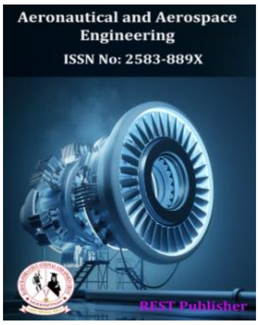
**Aeronautical and Aerospace Engineering**

**Vol: 1(1), March 2023**

**REST Publisher; ISSN: 2583-889X (Online)**

**Website: http://restpublisher.com/journals/aae/**

**DOI: https://doi.org/10.46632/aae/1/1/1**




# Assessment of Selection of Suitable for Spar of the Human-Powered Aircraft Using COPRAS Method

***Sudha Balasubramaniam, M. Ramachandran, Vimala Saravanan, Chandrasekar Raja**

*REST Labs, Kaveripattinam, Krishnagiri, Tamil Nādu, India.*

Corresponding Author Email: sudhabalamithra@gmail.com

**Abstract.** *Generally speaking, while making decisions, it is more customary to rely on intuition rather than any form of numerical technique. In areas where there are many options and many factors impacting the choice, such as the selection of materials, a more precise approach would be necessary. It is necessary to understand the material's characteristics, price, design principles, and interactions while making mechanical parts. Material science has not only produced traditional materials such as metals, ceramics, and polymers but has also given rise to various novel materials like composites, smart (intelligent) materials, and functionally graded materials.*

*A designer now has access to a wider range of materials than ever before thanks to the growth of knowledge. In these instances, a strategic choice must be made in order to satisfy all the functional specifications of the product while upholding client requests and preferences. The performance criteria of the component must be specified, along with a general description of the properties and processing needs of the primary material, As the first stage of the material selection process. Consequently, certain material types might be ruled out, while others are chosen as potential options for the component. The relevant material properties are subsequently listed and assigned a priority ranking. The best material can then be chosen using optimization techniques. The result of the COPRAS analysis is followed by Al 2024-T4 is the first rank, Carbon 63% Epoxy is last rank. Based on the analysis, the materials ranked highest for usage are as follows: Al 2024-T4 aluminum alloy, E-glass 73%-Epoxy, E-glass 56% Epoxy, and E-glass 65% Polyester. These selections have been carefully assessed and determined to be the most suitable options, taking into account their specific properties and how well they align with the intended application. The Al 2024-T4 aluminum alloy exhibits excellent strength-to-weight ratio and corrosion resistance, making it an ideal choice for structural components. E-glass 73%-Epoxy, E-glass 56% Epoxy, and E-glass 65% Polyester offer a combination of strength, flexibility, and durability, catering to various requirements within the application. The meticulous evaluation of these materials ensures that the chosen ones will deliver optimal performance and reliability in the designated context.*

**Keywords:** *Aircraft structures, neural network, MCDM.*

## 1. INTRODUCTION

It is common knowledge that materials are crucial to engineering designs. Designers must always choose materials with specified attributes while satiating all current restrictions. In many academic disciplines, material selection is a crucial task [1]. The process of choosing materials is challenging since there are many materials available and many of them have complicated interactions with different selection criteria. The process of choosing materials is frequently challenging as well as the intricate interactions between the various selection criteria. Additionally, it has become more difficult than before because of the wide variety of materials available, each of which has unique properties, uses, advantages, and restrictions [2,3]. Different methods for selecting materials have been proposed and used by various researchers, mostly based on the quantitative and qualitative qualities of materials. The fuzzy logic technique or neural network approach have been utilized to deal with qualitative material attributes [4]. The Daedalus from Massachusetts Institute of Technology is one of the most advanced HPAs (MIT). It was constructed in an effort to emulate the legendary flight of its namesake, who is claimed to have made his own wings out of feathers and wax [5]. In many industrial items, shape differences caused by flaws in the production process or damage are frequently seen. Strong design optimization is noteworthy A good way to avoid the difference in performance The strategy is because of the frequent changes in performance Aggravating or impairing abilities does not have Strong Aerodynamic The use of the design is widespread. however, Movement such as Mach number and angle of attack They often account for changes in levels take, and they produce Defects, variations and tolerances are only occasionally taken into account [6]. Any aircraft's main wing component, the spar, serves as a beam. This component spans the whole span of the aircraft's wing and can withstand all direct and indirect aerodynamic and static loads [7]. Because the permissible weight for an aircraft's construction is so limited, material choice and design are particularly crucial [8]. One of the more crucial glasses from a technological standpoint is definitely s-glass. Its strength, stiffness, and softening point are the highest of any commercially available reinforcement glass fiber. When compared to alternative reinforcements, the elastic moduli of e-glass fibers are comparably low. Additionally, E-glass fibers can creep and burst under stress [9,10]. The standard unit of measurement for tensile strength is the force in psi (pounds per square inch) or MPa (megapascals) required to pull a specimen until the material fails. A substance's elastic modulus, or Young's modulus, can be thought of as its resistance to elastic deformation; the stiffer a substance is, the greater its elastic modulus. [11]. The ability of a solid substance to resist "creep," which refers to the tendency of a material to slowly deform over time when exposed to high amounts of stress, is referred to as creep resistance [12].

## 2. MATERIALS AND METHODS

COPRAS (COmplex PRoportional ASsessment), selects the workable options by calculating a solution. Many scholars use this method to address decision-making challenges [13]. In 1994, the MCDM approach COPRAS was first introduced. This technique assumes that the set of criteria that adequately specifies the alternatives, as well as their weights and values, determine the relevance and usefulness level of the studied versions in a direct and proportionate manner [14].

