VFP600). The setup of the electrochemical corrosion test consists of AMC as working electrode and SC (saturated calomel) electrode for reference and graphite as a counter electrode. The electrochemical corrosion test was carried out using 8wt.% NaCl solution as electrolyte. The scan rate of0.2mV/s is used to obtain potentiodynamic polarization activity of the fabricated AMCs.

2.5 Multi-Criteria Decision Analysis: COPRAS and CRITIC-AHP

Figure 5 presents the main steps used during decision-making methodology.

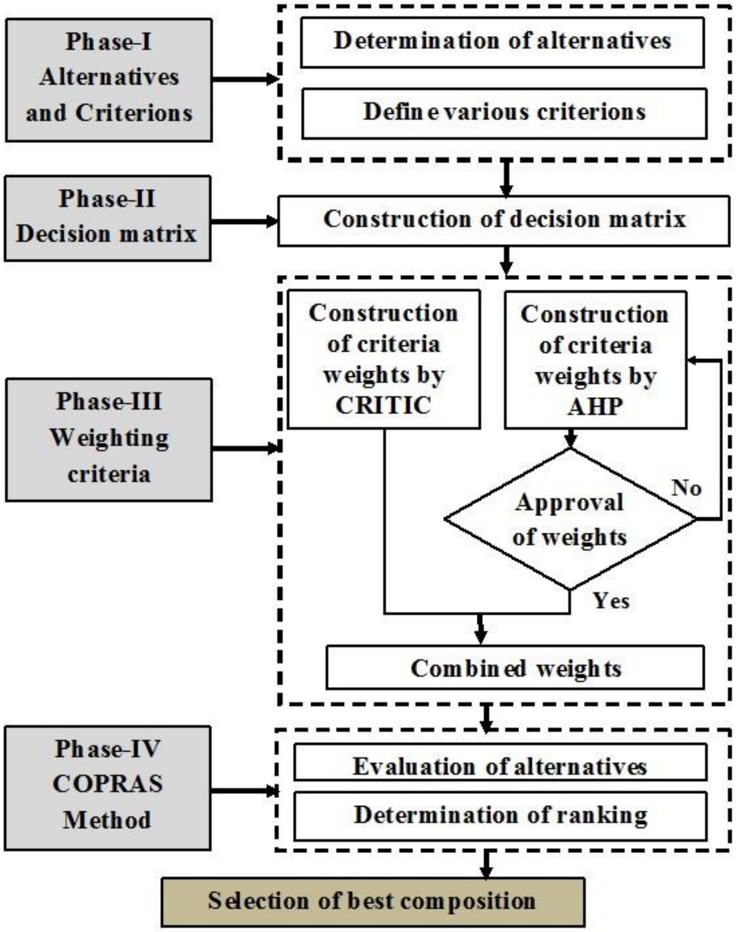


Figure 5: Diagram showing the multi criteria decision making step analysis

At the incipient stage, some potential alternatives and criteria's/attributes can be identified as indicated in figure 5 (Phase-I). The next step is to formulate a decision matrix. There, we can consider p as alternatives which can be assessed in respect to q attributes. The mathematical formulation of decision matrix is represented as Eq. 1.

$$T_{p\times q} = \begin{array}{c|cccc|} & C_1 & C_2 & \cdots & C_q \\ A_1 & T_{11} & T_{12} & \cdots & T_{1q} \\ A_2 & T_{21} & T_{22} & \cdots & T_{2q} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ A_p & T_{p1} & T_{p2} & \cdots & T_{pq} \end{array} \quad (1)$$

Where, A_i represents the i^{th} alternative (A_i, i=1, 2,....,p); C_j is the j^{th} attribute (C_j, j =1, 2,…, q) and $T_{p\times q}$ denotes the value of performance of i^{th} alternative determined in respect to j^{th} attribute.

The weight calculation of all the criterion/attributes is a vital step for the applied COPRAS-CRITIC/AHP methodology. Here, the criterion/attributes weights were achieved by applying CRITIC(criteria importance through inter-criteria correlation) and AHP (analytic hierarchy process) strategy separately as shown in figure 5 (Phase III). Furthermore, the final criterion/attributes weights were obtained by combining these two strategies. The objective weighting method which is incorporated in CRITIC is described though SD approach which was proposed in Diakoulaki et al. [36]. The criteria were firstly normalized by applying Eq. (2) and Eq. (3) and for correlation was applied Eq. (4). The correlation is applied generally to detect the dependency created between two variables. The weights calculation was obtained by applying Eq. (5) and Eq. (6).

$$H'_{ir} = \frac{x_{ir} - x_r^{\min}}{x_r^{\max} - x_r^{\min}} \qquad \textit{i=1,....,m; r=1,...,n it trigger criteria for bigger values}(2)$$

