University of Baghdad College of Engineering

# Journal of Engineering

journal homepage: www.joe.uobaghdad.edu.iq

Volume 29 Number 7 July 2023

# Material Selection for Unmanned Aerial Vehicles (UAVs) Wings Using Ashby Indices Integrated with Grey Relation Analysis Approach Based on Weighted Entropy for Ranking

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## ABSTRACT

The designer must find the optimum match between the object's technical and economic needs and the performance and production requirements of the various material options when choosing material for an engineering application. This study proposes an integrated (hybrid) strategy for selecting the optimal material for an engineering design depending on design requirements. The primary objective is to determine the best candidate material for the drone wings based on Ashby's performance indices and then rank the result using a grey relational technique with the entropy weight method. Aluminum alloys, titanium alloys, composites, and wood have been suggested as suitable materials for manufacturing drone wings. The requirements for designing a drone's wings are to make them as light as possible while meeting the stiffness, strength, and fracture toughness criteria. The conclusion indicates that Carbon Fiber-Reinforced Polymer (CFRP) is the best material for producing drone wings. In contrast, wood and aluminum alloys were the cheapest materials when the design had to be inexpensive.

**Keywords:** Material selection, drone wings, Material Performance Index, Grey Relation Analysis, Weighted Entropy Method.

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Peer review under the responsibility of University of Baghdad.

https://doi.org/10.31026/j.eng.2023.07.12



Article received: 14/01/2023

Article accepted: 23/02/2023

Article published: 01/07/2023

# اختيار المواد لأجنحة الطائرات بدون طيار(UAVs) باستخدام مؤشرات اداء Ashby المدمجة مع نهج تحليل العلاقة الرمادية استنادًا إلى الأنتروبيا الموزونة للترتيب

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**الخلاصة**

يجب أن يجد المصمم التطابق الأمثل بين الاحتياجات الفنية والاقتصادية للمنتج وبين متطلبات الأداء والإنتاج للمواد المختلفة عند اختيار المواد لتطبيق هندسي. تقترح هذه الدراسة استراتيجية متكاملة (هجينة) لاختيار المادة المثلى للتصميم الهندسي اعتمادًا على متطلبات التصميم. الهدف الأساسي هو تحديد أفضل مادة مرشحة لأجنحة الطائرات بدون طيار استنادًا إلى مؤشرات أداء Ashby ثم ترتيب النتيجة باستخدام تقنية العلائقية الرمادية مع طريقة الوزن الإنتروبيا. تم اقتراح سبائك الألومنيوم وسبائك التيتانيوم والمركبات والخشب كمواد مناسبة لتصنيع أجنحة الطائرات بدون طيار. متطلبات تصميم أجنحة الطائرات بدون طيار هي جعلها خفيفة قدر الإمكان مع تلبية معايير الصلابة والقوة وصلابة الكسر. يشير الاستنتاج إلى أن البوليمر المقوى بألياف الكربون (CFRP) هو أفضل مادة لإنتاج أجنحة الطائرات بدون طيار. في المقابل ، كان الخشب وسبائك الألومنيوم أرخص المواد عندما كان على التصميم أن يكون غير مكلف.

**الكلمات الرئيسية:** اختيار المواد، أجنحة الطائرات بدون طيار، مؤشر أداء المواد، تحليل العلاقة الرمادية، طريقة الانتروبيا الموزونة.

## 1. INTRODUCTION

Material selection is among the most challenging topics developers adopt because it relates to process performance. Designers, engineers, and manufacturers constantly look for new and better materials to increase performance and reduce costs to maintain market competitiveness **(Al-Mendwi, 2009; Mehmood et al., 2018)**. The selection of material for an engineering application necessitates that the designer determines the best fit between the object's technical and economic needs and the performance and production requirements of the available material alternatives. Finding this optimal combination is complex and requires the designer's experience and good sense **(Ashby et al., 2004)**. "A drone is an Unmanned Aerial Vehicle (UAV) guided by remote control or onboard computers." Drones, formerly associated with the military, are today employed by people and enormous corporations for various purposes **(Uddin, 2020)**. It has recently gained widespread military and civilian approval. These uses include environmental pollution research and polar region scanning, in addition to its military significance. The wing is a critical component of every airplane. Choosing materials for UAV manufacture is quite essential. UAVs are usually made of metals like aluminum, which is heavy and expensive. Polymer composites are used in aerospace, automobiles, structural applications, and UAVs because of their excellent mechanical properties and low cost compared to conventional materials **(ElFaham et al., 2020)**. In recent years, decision-makers have utilized Multi-Criteria Decision-Making (MC-DM) techniques while selecting materials. MC-DM techniques are generally described as a methodology for selecting, sorting, or classifying two or more alternatives based on quantitative and qualitative criteria that frequently clash with one another **(Özcan and Çelik, 2021)**. Identifying the objective, formulating the selection criteria, identifying the most suitable alternatives, and making the final selection are the four steps of the selection process **(Erzaij and Bidan, 2016)**. MC-DM techniques have been the