**Step 1:** A decision matrix, denoted as X, is constructed to illustrate how different options perform concerning specific criteria.

$$x_{ij} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & x\cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

**Step 2:** The criteria's weights are given as

$$w_j = [w_1 \cdots w_n], \quad (2)$$

where, $\sum_{j=1}^{n} (w_1 \cdots w_n) = 1$

**Step 3:** The matrix $x_{ij}$'s normalized values are computed as

$$n_{ij} = \frac{x_{ij}}{\sum_{j=1}^{n} x_{ij}} \quad (3)$$

**Step 4:** Weighted normalized matrix $N_{ij}$ is calculated by following formula

$$N_{ij} = w_j \times n_{ij} \quad (4)$$

**Step 5:** sum of benefit criteria and the sum of cost criterion are calculated by following equations 5 and 6 respectively.

$$B_i = \sum_{j=1}^{k} N_{ij} \quad (5)$$

$$C_i = \sum_{j=k+1}^{m} N_{ij} \quad (6)$$

**Step 6:** Relative significance Qi of each alternative is calculated using equation 5 and 6.

$$Q_i = B_i + \frac{min\ (C_i) \times \sum_{i=1}^{n} C_i}{C_i \times \sum_{i=1}^{n} (\frac{min\ (C_i)}{C_i})} \quad (7)$$

**Step 7:** Next $U_i$ is calculated.

$$U_i = \frac{Q_i}{max\ (Q_i)} \times 100\% \quad (8)$$

The goal in developing a spar for a human-powered aircraft is straightforward: The spar needs to be as light as it can be while maintaining adequate stiffness to maintain the wings' aerodynamic efficiency. Other goals include cost, cost-effectiveness, and strength. Balsa, plywood, and aluminium were used to construct the first single-seat aircraft, which was then coated in nylon. The pilot pedalled bicycle pedals attached to the front of the aircraft to power it, giving it forward motion on the ground and powering the enormous propeller [15]. Tensile strength, often referred to as ultimate tensile strength, is a measure of the force required to pull a specimen until the material reaches the point of failure or rupture [16]. It is commonly used to represent the maximum stress that a material can withstand under tensile loading before it breaks or experiences permanent deformation. The stiffness of an elastic material measured in GPa. It's a term used to describe the behaviour of elastic materials such as wires, rods, and columns when they're compressed or tensed. [17]. The compressive strength (measured in MPa) of a plastic specimen refers to the highest compressive stress it can endure before rupturing or deforming by a specified amount, such as 1% or 10% deformation. This property indicates the material's ability to withstand compressive forces without experiencing failure or permanent deformation. Compressive strength has a specific value when failure by shattering fracture occurs, but it is arbitrary for polymers that do not fail by shattering fracture and is determined by the degree of distortion [18]. For structural materials with possible high temperature uses, such as in aircraft gas turbines and spacecraft airframes, creep resistance is a crucial quality to consider. According to a review of the literature, adding ceramic reinforcements to the matrix alters both the creep resistance and the creep mechanism, which in turn affects the creep behaviour in a complex way [19]. Material density (Mg/m3) is a key factor in determining the structural effectiveness of aero planes and spacecraft, along with the elastic modulus. The aerospace industries are using titanium alloys increasingly frequently as a result of their low density and strong strengths, particularly at high temperatures. moderate cost, great corrosion resistance, and high ductility are just a few of the characteristics that make polymers suitable for use as aviation materials (except thermosets) [20].

## 3. RESULTS AND DISCUSSION

**TABLE 1.** Performance rating matrix

| | Tensile strength (Mpa) | Young's modulus (GPa) | Compressive strength (Mpa) | Creep resistance | Density (Mg/m3) | Price (₹/kg) |
|---|---|---|---|---|---|---|
| Al 7075-T6 | 572 | 71.7 | 572 | 4 | 3 | 600 |
| Al 2024-T4 | 423.84 | 72.486 | 423.84 | 4 | 2.6 | 291.92 |
| Ti–6Al–4V | 950 | 113.8 | 950 | 5 | 4.43 | 2000 |
| Ti–2Fe–3Al | 1310 | 120 | 1310 | 5 | 4.5 | 3000 |
| S-glass70%-Epoxy cont. fibers | 2098.57 | 62.967 | 2098.57 | 3 | 2.11 | 990 |
| S-glass70%-Epoxy fabric | 678.68 | 21.896 | 678.68 | 3 | 2.11 | 880 |
| Carbon 63%-Epoxy | 1722.85 | 157.685 | 1722.85 | 3 | 1.61 | 4424 |
| Aramid 62%-Epoxy | 1308.67 | 82.689 | 1308.67 | 3 | 1.38 | 2400 |
| E-glass73%-Epoxy | 1641.58 | 55.967 | 1641.58 | 3 | 2.17 | 412 |
| E-glass56%-Epoxy | 1026.98 | 42.786 | 1026.98 | 2 | 1.97 | 430 |
| E-glass65%-Polyester | 338.97 | 19.567 | 338.97 | 2 | 1.8 | 420 |

Table 1 presents the dataset of performance ratings for materials utilized in the Spar of Human Powered Aircraft. The alternatives considered in this analysis include Al 7075-T6, Al 2024-T4, Ti–6Al–4V, Ti–2Fe–3Al, S-glass 70% Epoxy continuous fibers, S-glass 70% Epoxy fabric, Carbon 63% Epoxy, Aramid 62% Epoxy, E-glass 73%-Epoxy, E-glass 56% Epoxy, and E-glass 65% Polyester. The evaluation parameters employed in this study encompass Tensile strength (Mpa), Young's modulus (GPa), Compressive strength (Mpa), Creep resistance, Density (Mg/m3), and Price (₹/kg).

