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A COMPARISON BETWEEN VARIOUS PACKAGE CUSHIONING MATERIALS
BASED ON PERFORMANCE AND ENVIRONMENTAL CONCERNS

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A COMPARISON BETWEEN VARIOUS PACKAGE CUSHIONING MATERIALS BASED ON PERFORMANCE AND ENVIRONMENTAL CONCERNS

By

Nopporn Charnnarong

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ABSTRACT

A COMPARISON BETWEEN VARIOUS PACKAGE CUSHIONING MATERIALS BASED ON PERFORMANCE AND ENVIRONMENTAL CONCERNS

By

Nopporn Charnnarong

The solid waste problem associated with the increasing proportion of plastic packaging materials has become a serious public concern. Many innovative cushioning materials have been created with the intent to protect the environment from overpopulation of non biodegradable materials. In this study, ten cushioning materials were chosen to evaluate the performance and develop " Environmental Cushion Curves " which describe the level of protection for Cushion Weight to Product Weight Ratios and Cushion Volume to Product Weight Ratios. Three different drop heights were used to evaluate each cushioning material. The results show that most of the polymer cushioning materials perform better with smaller percent weight usage than the paper-based cushioning materials.

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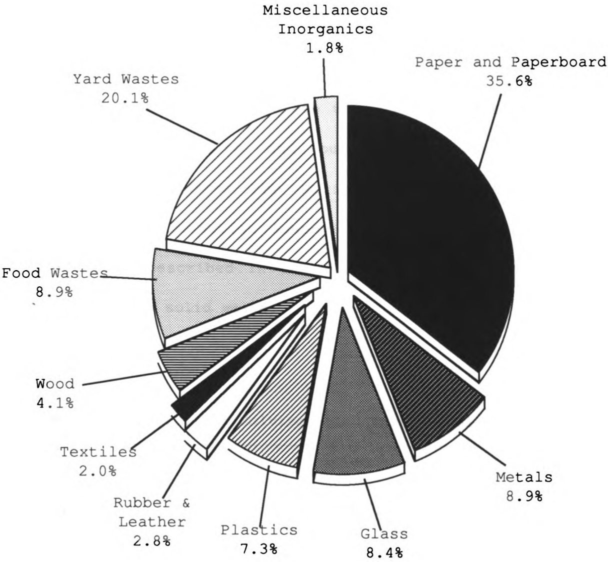
CHAPTER 1

INTRODUCTION

The American public is increasingly concerned with environmental issues, which will dominate the national agenda in the United States throughout the coming years.(18) One of these issues is municipal solid waste, of which two hundred million tons is generated each year. Each day, the average American person generates about 4 pounds of solid waste. This is nearly double the rate 30 years ago. The largest contributor to the nation's municipal solid waste is expendable packaging. Plastics in particular constitute about one-third of all municipal solid waste. Plastic packaging, including cushioning materials which represent about 7.9% of all plastics packaging produced in U.S. (in dollar value), accounts for about 6 percent by weight of all municipal solid waste. The plastic content of solid waste is small on weight basis but is nevertheless significant on a volume basis. Paper and paperboard constitutes 35.6% of the total volume of municipal solid wastes (Figure 1).

Figure 1 : Weight Percent of Materials in Solid Waste Stream



Source : FRANKLIN ASSOCIATES, LTD., 1988

The solid waste problem can be solved if the government, packagers, suppliers all work together aggressively to educate consumers the realistic solutions that will address the solid waste problem. Unless make up function of landfills becomes clearly understood, well-intentioned efforts are likely to aggravate this problem. Landfilling, incineration, recycling, and source reduction will all be necessary to address the solid waste issue(7). The Environmental Protection Agency (EPA) has developed a hierarchy as described in Table 1 to address the problems associated with solid waste.

TABLE 1 : Hierarchy for Solving Solid Waste Problems

1	Source Reduction
2	Recycling or Composting
3	Incineration
4	Landfilling

Landfilling is an engineered method of disposing of solid wastes on land in a manner that minimizes environmental hazards. At a site that is carefully selected, designed and prepared, the wastes are spread in thin layers, compacted to smallest practical volume and covered with earth. The critical factors which must be considered in landfill design are leachate, gas production, odor, noise, aesthetics, air pollution, dust, fires and birds. Landfilling remains the most frequently used and economical means of safe disposal in United States. However it is estimated that one-fourth of the nations major cities will run out of such disposal sites by 1993 (11) (23). One-third of the existing landfills will be full, and the new landfills are becoming increasingly difficult to site (15).

Incineration is a means of disposing of refuse by high temperature oxidation. The residue left over will vary widely depending on the composition of the wastes. For example, waste paper yields ash which is as little as 1% of the mass of waste. Incineration reduces the volume of garbage to be landfilled by 90% and it also transforms waste to usable energy, but the cost associated is as much as twice that of landfilling. The 10% remaining ash, containing heavy metals which must be disposed off as hazardous waste, does not eliminate the need for landfills. It is second in tonnage among community disposal methods with landfill predominating by a large factor. There is also concern about the incineration of plastics that emit gaseous pollutants like HCl, HF or CO.(10)

Recycling is the other process that the public can directly contribute to the solid waste problem. It is the most attractive approach for a number of reasons. It saves energy expended for retrieval and the type of material recycled. It also conserves valuable raw material resources. For example recycled plastics and paper can be more economical alternatives than the corresponding virgin material. However they suffer some degradation during reprocessing, but they are nevertheless useful and viable alternatives. The three major factors that influence recycling are collection, separation, and cleaning. The public can provide mechanisms to address the first two issues. The fourth criteria to accomplish successful recycling is listed below,

(1) continuing source of scrap

(2) variable recycling and reprocessing technology

(3) good economics

(4) application and market for products derived from the recycled waste.

Cushioning is a prime application for recycled materials. This however would not be suitable for consumer packages such as the primary food container where direct food contact with recycled material will not be approved by the Food and Drug Administration.

Traditional approaches and add-on solution of waste management alone cannot easily solve the solid waste problems. All waste management practices have associated economic and environmental costs, and can simply shift pollution problems from one environmental medium to another. Creative, new approaches are needed at the source of garbage problems. It is source reduction which is the most significant and important practice to reduce solid waste stream by designing, manufacturing, purchasing or using materials and packages to reduce their amount or toxicity before they enter the municipal solid waste stream. In addition they should not increase the net amount or toxicity of wastes generated throughout the life of material.(18) (24)

The political leaders at all levels have already been actively involved in a mirage of proposed packaging bans. The Environmental Protection Agency (EPA) has provided the outlining of hierarchy for integrated waste management to be considered at seminars, workshops and research projects. The proposed recyclable Materials Science and Technology Development Act has required the Department of Commerce to recommend the measures for ensuring the development of technologies for recycling nondurable consumer product packaging and the expansion of markets for recycled products. Over 20 states had procurement guidelines for the acquisition of recycled materials. Nine of these states had deposit laws and waste management laws to assist their activities.

Many environmentally conscious packaging materials and manufacturing methods have been developed in the past few years to respond to this crisis. In 1990 Astro-Valcour had successfully eliminated the CFCs and HFCs from the manufacturing process by replacing it with a hydrocarbon-based blowing agent. Most of the polystyrene industries are also eliminating the use of Chlorofluorocarbons as a blowing agent. Man-made Chlorofluorocarbons (CFCs) are believed to have been a major cause in destroying the ozone layer which shields earth from harmful ultraviolet radiation. NASA satellites have found an ozone hole which covers an area of 5.5 million square mile at the South Pole.

Plastic cushioning materials have also been scrutinized by environmentalists and city engineers. They have negative images to the consumers with regard to their long-term life in landfill sites and their volume used in packaging has essentially doubled in the past 10 years. Consequently, many manufacturers have shown their significant interests in new cellulose-based cushioning materials (17) like curled wood shavings, popcorn, zigzag shredded kraft paper, honeycomb or Quadrapak (an innovative structural kraft paper) that were supposed to be more environmentally friendly since they can biodegrade. Berry Hill, a small mail order firm in St. Thomas, Ontario, uses about 100 pounds of fresh popped corn daily for packing and shipping of farm equipment.(2)

In the Packaging Magazine issue, November, 1990, Melissa Larson described the environmental concerns of standard plastic loose-fill materials and an interest in alternative materials (16). Based on this, a survey was done to request cushion performance data from a list of manufacturers provided in the article.

The purpose of this study was to evaluate cellulose-based cushioning materials to the polymer cushion materials by comparing the environmental performance measured as the ratio of weight and volume of the cushioning material to the weight of product, required to provide the same level of protection to the product.

Specifically, the objectives of this study were

1 To quantify the cushioning performance of the "environmentally conscious " materials like popcorn, zigzag shredded paper and Honeycomb.

2 To provide a means of comparing the percent utilization of cushioning materials of various kinds to provide the same level of protection to the product.

CHAPTER 2

MATERIALS AND METHODS

2.1 Materials

Seven different commercially available types of polymer cushioning materials were chosen to be evaluated and compared with three "environmentally conscious" materials. The cushions selected and the appropriate manufacturers are listed in Table 2.

All materials evaluated in this study are described in alphabetical order in section 2.1.1 to 2.1.11

2.1.1 Arcel 310

It is ARCO Chemical's moldable Polyethylene copolymer which falls between EPS and EPE in performance but exceeds both materials in toughness. It has good multiple impact performance, better tensile and puncture resistance than any other moldable resilient foam available in US today. The price is in the $2.50 per pound range.

Table 2 : Cushiong Materials Evaluated in this Study

Material Classification	Tradename	Manufacturer	Telephone no.
Expanded Polyethylene Copolymer	Arcel 310	Arco Chemical Company	(800)-321-7000
Expanded Polyethylene bead	Arpak 4322	Arco Chemical Company	(800)-321-7000
Styrene Acrylonitrile foam	Arsan 600	Arco Chemical Company	(800)-321-7000
Polyethylene foam	Ethafoam 220	Dow Chemical Corporation	(800)-441-4369
Kraft paper	Honeycomb	International Honeycomb Corp	(800)-323-9161
Polyurethane foam	Instaflex	Sealed Air Corporation	(201) 797-4000
Popped Corn	Popcorn	-	-
PE / Nylon / PE Air bubble	Polycap PD230	Sealed Air Corporation	(201)-797-4000
Expandable Polystyrene	Pelaspan Mold-a-pac	Dow Chemical Corporation	(800)-441-4369
Kraft paper	Quadrapak	Eco-pack Industries, Inc.	(201) 251-0918

2.1.2 Arpak 4322

It is ARCO Chemical's Expanded Polyethylene bead. The properties are similar to Dow Chemical's Ethafoam 220. It is a low density semirigid, closed-cell polyethylene homopolymer which is soft, nonabrasive, provides good multiple impact cushioning, has good vibration-damping characteristics, high mechanical strength, and good chemical resistance. The raw material cost is in the $2.25 per pound range.(4)

2.1.3 Arsan 600

It is ARCO Chemical's Styrene Acrylonitrile copolymer foam which is an attempt to take the best properties from EPS and EPE, and combine them into a moldable, lightweight, semi-rigid, closed cell, high resilient styrene copolymer resin. The resin relies on a fluorocarbon blowing agent to pre-expand and fuse the material during its molding phase. It provides good impact protection, good insulation, and good vibration damping characteristics. Its advantage over EPS is the ability to withstand repeated drops. The cost of resin is in the $2.00 - $2.50 per pound range. These properties make it suitable for application where multiple impact, low fragility, high static loading and high value items are involved.(5)

2.1.4 Ethafoam 220

This is the trademark for Dow Chemical's Polyethylene foam. The general characteristic is the same as Arcel 310 : tough, closed cell materials which are energy absorbent, resilient, lightweight, moisture and chemical resistant and easy to fabricate. Potential disadvantages of PE foam include : it is more expensive than most other common cushioning materials on volume basis, slightly abrasive for some highly polished or very sensitive painted surfaces.

Ethafoam has been in use for the past two decades. It is extruded in planks which are fabricated to provide required cushions. It is economical as a cushioning material for sensitive products when shipping volumes are small and molded cushion per product costs are expensive.(13)

2.1.5 Honeycomb

It was developed by the Structural Mechanical Research Laboratories at the University of Texas, Austin during 1953 to 1959. They had investigated many kinds of cushioning materials to determine the best available material for single drop aerial delivery and Honeycomb was determined to be the most suitable for this particular use.

The structure of Honeycomb is a sandwich construction, consisting of oval cells, glued between two thin, high strength facings. The loads are transferred from the face, to the core, to the second face. It can be best understood by comparing it to the I-beam structure, resisting shear loads and increasing structural rigidity by spreading the opposite faces apart. Unlike the I-beam, however, the honeycomb core gives the continuous support to the facing because of its network configuration.(14)

The entire structure is made of unbleached Kraft paper. The oval core is made from kraft paper with 33 pound basis weight and the face panel from 69 pound basis weight. It is available in different size of core cells and thicknesses. In 1986, the cushion curves were experimentally developed by Singh (22), to evaluate the effect of core size, the cushion thickness and drop height on shock transmission.

The Honeycomb used in this study has a 7/16 inch core size and is 2 inches thick. The density, impact velocity, moisture content and temperature are known to affect the dynamics stress and strain curve of Honeycomb.(8)

2.1.6 Instaflex

It is a semi-rigid, CFC free Foam-in-Place developed by Sealed Air Corporation. The material is produced on site by pumping Polyurethane resin and Polymeric Isocyanate through the heated line to the dispenser at which the two chemicals are mixed to the proper ratio. As the liquid mixture is dispensed out, it quickly expands and solidifies to form a custom fit cushioning foam. Water vapor and Carbondioxide are emitted during the raising period that might cause concern to the operator. Adequate air circulation is therefore required in the operation place.