subject of several research investigations into the best approach for making optimal selections. **(Delibas et al., 2017**) aimed to select the optimal materials for particular spur gear designs. According to their material index, suitable materials were identified using Ashby's method, an advanced tool for material selection **(Delibaş et al., 2017)**. **(Moradian et al., 2019)** presented an approach for MC-DM methods in which criteria are weighted using Entropy Weight Method (EWM) and Analytic Hierarchy Process (AHP) techniques. Multi-objective optimization based on ratio analysis (MOORA), the Technique of Ranking Preferences by Similarity of the Ideal Solutions (TOPSIS), and Vlse Kriterijumska Optimizacija Kompromisno Resenje (VIKOR) are used to rank and determine the optimal material **(Moradian et al., 2019)**. **(Duryat, 2020)** employed a systematic methodology that involves material indices according to the Ashby technique and ranking according to the digital logic method (DL). **(Vatansever et al., 2018)** employed MC-DM techniques using the EWM and Grey Relational Analysis (GRA) methods to evaluate airline websites. The variable weights were computed using the EWM method, and website rankings were determined using the GRA method **(Vatansever and Akgűl, 2018)**. **(Wu et al., 2018)** design a hybrid comprehensive evaluation methodology to analyze a unit operational performance. The methodology combines GRA with AHP and an unique entropy-based approach (abbreviated as BECC), which integrates bootstrap method and Correlation Coefficient (CC) into entropy principle to achieve the objective weight of indices **(Wu et al., 2018)**. **(Doos et al. 2023)**, utilize the weighted factor method (WFM) to select the optimal frictional material for the clutch disc.
This study proposes an integrated (hybrid) technique for selecting the optimal material for UAV wings. The primary objective is to determine the best candidate material for the lightweight drone wings based on Ashby's performance indices and then rank the result using the GRA technique with the EWM method.

## 2. AN OVERVIEW OF THE GREY RELATIONAL ANALYSIS (GRA) METHOD

The GRA method was founded on the gray system theory **(Vatansever and Akgűl, 2018)**. This concept has been demonstrated to aid in processing uncertain, incomplete, or inaccurate data **(Maidin et al., 2022)**. GRA is often used to measure financial performance, logistic performance, and process optimization **(Patil et al., 2017)**. The following are the procedures involved in the traditional grey relational analysis:

- Grey relational sequence generation is formed by normalizing the decision matrix and producing the attribute comparability sequence, with the larger, the better (or benefit attributes), as follows **(Wu et al., 2018)**:

$$y_{ij} = \frac{x_{ij} - min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})}, (1 \le i \le n, 1 \le j \le m) \quad (1)$$

Additionally, the cost attribute index, where the smaller, the better, can be normalized as follows **(Wu et al., 2018)**:

$$y_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})}, (1 \le i \le n, 1 \le j \le m) \quad (2)$$

where $x_{ij}$ is the value of performance indices for each material, and $y_{ij}$ is the linear scale standardized matrix **(Wu et al., 2018)**.

- Derivation of the reference sequence, X0, with values equal to 1, was defined and compared to the generated sequence. The following is the reference sequence **(Maidin et al., 2022)**:

$$X0 = (x01, x02, \ldots, x0j, \ldots, x0n) = (1,1,\ldots,1\ldots,1) \tag{3}$$

where $X0$ is the reference sequence value.
The matrix can be written as **(Wu et al., 2018)**:

$$Z = (z_{ij})_{n*m} = \left|x_{0j} - x_{ij}\right|, (1 \le i \le n, 1 \le j \le m) \tag{4}$$

Where $z$ is the reference sequence matrix.

