Material selection in a sustainable manufacturing practice of a badminton racket frame using Elimination and Choice Expressing Reality (ELECTRE) Method

Muhammad Firdhaus Che Hassan, Mohd Uzair Mohd Rosli and Muhammad Afiq Mohd Redzuan

Department of Mechanical Engineering Technology, Faculty of Engineering Technology, Universiti Malaysia Perlis 02100 Padang Besar, Perlis, Malaysia

firdhaus@unimap.edu.my / muhammadfirdhauschehassan@gmail.com

Abstract. Badminton is one of the leading sports in the world. It has its own set of rules on the equipments used and general game play. One of the main equipment used is the badminton racket. Each sections of a badminton racket have its own design requirements and one of it is the racket’s material selection. Therefore, material selection is very important to improve the usage of a badminton racket. This study describes the use of the Elimination and Choice Expressing Reality (ELECTRE) method in the material selection of a badminton racket frame with reference to the sustainable manufacturing practice of the frame. By categorizing the materials of the badminton racket frame according to mechanical, physical, chemical and environmental properties, and further detailed sub criteria were set according to the usage of these frames, the ELECTRE I method was used to determine the dominant material. Out of the six materials usually used in the manufacturing of a badminton racket frame, carbon fibre was the dominant material selected from three out of the four properties which are the mechanical, chemical and most importantly the environmental properties, as to comply with the sustainable manufacturing practice of these frames.

1. Introduction

1.1. Background

In the sports world now there are different tools needed to perform the activities and develop and innovate it up to date. Increasing sophisticated technology in sports has contributed a lot to increase the usage of a sports equipment. The design requirements of a sports equipment is an important aspect and commonly associated with conceptual design, material selection and process selection in terms of principles of design and technology. This is especially to produce new material that improves the quality of the sports equipment specifically and the game itself generally [1]. The basic reason to produce a badminton racket is to improve the quality and use of the badminton racket. Factors that needed to be improved are the quality of materials and optimizing the design of a badminton racket [2].
To design is to apply the latest methods and ideas. Each design stage requires a decision with regard to materials in the manufacture of products and methods needed to produce it. The selection of material is important in the production of a product. It is a key element in developing a product because it is an impact or effect on a product developed. Material choice is a step inside the process of designing any physical item. In the context of product design, the principle intention of material selection is to minimize value even as meeting product performance desires [3].

In the manufacturing industry, any equipment which is derived require proper attention to avoid any losses occurred as a loss in the use of raw materials to produce a product. Therefore, steps should be taken to perform the sustainability in a manufacturing point of emphasis that whereby in every material used will not be wasted. According to the definition from the United States Environmental Protection Agency, sustainable manufacturing is the creation of a manufactured product with processes that have minimal negative impact on the environment, conserve energy and natural resources, are safe for employees and communities, and are economically sound [4].

The focus of this study was to determine the criteria and sub criteria of the material properties of a badminton racket frame, use ELECTRE I method to apply material selection thus the dominant material will be chosen.

1.2. Badminton Racket Frame
A badminton racket consists of a head, a shaft that is joined to the head, and it is between the head and a handle. Altogether it is called a frame. The head also holds strings to make it feasible to play with [5]. All of these parts are shown in figure 1 below.

![Badminton racket diagram](image)

**Figure 1**: Badminton racket - a) frame, b) head, c) shaft, d) handle and e) strings.

1.3. Materials in a Badminton Racket Frame
The following are the materials chosen to be included in this material selection process using ELECTRE I method.

1.3.1. Carbon Fibre Carbon fibre is made from organic fibre classics carbonization and graphitization processing. Carbon fibre consists of carbon that is 90% higher than that of inorganic polymer, consisting of 99% carbon graphite fibre [6].
1.3.2. **Boron Fibre** Boron fibre is a wire of tungsten with elemental boron deposited during a reaction of boron trichloride and hydrogen gas at 800°C to 2,000°C. Boron fibre is so stiff and strong that it has been used to patch across the fuselage of jet fighter aircraft to hold the wings on [7].