Foam-in-Place has some significant handling and storage advantages because the cushioning is produced when it is needed. It also provides an increased flexibility to pack a wide variety of product shapes, sizes and weights. It can be stored in liquid form, reducing the storage space and inventory cost. However, its density is not uniform as it varies depending on the shape and region dispensed. The molds used are made generally from wood and therefore are very economical as compared to EPS or EPE.

It is biostable, difficult to degrade and can be landfilled without contributing to air and water pollution. Another way to dispose is as a fuel for waste-to-energy incinerators.(19)

2.1.7 Pelaspan Mold-a-pac

The EPS loosefill is used to protect the product and fill voids. It is cost-effective protection for lightweight products. On the volume basis, it is the least expensive and the lightest of all plastic cushioning. However, it is messy and not designed to protect heavy products. Some will settle during transit due to vibration and may cause the product to shift and result in damage during subsequent handling.(1)

This Dow Chemical's bonded EPS loosefill can solve some problems of ordinary EPS loosefill. It comes in s-shape configuration. Each piece is coated with adhesive as it is dispensed from the overhead hopper into the container and plastic film is used to separate the loosefill from the product. It is uniform, has consistent density, forms a resilient cushion to better hold the product. It is a light weight cushioning with the density of only 0.26 pound per cubic feet, providing a clean and custom-designed appearance. It has a lower material cost than many other cushioning materials. It is typically used for a wide range of products where shipping volume are small and increased flexibility is required. It is used by several small mail order houses to ship a wide variety of products.(12)

2.1.8 Polycap Plus PD230

In 1960, Sealed Air Corporation invented an air cellular material for cushioning and surface protection, a significant breakthrough in packaging science. It was produced by encapsulating bubbles of air between two sheets of plastic film. It is typically flexible, soft, lightweight, transparent, water-resistant and heat-sealable. It is available in barrier and non-barrier types, determined by the size of the air bubble and the thickness of film. Since the air is the most important factor for this cushioning, the size of the bubbles, the thickness and the type of the film, and the number of wraps determine the level of protection. It is recommended only for short and predictable shipping cycles.(9)

Small air bubble wrap is used for protecting surfaces and wrapping small intricate items. Larger air bubble wrap is used to provide cushioning and void filling.

Unlike most ordinary polyethylene Air bubble wrap, Polycap Plus PD230 is coextruded film of PE-Nylon-PE which is resistant to the air to escape, and holds the air much longer under high pressure. The bubble cell evaluated had a 1 inch diameter and is 0.5 inch thick.(20)

2.1.9 Popcorn

Due to its biodegradable nature, popcorn cushioning has found an increased interest over foam peanuts. Popcorn is a special kind of flint corn. Popping occurs at about 350° F which is equivalent to a stream pressure of 135 psi inside the kernel. The water in the kernel is superheated and then converts to steam, which provides the driving forces for expanding the thermoplastic endosperm after the kernel ruptures. Expansion volume is the most critical quality factor of popcorn. Most commercial popcorn has a 30-40 fold expansion. There are two processes in popping,

Wet Popping	The corn is popped in vegetable oil.
Dry popping	Using the radiant heat at 410°F-430°F to pop the corn in large scale operations.

Popped corn rapidly absorbs air moisture and becomes tough at a moisture level above 3%RH. It is totally biodegradable and can also be used in composting facilities. However, it is also a source for insects, ants, and rodents that will result in impregnating the package and damaging the product.

A major safety concern is consumption of this industrial popcorn by infants resulting in fatal accidents. Industrial corn may have been treated to provide resistance to humidity and abrasion. These coatings or treatments are usually unsafe for human consumption.(3)

2.1.10 Quadrapak

It is formed from unbleached kraft paper which is slit, folded and compressed into a zigzag shape. With this shape, it retains a memory of its original shape, and after packing the material slowly springs back and interlocks like a nest. It is usually used as void filler which prevents the product from migrating to the package wall.

It is manufactured using up to 50% to 60% post-consumer recycled kraft paper which makes this material easily degradable. It can also be collected to be reused or recycled.(21)

2.2 Methods

Three different methods are used to determine the shock absorbing characteristic of the cushions according to the shape and structure of material. ASTM D 1596-78a, (Standard Test Method for Shock Absorbing Characteristics of Package Cushioning Materials) is applied to materials like Ethafoam 220, Arpak 4322, Arsan 600, Arcel 310, and Honeycomb. ASTM 4168-88 (Standard Test Methods for Transmitted Shock Characteristics of Foam-in-Place Cushioning Materials) is applied to materials like Instaflex, Pelaspan Mold-a-pac, Popcorn and Quadrapak. Table 3 lists the cushioning materials and published cushion performance data used in this study.

Cushion curves were developed for Popcorn and Quadrapak. The material was filled in 12"x12"x12" RSC corrugated box with the 8"x8"x8" wooden test block placed in the center of the corrugated box. The cushioning material was 2 inches thick distributed around the wooden test block. The ballast weights were placed inside the test block. A piezoelectric accelerometer with an output characteristic of 10 mV/g's was

Table 3: Reference Documents for Cushion Curve Data

Material	Reference document for cushion curves
Arcel 310	ARCO Chemical's Document ACC-P127-908.
Arpak 4322	ARCO Chemical's Document ACC-P106-8610.
Arsan 600	ARCO Chemical's Document ACC-P108-8610.
Ethafoam 220	Dow Chemical,"Product and Design Data for Ethafoam brand polyethylene foam".
Instaflex	Sealed Air Corporation, "Technical data report of Instaflex", 1988.
Pelaspan Mold-a-pac	Dow Chemical, "Combining the economies of loose fill with the protection of engineered, molded cushions", 1987.
Polycap Plus	Sealed Air Corporation, "Technical data report of Polycap Plus PD230", 1990.

mounted on the top of platen of ballast weight. The accelerometer responds to the shock incurred by dropping the whole box on the shock table and recording the acceleration in accordance with ASTM 4168.

Data were collected for three drop heights of 24 inches, 30 inches and 36 inches.

Using the cushion curves which represent the shock absorbing characteristic of the material, the Cushion Weight to Product Weight Ratio and the Cushion Volume to Product Weight Ratio are determined by the following equation :

Cushion Weight to Product Weight Ratio

$$= \frac{\text{Weight of Cushion}}{\text{Weight of Product}} \times 100 \qquad (\ 2\text{-}1\ )$$

$$= \frac{t \times D \times 100}{\sigma \times 1728} \qquad (\ 2\text{-}2\ )$$

where t = Cushion Thickness (inches)

D = Cushion Density (lb./ ft^3.)

σ = Static Loading (lb./in^2.)

therefore,

Minimum Cushion Weight to Product Weight Ratio (%)

$$= \frac{t \times D \times 100}{\sigma_{max} \times 1728} \qquad (\ 2\text{-}3\ )$$

Maximum Cushion Weight to Product Weight Ratio (%)

$$= \frac{t \times D \times 100}{\sigma_{min} \times 1728} \qquad (\ 2\text{-}4\ )$$

Similarly, the Cushion Volume to Product Weight is expressed by;

Cushion Volume to Product Weight Ratio

$$= \frac{\text{Cushion volume}}{\text{Product weight}} \qquad (\ 2\text{-}5\ )$$

$$= \frac{\text{Area x Thickness}}{\text{Area x Static Loading}} \qquad (\ 2\text{-}6\ )$$

$$= \frac{t}{\sigma} \quad \frac{(in^3)}{(lb.)} \qquad (\ 2\text{-}7\ )$$

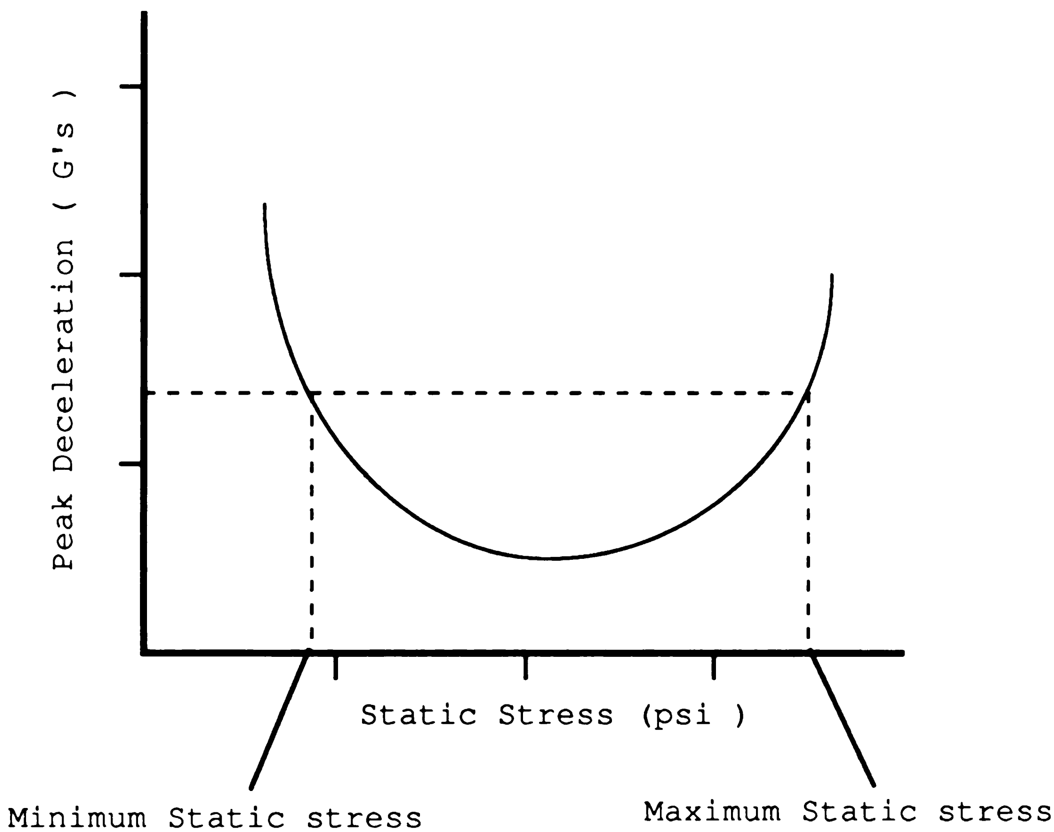
Minimum Volume to Product Weight Ratio

$$= \frac{t}{\sigma_{max.}} \qquad (\ 2\text{-}8\ )$$

Maximum Volume to Product Weight Ratio

$$= \frac{t}{\sigma_{min}} \qquad (\ 2\text{-}9\ )$$

Figure 2 : Minimum and Maximum Static Stresses were Obtained From Each Cushion Curve.



CHAPTER 3

DATA AND RESULTS

The experimental data for the shock transmission values for Popcorn, Honeycomb and Quadrapak are shown in Table A1 through Table A3 in Appendix A. The cushion curves for these materials are provided in Figure B5, B9 and B10 in Appendix B.

The Cushion Weight to Product Weight Ratios were calculated for all the materials as described by equation (2-3). Table 4 describes these computed values for the cushioning materials for multiple (2-5 average) impacts from a drop height of 24 inches. The values are presented for various levels of protection from 20 g's up to 150 g's with an increment of 10 g's. Similarly, Table 5 and 6 present the data for drop height of 30 inches and 36 inches respectively. All materials in this study were evaluated for a thickness of 2 inches.

Table 4 : Required Cushion Weight to Product Weight Ratio (%) for a given level of protection (G) in average 2-5 impacts from 24 inches drop height

G	20	30	40	50	60	70	80	90	100	110	120	130	140	150
Ethafoam 220			0.30	0.18	0.14	0.11								
Arpak 4322				0.17	0.14									
Arsan 600				0.10	0.07									
Arcel 310				0.16	0.12	0.10	0.09	0.08						
Instaflex		0.26	0.14											
Pelaspan Mold-a-pac				0.03										
Polycap PD 230				0.20	0.15	0.14								
Popcorn											0.35	0.29	0.26	0.23
Quadrapak					0.65	0.44								
Honeycomb 7/16" cell									0.25	0.22	0.21	0.20	0.19	0.18

Table 5 : Required Cushion Weight to Product Weight Ratio (%) for a given level of protection (G) in average 2-5 impacts from 30 inches drop height

G	20	30	40	50	60	70	80	90	100	110	120	130	140	150
Ethafoam 220				0.29	0.21	0.17	0.14	0.12	0.11					
Arpak 4322				0.38	0.23	0.19	0.17							
Arsan 600						0.10	0.08							
Arcel 310					0.13	0.11	0.10	0.09	0.08					
Instaflex			0.20	0.18	0.15									
Pelaspan Mold-a-pac					0.04	0.03								
Polycap PD 230						0.56	0.38	0.32	0.29					
Popcorn													0.40	0.33
Quadrapak						1.02	0.71	0.54						
Honeycomb 7/16" cell	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

* N/A means there is no data for that material for 2-5 impacts from this drop height

Table 6 : Required Cushion Weight to Product Weight Ratio (%) for a given level of protection (G) in average 2-5 impacts from 36 inches drop height

G	20	30	40	50	60	70	80	90	100	110	120	130	140	150
Ethafoam 220					0.37	0.28	0.21	0.18	0.16					
Arpak 4322						0.30	0.24	0.21						
Arsan 600							0.13	0.10						
Arcel 310						0.19	0.14	0.13	0.12					
Instaflex				0.25	0.19	0.16								
Pelaspan Mold-a-pac					0.08	0.04	0.03							
Polycap PD 230	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Popcorn											0.46	0.40	0.37	0.35
Quadrapak						0.98	0.59	0.48						
Honeycomb 7/16" cell	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

* N/A means there is no data for that material for 2-5 impacts from this drop height

The calculated data for Cushion Volume to Product Weight Ratio were determined using equation (2-9). The Cushion Volume to Product Weight Ratio values are presented in cu.in./$_{\text{lb.}}$. Table 7 describes the calculated values for the different cushioning materials for multiple impacts (2-5 average) from a drop height of 24 inches. Table 8 and 9 present the data for drop heights of 30 and 36 inches respectively.

