UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF EXPANDED POLYSTYRENE CUSHION DESIGN GUIDELINES FOR RELIABLE FLAT-SCREEN TELEVISION PACKAGING

NORMAH BINTI KASSIM

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By

NORMAH BINTI KASSIM

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

September 2020

DEDICATION

For all the time lost in seeking this invaluable source of knowledge,
I dedicate my work to the love of my life -

Allahyarham Hj. Kassim bin Jamal
Hjh. Halimah binti Jusuf
Ahmadea bin Ahmad
Abu Ubaidah bin Ahmadea
Ayra Maryam binti Ahmadea
My siblings and their family's
&
My family's in law

With love, respect and a bunch of memories.
Indeed, we belong to Allah and indeed to Him we will return.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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NORMAH BINTI KASSIM

September 2020

Chairman : Associate Professor Zulkiflle bin Leman, PhD
Faculty : Engineering

The packaging is a method used to protect products from damage that involves input from a variety of disciplines like engineering, sciences, economics, and packaging design knowledge including the home appliances products. Therefore, this study is mainly to produce the EPS cushion design guidelines for flat-screen television packaging. Further, to increase the effectiveness of EPS cushion packaging reliability, also to decrease the cost and time of EPS cushion packaging development. This research is comprehensively studying on a packaging design by using quantitative and qualitative methods; EPS cushion design validation by comparing the results between destructive testing and finite element analysis using ANSYS software, also reverse engineering analysis about the existing EPS cushion packaging design and process. Meanwhile, the simulation analysis results have been effectively proven that it can be used for the prediction of a possible defect or the design weakness of EPS cushion through clamping test, limit drop test, and drop test. So, these methods preciously effective to identify the major factors in designing EPS cushions design, especially flat-screen television packaging. As a result, found that are five types of factors need to be considered in the designing process of EPS cushion packaging's, such as rib positioning, layout of packaging, and thickness. Besides that, also found that finite element analysis is an effective method to be used and implemented especially in the manufacturing industry to enhance the television packaging design reliability. Moreover, the design guideline provides achievement in terms of cost and time reduction as well the packaging development process is improved.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN PANDUAN REKA BENTUK KUSYEN POLYSTYRENE DIPERCAYAI UNTUK PEMBUNGKUSAN TELEVISYEN SKRIN RATA

Oleh

NORMAH BINTI KASSIM

September 2020

Pengerusi : Profesor Madya Zulkiflle bin Leman, PhD
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Pembungkusan adalah kaedah yang digunakan untuk melindungi produk dari kerosakan yang melibatkan input dari pelbagai disiplin ilmu seperti kejuruteraan, sains, ekonomi dan pengetahuan reka bentuk pembungkusan termasuk produk perkakas rumah. Oleh itu, kajian ini bertujuan untuk menghasilkan garis panduan reka bentuk kusyen EPS untuk pembungkusan televisyen skrin rata. Selanjutnya, untuk meningkatkan keberkesanan kebolehpercayaan pembungkusan kusyen EPS, juga untuk mengurangkan kos dan masa pengembangan kemasan kusyen EPS. Penyelidikan ini mengkaji secara menyeluruh mengenai reka bentuk pembungkusan dengan menggunakan kaedah kuantitatif dan kualitatif; Pengesahan reka bentuk kusyen EPS dengan membandingkan hasil kajian antara ujian merosakkan dan analisis elemen terhingga menggunakan perisian ANSYS, juga analisis kejuruteraan terbalik mengenai reka bentuk dan proses pembungkusan kusyen EPS yang sedia ada. Sementara itu, hasil analisis simulasi telah terbukti secara efektif bahawa dapat digunakan untuk meramalkan kemungkinan kecacatan atau kelemahan reka bentuk kusyen EPS melalui ujian pengapit, ujian penurunan had, dan ujian penurunan. Oleh itu, kaedah ini sangat berkesan untuk mengenal pasti faktor utama dalam merancang reka bentuk kusyen EPS, terutamanya untuk pembungkusan televisyen skrin rata. Hasilnya, didapati bahawa lima jenis faktor perlu dipertimbangkan dalam merancang proses reka bentuk pembungkusan kusyen EPS, seperti kedudukan tulang rusuk, susun atur pembungkusan dan ketebalan. Selain itu, juga didapati bahawa analisis elemen terhingga adalah kaedah yang efektif untuk digunakan dan dilaksanakan terutama dalam industri pembuatan untuk meningkatkan kebolehpercayaan pembungkusan televisyen. Lebih-lebih lagi, garis panduan reka bentuk memberikan pencapaian dari segi pengurangan kos dan masa serta proses pembangunan pembungkusan kusyen EPS ditingkatkan.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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Declaration by graduate student

I hereby confirm that:

