

## Design for Disassembly in Electric Rice Cooker Manufacturing

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**Abstract:** Most of the broken or damaged electric rice cooker will be simply dumped as e-waste without planning for repair or reuse due to its complexity. Hence, the main objective of this research is to propose the design for disassembly in electric rice cooker manufacturing for easy disassembly without the assistance of tooling so that components can be repaired, reused or recycled. To achieve the objectives of the study, a questionnaire survey was carried out to determine the part that most easily broken in the electric rice cooker from respondents. Based on the survey results, the redesign will be focused on the mechanical part of the electric rice cooker which is the part that most easily broken so that it can be accessed and disassemble in a shorter time. In this research, two designs were proposed which are Design A and Design B. Then, the mechanical properties of the proposed electric rice cooker were analysed using simulation in SolidWorks software. Finite Element Analysis (FEA) will be run in this research which are stress and thermal analysis to predict how the existing and proposed electric rice cooker reacts to forces, heat and other physical effects. After FEA was completed, Design for Manufacturing and Assembly (DFMA) analysis was applied to compare the cost and the design efficiency of the existing and proposed electric rice cooker. From the result obtained, Design B which was applied circular pattern snap-fit mechanism to replace the screw as the fasteners had been chosen as the best design. Design B has the highest DFA index which the value is 84.10 and lowest manufacturing cost which is \$ 63.41.

**Keywords:** Design for Disassembly, DFMA, Rice Cooker

### 1. Introduction

Design for Disassembly (DFD) is the method applied to design the product disassembles easily for repair, maintenance and reuse of material that can lead to reducing the impact on the environment at the end of life product [1]. The components of the product that implementing DFD concept in design

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specification is better suited for reuse, remanufacture and recycling [2]. Eco-design approaches such as DFD used to guide designers in designing products which are easy to disassemble by giving a set of rules and principles. DFD makes the proficient de-manufacturing plan of components and it reflected for product components with a high value which can be divided from the others for reusing, recycling or remanufacturing[3]. When reusability and recycle ability had increased, many resources will be saving up as well as the useful life-time of products and functional units extend [4].

The electric rice cooker is one of the most popular household appliances in our society. However, it will be damaged sometimes just as in the part of the power cord, fuse, heating plate, magnet, switch and so on. The complexity makes users difficult to disassemble and repair then they will reject to repair the broken part of the electric rice cooker. Once products reach their end-of-life (EOL) cycle, many are being dumped as e-waste and leading to landfills formation [5]. E-waste is one of the fastest rising waste streams in our society now [6]. E-waste is known as Waste Electrical and Electronic Equipment (WEEE) also which describes all items of electrical and electronic equipment (EEE) or its parts that have been discarded by their users as waste without the plan of re-use. E-waste will extremely result in environmental pollution, change the landscape and have an effect on ill-health if improperly handled [7].

The aim of this study is design for disassembly to construct a simple structure for the electric rice cooker for household usage which focuses on the mechanical part so that it can be disassembled easily for repair or remove without the assistance of tooling. Implementing the DFD concept into the product design specification enables the components of the product to be better suited for reuse, repair or recycling [8]. The result of this study will benefit the society since the electric rice cooker can be disassembled and separate easily in a shorter time. The efficient and simple design of the electric rice cooker leads to labour cost and time-saving due to its ease of dismantling and access. The products that are designed for disassembly can deliver much greater savings and bring benefits through remanufacturing from the reuse of resources [9]. Remanufacturing is a valuable way to bring a product back to its life cycle, consequently being freed from landfill [10].

