International Science and Technology Journal
المجلة الدولية للعلوم والتقنية

عدد خاص بالمؤتمر الليبي الدولي للعلوم التطبيقية و الهندسية دورته الثانية
LICASE -2
2024 / 10 / 30-29

المجلة الدولية للعلوم والتقنية
International Science and Technology Journal
ISTJ

تم استلام الورقة بتاريخ:9/ 10/2024م | وتم نشرها على الموقع بتاريخ: 30/ 10/2024م

Material Selection for Home Appliance Eco-Design: Case Study of Electric Ironing Device

http://www.doi.org/10.62341/licase2070

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Abstract

Eco-design is an important consideration in the development of home appliance products. It encourages the use of more environmentally friendly materials in the manufacturing of appliances to reduce carbon dioxide emissions, limit energy consumption and improve product performance. This paper offers a thorough method for eco-design using CAD tools, emphasizing material selection to reduce environmental impacts throughout a product's lifecycle. CAD systems are combined with Life Cycle Assessment (LCA), as demonstrated in a case study involving an electric iron device. The research presents a systematic approach to minimizing adverse effects by evaluating environmental impacts, particularly CO_2 emissions and energy consumption, and comparing alternative materials. According to the findings, the substitution of aluminium oxide for stainless steel in the iron plate component can significantly reduce the environmental impact, resulting in reductions in carbon dioxide emissions and energy consumption by 82.02 % and 80.42% respectively. This method will help designers to make well-informed choices early in the design process to improve product sustainability and efficiency. The results highlight the importance of material selection to eco-design as well as how the use of CAD-integrated LCA tools may promote the creation of sustainable products.

Keywords: Life Cycle Assessment (LCA), Computer-aided design (CAD), Eco-design, Home appliance product, Environmental impact reduction, CO_2 emissions, Energy consumption.

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وتم نشرها على الموقع بتاريخ: 30/ 2024/10م

اختيار المواد اللازمة لتصميم الأجهزة المنزلية الصديقة للبيئة: دراسة حالة جهاز الكي الكهربائي

محمد بن حسين، نوري بحيح، صلاح الغرياني
الهيئة الليبية للبحث العلمي– المركز الفني العالي للتدريب والإنتاج

الملخص

تعتبر التصاميم الهندسية من أجل الحفاظ على البيئة أحد الاعتبارات الهامة التي يجب أخدها في الحسبان خصوصاً عند تطوير المنتجات والأجهزة المنزلية للحد من الانبعاثات الكربونية والتقليل من الإستهلاك المفرط للطاقة. تقدم هذه الورقة منهجية علمية منظمة تساعد في تصميم وتطوير منتجات غير مضرة بالبيئة من خلال اختيار مواد صديقة للبيئة تساهم في الحد من التأثيرات البيئية خلال كامل دورة حياة المنتج وذلك باستخدام أدوات التصميم بمساعدة الكمبيوتر(CAD). تعتمد هذه المنهجية على دمج برامج التصميم بمساعدة الكمبيوتر (CAD) مع أدوات تقييم دورة الحياة المنتج (LCA) اثناء مرحلة التصميم، حيث تم تطبيق المنهجية المشار إليها في هذه الدراسة على منتج تجاري للإستخدام المنزلي (جهاز مكواة كهربائي). تهدف هذه الدراسة بشكل أساسي للتقليل من الآثار البيئية للمنتج من خلال تقييم المواد المستخدمة في صناعة أجزاء المنتج وتحديد اكثر المكونات تأثيراً على البيئة ومن ثم اختيار بدائل أقل ضرراً. المنهجية المقترحة في هذا البحث ستساعد المصممين على إتخاذ الخيارالصحيح خلال جميع مراحل التصميم، كما تعمل على تعزيز إستدامة المنتج وتحسين كفاءته أثناء آداءه للوظيفة المصمم من أجلها. تم التركيز في هذه الدراسة على أهم مسببات التلوث البيئي وهي انبعاثات غاز ثاني أكسيد الكربون باعتباره المسبب الرئيسي لظاهرة الاحتباس الحراري، وكذلك التقليل من الإستهلاك المفرط للطاقة باعتبارها المصدر الرئيسي لغاز ثاني أكسيد الكربون. وفقاً لنتائج الدراسة، فإن مادة أكسيد الألومنيوم (Alumina) تعد الخيار الافضل مقارنة بباقي المواد المقترحة من خلال أدوات تقييم دورة حياة المنتج (LCA) كبديل للمادة الأصلية (Stainless steel) المستخدمة في صناعة مكون قاعدة لوحة التسخين باعتباره أكثر مكونات المنتج ضرراً على البيئة، حيث يمكن لهذه المادة البديلة (Alumina) أن تقلل بشكل كبيرمن التأثيرات البيئية مقارنة بالمادة الاصلية، حيث خلصت الدراسة بأن هناك إنخفاض ملحوظ في انبعاثات ثاني أكسيد الكربون بنسبة 80.02% وكذلك إنخفاض واضح في معدل استهلاك الطاقة بنسبة 80.42%. أكدت النتائج أيضاً على أهمية إختيار المواد لتحقيق منتجات صديقة للبيئة وكذلك على قدرة المنهجية المتبناه في هذه الدراسة على تعزيزإنشاء منتجات مستدامة صديقة للبيئة تحد من ظاهرة الإحتباس الحراري.