- Calculating the Grey Relational Coefficient computed using the equations below **(Wu et al., 2018)**:

$$\xi_{ij} = \frac{\text{minmin}\{z_{ij}\} + \rho \max max\{z_{ij}\}}{z_{ij} + \rho\text{max}\max\{z_{ij}\}}, (1 \le i \le n, 1 \le j \le m) \tag{5}$$

where $\xi_{ij}$ is the grey relational coefficient of the $jth$ index of the $ith$ alternative
The factor ρ ∈ [0, 1] is the distinguishing coefficient and is usually set to 0.5 **(Sarraf and Nejad, 2020)**.

- Grey relational grade distributed between zero and one, obtained by using the formula below **(Sarraf and Nejad, 2020)**:

$$\Gamma\,(x_0, x_i) = \sum_{j=1}^{n} W_j \;\xi_{ij} \tag{6}$$

where $W_j$ is the weight assigned to the attribute j. The total weight assigned to the attributes is unity **(Maidin et al., 2022)**,

$$\sum_{j=1}^{n} W_j = 1 \tag{7}$$

## 3. AN OVERVIEW OF THE ENTROPY WEIGHTING (EWM) METHOD

The EWM Method technique is used to assign weights to the requirements. It is an essential information-weighting method that eliminates the effects of personal factors on variable weighting. The weight determination procedure is outlined below **(Vatansever and Akgűl, 2018)**.
The first step is the building of a decision matrix (X). The decision matrix of the n*m performance matrix can be written as follows **(Wu et al., 2018)**:

$$X = (x_{ij})_{n*m}, i = 1,2,\ldots,n; j, 1,2,\ldots,m \tag{8}$$

where $x_{ij}$ is a numerical number indicating the alternative's performance
The second step is the normalization of the decision matrix (performance indices) as follows **(Zhu et al., 2020)**:

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}}, i = 1,2,\ldots,n; j = 1,2,\ldots,m \tag{9}$$

The third step is to calculate the entropy **(Zhu et al., 2020)**

$$e_j = \frac{\sum_{i=1}^{n} p_{ij} ln p_{ij}}{\ln n} \tag{10}$$

The fourth step is to calculate the objective weight value:

$$w_j = \frac{1-e_j}{\sum_{j=1}^{m}(1-e_j)}, j = 1,2, \dots, m \quad (11)$$

## 4. MATERIALS AND DESIGN REQUIREMENTS FOR (UAVs)

Developing lightweight drone wing materials aims to enhance mechanical properties and reduce costs. Depending upon those basic parameters, material density, yield strength, Young's modulus, fracture toughness, and cost are relevant attributes. Aluminum alloys, Titanium alloys, Composites, and Wood have been suggested as suitable wing materials for drones. Wood is utilized since it is an adaptable raw resource and the only recyclable construction material. The main benefit of wood is that it is light and inexpensive **(Kumar and Kumar, 2019)**. UAVs are typically constructed from metals like aluminum and titanium alloys, considered heavy and expensive. Composite materials such as (CFRP) and Glass Fiber-Reinforced Polymers (GFRP) have been characterized by their ease of preparation, production, and cost reduction **(ElFaham et al., 2020)**. The requirements for designing a drone's wings are to make it as light as possible while meeting the criteria for deformation, stiffness, and strength **(Yu, 2018)**. The UAV's precision and accuracy throughout flight were critical requirements. A high strength-to-weight ratio was the most important requirement **(Balachandran et al., 2014)**. Depending on the design requirement, the following are the material indices:

- Maximize stiffness while minimizing weight, the design must be aerodynamic, and the material must be easily formable or shapeable. Constructing a strong, stiff, stable structure, wings, fuselage, etc. **(Kumar and Kumar, 2019)**.

$$M2 = E^{1/2}/\rho \quad (12)$$

- Maximum Strength at Minimum Weight: A material's strength-to-weight ratio is among the most important requirements when selecting the material in aero engineering applications **(Mohammed, 2017)**. The index that maximizes the ratio of strength to weight is as follows:

$$M1 = \sigma y^{2/3}/\rho \quad (13)$$

- The material's fracture toughness is another important attribute to consider. Increasing the fatigue life with high fracture toughness **(Najam et al., 2018)**. Maximizing fracture toughness index is as follows:

$$\mathrm{M3 = k1c/\rho} \quad (14)$$

Performance indices evaluate materials; the material with the highest M value is optimal for producing an engineering design. The materials in the shortlist are optimized using performance indices. The performance weight was determined using the EWM method, and the results were ranked using the GRA method. Supporting information is gathered to rank materials to a final choice, offering a close fit between design requirements and material attributes. The list of candidate materials that meet the design's requirements is given in **Table 1**.