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LIST OF ABBREVIATIONS

EPS	Expanded Polystyrene
PS	Polystyrene
LCD	Liquid Crystal Display
LED	Light-Emitting Diodes
EPE	Expanded Polyethylene
GPPS	General Purpose Polystyrene
HIPS	High Impact Polystyrene
SPS	Syndiotactic Polystyrene
ICF	Insulated Concrete Foam
XPS	Extruded Polystyrene
SAN	Styrene-acrylonitrile
SPI	Society for Plastic Industry
CLE	Container Loading Efficiency
H	Height
L	Length
SILO	Intermediate Maturing and Stabilization
F	Force
g	Gravity
CAD	Computer-aided Design
CAM	Computer-aided Manufacturing
CAE	Computer-aided Engineering
BOM	Bill of Materials
ISDX	Interactive Surface Design Extension
PTC	Parametric and Freestyle Surfacing

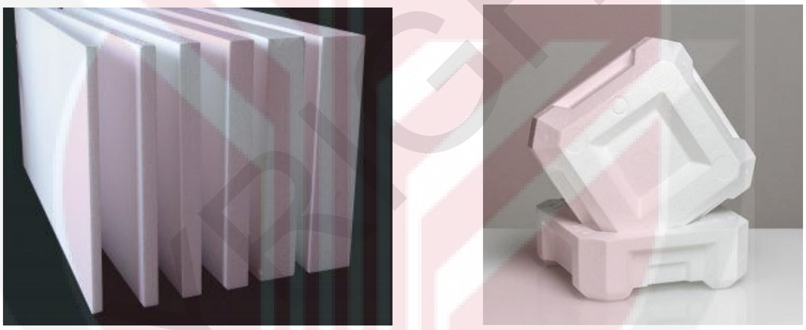
CFD	Computational Fluid Dynamic
MES	Mechanical Event Simulation
FEM	Finite Modeling
FEA	Finite Element Analysis
PPE	Polyphenylene Ether

CHAPTER 1

INTRODUCTION

1.1 Background

The most ancient cushioning materials used in packaging for the protection of products during transportation and storage are made from wood shavings (excelsior), straw (bagasse) and crumpled or shredded wastepaper. While these materials are still used in various amounts, they have largely been replaced with cushioning materials created from polymers tailored for more precise protection. Nowadays, the most popular polymer-based cushioning includes polyethylene foam, polypropylene foam, polystyrene foam and polyurethane foam sheets. There are two types of polystyrene foam as shown in Figure 1.1: the expanded rigid open-cell material that is available in the form of slabs and logs, and the expanded flexible closed-cell foam which can be moulded and extruded into many shapes (Hanlon, et al., 1998; Kelsey, 2007).



Open-cell foam Closed-cell foam

Figure 1.1 : Open-cell and closed-cell of polystyrene foam
(PLASTIMO & OMNEXUS, 2020)

According to Horvath (Horvath, et al., 2019), the closed-cell expanded polystyrene (EPS) foam was developed in the 1950s by Germany's Badische Anilin-Soda-Fabrik AG. The closed-cell material is made from beads of polystyrene (PS) impregnated with about 8 percent petroleum ether or pentane. These beads are pre-expanded in a large drum to about 25 to 40 times their original size by the introduction of steam at 85 to 96ºC (185 to 205ºF), attaining a density of 16 to 26 lb/m^3 (1.0 to 1.6 lb/ft^3). EPS beads are manufactured in three sizes: small, medium and large. The required bead size depends on the wall thickness of the moulded parts. Large beads can be used for thick walls, and small beads are necessary for products with thin walls. Figure 1.2 is an example of EPS beads. (Hanlon, et al., 1998; Selke, et al., 2004).

Figure 1.2 : Expanded Polystyrene (EPS) beads (CIGA et al., 2020)

EPS is white hard foam that is mostly used as packaging material or as shock absorbers (inserts) for a wide range of applications because EPS have good absorption impacts and can be designed into virtually any shape or size. This includes packing of commercial or electronic goods, home appliances as well as highly sensitive appliances such as televisions; as shown in Figure 1.3 (Anon, 2005; Kun et al., 2017; Tan et al., 2005). The development of the packaging design has included a series of process that includes briefing, research, conceptual design, design development, testing and refinement, and design finalisation of product (Stewart, 2012). Figure 1.3 shows the packaging development process.

The packaging processes start with makes a target and design intention by identifying the packaging size, design of product and packing review. Then, continues to the design concept. At this step, design specifications require the skills and expertise of packaging designers. The design phase is the most crucial step when producing television packaging. The third step is the design concept evaluation through discussions, comments and data updates. Next, the packaging design concept is confirmed by developing a packaging prototype or handmade which undergoes reliability testing to finalise the design shape as well as identify moulding and tooling development. Simultaneously, determine the tooling maker after completing the cost comparison based on final design of packaging through quotation request and allocation.

Packaging engineers usually begin the design effectiveness process of packaging within five weeks before production trial, known as the introduction stage. In this stage, production processes must run in actual conditions, the same as mass production processes, including the packaging section. The product will be assembled in complete packaging form until it is ready for the market. After the production trial, packaging engineers must conduct testing to ensure that the packaging design can withstand any shock or impact to meet that product design specification. Evaluation stage would repeatedly conduct until packaging design achieves the product design specifications in order to ensure the effectiveness of packaging in protecting the product.