الكلمات الدلالية: أدوات تقييم دورة حياة المنتج (LCA)، التصميم بمساعدة الحاسوب (CAD)، منتجات أجهزة منزلية، التصميم الصديق للبيئة، تخفيض الإنبعاثات الكربونية، التقليل من الإستهلاك المفرط للطاقة.

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1 Introduction

Designers have traditionally aimed to design products that meet requirements relating to performance, quality, cost, and efficiency. Due to the significant pressures of global climate change, current design trends have changed and designers are now required to take into consideration significant factors concerning the environmental impacts of products during the design process and to focus on creating products with minimal environmental impact. Carbon dioxide (CO_2) is a key contributor to climate change and its emissions correlate directly with energy consumed during the entire life of the product. In 2000, approximately 65% of global greenhouse gas emissions (GHG) were linked to carbon dioxide [1]. Energy generation is driven by consumption demand, and increasing energy consumption leads to increases in carbon dioxide emissions, and about 24% and 14% respectively of global carbon dioxide emissions come from power generation and industrial activity [2]. Products of all kinds cause significant environmental damage throughout their life cycle, and greenhouse gas emissions grew by 4% in 2020, with industry ranked the third largest emitter after the energy production and transportation sectors [3]. Therefore, designers have become more interested in the reduction of the environment impact of their products by taking into account environmental requirements from the early design stages in addition to traditional design criteria. This paper presents a systematic approach that helps designers to introduce and develop an eco-friendly product while enhancing performance with the aim to achieve a significant reduction in environmental impact during the design stage, the most appropriate material is selected from various options with different properties using CAD sustainability systems. This study considers only CO_2 emissions and energy consumption as the main sources of global warming during each stage of the lifecycle of the product and throughout its lifetime.

1.1 Concept of eco-design

Many terminologies have been reported in studies related to the production and development of environmentally friendly products, including eco-design, green design, environmental design, environmentally conscious design, life cycle design, and environmentally friendly design [4]. By the end of the 1980s, 'eco-design' had become a common term for products that are environmentally friendly [5].

Eco-design is an approach to the creation of new products or improvements to existing products so that they have a minimal impact on the environment [6].

Eco-design aims to contribute to reductions in global warming emissions which result from activities associated with the product by assessing its likely impacts at an early stage and identifying the stages with the greatest impact [7].

1.2 Material selection and eco-design

Material selection has become a central topic in eco-design research [8]. The selection process involves crucial decisions that designers make at an early stage, and it is estimated that 80% of the environmental impact of a product result from decisions made during the

design and development processes [9]. Choosing the correct material for a specific application from a vast array of options with different properties is not a simple task. Therefore, designers need to understand the possible environmental impact of each type of material and to make more appropriate decisions in order to meet environmental requirements [10]. More than 80,000 different materials are currently in use to manufacture a wide range of products [11], which illustrates the difficulty designers face in choosing the optimal material for eco-design. Each material is characterized by a range of properties such as hardness, tensile strength, electrical conductivity, and thermal conductivity. Selecting materials with specific properties to achieve certain goals may not result in other requirements being met. For example, the use of a stronger material may not necessarily involve less energy consumption [12]. Thus, systematic methods of resolving conflicts between objectives are needed to achieve success. Material selection is crucial for the enhancement of the properties of products as well as better eco-design [13]. The specific properties identify the type of material, which in turn affects directly on efficiency and environmental impact of the product. For example, the toughness, strength, hardness, flexibility, and electrical conductivity of a material can determine its suitability for specific applications, which is why material selection is a vital decision in the design process [14].
Each material property plays a critical role in determining a product's ability to achieve the defined requirements for applications with maximum efficiency, reliability, and with minimal environmental impact. The properties of materials may be categorised as mechanical, electrical, thermal or chemical properties, all of which can have a strong impact on the environment. For example, choosing a material with lower density can reduce weight and therefore fuel consumption in transportation stage, while choosing a material with a higher corrosion resistance can extend the lifespan of the product.

1.3. Material assessment tools for eco-design

Environmental impacts occur at all stages of a product's life cycle, from the material extraction process to manufacturing, distribution, usage and finally disposal or recycling [15], as shown in Figure 1.
As a rule of thumb every engineering material has a life cycle; therefore, it is necessary to assess its environmental impact and how it affects the product throughout the product life cycle.
The assessment process can be carried out using a wide range of tools and methods. Life Cycle Assessment (LCA) is one of the most significant tools used in assessing environmental impact and is introduced next.

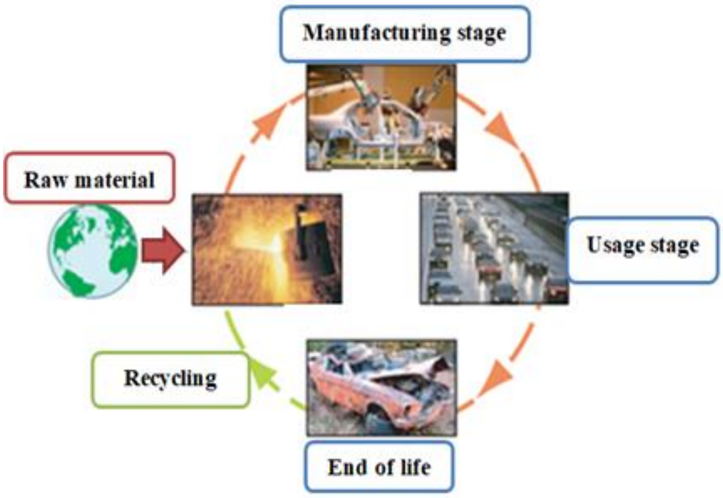

Figure1. The product life cycle stages [16]

1.4 Life cycle assessment (LCA)

One of the most common methods for assessing environmental impact is the life cycle assessment (LCA). LCA is a technique used to assess the environmental impacts of a product in each stage of its life cycle in terms of specific factors such as the materials used, manufacturing process, means of transport, and locations of extraction, manufacturing, and usage [16]. LCA helps designers to make the best decisions concerning material selection. Simple LCA applications include SimaPro, GaBi and Open LCA [3]. CO2 emissions and energy consumption rates are indicators that can be calculated using life cycle analysis.
CO_2 emissions and energy consumption measured in kilograms (kg) and megajoules (MJ) respectively are among the indicators that can be calculated for LCA [17].