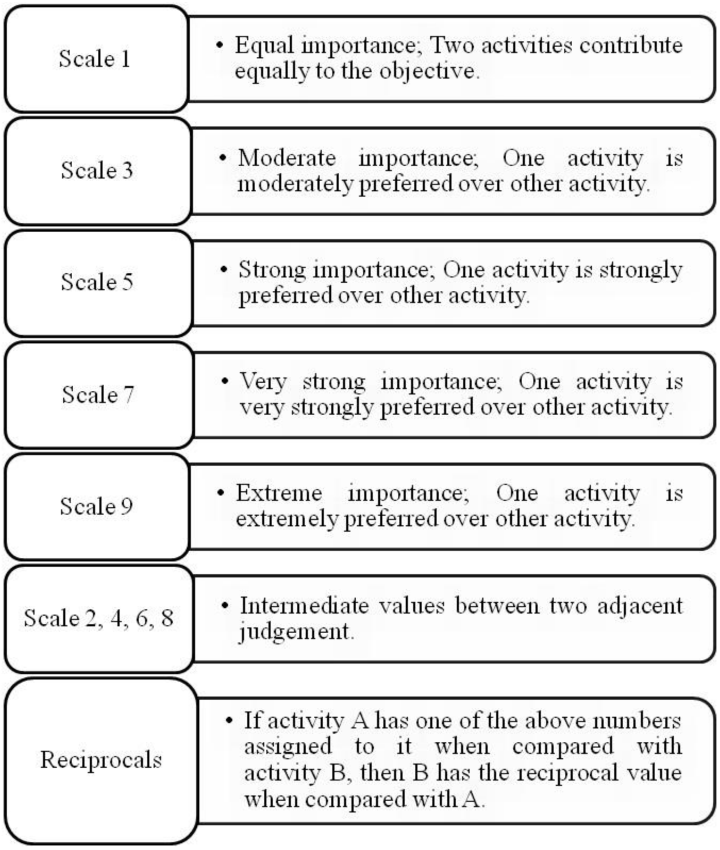
$$H'_{ir} = \frac{x_r^{\max} - x_{ir}}{x_r^{\max} - x_r^{\min}} \qquad \textit{i=1,....,m; r=1,...,n t trigger criteria for lower values} \quad (3)$$

$$\psi'_{rv} = \frac{\sum_{i=1}^{m}(H_{ir} - \overline{H}_r)(H_{iv} - \overline{H}_v)}{\sqrt{\sum_{i=1}^{m}(H_{ir} - \overline{H}_r)^2 \sum_{i=1}^{m}(H_{iv} - \overline{H}_v)^2}} \qquad \textit{r, v=1,.....,n} \quad (4)$$

$$w_j^1 = \frac{G'_j}{\sum_{j=1}^{n} G'_j} \qquad \textit{j=1,.....,n} \qquad (5)$$

$$G'_j = \sigma_j \sum_{\mathrm{j=1}}^{\mathrm{n}} (1 - \psi'_{rv}) \qquad \textit{j=1,.....,n} \qquad (6)$$

AHP method requires determination of criteria by using a pair-wise comparison matrix. In which, the majority of criteria are compared against each other considering a nine-point scale [8] as depicted in figure6.



Scale 1	- Equal importance; Two activities contribute equally to the objective.
Scale 3	- Moderate importance; One activity is moderately preferred over other activity.
Scale 5	- Strong importance; One activity is strongly preferred over other activity.
Scale 7	- Very strong importance; One activity is very strongly preferred over other activity.
Scale 9	- Extreme importance; One activity is extremely preferred over other activity.
Scale 2, 4, 6, 8	- Intermediate values between two adjacent judgement.
Reciprocals	- If activity A has one of the above numbers assigned to it when compared with activity B, then B has the reciprocal value when compared with A.

Figure 6: AHP Pair-wise comparison scale

The comparison matrix ($Z_{u\times u}$) was computed by applying Eq.7. Here, $Z = \{Z_j \; where \; j = 1,2,\dots,u\}$ denotes the entire group for all criterions, while Z_{ij} represents the relative criterion importance i in respect to criterion j.

$$Z_{u\times u} = \begin{array}{c} \\ Z_1 \\ Z_2 \\ \vdots \\ Z_u \end{array} \begin{array}{c} \begin{array}{cccc} Z_1 & Z_2 & \cdots & Z_u \end{array} \\ \begin{bmatrix} Z_{11} & Z_{12} & \cdots & Z_{1u} \\ Z_{21} & Z_{22} & \cdots & Z_{2u} \\ \vdots & \vdots & \ddots & \vdots \\ Z_{u1} & Z_{u2} & \cdots & Z_{uu} \end{bmatrix} \end{array} \quad (7)$$

$Z_{ii} = 1$, $Z_{ji} = 1/Z_{ij}$, $Z_{ij} \neq 0$

The weights (w_j) for individual attribute were calculated by computing the geometric mean (GM) followed by a normalization using the pair-wise comparison matrix (Eq.8 and Eq. 9).

$$GM_j = \left[\prod_{j=1}^{u} Z_{ij}\right]^{1/u} \qquad (8)$$

$$w_j^2 = \frac{GM_j}{\sum_{j=1}^{u} GM_j} \qquad (9)$$

As per the details described in [8], a Consistency Ratio (CR) was determined. There was settled a higher limit such as CR is ≤0.1. If the higher limit is not imposed the process evaluation requires major adjustments to improve the consistency. Eq.10 describes the mathematical formula to evaluate the weights generated by the combination of CRITIC and AHP methods.

