THESIS

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A COMPARISON OF VARIOUS PACKAGING LOOSE FILL CUSHIONING MATERIALS BASED ON PROTECTIVE PERFORMANCE AND ENVIRONMENTAL CONCERNS

BY

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ABSTRACT

A COMPARISON OF VARIOUS PACKAGING LOOSE FILL CUSHIONING MATERIALS BASED ON PROTECTIVE PERFORMANCE AND ENVIRONMENTAL CONCERNS

By

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This study investigated the cushioning properties of various loose fill packaging materials. The objective of this study was to determine the shock absorbing characteristics of different loose fill packaging cushioning materials that are commercially available. Seven different materials were compared in this study using a 3 inch thick cushion encapsulating a block. The transmitted shock level was presented in the form of conventional cushion curves. Using this information and the density of materials, "Environmental Cushion Curves" were developed to compare the various materials. These comparisons were made on the basis of the level of protection in G's versus the ratio of required cushion weight or cushion volume to the product weight. The results of the comparisons showed that starch based loose fill materials (Naturpack and Eco-Foam) and Fiberflow showed the best protective performance for the volume of material used and the 100% recycled EPS showed the best performance in terms of percent weight utilization. Other materials like popcorn and wood shavings showed poor material utilization. Corrugated loose fill showed the least amount of settling due to vibration.

This thesis is dedicated to my beloved parents,
Dr. Athorn - Mrs. Pornrattana Chonhenchob
for the love and support they have always provided

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1.0 INTRODUCTION

It has been over 20 years since the first Earth Day international conference was held in 1970. The concern for the steady decline of the natural resources and problems associated with a safe ecosystem have steadily increased. The concern has been greatly influenced by various environmental groups for social, political, and economical reasons. However, the lack of a unified approach has caused confusion and frustration and the overall mandate needs to be seriously considered. Thus a unified, holistic, and interrelated dedication is ultimately required to preserve our planet's environment.

There are several reasons for this lack of coherent plan leading to confusion and frustration to both industry and the consumer sectors. These include the inconsistency in environmental legislation and also contradictions at the consumer level (Grand Rapids Label Co., 1991).

There are six areas of continuing concern that have been identified and constitute the overall environmental view:

1) Energy Resource Depletion
2) Deforestation
3) Water Pollution
4) Air Pollution

5) Ozone Layer Depletion

6) Solid Waste Overload

These topics relate to consumer's environmental awareness and particularly are applicable to the solid waste problem which is often related to the packaging industry. One of the largest contributor to the nation's municipal solid waste is expendable packaging. The municipal solid waste (MSW) crisis is one of the most visible environmental challenges that affects the packaging industry. This national problem cannot be ignored any longer. The United States Environmental Protection Agency (EPA) has challenged the nation to reduce and recycle at least 25 percent of the MSW by 1995. Municipal solid waste is defined as primarily residential solid waste with some contribution from commercial and institutional source (EPA, 1989).

Approximately 195 million tons of municipal solid waste (MSW) are generated annually in the United States. This results in an average of 4.3 pounds of MSW per person each day (EPA, 1992a). One-third of this is attributed to packaging materials. Solid waste has a great relevance to the packaging industry. The percentage of materials found in the solid waste stream in the United State, by weight, are shown in Figure 1 (EPA, 1992b). The largest contributor to the municipal solid waste is paper and paperboard materials constituting 37.5% of the total. Plastics constitute about 8.3% by weight of total solid waste.

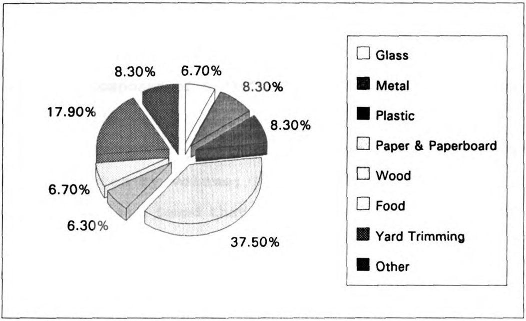


Figure 1: Characterization of Municipal Solid Waste in the United States in 1992 by weight.
Source: U.S. Environmental Protection Agency.

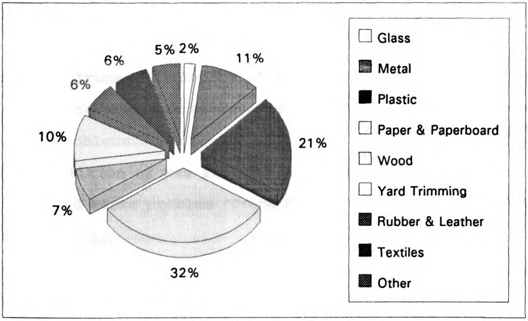


Figure 2: Characterization of Municipal Solid Waste in the United States in 1992 by volume.
Source: U.S. Environmental Protection Agency.

However they are significantly higher by volume due to their low density. Glass, metal and wood materials are 6.7%, 8.3% and 6.3% respectively. The rest of the solid waste stream is composed of 6.7% food, 17.9% yard trimming and 8.3% other materials.

The characterization of Municipal Solid Waste in the United States by volume; 1990 is also shown in Figure 2. Researchers have found that, by far, paper and paperboard make up the largest single portion of the municipal waste stream composition going into landfills, comprising 32% by volume while plastics constitute about 21%. The rest of the solid waste stream is composed of 11% metal; 2% glass; 7% wood; 10% yard trimmings; 6% rubber and leather; 6% textiles and 5% other materials.

1.1 Environmental Impact of Packaging.

There are several ways to successfully manage the solid waste problems. Six common approaches have been identified by the Coalition of New England Governors (CONEG) to alleviate the solid waste problem (Grand Rapids Label Co., 1991). These are:

1) No-Packaging
2) Source Reduction
3) Reuse / Refillability
4) Recycling
5) Incineration

6) Landfill

Each of these six categories is discussed briefly in this chapter with reference to packaging. The no-packaging situation is usually referred to as the acquisition, containment, and transportation of products in bulk. Thus, these products will either have no container or be contained in a package provided by the consumer. These are usually related to transport of such commodities as milk, sugar, and other granular products that are usually directly shipped to manufacturing plants. Similarly, consumers can buy distilled water at retail stores where they can fill it in their own bottles.

Source reduction is also a viable means to address the solid waste problem particularly associated with both packagers and suppliers. It is the most basic approach to waste management. Source reduction refers to minimizing the amount of material used in order to reduce the amount that must be discarded. In addition, it applies to products that present difficulty in separation of materials for recycling. In order to reduce waste at its source, it is recommended by the U.S. Environmental Protection Agency (EPA) to redesign product packaging and emphasize reusability over disposability. Reduction of packaging materials is not only a key to dealing with the solid waste crisis but also a strategic way to achieve cost reduction as recommended by the Plastic-Loose Fill Producers' Council (1993). In addition, it also asks the consumers to be more environmentally responsible. However, minimizing of packaging materials is often not integral to a package's functions (e.g., physical protection, preservation, utility, and communication. Source reduction is one packaging trend that is becoming increasingly popular and possible, however, it could result in severe product problems including damage, contamination, and loss of function such as dispensing, reclosure, etc. It is important to evaluate the new package and product configuration for all the expected hazards before opting for source reduction.

The third approach identified as reuse and refillability are relatively old concepts since they have relied upon practice for a period of time. These are common practices in a lot of the third-world nations, but have had a slow acceptance in the United States. However, there are some specific examples of refilled beverage containers, especially in the beer industry. Another major user of reusable packaging is the automotive industry, which uses a significant portion of plastic and metal containers to ship parts from the various parts plants to automotive assembly plants. Most of these types of reusable packaging require closed-loop distribution between the manufacturer and consumer of the commodity packaged.

Recycling is perhaps the most attractive approach to solid waste stream management, even though it has yet to attain its full potential. It has been reported that the overall recycling rate in the nation was about 17% in 1990 (EPA, 1992a). Recycling efforts are increasing rapidly with the development of newer materials and technology that allows these packaging alternatives to be cost effective and still maintain uniform properties. Landfills and incinerators are usually not perceived to be adequate solutions to the solid waste crisis. Currently, a number of recycling programs have started that separate packaging materials that would have eventually ended up in the solid waste stream. A recent program introduced by Waste Management Inc. separates and collects corrugated fiberboard. In a joint venture agreement with Stone Container they use this material to manufacture a 100% recycled corrugated board at their new facility in Jacksonville, Florida. Some of the key benefits of recycling as recommended by the EPA are:

- Conserve valuable, reusable, and natural resources.
- Save landfill space in overpopulated areas.
- Reduce the waste stream.

The paper industry has remained committed to continue a tradition of recycling since 1690. According to the Paper Institute, only 27% of all paper products are currently being recycled. The U.S. paper industry is expected to reach a recycling goal of 40% by the end of 1995 (Menasha Co., 1993). This will, however, require the participation of manufacturers, suppliers, consumers, and possibly government legislation. The most apparent benefits of paper recycling include energy conservation. The recycled fiber takes less energy to manufacture than virgin fiber. It also conserves tree acreage and landfill space.

Plastic cushioning materials have been identified by environmentalists as primary targets due to their long-term life in landfill sites, and because their volume used in packaging has sharply increased in the last decade. Plastics are the fastest-growing component of the waste stream today. Even though plastics are easily recycled, they have until recently been ignored as a recycling alternative and are often termed as material that never degrades and therefore would be a problem for the natural environment on this planet. The EPA estimated that in 1991 only 0.1% of all plastics were being recycled. Plastic recycling rate has increased from zero over the past decade. By 1995, as much as 25% of all plastic containers may be extracted from the solid waste stream.

Recycling of plastic packaging material is also a highly energy-efficient means of diverting post-consumer waste from landfills. It takes about 1000 BTU's to recycle a pound of plastic. The Plastic Loose Fill Producers' Council has recently implemented a program to make reuse and recycling of plastic loose fill easier for users and consumers. The National Polystyrene Recycling Company expects to soon be recycling 25% of all disposable polystyrene products. In the near future, all loose fill manufacturers will incorporate a recycling plan for their products. In fact, loose fill products made from 100% recycled materials are currently being marketed and were used in this study.

Incineration has always been an attractive waste disposal technique. This means for disposing of matter by high temperature oxidation reaction can retrieve a useful inexpensive energy as a by-product. Incineration is, however, considered to be detrimental for its effect to the atmosphere. Also, incineration results in acid rain if the contents contain chlorides, sulfides, or nitrides, and there are not retrieved before letting the gases escape.

A new high-temperature incinerator has been recently developed. Many of the toxic elements can be removed in this furnace.

Landfilling has been the most conventional and necessary means for disposing of municipal solid waste. More than 70% of the trash ends up in the landfill. The largest component of landfills in the United States is paper, constituting 41% of the total. According to the EPA, the problems associated with landfilling include leachate resulting in groundwater contamination, rising land costs in densely populated areas, and difficulty in siting new landfills due to population concerns. There is a need for alternatives to landfilling since nearly 5,500 landfills are nearing or at capacity and the annual trash disposal cost is approximately $15 billion.

In the last decade manufacturers have come under pressure to reconsider their approach to waste. In Northern Europe, environmental concerns related to the waste problem are even greater. The costs of both landfill space and waste incineration in various countries such as Germany, Denmark, Netherlands, Norway, and Ireland are much higher than in the United States. Lack of space and high cost of incineration has forced the governments to adopt recycling. Northern Europe nations currently require the manufacturer to be responsible for the product throughout its life cycle. Germany has designed a manufacturer-funded system to collect packaging waste for recycling in response to the ecological problem. The German Ordinance for the Avoidance of Packaging Waste was started in 1991 to force manufacturers to consider the waste issues. The ordinance requires manufacturers to re-use packaging or maintain the costs of having it recycled (Ryan, 1993).

In response to the ordinance, a private, nonprofit company called the Duales System Deutschland (DSD), or "dual German system", was formed by more than 600 companies. Manufacturers submit a sample of their packaging to a contractor to determine that materials are recyclable. If the system rejects a package, it must be altered before receiving certification. Once approved, the packaging can be given the 'green dot' which is the DSD's trademark logo for an acceptable package. The system has been relatively successful in collecting packaging, which is an important part of solving the solid waste problem (Ryan, 1993).