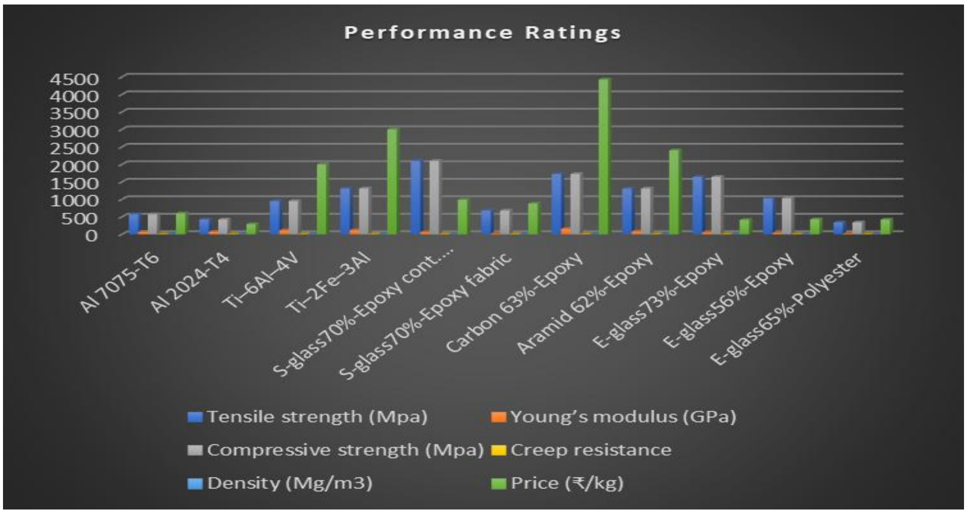



**FIGURE 1.** Performance ratings

The performance ratings of the materials used are represented graphically in this figure 1.

**TABLE 2**. Normalized matrix

| | | | | | | |
|---|---|---|---|---|---|---|
| Al 7075-T6 | 0.0474 | 0.005939 | 0.04738 | 0.00033 | 0.00025 | 0.0497 |
| Al 2024-T4 | 0.0351 | 0.006004 | 0.03511 | 0.00033 | 0.00022 | 0.0242 |
| Ti–6Al–4V | 0.0787 | 0.009427 | 0.07869 | 0.00041 | 0.00037 | 0.1657 |
| Ti–2Fe–3Al | 0.1085 | 0.00994 | 0.10851 | 0.00041 | 0.00037 | 0.2485 |
| S-glass70%-Epoxy cont. fibers | 0.1738 | 0.005216 | 0.17384 | 0.00025 | 0.00017 | 0.082 |
| S-glass70%-Epoxy fabric | 0.0562 | 0.001814 | 0.05622 | 0.00025 | 0.00017 | 0.0729 |
| Carbon 63%-Epoxy | 0.1427 | 0.013062 | 0.14271 | 0.00025 | 0.00013 | 0.3665 |
| Aramid 62%-Epoxy | 0.1084 | 0.00685 | 0.1084 | 0.00025 | 0.00011 | 0.1988 |
| E-glass73%-Epoxy | 0.136 | 0.004636 | 0.13598 | 0.00025 | 0.00018 | 0.0341 |
| E-glass56%-Epoxy | 0.0851 | 0.003544 | 0.08507 | 0.00017 | 0.00016 | 0.0356 |
| E-glass65%-Polyester | 0.0281 | 0.001621 | 0.02808 | 0.00017 | 0.00015 | 0.0348 |

Table 2 above illustrates the normalized matrix of Performance Ratings of Materials Used in the Spar of Human Powered Aircraft. Equation 3 was employed to derive this matrix.

**TABLE 3.** Weight Distribution

| | | | | | | |
|---|---|---|---|---|---|---|
| Al 7075-T6 | 0.17 | 0.17 | 0.17 | 0.17 | 0.16 | 0.16 |
| Al 2024-T4 | 0.17 | 0.17 | 0.17 | 0.17 | 0.16 | 0.16 |
| Ti–6Al–4V | 0.17 | 0.17 | 0.17 | 0.17 | 0.16 | 0.16 |
| Ti–2Fe–3Al | 0.17 | 0.17 | 0.17 | 0.17 | 0.16 | 0.16 |
| S-glass70%-Epoxy cont. fibers | 0.17 | 0.17 | 0.17 | 0.17 | 0.16 | 0.16 |
| S-glass70%-Epoxy fabric | 0.17 | 0.17 | 0.17 | 0.17 | 0.16 | 0.16 |
| Carbon 63%-Epoxy | 0.17 | 0.17 | 0.17 | 0.17 | 0.16 | 0.16 |
| Aramid 62%-Epoxy | 0.17 | 0.17 | 0.17 | 0.17 | 0.16 | 0.16 |
| E-glass73%-Epoxy | 0.17 | 0.17 | 0.17 | 0.17 | 0.16 | 0.16 |
| E-glass56%-Epoxy | 0.17 | 0.17 | 0.17 | 0.17 | 0.16 | 0.16 |
| E-glass65%-Polyester | 0.17 | 0.17 | 0.17 | 0.17 | 0.16 | 0.16 |

The preferred weight for the evaluation parameters is shown in Table 3. In this case, 0.17 kg and 0.16 is used.