Previous studies on product fragility have described that the most fragile and delicate products have to be protected below 40 g's. These usually are precision aligned test instruments or electronic equipment. Most mechanical and electrical products have a fragility between 40 and 85 g's Rugged industrial machinery and appliances have a fragility higher than 85 g's.

Cushioning materials, that can provide lower shock transmission values in G's with smaller values of Cushion Weight to Product Weight Ratio will be the more environmentally sensitive solutions.

Table 7 : Required Cushion Volume to Product Weight Ratio (cu.in./lb.) for a given level of protection (G) in average 2-5 impacts from 24 inches drop height

G	20	30	40	50	60	70	80	90	100	110	120	130	140	150
Ethafoam 220			2.33	1.43	1.1	0.87								
Arpak 4322				1.33	1.12									
Arsan 600				1.69	1.21									
Arcel 310				1.82	1.33	1.15	1.05	0.94						
Instaflex		3.23	1.67											
Pelaspan Mold-a-pac				1.98										
Polycap PD 230				7.09	5.48	4.88								
Popcorn											2.82	2.29	2.11	1.87
Quadrapak					4.44	3.03								
Honeycomb 7/16" cell									1.40	1.26	1.18	1.11	1.06	1.04

Table 8 : Required Cushion Volume to Product Weight Ratio (cu.in./lb.) for a given level of protection (G) in average 2-5 impacts from 30 inches drop height

G	20	30	40	50	60	70	80	90	100	110	120	130	140	150
Ethafoam 220				2.30	1.67	1.33	1.08	0.95	0.83					
Arpak 4322				2.99	1.79	1.52	1.33							
Arsan 600						1.65	1.38							
Arcel 310					1.48	1.21	1.11	1.03	0.95					
Instaflex			2.50	2.17	1.82									
Pelaspan Mold-a-pac					2.50	1.72								
Polycap PD 230						20.00	13.33	11.43	10.26					
Popcorn													3.23	2.67
Quadrapak						8.00	4.88	3.70						
Honeycomb 7/16" cell	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

* N/A means there is no data for that material for 2-5 impacts from this drop height

Table 9 : Required Cushion Volume to Product Weight Ratio (cu.in./lb.) for a given level of protection (G) in average 2-5 impacts from 36 inches drop height

G	20	30	40	50	60	70	80	90	100	110	120	130	140	150
Ethafoam 220					2.90	2.17	1.67	1.43	1.24					
Arpak 4322						2.33	1.85	1.67						
Arsan 600							2.22	1.74						
Arcel 310						2.22	1.67	1.52	1.34					
Instaflex				3.08	2.33	2.00								
Pelaspan Mold-a-pac					5.26	2.86	2.17							
Polycap PD 230	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Popcorn											3.64	3.23	2.99	2.78
Quadrapak						6.67	4.00	3.28						
Honeycomb 7/16" cell	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

* N/A means there is no data for that material for 2-5 impacts from this drop height

The " Environmental Cushion Curves " are a plot of the percent Cushion Weight to Product Weight Ratio for a given level of protection. These plots describe the performance of different cushioning materials for a given thickness. Materials that show good shock attenuation have lower ordinate values. Materials that will be used in smaller quantities for a given level of protection will have lower abscissa values. The ideal cushioning material that will address both protection and environmental concerns will be the closest to the origin. Figure 3, 4, and 5 are the Environmental Cushion Curves comparing the different materials based on Percent Cushion Weight to Product Weight Ratio for drop heights of 24, 30, and 36 inches respectively.

Figure 6, 7, and 8 are the Environmental Cushion Curves comparing the different materials based on Cushion Volume to Product Weight Ratio (cu.in./lb.) for drop heights of 24, 30, and 36 inches respectively.

Based on these curves, Arsan 600 and Instaflex show the best performance since they provide maximum protection for the least amount of cushion material used both by weight and

Figure 3 : Comparison of Cushion Weight to Product Weight Ratio (%) vs level of protection, 24 inches drop height, 2 inches thick cushion, average 2-5 impacts

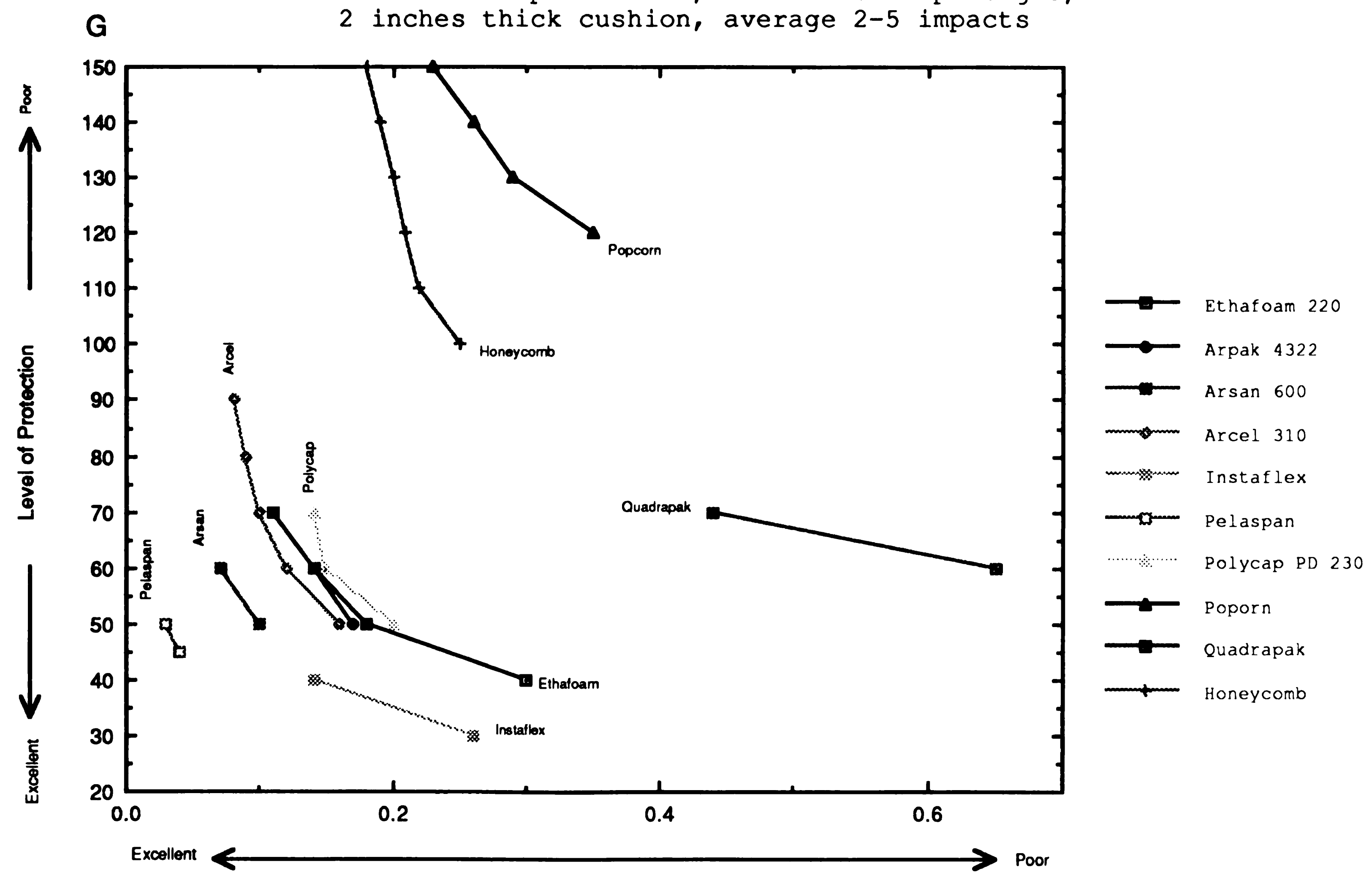


Figure 4 : Comparison of Cushion Weight to Product Weight Ratio (%) vs. Level of Protection, 30 inches drop height, 2 inches thick cushion, average 2-5 impacts

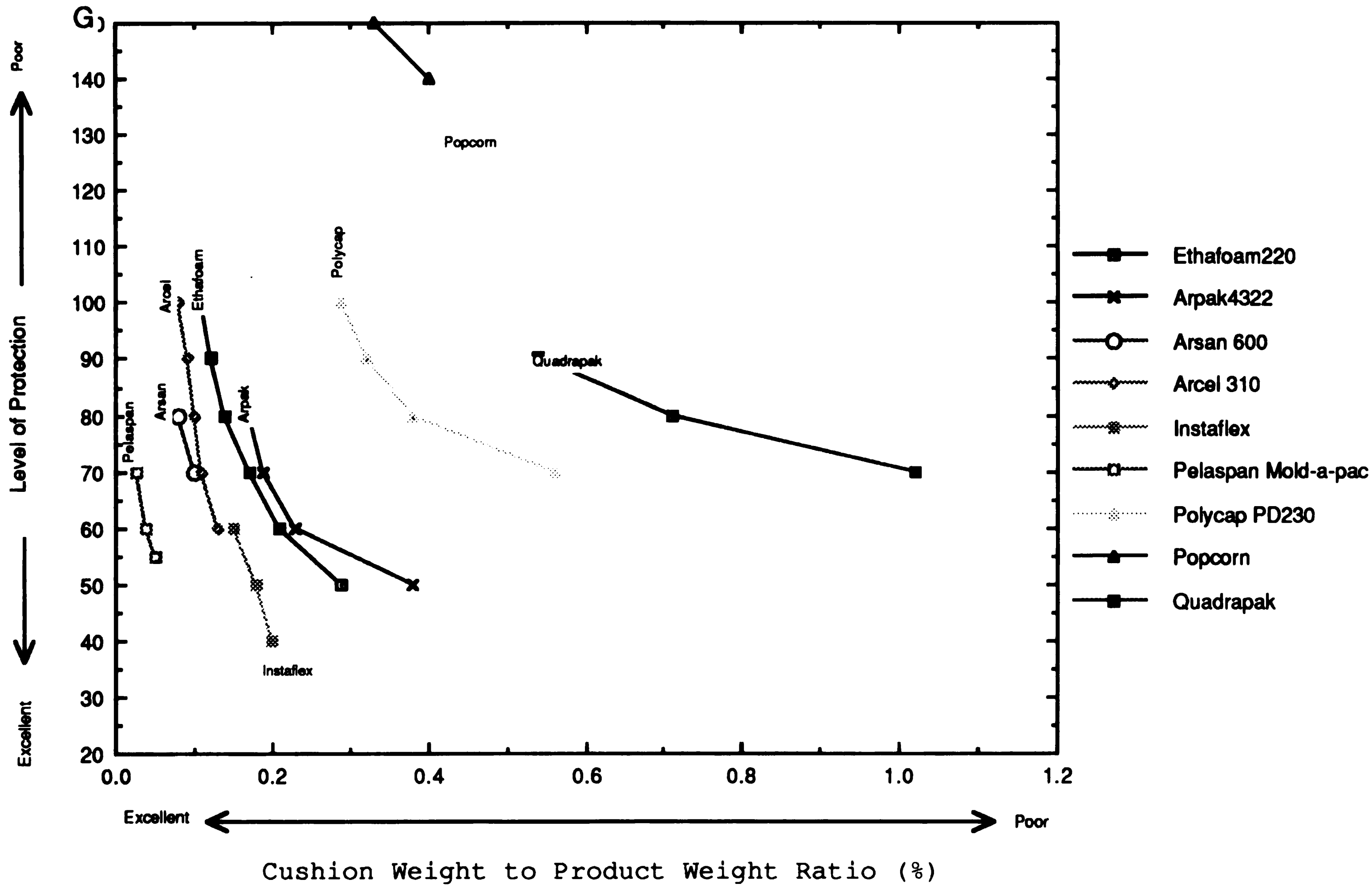


Figure 5 : Comparison of Cushion Weight to Product Weight Ratio (%) vs Level of Protection, 36 inches drop height, 2 inches thick cushion, average 2-5 impacts

