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Structural and Capacity Improvement of Polypropylene Disposable Food Containers Using FEA Software

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Abstract

This study aims to enhance the structural integrity and capacity of polypropylene disposable food containers using Finite Element Analysis (FEA) in SolidWorks 2023. The original design, featuring a 4mm curve, exhibited structural instability and trapped food residues, contributing to food waste. To address these issues, the curve size was increased to 5mm and 6mm. FEA simulations were conducted to evaluate stress distribution and displacement under various loading conditions. The results demonstrated that enlarging the curve significantly improved stress distribution, reduced displacement, and enhanced overall structural stability. Notably, the 6mm curve design exhibited exceptional material efficiency and structural stability, with stress values remaining well within safe limits for polypropylene. Prototypes were initially fabricated using PLA 3D printing to test the design, with the final product intended for injection molding in polypropylene to ensure food safety and long-term durability. This research highlights that optimizing curve parameters not only enhances the mechanical performance of food containers but also reduces food waste by preventing residue buildup. The findings support cost-effective manufacturing solutions, with the 6mm design proving to be the most viable and efficient option for both structural integrity and material usage.

1. Introduction

Polypropylene (PP) disposable food containers are widely utilized in the food packaging industry due to their cost-effectiveness and chemical resistance [1]. However, these containers often fail under heavy loads or high temperatures, leading to leaks, spills, and food waste, which contribute to global sustainability challenges. Design flaws, such as inward curves and low structural integrity, hinder scooping efficiency and result in significant food waste [2]. Given these issues, improving the usability and durability of food containers is crucial not only for enhancing customer satisfaction but also for addressing environmental sustainability by reducing food waste and minimizing resource inefficiencies [3].

Existing research emphasizes the importance of optimizing structural designs to improve the performance of disposable food containers. Finite Element Analysis (FEA) has proven to be an effective tool for evaluating stress and displacement without the need for physical prototypes [4]. Additionally, advanced 3D printing techniques enable the production of complex geometries and small-scale manufacturing, which are valuable in design optimization. Studies have shown that improved structural designs can enhance both stability and usability, ultimately reducing food waste and supporting environmental conservation.

This research aims to address the limitations of existing polypropylene food containers by redesigning them to improve strength, usability, and capacity while minimizing food waste caused by the original curve parameters. Using SolidWorks 2023 and non-linear FEA simulations, the study will analyze Von Mises Stress and displacement to propose optimized designs. Prototypes of the redesigned containers will be produced using advanced 3D printing techniques to validate their performance. The ultimate goal is to create a functional, durable food container that enhances the user experience, reduces waste, and supports sustainable practices.

2. Methodology

2.1 Redesign Process

The redesign process includes curve size enlargement and strengthening the flimsy structure [5]. To improve disposable food containers, the curve sidewall will be enlarged from 0.8 cm to 2.4 cm to ensure the easier scooping for reducing food waste. This change makes sure for better usability and for customer to be satisfied. Furthermore, strengthening the flimsy structure of the containers is important to prevent bending or failure. Using stronger materials like polypropylene (PP) and reinforcing weak points with extra support or layers can enhance the durability of the product and the load bearing capacity [6]. Finite Element Analysis (FEA) will validate these improvements by analyzing stress and strain distribution.

2.2 Modelling and Simulation

SolidWorks 2023 is powerful CAD and CAE software used for creating 3D models and performing simulations like Finite Element Analysis (FEA). It allows the users to design and modify 3D objects using feature-based, parametric approaches, start with 2D sketches and adding features like extruded and extrusion. FEA in SolidWorks helps analyze how the designs interact under different loads by defining the material properties, fixtures and doing simulations such as static or nonlinear analyses [7]. Nonlinear analysis is particularly critical for materials like polypropylene, which may exhibit nonlinear behavior under stress. This analysis will ensure that the design holds up under real-world conditions. Simulation settings such as material properties (Young's Modulus, Poisson's ratio, and yield strength), boundary conditions (fixed supports, load application), and mesh refinement will be carefully chosen to reflect the actual behavior of polypropylene under load. Von Mises Stress is used to predict when a material will yield under complex loads by combining normal and shear stresses into a single value. Displacement analysis assesses the deformation of the model under applied forces, allowing for a better understanding of shape changes and stress distribution, which will be crucial in refining the design for integrity and performance.