$$W_j = \frac{(w_j^1 * w_j^2)^{\frac{1}{2}}}{\sum_{j=1}^{n} (w_j^1 * w_j^2)^{\frac{1}{2}}} \qquad (10)$$

COPRAS method associated to Phase IV is computed by using different steps as follow:

Step 1: is completed by obtaining a normalization of decision matrix applying Eq. (11):

$$H_{ir} = \frac{x_{ir}}{\sum_{i=1}^{m} x_{ir}} \qquad (11)$$

Step 2: is completed by obtaining the weighted of normalized decision matrix as Eq. (12):

$$k_{ij} = H_{ir} \times w_j \quad (i=1,2,\ldots,m\ ;\ j=1,2,\ldots n) \qquad (12)$$

Step 3: requires the calculation of sums for the weight normalized scores which is beneficial to detect the cost criteria by applying eq. (13):

$$\left.\begin{aligned} S_{+i} &= \sum_{j=1}^{n} k_{+ij} \\ S_{-i} &= \sum_{j=1}^{n} k_{-ij} \end{aligned}\right\} \qquad (13)$$

where, k_{+ij} enable to maximize the criteria while k_{-ij} allows to minimize the criteria. Further, S_{+ij} indicate the potential for a higher choice while S_{-ij} is associated to lower option. The S_{+ij} and S_{-ij} dictate the level of objectives which can be obtained by option *i.*

Step 4: permits to detect the relative priority for the options, i.e., Q_i applying Eq. (14):

$$Q_i^{'} = S_{+i} + \frac{\sum_{i=1}^{m} S_{-i}}{S_{-i} \sum_{i=1}^{m} \frac{1}{S_{-i}}} \qquad (i=1,\ 2, \ldots\ldots, m)(14)$$

As rule we consider as best the alternative which has the highest value of Q_i *(Q_{max})* is the best.

Step 5: requires calculating the performance level (χ_i) of option i.

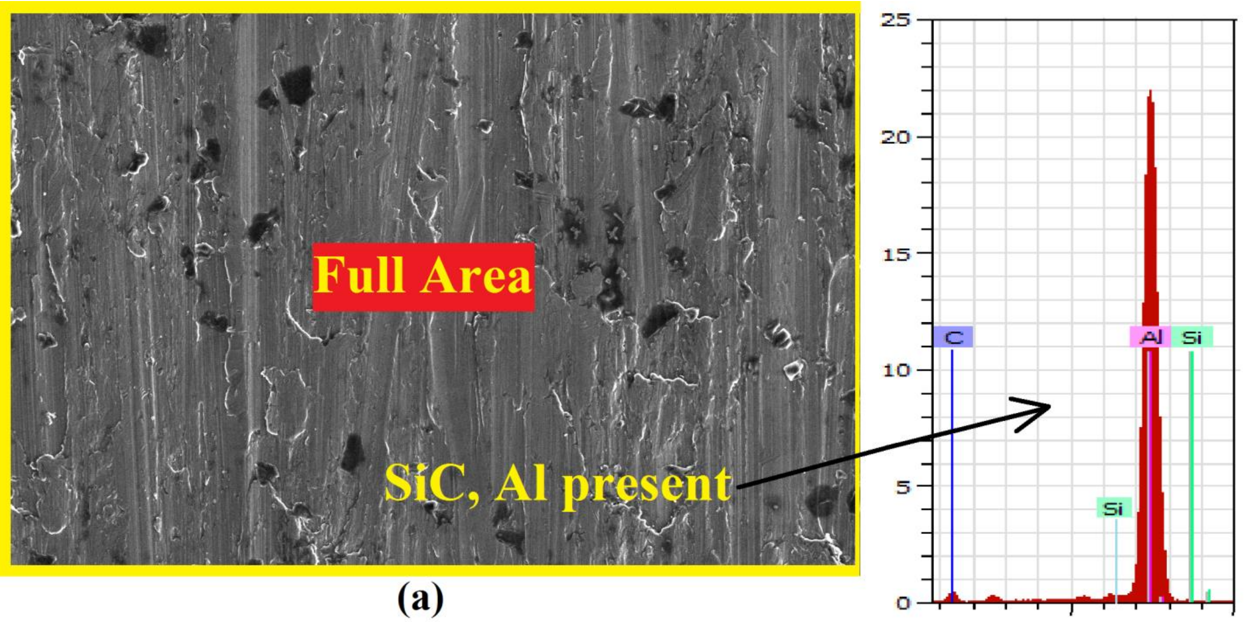
χ_i help to detect the absolute priority which is shown as mathematical formula as Eq. (15):

