FINITE ELEMENT ANALYSIS OF RIB CUSHION POSITIONING FOR EXPANDED POLYSTYRENE PACKAGING

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ABSTRACT: The home appliance industry often chooses to use expanded polystyrene as a product packaging medium because of its rigidity as well as its undeniable effectiveness in protecting various products. However, the effectiveness of this type of packaging needs to be demonstrated through destructive testing such as side-clamping evaluation. Forklift clamping is a machine test applied to evaluate the packaging of flat screen televisions to ascertain if the model has potential risk. In addition, destructive testing evaluation will be repeatedly conducted until a solution is found. Indirectly, this method increases the working hours and development costs of television packaging. Thus, a cushion with a density of 20 kg/m3 and different rib cushion positions was analyzed to see the existing stress distribution and cushion deformation. The analysis was run using the ANSYS software. The results showed that the rib cushion combination design was the best according to the maximum stress values of 6.222 MPa and 4.056 MPa. All results are presented and discussed. In conclusion, the cushion performance was significantly influenced by the rib cushion positioning.

KEYWORDS: *Expanded Polystyrene (EPS); Clamping Test; Finite Element Analysis; Stress Distribution*

1.0 INTRODUCTION

Since mid-twentieth century, there have been significant changes in the lifestyle of developed countries which in turn, has a major influence on how goods are packed. This applies particularly to food and drinks, and also to all other fast-moving consumer goods and electronic appliances [1]. Expanded polystyrene packaging has a pivotal role in the packaging of electronic appliances such as televisions, personal computers, and DVD players. These products rely on packaging reliability to protect against potential damages that may be encountered in the distribution chain [2].

Previous studies have reported that plastic polystyrene was first developed by a German chemist, Eduard Simen in 1938 by distilling or pyrolyzing liquid storax [3-4]. It is interpreted that Polystyrene is an additional polymerization product of phenylethane (commonly known as styrene). Polystyrene can be further categorized as Expanded Polystyrene (EPS), Extruded Polystyrene (XPS), and Styrene Copolymer which is also known as styrene-acrylonitrile (SAN) [5-6]. However, most studies have only been carried out on EPS packaging as a well-known type of polystyrene. In the packaging industry, the EPS manufacturing process consists of three processing stages. The first development process is known as the pre-expansion process, followed by the maturing process and molding process.

Expanded polystyrene (EPS) packaging is rigid foam which has been used in a variety of applications including impact mitigation packaging, protective helmets, roadway construction material, and electrical appliances' packaging as it is lightweight and recyclable. Also, its exceptional shock-absorbing characteristics make it ideal for the storage and transport of fragile and expensive items such as home appliances [7-11]. Moreover, its good compression resistance means that EPS is ideal for stacking packaging goods for storage purposes.

Many literatures concluded that the importance of expanded polystyrene cushions for the packaging of television products cannot be denied [12]. Therefore, the aim of this paper is to ensure that products are safe throughout the transportation process such as when going through forklift, truck, air, and boat handling. It has been argued that cushion damages might be caused by poor design strength. Therefore, the risk of damages must to be taken into consideration, including those resulting from shock and vibration, atmosphere, loading, compression, and movement.

Expanded polystyrene packaging is popularly utilized to protect various fragile products. This is why packaging can help save fragile products during transportation. Although more bulky cushions can be designed to protect products, the transportation cost may however also increase. Consequently, the development process requires more attention in order to produce proper cushion packaging design. Moreover, rib cushion positioning has to be well-designed. Nowadays, cushioning packages are designed based on past experiences without any systematic approach. The strength of the packaging design is validated through constructive testing such as clamping and drop testing. However, more time and costs are needed [13-15]. If the desired results are not achieved, iterative testing through continuous try and error would be carried out.

The evaluation review has identified that most energy-absorbing applications are focused on the single loading of EPS foam, either through experimental and numerical studies on multiple loadings and unloadings [16]. On the other hand, products packaged can be exposed to multiple loading impacts in terms of surface clamping test, stacking or vertical drop, etc. Therefore, this study chooses to focus on the impact of multiple loadings using the clamping test as an experimental method in order to determine the stress exposed to television screen panels cushioned using three different rib cushion designs made of expanded polystyrene packaging.