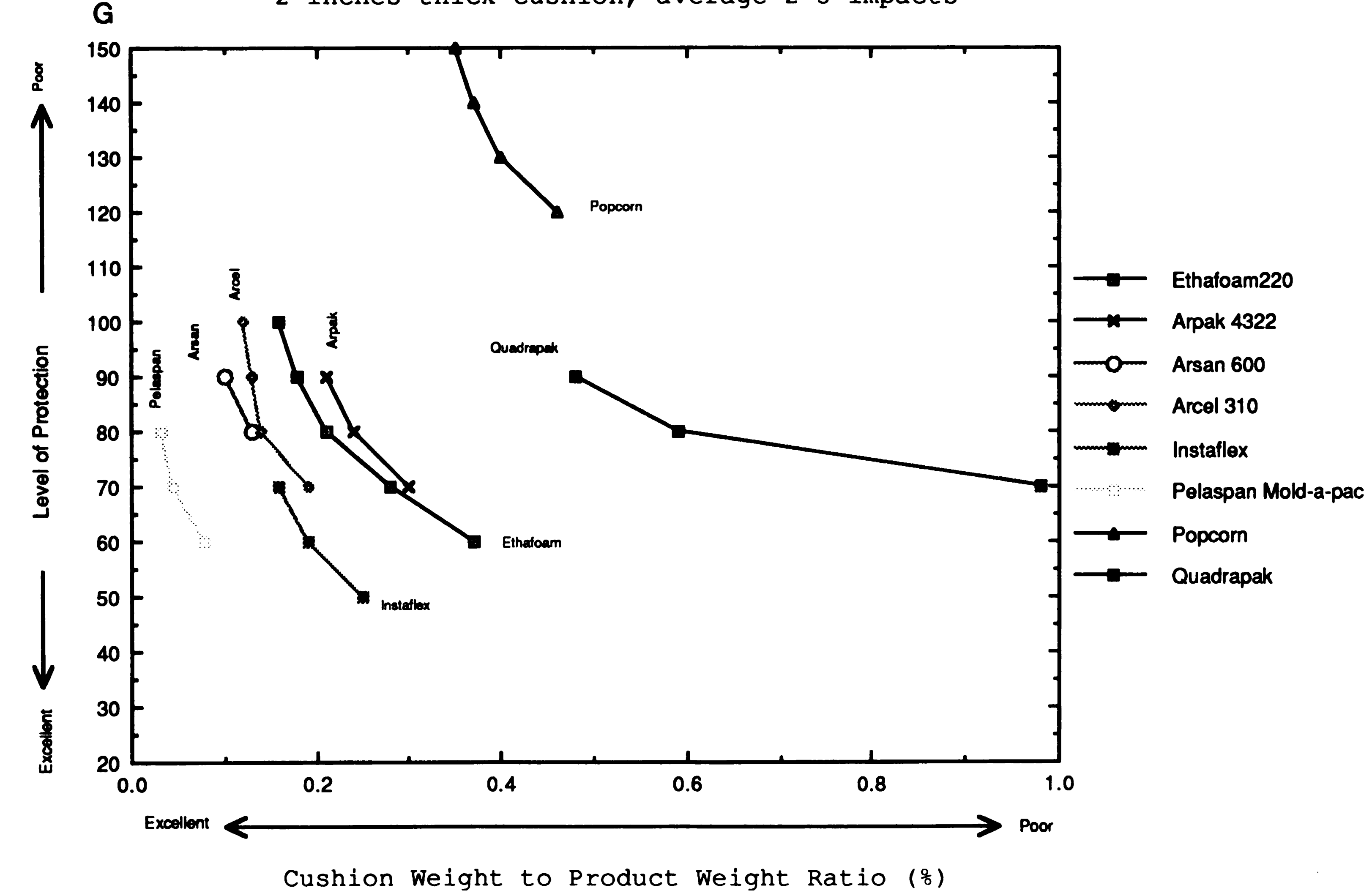


Figure 6 : Comparison of Cushion Volume to Product Weight Ratio vs Level of Protection, 24 inches drop height, 2 inches thick cushion, average 2-5 impacts,

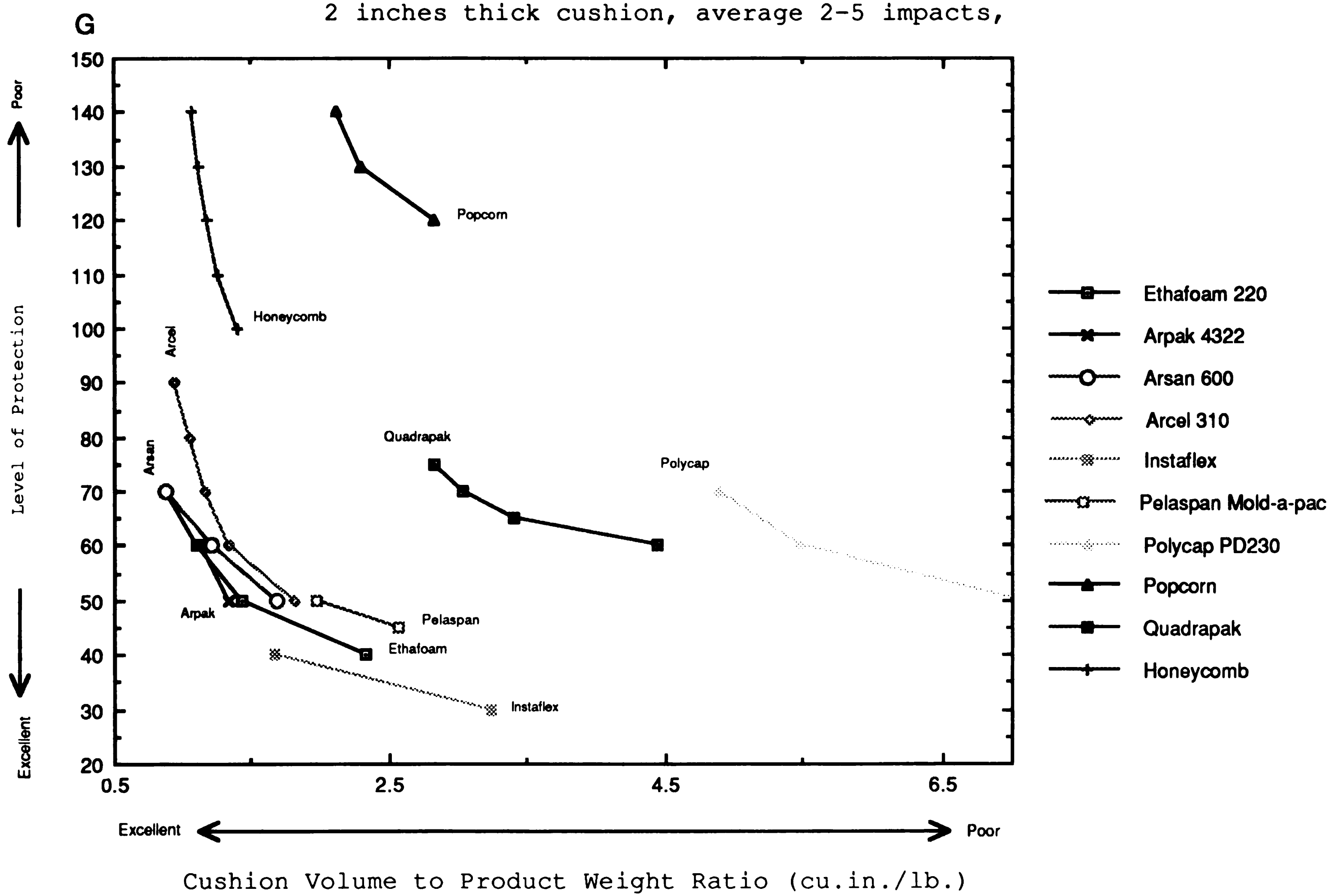


Figure 7 : Comparison of Cushion Volume to Product Weight Ratio (%) vs. Level of Protection, 30 inches drop height, 2 inches thick cushion, average 2-5 impacts

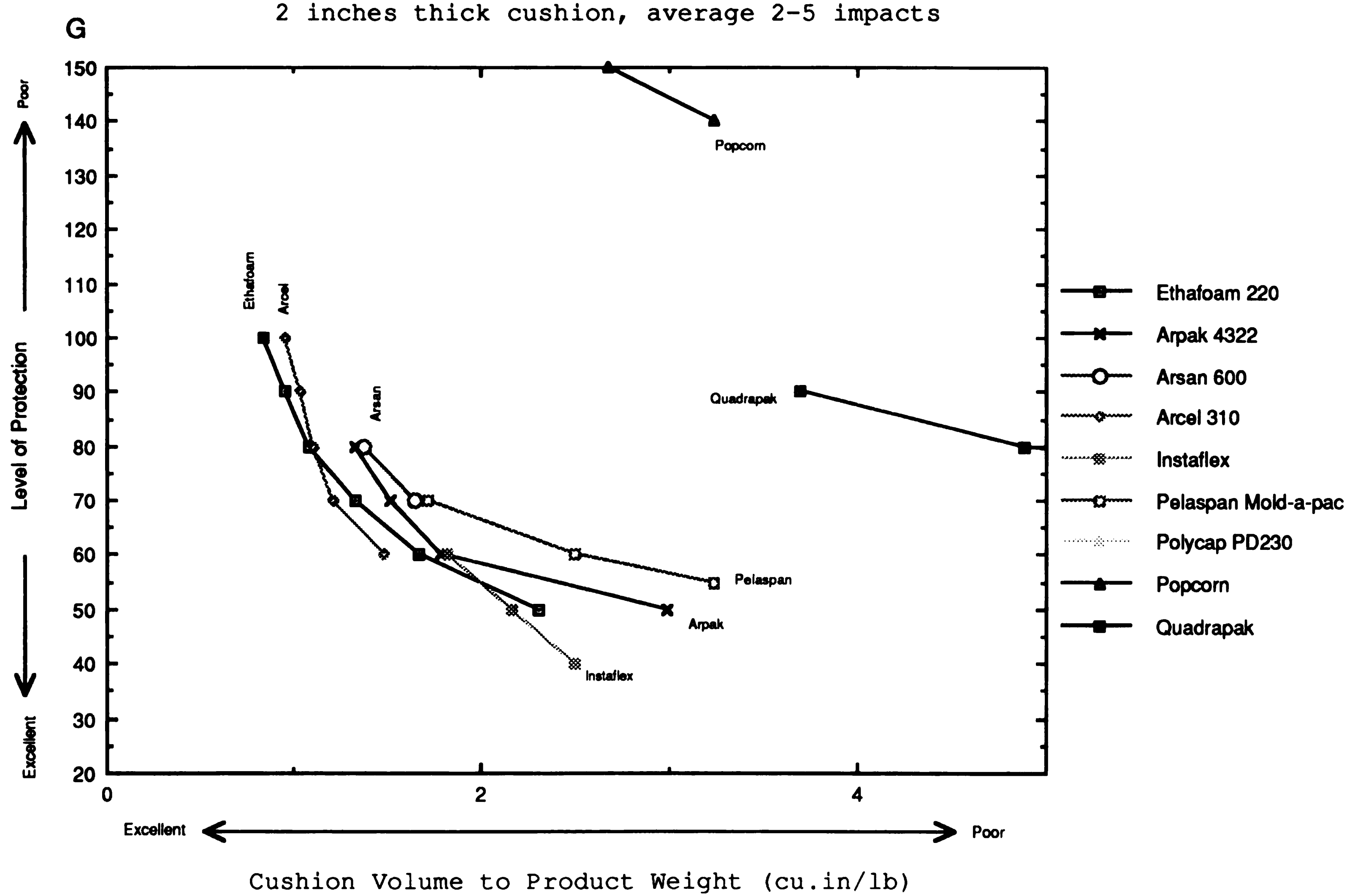
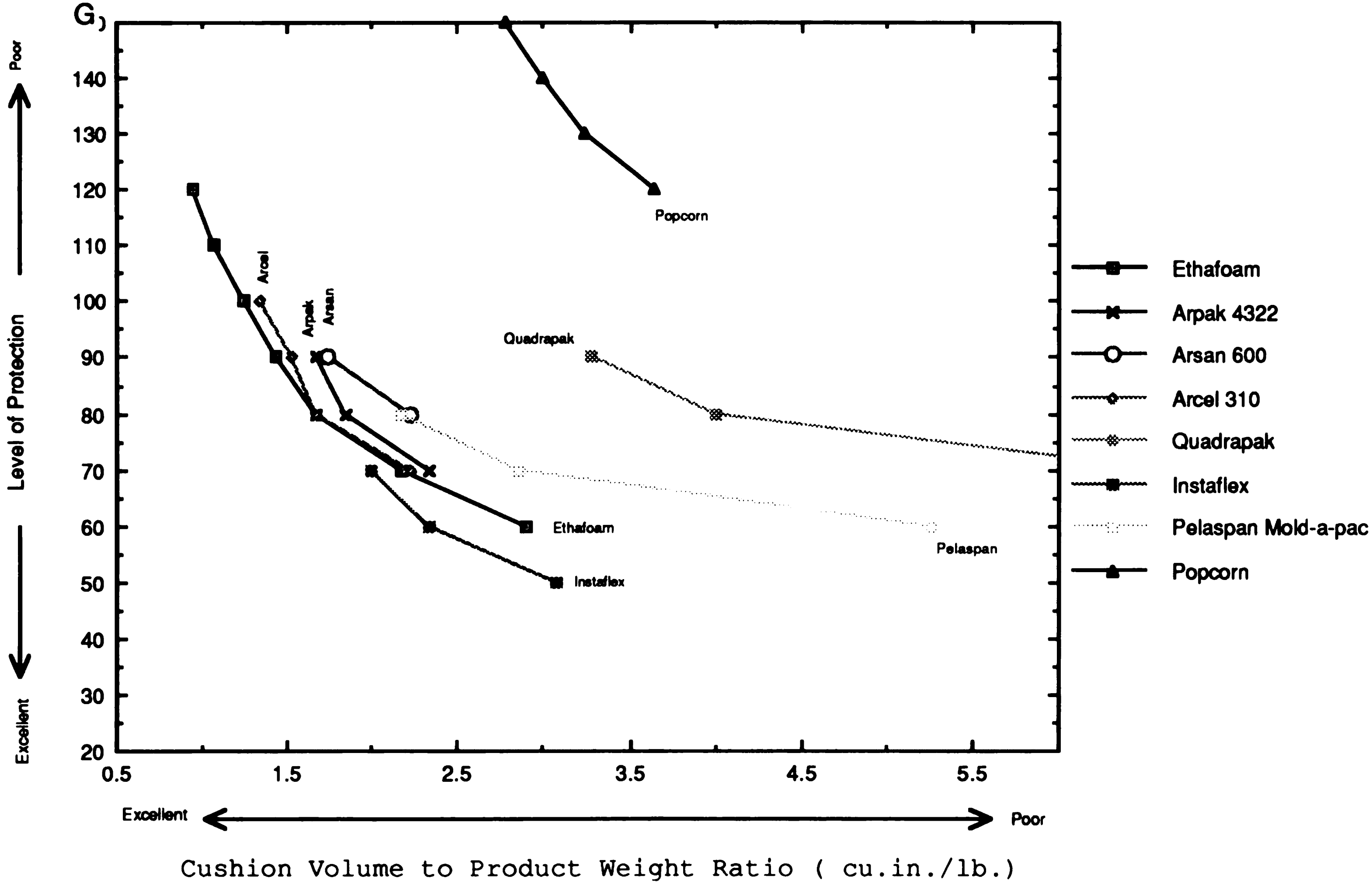


Figure 8 : Comparison of Cushion Volume to Product Weight Ratio vs. Level of Protection, 36 inches drop height, 2 inches thick cushion, average 2-5 impacts



volume. Pelaspan shows very good performance when comparing Percent Weight Ratios but deteriorates when evaluated on the volume basis.