1.5 CAD systems for eco-design

Many designers may not be aware of LCA assessment tools or how they can use them to create more environmentally friendly products; others may think that they are too complicated [18]. Thus, there have been some attempts to integrate computer-aided design (CAD) and LCA systems to link each component of product to the environmental data that is available from the LCA method for the calculation of environmental impact. For example, in 2009 Dassault Systems linked LCA (GaBi) with the SolidWorks system to create a sustainable design tool [19]. SolidWorks Sustainability system measures product impacts over a design's entire lifecycle; each impact is examined using the science of Life Cycle Assessment through a partnership with PE International, a pioneer in the LCA field. PE International aims to help companies improve the environmental performance of their products and processes.
GaBi is one of the most important software tools for life cycle assessment of products.

It is widely used in assessing the environmental impact of products and processes through empirical data gathered over decades and has become the worldwide standard for environmental impact data. [20]. By calculating the environmental impact and showing which parts have most impact during the product's lifecycle, designers can make significant improvements to its environmental performance. SOLIDWORKS Sustainability is used in this study as a CAD tool to demonstrate the ability of the approach presented in this study to achieve significant reductions in environmental impact by replacing materials which have the most environmental impact with safer materials

2. Research approach

The approach suggested in this research focuses on the relationship between environmental impact and the functionality of products and the materials. The core idea lies in identifying the components with the greatest environmental impact and then seeking alternative materials that have less impact while maintaining essential product functionality. These operations are conducted during the design process using features available in SolidWorks Sustainability. The selection of materials takes into account environmental criteria during the design process and concentrates on the features that enable the product to perform the functions for which it was designed with the highest efficiency. Figure 2 shows the flow chart of the research approach.

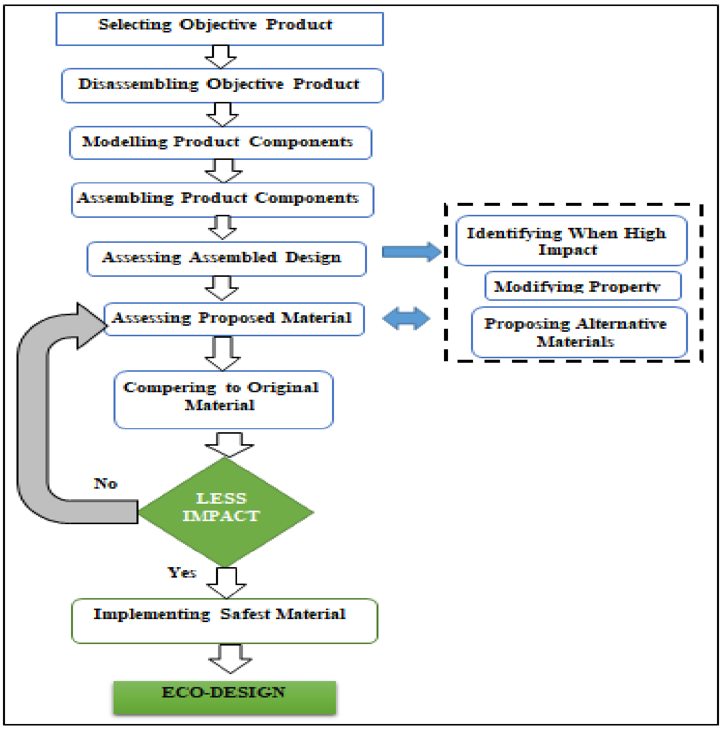

Figure 2. Flowchart of the research approach

The approach consists of six steps as follows:

Step 1: Disassembly of the selected product for improvement, which is taken apart in order to identify the geometry and determine the materials used in each component.

Step 2: Modelling of each component using SolidWorks with precise details such as dimensions and material types.

Step 3: In this step all 3D modelled components of the product are assembled using SolidWorks software.

Step 4: Assessment of the environmental impact of the virtual design using SolidWorks Sustainability, in order to identify which components, have the greatest impact.

Step 5: Seeking alternative materials and to identify the safest choice through available features in SolidWorks Sustainability that allow changing the properties.

Step 6: Finally, the safest material is implemented in the component .

3. Case study: electric ironing device

To understand the relationship between material selection and a product's environmental impact, the proposed approach was applied to a product available in the local market. The product selected is a commercial electric iron device, branded as HOMMER and manufactured in China. The electric iron device is a small household appliance used to remove wrinkles from fabric by applying heat and pressure. The iron is one of the most common household appliances which is also widely used in hotels and laundries for ironing clothes. Thus, it is considered to be a critical source of environmental impact, not only during usage where high energy is consumed, especially at high temperatures or for extended periods, but also throughout its entire lifecycle. Moreover, this product consists of various different materials, including metals, plastics, and electronic components. For these reasons it was chosen for this study to prove the ability of the proposed approach to achieve a significant reduction in environmental impact.