1.3.3. **Aluminium** Primary aluminium is aluminium tapped from electrolytic cells or pots during the electrolytic reduction of metallurgical alumina (aluminium oxide – Al2O3). It thus excludes alloying additives and recycled aluminium. [8].

1.3.4. **Carbon Steel** Carbon steel is the most extensively used materials in the industry. This material is very strong and holds shape memory well, making it ideal for springs and wire. Carbon steel is a composite comprising of iron and carbon [9].

1.3.5. **Nickel Titanium** Nickel titanium (NiTi) is a combination of two different metals which are nickel and titanium metals, where these elements have the same percentage of atoms. Nickel titanium was developed 40 years ago in the Naval Ordnance Laboratory (NOL) in Silver Springs, Maryland thus creating the acronym NiTiNOL, which is used worldwide for this special type of alloy [10].

1.3.6. **Titanium Alloy** Titanium alloys are widely used in the engineering field, namely in the aerospace, automotive and biomedical parts, because of their high specific strength and exceptional corrosion resistance [11].

1.4. **Sustainable Manufacturing**

Sustainable manufacturing has been adulated as of late for its huge advantages coordinated at triple main concern factors (social, economy, and financial), but the majority of manufacturing strategies remain limited to either one or two factors. No dependable rules exist to ensure the fruitful usage of feasible assembling; accessible writing neglects to investigate such an unpredictable research theme [12].

1.5. **Elimination and Choice Expressing Reality (ELECTRE)**

Elimination and Choice Expressing Reality or ELimination Et Choix Traduisant la RÉalité (ELECTRE) methods have a variety of methods such as ELECTRE have been produced including ELECTRE I, II, III, IV and TRI. All of these techniques are the same, but different in terms of operation. Each technique based on the same basic concept but its operation is different. The important thing of ELECTRE approach is the utilization of the idea of outranking relationship [13]. ELECTRE I is to determine higher-degree relations between exclusive bid schemes, thru accordance and disaccord examine, and seek for the non-inferior scheme subset unceasingly, in the end, decide the first-class bid scheme. This approach considered the actual situation and the fee preference of creation units and overcame the supplementary state of affairs among evaluative indicators, and it's going to offer a brand-new approach foundation for the selection-makers [14].

2. **Methodology**

2.1. **Material Properties (Criteria) and Sub Criteria Identification**

The material properties or criteria and its sub criteria were chosen based on the function or usage of the badminton racket frame. Its function includes game playing, storing at home or travelling with in transports. These provide clues as to which criteria and sub criteria to choose from and applied in the calculations of ELECTRE I.

2.1.1. **Mechanical Properties** This was chosen with the sub criteria of Ultimate Tensile Strength (Mpa), Elastic Modulus (Gpa), Poisson’s Ratio and Rockwell Hardness in mind, all relating to the game play effect on the badminton racket frame.
2.1.2. **Physical Properties** The following sub criteria was identified with game play, storing and travel use in mind - Density (g/cm$^3$), Thermal Conductivity (W/m-K), Melting Point (°C) and Hardness (Mpa).

2.1.3. **Chemical Properties** The sub criteria of Corrosion Resistant, Heat of Combustion (kJ/kg) and Wear Resistance are more into the storing and travel usage in mind.

2.1.4. **Environmental Properties** These sub criteria are critical as it is related to the sustainable manufacturing of this product, and it is the following: Energy Content (MJ/kg), CO2 Emission (g) and Flammability.

2.2. **ELECTRE I**

The ELECTRE I technique is basically connected to the treatment of discrete options esteemed quantitatively, to a fractional appointment of choices. The point is to isolate from the entire of the choices the ones that are favoured on most of the assessment criteria and which don’t bring about inadmissible level of discontent on other criteria.