2.0 METHODOLOGY

Current practices in expanded polystyrene packaging design and evaluation methods rely solely on constructive test criteria and designers' experience. Thereby, this paper conducts a comprehensive study using the side clamping test to determine the proper rib cushion positioning design. Packaging designers know that rib position is the main factor protecting flat screen televisions from any damages, especially during the handling or transportation processes. After that, all corrective and preventive actions would be provided quantitative evidence through the design and analysis of the rib cushion using the ANSYS software. Eventually, a finite element analysis is discussed to establish the impact of stress simulation to the rib cushion positioning of expanded polystyrene cushions.

2.1 Rib Positioning Design

For flat screen televisions, appearance is the most valuable factor that should be protected against any damages. Therefore, weaknesses in terms of cushion design will affect packaging reliability. The position of rib cushion is the main factor to be considered. Thus, this study compares three designs of rib cushion positioning in order to refine the stress impact analysis. Figure 1 shows an example of a flat screen television. The striped area must be secured so that no panels will be broken. Meanwhile, Figure 2 shows a warping defect that must be avoided when producing flat screen televisions. From both pictures, it can be summarized that rib cushion positioning does affect packaging performance.

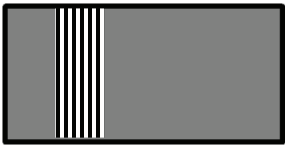


Figure 1: Broken screen panel

Figure 2: Warping defect

A prominent example of a television rear cover was selected to be considered in the design consideration for rib cushion positioning. To decide the rib cushion positioning, two main factors need to be considered which are the television's panel screen and rear cover. However, differences in rib position are majorly influenced by the television's construction strength. The rib was first decided to be placed at the screw position, as shown in Figure 3, since the packaging designer had assumed that the area is the strongest part of the television structure. Accordingly, the rear side of the television must be recognized as the contact area of the rib cushion used to hold the product. Using this design, the first design consideration has therefore been met.

Figure 3: Screw hole position

However, packaging design constraints occur when there is a second factor to be considered, which is the avoidance of any impact on the screen television panel. This is because the designer had previous experience where there were problems in the rib cushion positioning using the symmetric design as shown in Figure 4. Destructive testing indicated that damages may occur due to the rib's position which is located at the television's sensitive areas such as the panel clipboard. This clipboard is placed in the front of the television and is used as a holder for each layer of the television's projector. The screen panel clipboard must not be exposed to any high impact; thereby imposing design constraints to the rib cushion positioning, especially if the positions of both the screw hole and clipboard are parallel.

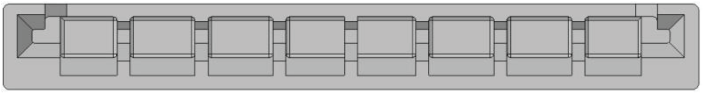


Figure 4: Rib cushion position (Symmetric)

The second scenario normally occurs during the development of a new television model where the earlier structure has been considered. Other defects such as warping on the plastic parts must not occur. This can be ensured by selecting the closest part to the screw-hole position such as in the cushion design shown in Figure 5. The design improvement can only be obtained through real experience. No scientific study has shown that the available cushion designs are good. In addition, evaluation results also vary depending on the respective packaging designers' expertise and experience. Thus, this study had set out to investigate the impact of clamping force on rib cushion positioning design in order to produce good packaging without needing the use of repeated destructive testing. At the same time, improvements to the design will be implemented in order to enhance the EPS packaging's reliability.

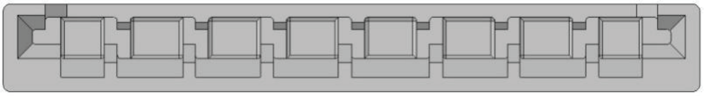


Figure 5: Rib cushion position (Asymmetric)

To explore on the stress distribution of rib cushion design, the author did a design modification to the combination of rib positioning by considering other factors such as the positions of screws, clipboard point, power supplier connector, speaker, and etc. The third cushion design was created as shown in Figure 6.