3.1 Implementation of the research approach to the eco-design process

Step1: **Disassembly of the product**

To model the objective product as actual geometry, it is necessary to measure the specific details of each component, such as its dimensions, geometry, and material type from the disassembled product as shown in Figure 3.

Step 2: Construction of the bill of materials (BoM)

During the disassembling process of the product, the bill of materials (BoM) is constructed which contains all components with their type of material used as shown in Table 1.

Step 3: Modelling of the product components

After the disassembly process has been carried out, all components are modelled with detailed information including dimensions, geometry and material type as shown in Figure 4.

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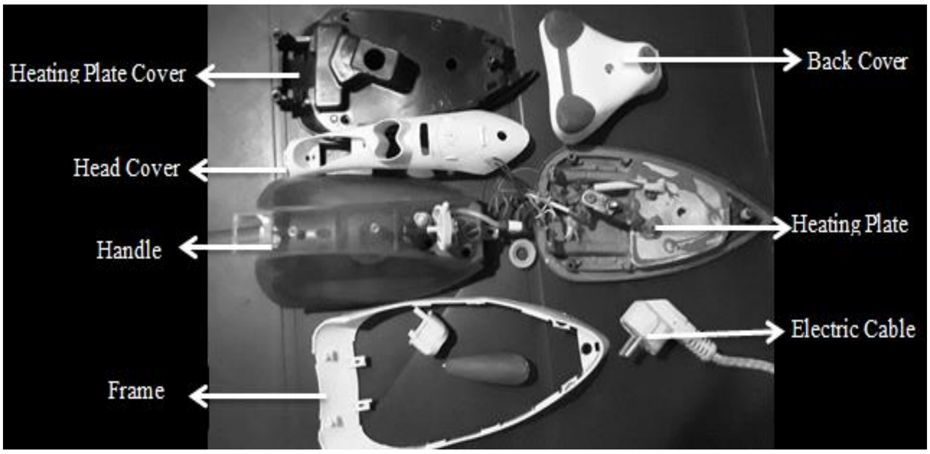


Figure 3. Captured image of the electric ironing device components

Table 1. Bill of materials (BoM)

No	Component	Material used based on the manufacturer's technical data sheet
1	Heating plate	Stainless steel (ferritic)
2	Heating plate cover	PBTP
3	Handle	Polypropylene (homopolymer)
4	Back cover	Polypropylene (copolymer)
5	Outer plate cover	Polypropylene (homopolymer)
6	Heating control circle	Polypropylene (homopolymer)

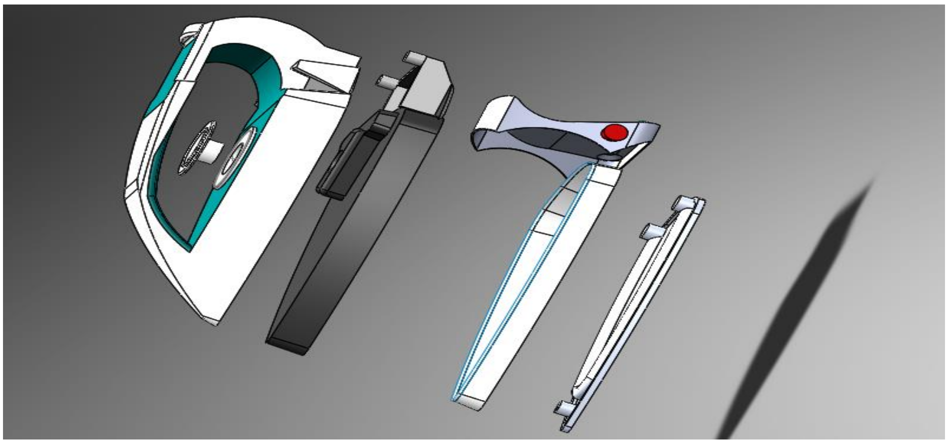


Figure 4. Exploded view of 3D modeling for electric ironing device components

Step 4. Assembly of the modelled components as one unit

The modelled components are then assembled as an actual design, as shown in Figure .5

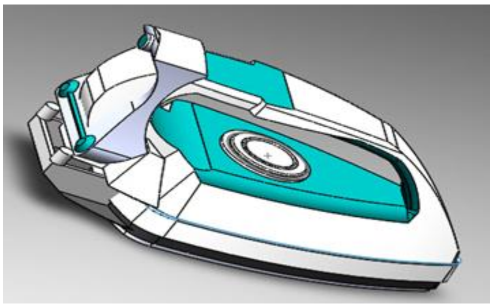


Figure 5. Assembled 3D model of the electric ironing device

Step 5: Assessment of the assembled model

An environmental assessment of the assembled design is conducted using SolidWorks Sustainability in order to identify which components have the highest impact on the environment. Figure 6 shows the heating plate component in the red colour, which means that this component has highest impact on the environment. Table 2 presents the results of the environmental assessment of the assembled model.