The establishment of a relation of preference R makes the comparison between alternatives not necessarily transitive. For example: $a_1, a_2$ and $a_3$ are the different alternatives. If $a_1 R a_2$, it means that $a_1$ is preferable to $a_2$. However, if $a_2 R a_3$ does not mean that $a_1 R a_3$. So, in the determination of the relation of preference R, the concept of agreement and disagreement are very important to making a good decision.

The agreement between two alternatives, $i$ and $j$, represent the will of the decision maker in choosing alternative $i$ over alternative $j$. The agreement calculation $i = \{1, 2, 3, ..., n\}$ represents the set of $n$ criteria evaluation, and $\{a_k : k = 1, 2, 3, ..., n\}$ represent the set of weights associated to $n$ criteria. These weights are determined by the judgment of value of the decision maker.

The following notation is used:

- $i$ is preferable to $j$: $i > j$
- $i$ is equally preferable to $j$: $i = j$

2.2.1. **Index of Agreement & Index of Disagreement**

The index of agreement may be understood as a pondered percentage of the calibre to which the alternative $i$ is preferred to alternative $j$. By definition, $0 \leq C(i,j) \leq 1$. It is convenient to present the indexes of agreement in an agreement matrix, $C$, where $C(i,j)$ is the element of row $i$ and column $j$. The index of agreement is meant as:

$$C(i,j) = \frac{(W^+ + 0.5W^\equiv)}{(W^+ + W^\equiv + W^-)}$$

This is whereby $C(i,j)$ are component of matrix C that can be structured with component of row $i$ and column $j$. $W^+$ is the positive weightage which follow the rule of Index of Agreement, $W^\equiv$ is the equal weightage and $W^-$ is the negative weightage which do not follow the rule of Index of Agreement.

The meaning of disagreement is complementary to the one of agreement and represents the discomfort experienced in the choosing of alternative $i$ above alternative $j$. In the order to calculate the index of disagreement it is meaning a numerical scale common to all calibre. This scale is used to compare of make a different the discomfort, to combine with all calibre, cause by the choosing of alternative $i$ instead of alternative $j$. By these considerations, the index of disagreement is meant as:

$$D(i,j) = \max k \in I \frac{z(j,k) - z(i,k)}{R^\equiv}$$
This is whereby $D(i,j)$ is the component of matrix $D$ that can be structured with component of row $i$ and column $j$, $z(j,k)$ is the evaluation of option $j$, based on the numerical scale of model $k$, and $R^*$ is the higher prevalent value of numerical scales.

Where $z(j,k)$ is the evaluation of alternative $j$, according to the numerical scale of the criterion $k$, and $R^*$ is the highest superior value of the numerical scales. A disagreement matrix $D$ can be formation, where $D(i,j)$ is the element of row $i$ and column for $j$.

The connection of preference $R$ is meaning when organize which by the Decision Maker as far as values $(p, q)$, between zero and one, so as alternative $i$ is contrived to a $j$ if and only if the $C(i,j) \geq p$ and $D(i,j) \leq q$. (usually $p \geq 0.75$ and $q \leq 0.2$)

2.2.2. ELECTRE Graph and Kernel’s Determination Inside this graph, every node or hub is shown as a circled number. Every node compares to a choice. For example, there are 4 choices or option in the set. The arrows exuding from the nodes are called coordinated ways and compare to an outranking connection. Here option number 4 outranks 1, 2 and 3, and 1 outranks 2. The bit of the diagram in this way comprises of four options and is the subset of non-overwhelmed options which the ELECTRE I method characterizes.

In the ELECTRE I method, the set of alternatives in consideration is reduced by determining of a subset denominated as Kernel, $K$, and defined by:

a) No system in $K$ dominates another system in also in $K$

b) Each system outside Kernel is dominated by at least in $K$

Kernel contains the good fine system based in $R$. The systems outside Kernel are eliminated from future considerations. The connections developed by ELECTRE I for this situation can be promptly communicated as a diagram such as in figure 2 below, knowing that by applying Kernel’s Determination, option number 4 is dominant and chosen.