The European Community is also planning a community directive. The overall reduction of packaging and elimination of certain types of packaging are expected. European countries are working towards reducing, reusing, and then recycling packaging as the means to address the solid waste problem.

1.2 Environmental Impact of Loose Fill Cushioning Materials

During this time of environmental awareness, many biodegradable cushioning materials have been developed by various manufacturers as packaging alternatives. It has been determined that biodegradable materials including Paper, Honeycomb, and Quadrapak provided shock protection characteristics for a single drop situation but resulted in poor environmental performance compared to polymer cushions (Charnnarong, 1991). The largest use of these loose fill cushioning materials is mail order shipments, which accounts for 65% of all loose fill used in the U.S. The total loose fill market is estimated to have a 6% annual growth until 1995 (Menasha Co., 1993). The domestic market share of loose fill packaging is shown in Table 1.

According to Table 1, expanded polystyrene loose fill (EPS) represented the highest percentage of market share (81%) while paper and starch based materials had a much smaller share (11% and 8%, respectively) of the market in 1992 (Menasha, 1992). These levels are expected to change over the next few years with an increase in the use of paper and starch based materials. Expanded polystyrene loose fill is lighter in weight, lower in cost, and more convenient to use than most alternative materials, and has therefore had the larger market share. However, most loose fill customers are currently looking for a "greener material" which provides similar cushioning performance but can be composted without great difficulty. It is estimated that the use of EPS loose fill will decrease, based on increased environmental consciousness (Larson, 1992).

Some other factors that affected the decline of the use of EPS include consumer awareness of it being linked to CFC's (Chlorofluorocarbons) as part of the manufacturing process. The initial studies that indicated the association of EPS to CFC's led to a major consumer resentment towards expanded polystyrene and its use in packaging and cushioning. This was also evident when McDonald's stopped the use of EPS clamshells for fast food items and replaced it with a multilayer laminate (paper tissue / polyethylene / paper) that has even more problems related to recycling and disposal than does EPS. The major suppliers of EPS loose fill, however, have introduced several environmentally friendly alternatives for their materials, including a photodegradable grade of EPS and a recycled-content grade of this popular loose fill. The National Polystyrene Recycling Company (NPRC) was established in 1989, with assistance and participation from the leading

Table 1 Market Share of Loose Fill Materials in 1992.

Materials	1992			1995		
	Volume MM ft^3	Value ($MM)	%Market Share	Volume MM ft^3	Value ($MM)	%Market Share
EPS	290	145	81	245	110	57
Paper-based	80	20	11	135	41	21
Starch-based	20	15	8	70	42	22
Total	390	$180	100%	450	$193	100%

MM- Million units

polystyrene resin manufacturers. The goal of NPRC is to recycle 250 million pounds of polystyrene annually by 1995. It is expected that 25% of the polystyrene produced in the U.S. each year for packaging and food service applications will be recycled in the near future. Another program was recently started by Dow Chemical Company, a leading manufacturer of this resin on a national level. This recovery program will reduce the amount of polystyrene in the waste stream by increasing the use of post-consumer material through recycling (Dow Chemical Company). The Plastic Loose-Fill Producers' Council, in cooperation with various local and national retailers, introduced a program in July 1991 that provides convenient locations serving as collection centers for plastic loose fill reuse and recycling.

Due to the various concerns that were raised on the use of plastic cushioning materials, a wide range of cushioning materials have been developed in the last five years that are starch or paper based. These, along with the recycled plastic materials, are finding greater consumer acceptance. Many manufacturers have shown significant interest in new cellulose-based cushioning materials (Larson, 1990) like curled wood shavings, popcorn, zigzag shredded kraft paper, honeycomb or Quadrapak (an innovative structural kraft paper) that are more environmentally friendly since they are compostable.

The use of starch-based products is expected to have the greatest increase over the next few years as shown in Table 1. Various starch-based loose fill materials have been developed in the past few years and are currently being marketed. These materials are usually extruded into a cylindrical shaped product. The starch is usually a corn or wheat derivative. The water solubility of these products make it an excellent choice as a biodegradable material. However, most of these types of loose fill products made from natural starches are hygroscopic and therefore sensitive to moisture. When these materials are used in packages that are stored under high temperature and humidity conditions for longer durations, they will absorb moisture and shrink. This can drastically reduce their performance as a cushioning material, and the moisture reaction will usually leave a residue on the product that may be aesthetically unacceptable. Their application is therefore limited to low humidity environments and shorter storage time. Eastman Kodak Co., Miles Laboratories, and Sony Corporation are a few examples of companies that are currently testing the use of these starch-based materials for certain products (Larson, 1992).

Similarly, various paper-based cushioning materials have recently been developed in response to the customer's environmental concerns (McKee, 1990). These types of materials range from shredded kraft paper, crumpled newsprint paper, to various types of multi-layer composites. These cushioning alternatives being paper based are also perceived to be more environmentally friendly since paper can be composted.

Loose fill materials are widely used by direct mail retailers who ship a wide variety of products that vary in size and weight. These direct mail houses such as Sharper Image, L. L. Bean, J. C. Penny, Lands End, etc., use a few standard size shipping boxes for the various products and fill the void space with loose fill cushioning materials to package them.

A loose fill material is necessary for providing protection to the product due to the various elements of the distribution environment, restraining the product in the package, and eliminating any void space. In addition to these basic functions it should be light weight, economical, abrasion resistant, and be environmentally friendly. Distributors, packagers and customers are continuously looking for alternative cushioning that could address these various factors.

The ideal development for loose fill materials therefore requires both product and process development. Several basic criteria that are considered necessary for the development of new loose fill materials (Menasha Co., 1993) are:

- A high volume source of material
- A low cost source of material
- Structural properties for excellent cushioning and void filling

- An environmentally friendly product
- A product which could be protected by patents

The manufacturing process requires equipment that can provide high productivity at low direct and indirect costs, making the product cost competitive to existing materials.

2.3 Study Objectives.

The purpose of this study was to investigate the cushioning performances of various loose fill materials including: recycled EPS; popcorn; corrugated trim; wood shaving; starch-based peanuts, and paper-based peanuts. These materials have been recently developed as environmentally friendly alternatives to EPS loose fill. The objective of this study was to determine the shock absorbing characteristics of the various materials selected, and compare them on the basis of cushioning protection and amount of material required (by weight and volume) to protect products. Although various types of loose fill alternatives continue to be introduced based on increased environmental awareness, the significant function of a cushioning material to provide physical protection remains the most important selection criterion for distributors.

In this study cushion curves for seven different loose fill materials were developed based on the transmitted shock data collected experimentally. The comparison of various loose fill cushions was presented in terms of "Environmental

Cushion Curves" where the transmitted shock level in G's was presented as a function of cushion weight and volume to product weight ratio. This study also investigated the performance of these materials when subjected to lab simulated transport vibration, and compared the settling of these materials due to these dynamic levels. Large amounts of settling of a loose fill material during vibration can result in increased void space that makes the product very susceptible to damage.

Specifically, the objectives of this study were as follows:

1) Determine the shock absorbing characteristics of the various loose fill package cushioning materials.
2) Develop "Cushion Curves" for these various materials that allow various users of these materials to provide optimum protection to the product.
3) To compare the cushioning performance of these various types of loose fill materials in terms of the "Environmental Cushion Curves".
4) To estimate the effect of simulated random vibration on the settling characteristics of these loose fill materials.

2.0 MATERIALS AND METHODS

In this study, seven different types of cushioning materials were investigated. These included compostable and recyclable materials which have been described as "environmentally friendly" or "green" alternatives by various manufacturers and distributors.

2.1 Loose Fill Cushioning Materials.

The compostable materials included paper-based, starch-based, cellulose-based, and popped corn (popcorn) derivatives. Also, a new 100% recycled-content grade of expanded polystyrene (EPS) loose fill was also studied.

The test materials were all preconditioned for at least 24 hours at 72°F and 50% Relative Humidity in accordance with ASTM D 3332.

The specific details of the seven materials used in this study are described in this Chapter. Table 2 lists the various sources of these cushioning materials and their contact information.

2.1.1 100% Recycled EPS loose fill.

This 100% recycled-content grade of the popular loose fill material was recently introduced. Recycled-content EPS

Table 2: Information for the sources of loose fill materials.

Materials	Company	Address	Telephone no.
Corrugated	Menasha	Coloma, MI	616-468-3153
Curl Pak	Meadow River Lumber Co.	416 Sawmill Court Suwanee, GA 30174	404-271-7650
Eco Foam	Associated Bag Co.	400 West Boden St. Milwaukee, WI 53207	414-769-1000
EPS 100% Recycled Content	Free-Flow Packaging Corp.	16850 Canal Street Thornton, IL 60476-1078	708-877-5180
Fiberflow	Fiberflow, Inc.	175 Rochester St. P.O. Box 148 Salamanca,NY 14779	716-933-8703
Naturpack	WELA/BIO SUNN GmbH	Im Gewerbegebiet 4 92256, Hahnbach, Germany	49-9664-1400
Popcorn	Local Store	-	-

is a plastic loose fill that is now available from several suppliers. In some cases a green color additive is used to signify that this is an "environmentally friendly" material as compared to the virgin EPS loose fill. The test material for this study was produced by the Free-Flow Packaging Corporation, Thornton, IL. EPS loose fill is used for efficient product protection and void filling. EPS loose fill is generally a uniform cushion due to a better control in the manufacturing process. It also provides a better product holding being more resilient than other loose fill materials. It is however electrostatic sensitive especially at low humidities, which causes it to cling to products or customers clothes making it messy during unpacking.

EPS loose fill is light in weight with a density of approximately 0.25 - 0.30 lb/ft^3. In addition, it is very cost competitive and also very convenient to use through overhead bags with free flow gravity dispensing. Loose fill EPS also reduces waste since it shows much better cushioning properties and therefore requires less packaging material as a source. Also all EPS today is made without any fully halogenated CFCs (Chlorofluorocarbons) and therefore will not be a cause of ozone depletion in the planet's atmosphere. Figure 3 shows the loose fill cushioning materials used in this study. It was approximately in 1.5 inches in length and 0.75 inches in diameter. The material is shaped like the number 8 (see Figure 3).

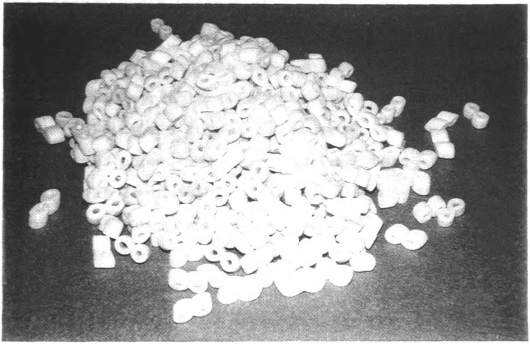


Figure 3: Picture of 100% Recycled EPS (Free-Flow Packaging Corporation).

Figure 4: Picture of Eco Foam (Associated Bag Co.).

2.1.2 Starch-Based Loose Fill - (Eco-Foam$^{(R)}$).

Eco-Foam is a trademark of the National Starch and Chemical Company. It is a made of over 95% corn starch and small amount of synthetic additive. The synthetic additive is a product that is a common ingredient used in adhesives, textiles, and paper coatings. The corn is a special hybrid variety that is grown in the U.S. and the starch is FDA approved for human consumption. The flavor and aroma components of cornstarch used in Eco-Foam are removed by the manufacturing process. This process makes it less susceptible to attacks by rodents and insects. Eco-Foam is approved by the FDA regulations for food contact. Although Eco-Foam is not a food for human consumption, it does not cause any injury, if accidental ingestion occurs. Due to the high starch content of Eco-Foam, it is sensitive to shrinking and/or dissolving under conditions of very high temperature and humidity. It can also become sticky and leave a residue on the packaged product under these severe conditions. Eco-Foam is a hygroscopic product and will absorb water from the surrounding environment.