$$\chi_i = \frac{Q_i}{Q_{\max}} \times 100 \qquad (15)$$

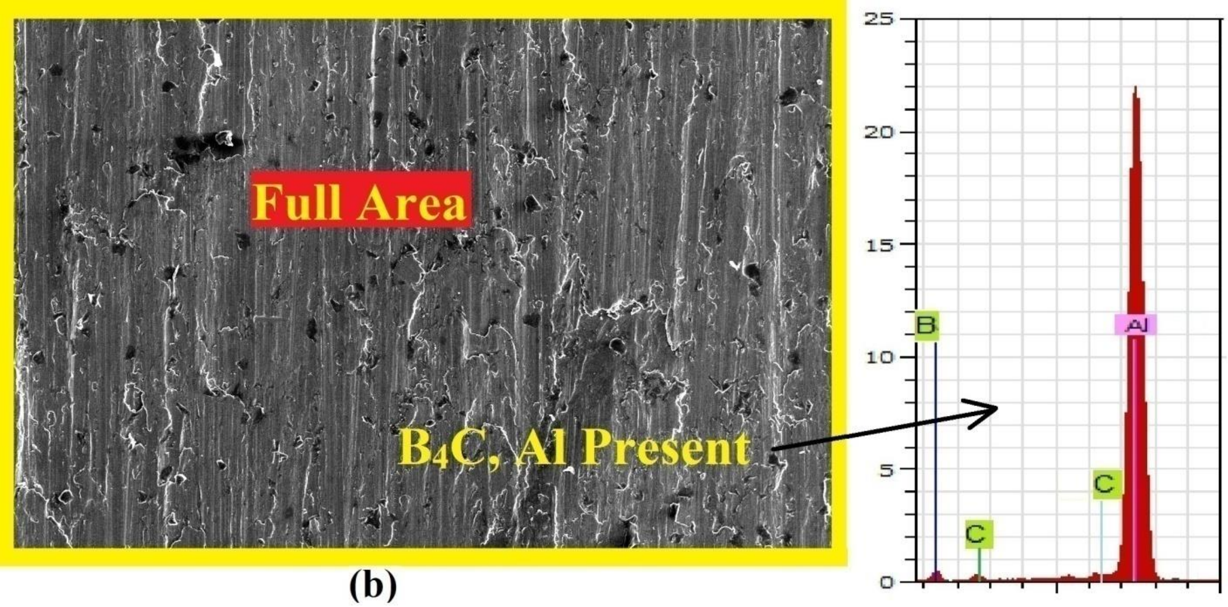
In Eq. (15), Q_{max} denotes the upmost relative importance score.

3. Results and Discussion

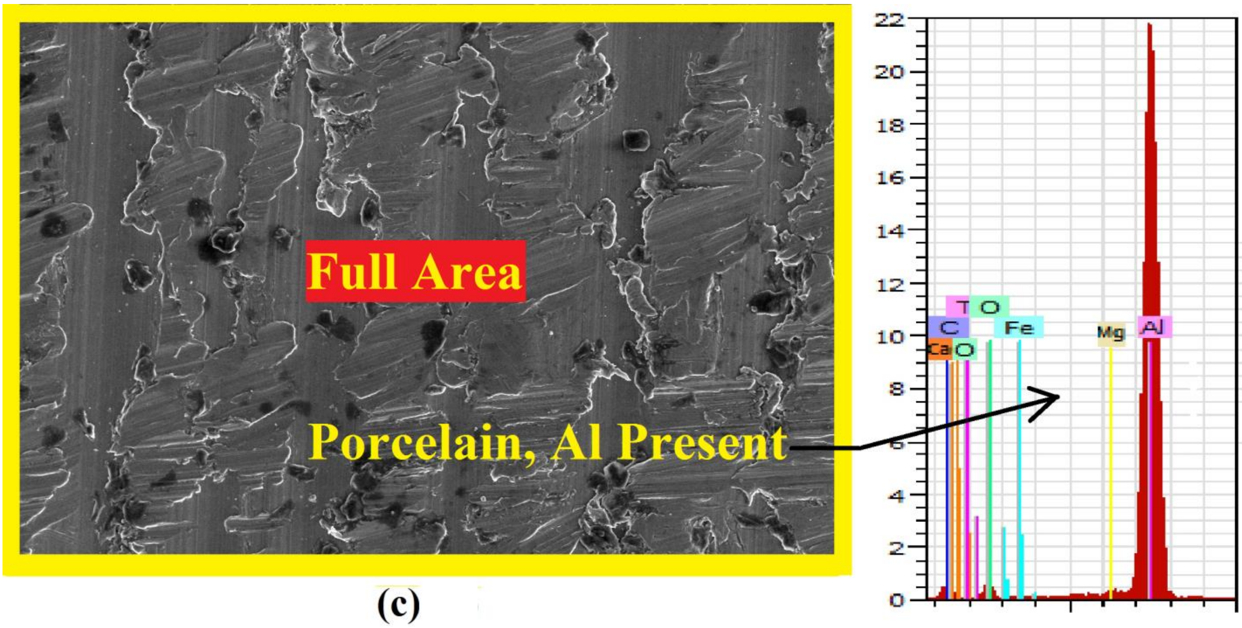
FESEM micrographs of the microstructures and their corresponding EDS results for the casted samples (ASBP-4, ASBP-8, and ASBP-12) are represented in figure7a-7c. The EDS test results are considered in this study based on a particular area scan (see fig 7a-7c), and it is clear from the spectrum that the base constituents (Fig.7a and 7b) i.e., Si, C, B and Al elements were present, suggesting that only SiC/B_4C and Al of base composition were present. As the quantity of porcelain mixed in the matrix then a variety of peaks namely Al, O, Mg, Ca, and Fe were recorded (Fig.7c). Therefore, it can be presumed that apart from base composition Al_2O_3, SiO_2, CaO, MgO, Fe_2O_3 are present as these are the key constituents of porcelain.