2.3 Selection of materials

Selection of materials in SolidWorks includes a systematic process that considers factors like mechanical properties, cost, environmental impact to meet design needs and improve product performance [8][9]. Polypropylene homopolymer (PPH) is a popular thermoplastic used for disposable food containers due to its lightweight, chemical resistance and strength. PPH is also cost effective and compliant with food safety standards, giving to both functionality and sustainability in the food [10]. The stress strain curve of PPH shows its mechanical behavior underload, showing an initial elastic region where deformation is reversible. For example, see Fig. 1

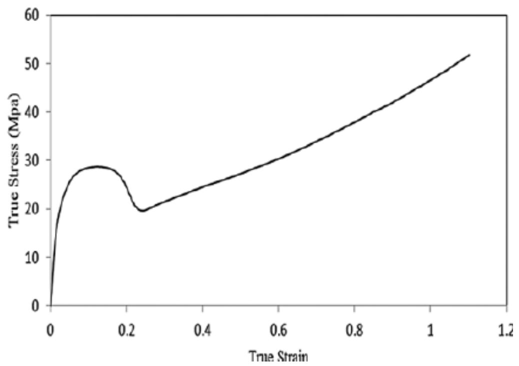


Fig. 1: True Stress-Strain Curve of PP Homoplymer

2.4 3D Printing

Additive manufacturing or 3D printing, produce objects layer by layer based on the digital design using materials like PLA filament. It was used as a prototype for first try user because it is sustainable and easy to print avoiding warping issues common with using polypropylene materials and also requiring less energy [11]. The prototype was created using Ultimaker 3 Extended printer and prepared with UltiMaker Cura software, which includes setting up the printer, importing the 3D model, and adjusting its size to fit the print bed as a scaled-down version of the design.

3. Result and Discussion

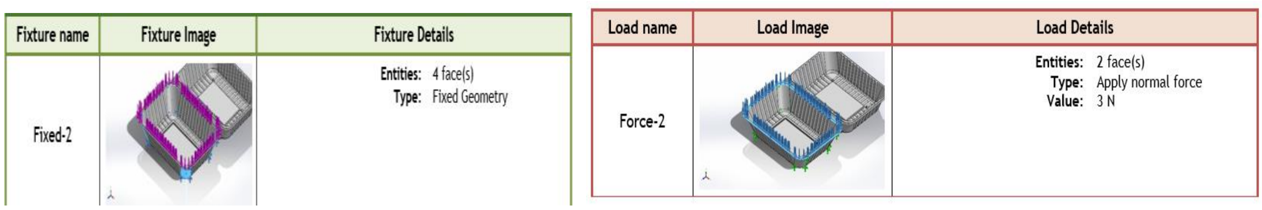
3.1 New Design

Testing multiple designs with the enlarged curve parameters which are 5mm and 6mm helps to know how these changes affect the structure's overall performance and durability. Enlarging the curves parameter from the original (4mm) to aims like addressing the issues like reducing structural strength and stress while making scooping food more easily. To be precise, larger curves parameters include more rigidity, making the disposable food container easier to use for scooping out all kinds of content inside the container without bending. This design adjustment enhances the stability under pressure and makes sure the container remains durable.

This design change enhances the container's stability under pressure and ensures its durability. The design process involves modifying the geometry in SolidWorks, testing the redesign through FEA for stress distribution and safety, and comparing the results with the original 4mm curve. Larger curves are expected to improve structural integrity by reducing stress concentrations at the edges, making the design more ergonomic. Prototypes of the 6mm design will be produced through 3D printing for real-world testing to verify the practical feasibility of the new curves for manufacturing.

3.2 Material Properties and Load Analysis for PP Disposable Food Containers in FEA simulation

To run the FEA simulation for polypropylene (PP) disposable food containers, students need to make sure the material properties such as the elastic modulus should not exceed 1790 MPa and the tensile strength should not exceed 39 MPa. It is essential for predicting stress, displacement and failure points under load. The material's lightweight nature, and plastic properties make it great for accurate nonlinear simulations, including deformation during impact and crushing. In SolidWorks, fixed geometry constraint is applied to the container's corner to stabilize it and mimic real-world conditions as shown in Fig. 2. For each of the curve parameter design, a 3N load which equal to 0.3 kg is applied, showing the nominal weight of typical food portions as shown in Fig. 3. Using rounded 3N load simplifies calculations while providing a safety margin, helping identify stress distribution, deformation and weak points for optimizing the design.