All polymer based cushion materials like Arcel 310, Arpak 4322, Ethafoam 220, Polycap, show good protection capabilities between 40 g's and 100 g's using much lesser material by weight and volume as compared to Popcorn, Honeycomb and Quadrapak.

All materials were evaluated for a cushion thickness of 2 inches. From the cushion curves of Popcorn (Appendix B) it is clear that a 2 inches thick popcorn cushion can barely protect a product for 100 g's for multiple impacts. Based on free fall shock equations we know that the shock transmitted through a cushion is inversely related to the square root of the thickness. Most 2 inch thick polymer cushions evaluated like Arcel 310, Arpak 4322, Ethafoam 220,etc. show protection below 50 g's. It is clear that for popcorn to provide protection levels of 50 g's, we would need

$$= [\ 100 \div 50\ ]^2 \times 2 = 8 \text{ inch thick cushion.}$$

A popcorn cushion would therefore occupy four times the thickness of these polymer cushions. This not only results in poor performance in terms of source reduction but results in a poor economic solution based on larger size boxes, poor loading efficiencies in trailers, increased transport costs, increased disposal concerns. A similar trend is seen with Honeycomb and Quadrapak.

However, Popcorn, Honeycomb, and Quadrapak show much better protection performance for the single impacts as seen in Appendix B.

CHAPTER 4

CONCLUSION

For multiple impact, Honeycomb, Popcorn, and Quadrapak show poor environmental performance by using more weight and more volume than the polymer cushions when compared at moderate levels of protection (40-85 g's). Figure 3 through 8 are means of comparing the environmental performance of each cushions. If the fragility and expected drop height were known, the Cushion Weight to Product Weight Ratio and Cushion Volume to Product Ratio can be determined. For example, a given product of 10 pounds with a fragility of 60 g's and 24 inches expected drop height, using Figure 3, Arsan 600, Arcel 310, Ethafoam 220 and Arpak 4322 provide the lightest weight of cushion respectively. Popcorn and Honeycomb barely protect at 100 g's. Quadrapak is the only " environmentally conscious " cushion that provides protection but the weight is almost 3 to 4 times more than those polymer cushions indicated above. Similarly, from

Figure 6, Quadrapak needs 3 to 4 times larger volume than those polymer cushions.

Popcorn and Honeycomb are interesting alternatives only for rugged products which need the cushion as a void filler.

Specifically this study concludes the following :

1 Biodegradable material like Popcorn, Honeycomb, and Quadrapak demonstrate shock isolation properties for single impact. However, they show poor protection properties for multiple impacts.

2 Expanded polyethylene based cushions show the best performance for protection and the least amount of materials used.

3 Biodegradable cushion alternatives evaluated show poor environmental performance, since as much as three to four times material is required as compared to polymer cushions for a given level of protection.

APPENDICES

APPENDIX A

Table A 1 : Shock Transmission Data For Honeycomb, with 7/16" cell size and 2 inches thick

Static Stress (psi)	Impact number	24"drop ht. G	30"drop ht. G	36"drop ht. G
0.3	1	200.0	-	-
0.3	2	200.0	-	-
0.3	3	200.0	-	-
0.3	4	200.0	-	-
0.3	5	200.0	-	-
0.6	1	150.0	-	-
0.6	2	140.0	-	-
0.6	3	135.0	-	-
0.6	4	135.0	-	-
0.6	5	135.0	-	-
0.9	1	110.0	-	-
0.9	2	90.0	-	-
0.9	3	95.0	-	-
0.9	4	95.0	-	-
0.9	5	95.0	-	-
1.2	1	75.0	-	-
1.2	2	70.0	-	-
1.2	3	62.0	-	-
1.2	4	120.0	-	-
1.2	5	190.0	-	-
1.5	1	70.0	-	-
1.5	2	58.0	-	-
1.5	3	60.0	-	-
1.5	4	100.0	-	-
1.5	5	200.0	-	-
1.8	1	50.0	-	-
1.8	2	50.0	-	-
1.8	3	90.0	-	-
1.8	4	160.0	-	-
1.8	5	200.0	-	-

Table A 2 : Shock Transmission Data For Popcorn, 2 inches thick

Static Stress (psi)	Impact number	24"drop ht. G	30"drop ht. G	36"drop ht. G
0.1	1	84.4	99.0	112.5
	2	112.5	125.4	148.8
	3	131.2	151.2	181.6
	4	140.6	171.2	209.8
	5	147.7	181.1	226.3
0.32	1	66.2	65.6	85.0
	2	112.5	116.6	141.8
	3	132.4	128.9	157.6
	4	144.1	133.6	171.1
	5	154.1	139.5	177.0
0.51	1	50.4	55.1	63.3
	2	77.9	84.4	107.2
	3	94.9	100.8	124.8
	4	103.1	113.7	145.3
	5	109.6	118.9	162.3
0.77	1	46.3	49.2	45.7
	2	75.0	83.8	79.7
	3	100.8	99.6	101.4
	4	127.4	124.1	117.2
	5	141.3	131.7	128.3
0.94	1	52.7	60.9	90.0
	2	100.2	124.8	213.3
	3	140.7	187.9	318.7
	4	189.8	237.9	-
	5	219.1	272.5	-
1.3	1	41.0	65.6	-
	2	100.0	155.1	-
	3	147.1	233.2	-
	4	191.6	305.9	-
	5	217.5	347.7	-
1.66	1	48.9	63.9	-
	2	123.0	159.3	-
	3	207.4	249.0	-
	4	276.6	333.9	-
	5	336.3	400.0	-

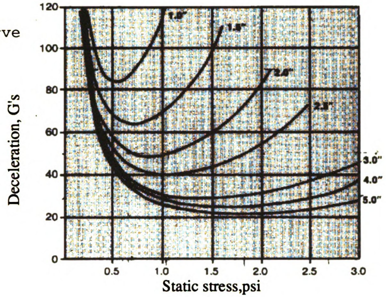
Table A 3 : Shock Transmission Data For Quadrapak, 2 inches thick

Static Stress (psi)	Impact number	24"drop ht.	30"drop ht.	36"drop ht.
		G	G	G
0.1	1	58.8	46.9	50.4
	2	61.8	55.4	70.9
	3	64.1	59.0	80.5
	4	65.3	63.4	85.6
	5	70.9	65.8	89.1
0.266	1	37.0	47.8	44.1
	2	49.0	62.6	57.2
	3	56.1	71.2	66.8
	4	62.0	76.2	74.8
	5	64.3	80.7	79.4
0.344	1	34.6	47.8	42.5
	2	46.6	61.4	61.3
	3	57.4	73.9	75.4
	4	60.8	82.3	82.6
	5	67.2	83.9	91.7
0.5	1	37.9	49.3	45.5
	2	65.5	67.0	60.6
	3	68.7	83.2	72.4
	4	79.6	93.1	78.5
	5	78.2	118.4	92.9
0.85	1	34.9	54.4	54.1
	2	54.2	94.7	85.5
	3	66.7	102.4	108.7
	4	80.8	104.8	128.4
	5	100.5	153.1	158.4

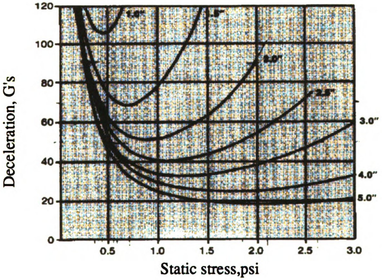
APPENDIX B

Figure B1 :
Arcel 310's Cushion Curve
Density = 1.5 PCF
average 2-5 impacts

24" drop height



30" drop height



36" drop height

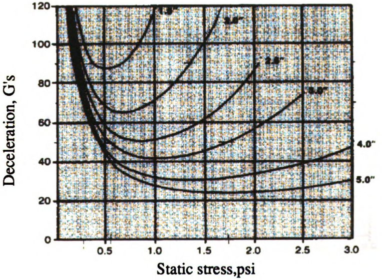
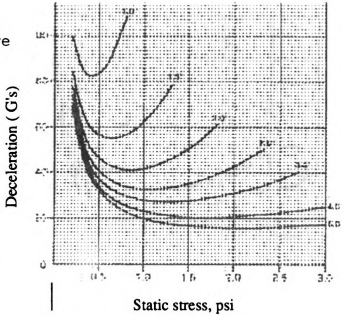
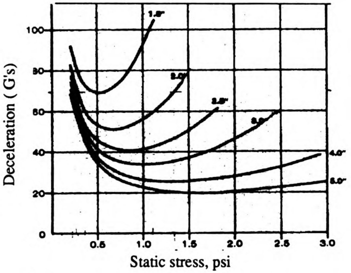


Figure B2 :
Arpak 4322's Cushion Curve
Density = 2.2 PCF
average 2-5 impacts

24" drop height



30" drop height



36" drop height

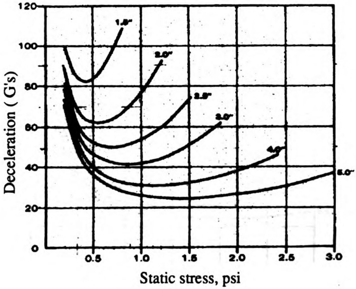
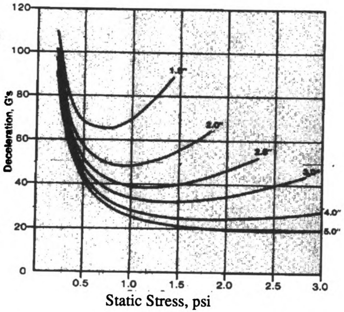
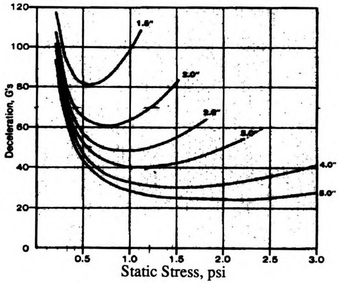


Figure B3 :
Arsan 600 's Cushion Curve
Density = 1.0 PCF
average 2 - 5 impacts

24" drop height



30" drop height



36" drop height

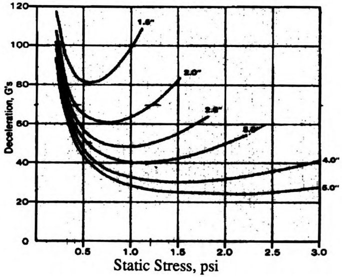
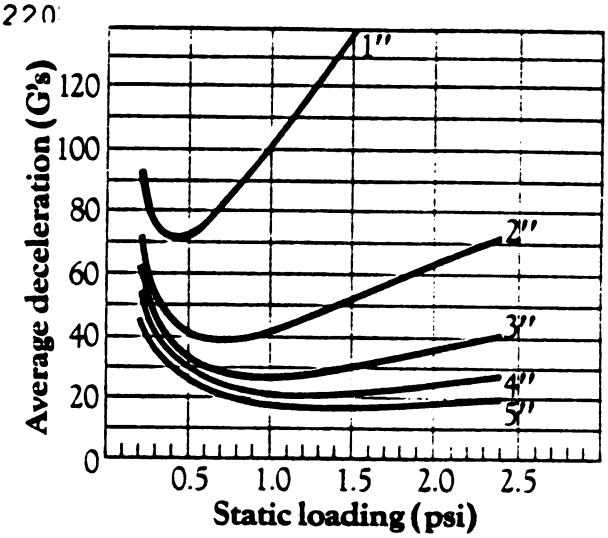
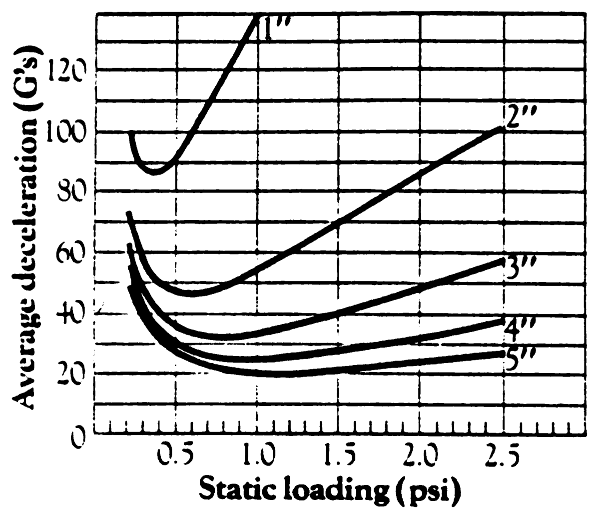


Figure B4 :
Cushion Curve For Ethafoam 220
Density = 2.2 PCF
average 2-5 impacts

24" drop height



30" drop height



36" drop height

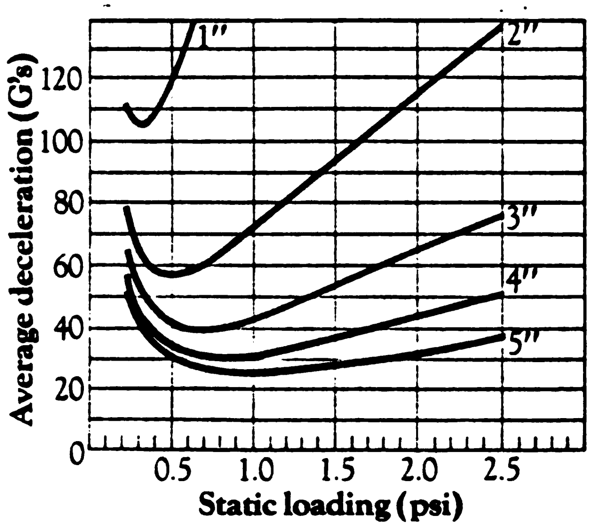
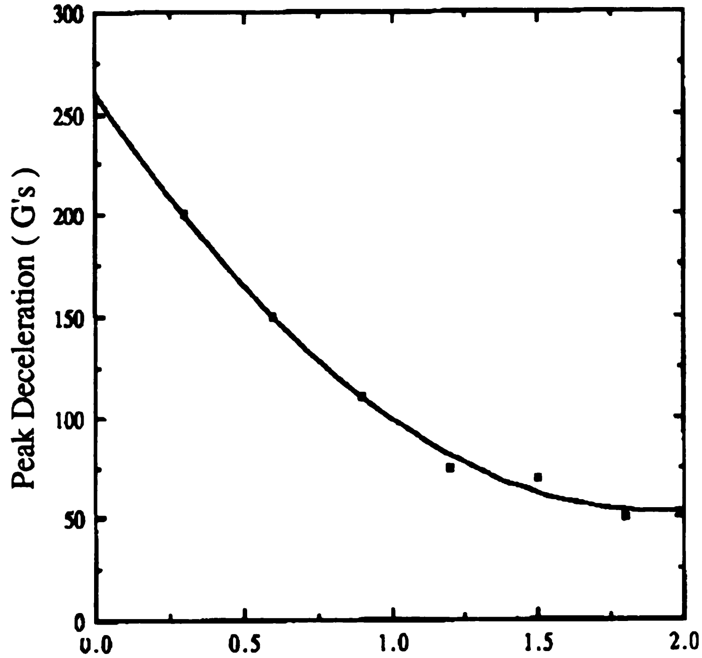