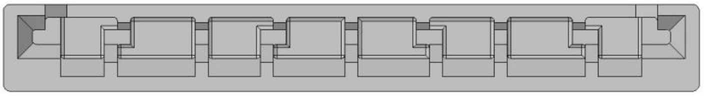


Figure 6: Rib cushion position (Symmetric & Asymmetric)

Actually, the position of ribs in each cushion packaging between the front and rear surfaces is intended to either be symmetric or otherwise as some factors need to be considered in designing the cushion as explained above. In one case where a strong set television construction has been found to be parallel to the front and rear, a symmetrical rib cushion position is hence produced. Although the accuracy of this expectation needs to be proven through destructive testing, but it is easier if the design analysis is done at the beginning of the project. Consequently, a finite element analysis is carried out to determine the design's cushion material, packaging dimension, and density and cushion weight. All cushion parameters are summarized in Table 1 [17-18]. The cushion packaging was designed using 3D software, while the ANSYS software was used to see the stress distribution according to the positioning of the cushion rib.

Table 1: Cushion packaging parameters

Expanded polystyrene (EPS)	
Dimension	Length: 964mm
	Width: 120mm
	Height: 240mm
Material	Polystyrene
Density	20kg/m^3
Weight	2.2kg
Young's Modulus	2400Mpa
Poisson's Ratio	0.4

2.2 Side Clamping Evaluation

A clamping test method was conducted by pressing concurrently on the front and rear surfaces using a 11,121 N clamp with full support on one side and 760mm support on the other side as shown in Figure 7. The same procedures were applied to the opposite side and clamped using a forklift machine. A total clamping force of 11,121 N was calculated because it is the maximum force that can be charged by a forklift clamp in the industry. The force is measured using a clamp force indicator such as shown in Figure 8 where pressure must be applied using one continuous movement until the pressure regulator stops for 1 second. In contrast, this paper investigates the effectiveness of the rib cushion using the ANSYS finite element analysis. Hence, the force chosen to be applied is 5560 N on both the front and rear surface of cushion packaging. The force is selected due to the fact that the destructive testing of the cushion packaging should be placed between the pads' clamper. Thus, the average force is estimated to be the same on both the surfaces of the cushion packaging.

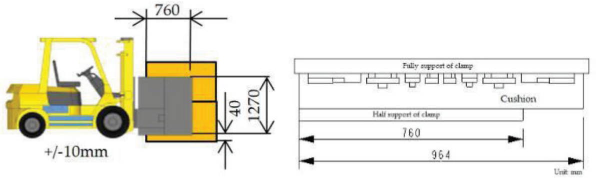


Figure 7: Side clamping condition

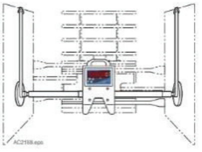


Figure 8: Example of clamp force by Cascade Corporation [19]

The evaluation results must confirmed that no screen panels were broken, and no warping defect, dent or other possible risks had happened to the televisions. As shown in Figure 7 above, the side-clamping testing method is used in the manufacturing of electrical and electronic products. Similarly, a reliability test was carried out based on the actual television production operations until a good cushion structure to protect products from hazard impact was produced.

2.3 Finite Element Analysis

Static structural analysis is mainly conducted to find out the behavior of a physical structure when subjected to force [20-21]. In a meshing model, quadratic tetrahedral elements are chosen. The quadratic tetrahedron is also called the ten-node tetrahedron, while in the programming context, the design is called Tet10. For stress calculations, the aforementioned design behaves significantly better than the four-node (linear) tetrahedron [22]. In this study, the skewness meshing metric was used and the cushion's body size was reduced to 10 mm for all cushions in order to get accurate results. Table 2 shows the detailed meshing results obtained using side clamping simulation with supported of 760 mm clamper length on the front surface and fully support on rear surface.