**Table 1.** Displays the short-listed materials and their properties.

| Candidate Material | ρ ($Mg/m^3$) | σy (MPa) | E (GPa) | K1C $MPa*m^5$ | Cm ($/kg) |
|---|---|---|---|---|---|
| CFRP | 1.55 | 800 | 109.5 | 47.05 | 42 |
| GFRP | 1.86 | 151 | 21.5 | 15 | 20 |
| Al-alloys | 2.7 | 265 | 75 | 28.5 | 1.6 |
| Ti-alloys | 4.6 | 747.5 | 105 | 67 | 70.5 |
| Wood | 0.7 | 50 | 13 | 7 | 0.9 |

## 5. MATERIALS SELECTION METHODOLOGY

This paper proposes computer-aided material selection (CA-MS) software to select and optimize the appropriate material for an engineering design based on material properties and performance indices. The computerized material selection system helps industrial engineers choose the best material during product design. The main objective is to identify the best material from the short-listed materials using performance indices derived from Ashby's methodology and rank them according to their highest performance value using MCDM techniques (Grey Relational-based Entropy Wight Method).
The CA-MS software was written in C# language and linked to the SQLite database management system. The database contains data about materials and their properties. The material information is gathered from public sources and efficiently displayed to designers working on a design.

## 6. (CA-MS) SYSTEM SOFTWARE DEFINITION

The primary section of the (CA-MS) system software, known as "Computer Aided Material Selector (CA-MA) software," is constructed of selection modules as well as the Database Module Figure 1 shows the main form of the software. Both levels of material selection are screened using go/no-go parameters and then optimized based on the performance indices. Only the optimization is made in two different ways. In level one, the optimization is based on one index, with the highest being the better, while the optimization for level two is based on multiple indices. The ranking is done by the grey relational method based on the entropy-weighted method, and the material with the highest grade value ranks at the top. The procedure for both levels is accomplished in two phases.
**Phase 1**: Identification of the Design Requirement.
The Property Displaying Module will assist users in choosing materials. Figure 2 displays the design specifications window, which considers density, yield strength, tensile strength, Young's modulus, fracture toughness, and cost. The properties combo box lets the user enter a maximum and minimum value directly. The algorithm solves the material selection problem by eliminating candidates who cannot do the job due to one or more particular characteristics outside the constraints. The "choose material" combo box lets users construct a brief choice of materials that meet design requirements. After pressing "calculate," the program continues working on the material selection problem and moves on to the second stage, which displays the performance indices.

**Phase 2**: Ranking (optimization procedure).
After clicking "calculate," a new form will offer performance indices to help filter the remaining candidates depending on optimization criteria. The constraint button, which has stiffness, strength, and fracture toughness indices, and the load button, which has a tie, beam,

shaft, and column, allow the user to choose the index for the design. Figure 4 shows user-available indices. Based on design requirements, the cost option is linked to performance indices and can be activated or deactivated in a separate button. After clicking "calculate," the program properties database fills as matrices using Eqs. (12 to14). The next procedure is for the program to start calculating the performance index weight using the EWM matrices according to Eqs. (8 to11) to compute the index weight, which is then integrated with the GRA matrices using Eqs. (1 to 7) to rank acceptable alternatives in descending order. This process generates a ranked list of optimal materials that satisfy the requirement.

## 7. APPLICATION AND RESULTS

This study aims to determine the optimal material for developing drone wings made of lightweight material. For a design to be acceptable, it must be stiff, strong, durable while also being lightweight and inexpensive. Regarding Ashby's method, the influence of benefit and non-benefit attributes in the design is required to identify the differences between attributes when generating the material indices. The objective is always to increase the benefit attribute's value and decrease the non-benefit attribute's value. Density and cost are considered non-benefit attributes, whereas the remaining attributes are considered to benefit attributes. The material indices are maximized or minimized according to their requirements. The following indices confirm that a given design's component performs at an optimum level:

