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Design Optimization and Cost Reduction of Injection Molded Packaging Parts

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Abstract

The primary goal of this project was to optimize the designs of packaging components to reduce costs for the new PE72module. Initially, the existing packaging components for the PE60 product were analyzed. Following this, an in-depth study of injection molding and the key factors influencing manufacturing costs was conducted. Subsequently, cost-reduced versions of the packaging components were designed using CAD, ensuring they retained the form and function of the PE60 packaging components. Finally, the designs were revised to meet ASTM standard specifications. This optimization resulted in a 26% cost reduction for the packaging components (for one corner plus one center) while ensuring that the PE72 modules complied with ASTM standards.

Keywords: PE, CAD, ASTM, Module, Injection Molding

1. Introduction - Packaging Pieces

Packaging pieces play a critical role in the solar module stack during post-manufacturing processes like storage and transportation. There are three primary functions that these packaging pieces must perform effectively: (1) They must be able to support the load of the modules in the stack. (2) They should prevent the slipping of modules from the stack to avoid accidents during transportation. (3) They should maintain some distance between two modules in the stack to prevent damage. During the design of these packaging pieces, the worst-case scenario was considered, specifically, the packaging pieces on the bottom-most module in a stack of 35 to 40 modules.

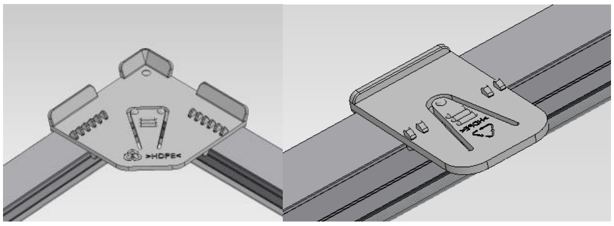

Figure 1: PE60 corner design (left) and center design (right)

Analysis of PE 60 design

1. **Mass of a Single Module**: The PE60 module has a weight of 18 kilograms for each individual piece.

2. **Combined Mass of Multiple Modules**: When considering a total of 39 PE60 modules, the combined weight is calculated to be 702 kilograms (18 kg per module multiplied by 39 modules).
3. **Force on Lowest Pieces**: In a stack or arrangement, the force exerted on the lowest pieces, due to the weight of the entire stack, amounts to 6887 Newtons. This force is derived from the weight of the entire mass acting downward due to gravity.
4. **Load Distribution Assumption**: For simplicity and safety in design, it is assumed that only the four corner pieces at the bottom of the stack are responsible for bearing the entire load of the modules above them. This is a common assumption to ensure that the load is adequately supported without overloading any single piece.
5. **Force on Each Corner Piece**: Given that the total load is distributed evenly among the four corner pieces, each corner piece would then bear a force of 1722 Newtons. This is calculated by dividing the total force (6887 Newtons) by four (the number of corner pieces).

In summary, it was observed that no pressure was being exerted on the centerpiece, indicating a potential area for improvement in the load distribution. The center piece did not contribute significantly to supporting the modules in the stack, as the top nub was found to be too short. Consequently, the centerpiece functioned merely as a spacer rather than providing substantial structural support.

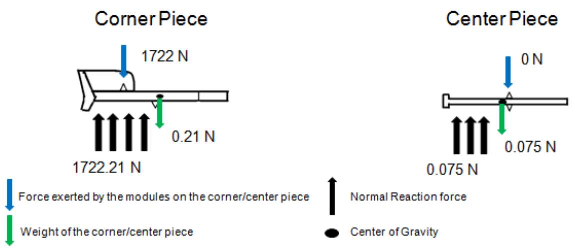

Figure 2: Free Body diagram of PE60 Pieces

Table 1: Static Analysis of PE60 Pieces

Type	Corner Piece	Centre Piece
Volume (mm^3)	21815	7981
Thickness (mm)	3	3
#Nub/piece **Force/piece (N)** **Force/Nub (N)**	12 1722 144	4 0 0
Area (mm^2)	A_{nub}=1.21 A_{bottom}= 3584	A_{bottom}= 1112
Pressure (MPa)	P_{nub}= 119 P_{bottom}= 0.5	P_{bottom}= 0
Nub Height (mm)	4	4

2. Methodology– Design Intent

- The initial design aims to reduce the cost per piece by incorporating holes and cavities, leading to material savings without compromising structural integrity
- The center piece is specifically designed to enhance load-bearing capacity, thereby contributing to the overall stability and support of the stacked modules
- The modifications are also intended to ensure that the new PE72 modules meet the requirements of the ASTM standard certification [1]

Cost Reduction Techniques in Injection Molding

There are two primary methods to reduce costs in the injection molding process:

1. **Volume of Material**: The cost of manufacturing a part is directly proportional to the volume of material used [2]. Therefore, reducing the material volume results in cost savings. In this design, two approaches were employed to achieve material reduction:
    - Creating through holes in non-critical areas of the part.
    - Reducing the thickness of the part.
2. **Optimizing Cycle Time**: The injection molding process comprises five distinct steps: plasticization, injection, holding, cooling, and ejection. The duration from the injection of the melt into the cavity to the ejection of the finished part, known as the cycle time, significantly influences the manufacturing cost of plastic parts [3][4]. Key strategies for optimizing cycle time include:
    - Maintaining uniform thickness throughout the part to ensure a better flow rate of the molten material, thus enhancing the cycle time [3]
    - Incorporating draft angles into the design to facilitate easy part ejection from the mold, which further reduces the cycle time [4]

Taking these cost reduction techniques and critical functionalities into account, the PE72designs were developed using CAD as shown in figure 3 below.