Eco-Foam is an extruded, cylindrical product that measures approximately 1.75 inches in length and 0.5 inch in diameter and is green in color. It has a packing density of 0.77 lb/ft^3. It is produced in an extruder in a process similar to processing of breakfast cereal and other starch based snack foods. It is expanded by both mechanical action and heat of the extruding process. This method does not require either CFCs or other harmful chemicals to develop the product. Eco-Foam loose fill looks and performs similar to EPS peanuts. Eco-Foam loose fill is also light weight and can be used in existing EPS loose fill systems that allow for gravity dispensing from bulk bags through a discharge tube into packages. A significant advantage of Eco-Foam is the ease of disposal since it dissolves in water. Small amounts of this loose fill material can be disposed by the customer by flushing down the toilet, washing down the sink, or simply leaving out in the rain. It quickly dissolves in water, and decomposes in soil, and does not cause any harm in small quantities. Figure 4 is a picture of this material.

2.1.3 Starch Based Loose Fill (Naturpack$^{(R)}$).

This starch based alternative is a trademark of the Zur Natur Zuruck Company, Germany and is also available in Canada and U.S. Naturpack is made of 100% annual growing plants (starch). It is also compostable, resilient and inert. It provides high protection for the product in terms of cushioning properties. It is hygroscopic and therefore sensitive to high temperature and humidity environments.

Naturpack is produced in an extrusion process similar to Eco-Foam loose fill discussed before. It has a higher packing density than Eco-Foam as shown in Table 3. Naturpack is a reusable product that can be reused several times due to its

Table 3: Density of Various Loose Fill Materials Tested

MATERIALS	DENSITY (lb/ft^3)
Corrugated Loose Fill	2.40
Curl Pak	1.12
Eco Foam	0.77
EPS 100% recycled content	0.29
Fiberflow	1.05
Naturpack	1.94
Popcorn	2.97

higher density, and is also more resilient than Eco-Foam. This loose fill material has a length of approximately 1 inch and a diameter of 0.75 inch. The Naturpack material is yellow in color. It has very similar disposal properties like Eco-Foam since it also dissolves in water. Figure 5 shows a picture of this loose fill material.

2.1.4 Paper-Based Corrugated Loose Fill.

The paper corrugated loose fill tested was a new product developed by Menasha Corporation. This material had the highest packing density (3 lb/ft^3) of all commercially developed loose fill materials studied. The source of this material is the high volume scrap of corrugated side trim that is usually 0.75 to 1.5 inches wide on either side of the corrugated sheet manufacturing process. This loose fill is unique with patents pending on both the product and the process. It is continuously manufactured on the corrugator as the material is slit and is rolled on a die that develops the unique shape. The "M" shape that is made during this process provides resiliency to this material (see Figure 6). The weight of corrugated loose fill is a function of its density. This density can range from 2 lb/ft^3 to 4 lb/ft^3 depending on the basis weight of the paper used for the liners and medium that is used to make the corrugated board. However 200 psi burst strength C-flute corrugated material is the most commonly manufactured material and offers the lowest density

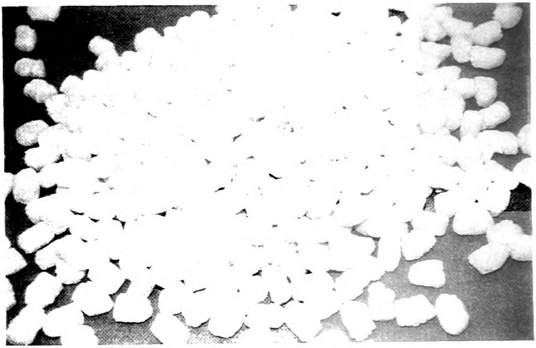


Figure 5: Picture of Naturpack (Zur Natur Zuruck Co.).

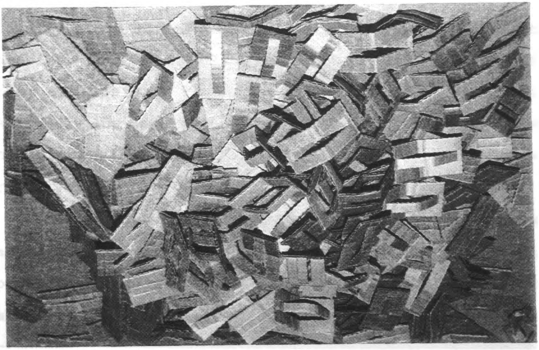


Figure 6: Picture of Corrugated Loose Fill (Menasha Co.).

since it uses the thinnest paper liners and medium. Corrugated loose fill is also considered to be an environmentally friendly alternative, since it is formed from kraft paper used to make the corrugated sheets and is also compostable. It can be landfilled and incinerated as well.

A major concern that has been expressed about corrugated loose fill is that it is heavier than EPS. This increased weight can add shipping costs since most loose fill is used in next day parcel delivery services. These services are offered by various companies and government agencies like Federal Express, United Parcel Service, United States Postal Service, Airborne Express, etc., whose shipping rates can depend on fractions of a pound. This material does not offer good dispensing features in existing gravity-fed systems. It usually clogs such dispensing systems. Also due to its high density, such overhead systems need to be reinforced since they are designed to handle materials like EPS that have extremely low densities. Menasha Corporation has developed a new dispensing system that allows using this product with relative ease.

Corrugated loose fill can be used for many kinds of applications, mostly in express mail order and electrical product shipments. Interest in this material has also been shown by manufacturers of instruments, glass, and ceramic products.

2.1.5 Loose Fill Molded Paper Pulp (Fiberflow(R)).

Fiberflow is a trademark of Fibercel Corporation. This is a paper-based loose fill which is made of 100% recycled paper fiber material. It is manufactured from 100% post consumer recycled newsprint (removed from waste stream). The process involves repulping the paper fiber using water and does not require any harmful chemicals. The material is then formed into peanut half shell shaped pieces. These are approximately 1.5 inches in length and have a diameter of 0.75 inch. Figure 7 shows a picture of this loose fill material.

This loose fill is anti-static and flowable, allowing it to encapsulate the product quickly and with ease. It can also adapt to most existing gravity-fed systems. It is non-toxic and cost effective loose fill alternative. Fiberflow provides an excellent cushioning performance in most applications. Unlike most starch-based products, Fiberflow is not sensitive to high relative humidity. It can also be composted. Water saturation enhances the decomposition. Fiberflow loose fill material can also be recycled in the existing manufacturing process to create more of the same cushioning material. This product can be readily separated from the solid waste system.

Fiberflow is currently being tested for a wide variety of products including: consumer goods, electronics, sport equipment, office products, toys, etc.

Figure 7: Picture of Fiberflow (Fiberflow Inc.).

Figure 8: Picture of Curl Pak (Meadow River Lumber Co.).

2.1.6 Wood Shavings (Curl Pak).

This material is produced by the Meadow River Lumber Company. It is made from wood waste that is developed in the lumber industry as trees are cut down to standard sizes of construction lumber. The unique manufacturing process can take these pieces of wood waste and process them into wood shavings. The shavings can be formed into various lengths, thickness of shaving and diameter. This is also a function of the type of wood used.

The material tested for this study varied approximately 1 to 2 inches in length, and had a curl diameter between 0.25 to 0.75 inches. This process does not provide consistent sized (dimensionally same) wood shavings since the wood waste used to manufacture by varies in size. However it has been recognized at recent Institute of Packaging Ameristar Awards as a "environmentally friendly" material since it is also truly biodegradable. Figure 8 shows a picture of this material.

2.1.7 Popped Corn (Popcorn).

After several decades, popcorn has recently remerged as an alternative loose fill cushioning material. It was initially tried as a packing material during World War II, due to lack of other materials during deployment of large quantities of supplies for Allied forces. The U. S. Patent Office issued a patent titled "Fragile Article Packaged in

Popped Corn" to Albert Rausch of Sterling Drug Inc. in 1953 (U. S. Patent No. 2,649,958, August 25, 1953). Popcorn is also a biodegradable material and therefore has found attention from environmental groups. It is a naturally compostable product which can decompose with time and moisture over a short period of time as compared to other packaging materials. Berry Hill, a small mail order firm in St. Thomas, Ontario, uses about 100 pounds of fresh popped corn daily for packing and shipping farm equipment (Anon., 1990).

The endosperm of a corn constitutes a translucent and an opaque section. The translucent portion effects the degree of expansion, which indicates the quality of the popcorn. The opaque portion is composed of air.

During the "popping" process to make popcorn, the corn is heated, causing the moisture in the kernel to evaporate. This causes the kernel to expand. The water in the kernel is superheated due to the fact that the pericarp of the popcorn develops a high pressure during heating. When a certain temperature is reached, the pressure is high enough to rupture the pericarp. At this stage the endosperm expands therefore forming popped corn also referred to as popcorn.

Two major popping processes are used to make popcorn. These include the wet popping process where the corn is popped in vegetable oil or butter and is often used to make edible popcorn. The second is the dry popping process which uses dry heat at high temperatures in the range of 410°-430°F. Most commercial popcorn is formed with this process.

There are several factors affecting the popping quality of corn. These include moisture content, kernel size, process condition, salt, and oil. The optimum moisture content should lie between 12.5 and 13.5%. The popcorn used in this study was obtained from a local retail store and ranged in size from 0.5 to 1.25 inches in diameter.

Although it is cost effective, popcorn has many drawbacks including its very high packing density of approximately 3 lb/ft^3. In addition, it is very sensitive to being attacked by rodents and ants due to its aroma. A major safety concern is the consumption of industrial popcorn which may have been treated to provide resistance to humidity and abrasion. These coatings or treatments are usually unsafe for human consumption (Inc. Magazine, 1990).

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

2.2 Test Methods for Transmitted Shock Characteristics.

The experimental procedure used to determine the shock absorbing characteristics of these test materials is described in ASTM D 4168-88 (ASTM, 1992).

2.2.1 Test Setup.

The procedure consists of using an instrumented test block that can contain the necessary weights to obtain the necessary static weight loadings and contains the instrumentation to measure the transmitted shock. The instrumented test block is shown in Figure 9. The test block is made from 1/2 inch thick plywood and has outside dimensions measuring 8 x 8 x 8 inches. The inside of the block is designed to provide a restraining fixture to fix internal ballast weights simulating the product weight inside a package. The internal weights can be easily changed to obtain the necessary weight loadings. An accelerometer was mounted on the top of the ballast weight to measure the transmitted shock level in the vertical direction.

The instrumented test block was placed in a corrugated box with the required cushion thickness (3 inches) encapsulating the instrumented test block. The corrugated box containing the cushioning material and the instrumented test block are shown in Figure 10.

2.2.2 Test Procedure.

The sample box was fixed on the shock table. The shock machine was set to produce a velocity change of 136.1, 152.2, and 166.8 in/s, representing the equivalent free fall drops of 24, 30, and 36 inches respectively. The impacts were

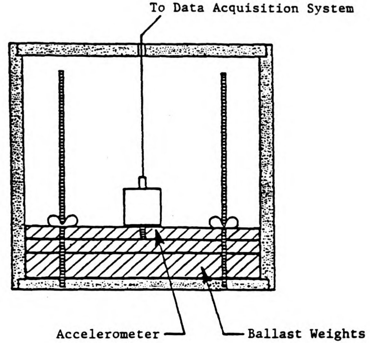


Figure 9: Instrumented Test Block.

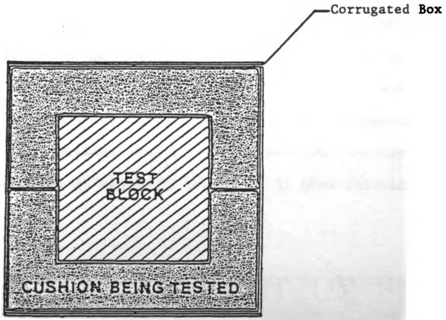


Figure 10: Loose Fill Cushion in Package Ready for Test.

performed using a Lansmont programmable shock machine. A piezoelectric accelerometer was mounted on the shock table to measure the required velocity change of the input shock pulse. The plastic programmers were used to simulate the free fall drop conditions as recommended in the standard ASTM 4168.

The seven materials were tested at the three different drop height conditions. The shock table was dropped five consecutive times for each material at each static loading and drop height. Each impact was performed after at least a 1 minute interval allowing the material to recover. Five static loadings from 0.2 to 0.8 psi were investigated in this study. Each material was evaluated at each of the three specific heights and five load conditions for five consecutive impacts.