![Figure 2: The ELECTRE graph](image)

3. Results

3.1. Material Properties (Criteria) and Sub Criteria Value Identification
The values of all sub criteria was searched and identified from sources such as handbooks and material yearly reports to get the value usually used for these sub criteria towards the materials chosen.

3.1.1. Mechanical Properties Values Table 1 below shows the Mechanical Properties’ sub criteria values.

| Criteria   | Sub Criteria | Carbon Fibre | Boron Fibre | Aluminium Alloy 7000 | High Carbon Steel | Nickel Titanium 60 | Titanium Alloy 6Al-4V |
|------------|--------------|--------------|-------------|----------------------|-------------------|--------------------|----------------------|
| Mechanical | Ultimate     | 4127         | 3500        | 600                  | 1750              | 1172               | 950                  |
### Properties

| Criteria                  | Sub Criteria       | Carbon Fibre | Boron Fibre | Aluminium Alloy 7000 | High Carbon Steel | Nickel Titanium 60 | Titanium Alloy 6Al-4V |
|---------------------------|--------------------|--------------|-------------|----------------------|------------------|--------------------|----------------------|
| Tensile Strength (Mpa)    |                    | 300          | 40          | 79                   | 210              | 110                | 113.8                |
| Elastic Modulus (Gpa)     |                    | 40           | 40          | 79                   | 210              | 110                | 113.8                |
| Poisson’s Ratio           |                    | 0.28         | 0.27        | 0.34                 | 0.33             | 0.33               | 0.34                 |
| Rockwell Hardness (HR)    |                    | 57           | 40          | 49.8                 | 70               | 62                 | 36                   |

#### 3.1.2. Physical Properties Values

Table 2 below shows the Physical Properties’ sub criteria values.

**Table 2: Physical properties values.**

#### 3.1.3. Chemical Properties Values

Table 3 below shows the Physical Properties’ sub criteria values.

**Table 3: Chemical properties values.**

#### 3.1.4. Environmental Properties Values

Table 4 below shows the Environmental Properties’ sub criteria values.

**Table 4: Environmental properties values.**
3.2. **ELECTRE I Calculations**

For the next step, the calculations of ELECTRE I will be applied and only the Mechanical Properties values will be shown.

3.2.1. **Index of Agreement and Index of Disagreement for Mechanical Properties**

The first step is to calculate the Index of Agreement. For this step, decide on a weightage for each sub-criteria based on the Decision Maker’s Preferences: Ultimate Tensile Strength is 5, Elastic Modulus is 3, and the values for Poisson’s Ratio and Rockwell Hardness are 1. All values used must be enough and no more than 10. Table 5 below shows the weights attributed to all sub-criteria of mechanical criteria.

| Sub Criteria                  | Weight |
|-------------------------------|--------|
| Ultimate Tensile Strength    | 5      |
| Elastic Modulus              | 3      |
| Poisson’s Ratio              | 1      |
| Rockwell Hardness            | 1      |
| **Total Weightage**          | **10** |

Each sub-criterion should have its own rank and code values. For these mechanical criteria, each sub-criterion has six fractional value levels. For the Ultimate Tensile Strength sub-criteria, the values of level used are divided into: than 4100 for code A, range from 3501 to 4100 for code B, 1800 to 3500 for code C, 1200 to 1799 for code D, 701 to 1199 for code E and 0 to 700 for code F. For the Elastic Modulus sub-criteria, the values of level used are divided into: more than 250 for code G, range from 200 to 250 for code H, 150 to 199 for code I, 100 to 149 for code J, 50 to 99 for code K and 0 to 49 for code L. As for Poisson’s Ratio sub-criteria, it is also divided into six (6) values of sub-criteria which are: more than 0.35 for code M, range 0.29 to 0.35 for code N, 0.23 to 0.28 for code O, 0.17 to 0.22 for code P, 0.11 to 0.16 for code Q and 0 to 0.10 for code R. And last of the sub-criteria of mechanical properties is Rockwell Hardness, it is divided into: more than 70 for code S, range from 58 to 69 for code T, 46 to 57 for code U, 35 to 45 for code V, 23 to 34 for code W and 0 to 22 for code X. All of these data are shown in table 6 below.