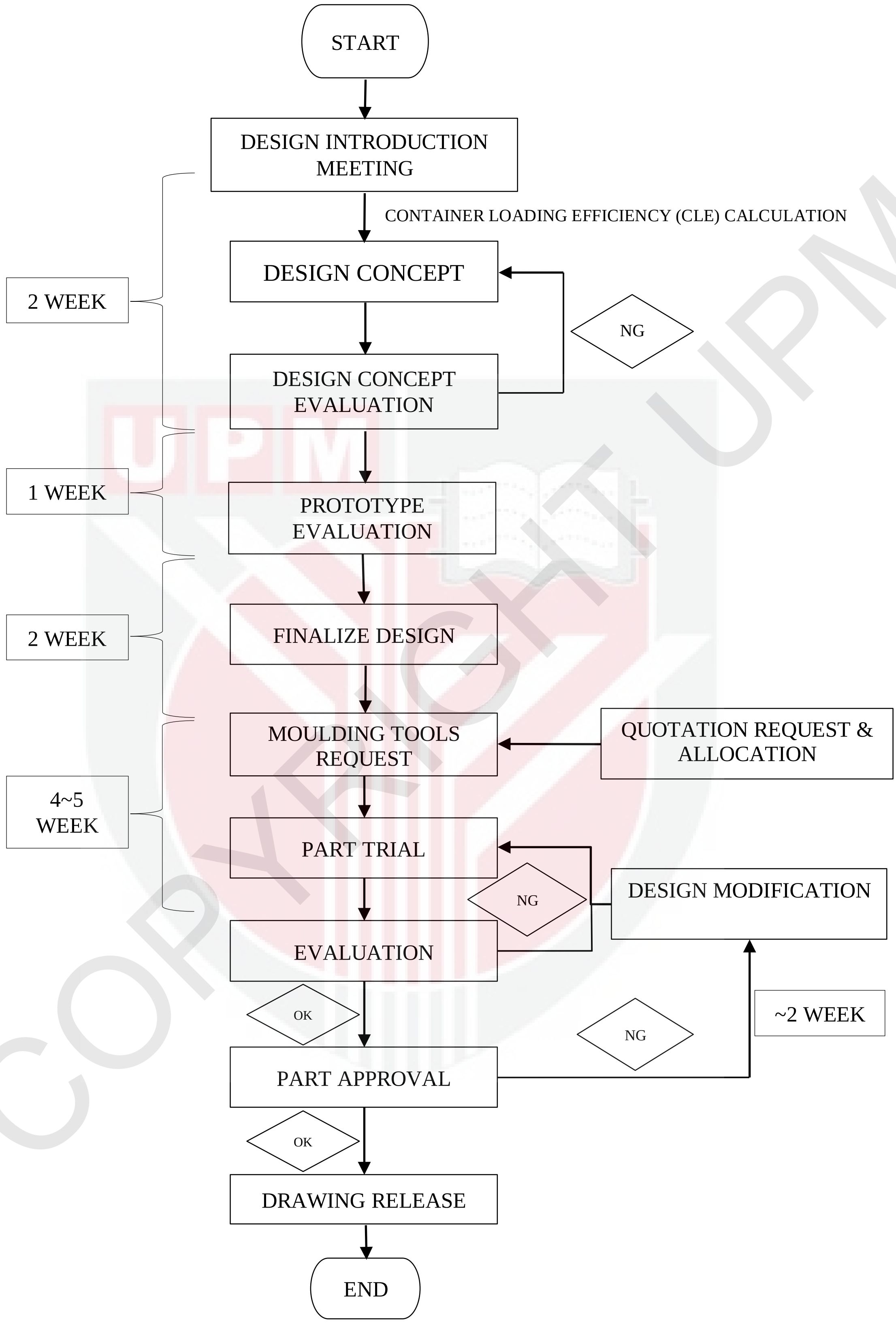


Figure 1.3 : Flow chart of packaging development process

These packaging evaluations actually were carried out to see the reliability and effectiveness of the packaging design in protecting the product from damage. If damage occurs during evaluation, design modification will proceed until the problem is solved. Finally, approval and drawing release will be issued after all evaluations are complete and packing requirements are achieved. In conclusion, the packaging design process goes through a long process, starting with prototype testing, packing test tool evaluation and final design evaluation. The accomplished evaluation is the actual testing, known as destructive testing, where it is frequently repeated until the problem is resolved. In terms of application, it has been widely used in numerous industries not only to food and drink packaging but also to all other fast-moving consumer goods and electronic appliances as a protective packaging to shield a product from shock due to impact and vibration (Emblem, 2012a; Lye, et al., 2004).