### 1.1 Product life cycle

The life cycle of a product starting from the extraction of raw materials due to a market need [11]. The raw materials such as iron, copper, aluminium, platinum and critical elements are commonly found in Electric and Electronic Equipment (EEE). These materials and elements are excavated from the earth and processed to manufacture the products. The manufacturers have a high impact on environmental and they should play a significant role in fulfilling the requirements of consumers at the same time. It should be paying attention that sustainable development not only involves environmental protection but also significant economic issues. During the design and manufacturing process, the designer should apply the principle of DFD into the design. The introduction of disassembly systems aims "closing the loop" of a product at its life cycle. Modifications have to be made between the requirements and the actual possibilities considering the environmental requirements for production in the current technology and economy. There is a need for a comprehensive disassembly strategy concerning the recovery of industrial goods.

### 1.2 Principle of Design for Disassembly

Products that are designed for disassembly are more serviceable for users and aid in maintenance and reparability. The designers must consider the important factors of DFD so that the product subassemblies to be easily disassembly, reuse or remanufacturing and reduced environmental impact at the end of life of the product. DFD guidelines have been provided to serve as a basis for designers to integrate an easy to disassemble thoughts during product design. There are three main fundamental requirements in the context of DFD which are material selection, fasteners and connections selection,

product structure and component design [12]. The rest factors are characteristics of components for disassembly conditions. Table 1 shows the DFD guidelines that must be considered by designers [13].

**Table 1: DFD guidelines**

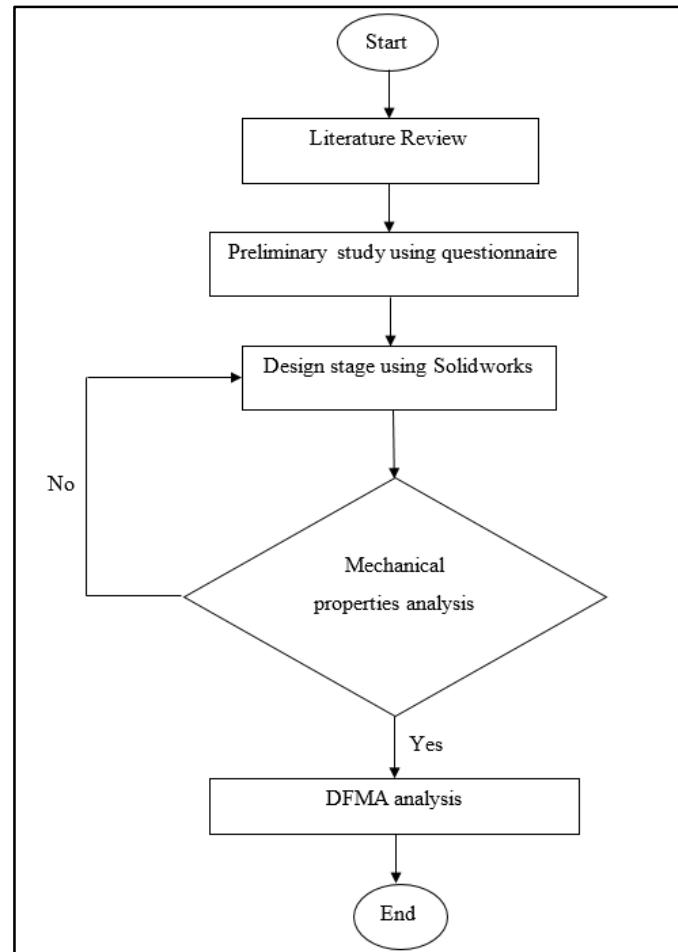
No	Factors affecting the disassembly process	Guides to improve disassembly
1	Materials	<ul style="list-style-type: none"> <li>• Minimise the use of different materials</li> <li>• Use recyclable materials</li> <li>• Eliminate toxic or hazardous materials</li> </ul>
2	Fasteners, joints and connections	<ul style="list-style-type: none"> <li>• Minimise the number of joints and connections</li> <li>• Make joints visible and accessible, eliminate hidden joints</li> <li>• Use joints that are easy to disassemble</li> <li>• Mark non-obvious joints</li> <li>• Use fasteners rather than adhesives</li> </ul>
3	Product structure	<ul style="list-style-type: none"> <li>• Create a modular design</li> <li>• Minimise the component count</li> <li>• Optimise component standardisation</li> <li>• Minimise product variants</li> </ul>
4	Characteristics of components for disassembly	<ul style="list-style-type: none"> <li>• Good accessibility</li> <li>• Low weight</li> <li>• Robust, minimise fragile parts</li> <li>• Non-hazardous</li> <li>• Preferably unpainted</li> </ul>
5	Disassembly conditions	<ul style="list-style-type: none"> <li>• Design for automated disassembly</li> <li>• Eliminate the need for specialised disassembly procedures DFD with simple and standard tools</li> </ul>