Full Area
SiC, Al present
25
20
15
10
5
0
C
Al
Si
Si

(a)


Full Area
B_4C, Al Present
25
20
15
10
5
0
B
Al
C
C

(b)



(c)

Figure7: FESEM and EDX analysis for (a) ASBP-4, (b) ASBP-8, and (c) ASBP-12 samples

3.1 Interpretations of SiC/B_4C/Porcelain on various criterions

The measured values of density, mechanical strength (i.e., hardness, tensile/compressive/flexural strength), coefficient of friction and wear behaviour (at 40N normal load and sliding velocity of 5.024 m/sec), and corrosion rate were selected as criteria. Table 2 display the descriptions of the measured criteria and testing conditions. Furthermore, Table 3presents details of the test results achieved for twelve AMCs samples studied. The criterion-1 (density, g/cm^3) remains in the range of 2.718-2.772 and records a minimum for composite ASBP-12 having 7.5 wt.% porcelain content. This is expected, as the density of porcelain (2.4 g/cm^3) is less than one of the AA7075 (2.8 g/cm^3), SiC (3.21 g/cm^3), and B_4C (2.5 g/cm^3).The hardness (criterion-2) obtained was varied between 109-154 on Vicker scale for most of the produced AMCs samples with small exception forASBP-8 where it was recorded a maximum value of 162 Hv. The increase in hardness was quite evident and expected since hard B_4C particles were combined with AA7075 metal alloy [37] and consequently contributed to effectively increase the hardness of the AMCs samples. An enhancement of the load carrying by the particle load bearing (which was matrix only) may be causing this improvement. Tensile strength (Criterion-3), compressive strength, and flexural strength of the AMCs produced was in the range of 223-298 MPa, 150-221 MPa, and 167-267 MPa respectively, and recorded a maximum mechanical strength for composite ASBP-8. The test result of the tensile, compressive, and flexural strength follows the same trend as the hardness result. A maximum increase of approximately 48% in hardness, 34% in tensile strength, 47% in compressive strength and 59% in flexural strength were achieved by introducing 7.5 wt.% B_4C.This increase in the mechanical strength can be justified by the attachment of the particulates to the matrix. Presumably the loads are now borne by the particles, which was borne previously by the matrix only, causing a good load bearing capacity [38]. Moreover, we can add, the restricted plastic flow which is caused by the B_4C particles (as it is hard) may be a reason for the increase in the tensile strength, especially in the uniaxial tensile load condition of AA7075.In the analysis of criterion-6 (wear, at 40N) and criterion-7 (wear, at 5.024 m/sec), the ASBP-1 (AA7705-1.5 wt.% of SiC) revealed the maximum wear loss while the aluminum-matrix composite containing 4.5wt.% of porcelain (ASBP-11) exposed the minimum wear loss either for Criterion-6 and Criterion-7. The loss of wear found less, and this can be attributed to the enhanced bonding of the interface matrix and the particulates. This integration of the porcelain and matrix is noted for the a good resistance to the wear, as well as a hardness superiority [8]. The coefficients of frictions at 40 N load (Criterion-8) and at 5.024 m/sec sliding velocity (Criterion-9) of all the AMCs were found between 0.47-0.75 and the best friction were detected for ASBP-11 (containing 6wt.% porcelain) composite for both the criterions. Corrosion rates (Criterion-10) were also obtained for all the AMCs produced and found to be the lowest (391 mm/yr) for ASBP-12 composites, which is superior to one of the most promising material (AA5083 alloy) which is used in corrosive and cryogenic environment having corrosion rate value of 472.836mm/yr as illustrated in ref[39]. An improvement of approximately 18% in wear performance, and 17% in corrosion rate were achieved by introducing 6 wt.% and 7.5 wt.% of porcelain respectively. The interpretation of the findings has evidently demonstrated that there is no certain alternative that has better efficiency when evaluating all the criteria at a time. The COPRAS-AHP/CRITIC hybrid solution was then introduced to consider the best option.