| Sub Criteria                  | Level     | Code |
|-------------------------------|-----------|------|
| Ultimate Tensile Strength    | >4100     | A    |
|                               | 3501-4100 | B    |
| (Mpa)                         | 1800-3500 | C    |
|                               | 1200-1799 | D    |
|                               | 701-1199  | E    |
|                               | 0-700     | F    |
| Elastic Modulus (Gpa)         | >250      | G    |
|                               | 200-250   | H    |
|                               | 150-199   | I    |
|                               | 100-149   | J    |
|                               | 50-99     | K    |
|                               | 0-49      | L    |
| Poisson’s Ratio               | >0.35     | M    |
|                               | 0.29-0.35 | N    |
|                               | 0.23-0.28 | O    |
|                               | 0.17-0.22 | P    |

Table 5: Weightage of the sub criteria in the mechanical properties criteria.

Table 6: The levels and codes of sub criteria in mechanical properties criteria.
Next step is spread out the matrix of the material selection evaluation of the badminton racket frame for the mechanical criteria. Each of the materials is classified to number and as follows; (1) Carbon Fibre, (2) Boron Fibre, (3) Aluminium Alloy 7000 series, (4) High Carbon Steel, (5) Nickel Titanium 60, and (6) Titanium Alloy 6Al-4V. The table 7 below shows the matrix of material selection of the badminton racket frame for the Mechanical Properties criteria.

**Table 7: Matrix of the material selection evaluation for mechanical properties criteria.**

| Sub-criteria                      | Material |
|-----------------------------------|----------|
|                                   | 1 2 3 4 5 6 |
| Ultimate Tensile Strength (Mpa)   | A B E C D E |
| Elastic Modulus (Gpa)             | G L K H I J |
| Poisson’s Ratio                   | N O N N N N |
| Rockwell Hardness                 | T V T S T V |

Now, the calculation can be done for index of agreement. Below shows an example of calculation for Index of Agreement for Mechanical Properties between material 1 and 2.

\[
C(1, 2) = \frac{1}{10} (5 + 3 + 0 + 1) = 0.9
\]

Do this for all possible materials contradictions for which every answer is then combined in a matrix form, for it to become the Index of Agreement for Mechanical Properties, as below.

\[
C(\text{Mechanical Properties}) = \begin{bmatrix}
- & 0.9 & 0.9 & 1 & 0.85 & 0.95 \\
0.1 & - & 0.1 & 0.5 & 0.05 & 0.2 \\
0.1 & 0.9 & - & 0.5 & 0.05 & 0.95 \\
0 & 0.5 & 0.5 & - & 0.5 & 0.55 \\
0.15 & 0.95 & 0.95 & 0.45 & - & 0.05 \\
0.05 & 0.4 & 0.05 & 0.45 & 0.05 & -
\end{bmatrix}
\]

Next, make the calculations Index of Disagreement for Mechanical Criteria. For Index of Disagreement, use the Decision Maker’s Preferences of Numerical Scale Value. Decide the Numerical Scale Value for each sub criteria of Mechanical Criteria. The maximum Value of Numerical Scale is 100. Decide the Numerical Values on each sub criteria. The sub criteria’s numerical values: Ultimate Tensile Strength is 100, Elastic Modulus is 70, Poisson’s Ratio is 50 and the Rockwell Hardness value is 40, as shown in table 8 on the next page.
Table 8: Maximum values of numerical scales in the mechanical properties criteria.

| Sub Criteria                        | Numerical Scale Value |
|-------------------------------------|-----------------------|
| Ultimate Tensile Strength (Mpa)     | 100                   |
| Elastic Modulus (Gpa)               | 70                    |
| Poisson’s Ratio                     | 50                    |
| Hardness Rockwell                   | 40                    |

Then, arrange and determine the codes and Numerical Scale Value for Index of Disagreement for each Numerical Scale Value of criteria as in table 9.