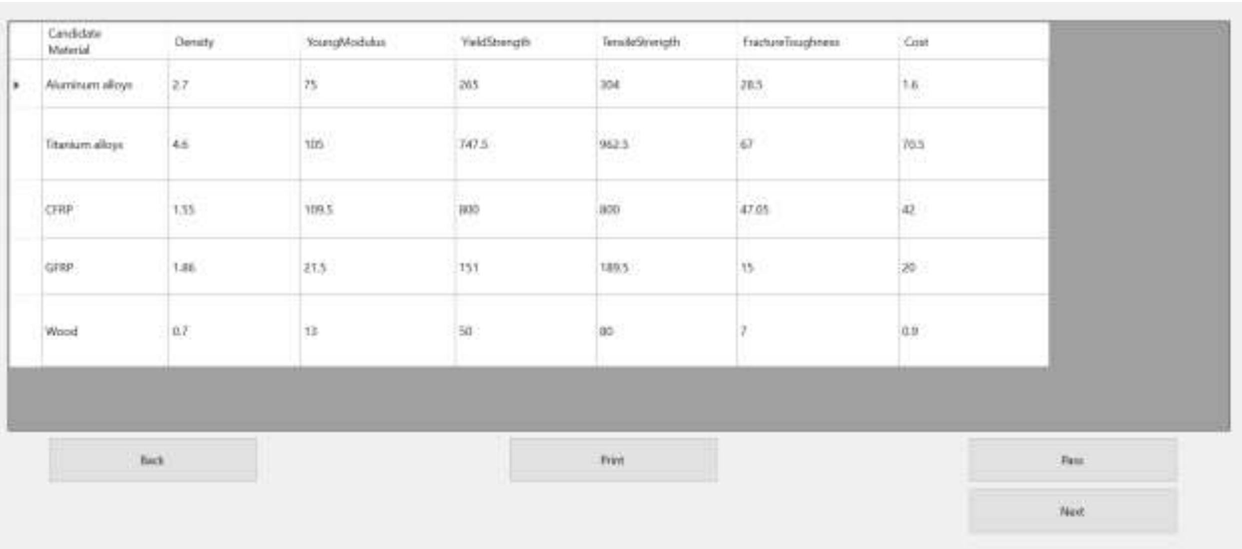
- Young's modulus versus density $E^{1/2}/\rho$
- Young's modulus versus cost $E^{1/2}/\rho Cm$
- Yield strength versus density $\sigma y^{2/3}/\rho$
- Yield strength versus cost $\sigma y^{2/3}/\rho Cm$
- Fracture toughness versus density $k1c/\rho$
- Fracture toughness versus cost $k1c/\rho Cm$

Implementing the Case Study in the (CA-MS) System Software begins by clicking the selection model (Level Two) for the multi-indices phase in the program's main form, as shown in **Fig. 1**.


**Figure 1.** The (user interface) main window.

A property form is displayed as shown in **Fig. 2**, and clicking "select material" generates a list of candidate materials that meet the design's requirements. The candidate materials are shown in **Fig. 3**.


**Figure 2.** The design specifications window for level two.



| Candidate Material | Density | YoungModulus | YieldStrength | TensileStrength | FractureToughness | Cost |
|---|---|---|---|---|---|---|
| Aluminum alloys | 2.7 | 75 | 265 | 304 | 28.5 | 1.6 |
| Titanium alloys | 4.6 | 105 | 747.5 | 962.5 | 67 | 70.5 |
| CFRP | 1.55 | 109.5 | 800 | 800 | 47.05 | 42 |
| GFRP | 1.86 | 21.5 | 151 | 189.5 | 15 | 20 |
| Wood | 0.7 | 13 | 50 | 80 | 7 | 0.9 |