### 1.3 Finite element analysis

The finite element method also can be stated as finite element analysis (FEA) which is an essential computational technique used in the design and analysis of complex real-life problem situations [14]. A 3D model had to be constructed to specify the material properties for every part in the model before FEA modelling. The physical effects applied to the model were recognised to specify the analysis type and element types properly. According to the type of physical effects being studied, the field variables may contain the temperature, stress, displacement, strain and heat flux [15].

## 2. Materials and Methods

The methods that are covered in this study are survey by using a questionnaire, the design stage, the simulation of design using SolidWorks software and analysis using Design for Manufacturing Assembly (DFMA) analysis. Figure 1 shows the methodology used to carry out this research.



**Figure 1: Flow chart of the research**

### 2.1 Survey by using the questionnaire

Data were collected using a questionnaire to determine the part that most easily broken in the electric rice cooker from more than 50 respondents. The questionnaire is divided into two parts. Part A is designed to collect demographic data for a respondent profile, including gender, age, marital status, household income and occupation. In Part B, it is a list of question about the domestic use of electric rice cooker. The survey will be conducted using Google form. The Google form link was sent by emails to the respondents and all the respondents involved in this survey were staff working in Universiti Tun Hussein Onn Malaysia.

### 2.2 Design stage

Based on the data collected from the questionnaire, 55.00 % of respondents voted the switch as the part that most easily broken and 80.40 % of respondents think that redesign the electric rice cooker is necessary so that it can be disassembled easily without the assistance of tooling in shorter time. So, the design focus on the base cover of the electric rice cooker to access easily and quickly to the switch. The screws on the base cover will be eliminated and being replaced by a snap-fit mechanism. Two designs

will be proposed without any screw part to attach the electric rice cooker. SolidWorks 2019 software will be used to sketch a 3D model of the electric rice cooker.

### 2.3 Simulation of design using Solidworks software

SolidWorks 2019 software was used to carry out SolidWorks Simulation which is structural analysis tool that use Finite Element Analysis (FEA) to analyse the mechanical properties of the design. Some basic analysis will be tested or run in this study which are stress, displacement, strain and thermal analysis. By using SolidWorks 2019 software, the effect of the force will be simulated and the stress, displacement and strain results were determined. Thermal analysis can be developed to show temperature distribution, temperature, heat flowing in the electric rice cooker [15]. The critical areas and safety levels in various regions in the proposed design also will be shown. Based on these results, the unsafe parts can be strengthened and removed from the design.

### 2.4 Comparison using DFMA analysis

Design for Manufacturing and Assembly (DFMA) is a combination of Design for Manufacturing (DFM) and Design for Assembly (DFA) methods which is a practical design approach that provides for primary consideration of manufacturing and assembly aspect of production. DFA concern on the part consolidation for ease of assembly process. Meanwhile, DFM helps in reducing the manufacturing cost [16]. As the basic principles of DFMA are to reduce part, it plays a key role in product development. It gives a higher profit to the manufacturer due to improving the design efficiency and minimizing production cost without sacrificing customers' needs [17]. In this research, the design of the existing product and two proposed design will be compared using DFMA analysis. Analysis of these designs will be shown by the costing product design and the efficiency in terms of assembly.