**TABLE 4.** Weighted normalized decision matrix

| | | | | | | |
|---|---|---|---|---|---|---|
| Al 7075-T6 | 0.008 | 0.00101 | 0.0081 | 5.63E-05 | 3.9761E-05 | 0.007952194 |
| Al 2024-T4 | 0.006 | 0.00102 | 0.006 | 5.63E-05 | 3.446E-05 | 0.003869007 |
| Ti–6Al–4V | 0.013 | 0.0016 | 0.0134 | 7.04E-05 | 5.8714E-05 | 0.026507314 |
| Ti–2Fe–3Al | 0.018 | 0.00169 | 0.0184 | 7.04E-05 | 5.9641E-05 | 0.03976097 |
| S-glass70%-Epoxy cont. fibers | 0.03 | 0.00089 | 0.0296 | 4.22E-05 | 2.7965E-05 | 0.01312112 |
| S-glass70%-Epoxy fabric | 0.01 | 0.00031 | 0.0096 | 4.22E-05 | 2.7965E-05 | 0.011663218 |
| Carbon 63%-Epoxy | 0.024 | 0.00222 | 0.0243 | 4.22E-05 | 2.1338E-05 | 0.058634178 |
| Aramid 62%-Epoxy | 0.018 | 0.00116 | 0.0184 | 4.22E-05 | 1.829E-05 | 0.031808776 |
| E-glass73%-Epoxy | 0.023 | 0.00079 | 0.0231 | 4.22E-05 | 2.876E-05 | 0.005460507 |
| E-glass56%-Epoxy | 0.014 | 0.0006 | 0.0145 | 2.82E-05 | 2.611E-05 | 0.005699072 |
| E-glass65%-Polyester | 0.005 | 0.00028 | 0.0048 | 2.82E-05 | 2.3857E-05 | 0.005566536 |

The Performance Ratings of Materials Used in Spar of Human Powered Aircraft are shown in Table 4 as a normalized matrix. Equation 4 was used to calculate this matrix, which was produced by multiplying tables 2 and 3.

**TABLE 5.** Sum of benefit criteria and the sum of cost criterion

| | Bi | Ci |
|---|---|---|
| Al 7075-T6 | 0.017176 | 0.007991955 |
| Al 2024-T4 | 0.013014 | 0.003903467 |
| Ti–6Al–4V | 0.028429 | 0.026566027 |
| Ti–2Fe–3Al | 0.038655 | 0.039820612 |
| S-glass70%-Epoxy cont. fibers | 0.060033 | 0.013149085 |
| S-glass70%-Epoxy fabric | 0.019465 | 0.011691183 |
| Carbon 63%-Epoxy | 0.050785 | 0.058655516 |
| Aramid 62%-Epoxy | 0.038064 | 0.031827066 |
| E-glass73%-Epoxy | 0.047064 | 0.005489267 |
| E-glass56%-Epoxy | 0.029555 | 0.005725182 |
| E-glass65%-Polyester | 0.00985 | 0.005590392 |

Table 5 displays the total cost and total benefit criteria that were determined using equations 5 and 6.

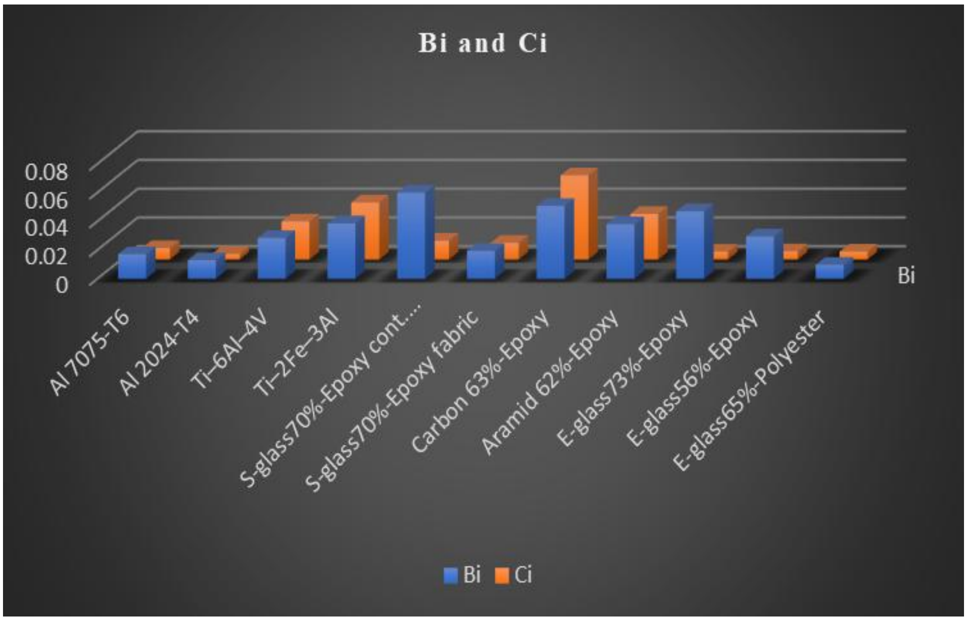



**FIGURE 2.** Bi and Ci

Equations 5 and 6 were used to calculate the total beneficial criteria and total cost criterion shown in Figure 2.