The instrumentation consisted of a 10 mV/g piezoelectric accelerometer and a data acquisition system. This was connected to a charge amplifier using an accelerometer cable. The output from the charge amplifier was connected to a data acquisition computer card (Test Partner, Lansmont Corporation). The Test Partner software package was used to analyze the transmitted shock pulse. The peak acceleration (G's) and duration of measured shock pulses were collected and analyzed.

2.2.3 Test Method to Measure Settling Due to Vibration.

It is important to measure the settling of loose fill materials due to the vibration forces that occur during transportation. Settling of cushioning materials often increases the void space in the package so that the product is likely to get damaged when the package is dropped. In this study lab simulated random vibration was used to estimate the effect of transport vibration on the settling characteristics of these loose fill materials. The random vibration was performed in accordance with ASTM D4728 (Figure X1.2, Composite Truck Spectrum). A special see through container was made from plexiglass. This plexiglass sample box had an inside dimension of 14 x 14 x 20 inches. The sample box was filled with 3 inches of cushioning encapsulating the instrumented box as shown in Figure 11. The instrumented test block was used as a dummy product inside this container with a static loading of 0.5 psi. The random vibration test was performed for 30 minutes. The cushioning material was then removed from the top and measurements taken with reference to the top of the instrumented block to determine the degree of settling (Figure 12).

The data collected and analyzed for the various tests is presented in Chapter 3.

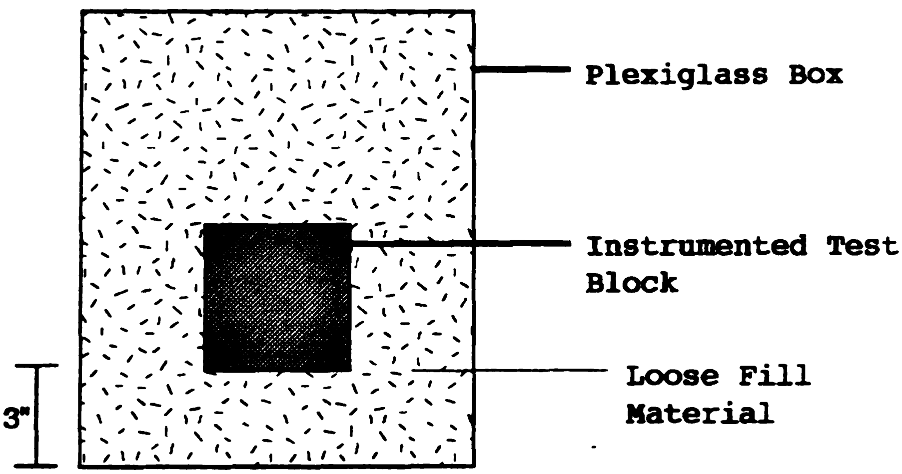


Figure 11: Test Setup of Settling of Loose Fill Material During Vibration.

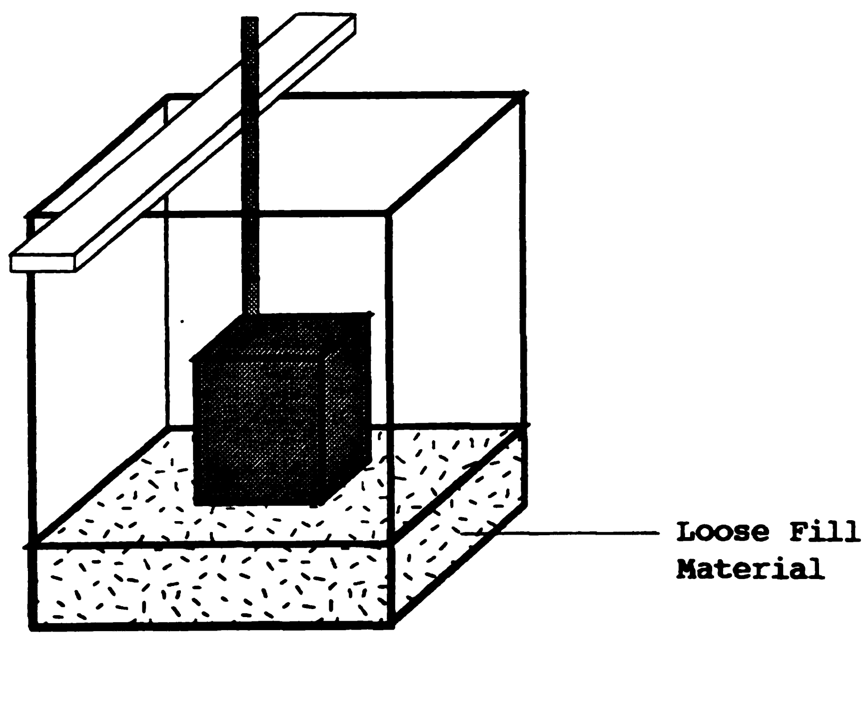


Figure 12: Measurement of Settling of Loose Fill Material.

3.0 DATA AND RESULTS

This study examined the seven different packaging loose fill cushioning materials for their dynamic performance characteristics and environmental concerns. The data was filtered using the internal 'auto' filter setup as well as at 156 Hz. Tables A1 to A7 (Appendix A) list all the data that was analyzed at these conditions.

Cushion curves relate the peak deceleration experienced by the cushioned weight in a free fall drop to the static loading "σ" defined as;

$$\sigma = \frac{W}{A} \qquad (3\text{-}1)$$

where "W" is the weight of the product and "A" is the support area underneath the weight (contact area between the weight and cushion). The curves are normally presented in graph form with peak deceleration (G) on the vertical axis and static loading (lb/in^2) on the horizontal axis.

The data collected using the "auto" filter for the first drop condition from Tables A1 to A7 was used to plot the cushion curves for these materials. The first impact data was used since package design using loose fill materials is often done for a single impact on a given face. Multiple impact data will increase the transmitted shock levels for these curves based on the data in Tables A1 to A7. Figures B1 to

B21 (Appendix B) represent all the cushion curves for the seven cushioning materials.

Cushion curves represent both the cushion thickness and the bearing area. The amount of cushion volume may be obtained as a product of area and thickness. Similarly cushion weight may be determined as a product of density and volume. The density values for all the cushioning materials were measured and listed in Table 3 (Chapter 2)

A measure of the relative amount of cushioning used to protect the product is the ratio of the weight of the cushion supporting the product to the weight of the product itself. This can be mathematically described as;

$$\text{Percent Weight Ratio} = \frac{DAt}{W} \times 100 = \frac{Dt}{\sigma} \times 100 \qquad (3\text{-}2)$$

where

D	=	Cushion Density (lb/in^3)
A	=	Bearing Area (in^2)
t	=	Cushion Thickness (inches)
W	=	Product Weight (lb)
σ	=	Static Loading (lb/in^2)

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

$$\text{Cushion Volume to Product Weight Ratio} = \frac{At}{W} = \frac{t}{\sigma} \qquad (3\text{-}3)$$

Since cushion weight and volume are considered in different application, the relative cushion weight to product weight ratio and cushion volume to product weight ratio were determined in this study. For most resilient cushioning materials the cushion curves slope downward at low static loadings, level off, and then slope upward as the static loading is further increased. This means that the same shock (G) level may be produced at two different static loadings. The larger static loading represents the more efficient use of the cushion, since it corresponds to the lower volume of material used. For this reason, the required percent weight ratio (or volume ratio) for a given G-level of protection will be computed using the maximum static loading for this G level.

This way, all of the cushion curve information determined in Figures B1 to B21, "G" versus "σ", can be transformed into "Environmental Cushion Curves", representing G versus percent weight ratio (or volume ratio), using equation (3-2) or (3-3).

Tables 4 to 9 represent the various values determined from the cushion curves (Figures B1 to B21), and the density of the materials (Table 3) to plot the "Environmental Cushion Curves". Figures 13, 14, and 15, are the "Environmental Cushion Curves" showing the percent weight ratio, and Figures 16, 17, and 18, describe the volume ratio for the seven materials.

The efficient use of cushioning materials to protect a product from a given impact condition is a major factor in reducing packaging waste. The "Environmental Cushion Curves" can be used to assess the relative performance of different cushioning materials based on the amount of material required by weight or volume to provide similar protection.

Table 4: Comparison between different materials. Number shown are Cushion Weight to Product Weight Ratio (%), 24 Inches Drop Height, First Impact.

G / Material	20	25	29	30	31	32	34	35	36	40	45	50	55	60	65	70	75
Corrugated				1.04				0.53									
Curl Pak											0.31	0.28	0.27				
Eco Foam	0.23	0.19		0.19													
EPS				0.10				0.08		0.07	0.07						
Fiber Flow		0.29		0.25													
Naturpack				0.50				0.18									
Popcorn						0.85	0.79		0.75								

Table 5: Comparison between different materials. Number shown are Cushion Weight to Product Weight Ratio (%), 30 Inches Drop Height, First Impact.

G / Material	20	25	29	30	31	35	36	40	45	50	55	60	65	70	75	80	90
Corrugated								0.87	0.6	0.47	0.43						
Curl Pak												0.35	0.31	0.29	0.27	0.26	
Eco Foam						0.21		0.19									
EPS								0.09	0.08	0.07	0.07						
Fiber Flow				0.31		0.28											
Naturpack			0.18	0.18	0.18												
Popcorn						0.87		0.74									

Table 6: Comparison between different materials. Number shown are Cushion Weight to Product Weight Ratio (%), 36 Inches Drop Height, First Impact.

G / Material	30	31	32	35	40	45	50	55	60	65	70	75	80	90	100	110	120
Corrugated									0.64	0.55	0.47	0.44					
Curl Pak													0.43	0.34	0.31	0.29	0.27
Eco Foam					0.23	0.20	0.18										
EPS							0.09	0.08	0.07								
Fiber Flow				0.31	0.26												
Naturpack	0.19		0.19														
Popcorn					0.81	0.73											

Table 7: Comparison between different materials. Number shown are Cushion Volume to Product Weight Ratio (cu. in/lb), 24 Inches Drop Height, First Impact.

G / Material	20	25	29	30	31	32	34	35	36	40	45	50	55	60	65	70	75
Corrugated				7.50				3.85									
Curl Pak											4.76	4.29	4.11				
Eco Foam	5.08	4.35		4.17													
EPS				5.77				4.69		4.17	3.90						
Fiber Flow		4.76		4.17													
Naturpack				4.41				4.05									
Popcorn						4.92	4.62		4.35								

Table 8: Comparison between different materials. Number shown are Cushion Volume to Product Weight Ratio (cu. in/lb), 30 Inches Drop Height, First Impact.

G / Material	20	25	29	30	31	35	36	40	45	50	55	60	65	70	75	80	90
Corrugated								6.25	4.29	3.37	3.09						
Curl Pak												5.45	4.76	4.48	4.23	4.05	
Eco Foam						4.76		4.29									
EPS								5.08	4.48	4.11	3.95						
Fiber Flow				5.17		4.55											
Naturpack			4.11	4.00	3.95												
Popcorn						5.08		4.29									

Table 9: Comparison between different materials. Number shown are Cushion Volume to Product Weight Ratio (cu. in/lb), 36 Inches Drop Height, First Impact.

G Material	30	31	32	35	40	45	50	55	60	65	70	75	80	90	100	110	120
Corrugated									4.62	3.95	3.37	3.16					
Curl Pak													6.67	5.26	4.76	4.41	4.23
Eco Foam					5.08	4.48	4.00										
EPS							5.26	4.62	4.35								
Fiber Flow				5.17	4.35												
Naturpack	4.35		4.17														
Popcorn					4.69	4.23											

Figure 13: Cushion Weight to Product Weight Ratio (%) vs G's, 24 inches Drop ht., First Impact.