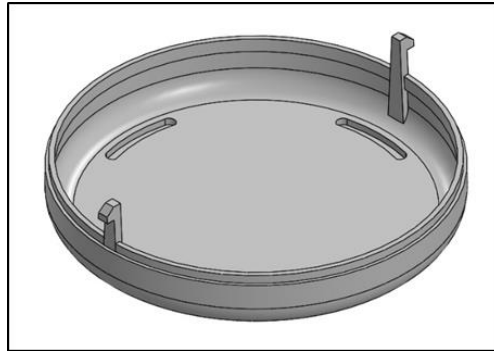
## 3. Results and Discussion

The result of the design stage, the simulation of SolidWorks and Design for Manufacturing and Assembly (DFMA) analysis will be shown. The redesigns of electric rice cooker that meet the design for disassembly were created by using SolidWorks software. The SolidWorks software was continued to be used to process the simulation to analyse the mechanical properties of the redesigns of the electric rice cooker. After the Finite Element Analysis (FEA) and the thermal analysis had been done, DFMA software was used to compare the total cost and efficiency from DFA Index between the existing product and the proposed designs.

### 3.1 Design stage

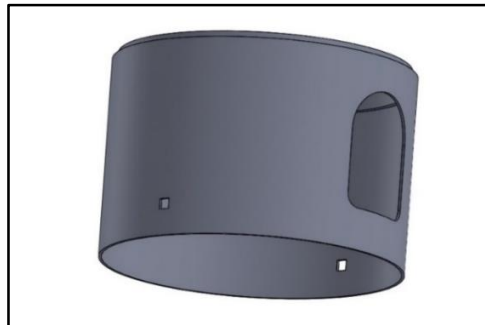
Two designs were proposed which is labelled as Design A and Design B in this research. These designs were created using SolidWorks 2019 software. These designs were focused on the base cover of the electric rice cooker that can be accessed easily and quickly to the switch. The electric rice cooker existing product consists of 18 parts. After the redesign, the four screws on the base cover were eliminated and being replaced by a snap-fit mechanism to increase efficiency. Design A and Design B consist of 14 parts respectively.

Design A shows two flexible snap hooks on the base of electric rice cooker that replace the usage of the screw and apply the design of snap-fit to allow the base part to be disassembled in a shorter time without the assistance of screwdriver or any other tools. The base of electric rice cooker is made up of polypropylene (PP) which is a rigid and crystalline thermoplastic material that widely used for manufacture household kitchen appliances such as the electric kettle and electric rice cooker [18]. Figure 2 shows the base of the electric rice cooker in Design A.



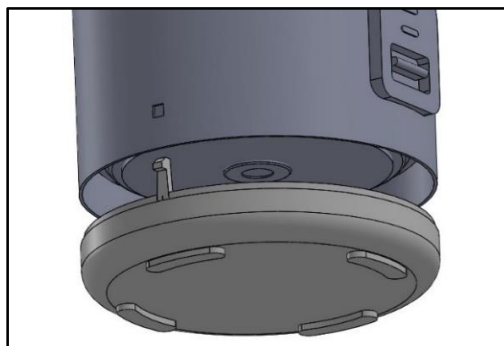
**Figure 2: The base of the electric rice cooker in Design A**

The body of the electric rice cooker was extruded cut respectively in two sides to connect the snap hook of the base. The extruded cut parts were measured for a proper fit to specify the definite size of the snap hooks. The extruded cut parts and snap hooks should have a proper fit when assembled to the electric rice cooker for functioning properly. It depends on the correct size relationships between the two mating parts. The body of the electric rice cooker is made up of stainless steel. Figure 3 shows the body of the electric rice cooker in Design A.



**Figure 3: The body of the electric rice cooker in Design A**

The snap hooks used to connect the base and the body of the electric rice cooker and able to assemble or disassemble these two parts. The snap hooks were pushed both sides toward the body to disassemble the base from the assembly parts. The mechanism used in Design A is the snap-fit design. It is formed by two flexible snap hook which is attached on both side of the base part. The mechanical joints are accomplished with locating and locking features that can push the parts to interlock to each other. Figure 4 shows the mechanism of disassembly for Design A.