Table 2: Details of criterions, testing settings and their respective objectives

Criterions	Parameters	Performance implication	Test conditions	
C-1	Measured Density in g/cm^3	Min	Archimedes method	
C-2	Hardness in Hv	Max	ASTM E-92 standards	
C-3	Tensile strength in MPa	Max	ASTM E8-99 standards	
C-4	Compressive strength in MPa	Max	ASTM E9-09 standards	
C-5	Flexural strength in MPa	Max	ASTM-E290 standards	
C-6	wear loss in grams	Min	L=40N	SD=1300m
C-7			SV=5.026m/sec	SD=1300m
C-8	Coefficient of friction	Min	L=40N	SD=1300m
C-9			SV=5.026m/sec	SD=1300m
C-10	Corrosion rate in mm/yr	Min	Ringer solution with 7.15 pH	

L =Normal load; SD = Sliding distance; SV= Sliding velocity

Table 3: Results obtained for each criterion

	C-1	C-2	C-3	C-4	C-5	C-6	C-7	C-8	C-9	C-10
ASBP-1	2.739±0.001	109±1.00	223±0.836	150±0.836	167±0.837	0.00318±0.00001	0.0285±0.00001	0.752±0.002	0.62±0.001	473±1.00
ASBP-2	2.747±0.002	114±1.30	244±0.894	161±0.837	186±0.836	0.00298±0.00001	0.0262±0.00001	0.732±0.002	0.54±0.001	454±0.89
ASBP-3	2.756±0.002	136±0.89	267±0.837	168±0.894	197±0.836	0.00272±0.00001	0.0256±0.00001	0.721±0.001	0.49±0.002	423±0.83
ASBP-4	2.772±0.001	146±1.30	278±0.894	175±0.836	231±0.894	0.00285±0.00001	0.0259±0.00001	0.727±0.001	0.51±0.002	398±0.89
ASBP-5	2.737±0.002	131±1.00	262±0.836	171±0.837	212±0.837	0.00316±0.00001	0.0266±0.00001	0.71±0.001	0.59±0.001	472±1.00
ASBP-6	2.731±0.002	139±1.34	278±0.837	185±0.894	235±0.894	0.00301±0.00001	0.0247±0.00001	0.62±0.002	0.51±0.001	446±1.00
ASBP-7	2.726±0.001	148±0.89	286±0.894	199±0.894	248±0.894	0.00281±0.00001	0.0236±0.00001	0.609±0.002	0.47±0.002	418±0.89
ASBP -8	2.720±0.001	162±1.00	298±0.836	221±0.837	267±0.837	0.00299±0.00001	0.0242±0.00001	0.616±0.001	0.49±0.002	396±0.83
ASBP-9	2.734±0.001	119±0.83	260±0.894	167±0.836	221±0.894	0.00298±0.00001	0.0265±0.00001	0.569±0.002	0.68±0.002	434±0.89
ASBP-10	2.729±0.002	127±0.89	276±0.837	176±0.894	246±0.836	0.00277±0.00001	0.0248±0.00001	0.541±0.001	0.54±0.002	426±0.83
ASBP-11	2.724±0.002	142±0.89	287±0.894	189±0.837	257±0.894	0.00261±0.00001	0.0231±0.00001	0.536±0.001	0.47±0.002	412±1.00
ASBP-12	2.718±0.002	154±0.83	296±0.836	219±0.894	263±0.837	0.00268±0.00001	0.0239±0.00001	0.539±0.002	0.52±0.001	391±0.89

3.2 Materials ranked as a function of various criterions

The aluminium-matrix composite produced were subjected to a selection criterion formed from10criterion/attributes and 12 alternatives/AMCs. It is derived from the decision matrix introduced in table 3. Eq. 2 and Eq. 3 were used to conduct a normalization for the decision matrix. The selected criteria weights introduced in Table 4 were computed by CRITIC method applying Eq.4-6.

Table 4: Details of weights criterion determined using CRITIC method

Criterions	ψ'_{rv}	G'_j	w_j^1
C-1	0.29168	2.71819	0.09114
C-2	0.30609	2.99630	0.10046
C-3	0.29013	2.98989	0.10025
C-4	0.30998	3.12874	0.10490
C-5	0.31791	3.30951	0.11096
C-6	0.32224	2.68144	0.08991
C-6	0.28547	2.54132	0.08521
C-8	0.38942	3.42523	0.11484
C-9	0.29781	2.78758	0.09346
C-10	0.34239	3.24679	0.10886

Likewise, the weights for each criterion for AHP method were determined by applying Eq.7-9. It enables formation of a hierarchy structure (Figure8) with10criterions. The analysis was conducted in pair-wise manner which allows to detect the importance for each criteria by means of the nine-point scale. Table 5 shows the released pair-wise matrix by using nine-point scales. Once the pair-wise matrix is registered, the weights of each criterions and their consistency ratio (CR) can be computed. Table 6 presents the achieved results. It can be noted that the CR value is below 0.1 (0.080) which endorse the results as appropriate. Eq. 10 was then used to combine the criterion weights detected using CRITIC and AHP. Table 7 presents details of the combined weights transposed within COPRAS methodology which leads to the ranking order.