Table 2: Meshing results

EPS Cushion	Rib position	Result		Result	
		760mm support front surface		760mm support rear surface	
		Nodes	Element	Nodes	Element
Rib 01	Symmetric	17, 6059	11, 2229	17, 6059	11, 2229
Rib 02	Asymmetric	17, 5713	11, 2029	17, 5647	11, 1982
Rib 03	Both	17, 6393	11, 2367	17, 6329	11, 2324

The boundary conditions for the cushion packaging model were fixed. Since this analysis is only intended to investigate the potential damage that may occur if an impact force exists on the front and rear of the cushion surface, this analysis will particularly ensure that the television panel is fully hold by the rib cushion. Then, this study is to look at the effects of pressure on the design of cushion packaging, this factor is therefore reviewed comprehensively. Figure 9 shows that a 5560 N force is applied to the front and rear surfaces of the cushion packaging for the design structure analysis.

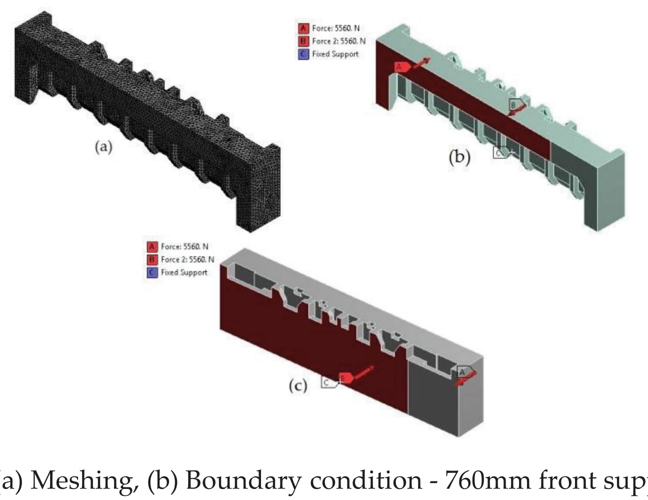


Figure 9: (a) Meshing, (b) Boundary condition - 760mm front support and (c) Boundary condition - 760mm rear support

3.0 RESULT AND DISCUSSION

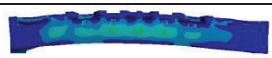
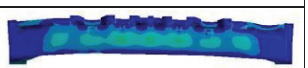
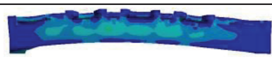
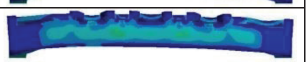
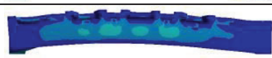
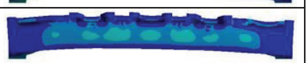
The study's initial objective is to identify the best rib cushion positioning that can influence packaging reliability. The most significant finding on the equivalent stress of each rib cushion position is much different. The difference in value is between 0.495 MPa to 1.508 MPa for both supported surfaces. Firstly, the maximum stress results obtained from the combined symmetric and asymmetric rib positioning are the highest at 6.222 MPa and 4.056 MPa as shown in Table 3. While, rib design 01 showed a slight differentiate in the 0.419 MPa value of maximum stress between rib 02 in 760 mm front surfaces supported. It was also found that there is a 0.696 MPa difference in maximum stress between rib 01 and rib 02 for the 760 mm rear supported surface. In conclusion, the results for rib 03 are better than for rib 01 and rib 02, hence the ability to protect the product is higher when the combined symmetric and asymmetric rib positioning design is implemented.

Table 3: Maximum stress results

760mm support surface	Front	Rear
Rib 01 (Symmetric)	5.133 MPa	3.561 MPa
Rib 02 (Asymmetric)	4.714 MPa	2.865 MPa
Rib 03 (Both)	6.222 MPa	4.056 MPa

In addition, the rib cushion positioning was also discussed in this clamping analysis to see if the cushion's appearance can damage the television's flat screen. As shown in Table 4, all cushions have the tendency to cause negative warping, which means that there is a high possibility of panel screen damages.