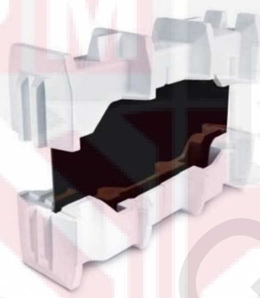


Figure 1.4 : Example of EPS Packaging Application (STOROPACK, 2020)

EPS packaging has good material properties; it is ultra-lightweight, durable, absorbs acoustics, has low thermal conductivity and sufficiently absorbs impacts. It can also be cut, shaped and moulded to any size to fit a particular application, is moderately priced and possesses outstanding mechanical and insulating properties suitable for use in resin-moulding such as TV cabinets and packaging foams (Chaukura, et al., 2016; Chen et al., 2015; Horvath, 1994; Inagaki, et al., 1999). Further, packaging is defined as a method or container made to protect products from damage. The products included, but are not limited to, food, electronics, manufactured goods, and etc. Also, the design process of packaging development involves input from a variety of disciplines and influences including history, science, engineering, economics, politics and social responsibility; it is mostly dependent on the engineer's knowledge and experience (Fadiji, Coetzee, Berry, Ambaw, & Opara, 2018; Yam, 2010).

Thus, in packaging technology draws knowledge from other disciplines such as mechanical engineering, chemical engineering, logistics management, packaging science, electronic and electrical engineering and physics. Meanwhile, there are also depends on number of critical factors; target customers, retail environment, structural or visual, company policies and types of products that need to be considered. Concurrently, package designer should have a good knowledge about the product, types of material, the functional and structural, method of distribution or selling products, and the packaging size (Natarajan, et al., 2014; Emblem, 2012).

Normally, for packaging performance is identified based on reliability to meet standard testing requirement. Agree with Han et al. (Han, et al., 2015) finding in order to verify the TV packaging design by performing the standard tests, where drop test are typical standard test were carried out. Also, referring the Standard Guideline for Transport Packaging Design (ASTM D6198-18) purpose is to assist in the development of packaging intended for the protection of goods while being in transit from the point of origin to final destination. In transport packaging, distribution is generally defined as inclusion of handling, storage, and transportation factors (Anon, 2005; Yucel, 2016). Therefore, for packaging performance, it can be evaluated by the reliability result through packaging testing in the development process (Blanco, Ortalda, & Clementi, 2015; Yam, 2010). In the article Virtual Prototyping of Drop Test Using Explicit Analysis by Todorov (Todorov et al., 2017), were stated that human operated packages and containers are tested in many ways to determine their properties. The manufactures are required to demonstrate that the products can withstand loads that could occur under operation and accidently conditions. One way is to perform drop tests that give an approximated value of the drop height for the products. This method has to be performed at a large number of products to evaluate their ability to resist an impact. Thus, the good performances of packaging are able to protect the product from characteristics of the impact hazard as shown in Figure 1.5.

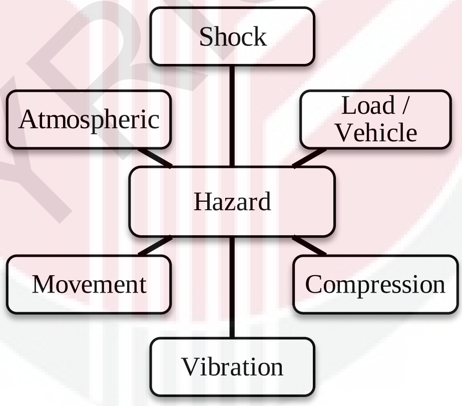


Figure 1.5 : Types of hazard in packaging distribution (Natarajan, et al., 2014)

Then, the level of fragility is one of the elements that need to be emphasized on a product. Product fragility is generally determined by actual product testing. It will often be measured in terms of fragility or impact load factor, G. The impact load factor, G, is a product-specific slowdown ratio packed at the impact point to acceleration due to gravity (ASTM D-1596-78a). In the packaging of the product if the G-level 50 means the packaging can withstand the reaction force at the impact point equal to 50 times the acceleration due to gravity. In other words, a product with a high impact load factor can endure more severe impact shock and thus requires less cushioning protection (Farris et al., 2009).

A cushioning curve describes the variation of the impact load factor, G, with the static stresses encountered by a packaging material. The static stress is the ratio of the weight of the product to the cushioning area. A family of such curves may be constructed for a given packaging material of different densities and height/thickness ratios. To determine the amount of cushioning area required in each face of the product, the density, drop heights, and lowest tolerable impact load factor, G, of the product are first determined. From these values, the corresponding maximum permissible static stress can be derived which when divided over the product weight would give the minimum cushioning area required for that face (Lye et al., 2004; Todorov et al., 2017).

For cushioning properties determined based on reliability to provide the necessary protection in term of inputs such as shock (impact) and vibration. The shock resistance of EPS will depend upon the density and thickness of foam. Cushion curves can be used to determine the bearing area (static loading) and the thickness of a cushioning material required for a particular application. Typically, cushion curve data for 1.25, 1.5, and 2.0pcf at various drop height indicate that EPS foam can absorb impact efficiently and recover its physical shape quickly, making it ideal for packaging fragile items within a wide range of weights and sizes. As conclusion, cushion curves relate the peak product acceleration to the foam thickness, the drop height, and the static stress (Todorov et al., 2017; Mills, 2007; EPS Industry Alliance, 2005; Sek, et al., 2000).