**TABLE 6.** Relative significance and Utility degree

| | Qi | Ui |
|---|---|---|
| Al 7075-T6 | 0.5056 | 49.9105 |
| Al 2024-T4 | 1.01301 | 100 |
| Ti–6Al–4V | 0.17536 | 17.31104 |
| Ti–2Fe–3Al | 0.13668 | 13.49255 |
| S-glass70%-Epoxy cont. fibers | 0.3569 | 35.23104 |
| S-glass70%-Epoxy fabric | 0.35335 | 34.88068 |
| Carbon 63%-Epoxy | 0.11733 | 11.58268 |
| Aramid 62%-Epoxy | 0.16071 | 15.86456 |
| E-glass73%-Epoxy | 0.75817 | 74.84326 |
| E-glass56%-Epoxy | 0.71136 | 70.22224 |
| E-glass65%-Polyester | 0.7081 | 69.89992 |

In Table 6, the utility degree values for each material have been calculated using equations 7 and 8, providing insights into their relative performance and suitability for the Spar of Human Powered Aircraft. Among the materials evaluated, Al 2024-T4 stands out with a perfect utility degree of 100, indicating its exceptional performance across the considered criteria. E-glass 73%-Epoxy follows closely behind, boasting a high utility degree of 74.84326, demonstrating its strong suitability for the application. E-glass 56% Epoxy and E-glass 65% Polyester also display favorable utility degree values of 70.22224 and 69.89992, respectively, positioning them as promising choices. On the other hand, Carbon 63% Epoxy exhibits a relatively lower utility degree of 11.58268, suggesting some limitations in its performance concerning the evaluation parameters. The utility degree analysis aids in identifying the most advantageous materials, assisting in the informed selection of materials for the optimal design and construction of the Spar in Human Powered Aircraft.

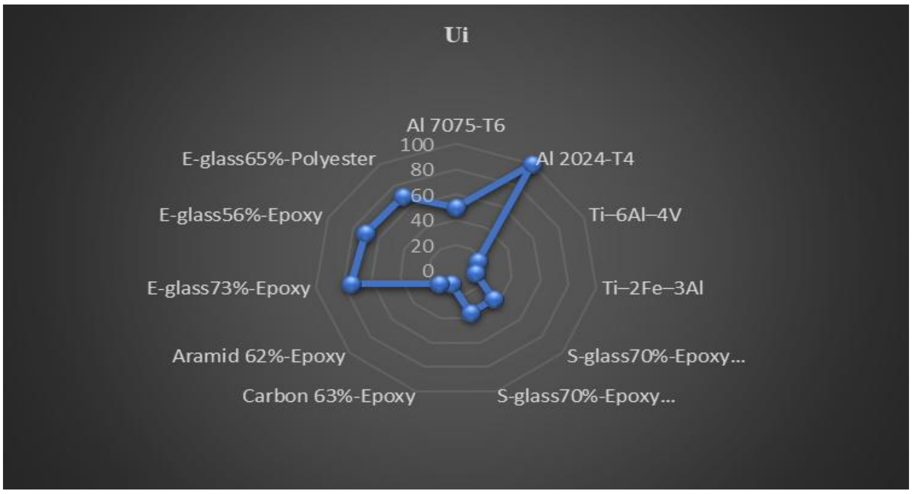



**FIGURE 3**. Utility Degree

The graphical representation in Figure 3 allows for a visual comparison of the materials' utility degrees, clearly indicating the varying degrees of suitability and performance. Al 2024-T4 is depicted as the most suitable material with a utility degree of 100, while Carbon 63% Epoxy shows the lowest utility degree of 11.58268, signifying its relatively weaker performance compared to other materials. This graphical analysis aids in better understanding and decision-making regarding the material selection process for the Spar in Human Powered Aircraft.

**TABLE 7.** Rank

| | Rank |
|---|---|
| Al 7075-T6 | 5 |
| Al 2024-T4 | 1 |
| Ti–6Al–4V | 8 |
| Ti–2Fe–3Al | 10 |
| S-glass70%-Epoxy cont. fibers | 6 |
| S-glass70%-Epoxy fabric | 7 |
| Carbon 63%-Epoxy | 11 |
| Aramid 62%-Epoxy | 9 |
| E-glass73%-Epoxy | 2 |
| E-glass56%-Epoxy | 3 |
| E-glass65%-Polyester | 4 |

Table 7 presents a comprehensive ranking of alternative materials, such as Al 7075-T6, Al 2024-T4, Ti–6Al–4V, Ti–2Fe–3Al, S-glass 70% Epoxy continuous fibers, S-glass 70% Epoxy fabric, Carbon 63% Epoxy, Aramid 62% Epoxy, E-glass73%-Epoxy, E-glass 56% Epoxy, and E-glass 65% Polyester, based on their respective utility degree values derived from the COPRAS method (as seen in Table 6). Through this evaluation, a clear order of preference has emerged, aiding in the decision-making process for selecting the most suitable material for the Spar of Human Powered Aircraft. Al 2024-T4 claims the top position with the highest rank, underscoring its exceptional performance and desirability. Conversely, Carbon 63% Epoxy secures the last rank, signifying its relatively lower suitability compared to the other materials. The ranking provided by the COPRAS method offers valuable insights into the materials' relative strengths and weaknesses, guiding engineers and designers in making informed choices to optimize the Spar's performance and overall efficiency in the context of Human Powered Aircraft.


**FIGURE 4**. Rank

In Figure 4, Al 2024-T4 emerges as the top-ranked material, signifying its superiority and strong suitability for the application. Conversely, Carbon 63% epoxy ranks last among the materials evaluated, indicating its comparatively lower performance compared to the others. This visual representation of rankings offers a quick and intuitive understanding of the materials' relative positions, guiding decision-makers in selecting the most appropriate material for the Spar of Human Powered Aircraft.