**Figure 4: Mechanism of disassembly for Design A**

Design B shows the circular pattern design on the base of electric rice cooker which eliminates the screw and apply the design of snap-fit to allow the base part can be disassembled in a shorter time without the assistance of screwdriver or any other tools. The base of electric rice cooker is made up of

polypropylene (PP) which is a rigid and crystalline thermoplastic material that widely used for manufacture household kitchen appliances such as the electric kettle and electric rice cooker [18]. Figure 5 shows the base of the electric rice cooker in Design B.



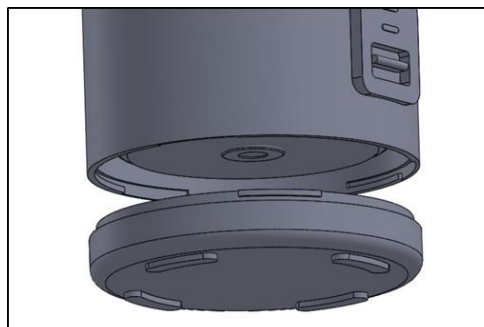
**Figure 5: The base of the electric rice cooker in Design B**

The body of electric rice cooker was designed with snap-fit circular pattern also. The circular pattern parts of the body were measured for a proper fit to make sure it can fit with the circular pattern parts of the base. Both snap-fit circular patterns should have a proper fit when assembled for the electric rice cooker to function properly. The body of the electric rice cooker is made up of stainless steel. Figure 6 shows the body of the electric rice cooker in Design B.



**Figure 6: The body of the electric rice cooker in Design B**

The snap-fit circular pattern used to connect the base and the body of electric rice cooker and able to assemble or disassemble these two parts. The base of the electric rice cooker had to be turned anticlockwise to disassemble the base from the assembly parts. The mechanism used in Design B is the circular pattern snap-fit design. It is formed by three snap-fit parts which are attached inside the base and body of electric rice cooker. The mechanical joints are accomplished with locating and locking features that can push the parts to interlock to each other. Figure 7 shows the mechanism of disassembly for Design B.



**Figure 7: Mechanism of disassembly for Design B**

### 3.2 SolidWorks simulation

SolidWorks 2019 software was used to carry out SolidWorks simulation which is structural analysis tool that use Finite Element Analysis (FEA) to analyse the mechanical properties of the design. The finite element method also can be stated as finite element analysis (FEA) which is an essential computational technique used in the design and analysis of complex real-life problem situations [14]. To create a static study, the proposal designs which are Design A and Design B started from define material for each model, continues to define the restraints and external loads and then the model was meshed. The study was run and the results of stress, displacement and strain were formed. These steps were repeated to create thermal analysis.

Table 2 shows the result of static and thermal analysis which using SolidWorks Simulation to applied the Finite Element Analysis (FEA) on the body part of Design A. The results include the maximum and minimum plot of stress, displacement, strain and thermal.

**Table 2: The result of static and thermal analysis on the body of Design A**

No	Description	Result	Unit
1	Stress	Maximum	6.430e + 00
		Minimum	1.022e - 04
2	Displacement	Maximum	3.231e - 04
		Minimum	1.000e - 30
3	Strain	Maximum	2.276e - 05
		Minimum	9.470e - 10
4	Thermal	Maximum	1.000e + 02
		Minimum	1.000e + 02

Two snap hooks were created in Design A as the connection of base and body. Table 3 shows the result of static and thermal analysis which using SolidWorks Simulation to applied the Finite Element Analysis (FEA) on the base part of Design A. The results include the maximum and minimum plot of stress, displacement, strain and thermal.