Fixture name	Fixture Image	Fixture Details
Fixed-2		Entities: 4 face(s) Type: Fixed Geometry

Load name	Load Image	Load Details
Force-2		Entities: 2 face(s) Type: Apply normal force Value: 3 N

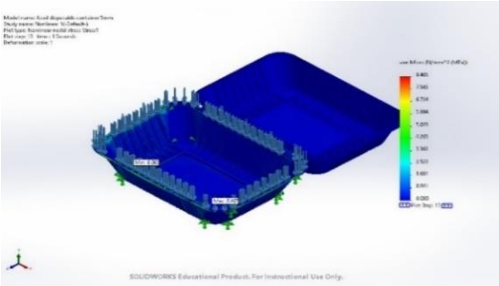
(a) **(b)**

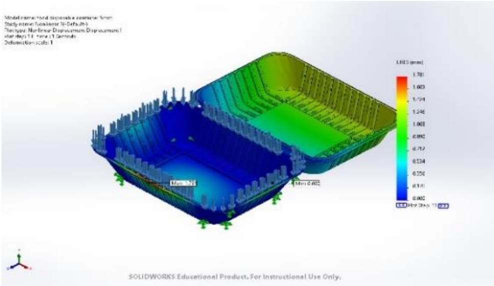
Fig. 2: Fixture and Force applied (a) Fixture (b) Load

3.3 Effect of Curve Modification between three parameters

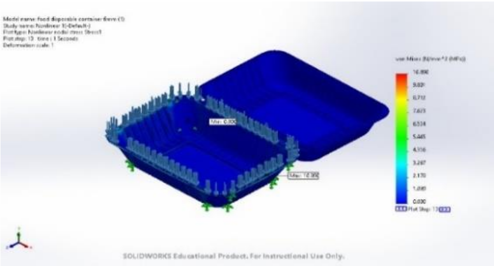
Increasing the curve parameter of polypropylene disposable food containers from 4mm, 5mm and 6mm shows their ability to handle stress and displacement under a load of 3N. the enhanced curve design helps distribute weight evenly, reducing stress at weak points and allowing rib structures to strengthen the container without using much extra material. A 6mm curve provides better rigidity since it has a lower maximum displacement of 1.541mm compared to 1.781 mm for the 5mm curve, making it great for heavier loads. Furthermore, the 5mm curve offer great strength to handling loads. The 6mm containers slightly higher weight which is 0.0100926 kg and volume also increase capacity and make scooping food easier, especially when the food stuck in the curves.

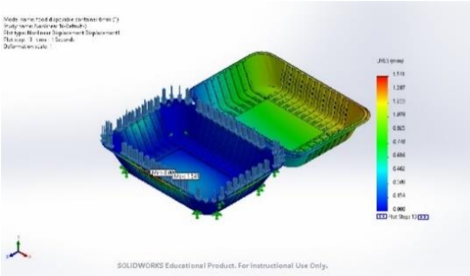
Fig. 3 shows the stress and displacement for the 5mm and 6mm curve parameters, meanwhile Fig. 4 shown the displacement result, meanwhile, Table 1 shows the stress and displacement data.