**Figure 3.** Candidate materials used for manufacturing Drone wings.

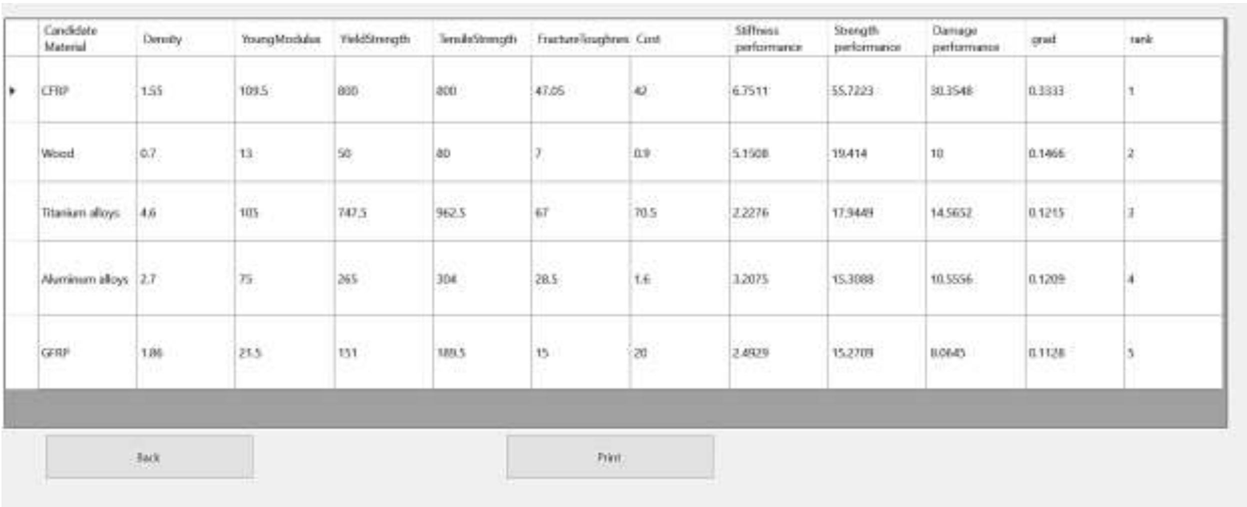
Once the user clicks "next," the process advances to the second phase, which displays the form for selecting performance indices. According to the design requirements, the performance indices stiffness, strength, and fracture toughness are shown in **Fig. 4**.

### 7.1 Performance Evaluation Without Cost Criteria

The Structure of the software consists of three steps. The first includes calculating the performance indices using Eqs. (12 to 14). The EWM Method is used in the second step to


**Figure 4.** Drone wings performance indices.

determine the indices' weights using Eqs. (8 to 11). In the last step, the performance indices were ranked using the GRA method to select the optimal material using Eqs. (1 to 7). By deactivating cost and pressing "calculate," the software runs on the material selection problem based on design requirements. The software results show that CFRP is the best candidate material due to its excellent stiffness and strength performances, while AL-alloys, followed by GFRP, perform the least, as shown in **Fig. 5**.



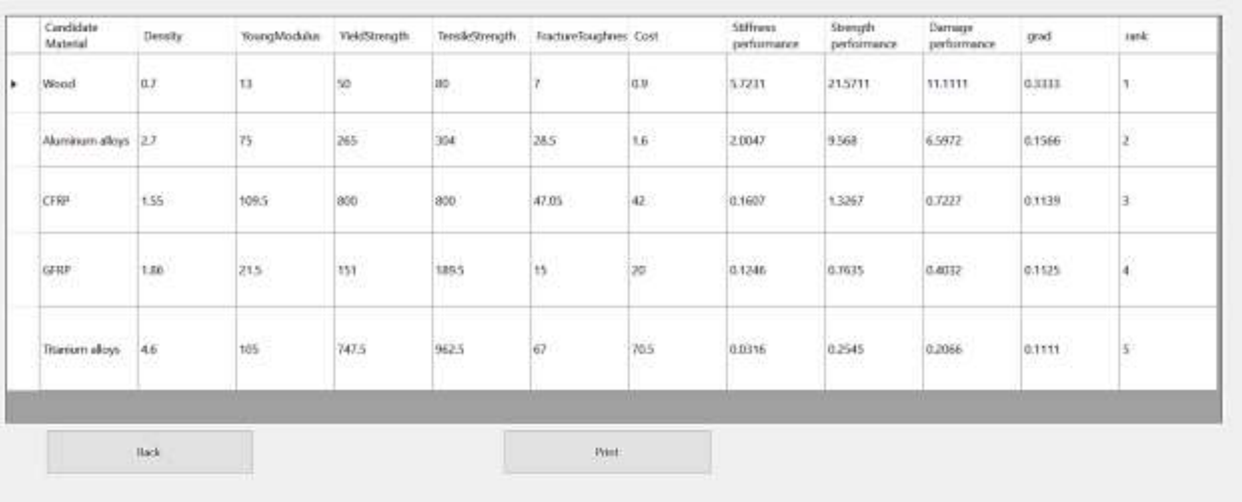
| Candidate Material | Density | YoungModulus | YieldStrength | TensileStrength | FractureToughness | Cost | Stiffness performance | Strength performance | Damage performance | grad | rank |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CFRP | 1.55 | 109.5 | 800 | 800 | 47.05 | 42 | 6.7511 | 55.7223 | 30.3548 | 0.3333 | 1 |
| Wood | 0.7 | 13 | 50 | 80 | 7 | 0.9 | 5.1508 | 19.414 | 10 | 0.1466 | 2 |
| Titanium alloys | 4.6 | 105 | 747.5 | 962.5 | 67 | 70.5 | 2.2276 | 17.9449 | 14.5652 | 0.1215 | 3 |
| Aluminum alloys | 2.7 | 75 | 265 | 304 | 28.5 | 1.6 | 3.2075 | 15.3088 | 10.5556 | 0.1209 | 4 |
| GFRP | 1.86 | 21.5 | 151 | 189.5 | 15 | 20 | 2.4929 | 15.2709 | 8.0645 | 0.1128 | 5 |