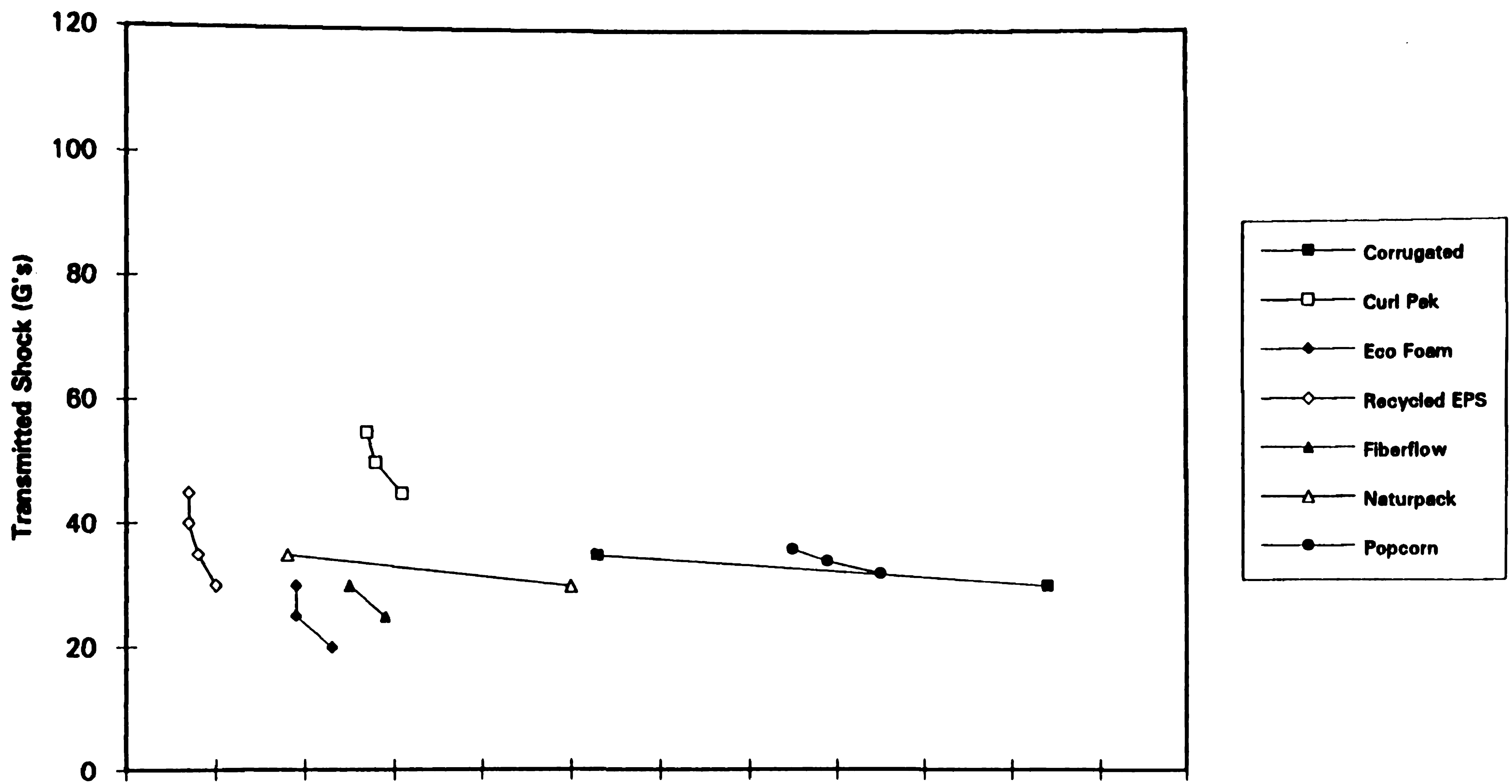


Figure 14: Cushion Weight to Product Weight Ratio (%) vs G's, 30 Inches Drop ht., First Impact.

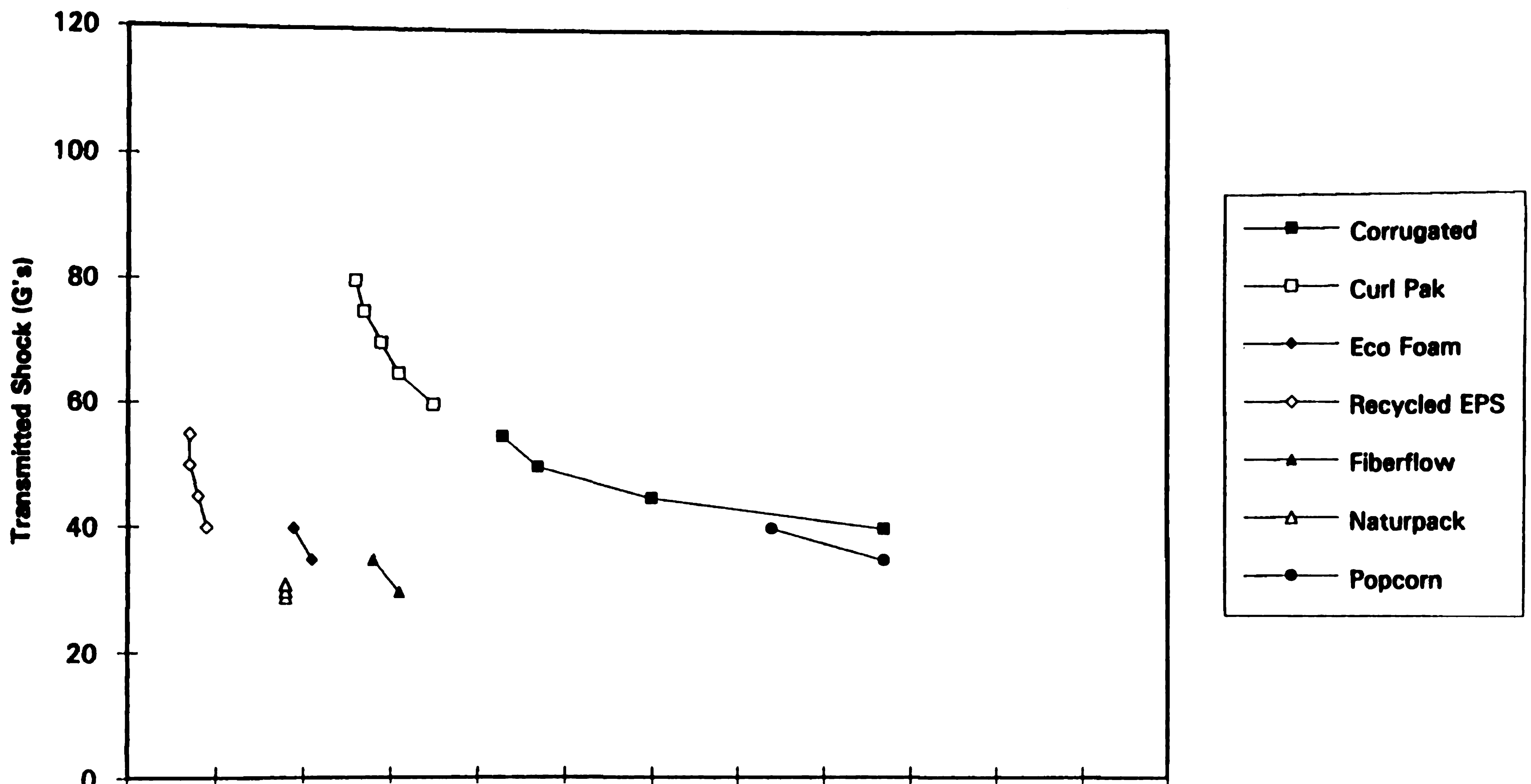


Figure 15: Cushion Weight to Product Weight Ratio (%) vs G's, 36 Inches Drop ht., First Impact.

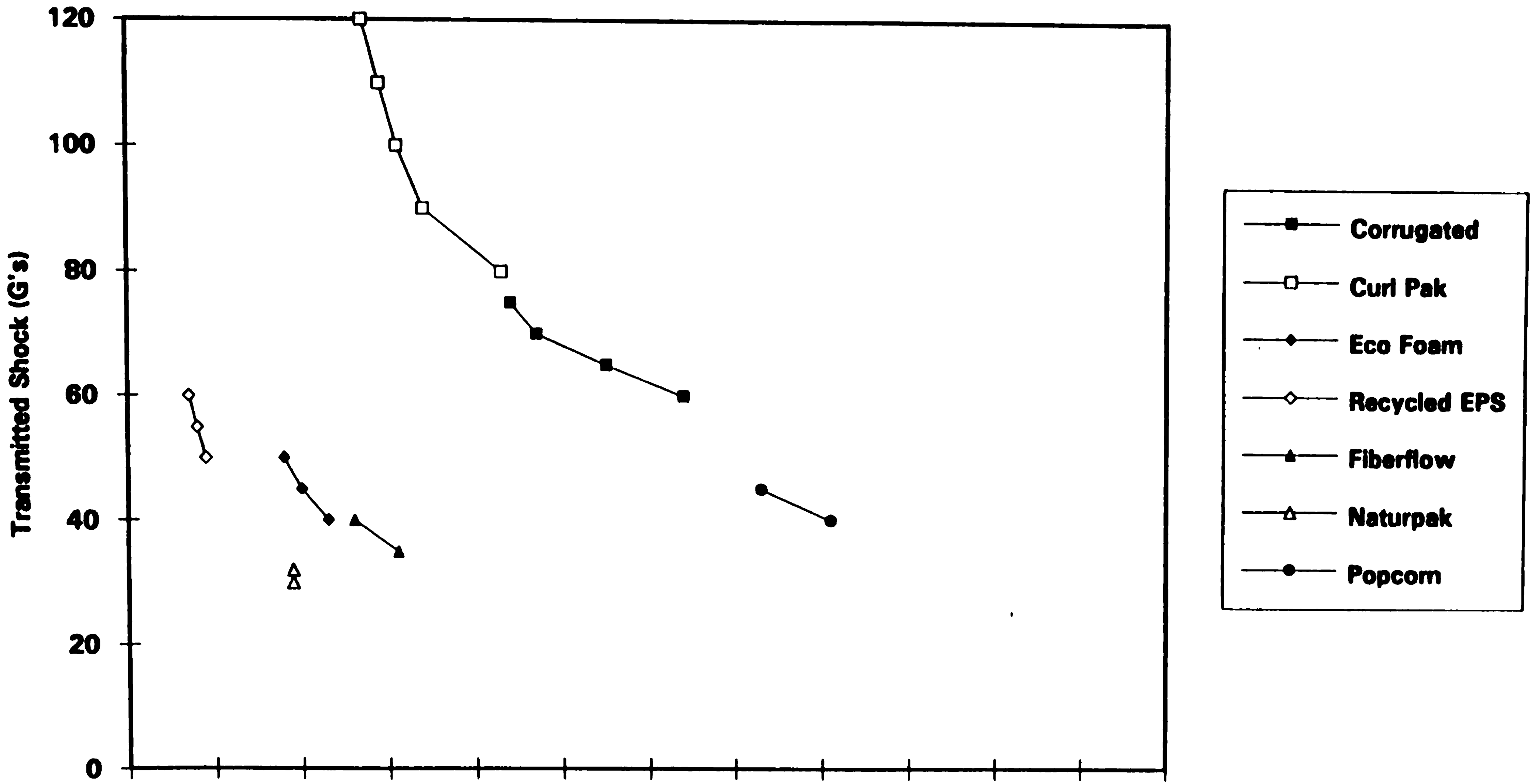


Figure 16: Cushion Volume to Product Weight Ratio (cu. in./ lb.) vs G's, 24 inches Drop ht., First Impact.