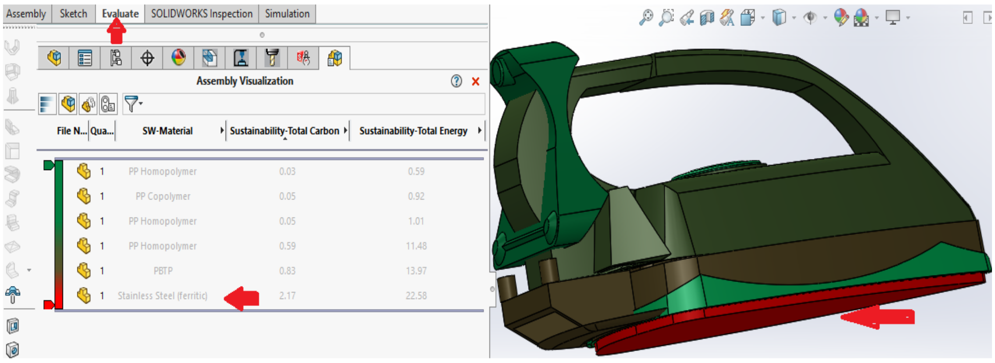


Figure 6. Assessment process results of the assembled model

Table 2. Assessment results for the product components

Component	Material used	Environmental impacts	
		CO_2 (KG) emitted (Kg)	Energy consumed (MJ)
Temperature control circle	**Polypropylene (homopolymer)**	**0.03**	**0.59**
Back	**Polypropylene (copolymer)**	**0.05**	**0.92**
Outer cover	**Polypropylene (homopolymer)**	**0.05**	**1.01**
Handle	**Polypropylene (homopolymer)**	**0.59**	**11.48**
Plate cover	**PBTP**	**0.83**	**13.97**
Heating plate	**Stainless steel (ferritic)**	**2.17**	**22.58**

Step 6: Selection of the safest material

SolidWorks Sustainability helps designers to find alternative materials with best features by modifying some crucial properties of the original material that strongly influence the essential functions of the product. In this case, thermal performance needs to be improved, and therefore the most important properties are thermal expansion and thermal conductivity as shown in Figure 7.

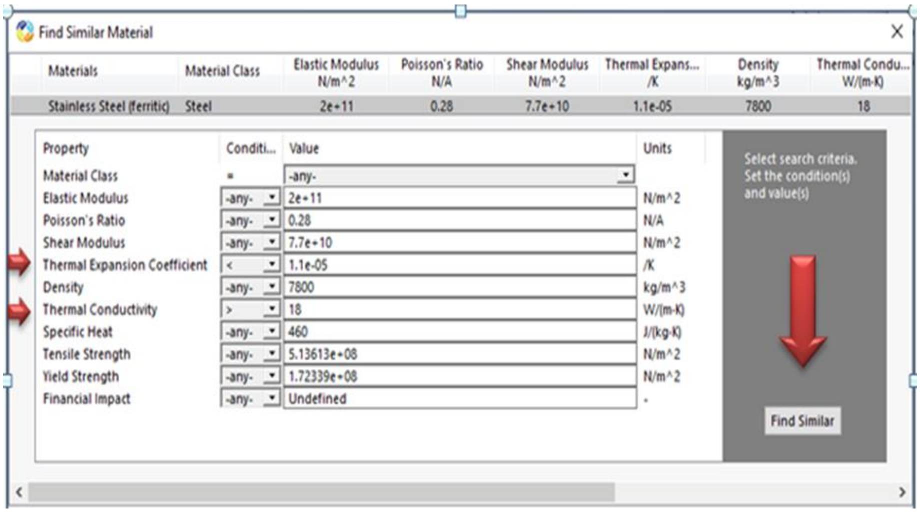
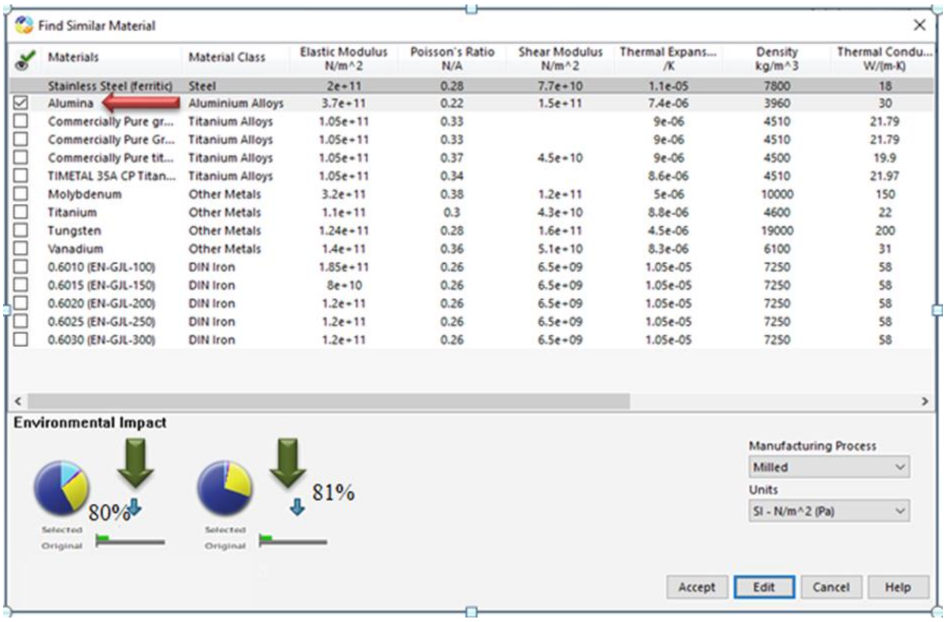


Figure 7. Captured image from SolidWorks clarifying modification process on the material property

Thermal performance is a critical consideration, especially in applications which operate at high temperatures. The materials selected should have high thermal conductivity so as to increase the efficiency of the product and reduce energy consumption. Additionally, they should have a lower coefficient of expansion in order to withstand temperature fluctuations without significant expansion, deformation, structural failure, or loss of mechanical properties, thereby helping to extend the product's life. Therefore, a material with a higher value of thermal conductivity and a lower value of the thermal expansion property should be identified which would improve the efficiency and performance of the product, which in turn would reduce the impact on the environment. Meanwhile, levels of properties not strongly related to product performance will be kept constant.