1.2 Problem Statement

Manufacturing technology today is rapidly developing, producing advanced and competitive products. Product development evolves in parallel with advanced technology. Manufacturers compete to produce product in a wide variety of materials, shape, size, colour, texture, and protect product to meet consumer satisfaction. Therefore, manufacturers must be more creative and innovative in designing product by considering those aspects especially packaging design. Normally, in packaging each product must be well design and packaged in order to ensure product safe throughout the distribution process, and also for market purpose (Ampuero et al., 2006; Hughes et al., 2018).

In general, since the middle of the twentieth century, there has been a significant lifestyle change in developed countries; this has become a major influence on how goods are packed, not only food and drink packaging, but all other fast-moving consumer goods as well (Emblem et al., 2012). Due to the recent change in the modern lifestyle, there has been a steeply increasing demand for large-sized home appliances, such as refrigerators, washing machines, and wide-screen televisions. These home appliances are designed to maintain their performance and quality under the various types of vibration and drop conditions caused by the transportation and delivery processes. Moreover, even small defects on the external appearance after transportation can be a cause of recall from consumers. As a consequence, cushioning materials such as Expanded Polystyrene (EPS) foam and

Expanded Polystyrene Plastic (EPP) have been widely used for the protection of home appliances from damages (Kim, Kum, & Park, 2009).

Besides, use EPS has found in numerous application areas across a wide range of industries due to its light weight, rigidity, and thermal and acoustic insulating properties. EPS has low thermal conductivity, shock and sound absorbing characteristics, and moisture resistant properties. In term of application, the electronic appliances mainly increasing the use of expanded polystyrene for electronic appliances such as blenders, washing machines, air conditioners, personal computers, scanners, and television screens to protect these products and to ensure safe transportation while distributed. In distributing products drop impacts are big issues, so to protect electronic products, buffer materials like Expandable Polystyrene (EPS), and Expandable Polypropylene (EPP) are used in packaging especially electronic products because are more vulnerable to damage that may occur during the distribution process (Technavio, 2020; Han, et al., 2015).

EPS packaging are mostly used among manufacturers of electric and electronic manufacturing industry, either for the protection of products or in distribution and handling purposes, due to good absorption capability. Also, it is lightweight and has outstanding insulation abilities suitable for protective packaging especially for fragile items, insulation in buildings and even for bicycle helmets (Fernandes et al., 2013; Krundaeva, et al., 2016). Nowadays, Expanded Polystyrene (EPS) cushion are still popular packaging and used in protecting product because lightweight, good cushion absorption, easy moulded and rigid (Chen et al., 2015; Horvath, 1994; Liu, et al., 2003; Liu et al., 2014). This statement also supported by Chen (Chen et al. 2015) where it has been found that EPS is commonly used in a variety of applications because of its features of light weight, good thermal insulation, moisture resistance, durability, acoustic absorption and low thermal conductivity.

Previous researches also had admitted that EPS packaging is valuable for packaging protection and has been used in a variety of applications. The following statements will showed the same opinion derived that EPS is a rigid, tough, recyclable, closed-cell, cellular plastic material used in a variety of applications including impact mitigation packaging, protective helmet, structural crashworthiness, construction material filling for road embankments, insulated concrete form (ICF) structures as well as lightweight EPS and reduction on material costs (Fernandes et al., 2013).

EPS is an inexpensive foam packaging material compared to other foams. It is lightweight with relatively good compression strength and moisture resistant. In industrial packaging, the flexibility of EPS makes it easy to be pre-formed into shapes for packaging fragile items such as glassware, domestic appliances and electronic goods. Additionally, its low water absorption surface and good anti-permeability can effectively stand against damp mouldy walls. At high temperature, polystyrene foam board will not melt due to the embrittlement phenomenon (Malone, 2016; Anne et al., 2012; Paine, 1991).

The advantages of EPS include good impact resistance and the ability to change and respond to the shape of the external impact of force buffering; with an independent bubble structure, a small area of damage will not affect the entire surface of the wall. EPS moulding provides excellent shock absorption, where the cell structure of the expanded cellular plastic withstands the normal vibrations of the packaged goods as well as the energy of an impact in a crash. Solutions in the field of electronic devices must successfully pass in prototypes before mass production by performed crash tests in the test laboratory (Amy, et al., 2009; Mas et al., 2013; Liu et al., 2014). Further, EPS cushion also one of the multipurpose polymers available for a variety of applications. Polymeric foams are extensively used as energy absorbing materials in packaging industry because they are cheap, light and are easily formed into complex shapes. Among these, the most frequently used materials are expanded polystyrene (EPS) and polyethylene (PE) (Ozturk et al., 2007).