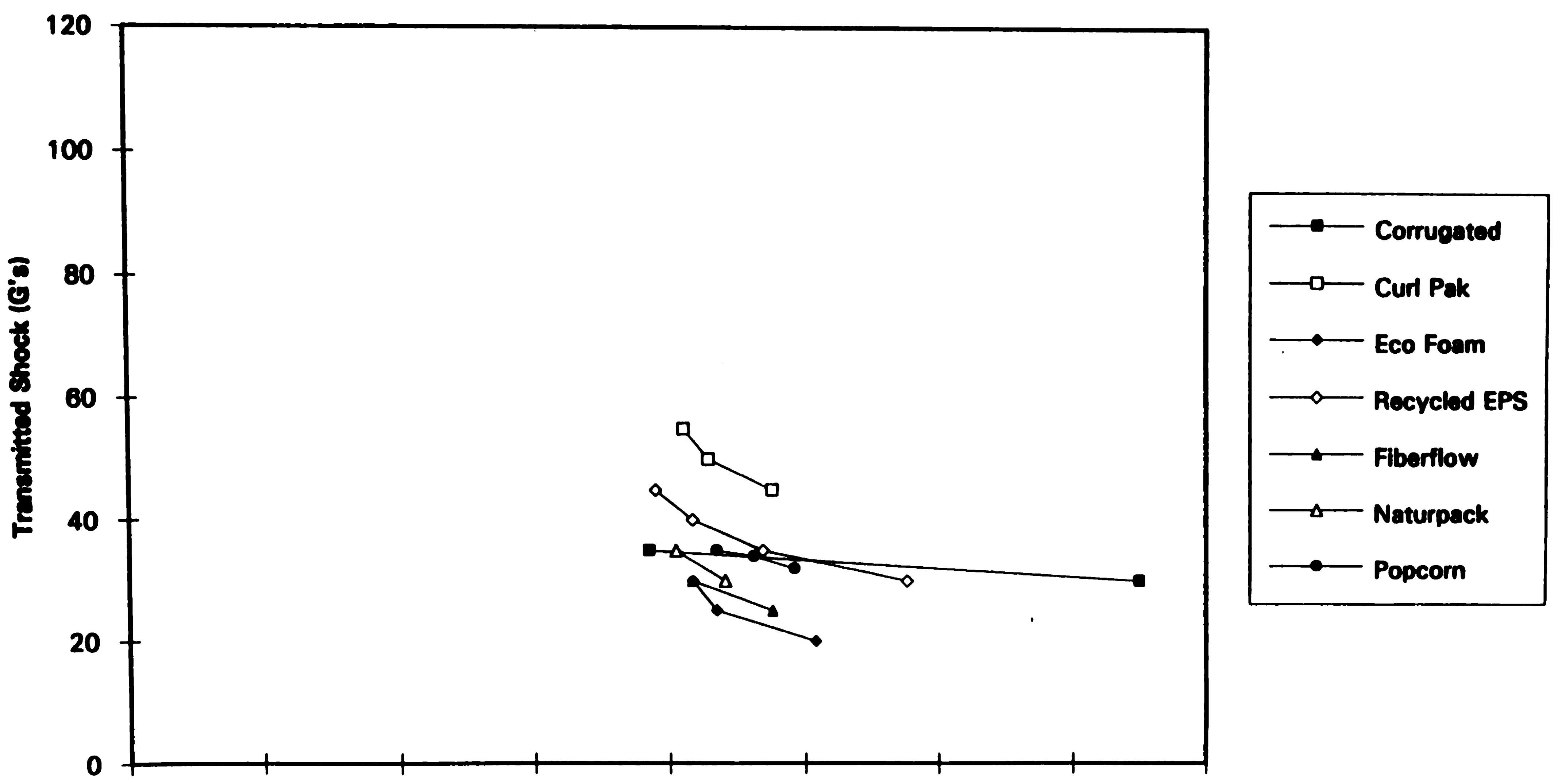


Figure 17: Cushion Volume to Product Weight Ratio (cu. in./ lb.) vs G's, 30 Inches Drop ht., First Impact.

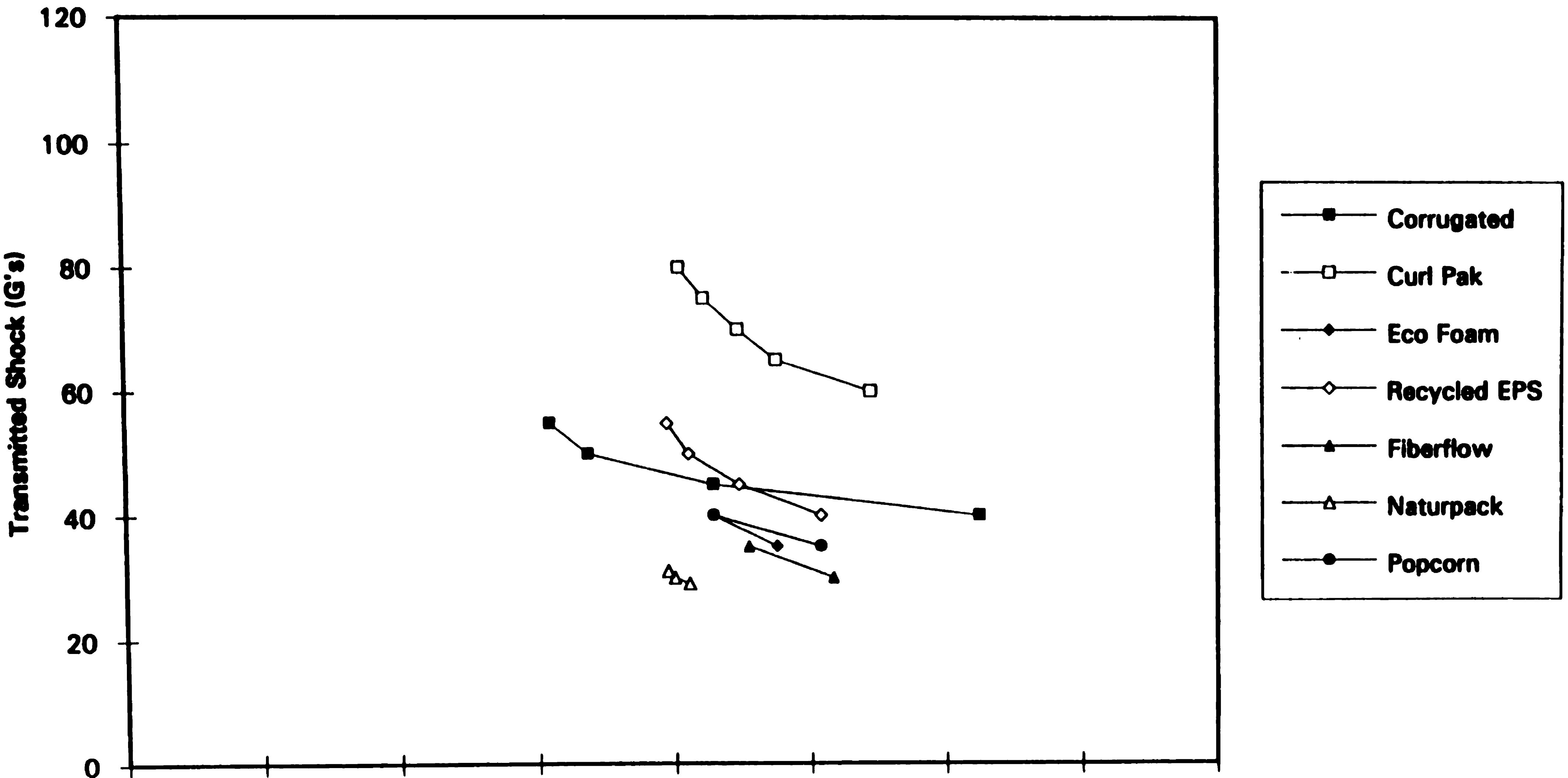
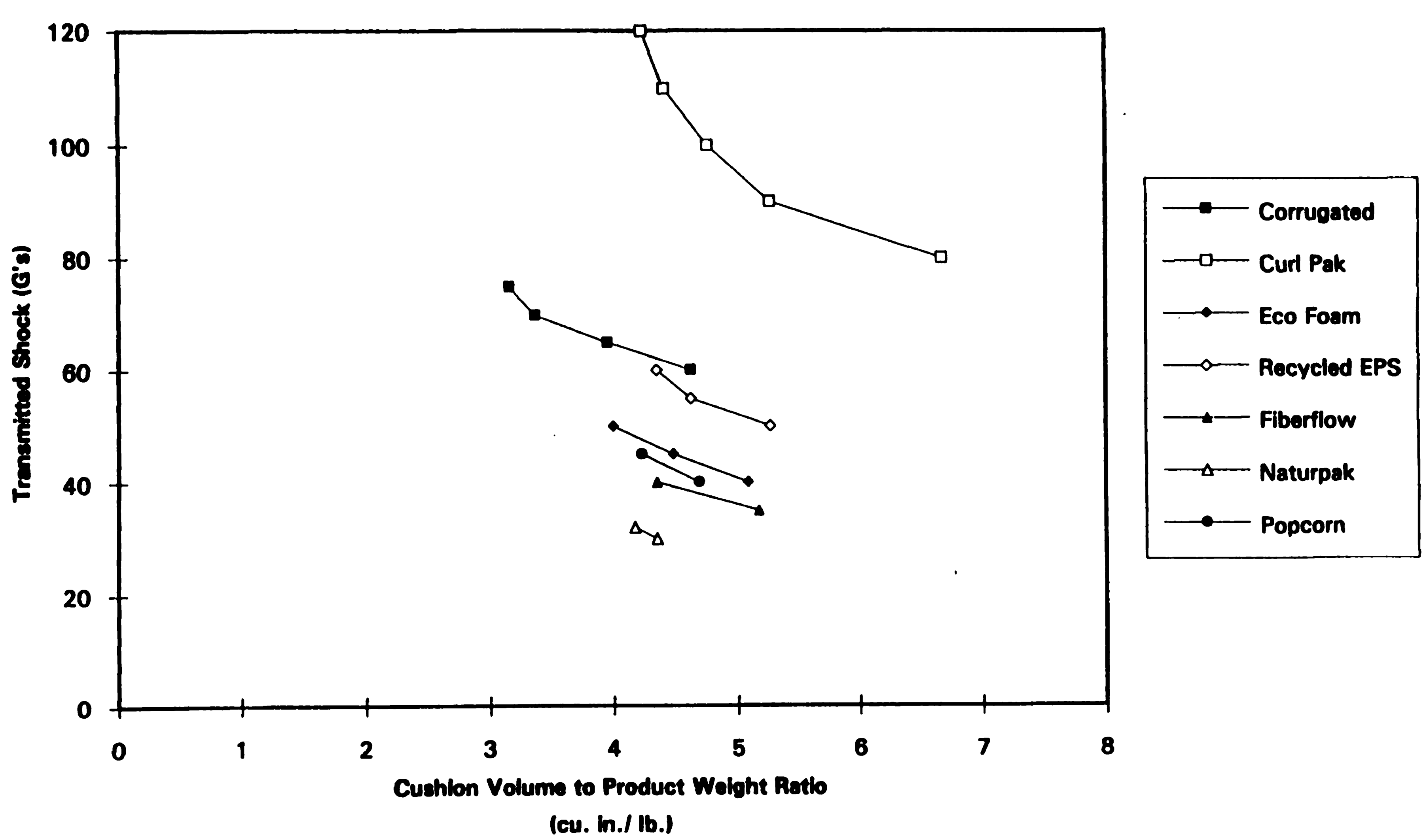


Figure 18: Cushion Volume to Product Weight Ratio (cu. in./ lb.) vs G's, 36 Inches Drop ht., First Impact.



Materials that show good shock attenuation have lower transmitted shock "G" values. Materials that will be used in smaller quantities for a given level of protection will have lower percent weight (or volume) ratio values. The ideal cushioning material for both protection and environmental concerns will therefore lie closest to the origin.

Based on the data presented in Figures 13 to 18, it is clear that materials such as popcorn and wood shavings (curl pak) show poor material utilization since larger amounts of cushioning material is needed both by weight and volume to achieve similar protection. 100% recycled EPS shows the best performance in terms of percent weight utilization as compared to other materials because of its low density and good shock protecting properties. Similarly the starch based loose fill (Naturpack and Eco-Foam) and Fiberflow showed better performance in terms of efficient use by volume.

The effect of settling of the test block during vibration was also studied. The data for the amount of material that settled based on the reference plane of a 3 inch thick cushion at start was measured at all the four corners of the instrumented test block. The data is presented in Table 10. The results show that the corrugated loose fill showed the lease amount of settling due to vibration. Eco-foam, Fiberflow, and popcorn showed intermediate settling. Curl-Pak and the 100% recycled EPS showed the poorest performance with over 1 inch settling.

Table 10: The settling data of the test block (in) for various loose fill cushioning materials.

Materials	Settling of the test block (in) *					Average Strain	Rotation (degrees)
	corner # 1	corner # 2	corner # 3	corner # 4	Average		
Corrugated	+0.250	+0.125	-0.500	-0.375	-0.125	4.167	7.66
Curl Pak	-1.125	-1.125	-1.250	-1.250	-1.188	39.600	0.89
Eco Foam	-0.350	-0.350	-0.375	-0.375	-0.363	12.100	0.18
100 % Recycled EPS	-1.563	-1.563	-1.000	-1.000	-1.282	42.733	4.02
Fiberflow	-0.250	-0.500	-0.375	-0.125	-0.313	10.433	2.00
Naturpack	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Popcorn	-0.500	-0.375	-0.250	-0.375	-0.375	12.500	1.27

* (+) and (-) indicate the thickness of cushion higher and lower than that of original position (3 inches) respectively.
N/A means sufficient material was not available to collect data for this material.