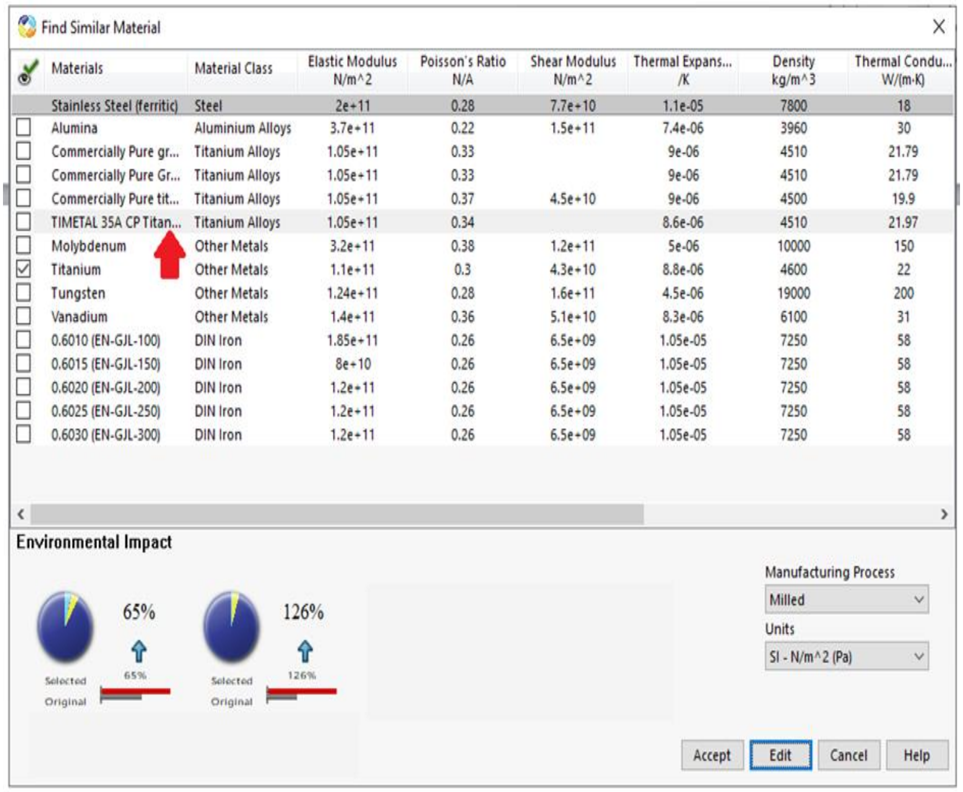
4-Result and discussion

Following the modification of the original material properties, the the application of SolidWorks Sustainability presented various alternative materials that would meet the required criteria. From the sustainability assessment all potential materials compared to the original material (stainless steel), the safest material was then identified. The environmental impact indicators in Figures 8 and 9 show the material with the lowest impact compared to other materials.



Materials	Material Class	Elastic Modulus N/m^2	Poisson's Ratio N/A	Shear Modulus N/m^2	Thermal Expans... /K	Density kg/m^3	Thermal Condu... W/(m-K)
Stainless Steel (ferritic)	Steel	2e+11	0.28	7.7e+10	1.1e-05	7800	18
Alumina	Aluminium Alloys	3.7e+11	0.22	1.5e+11	7.4e-06	3960	30
Commercially Pure gr...	Titanium Alloys	1.05e+11	0.33		9e-06	4510	21.79
Commercially Pure Gr...	Titanium Alloys	1.05e+11	0.33		9e-06	4510	21.79
Commercially Pure tit...	Titanium Alloys	1.05e+11	0.37	4.5e+10	9e-06	4500	19.9
TIMETAL 35A CP Titan...	Titanium Alloys	1.05e+11	0.34		8.6e-06	4510	21.97
Molybdenum	Other Metals	3.2e+11	0.38	1.2e+11	5e-06	10000	150
Titanium	Other Metals	1.1e+11	0.3	4.3e+10	8.8e-06	4600	22
Tungsten	Other Metals	1.24e+11	0.28	1.6e+11	4.5e-06	19000	200
Vanadium	Other Metals	1.4e+11	0.36	5.1e+10	8.3e-06	6100	31
0.6010 (EN-GJL-100)	DIN Iron	1.85e+11	0.26	6.5e+09	1.05e-05	7250	58
0.6015 (EN-GJL-150)	DIN Iron	8e+10	0.26	6.5e+09	1.05e-05	7250	58
0.6020 (EN-GJL-200)	DIN Iron	1.2e+11	0.26	6.5e+09	1.05e-05	7250	58
0.6025 (EN-GJL-250)	DIN Iron	1.2e+11	0.26	6.5e+09	1.05e-05	7250	58
0.6030 (EN-GJL-300)	DIN Iron	1.2e+11	0.26	6.5e+09	1.05e-05	7250	58