Ultimately, the main objective of packaging design is to minimise mechanical damage to packed produce during the distribution cycle and improve the overall packaging performance (Opara et al., 2014). A few years ago, Yeong (Yeong et al., 1993) found that manufactured products are protected from damage during handling and transportation by some form of packaging. It is also acknowledged through recent studies of Lye (Lye et al.,2014) where manufactured products are commonly encased in moulded protective packaging buffers to protect them from damage due to impact shock during handling and transportation.

Next, packaging is used to protect products in transit. If it fails, the cost of the lost product can be many times the cost of the packaging itself (Verghese et al., 2007). The cushioning protection are popularly utilized to protect various products, and to help safe transportation of fragile products such as monitor. A large volume of cushioning can protect a product more safely; however, the cost is increased. Therefore, much attention is needed for the proper design of the cushioning package. Since the outside of monitors is generally made of brittle materials, the cushioning materials have to be well designed. The cushioning part of a monitor is mostly made of EPS (Todorov et al., 2017; Yi et al., 2005; Paine, 1991). With the recent pattern of economic globalization, product distribution has become global and consumer demand for products has increased significantly. Such products may suffer from various types of damage during distribution, such as chemical damage and physical damage. Thus, packaging is essential for protecting the products from these hazards; in particular, shock hazards are greatly reduced by the use of cushioning packages (Piao, et al., 2017; Goodwin et al., 2011).

Actually, optimum packaging design must be able to maintain adequate mechanical strength and stability of the package. Traditionally, to prevent impact-induced damage on a product, a reliability test is done using the ‘design–prototype-test-redesign’ approach which can be expensive, tedious and time consuming. Additionally, in validate the prototype products the design should be verified faster, however, making prototype products for performing experiments are very cost burden. Therefore, it is necessary to shorten the overall time required for development by shortening the time required for the simulation (Fadiji, et al., 2018; Han et. al, 2015).

Based on finding by Yi (Yi et al., 2015), although EPS it is lightweight, the usage of EPS considerably increases the volume of the packing box. Therefore, industries are trying to minimize the volume while maintaining the strength. Currently, the cushioning package of monitors is designed based on past experience, not with a systematic approach. When a design is finished, the strength is validated by drop tests that are very expensive. If the design is not satisfied, an iterative process with trial and error is carried out. The main purpose of packaging material is to prevent damage like deformation and crack during transporting to consumer. The shape and form of the packing material varies widely depending on the type of product. Most of TV packaging design is a typical area for performing design engineers rely on the know-how and intuition. To verify the TV packaging design, it should be performed by the standard tests (Han et al., 2015). Meanwhile, the product value also can be achieved by product packaging design. Consumer electronics products are mainly defined as three categories of products: display (flat-panel television, laptop), image (digital cameras, printer), and mobility (phone, PDA and MP4 player). As electronic components are becoming increasingly integrated, the size of electronic components is becoming more and more precise and the alignment of the board is becoming more and more complex, which puts forward higher requirements on the electrostatic, mechanical, moisture-proof and other packaging protection. Therefore, important for the packaging design of electronic products to adapt to these changes, and paid attention to in the electronic product packaging designs (Zhang, 2017).

The usual practice in designing EPS cushion of flat screen television are only considers reducing packaging size to reduce transportation cost directly. But there are other factors that should be considered in term of cost reduction such as size optimization of cushion foam, as well properly design the EPS cushion to ensure product reliability along the distribution chain (Castiglioni, et al., 2017; Han et al., 2015; Zhang, et al., 2012). Many literature reviews have emphasised the importance of EPS cushions as protection to ensure product safety throughout drop impact also the process of transportation and handling. However, there is a lack of proper standard design procedure on how to design EPS cushion packaging, especially from the first packaging development process. This is because; the design's effectiveness will only be proven through evaluation or destructive testing. Moreover, EPS cushion is currently designed based on past experience, not with a systematic approach. If the design is not satisfied, an iterative process with trial and error is carried out. The testing results would influence the effectiveness and reliability of EPS cushion packaging (Castiglioni et al., 2017; Yi et al., 2005; Zhou, et al., 2008).

The packaging evaluation method involved is a reliability test that assesses the shock, impact or any hazard that may cause products to become damaged, that also known as destructive testing. The examples of packaging test include drop test, environment test, stacking test and compression test. With the evolution of electronics industry, consumers demand for higher performance and multi-functions in electronic components and products. Thus, the product reliability becomes more important. Further, there are many ways to cause failures in an electronic device; among them, the most dramatic one is by dropping. However, the drop test method was involving to design validation that affects to cost and time because repeated tests must be conducted until the cushion reliability is proven (Hult, et al., 2005; Mills, 2007b; Todorov et al., 2017; Wu, et al., 1998b; Yeh et al., 2014). Therefore, in this thesis, the EPS cushion design needs to be well designed and to save cost by the idea of reducing design modification number throughout of packaging development process. Table 1.1 are presenting the expenses cost, number of moulding tool modification, and time among development and modification of EPS cushion packaging design during a 6-month period of flat screen television project development. Concurrently, if the EPS cushion design is changing, the EPS cushion mould modification also needs the design modification. Then, reliability test must be repeated to ensure the design improvement of EPS cushion packaging is capable to solve packaging defects and as well protecting the flat-screen television.