**Table 3: The result of static and thermal analysis on the base of Design A**

No	Description	Result	Unit
1	Stress	Maximum	8.051e + 01
		Minimum	5.754e - 05
2	Displacement	Maximum	2.406e + 00
		Minimum	1.000e - 30
3	Strain	Maximum	1.855e - 02
		Minimum	4.681e - 08
4	Thermal	Maximum	1.000e + 02
		Minimum	1.000e + 02

Snap-fit circular pattern was created in Design B as the connection of base and body. The Finite Element Analysis (FEA) will be applied in base and body of Design B. Table 4 shows the result of static and thermal analysis which using SolidWorks Simulation to applied the Finite Element Analysis (FEA) on the body of Design B. The results include the maximum and minimum plot of stress, displacement, strain and thermal.

**Table 4: The result of static and thermal analysis on body of Design B**

No	Description	Result	Unit
1	Stress	Maximum	6.370e + 00
		Minimum	6.401e - 06
2	Displacement	Maximum	1.340e - 04



3	Strain	Minimum	1.000e - 30	ESTRN
		Maximum	2.306e - 05	
4	Thermal	Minimum	6.965e - 11	Temp (Celsius)
		Maximum	1.000e + 02	
		Minimum	1.000e + 02	

The analysis was continued for the base of Design B. The snap-fit circular part was designed to assemble and disassemble the body and base of Design B easily. Table 5 shows the result of static and thermal analysis which using SolidWorks Simulation to applied the Finite Element Analysis (FEA) on the base part of Design B. The results include the maximum and minimum plot of stress, displacement, strain and thermal.

**Table 5: The result of static and thermal analysis on the base of Design B**

No	Description	Result	Unit
1	Stress	Maximum	2.377e + 01
		Minimum	7.064e - 07
2	Displacement	Maximum	2.399e - 02
		Minimum	1.000e - 30
3	Strain	Maximum	4.072e - 03
		Minimum	2.216e - 10
4	Thermal	Maximum	1.000e + 02
		Minimum	1.000e + 02

### 3.3 Comparison of design in DFMA

The existing product and two proposed design were analysed by using DFMA software to compare their DFA index and the total cost. The most efficient design was chosen from the comparison between the existing product and two proposed design. The DFA software was used to estimate the assembly labour time. The electric rice cooker existing product assembly has 18 parts. It has 14 parts meet minimum part criteria and 4 parts are a candidate for elimination. The parts are the candidate for elimination are 4 screws that used for assembling the body and the base of the electric rice cooker. Therefore, Design A and B had eliminated the fasteners which are fours screws and applied the snap-fit design to the base of the electric rice cooker. Both of the design assemblies remains with 14 parts only. Table 6 shows the Analysis Totals for DFA between existing product, Design A and B.

**Table 6: Analysis Totals for DFA between existing product, Design A and Design B**

Entries including repeats	Existing product	Design A	Design B
Parts meet minimum part criteria	14	14	14
Parts are candidates for elimination	4	0	0
Analyzed subassemblies	0	0	0
Separate assembly operations	0	0	0
Total entries	18	14	14
Assembly labor time, s			
Parts meet minimum part criteria	57.77	63.10	60.53
Parts are candidates for elimination	170.84	0	0
Insertion of analysed subassemblies	0	0	0
Separate assembly operations	0	0	0
Total assembly labor time	228.61	63.10	60.53

Design efficiency			
DFA index	22.26	80.66	84.10

Existing product has 170.84 s of assembly labour-time of the parts are a candidate for elimination. Addition with the assembly labor time of the parts meet minimum part criteria 57.77 s, the total assembly labor time of the existing product is the longest which is 228.61 s. However, the total assembly labor time of Design A and B are 63.10 s and 60.53 s respectively. Hence, Design B has the shortest total assembly labour time between these designs.

There is a big difference between the design efficiency of the existing product, Design A and Design B. Based on the comparison, the existing product has the lowest DFA index which is 22.26 while Design A and Design B have the DFA index of 80.66 and 84.10. The DFA index represents the efficiency of a design. The higher the DFA index, the higher the design efficiency. Therefore, the design efficiency of Design B is the highest and it is the most efficient design compared to the other designs.