4.0 CONCLUSIONS

Seven types of packaging loose fill cushioning materials were compared to evaluate the protective performance of these materials and volume and weight utilization. The study concluded the following:

1. The starch based loose fill materials (Naturpack and Eco-Foam) and Fiberflow showed the best protective performance and minimum material utilization by volume. The 100% recycled EPS showed the best performance in terms of percent weight utilization.

2. Materials such as popcorn and wood shavings (curl pak) show poor material utilization since a much larger amount of these materials was required both by weight and volume to achieve similar protection offered by other materials.

3. The study showed that corrugated loose fill material did not show the flow easily due to vibration, followed by Eco-foam, Fiberflow, and popcorn. Curl-Pak and the 100% recycled EPS showed the maximum settling among all materials.

APPENDICES

APPENDIX A

Table A1 Transmitted Shock Data for 3 inch thick EPS 100% recycled content.

Static Load (psi)	DROP #	DECELERATION (G'S) 24" Drop ht. AUTO	24" Drop ht. 156 Hz	30" Drop ht. AUTO	30" Drop ht. 156 Hz	36" Drop ht. AUTO	36" Drop ht. 156 Hz
0.2617	1	30.45	29.95	40	38.99	48.22	46.99
	2	40.45	39.39	53.78	52.64	71.56	69.07
	3	47.37	45.84	60.11	58.22	81.36	77.54
	4	56.41	54.56	68.72	66.23	95.16	90.29
	5	61.7	59.23	72.71	69.35	101.13	95.02
0.418	1	35.46	34.24	52.54	51.07	56.31	54.48
	2	41.48	39.96	54.78	52.45	82.24	80.95
	3	50.35	48.72	68.42	66.83	108.64	105.32
	4	58.41	56.16	67.29	65.77	107.73	103.76
	5	60.22	58.04	74.07	72.6	111.26	100.28
0.4961	1	31.52	31.05	39.67	38.6	59.05	57.56
	2	47.13	46.17	58.88	56.33	81.23	77.13
	3	54.6	52.8	69.84	66.49	97.11	88.57
	4	59.17	56.98	68.72	64.72	112.47	102.26
	5	56.66	54.99	75.08	71.56	112.97	99.96
0.5742	1	35.36	34.82	38.66	38.07	42.04	41.32
	2	48.98	47.82	53.76	51.32	57.19	55.87
	3	56.36	53.81	59.1	57.23	67.12	64.42
	4	59.22	56.77	65.83	62.02	75.18	71.34
	5	63.69	60.25	79.73	72.26	89.16	82.57
0.7305	1	30.16	29.83	47.46	46.14	50.63	49.39
	2	42.91	41.49	70.9	66.26	72.81	67.58
	3	52.41	50.68	121.31	83.54	107.92	84.96
	4	59.1	55.07	174.55	94.05	169.57	99.03
	5	62.85	58.93	180.96	119.55	207.77	115.6

Table A2 Transmitted Shock Data for 3 inch thick ECO-FOAM.

Static Load (psi)	DROP #	DECELERATION (G'S) 24" Drop ht. AUTO	24" Drop ht. 156 Hz	30" Drop ht. AUTO	30" Drop ht. 156 Hz	36" Drop ht. AUTO	36" Drop ht. 156 Hz
0.2617	1	26.22	25.96	31.78	31.32	41.27	40.49
	2	35.19	34.41	43.19	42.29	59.38	57.81
	3	40.73	39.91	50.69	49.21	69.65	66.88
	4	45.33	44.17	56.18	54.19	78.97	75.33
	5	50.37	48.77	61.42	58.66	85.97	81.14
0.418	1	24.93	24.65	35.6	34.63	40.57	39.78
	2	34.15	33.75	46.71	45.56	60.51	58.32
	3	40.98	39.6	59.66	57.56	73.29	69.67
	4	44.74	43.54	69.56	66.32	79.43	74.63
	5	51.18	49.64	77.78	73.27	93.07	86.69
0.4961	1	23.19	22.99	30.64	30.16	38.57	38.05
	2	36.55	35.81	47.13	45.18	59.28	57.13
	3	43.75	42.63	55.5	53.41	71.02	68.04
	4	49.22	47.77	61.32	58.79	82.27	78.34
	5	54.18	51.91	66.34	63.58	89.5	83.22
0.5742	1	19.43	19.25	28.5	28.09	34.26	33.81
	2	32.01	31.43	46.43	44.72	51.89	50.17
	3	41.58	40.2	56.37	54.14	65.55	62.51
	4	46.89	45.29	63.43	61.24	75.49	71.24
	5	52.59	49.73	69.13	65.69	87.53	82.03
0.7305	1	24.78	24.31	36.39	27.77	38.01	36.74
	2	38.65	37.79	46.32	44.55	64.6	62.12
	3	49.44	45.06	61.22	57.75	89.77	81.82
	4	53.19	50.53	67.05	63.61	114.58	97.88
	5	58.5	55.45	77.48	69.86	133.84	115.77

Table A-3 Transmitted Shock Data for 3 inch thick Naturpack.

Static Load (psi)	DROP #	DECELERATION (G'S) 24" Drop ht. AUTO	24" Drop ht. 156 Hz	30" Drop ht. AUTO	30" Drop ht. 156 Hz	36" Drop ht. AUTO	36" Drop ht. 156 Hz
0.2617	1	42.81	41.69	48.8	47.35	51.74	50.09
	2	50.88	49.41	54.42	53.07	59.93	58.22
	3	55.16	53.37	60.29	58.62	69	66.71
	4	57.62	55.54	65.65	62.87	78.5	73.73
	5	59.1	57.05	69.46	66.67	84.07	79.49
0.418	1	32.77	32.34	35.67	35.09	36.35	35.76
	2	39.97	38.53	46.29	44.63	47.11	45.79
	3	44.56	43.09	53.36	51.36	57.76	56.46
	4	48.5	46.63	59.99	57.73	65.79	63.55
	5	52.94	51.01	66.89	64.49	76.4	72.81
0.4961	1	27.91	27.64	32.65	32.17	35.76	35.07
	2	35.48	34.85	45.73	44.02	48.97	47.89
	3	41.1	40.36	52.17	50.28	60.28	58.13
	4	46.14	44.57	58.89	57.22	71.18	67.17
	5	50.35	48.82	65.67	62.49	81.85	76.21
0.5742	1	26.33	26.2	29.9	29.46	33.11	32.39
	2	33.62	33.24	40.45	39.84	47	45.79
	3	39.37	38.66	49.48	48.09	58.01	56.56
	4	42.87	42.18	57.92	55.75	68.57	65.66
	5	46.72	45.84	65.56	63.05	80.37	76.53
0.7305	1	35.45	23.59	24.76	27.89	28	27.81
	2	44.53	31.98	45.89	40.61	43.95	43.24
	3	41.09	38.67	57.2	50.84	59.35	56.98
	4	46.78	43.99	70.35	58.96	72.86	68.17
	5	54.71	49.51	83.03	66.94	88.11	78.75

Table A4 Transmitted Shock Data for 3 inch thick loose fill Corrugated.

Static Load (psi)	DROP #	DECELERATION (G'S)		
		24" Drop ht.	30" Drop ht.	36" Drop ht.
		AUTO	AUTO	AUTO
0.2617	1	28.41	38.51	51.91
	2	45.27	54.25	77.4
	3	55.45	61.61	78.91
	4	62.22	71.04	89.79
	5	69.94	80.21	99.17
0.418	1	32.3	36.64	53.4
	2	54.41	56.05	76.24
	3	62.5	70.06	98.79
	4	79.82	71.21	87.66
	5	65.14	87.8	98.48
0.5742	1	31.3	39.39	55.7
	2	55.79	73.29	97.63
	3	66.59	83.82	94.51
	4	81.55	71.81	99.72
	5	75.88	71.68	129.52
0.7305	1	35.35	44.3	62.1
	2	69.91	86.2	110.32
	3	88.45	85.24	110.85
	4	84.07	90.95	69.85
	5	67.01	96.72	99.81
0.9578	1	36.11	49.45	73.52
	2	55.57	93.6	158.21
	3	66.5	71.51	147.79
	4	73.93	81.92	79.45
	5	79.07	114.86	160.1

Table A-5 Transmitted Shock Data for 3 inch thick Fiberflow.

Static Load (psi)	Drop #	DECELERATION (G's)					
		24" Drop Ht.		30" Drop Ht.		36" Drop Ht.	
		AUTO	156 Hz	AUTO	156 Hz	AUTO	156 Hz
0.2617	1	26.89	26.79	34.03	32.48	36.51	35.87
	2	39.2	38.7	47.15	46.24	58.66	57.44
	3	52.13	50.63	61.45	59.49	89.85	85.74
	4	64.81	62.04	83.58	79.34	121.84	109.77
	5	77.97	73.22	102.05	94.72	146.85	129.03
0.418	1	23.18	23	28.59	28.22	36.67	35.83
	2	38.33	38.04	50.41	48.38	67.38	65.09
	3	56.55	53.84	78.51	75.88	127.9	125.5
	4	67.72	65.36	101.64	99.82	158.46	155.98
	5	84.31	80.42	108.87	105.21	166.27	164.53
0.4961	1	20.01	19.84	26.26	25.96	30.12	29.87
	2	37.95	37.2	52.29	50.78	75.38	72.09
	3	60.85	57.84	82.21	76.26	143.39	126.36
	4	69.56	64.45	111.94	96.38	165.9	134.59
	5	89.25	81.61	134.51	108.64	179.27	131.5
0.5742	1	21.92	21.8	28.64	28.21	33.66	32.98
	2	44.05	42.88	77.77	72.98	117.78	103.12
	3	72.59	68.19	142.74	118.88	151.26	110.87
	4	91.06	84.57	155.82	118.82	185.46	122.53
	5	116.79	100.9	188.2	114.03	200.61	121.79
0.7305	1	18.49	18.33	24.01	23.73	32.57	31.91
	2	40.05	38.79	66.11	62.1	130.92	116.27
	3	65.66	61.31	122.61	103.1	181.95	143.78
	4	97.12	86.38	180.36	123.72	151.3	104.79
	5	103.12	82.35	232.94	134	220.57	135.28

Table A6 Transmitted Shock Data for 3 inch thick Curl Pak.

Static Load (psi)	DROP #	DECELERATION(G'S)					
		24" Drop ht.		30" Drop ht.		36" Drop ht.	
		AUTO	156 Hz	AUTO	156 Hz	AUTO	156 Hz
0.2617	1	59.57	55.89	61.05	57.31	60.22	57.12
	2	101.57	89.36	117.46	104.73	133.25	114.06
	3	121.41	102.01	124.13	105.49	174.31	140.78
	4	146.06	116.75	163.29	125.91	189.7	133.82
	5	159.89	123.35	191.07	142.08	206.83	143.8
0.418	1	42.06	40.71	63.06	58.82	98.81	87.28
	2	99.46	89.77	178.82	130.5	209.24	132.8
	3	133.27	112.28	232.49	145.55	235.54	141.5
	4	175.62	130.44	222.01	128.32	279.63	161.22
	5	191.32	136.39	289.89	160.76	250.87	150.32
0.4961	1	49.08	44.26	74.14	67.97	103.09	88.96
	2	89.01	74.18	186.34	132.91	262.01	150.53
	3	154.23	103.26	210.67	121.57	287.5	141.43
	4	157.15	116.81	310.07	154.24	301.71	161.27
	5	187	133.46	326.28	167.32	455.96	157.59
0.5742	1	46.13	43.86	39.1	37.77	74	68.27
	2	88.15	79.23	110.24	94.86	237.41	179.77
	3	141.85	120.14	173.99	128.11	342.53	234.86
	4	192.24	147.37	213.25	120	415.56	260.85
	5	227.22	161.33	249.2	141.85	252.39	171.95
0.7305	1	28.56	27.92	80.48	70.62	124.78	104.36
	2	64.77	61.4	203.91	138.73	216.58	150.59
	3	109.29	86.78	192.05	117.19	193.87	137.96
	4	129.24	101.17	226.22	134.72	317.92	127.21
	5	182.93	113.11	219.95	125.4	310.69	133.24

Table A-7 Transmitted Shock Data for 3 inch thick popcorn.