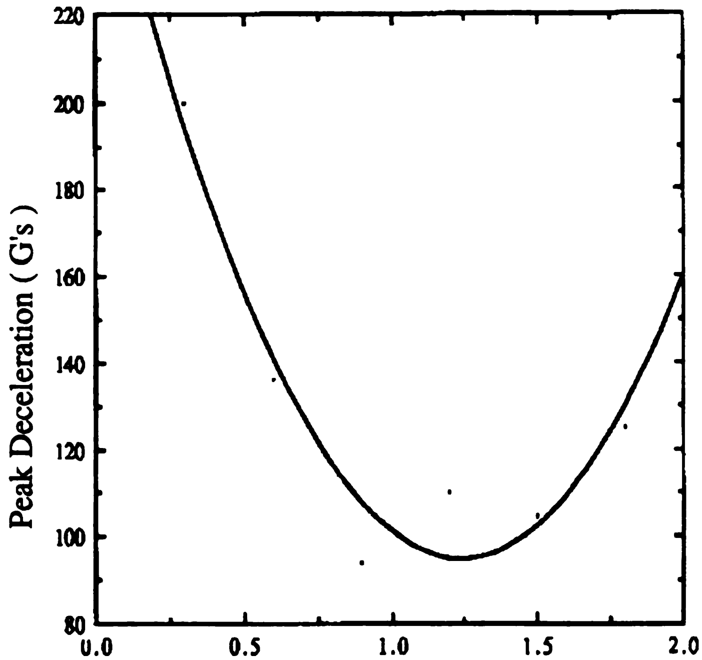
Figure B5 :
Cushion Curve For Honeycomb
Cell size = 7/16"
2' thick

24" drop height
First Impact



Static Stress (psi)

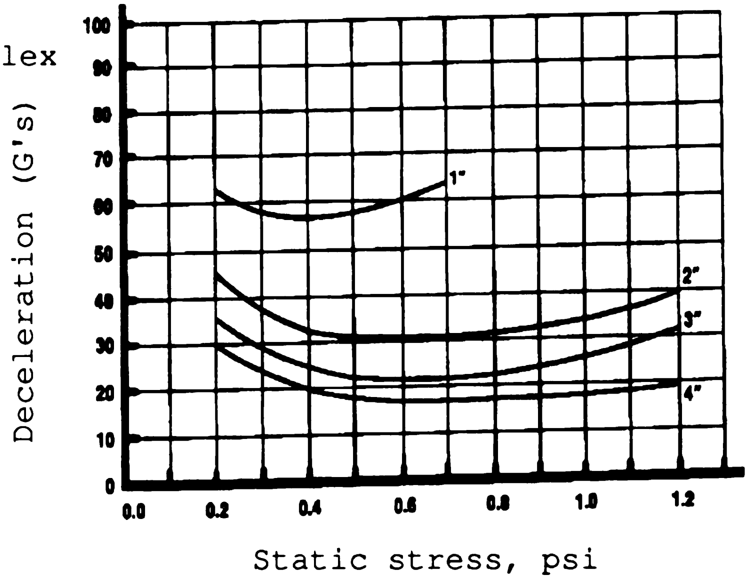
24" drop height
average 2-5 Impacts



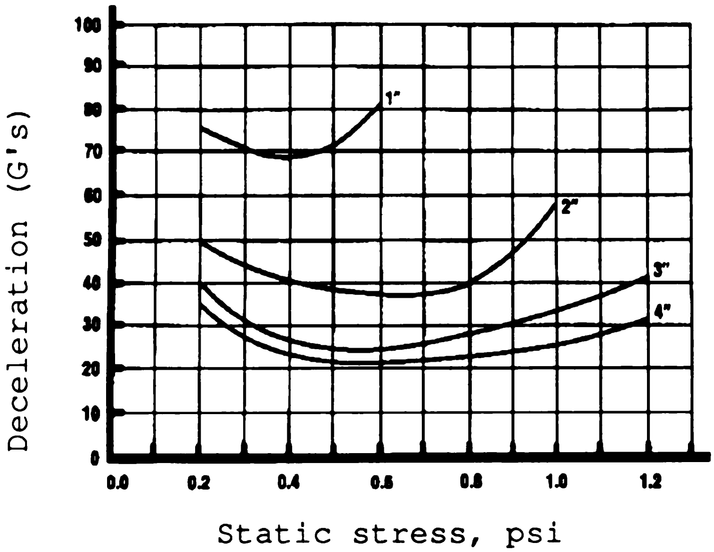
Static Stress (psi)

Figure B6 :
Cushion Curve For Instaflex
average 2 - 5 impacts

24" drop height



30" drop height



36" drop height

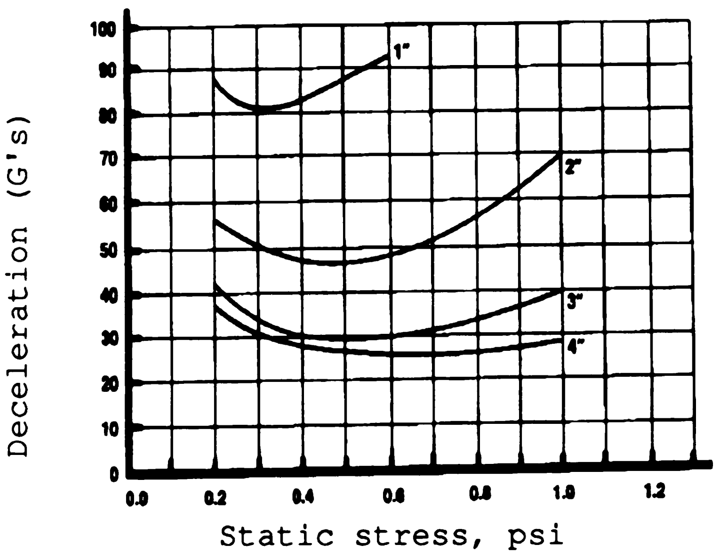
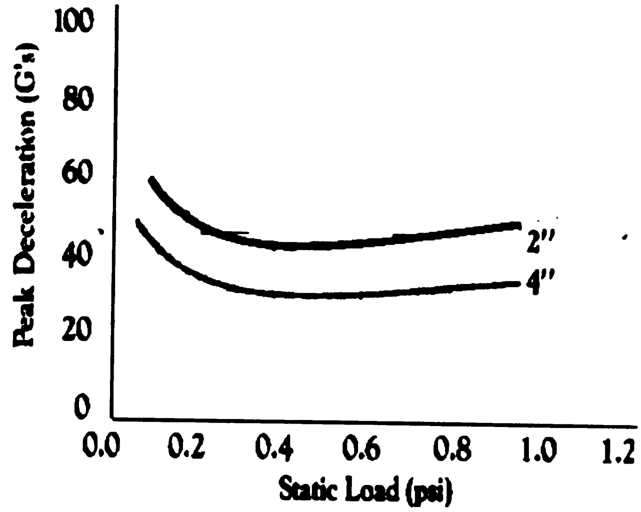
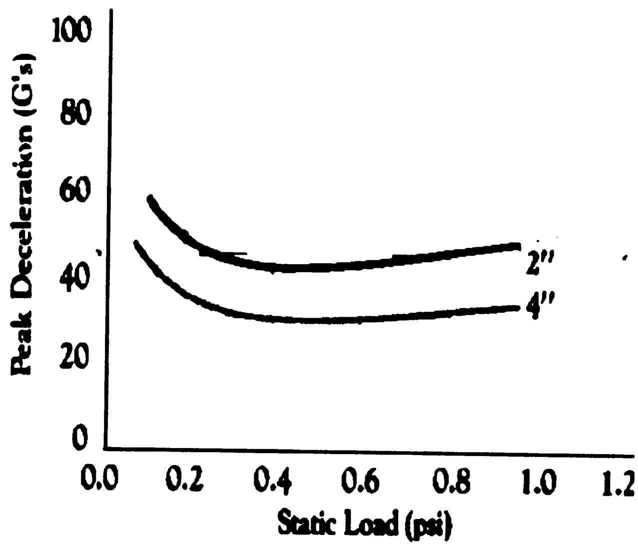


Figure B7 :
Cushion Curve For
Pelaspan Mold-a-pac
average 2-5 impact

24" drop height



30" drop height



36" drop height

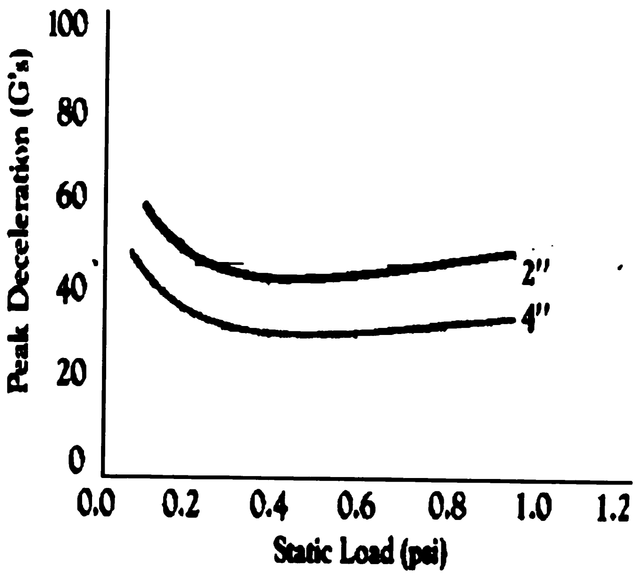
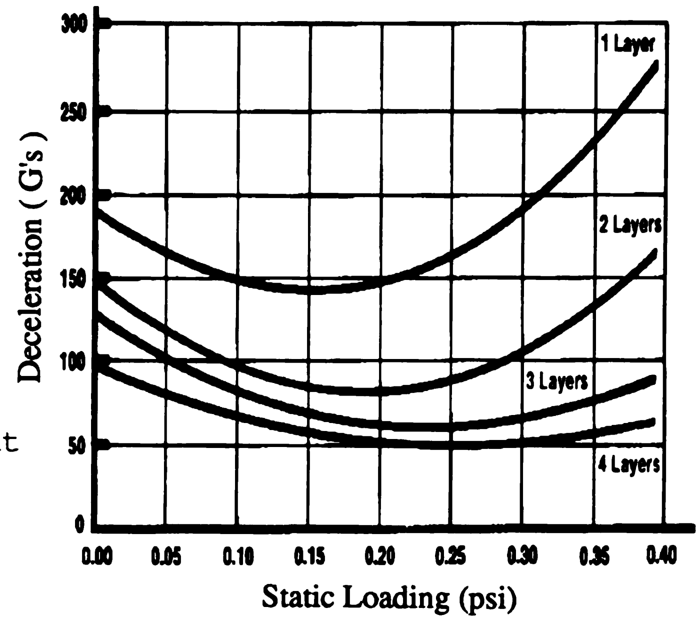


Figure B8 :
Cushion Curve For
Polycap Plus PD230
average 2 - 5 impacts

24" drop height



30" drop height

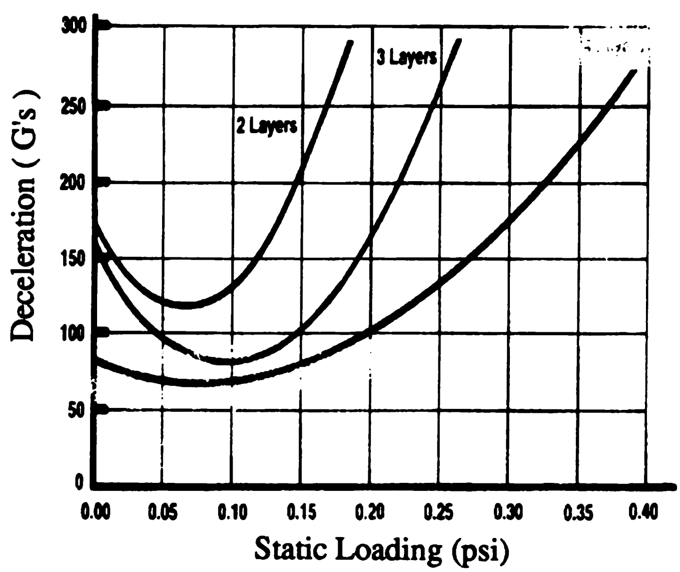
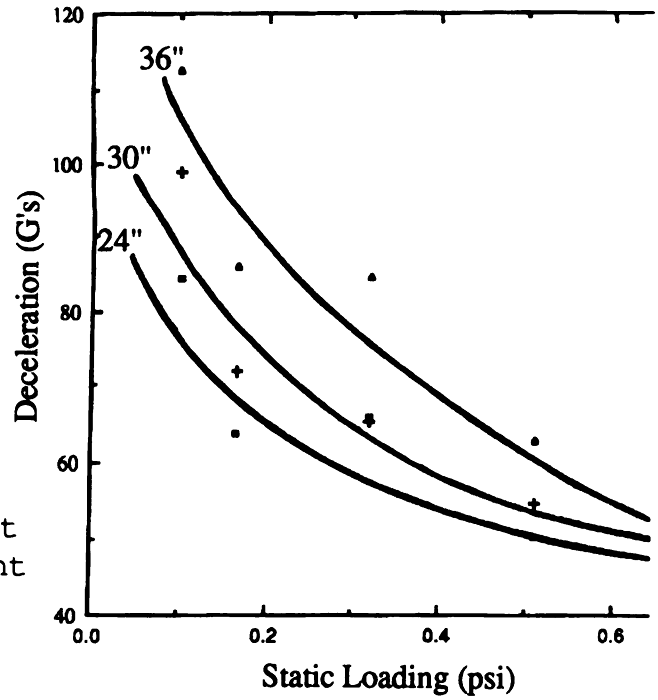