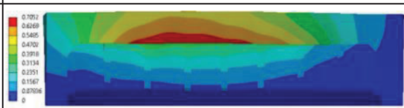
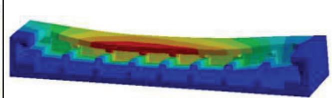
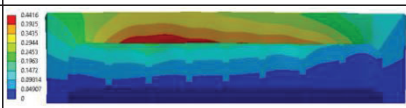
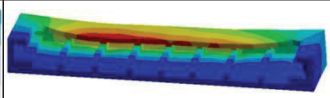
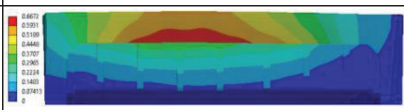
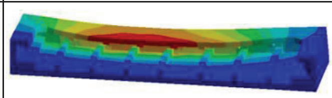
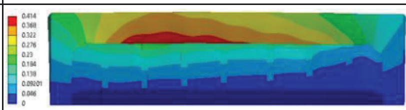
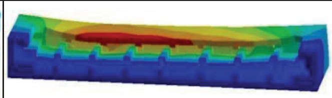
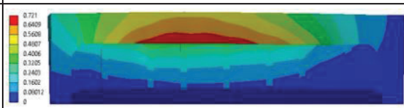
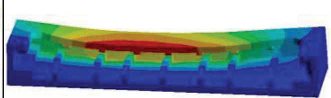
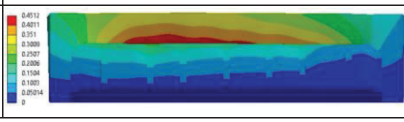
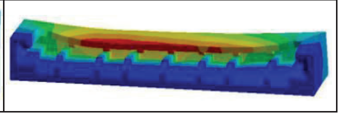
Table 4: Warping conditions

760mm support surface	Front	Rear
Rib 01 (Symmetric)		
Rib 02 (Asymmetric)		
Rib 03 (Both)		

From the table, it is proven that the analysis results are similar to the actual test results. However, in the destructive testing, the cause of damage to the ribs is not easily identifiable. These results will help packaging designers to determine the rib parts that need to be emphasized on, as well as understanding the focus of the rib cushion before designing the good cushion packaging.

Finally, the deformation cushion results are shown in Table 5 from two angles. These three results show that cushion deformation is concentrated on the front surface of cushion and in the middle. Whereas, coverage of the deformation area for these three cushions is approximately same. The maximum deformation area for the rib cushion differs between the full support front surface and rear surface. All result the deformation value on the 760 mm rear surface supported is lower than that of the 760 mm front surface supported. These analysis results show that the force applied to entire front surface of cushion with supported of 760 mm to rear surface is more easy cause to the panel screen damage. Therefore, the new design of cushion packaging will consider the evaluation effect for clamping test with 760 mm supported length for both surfaces when producing expanded polystyrene packaging of television.

Table 5: Cushion deformation

Clamping test with 760 mm surface supported	**Front view**	**Isometric view**
Rib 01 (Front surface)		
Rib 01 (Rear surface)		
Rib 02 (Front surface)		
Rib 02 (Rear surface)		
Rib 03 (Front surface)		
Rib 03 (Rear surface)		

4.0 CONCLUSION

Finite element analysis was used to simulate the clamping test conditions for rib cushion positioning of expanded polystyrene packaging. The findings were discussed in terms of equivalent stress for maximum stress distribution and direction of warping and deformation. The clamping analysis results show that the cushion packaging ability is strongly influenced by the rib cushion positioning. Thus, the packaging reliability can be enhanced by positioning the rib cushion using a combination of symmetric and asymmetric design. Besides, the establishment of rib cushion in the front should be examined at each design stage because the sensitivity of panel screen television. In conclusion, this analysis is very useful for the early stages of cushion packaging design for televisions. At the same time, improvements without going through the try and error process can be implemented in order to reduce modification costs as well.

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