Table 9: Values determined for the Index of Disagreement in the mechanical properties.

| Sub Criteria                        | Numerical Scale Value | Code |
|-------------------------------------|-----------------------|------|
| Ultimate Tensile Strength (Mpa)     | 100                   | A    |
|                                     | 83                    | B    |
|                                     | 66                    | C    |
|                                     | 49                    | D    |
|                                     | 32                    | E    |
|                                     | 15                    | F    |
| Elastic Modulus (Gpa)               | 70                    | G    |
|                                     | 59                    | H    |
|                                     | 48                    | I    |
|                                     | 37                    | J    |
|                                     | 26                    | K    |
|                                     | 15                    | L    |
| Poisson’s Ratio                     | 50                    | M    |
|                                     | 42                    | N    |
|                                     | 34                    | O    |
|                                     | 26                    | P    |
|                                     | 18                    | Q    |
|                                     | 10                    | R    |
| Hardness Rockwell                   | 40                    | S    |
|                                     | 33.5                  | T    |
|                                     | 27                    | U    |
|                                     | 20.5                  | V    |
|                                     | 14                    | W    |
|                                     | 7.5                   | X    |

Then, calculate all sub criteria for the Index of Disagreement for Mechanical Properties. For this calculation, use the same Matrix of the Material Selection Evaluation on table 7 for reference. Calculate each sub criteria one by one and then compile all the data in four (4) different matrices which are: Matrix D for Ultimate Tensile Strength sub criteria, Matrix D for Elastic Modulus sub criteria, Matrix D for Poisson’s Ratio sub criteria and Matrix D for Rockwell Hardness. The calculation of sub criteria for Ultimate Tensile Strength between material 2 and 1 is shown below. If a negative (-) value was calculated, automatically it will become a zero value.

$$D(2, 1) = \frac{(100 - 32)}{100} = 0.68$$
In this step, determine the calculations in the Index of Disagreement for all four (4) sub criteria.

\[
D(\text{Ultimate Tensile Strength}) = \begin{bmatrix}
- & 0 & 0 & 0 & 0 & 0 \\
0.68 & -0.17 & 0.51 & 0.34 & 0 \\
0.51 & 0 & -0.34 & 0.17 & 0 \\
0.17 & 0 & 0 & -0.17 & 0 \\
0.34 & 0 & 0 & 0.17 & -0 \\
0.68 & 0 & 0.17 & 0.51 & 0.34 & 0
\end{bmatrix}
\]

\[
D(\text{Elastic Modulus}) = \begin{bmatrix}
- & 0 & 0 & 0 & 0 & 0 \\
0.16 & -0 & 0 & 0 & 0 \\
0.31 & 0.16 & -0 & 0 & 0 \\
0.19 & 0.03 & 0 & -0 & 0 \\
0.6 & 0.47 & 0.31 & 0.16 & -0 \\
0.79 & 0.63 & 0.47 & 0.31 & 0.16 & -0
\end{bmatrix}
\]

\[
D(\text{Poisson's Ratio}) = \begin{bmatrix}
- & 0 & 0 & 0 & 0 & 0 \\
0 & -0 & 0 & 0 & 0 \\
0 & 0 & -0 & 0 & 0 \\
0.16 & 0.16 & 0.16 & -0.16 & 0.16 \\
0 & 0 & 0 & 0 & -0 \\
0 & 0 & 0 & 0 & -0
\end{bmatrix}
\]

\[
D(\text{Hardness Rockwell}) = \begin{bmatrix}
- & 0 & 0 & 0.16 & 0 \\
0 & -0 & 0 & 0.16 & 0 \\
0 & 0 & -0 & 0.16 & 0 \\
0.33 & 0.33 & 0.33 & -0.49 & 0 \\
0 & 0 & 0 & 0 & -0 \\
0.33 & 0.33 & 0.33 & 0.49 & -0
\end{bmatrix}
\]