Figure B9 :
Popcorn's Cushion Curve
2" thick

First Impact
24", 30" and 36" drop height



average 2-5 Impacts
24", 30" and 36" drop height

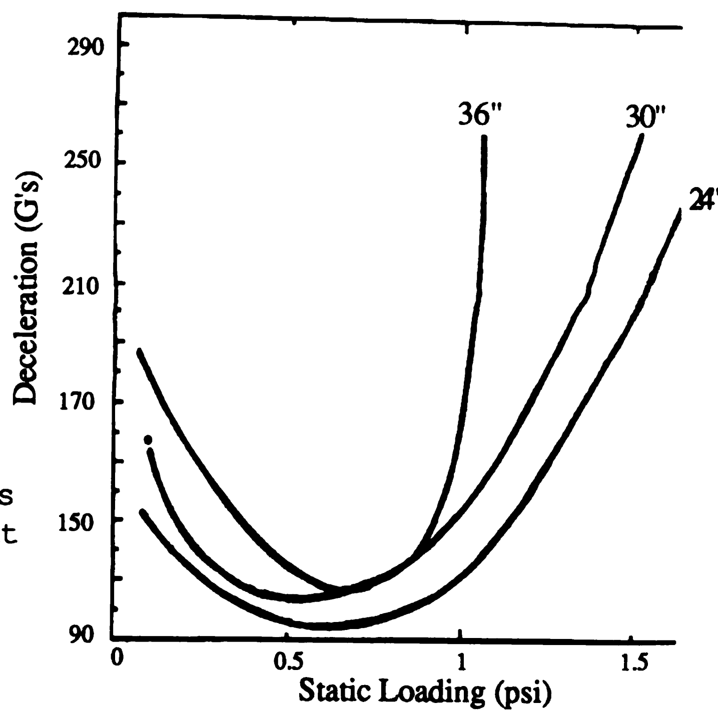
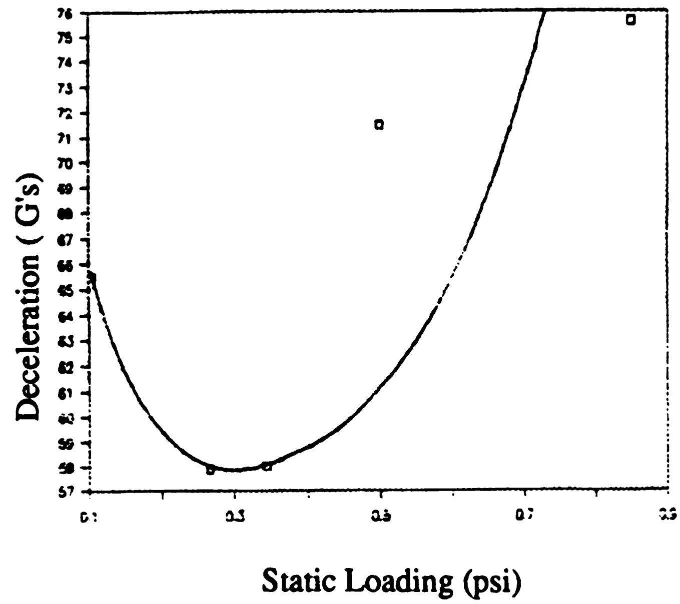
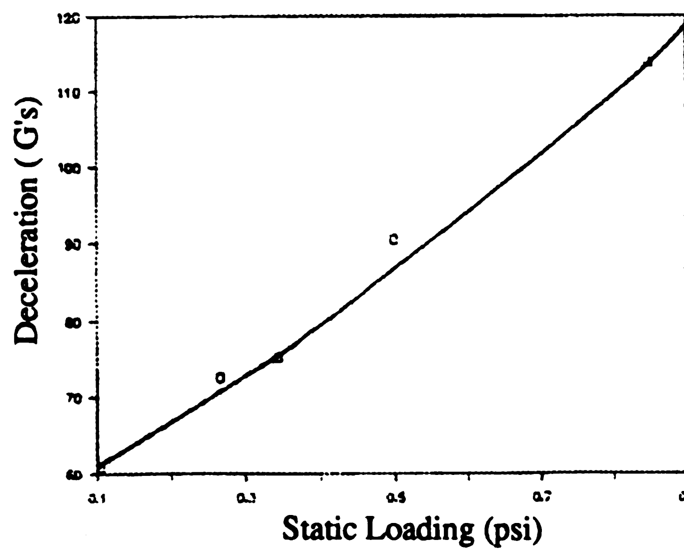


Figure B10 :
Quadrapak's Cushion Curve
2 -5 impacts
2" thick

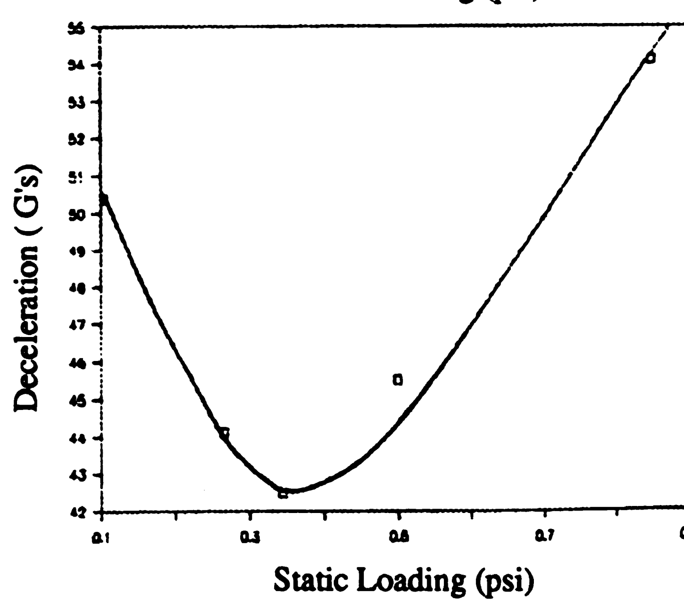
24" drop height



30" drop height



36" drop height



APPENDIX C

Table C 1 : Arcel 310's Weight and Volume to Product Weight Ratio

Impact	Density (pcf.)	Drop ht. (in.)	Thickness (in.)	G's (g)	S.L. min (psi)	S.L. max (psi)	% Wt.min.	% Wt.max.	Min. Vol (cu.in./lb.)	Max. Vol. (cu.in./lb.)
2-5 impacts	1.5	24	2	40	N/A	N/A	N/A	N/A	N/A	N/A
	1.5	24	2	50	0.70	1.10	0.16	0.25	1.82	2.86
	1.5	24	2	60	0.45	1.50	0.12	0.39	1.33	4.44
	1.5	24	2	70	0.49	1.74	0.10	0.35	1.15	4.08
	1.5	24	2	80	0.35	1.90	0.09	0.50	1.05	5.71
	1.5	24	2	90	0.26	2.12	0.08	0.67	0.94	7.69
	1.5	24	3	30	1.05	1.80	0.14	0.25	1.67	2.86
	1.5	24	3	40	0.65	2.70	0.10	0.40	1.11	4.62
	1.5	24	3	50	0.48	3.20	0.08	0.54	0.94	6.25
	1.5	30	2	60	0.55	1.35	0.13	0.32	1.48	3.64
	1.5	30	2	70	0.43	1.65	0.11	0.40	1.21	4.65
	1.5	30	2	80	0.35	1.80	0.10	0.50	1.11	5.71
	1.5	30	2	90	0.30	1.98	0.09	0.58	1.01	6.67
	1.5	30	3	40	0.70	2.10	0.12	0.37	1.43	4.29
	1.5	30	3	50	0.55	2.63	0.10	0.47	1.14	5.45
	1.5	30	3	60	0.30	3.00	0.09	0.87	1.00	10.00
	1.5	36	2	70	0.50	0.90	0.19	0.35	2.22	4.00
	1.5	36	2	80	0.35	1.20	0.14	0.50	1.67	5.71
	1.5	36	2	90	0.27	1.32	0.13	0.64	1.52	7.41
	1.5	36	2	100	0.22	1.50	0.12	0.79	1.33	9.09
	1.5	36	3	40	N/A	N/A	N/A	N/A	N/A	N/A
	1.5	36	3	50	0.55	1.72	0.15	0.47	1.74	5.45
	1.5	36	3	60	0.40	2.10	0.12	0.65	1.43	7.50

Table C 2 : Arpak 4322's Weight and Volume to Product Weight Ratio

Impact	Density (pcf.)	Drop ht. (in.)	Thickness (in.)	G's (g)	S.L. min (psi)	S.L. max (psi)	% Wt min.	% Wt max.	Min. Vol (cu.in./lb.)	Max. Vol. (cu.in./lb.)
2-5 impacts	2.2	24	2	50	0.40	1.50	0.17	0.64	1.33	5.00
	2.2	24	2	60	0.35	1.78	0.14	0.73	1.12	5.71
	2.2	24	2	70	0.25	N/A	N/A	1.02	N/A	8.00
	2.2	24	2	80	0.20	N/A	N/A	1.27	N/A	10.00
	2.2	24	3	30	0.80	1.90	0.20	0.48	1.58	3.75
	2.2	24	3	40	0.45	2.70	0.14	0.85	1.11	6.67
	2.2	24	3	50	0.38	N/A	N/A	1.01	N/A	7.89
	2.2	24	3	60	0.26	N/A	N/A	1.47	N/A	11.54
	2.2	30	2	50	0.67	0.67	0.38	0.38	2.99	2.99
	2.2	30	2	60	0.35	1.12	0.23	0.73	1.79	5.71
	2.2	30	2	70	0.30	1.32	0.19	0.85	1.52	6.67
	2.2	30	2	80	0.22	1.50	0.17	1.16	1.33	9.09
	2.2	30	3	40	0.49	2.10	0.18	0.78	1.43	6.12
	2.2	30	3	50	0.32	2.52	0.15	1.19	1.19	9.38
	2.2	30	3	60	0.28	N/A	N/A	1.36	N/A	10.71
	2.2	30	3	70	0.22	N/A	N/A	1.74	N/A	13.64
	2.2	36	2	70	0.32	0.86	0.30	0.80	2.33	6.25
	2.2	36	2	80	0.25	1.08	0.24	1.02	1.85	8.00
	2.2	36	2	90	0.20	1.20	0.21	1.27	1.67	10.00
	2.2	36	3	40	N/A	N/A	N/A	N/A	N/A	N/A
	2.2	36	3	50	0.40	1.45	0.26	0.95	2.07	7.50
	2.2	36	3	60	0.30	1.77	0.22	1.27	1.69	10.00

Table C 3 : Arsan 600's Weight and Volume to Product Weight Ratio

Impact	Density (pcf.)	Drop ht. (in.)	Thickness (in.)	G's (g)	S.L. min (psi)	S.L. max (psi)	% Wt.min.	% Wt.max.	Min. Vol (cu.in./lb.)	Max. Vol. (cu.in./lb.)
2-5 impacts	1	24	2	50	0.72	1.18	0.10	0.16	1.69	2.78
	1	24	2	60	0.45	1.65	0.07	0.26	1.21	4.44
	1	24	2	80	0.30	2.30	0.05	0.39	0.87	6.67
	1	24	2	90	0.25	N/A	N/A	0.46	N/A	8.00
	1	24	3	30	N/A	N/A	N/A	N/A	N/A	N/A
	1	24	3	40	0.70	2.50	0.07	0.25	1.20	4.29
	1	24	3	50	0.52	3.15	0.06	0.33	0.95	5.77
	1	24	3	60	0.39	N/A	N/A	0.45	N/A	7.69
	1	24	3	70	0.30	N/A	N/A	0.58	N/A	10.00
	1	30	2	60	N/A	N/A	N/A	N/A	N/A	N/A
	1	30	2	70	0.40	1.21	0.10	0.29	1.65	5.00
	1	30	2	80	0.32	1.45	0.08	0.36	1.38	6.25
	1	30	2	100	0.23	N/A	N/A	0.50	N/A	8.70
	1	30	3	40	1.00	1.20	0.14	0.17	2.50	3.00
	1	30	3	50	0.55	2.00	0.09	0.32	1.50	5.45
	1	30	3	60	0.40	2.40	0.07	0.43	1.25	7.50
	1	30	3	70	0.30	N/A	N/A	0.58	N/A	10.00
	1	30	3	80	0.26	N/A	N/A	0.67	N/A	11.54
	1	30	3	100	0.19	N/A	N/A	0.91	N/A	15.79
	1	36	2	70	N/A	N/A	N/A	N/A	N/A	N/A
	1	36	2	80	0.35	0.90	0.13	0.33	2.22	5.71
	1	36	2	90	0.30	1.15	0.10	0.39	1.74	6.67
	1	36	3	50	0.75	1.15	0.15	0.23	2.61	4.00
	1	36	3	60	0.45	1.70	0.10	0.39	1.76	6.67
	1	36	3	70	0.32	2.00	0.09	0.54	1.50	9.38
	1	36	3	80	0.28	N/A	N/A	0.62	N/A	10.71
	1	36	3	90	0.25	N/A	N/A	0.69	N/A	12.00
	1	36	3	100	0.20	N/A	N/A	0.87	N/A	15.00