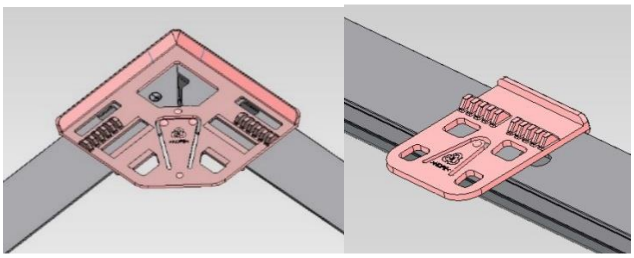

Figure 3: PE72 corner design (left) and center design (right)

Design Modifications for PE72 Packaging Pieces

1. **TopNub Design**: The thickness of the top nub was increased by 50% to ensure it can withstand dynamic loading. This design change is supported by Solidworks FEA results, which indicated high

stress concentration at the base of the nub when subjected to loading (refer to Figure 4). To address this high stress concentration, a fillet was added to the base, as it is well-documented that filleting improves stress distribution significantly.

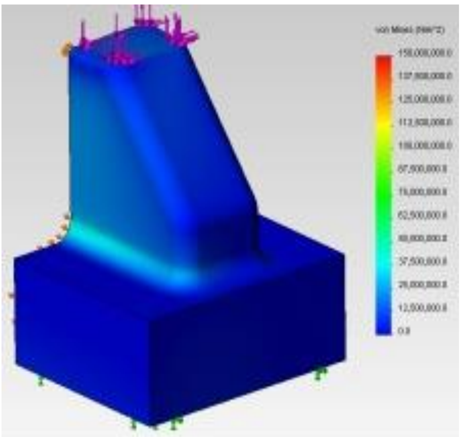

Figure 4: FEA of top nub

2. **Bottom Nub Design:** The height of the bottom nub was increased by 32% to prevent the module from slipping when the pallet is inclined. Additionally, the length of the ribs was extended to enhance the structural strength of the base. Solidworks FEA results confirmed that these design changes to the bottom nub would not introduce any new potential failure points (refer to Figure 5).

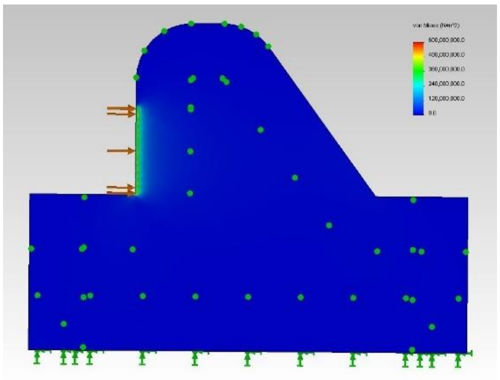

Figure 5: FEA of bottom nub

3. **Clearance:** The clearance between the bottom nub and the frame was reduced to zero to eliminate the risk of shearing due to inelastic collisions.

Analysis of PE 72 design

The table 2 below presents a detailed mechanical analysis of the PE72 packaging pieces, focusing on both the corner and center pieces. Key parameters such as total module load, volume, thickness, number of nubs on top, force per piece, force per nub, pressure, and nub height are meticulously documented. This analysis provides critical insights into the structural performance and load-bearing capacities of the individual components within the PE72 packaging design. By examining these metrics, we can better understand the distribution of forces and the overall mechanical behavior of the packaging pieces under various loading conditions.

Table 2: Static Analysis of PE72 Pieces

Type	Corner Piece	Centre Piece
Total module load (Kg)	666	286
Volume (mm^3)	19837	8222
Thickness (mm)	2.5	2.5
#Nubs on top **Force/piece (N)** **Force/Nub (N)**	12 1634 136	10 1401 140
Pressure (MPa)	P_{nub}= 20	P_{nub}= 21
Nub Height (mm)	4.5	4

3. Conclusions

In conclusion, the analysis and subsequent design modifications of the PE60 and PE72 packaging pieces demonstrate a comprehensive approach to enhancing mechanical properties, optimizing cost efficiency, and meeting industry standards. Through meticulous examination of the PE60 modules, it was identified that the center piece did not contribute significantly to load-bearing, highlighting an area for improvement. This led to design revisions in the PE72 pieces, focusing on both structural integrity and cost reduction.

Key strategies employed in the design of the PE72 packaging pieces included incorporating holes and cavities to reduce material volume, thereby lowering production costs. Additionally, optimizing the cycle time of the injection molding process was prioritized by ensuring uniform thickness and incorporating draft angles, which facilitated better flow rates and ease of part ejection. These measures collectively contributed to more efficient and cost-effective manufacturing.

The modifications to the top and bottom nubs of the PE72 pieces were crucial in enhancing the overall performance and stability of the packaging. The top nub was reinforced by increasing its thickness and adding a fillet to address high-stress concentrations, as supported by Solidworks FEA results. Similarly, the bottom nub was redesigned with increased height and rib length to prevent module slippage and improve structural strength.

Furthermore, reducing the clearance between the bottom nub and the frame eliminated the risk of shearing due to inelastic collisions, ensuring a robust and reliable design. These thoughtful adjustments not only enhanced the load-bearing capacity but also aimed at achieving ASTM standard certification, demonstrating a commitment to quality and compliance.

Overall, the PE72 packaging pieces exemplify a balanced approach to design and engineering, addressing both functional requirements and cost considerations. The comprehensive analysis and strategic design modifications underscore the importance of innovation and optimization in the development of high-performance packaging solutions.

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