Table 7 shows the Analysis Totals for DFMA between existing product, Design A and B. The DFM complements DFA to estimate the assembly process cost, manufacturing piece part cost and tooling cost. The analysis was set 100,000 as product life volume. Existing product has the highest assembly process cost compared to Design A and B. The assembly process cost of the existing product is 2.99 s. It means that the existing product is the most complex assembly and it uses the longest assembly time. After the redesign, the assembly process cost reduced greatly in Design A and Design B. The assembly process cost of Design A is 0.82 s and Design B is 0.79 s only.

**Table 7: Analysis Totals for DFMA between existing product, Design A and B**

Per product cost, \$	Existing product	Design A	Design B
Assembly process	2.99	0.82	0.79
Manufacturing piece part	62.47	61.71	61.64
Total cost without tooling	65.46	62.53	62.43
Total tooling cost	1.06	0.97	0.98
Total cost	66.52	63.50	63.41
Total tooling investment, \$			
Assembly tools and fixtures	0	0	0
Manufacturing tooling	106,000	97,000	98,000
Total investment	106,000	97,000	98,000
Production life data			
Life volume	100,000	100,000	100,000
Total production life cost, \$	6,651,837	6,350,490	6,341,120

Existing product has \$ 62.47 of manufacturing piece part cost which is the highest between these designs. It represents the highest amount of materials is needed to manufacture the existing product. Since the parts of Design A and Design B are less than the parts of the existing product, both of them have lower manufacturing piece part costs which are \$ 61.71 and \$ 61.64 correspondingly.

The total cost of an existing product is the highest which the cost is \$ 66.52 while Design A is lower than the existing product which the cost is \$ 63.50 and Design B is the lowest which the cost is \$ 63.41. From the result obtained in analysis, Design B is the most suitable design for manufacturing to save the production cost and increase the design efficiency of the electric rice cooker.

#### 4. Conclusion

Three objectives of this research had been accomplished. The first objective which is to propose the design for disassembly in electric rice cooker manufacturing for easy disassembly at the end of the product's life cycle was fulfilled successfully. Design A consists of two flexible snap hooks on the base of electric rice cooker that replace the usage of the screw and apply the design of snap-fit to allow the base part to be disassembled in a shorter time without the assistance of screwdriver or any other tools. The snap hooks were pushed both sides toward the body to disassemble the base from the assembly parts. However, Design B consist of circular pattern snap-fit design on the base and the body of electric rice cooker. The base of the electric rice cooker was turned anticlockwise to disassemble the base from the assembly parts.

The second objective in this research had been achieved completely with the mechanical properties of both proposal design structures were analysed using SolidWorks 2019 software. Stress, strain, displacement and thermal analysis were carried out to analyse Design A and Design B. Finite Element Analysis (FEA) was applied on the snap hooks for Design A while both circular patterns snap-fit design on the base and the body of Design B were analysed.

The last objective which is using DFMA analysis to compare the total cost and efficiency from DFA Index between the existing product and the proposed design had been completed successfully. According to the analysis, the total manufacturing cost of the existing product is the highest which the cost is \$ 66.52 while Design A is lower than the existing product which the cost is \$ 63.50 and Design B is the lowest which the cost is \$ 63.41. From the result obtained in analysis, the existing product has the lowest DFA index which is 22.26 while Design A and Design B have the DFA index of 80.66 and 84.10 respectively. The DFA index represents the efficiency of a design. Therefore, the DFA index of Design B is the highest and it is the most efficient design compared to the other designs.

Besides, there are several recommendations given for this research for improving the research to produce more precise and high quality result in the future. Except for the base cover, the other parts of the electric rice cooker also can be redesign in future research to increase the design efficiency. Next, the main material to manufacture electric rice cooker is stainless steel but it is high manufacturing cost material compared to other materials. So, the future research may analyse the other materials that can replace the stainless steel without changing the functionality of product so that the product manufacturing cost can be reduced and increase the profit at the same time.

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