## 4. CONCLUSION

A specialized field within aerospace engineering is dedicated to studying aircraft with an extraordinary level of energy efficiency, enabling them to achieve continuous flight by relying solely on human-generated power. These aircraft are commonly known as human-powered airplanes or human-powered aircraft (HPA). The unique challenge of HPAs lies in their power limitations, which distinguish them as a distinct and complex type of aircraft. These engineering endeavors focus on developing innovative solutions to minimize weight, optimize aerodynamics, and maximize the mechanical advantage of human propulsion. The ultimate goal is to create lightweight and efficient structures, advanced wing designs, and propulsion systems that push the boundaries of human-powered flight, inspiring the advancement of sustainable and eco-friendly aviation technologies for the future. The materials for this can be divided into two categories: alloys and composites. The unobserved components in this case might be associated in a certain domain (say, alloys or composites). A designer must exercise judgement at every level of the design process. Different methods for selecting materials have been proposed and used by various researchers, mostly based on the quantitative and qualitative qualities of materials. A fundamental aspect of the design process involves making choices among various options. In addition to traditional materials such as metals, ceramics, and polymers, material science has continuously produced an extensive array of new materials, including composites, smart (intelligent), and functionally graded materials. These advancements have opened up exciting possibilities for engineers and designers, enabling them to explore innovative materials that possess unique properties and functionalities. The availability of these diverse materials offers a wealth of opportunities to tailor the design of products, structures, and systems to meet specific performance requirements, leading to advancements in various industries and technologies. With the expansion of knowledge, a designer today has access to a wider range of materials than ever before. Similar to the majority of instances, the material in our study is regarded as a pre-assigned design parameter. The COPRAS approach was utilized in this analysis. The analysis's findings indicate that Al 2024-T4 aluminium alloy, E-glass 73%-Epoxy, E-glass 56% Epoxy, and E-glass 65% Polyester are the optimum materials for human-powered aircraft spars.

## REFERENCES


[1]. Jahan, Ali, Md Yusof Ismail, Faizal Mustapha, and Salit Mohd Sapuan. "Material selection based on ordinal data." *Materials & Design* 31, no. 7 (2010): 3180-3187.

[2]. Khabbaz, R. Sarfaraz, B. Dehghan Manshadi, A. Abedian, and R. Mahmudi. "A simplified fuzzy logic approach for materials selection in mechanical engineering design." *Materials & Design* 30, no. 3 (2009): 687-697.

[3]. Das, Debasis. "Selection of materials in engineering design using Ashby's chart and AHP-TOPSIS." PhD diss., 2012.

[4]. Fayazbakhsh, K., A. Abedian, B. Dehghan Manshadi, and R. Sarfaraz Khabbaz. "Introducing a novel method for materials selection in mechanical design using Z-transformation in statistics for normalization of material properties." *Materials & Design* 30, no. 10 (2009): 4396-4404.

[5]. Rathor, Ketan, Keyur Patil, Mandiga Sahasra Sai Tarun, Shashwat Nikam, Devanshi Patel, and Sasanapuri Ranjit. "A Novel and Efficient Method to Detect the Face Coverings to Ensurethe Safety using Comparison Analysis." In *2022 International Conference on Edge Computing and Applications (ICECAA)*, pp. 1664-1667. IEEE, 2022.

[6]. Shanmugasundar, G., Abhishek G. Shanker, V. S. Vinothabhilash, K. Vijayalayan, and S. Jayaraman. "Design and fabrication of solar powered surveillance drone for women safety." In *AIP Conference Proceedings*, vol. 2393, no. 1. AIP Publishing, 2022.

[7]. Vanderhoydonck, Bob, Gilberto Santo, Jan Vierendeels, and Joris Degroote. "Optimization of a human-powered aircraft using fluid–structure interaction simulations." *Aerospace* 3, no. 3 (2016): 26.

[8]. Sasaki, Daisuke, Takahito Kurishita, and Masaru Kamada. "Robust airfoil optimization of human-powered aircraft against manufacturing variations." In *2015 IEEE Congress on Evolutionary Computation (CEC)*, pp. 611-617. IEEE, 2015.

[9]. Kasaei, Afshar, Ali Abedian, and A. S. Milani. "An application of Quality Function Deployment method in engineering materials selection." *Materials & Design* 55 (2014): 912-920.

[10]. Kumar, Ashish, Ketan Rathor, Snehit Vaddi, Devanshi Patel, Preethi Vanjarapu, and Manichandra Maddi. "ECG Based Early Heart Attack Prediction Using Neural Networks." In *2022 3rd International Conference on Electronics and Sustainable Communication Systems (ICESC)*, pp. 1080-1083. IEEE, 2022.

[11]. Manjunath, C. R., Ketan Rathor, Nandini Kulkarni, Prashant Pandurang Patil, Manoj S. Patil, and Jasdeep Singh. "Cloud Based DDOS Attack Detection Using Machine Learning Architectures: Understanding the Potential for Scientific Applications." *International Journal of Intelligent Systems and Applications in Engineering* 10, no. 2s (2022): 268-271.

[12]. Rathor, Ketan, Anshul Mandawat, Kartik A. Pandya, Bhanu Teja, Falak Khan, and Zoheib Tufail Khan. "Management of Shipment Content using Novel Practices of Supply Chain Management and Big Data Analytics." In *2022 International Conference on Augmented Intelligence and Sustainable Systems (ICAISS)*, pp. 884-887. IEEE, 2022.

[13]. Mardanpour, Pezhman, W. R. Krüger, H. Haddadpour, and Diethelm Hoffmann. "Design and Testing of a Model Wing Section for a Human Powered Aircraft." *ICAS 2006-Proceedings* (2006).