Figure 8. SolidWorks sustainability results show that Alumina is the safest material



Materials	Material Class	Elastic Modulus N/m^2	Poisson's Ratio N/A	Shear Modulus N/m^2	Thermal Expans... /K	Density kg/m^3	Thermal Condu... W/(m-K)
Stainless Steel (ferritic)	Steel	2e+11	0.28	7.7e+10	1.1e-05	7800	18
Alumina	Aluminium Alloys	3.7e+11	0.22	1.5e+11	7.4e-06	3960	30
Commercially Pure gr...	Titanium Alloys	1.05e+11	0.33		9e-06	4510	21.79
Commercially Pure Gr...	Titanium Alloys	1.05e+11	0.33		9e-06	4510	21.79
Commercially Pure tit...	Titanium Alloys	1.05e+11	0.37	4.5e+10	9e-06	4500	19.9
TIMETAL 35A CP Titan...	Titanium Alloys	1.05e+11	0.34		8.6e-06	4510	21.97
Molybdenum	Other Metals	3.2e+11	0.38	1.2e+11	5e-06	10000	150
Titanium	Other Metals	1.1e+11	0.3	4.3e+10	8.8e-06	4600	22
Tungsten	Other Metals	1.24e+11	0.28	1.6e+11	4.5e-06	19000	200
Vanadium	Other Metals	1.4e+11	0.36	5.1e+10	8.3e-06	6100	31
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0.6020 (EN-GJL-200)	DIN Iron	1.2e+11	0.26	6.5e+09	1.05e-05	7250	58
0.6025 (EN-GJL-250)	DIN Iron	1.2e+11	0.26	6.5e+09	1.05e-05	7250	58
0.6030 (EN-GJL-300)	DIN Iron	1.2e+11	0.26	6.5e+09	1.05e-05	7250	58

Figure 9. Results of assessment of other materials compared to the original metal

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Therefore this material will be considered as an alternative material in manufacturing the heating plate component. Additionally, the results of the environmental assessment show that Alumina (Aluminium oxide) has a lower environmental impact compared to the other suggested materials. It also has excellent features compared to the original stainless steel. Figure 10 shows the key environmental impacts achieved by using Alumina instead of stainless steel for the heating plate.

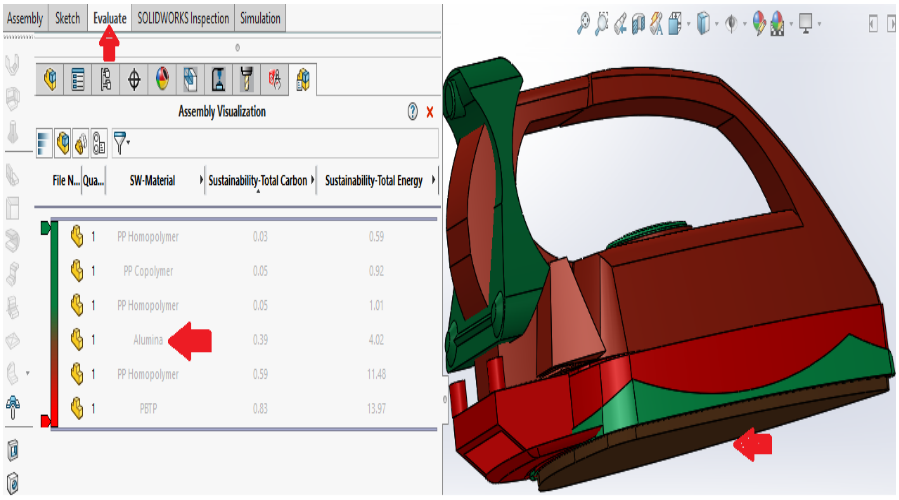

Figure 10. Results of the assessment process of the assembled model using Alumina material

It was noted that other components appeared in red, indicating that the heat plate component with the new material has less impact compared to the other components, as shown in Table3

Table 3. Assessment results of the product components using Alumina

Component	Material used	Environmental impacts	
		CO_2 (KG) emitted (Kg)	Energy consumed (MJ)
Temperature control circle	**Polypropylene (Homopolymer)**	**0.03**	**0.59**
Back	**Polypropylene (Copolymer)**	**0.05**	**0.92**
Outer cover	**Polypropylene (homopolymer)**	**0.05**	**1.01**
Heating plate	**Alumina**	**0.39**	**4.42**
Handle	**Polypropylene (homopolymer)**	**0.59**	**11.48**
Plate cover	**PBTP**	**0.83**	**13.97**

Table 4. Summary of the percentage reductions achieved in CO_2 emissions and energy consumption when using Alumina compared to the original material (stainless steel).

Table 4. Summary of comparison of materials

Environmental impact	Stainless steel	Alumina	Percentage decrease (%)
Carbone footprint CO_2	**2.17 kg**	**0.39kg**	**80.02%**
Energy consumption	**22.58MJ**	**4.42MJ**	**80.42%**

4.1 The alternative material (Aluminium oxide)

Alumina or Aluminium oxide (Al_2O_3) is one of the most cost-effective and widely used engineering materials in industrial applications, and is classified as an important element in the ceramics family [16]. Other sources such as the GaBi LCA software consider it to be one of the aluminium alloys. Alumina has a range of excellent properties, including high hardness where it comes second only to diamond. This makes it exceptionally wear-resistant, with a high thermal conductivity of about 38.5W/(m*k), and low thermal expansion of about: 10.9 µm/k, thus, it provides efficient thermal management, and has an extremely high melting point of approximately 2369°K making it suitable for applications exposed to high temperatures. Also, it is considered to exhibit excellent electrical insulation and is resistant to most corrosive substances, which contributes to its durability [21].