**Figure 5.** Drone wings result from the software without Cost Criteria.

### 7.2 Performance Evaluation With Cost Criteria

By activating the cost button in the performance indices form displayed in **Fig. 4** and then clicking "calculate," the result recommends using the least expensive material. The software results show that wood is the cheapest alternative material, followed by AL-alloys regarding design specifications, while Ti-alloy is the most expensive material, as shown in **Fig. 6**.



| Candidate Material | Density | YoungModulus | YieldStrength | TensileStrength | FractureToughnes | Cost | Stiffness performance | Strength performance | Damage performance | grad | rank |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Wood | 0.7 | 13 | 50 | 80 | 7 | 0.9 | 5.7231 | 21.5711 | 11.1111 | 0.3333 | 1 |
| Aluminum alloys | 2.7 | 75 | 265 | 304 | 28.5 | 1.6 | 2.0047 | 9.568 | 6.5972 | 0.1566 | 2 |
| CFRP | 1.55 | 109.5 | 800 | 800 | 47.05 | 42 | 0.1607 | 1.3267 | 0.7227 | 0.1139 | 3 |
| GFRP | 1.86 | 21.5 | 151 | 189.5 | 15 | 20 | 0.1246 | 0.7635 | 0.4032 | 0.1125 | 4 |
| Titanium alloys | 4.6 | 105 | 747.5 | 962.5 | 67 | 70.5 | 0.0316 | 0.2545 | 0.2066 | 0.1111 | 5 |



**Figure 6.** Drone wings result in Cost Criteria.

## 8. ALTERNATIVES EVALUATION

According to our hybrid methodology (integration of Ashby's performance indices with the entropy-grey relational method) used in the study, their grey relational grade and the ranked order of the alternatives are summarized in **Table 2.**

**Table 2.** Grad and Ranked Alternatives for (UAVs) wings results.

| materials | with Cost Criteria | | without Cost Criteria | |
|---|---|---|---|---|
| | GRAD | RANK | GRAD | RANK |
| Al-alloys | 0.1566 | 2 | 0.1209 | 4 |
| Ti alloys | 0.1111 | 5 | 0.1215 | 3 |
| GFRP | 0.1125 | 4 | 0.1128 | 5 |
| CFRP | 0.1139 | 3 | 0.333 | 1 |
| wood | 0.3333 | 1 | 0.1466 | 2 |

Based on the software results, we concluded that the CFRP alternative is the best candidate for drone wings when the design requirements are for the best alternative without a cost limit. The cost specification is included when the design must be cost-effective, and the software results show that the least expensive candidate is wood as the best alternative. In manufacturing lightweight and low-cost drone wings, aluminum alloys that emerge through the program results can be used as the second-best alternative. The complexity of producing the design in wood prevents mass production. Because of its reputation as a complex raw material to work with, production costs include increased time and resource consumption and waste of material.

## 9. CONCLUSIONS

The drone wings material was successfully selected using the hybrid methodology (integration of Ashby's performance indices with the entropy-grey relational method) for choosing the best material for an engineering design based on the performance indices.

Different materials are used for manufacturing drone wings, such as aluminum alloys, titanium alloys, composites, and wood. The performance indices chosen are stiffness, strength, and fracture toughness, with/without cost requirement. The performance weight was calculated using the entropy-weighted method, and the results were ranked using the grey relational analysis method.
Based on the results obtained, we come to the following major conclusions:
The performance indices proved the composite materials have excellent structural strength, stiffness, and toughness. The software results showed that CFRP is the optimum drone wing material for design requirements without a cost limit. Wood was the best and cheapest material when the design had to be economical. However, industrial production of wood products is difficult and prevents mass production.

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