The finalization of weights combination from each criterion within COPRAS method is then used to establish the alternative ranking. On the COPRAS analysis were used Table 8generated from Eq. 11 as a decision matrix. Eq. 11 were used to normalize the values of decision matrix to well compare them. By applying Eq. 12 was obtained the weighted normalized matrix (k_{ij}).Eq. 13 was used to calculate the sums for the weighted normalized values S_{+i} and S_{-i} respectively, associate to higher-the-better and lower-the-better criterion. By applying Eq. 14 were possible to obtain the relative significances ($Q_i^{'}$) for the alternatives. At the end of the process, we have used Eq. 15 to determine the quantitative utility value (χ_i) for each alternative. Table 8 presents the computed results using the COPRAS. It was found that the utility value (Ψ) for the alternative ASBP-12has the maximum performance (100), while the utility value (Ψ) for the alternative ASBP-1has the lowest performance (77.53). Therefore, the formulation ASBP-12(containing Al-6wt.% Porcelain) is considered as the best material candidate for given application.

The use of three different methodologies enabled a higher degree of optimization for the composite material selected. To further validate the proposed methodology in this study i.e. the COPRAS along with CRITIC and AHP approaches were compared with others MCDM approaches such as VIKOR[40], PSI [9] and TOPSIS approach [8], and the results were inserted in Table 9. The ranking order achieved in Table 9 using COPRAS methodology has the flowing structure: ASBP-12>ASBP-8>ASBP-11>ASBP-7>ASBP-6>ASBP-10>ASBP-4>ASBP-3>ASBP-9>ASBP-5>ASBP-2>ASBP-1 whereas ASBP-12>ASBP-8>ASBP-7>ASBP-11>ASBP-6> ASBP-10>ASBP-5>ASBP-3>ASBP-9>ASBP-4>ASBP-2>ASBP-1,ASBP-12>ASBP-8>ASBP-11 >ASBP-7>ASBP-10>ASBP-6>ASBP-4>ASBP-3>ASBP-9>ASBP-5>ASBP-2>ASBP-1 and ASBP-12> ASBP-8> ASBP-7>ASBP-6>ASBP-11>ASBP-10 >ASBP-5>ASBP-3>ASBP-9>ASBP-4>ASBP-2>ASBP-1 are the structure for ranking order using VIKOR, PSI and TOPSIS methods, respectively. The selected methods well converge indicating as the best material alternative ASBP-12, i.e., AA7075+7.5 wt.% porcelain reinforcement as the main option for a given application. It is confirmed that the proposed COPRAS methodology is reliable and can be employed for predicting with accuracy on the ranking of alternatives (i.e. automotive component materials).

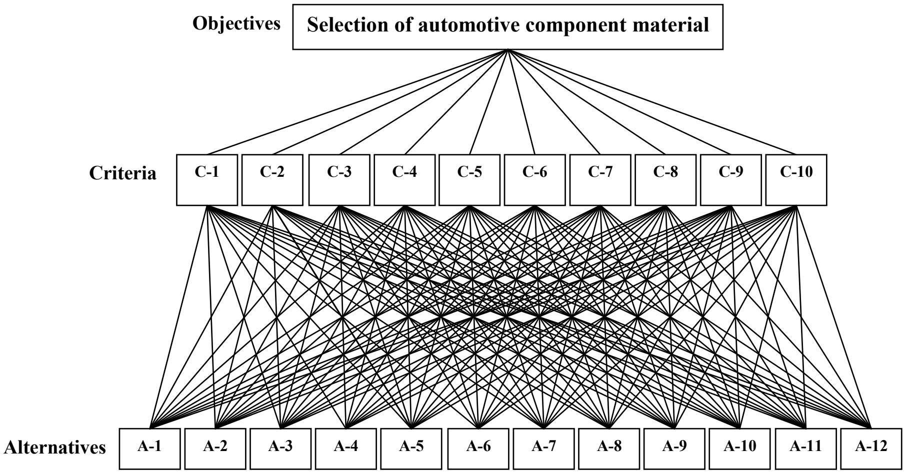


Figure 8: The hierarchy structure used in AHP

Table 5: Details of comparison matrix using Pair-wise approach

	C-1	**C-2**	**C-3**	**C-4**	**C-5**	**C-6**	**C-7**	**C-8**	**C-9**	**C-10**
C-1	1	2	2	4	4	3	4	5	4	8
C-2	1/2	1	2	4	5	4	4	6	4	5
C-3	1/2	1/2	1	2	4	6	4	6	4	5
C-4	1/4	1/4	1/2	1	2	2	5	4	5	5
C-5	1/4	1/5	1/4	1/2	1	2	5	4	6	5
C-6	1/3	1/4	1/6	1/2	1/2	1	2	3	3	3
C-6	1/4	1/4	1/4	1/5	1/5	1/2	1	2	1	3
C-8	1/5	1/6	1/6	1/4	1/4	1/3	1/2	1	2	3
C-9	1/4	1/4	1/4	1/5	1/6	1/3	1	1/2	1	3
C-10	1/8	1/5	1/5	1/5	1/5	1/3	1/3	1/3	1/3	1

Table 6: Relative weights released using the comparison matrix

Criterions	W_j^2	λmax, CI, RI	Consistency ratio (CR)
C-1	0.229217	λmax=12.071 CI = 0.120 RI = 1.49	CR = 0.080
C-2	0.20254		
C-3	0.166847		
C-4	0.108605		
C-5	0.097563		
C-6	0.062494		
C-6	0.041352		
C-8	0.035227		
C-9	0.035593		
C-10	0.020561		