[14]. Balaguru S, Vela Murali&Chellapandi P 2016, 'MeasurementoftheResidualStressesandInvestigationof TheirEffectsonaHardfacedGridPlatedueto ThermalCyclinginaPoolType Sodium-Cooled FastReactor', Science and Technology of Nuclear Installations (ISSN: 1687-6083), vol. 2016, pp. 1-8.

[15]. Liddicoat, Peter V., Xiao-Zhou Liao, Yonghao Zhao, Yuntian Zhu, Maxim Y. Murashkin, Enrique J. Lavernia, Ruslan Z. Valiev, and Simon P. Ringer. "Nanostructural hierarchy increases the strength of aluminium alloys." *Nature communications* 1, no. 1 (2010): 1-7.

[16]. Selvi, S. Annal Ezhil. "Implementation of Raaes: Reliability-Assured and Availability-Enhanced Storage System." *Journal of Algebraic Statistics* 13, no. 2 (2022): 3711-3720.

[17]. Selvi, S. Annal Ezhil, and Dr R. Anbuselvi. "A Detailed Analysis of Cloud Storage Issues." In *International Conference on Mathematical Methods and Computation (ICOMAC 2015)*, p. 14. 2015.

[18]. Balaguru S, Vela Murali&Chellapandi P 2017, 'Effects of different Operating Temperatures on the Tensile Properties of the Grid Plate Hardfaced with ColmonoyinaPoolType Sodium-Cooled FastReactor', Science and Technology of Nuclear Installations (ISSN: 1687-6083), vol. 2017, pp. 1-9.

[19]. Rathor, Ketan, Sushant Lenka, Kartik A. Pandya, B. S. Gokulakrishna, Susheel Sriram Ananthan, and Zoheib Tufail Khan. "A Detailed View on industrial Safety and Health Analytics using Machine Learning Hybrid Ensemble Techniques." In *2022 International Conference on Edge Computing and Applications (ICECAA)*, pp. 1166-1169. IEEE, 2022.

[20]. Shanmugasundar, G., R. Jaswanth Kumar, S. Yuvaraj, P. Govarthanan, and E. Akash. "Design And Development of Pneumatic Actuated Robotic Arm with Multipurpose Gripper." (2022).

[21]. Miller, W. S., L. Zhuang, J. Bottema, A_J Wittebrood, P. De Smet, A. Haszler, and A. J. M. S. Vieregge. "Recent development in aluminium alloys for the automotive industry." *Materials Science and Engineering: A* 280, no. 1 (2000): 37-49.