Table C 4 : Ethafoam 220's Weight and Volume to Product Weight Ratio

Impact	Density (pcf.)	Drop ht. (in.)	Thickness (in.)	G's (g)	S.L. min (psi)	S.L. max (psi)	% Wt.min.	% Wt. max.	Min. Vol (cu.in./lb.)	Max. Vol. (cu.in./ lb.)
2-5 impacts	2.2	24	2	40	0.55	0.86	0.30	0.46	2.33	3.64
	2.2	24	2	50	0.35	1.40	0.18	0.73	1.43	5.71
	2.2	24	2	60	0.25	1.82	0.14	1.02	1.10	8.00
	2.2	24	2	70	0.21	2.30	0.11	1.21	0.87	9.52
	2.2	30	2	50	0.40	0.87	0.29	0.64	2.30	5.00
	2.2	30	2	60	0.30	1.20	0.21	0.85	1.67	6.67
	2.2	30	2	70	0.23	1.50	0.17	1.11	1.33	8.70
	2.2	30	2	80	0.17	1.85	0.14	1.50	1.08	11.76
	2.2	30	2	90	N/A	2.10	0.12	N/A	0.95	N/A
	2.2	30	2	100	N/A	2.42	0.11	N/A	0.83	N/A
	2.2	36	2	60	0.34	0.69	0.37	0.75	2.90	5.88
	2.2	36	2	70	0.28	0.92	0.28	0.91	2.17	7.14
	2.2	36	2	80	0.21	1.20	0.21	1.21	1.67	9.52
	2.2	36	2	90	0.18	1.40	0.18	1.41	1.43	11.11
	2.2	36	2	100	N/A	1.61	0.16	N/A	1.24	N/A
	2.2	36	2	110	N/A	1.89	0.13	N/A	1.06	N/A
	2.2	36	2	120	N/A	2.11	0.12	N/A	0.95	N/A

Table C 5 : Honeycomb's Weight and Volume to Product Weight Ratio

Impact	Material	Density (pcf.)	Drop ht. (in.)	Thickness (in.)	G's (g)	S.L. min (psi)	S.L. max (psi)	% Wt.min.	%Wt.max.	Min. Vol (cu.in./lb.)	Max. Vol. (cu.in./lb.)
2-5 impacts	7/16"	3.07	24	2	100	1.03	1.43	0.25	0.34	1.40	1.94
		3.07		2	110	0.89	1.59	0.22	0.40	1.26	2.25
		3.07		2	120	0.75	1.70	0.21	0.47	1.18	2.67
		3.07		2	130	0.69	1.80	0.20	0.51	1.11	2.90
		3.07		2	140	0.60	1.88	0.19	0.59	1.06	3.33
		3.07		2	150	0.54	1.93	0.18	0.66	1.04	3.70

Table C 6 : Instaflex's Weight and Volume to Product Weight Ratio

impact	Density (pcf.)	Drop ht. (in.)	Thickness (in.)	G's (g)	S.L. min (psi)	S.L. max (psi)	% Wt.min.	% Wt. max.	Min. Vol (cu.in./ lb.)	Max. Vol. (cu.in./ lb.)
2-5 impacts	1.4	24	2	30	0.59	0.62	0.26	0.27	3.23	3.39
	1.4		2	40	0.27	1.20	0.14	0.60	1.67	7.41
	1.4		2	50	0.17	N/A	N/A	0.95	N/A	11.76
	1.4	30	2	40	0.42	0.80	0.20	0.39	2.50	4.76
	1.4		2	50	0.20	0.92	0.18	0.81	2.17	10.00
	1.4		2	60	N/A	1.10	0.15	N/A	1.82	N/A
	1.4	36	2	50	0.31	0.65	0.25	0.52	3.08	6.45
	1.4		2	60	0.15	0.86	0.19	1.08	2.33	13.33
	1.4		2	70	N/A	1.00	0.16	N/A	2.00	N/A
	1.4	24	3	25	0.4	0.96	0.25	0.61	3.13	7.50
	1.4		3	30	0.29	1.15	0.21	0.84	2.61	10.34
	1.4		3	35	0.20	1.30	0.19	1.22	2.31	15.00
	1.4	30	3	20	0.67	N/A	N/A	0.36	N/A	4.48
	1.4		3	30	0.35	N/A	N/A	0.69	N/A	8.57
	1.4		3	40	0.19	N/A	N/A	1.28	N/A	15.79
	1.4	36	3	30	0.31	0.88	0.28	0.78	3.41	9.68
	1.4		3	40	0.20	1.17	0.21	1.22	2.56	15.00
	1.4		3	50	N/A	N/A	N/A	N/A	N/A	N/A

Table C 7 : Pelaspan Mold-a-pac's Weight and Volume to Product Weight Ratio

Impact	Drop ht. (in.)	Density (pcf.)	Thickness (in.)	G's (g)	S.L. min (psi)	S.L. max (psi)	% Wt.min.	% Wt.max.	Min. Vol (cu.in./lb.)	Max. Vol. (cu.in./ lb.)
First drop	24	0.26	2	30	0.45	N/A	N/A	0.07	N/A	4.44
		0.26	2	40	0.22	N/A	N/A	0.14	N/A	9.09
		0.26	2	50	0.10	N/A	N/A	0.30	N/A	20.00
	30	0.26	2	40	0.40	N/A	N/A	0.08	N/A	5.00
		0.26	2	50	0.26	N/A	N/A	0.12	N/A	7.69
		0.26	2	60	0.18	N/A	N/A	0.17	N/A	11.11
		0.26	2	70	0.11	N/A	N/A	0.27	N/A	18.18
	36	0.26	2	40	0.50	N/A	N/A	0.06	N/A	4.00
		0.26	2	50	0.21	N/A	N/A	0.14	N/A	9.52
		0.26	2	60	0.12	N/A	N/A	0.25	N/A	16.67
		0.26	2	70	0.10	N/A	N/A	0.30	N/A	20.00
2-5 Impacts	24	0.26	2	45	0.28	0.78	0.04	0.11	2.56	7.14
		0.26	2	50	0.19	1.01	0.03	0.16	1.98	10.53
		0.26	2	60	0.11	N/A	N/A	0.27	N/A	18.18
	30	0.26	2	55	0.31	0.62	0.05	0.10	3.23	6.45
		0.26	2	60	0.23	0.8	0.04	0.13	2.50	8.70
		0.26	2	70	0.15	1.16	0.03	0.20	1.72	13.33
		0.26	2	80	0.12	N/A	N/A	0.25	N/A	16.67
	36	0.26	2	60	0.34	0.38	0.08	0.09	5.26	5.88
		0.26	2	70	0.15	0.7	0.04	0.20	2.86	13.33
		0.26	2	80	0.10	0.92	0.03	0.30	2.17	20.00

Table C 8 : Polycap Plus PD230's Weight and Volume to Product Weight Ratio

Impact	Density (pcf.)	Drop ht. (in.)	Thickness (in.)	G's (g)	S.L. min (psi)	S.L. max (psi)	% Wt.min.	% Wt.max.	Min. Vol (cu.in./lb.)	Max. Vol. (cu.in./lb.)
2-5 impacts	0.487	24	1	120	0.05	0.33	0.09	0.63	3.03	22.22
	0.487	24	1	130	0.03	0.34	0.08	1.13	2.92	40.00
	0.487	24	1	140	0.01	0.36	0.08	2.82	2.78	100.00
	0.487	24	1	150	N/A	0.38	0.08	N/A	2.67	N/A
	0.487	24	2	50	0.22	0.28	0.20	0.26	7.09	9.09
	0.487	24	2	60	0.14	0.37	0.15	0.40	5.48	14.29
	0.487	24	2	70	0.09	0.41	0.14	0.63	4.88	22.22
	0.487	24	2	80	0.06	N/A	N/A	1.02	N/A	36.36
	0.487	24	2	90	0.03	N/A	N/A	2.25	N/A	80.00
	0.487	30	1	120	0.06	0.08	0.35	0.51	12.50	18.18
	0.487	30	1	130	0.04	0.10	0.30	0.81	10.53	28.57
	0.487	30	1	140	0.02	0.11	0.26	1.41	9.09	50.00
	0.487	30	1	150	0.02	0.12	0.23	1.88	8.33	66.67
	0.487	30	2	70	0.05	0.10	0.56	1.13	20.00	40.00
	0.487	30	2	80	0.01	0.15	0.38	11.27	13.33	400.00
	0.487	30	2	90	N/A	0.18	0.32	N/A	11.43	N/A
	0.487	30	2	100	N/A	0.20	0.29	N/A	10.26	N/A

Table C 9 : Popcorn's Weight and Volume to Product Weight Ratio

Impact	Material	Density (pcf.)	Drop ht. (in.)	Thickness (in.)	G's (g)	S.L. min (psi)	S.L. max (psi)	% Wt.min.	% Wt.max.	Min. Vol. (cu.in/lb.)	Max Vol. (cu.in/lb.)
First Impact	Popcorn	2.164	24	2	50	0.59	N/A	N/A	0.42	N/A	3.39
		2.164		2	60	0.35	N/A	N/A	0.72	N/A	5.71
		2.164		2	70	0.20	N/A	N/A	1.25	N/A	10.00
		2.164		2	80	0.10	N/A	N/A	2.50	N/A	20.00
		2.164	30	2	60	0.39	N/A	N/A	0.64	N/A	5.13
		2.164		2	70	0.27	N/A	N/A	0.93	N/A	7.41
		2.164		2	80	0.19	N/A	N/A	1.32	N/A	10.53
		2.164		2	90	0.11	N/A	N/A	2.28	N/A	18.18
		2.164		2	100	0.05	N/A	N/A	5.01	N/A	40.00
		2.164	36	2	50	0.70	N/A	N/A	0.36	N/A	2.86
		2.164		2	60	0.57	N/A	N/A	0.44	N/A	3.51
		2.164		2	70	0.43	N/A	N/A	0.58	N/A	4.65
		2.164		2	80	0.32	N/A	N/A	0.78	N/A	6.25
		2.164		2	90	0.22	N/A	N/A	1.14	N/A	9.09
		2.164		2	100	0.14	N/A	N/A	1.79	N/A	14.29
		2.164		2	110	0.01	N/A	N/A	25.05	N/A	200.00
2-5 Impact	popcorn	2.164	24	2	120	0.25	0.71	0.35	1.00	2.82	8.00
		2.164		2	130	0.13	0.88	0.29	2.00	2.29	16.00
		2.164		2	140	N/A	0.95	0.26	N/A	2.11	N/A
		2.164		2	150	N/A	1.07	0.23	N/A	1.87	N/A
		2.164		2	160	N/A	1.20	0.21	N/A	1.67	N/A
		2.164		2	170	N/A	1.25	0.20	N/A	1.60	N/A
		2.164	30	2	140	N/A	0.62	0.40	N/A	3.23	N/A
		2.164		2	150	N/A	0.75	0.33	N/A	2.67	N/A
		2.164		2	160	N/A	0.88	0.28	N/A	2.27	N/A
		2.164		2	170	N/A	0.93	0.27	N/A	2.15	N/A
		2.164	36	2	120	0.39	0.55	0.46	0.64	3.64	5.13
		2.164		2	130	0.31	0.62	0.40	0.81	3.23	6.45
		2.164		2	140	0.26	0.67	0.37	0.96	2.99	7.69
		2.164		2	150	0.22	0.72	0.35	1.14	2.78	9.09
		2.164		2	160	0.20	0.76	0.33	1.25	2.63	10.00
		2.164		2	170	0.17	0.79	0.32	1.47	2.53	11.76

Table C 10 : Quadrapak's Weight and Volume to Product Weight Ratio

Impact	Material	Density (pcf.)	Drop ht. (in.)	Thickness (in.)	G's (g)	S.L. min (psi)	S.L. max (psi)	% Wt.min.	% Wt.max.	Min. Vol (cu.in./lb.)	Max. Vol. (cu.in./lb.)
First	Quadrapak	2.53	24	2	40	0.20	N/A	N/A	1.46	N/A	10.00
		2.53		2	45	0.16	N/A	N/A	1.89	N/A	12.90
		2.53		2	50	0.13	N/A	N/A	2.34	N/A	16.00
		2.53		2	55	0.11	N/A	N/A	2.66	N/A	18.18
		2.53	30	2	50	0.56	N/A	N/A	0.52	N/A	3.57
		2.53		2	55	0.88	N/A	N/A	0.33	N/A	2.29
		2.53	36	2	45	0.23	0.52	0.56	1.27	3.85	8.70
		2.53		2	50	0.11	0.70	0.42	2.66	2.86	18.18
		2.53		2	55	N/A	0.88	0.33	N/A	2.29	N/A
2-5 impacts	Quadrapak	2.53	24	2	60	0.29	0.45	0.65	1.03	4.44	7.02
		2.53		2	65	0.11	0.59	0.50	2.66	3.39	18.18
		2.53		2	70	N/A	0.66	0.44	N/A	3.03	N/A
		2.53		2	75	N/A	0.71	0.41	N/A	2.82	N/A
		2.53	30	2	70	N/A	0.25	1.17	N/A	8.00	N/A
		2.53		2	80	N/A	0.41	0.71	N/A	4.88	N/A
		2.53		2	90	N/A	0.54	0.54	N/A	3.70	N/A
		2.53	36	2	70	0.29	0.30	0.98	1.01	6.67	6.90
		2.53		2	80	0.12	0.50	0.59	2.44	4.00	16.67
		2.53		2	90	N/A	0.61	0.48	N/A	3.28	N/A

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