Table 7. Final weights using CRITIC and AHP weights

	C-1	**C-2**	**C-3**	**C-4**	**C-5**	**C-6**	**C-7**	**C-8**	**C-9**	**C-10**
Objective weight (W_j^1)	0.09114	0.10046	0.10025	0.10490	0.11096	0.08991	0.08521	0.11484	0.09346	0.10886
Subjective weight (W_j^2)	0.22922	0.20254	0.16685	0.10860	0.09756	0.06249	0.04135	0.03523	0.03559	0.02056
Final weights(W_j)	0.15538	0.15335	0.13903	0.11475	0.11185	0.08058	0.06381	0.06838	0.06200	0.05086

Table 8: Alternatives ranking

Samples code	**αi**	**βi**	**φ**	**Ψ (%)**	**ranking**
ASBP-1	0.03453	0.04367	0.07125	77.53	12
ASBP-2	0.03726	0.04162	0.07578	82.46	11
ASBP-3	0.04113	0.04005	0.08117	88.32	8
ASBP-4	0.04431	0.04049	0.08391	91.30	7
ASBP-5	0.04122	0.04254	0.07891	85.87	10
ASBP-6	0.04434	0.03994	0.08448	91.93	5
ASBP-7	0.04680	0.03846	0.08849	96.29	4
ASBP -8	0.05056	0.03901	0.09166	99.74	2
ASBP-9	0.04016	0.04132	0.07897	85.93	9
ASBP-10	0.04310	0.03878	0.08445	91.89	6
ASBP-11	0.04612	0.03736	0.08903	96.88	3
ASBP-12	0.04946	0.03777	0.09190	100.00	1

Table 9: Verification of COPRAS methodology against literature

Samples code	Proposed	VIKOR	PSI	TOPSIS
ASBP-1	12	12	12	12
ASBP-2	11	11	11	11
ASBP-3	8	8	8	8
ASBP-4	7	10	7	10
ASBP-5	10	7	10	7
ASBP-6	5	5	6	4
ASBP-7	4	3	4	3
ASBP -8	2	2	2	2
ASBP-9	9	9	9	9
ASBP-10	6	6	5	6
ASBP-11	3	4	3	5
ASBP-12	1	1	1	1

4. Conclusions

This work was focused to identify the optimal aluminium-matrix composite which can meet the best combination of mechanical strength, wear behaviour and corrosion resistance which is significant for the application in automobile industries. Hybrid AHP/CRITIC-COPRAS was used as the multi-criteria decision-makingcriteria.12composites containing various reinforcements (SiC, B_4C and waste Porcelain) of 3, 4.5, 6, and 7.5wt.% were manufactured via stir casting route. To obtain the best results 10criteria were imposed (i.e., composite density, hardness performances, tensile, compressive, flexural strength, friction coefficient, wear behaviour, and corrosion rate). Based on the results, the maximum hardness, compressive, tensile and flexural strength obtained are 162±1.00 Hv, 221±0.837 MPa, 298±0.836 MPa and 267±0.837 respectively. Besides, the density, corrosion rate, wear loss at 40 N and wear loss at 5.026 m/sec attained are 2.718±0.002 g/cm^3, 391±0.89 mm/yr, 0.00261±0.00001 grams, and 0.0231± 0.00001grams respectively. The corresponding coefficients of friction for normal load at 40 N attained are 0.536±0.001; hereas, for sliding velocity at 5.026 m/sec attained are 0.47± 0.002.The optimum combination of the criteria has been set to minimize the corrosion rate, tribological behaviour, and composite density and to maximize the mechanical strength (hardness performances, tensile, compressive and flexural strength) by using hybrid AHP/CRITIC-COPRAS approach. The used criteria reveal that the produced composites are influenced in high degree by the type and weight percentage of reinforcement added. COPRAS approach was integrated with AHP and CRITIC approach to find out the final ranking and find the best solution. The AHP and CRITIC methods were employed to compute the weights while COPRAS method was introduced to obtain the final alternatives ranking. As a result, the final ranking order is ASBP-12, ASBP-8, ASBP-11, ASBP-7, ASBP-6, ASBP-10, ASBP-4, ASBP-3, ASBP-9, ASBP-5, ASBP-2 and ASBP-1. The material ASBP-12 with maximum utility value (100) was found as the most promising candidate materials, and the ASBP-1 with the minimum utility value (77.53) was the least preferred material for automotive applications.

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Conflict of Interest

The author(s) declare that they have no conflict of interest.

Author Contribution

Amit Aherwar: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Supervision, Roles/Writing - original draft; **Catalin I. Pruncu:** Conceptualization, Methodology, Software, Visualization, Writing – review & editing; **Mozammel Mia:** Software, Validation, Visualization, Writing - review & editing

Availability of data and material

The authors declare that the data supporting the findings of this study are available within the article.

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Not applicable.

Consent to participate

Not applicable.

Consent for Publication

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