[22]. Jessintha, J. Persis, S. Annal Ezhil Selvi, and R. Jemima Priyadarsini. "An Efficient Sensory Based Cost-effective IoT Model for Prior Prediction of Covid-19." In *2021 International Conference on Advancements in Electrical, Electronics, Communication, Computing and Automation (ICAECA)*, pp. 1-5. IEEE, 2021.
[23]. Balaguru S, Mohammad Abid&Manoj Gupta 2020, Investigations on different hardfacing processes for High temperature applications of Ni-Cr-B-Si alloy hardfaced on austenitic stainless steel components, Journal of Materials Research and Technology (ISSN: 2238-7854), vol. 9, pp. 10062-10072.
[24]. Shanmugasundar, G., V. Fegade, M. Mahdal, and K. Kalita. "Optimization of Variable Stiffness Joint in Robot Manipulator Using a Novel NSWOA-MARCOS Approach. Processes 2022, 10, 1074." (2022).
[25]. Krishna, S. Rama, Ketan Rathor, Jarabala Ranga, Anita Soni, D. Srinivas, and Anil Kumar. "Artificial Intelligence Integrated with Big Data Analytics for Enhanced Marketing." In *2023 International Conference on Inventive Computation Technologies (ICICT)*, pp. 1073-1077. IEEE, 2023.
[26]. Balaguru S &Manoj Gupta 2021, Hardfacing studies of Ni alloys: A Critical Review, Journal of Materials Research and Technology (ISSN: 2238-7854) vol. 10, pp: 1210-1242.
[27]. Krishnan, G. Sai, G. Shanmugasundar, M. Vanitha, and S. Kumar. "Investigation on mechanical properties of metallic fiber reinforced concrete." In *AIP Conference Proceedings*, vol. 2747, no. 1. AIP Publishing, 2023.
[28]. Tien, Tzu-Li. "The indirect measurement of tensile strength of material by the grey prediction model GMC (1, n)." *Measurement Science and Technology* 16, no. 6 (2005): 1322.
[29]. Selvi, S. Annal Ezhil, and Dr R. Anbuselvi. "Ranking Algorithm Based on File’s Accessing Frequency for Cloud Storage System." *International Journal of Advanced Research Trends in Engineering and Technology (IJARTET) Vol* 4 (2017).
[30]. Friák, M., M. Šob‖, and V. Vitek. "Ab initio calculation of tensile strength in iron." *Philosophical Magazine* 83, no. 31-34 (2003): 3529-3537.
[31]. Rajakumar, M. P., S. Ganesan, N. Sankar Ram, D. Hemanand, and Rajesh Thumma. "IOT BASED DATA STREAMING IN DISTRIBUTED HYBRID CLOUD USING SPARKFLOW." *European Journal of Molecular & Clinical Medicine* 7, no. 02: 2020.
[32]. Yazdani, Morteza, Ali Alidoosti, and Edmundas Kazimieras Zavadskas. "Risk analysis of critical infrastructures using fuzzy COPRAS." *Economic research-Ekonomska istraživanja* 24, no. 4 (2011): 27-40.
[33]. Kaklauskas, Arturas, Edmundas Kazimieras Zavadskas, Saulius Raslanas, Romualdas Ginevicius, Arunas Komka, and Pranas Malinauskas. "Selection of low-e windows in retrofit of public buildings by applying multiple criteria method COPRAS: A Lithuanian case." *Energy and buildings* 38, no. 5 (2006): 454-462.
[34]. Meyers, Marc A., A. Mishra, and David J. Benson. "Mechanical properties of nanocrystalline materials." *Progress in materials science* 51, no. 4 (2006): 427-556.
[35]. Kokubo, Tadashi, Hyun-Min Kim, and Masakazu Kawashita. "Novel bioactive materials with different mechanical properties." *Biomaterials* 24, no. 13 (2003): 2161-2175.
[36]. Balaguru S, Vela Murali&Chellapandi P 2015, ‘Effects of Welding speeds on Macro and Microstructures in Hardfacing of Colmonoy on Un-grooved and Grooved 316 L(N) SS Base metal’, International Journal of Applied Engineering Research (ISSN 0973-9769), vol. 10, pp. 25627-2563.
[37]. Shanmugasundar, G., Ankur Bansod, Vladimira Schindlerova, and Robert Čep. "Influence of Filler Material on the Microstructural and Mechanical Properties of 430 Ferritic Stainless Steel Weld Joints." *Materials* 16, no. 4 (2023): 1590.
[38]. Stein, Julien, Blanka Lenczowski, Nicole Fréty, and Eric Anglaret. "Mechanical reinforcement of a high-performance aluminium alloy AA5083 with homogeneously dispersed multi-walled carbon nanotubes." *Carbon* 50, no. 6 (2012): 2264-2272.
[39]. Bawa, Surjit Singh. "Implement Gamification to Improve Enterprise Performance." International Journal of Intelligent Systems and Applications in Engineering 11, no. 2 (2023): 784-788.
[40]. Chembian, W. T., D. Hemanand, A. Thomas Paul Roy, P. Deepak Franklin, G. Krishna, N. C. Kumari, S. V. Hemanth, and A. Gnana Soundari. "A High-Performance Infrastructure for Remote Sensing Data Applications Using HPC Paradigms."
[41]. Deák, Tamás, and Tibor Czigány. "Chemical composition and mechanical properties of basalt and glass fibers: a comparison." *Textile Research Journal* 79, no. 7 (2009): 645-651.
[42]. Rajakumar, M. P., S. Ganesan, N. Sankar Ram, D. Hemanand, and Rajesh Thumma. "IOT BASED DATA STREAMING IN DISTRIBUTED HYBRID CLOUD USING SPARKFLOW." *European Journal of Molecular & Clinical Medicine* 7, no. 02: 2020.
[43]. Feih, Stefanie, E. Boiocchi, G. Mathys, Z. Mathys, A. G. Gibson, and A. P. Mouritz. "Mechanical properties of thermally-treated and recycled glass fibres." *Composites Part B: Engineering* 42, no. 3 (2011): 350-358.
[44]. Thwe, Moe Moe, and Kin Liao. "Durability of bamboo-glass fiber reinforced polymer matrix hybrid composites." *Composites science and technology* 63, no. 3-4 (2003): 375-387.

[45]. Shanmugasundar, G., M. Dharanidharan, D. Vishwa, P. Gokul, and L. Manojkumar. "A study on design of universal gripper for different part handling: Methods, mechanisms, and materials." In *AIP Conference Proceedings*, vol. 2393, no. 1. AIP Publishing, 2022.

[46]. College, College1 College2 College, J. Paul Rajasingh, and Chennai Ramapuram. "A Systematic Conceptual Review-Blockchain As A Next Generation E-Government Information Infrastructure." *European Journal of Molecular & Clinical Medicine* 7, no. 06: 2020. AmrutaPasarkar,

[47]. Bawa, Surjit Singh. "How Business can use ERP and AI to become Intelligent Enterprise."

[48]. S.Balaguru, 2022 ‘Development on Fatigue Testing of Hardfaced Components in Sodium Cooled Fast Reactors’, Engineering Failure Analysis, (ISSN: 1350-6307) vol. 137, pp. 106161, 2022. https://doi.org/10.1016/j.engfailanal.2022.106161.

[49]. Krishna Kumar TP, M. Ramachandran, Kurinjimalar Ramu, "Emergency Management Investigation Using COPRAS Method", Recent trends in Management and Commerce, 2(1), 2021: 32-37.

[50]. Nisha Bansal; M. Ramachandran; Sathiyaraj Chinnasamy; P. Sudha, "Assessment of the Comprehensive Performance of 5G Base Station using the COPRAS" Data Analytics and Artificial Intelligence, 3(5), 2023, 1-9.

[51]. Dr. N. subash, M. Ramachandran, Vimala Saravanan, Vidhya prasanth, "An Investigation on Tabu Search Algorithms Optimization", Electrical and Automation Engineering 1(1) 2022, 13-20.

[52]. Sarveshwar Kasarla; M. Ramachandran; Vidhya Prasanth, "Phase Change Material and Application of Stabilized PCM Emulsion", Materials and its Characterization, 1(1) 2022, 96-101.

[53]. D.S. Bishore; P. Ashika; M. Ramachandran; Kurinjimalar Ramu; Soniya Sriram, "Exploring Architecture Modeling and Design Studio", Sustainable Architecture and Building Materials, 1(1) 2022, 14-20.

[54]. Bawa, Surjit Singh. "Implementing Text Analytics with Enterprise Resource Planning." International Journal of Simulation--Systems, Science & Technology 24, no. 1 (2023).