5. Conclusion

This study has presented a systematic approach to develop an eco-friendly product for the minimization of the environmental impacts in terms of CO_2 emissions and energy consumption by selecting the best available material with the aid of a CAD system in the design process. It can be concluded that aluminium oxide was found to be a promising alternative material to replace the original stainless steel metal in the device studied. The alternative material would contribute to reductions in CO_2 emissions and energy consumption rates by 80.02% and 80.42% respectively during all stages of the product life. The outcome of this study should be immensely helpful to designers in evaluating products from an environmental point of view. It can provide alternatives that have the capabilities to meet environmental requirements as well as ensuring higher efficiency to achieve the purpose for which the product was designed.

6. Acknowledgments

The authors would like to express their sincere gratitude to Libyan Higher Technical Center for Training and Production, management, professors, and to Dr. Abdul Basit Al-Imam for their invaluable support, which greatly contributed significantly to the success of this work.

تم استلام الورقة بتاريخ:9/ 10/2024م
وتم نشرها على الموقع بتاريخ: 30/ 10/2024م

7. References

[1] M. Harun, Z. Taha, and H. Salaam, Sustainable manufacturing: Effect of material selection and design on the environmental impact in the manufacturing process. In: IOP Conference Series, Materials Science and Engineering. 2013. IOP Publishing.

[2] M. Rajemi, P. Mativenga, and A. Aramcharoen, Sustainable machining: Selection of optimum turning conditions based on minimum energy considerations. Journal of Cleaner Production, 2010. 18(10-11): p. 1059-1065.

[3] A .Alemam, and M. Benhusien, Integration of environmental quality function deployment into CAD software for impact assessment. In: International Conference on Mechanical and Industrial Engineering (ICMIE2022). 2022, ICMIE Libya.

[4] B. Marques, A. Tadua, J. Prito, and J. Almeada, perspective on the development of sustainable construction products: an eco-design approach. International Journal of Sustainable Development and Planning, 2017. 12(2): p. 304-314.

[5] N. Dahmani, A. Belhadi, and K. Benhida, Integrating lean design and eco-design to improve product design: From literature review to an operational framework. Energy and Environment, 2022. 33(1): p. 189-219.

[6] F. Vallet, B. Eynard, and D. Millet, Using eco-design tools: An overview of experts' practices. Journal of Design Studies, 2013. 34(3): p. 345-377.

[7] M. Borchardt, H.Marcos, M.Giancarlo and,A. Miguel, Redesign of a component based on ecodesign practices: environmental impact and cost reduction achievements. Journal of Cleaner Production, 2011. 19(1): p. 49-57.

[8] C. Peng, D. Feng, and S. Guo, Material selection in green design: a method combining DEA and TOPSIS. MDPI Journal: Sustainability, 2021. 13(10): p. 5497.

[9] E. Menguala, Raul. Lozanoa,b, R. Farrenya,b, J.Solàa, C. Gasola, and J, Rieradevalla, Introduction to the eco-design methodology and the role of product carbon footprint. Assessment of Carbon Footprint in Different Industrial Sectors. 1. 2014: Springer. 1-24.

[10] A. Taieb, and M. Amor, Eco-design design strategy: Case Study biomimicry approach in design product materials. Asian Journal of Environment and Ecology, 2023. 21(3): p. 1-20.

[11] M. Jaromin, Computer aided material selection in design process. In: Federated Conference on Computer Science and Information Systems (Position Papers). 2013. Poland: Citeseer.

[12] M. Mingtu, L. Fuhuo, and L. Hailong, ON the Relation between Material Property and Part Performance. Research & Development in Material science. RDMS. 2020.000822. 13(5).

[13] R. Aires, and L. Ferreira, A new multi-criteria approach for sustainable material selection problem. MDPI Journal: Sustainability, 2022. 14(18): p. 11191.

[14] G. Petropoulos, How does material selection impact product design success. 2024 [Accessed May 23rd, 2024]. Available at: www.inorigin.eu/how-can-material-selection-impact-product-design-success.

[15] X. Wang, H. Chan, and L. White, A comprehensive decision support model for the evaluation of eco-designs. Journal of the Operational Research Society, 2014. 65(6): p. 917-934.

[16] M. Ashby, Materials and the environment: Eco-informed material choice. 2012, UK: Elsevier. 603.

[17] P. Kyratsis, N. Efkolidis, and A. Tsagaris, CAD based material selection for sustainable design. International Journal of Engineering Research and Development, 2012. 1(8): p. 54-59.

[18] C. Torcătoru, and D. Săvescu, Analyzing the sustainability of an automotive component using SolidWorks CAD software. In: IOP Conference Series, Materials Science and Engineering. 2019. IOP Publishing.

[19] D. Łączny, W. Kruszelnicka, and J. wandowski, Computer-aided eco-design grinding machines using software SolidWorks Sustainability. In: MATEC Web of Conferences 2022. EDP Sciences.

[20] SolidWorks Sustainability. [Accessed 3th April, 2024]; available at: https://www.solidworks.com/sw/docs/SolidWorks_Sustainability_Datasheet_2011. p.

[21] Azom materials. [Accessed 10th April, 2024]; Available at: https://www.azom.com/properties.aspx?ArticleID=52