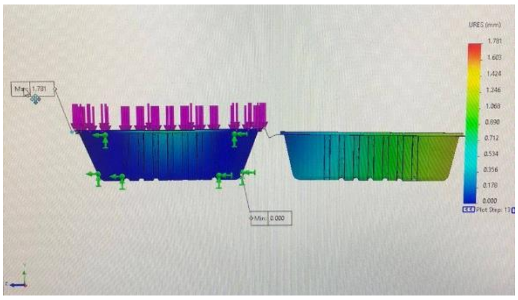
(a) **(b)**

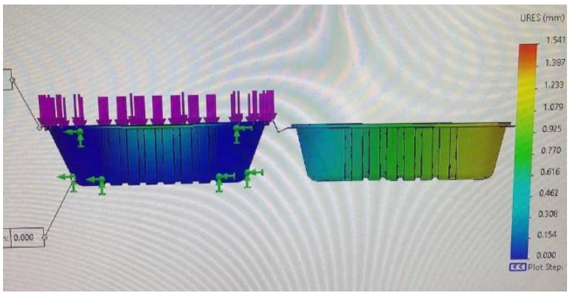




(C) **(d)**

Fig. 3: Stress and Displacement of 5 mm and 6 mm curve parameters (a) Stress 5mm (b) Displacement 5mm (c) Stress 6mm (d) Displacement 6mm





(a) **(b)**

Fig. 4: Bending Curve of 5mm and 6mm (a) 5mm (b) 6mm

Table 1: Stress and Displacement data

	4mm	**5mm**	**6mm**
Von Mises Stress (MPa)	32.312	8.405	10.890
Displacement (mm)	3.404	1.781	1.541
		47.68%	54.73%

3.4 Selected Design

The 6mm curved parameters for disposable food containers are the best choice due to its stability and rigidity, which make it great design for scooping food. It shows less displacement (1.541mm) under load compared to the 5mm curve (1.781mm), making sure that the container maintains its shape and does not deform even when force is applied during scooping. This is especially useful for handling food such as gravy. While the 6mm curve experiences slightly higher stress (10.890 MPa), it is still within the safe range for polypropylene, providing a balance of durability and usability. The 6m design is selected for its enhanced performance and comfort. A prototype will be made using PLA for demonstration, although the final product will be made from polypropylene via injection molding for mass production and food safety.

The cost analysis shows that the 6mm container is the most material-efficient and cheapest option, costing around RM0.45 per container, compared to RM0.47 for the 4mm and 5mm options. Despite the increase in curve thickness, the 6mm container has a lower mass (3.80g), which helps reduce material usage and cost. This small cost difference reflects the improved strength and efficiency of the 6mm design, which offers a balance between cost-effectiveness and performance. This is as shown in Table 2, meanwhile Fig 5 shows the example of the prototype after being produced by 3D printing using PLA filament.

Table 2: Mass of each design based on SolidWorks and Cost

Curves parameter (mm)	4mm	5mm	6mm
Mass (g)	3.93	3.90	3.80
Cost (RM)	0.47	0.47	0.45

(a) **(b)**

Fig. 5: Example of prototype by using 3D printing

4. Conclusion

In conclusion, redesigning polypropylene disposable food containers by increasing the curve parameters from 4mm to 5mm and 6mm improved both structural integrity and usability. The 6mm curve, in particular, enhanced stress distribution, reduced displacement, and maintained stability under load, making it ideal for applications like scooping food, as it resists deformation and provides better leverage. Prototypes made with PLA 3D printing demonstrated the design's functionality, although the final product will be injection-molded with polypropylene for durability and cost-effectiveness. For future work, several areas of improvement could further optimize the design. Dynamic analysis should be conducted to simulate real-world conditions, accounting for varying loads and impacts during food handling. Additionally, refining the selection of static points for applying constraints could help achieve more reliable simulation results. A mesh convergence study could also be implemented to ensure the accuracy and precision of the FEA simulations. To better align the product with user expectations, conducting user surveys or usability testing would provide valuable feedback on aspects such as ergonomics and ease of use. Finally, exploring environmental considerations, such as material recycling or reducing the container's carbon footprint during production, could enhance the sustainability of the design.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

This journal requires that all authors take public responsibility for the content of the work submitted for review. The contributions of all authors must be described in the following manner:

The authors confirm contribution to the paper as follows: ***study on how to do nonlinear simulations, produce the prototype and completed the report:*** *Yon Izmelisa Adha Yon Ismail;* ***helping in 3D Printing process:*** *Khairu Kamaruddin;* ***analysis and interpretation of results:*** *Yon Izmelisa Adha Yon Ismail, Muhammad A'imullah Abdullah, Khairu Kamaruddin;* ***draft manuscript preparation:*** *Yon Izmelisa Adha Yon Ismail, Muhammad A'imullah Abdullah. All authors reviewed the results and approved the final version of the manuscript.*

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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