Make comparison and combine all sub criteria by maintaining the highest value only. Below shows the matrix form for all sub criteria of Mechanical Properties.

\[
D(\text{Mechanical Criteria}) = \begin{bmatrix}
- & 0 & 0 & 0 & 0 & 0 \\
0.68 & -0.17 & 0.51 & 0.34 & 0 \\
0.51 & 0.16 & -0.34 & 0.17 & 0 \\
0.33 & 0.33 & 0.33 & -0.49 & 0.16 \\
0.34 & 0.47 & 0.31 & 0.17 & -0 \\
0.79 & 0.63 & 0.47 & 0.33 & 0.49 & -0
\end{bmatrix}
\]

Then, compare between the Index of Agreement (matrix C) and Index of Disagreement (matrix D). To make comparison, find the correlation using the rules. Below show the rules for comparison.

\[
C(i, j) \geq p \text{ where; } p \geq 0.75 \text{ (for Index of Agreement)}
\]

\[
D(i, j) \leq q \text{ where; } q \leq 0.20 \text{ (for Index of Disagreement)}
\]

From the matrices, value for the index of agreement must be 0.75 and above. Meanwhile, the value of disagreement must be 0.20 and below.

\[
C(\text{Mechanical Criteria}) = \begin{bmatrix}
- & 0.9 & 0.9 & 1 & 0.85 & 0.95 \\
0.1 & -0.1 & 0.5 & 0.05 & 0.2 \\
0.1 & 0.9 & -0.5 & 0.05 & 0.95 \\
0 & 0.5 & 0.5 & -0.5 & 0.55 \\
0.15 & 0.95 & 0.95 & 0.45 & -0.05 \\
0.05 & 0.4 & 0.05 & 0.45 & 0.05 & -0
\end{bmatrix}
\]
From this matrix, the values highlighted have been determined to comply with the rules set previously. Then, determine the same row and column to get the chosen materials contradictions from Matrix C and Matrix D. From these matrices, the materials that coincides are (1, 2), (1, 3), (1, 4), (1, 5), (3, 2) and (3, 6).

3.2.2. ELECTRE Graph for Mechanical Properties From the matrices, the indices identified for both sets are (1, 2), (1, 3), (1, 4), (1, 5), (3, 2) and (3, 6). ELECTRE graph can be constructed with using the chosen matrices. Figure 3 below shows the ELECTRE graph for Mechanical Properties criteria.

![Figure 3: ELECTRE graph for mechanical properties criteria.](image)

3.2.3. Kernel’s Determination for Mechanical Properties Criteria The Kernel’s Determination can be done by selecting the dominant node. From figure 3 above, only node number 1 satisfies this condition. From this graph, the material to be considered is material 1. So, the best material to be chosen for a badminton racket frame based on Mechanical Properties criteria is material 1 which is Carbon Fibre.

3.2.4. Repetition of Calculations The procedure from subsubsections 3.2.1 to 3.2.3 was repeated to get the dominant material to be chosen for Physical Properties, Chemical Properties and Environmental Properties criteria. The final ELECTRE graphs for all these criteria are shown below.

![Figure 4: ELECTRE graph of a) physical properties, b) chemical properties and c) environmental properties criteria.](image)
4. Discussion

4.1. Materials, Criteria and Sub Criteria Identifications
For this research, the chosen materials were the ones usually used as for now. Due to data restrictions from the industry and other sources, the criteria and sub criteria chosen was the ones that can get hold of. Some of them are the ones that are useful. Some has been changed to become a numerical data as it is more considerate to categorize them.