Table 1.1 : Data comparison of EPS cushion mould
(Sony, 2017; Tokopak, 2017; Zhaori, 2017; J&J, 2017)

Model	Price (RM)		Frequency of modification	Time (week)	
	Development	Modification		Development	Modification
A	35 300.00	34 800.00 6 000.00 1 800.00 2 000.00	4	5	4 2
B	38 585.85	5 400.00 5 250.00 5 250.00	3	5	2
C	N/A	44 000.00 5 000.00 3 400.00	3	N/A	4 2
D	39 400.50	7 000.00 3 800.00 1 700.00 2 200.00	4	4	4 2
E	33 567.20	5 500.00 2 500.00 2 500.00	3	4	2

Table 1.2 : Total cost expenses and time for modification of EPS cushion mould (Sony, 2017; Tokopak, 2017; Zhaori, 2017; J&J, 2017)

Model	Total Price (RM)		Total Time (week)		Frequency of modification
	Development	Modification	Development	Modification	
A	35 300.00	44 600	5	10	4
B	38 585.85	15 900	5	6	3
C	N/A	52 400	N/A	8	3
D	39 400.50	14 700	4	10	4
E	33 567.20	10 500	4	6	3
Total	146 853.55	138 100	18	40	17

Finally, the mould components of EPS cushion are formed using aluminium mould tools. These are generally of male and female form, with the shape between the two halves of the mould being the shape, being produced by injection moulding machine (BPF, 2020), Figure 1.6 shown an example of moulding tool of EPS cushion packaging.

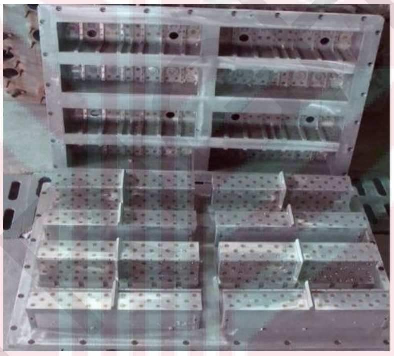


Figure 1.6 : Example of EPS moulding tools (PMPF CO., LTD)

Injection moulding is the most popular manufacturing technology and is extensively used to produce a variety of industrial products. With the introduction of modern machinery and computer-aided engineering (CAE), product shapes are becoming increasingly complicated. This complexity can result in surface defects and thermal damages. In a complex manufacturing process, there are various factors like machine conditions, product characteristics, process parameters, raw material, design, and several disturbances that affect the production plan and the final product quality. To compete effectively in the plastics marketplace, manufacturers, and researchers have focused on improving product quality by adopting different methodologies (Kumar, et al., 2020; Zhang, et al., 2016). Therefore, this study would develop the Expanded Polystyrene (EPS) cushion design guideline for reliability of flat-screen television packaging, as well can reduce a moulding tool modification, and the manufacturing process would improve in producing packaging by overcome that design challenges and constraint.

1.3 Objective of the Study

The aim of this research is to incorporate the design specifications of EPS cushion in developing design guidelines of flat screen television in order to improve packaging reliability. Overall, to ensure packaging design reliability, one must pay attention to the packaging reliability in the beginning of packaging development process instead of creating designs on a trial-and-error basis. A fundamental skill and design parameters are needed to define on how electronic components or appliances respond to shock and impact load.

This research extensively investigates on EPS cushion design to develop the appropriate specifications of packaging design guidelines for reliability improvement start from beginning of packaging development process, as well to reduce cost and time and of tools modification. This, this research employs the analytical approach by study the various input such as previous design, comparison validation result of simulation analysis and destructive testing, testing standards, and packaging development processes. The main objectives of this thesis are as follows:

1.3.1 To develop the design guidelines of Expanded Polystyrene (EPS) cushion for flat-screen television packaging,

1.3.2 To identify the effectiveness of EPS cushion design guideline in improving packaging reliability and development process,

1.3.3 To reduce the mould modification cost and time of EPS cushion packaging development,

1.3.4 To improve the packaging development process of EPS cushion design

1.4 Scope of Study

There are several scopes of the research emphasised in this study. Firstly, this research focuses on the developing design guideline of EPS cushion packaging for home appliances, namely is flat screen television products only. The types of televisions chosen are liquid crystal display (LCD) and light-emitting diodes (LED). The large-sized televisions of 40, 48, 50, 55 and 70 inches are selected. However, this study of EPS cushion design will focus on one of the leading manufacturers of flat screen television based in Malaysia, which Sony EMCS (M) Sdn. Bhd. This manufacturer plays a role as the research and development centre in designing and producing EPS cushion packaging to use by other Sony television manufacturers around the world such as China, Japan, Europe, Slovakia, Mexico, and Brazil. Secondly, this study would focus to define and analyse EPS cushion design by examining the possibility of defects on the appearance of a flat-screen television, it's not including the defect of the electronic component. Therefore, the development of EPS cushion design guidelines and specifications would be properly designed to improve packaging design, reliability, indirectly transform working practice in packaging development process into more effective way and conducive.