4.2. Applications
The method used, which was ELECTRE, can be applied in the industry of badminton racket frame production. Materials with the best characteristics can be identified and chosen in the conceptual design stage by using this method. From here, the customer or user can also identify which ones suit their playing style and prepare in advanced on storage and travelling usage of the badminton rackets.

5. Conclusion and Recommendation

5.1. Conclusion
The ELECTRE I method have chosen the dominant material of 1, which is Carbon Fibre as the material to be used in a sustainable manufacturing practice of a badminton racket frame. This is because it became dominant in Mechanical, Chemical and Environmental Properties criteria, with only the Physical Properties criteria not able to be dominant.

5.2 Recommendation
Industrial data sharing is a must to get the best materials, criteria and subcriteria to be used as part of the ELECTRE I calculations, whereby the locations of the production factories are all outside of Malaysia. This is to get the most accurate dominant material in a material selection process of a sustainable manufacturing practice of a badminton racket frame, and maybe more of the other parts too.

6. Acknowledgments
Authors wished to acknowledge assistance and support from Universiti Malaysia Perlis by giving out a Short Term Grant (9001-00518) to complete this research.

7. References

[1] Muller M, Senner V and Lindemann U 2007 Specific characteristics of sports equipment Proc. Int. Conf. on Eng. Des. (ICED ’07) (Paris)
[2] Nasruddin F A, Syahrom A, Harun M N, Abdul Kadir M R and Omar A H 2014 Finite-element study on effect of string tension toward coefficient of restitution of a badminton racket string-bed Adv. Mater. Res. 845 417-420
[3] Ashby M F 2005 Materials Selection in Mechanical Design (Oxford: Elsevier Butterworth-Heinemann)
[4] Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities 2015 Chapter 6: Innovating Clean Energy Technologies in Advanced Manufacturing
[5] Nasruddin F A, Syahrom A, Harun M N, Abdul Kadir M R, Omar A H and Öchsner A 2016 Finite Element Analysis on Badminton Racket Design Parameters ed H Altenbach et al (SpringerBriefs in Computational Mechanics) chapter 1 pp 1–14
[6] Zhang D, Liu H and Sun L 2015 Dynamic Analysis of Carbon Fiber-Reinforced Wood Composites Based on Finite Element Model BioResources 11(1)
[7] Kostick D S 2007 *U.S. Geological Survey Minerals Yearbook-2006: Boron* (U.S. Geological Survey Publications)

[8] International Aluminium Institute 2015 *Primary Aluminium Production Reporting Guidelines* (London)

[9] Popović O, Prokić-Cvetković R, Sedmak A, Grabulov V, Burzić Z, Rakin M 2010 Characterisation of high-carbon steel surface welded layer *Strojniški vestnik – J. of Mech. Eng.* 56(5) 295-300

[10] Ferreira M D A, Luersen M A and Borges P C 2012 Nickel-titanium alloys: A systematic review *Dent. Press J. of Orthodontics* 17(3)

[11] Veiga C, Davim J P and Loureiro A J R 2013 Review on machinability of titanium alloys: The process perspective *Rev. Adv. Mater. Sci.* 34 148-164

[12] Madan Shankar K, Kannan D and Udhaya Kumar P 2017 Analyzing sustainable manufacturing practices - A case study in Indian context *J. of Cleaner Prod.* 164 1332-43

[13] Rogers M, Bruen M and Maystre L Y 2011 *ELECTRE and decision support: Methods and applications in engineering and infrastructure investment* (New York: London: Springer)

[14] Wu Y, Huang Y and Chen W 2011 Construction project bid evaluation optimization model based on the method of ELECTRE - I *Proc. 2011 IEEE 18th Int. Conf. on Ind. Eng. and Eng. Man. (Changchun)* (Beijing: Institute of Electrical and Electronics Engineers, Inc.) p 1660-63