Thirdly, this study would verify the previous design of the EPS cushion in range of year 2013 to 2017, in order to produce an EPS cushion design guideline properly for flat screen television packaging. The verification method would be conducted by data comparison of destructive testing result and finite element analysis design. These comparison data must match to prove that design simulation is effective and would use or added in the packaging development process. While the destructive testing of EPS cushion design was conducted during the development phase before the introduction of mass production or if have packing issue such as market claim / defect.

Furthermore, in problem statement section, it is shown that the development cost of EPS cushion mould for model C is not considered, means are not included. But modification cost of EPS cushion mould will be studied. This is because the packaging of model C was originally produced using an inflatable air cushion. However, has failed to prove the effectiveness of this packaging material in protecting flat screen television so it was changed to EPS cushion packaging type.

In addition, the entire study was conducted using qualitative methods; design review of previous EPS cushion packaging, and quantitative; CAD modelling, simulation analysis, destructive testing (experimental) validation of EPS cushion packaging using finite element analysis method and comparing the results. Both methods would be able to solve research objectives. Then, in the quantitative study there are two types of software that will be used, namely Pro Engineer software for design EPS cushion modelling and ANSYS software for analysis design. Meanwhile, for experimental (destructive testing) referred to are clamping test, limit drop, and drop test. Finally, the results of the study will be used in identifying the main factor in effectively designing a good EPS cushion packaging.

1.5 Significance of Study

The study is to enhance the working process packaging engineers, in producing large-sized and fragile packaging products especially flat screen television. The packaging must be well protected from any possible damage during the distribution chain process. Therefore, expertise in design aspect significantly contributes to the effectiveness of EPS cushion packaging by producing the design guideline specially EPS cushion packaging. These will enable engineers to design packaging with proper knowledge and skills, and to identify potential problems that may arise through the design simulation process. This will ultimately provide several advantages in terms of manpower, time, and cost management. Through this development of design guidelines, the student's proof that design simulation is more effective in identifying design weaknesses than complex prototyping. Therefore, the finite element analysis process is proposed to include in the product development process of EPS packaging. Indirectly, this guideline will serve as a module for new EPS cushion packaging design, also benefit to new engineers. At the same time, it will create a conducive working environment as well granting a wide range of benefits.

1.6 Structure of Thesis

This thesis consists of five chapters. The first chapter includes an introduction to the research, followed by the problem statement, objectives, scope & limitations, significance of the thesis and lastly, thesis structure. The second chapter presents literature studies on related areas associated with flat screen television packaging EPS cushion design, standards testing of television packaging and etc. The third chapter illustrates the methods used in this research. The experiment is described, including a reliability test of television packaging, a simulation of the packaging design and a packaging design review. The fourth chapter presents the results and a discussion of the analyses, comparison of the different approaches used in case studies (destructive test and simulation results). This includes a comparison of results of EPS cushion design analyses to find the factor or specifications in EPS cushion packaging design guidelines. The final chapter summarises the research findings and its contribution to the body of knowledge as conclusions of studies. A recommendation for future research opportunities is also presented at the end of this thesis.

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BIODATA OF STUDENT

Normah binti Kassim was born in Tawau, Sabah on June 8th, 1987 as a younger daughter of Allahyarham Hj. Kassim bin Jamal and Hjh. Halimah binti Jusuf. The student is alumni of Universiti Putra Malaysia in course of Master of Engineering Management. The student obtained her first degree in Bachelor of Product Design Engineering on September 2011 from School of Manufacturing, Universiti Malaysia Perlis.

The student is a former Mechanical Engineer in JVC (M) Manufacturing Sdn. Bhd. for a year. She enhances her knowledge in Research and Development center as Design Engineer at Sony EMCS (M) Sdn. Bhd. Furthermore, the student had 5 years industrial experiences and resign as a Senior Design Engineer end of year 2016.

In year of 2016, the student also continues the further study in Doctor of Philosophy of Mechanical Engineering at Universiti Putra Malaysia. Currently, the student worked as a Fellow ('Tenaga Pengajar Muda") in Faculty of Mechanical Engineering Technology, Universiti Malaysia Perlis started 9th September 2017.

The student also mother of two kids but very interested in academia field. Her likes to teach student based on industrial experiences but following the Universiti requirement. Lastly, the research field of student is focusing on product design development, manufacturing process and improvement of working process.

LIST OF PUBLICATIONS

N. Kassim, Z. Leman, B.T.H.T. Baharudin and F. Abdul Aziz, (2019). Finite Element Analysis of Rib Cushion Positioning for Expanded Polystyrene. *Journal of Advanced Manufacturing Technology*. 105–118.

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