Static Load (psi)	DROP #	DECELERATION (G'S)					
		24" Drop ht.		30" Drop ht.		36" Drop ht.	
		AUTO	156 Hz	AUTO	156 Hz	AUTO	156 Hz
0.2617	1	42.91	41.69	47.76	46.11	55.87	53.9
	2	62.37	59.72	72.05	67.64	91.03	85.61
	3	78.46	72.81	90.24	82.85	113.86	104.95
	4	87.06	81.94	107.14	94.52	134.23	119.95
	5	98.01	89.44	111.17	102.83	143.3	125.8
0.418	1	35.67	34.96	40.63	39.47	52.74	50.21
	2	58.81	55.18	61.48	62.9	93.83	83.42
	3	75.33	68.79	78.12	80.48	129.25	106.84
	4	87.8	79.93	113.03	93.42	159.5	122.28
	5	106.61	86.26	159.57	102.39	176.8	134.25
0.4961	1	33.34	32.92	38.33	37.88	40.52	39.96
	2	62.13	58.14	64.63	60.35	66.2	62.93
	3	76.37	72.23	81.25	76.32	82.13	78.72
	4	90.15	84.31	98.88	90.27	101.51	90.52
	5	108.31	99.69	110.24	100.63	115.19	103.93
0.5742	1	30.41	29.88	33.62	32.25	35.16	34.32
	2	69.41	52.32	72.65	61.03	74.44	65.38
	3	81.27	72.41	86.49	79.54	90.32	80.15
	4	94.16	89.64	104.56	92.33	109.67	98.45
	5	103.12	95.41	114.37	100.26	144.53	108.45
0.7305	1	32.54	31.23	36.78	35.92	37.22	36.16
	2	77.92	69.45	85.51	78.36	106.23	96.45
	3	95.98	89.31	100.49	90.26	127.48	119.35
	4	101.13	94.68	114.17	101.23	144.67	136.65
	5	109.62	99.34	116.97	102.62	157.61	129.35

APPENDIX B

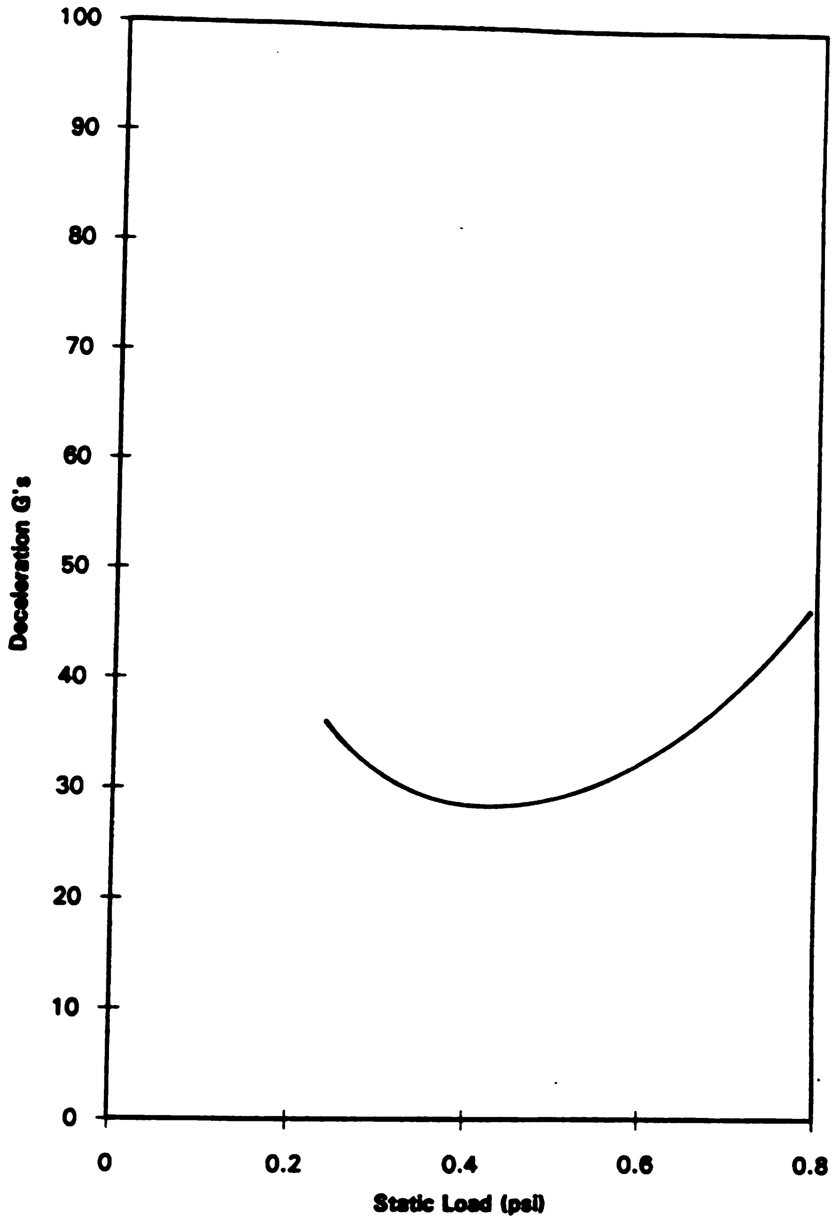


Figure B1: Cushion Curve for 3 inch thick EPS 100% recycled content from 24 inch drop height.

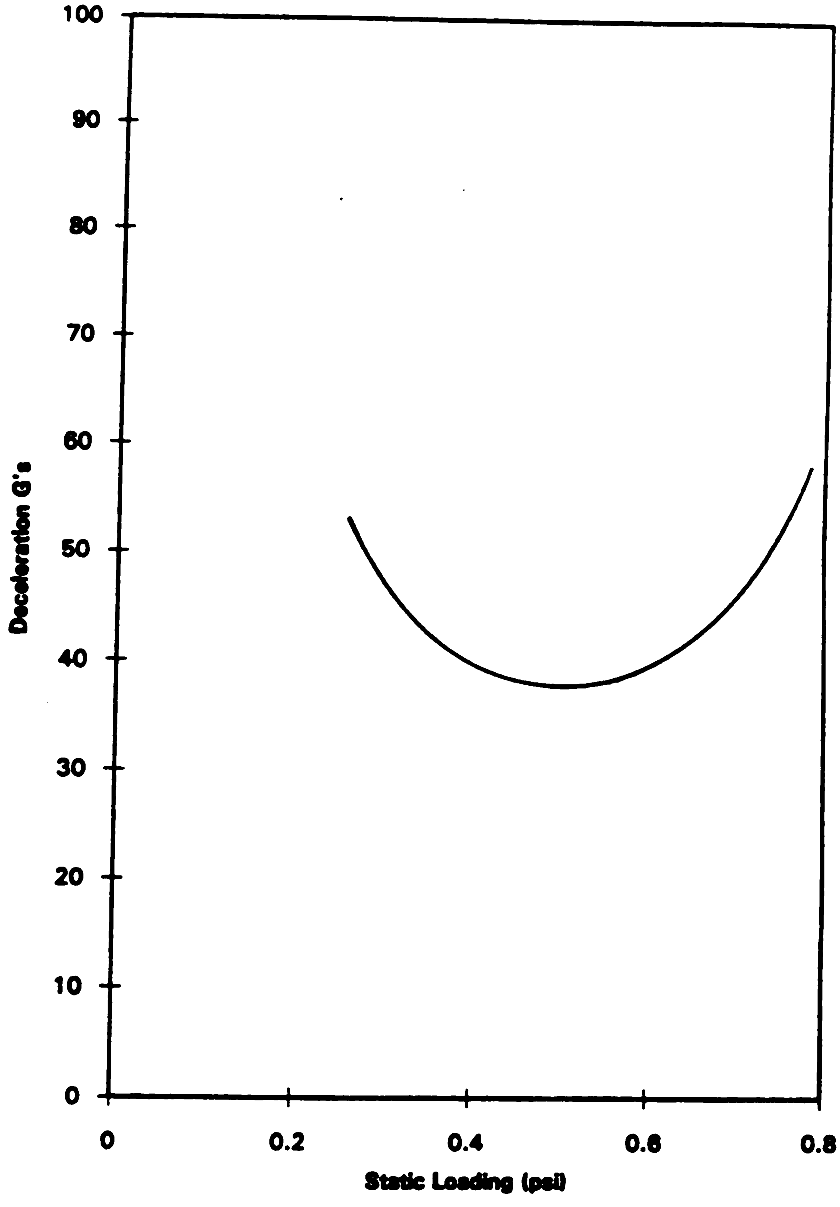


Figure B2: Cushion Curve for 3 inch thick EPS 100% recycled content from 30 inch drop height.

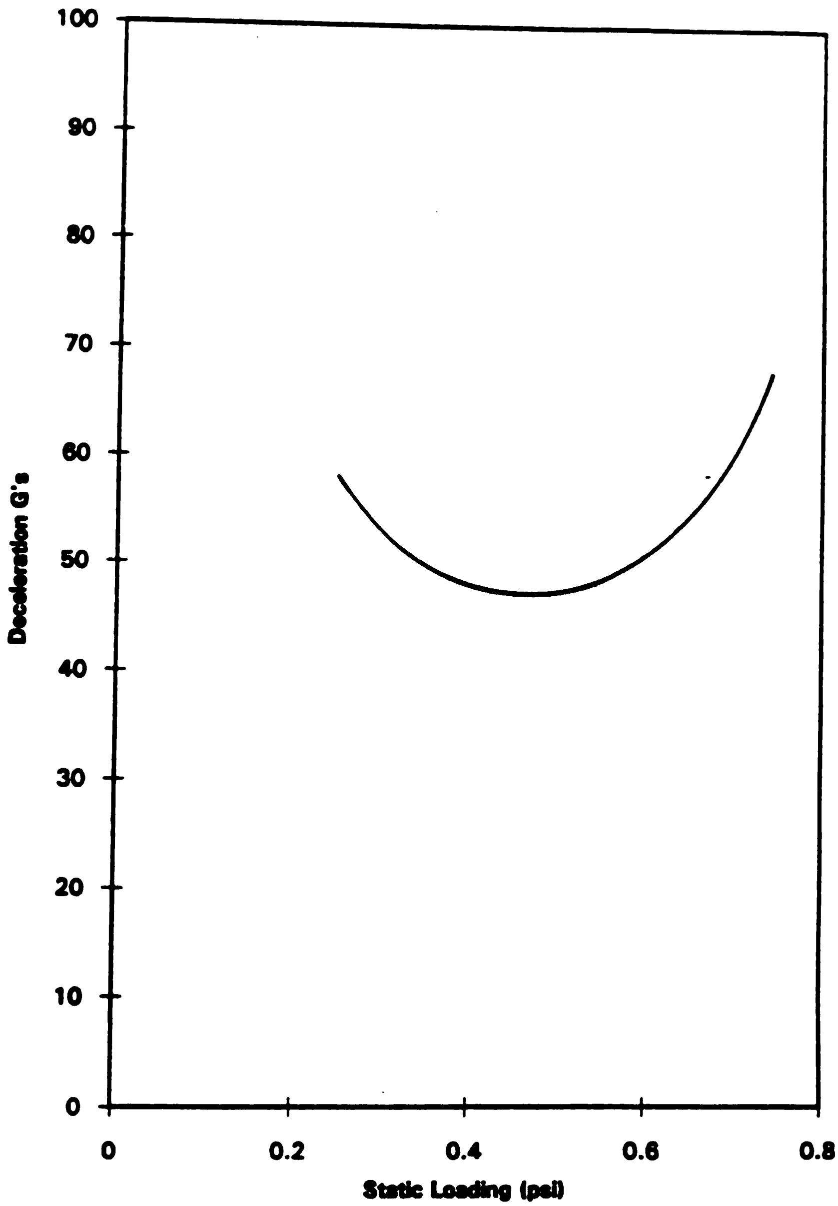


Figure B3: Cushion Curve for 3 inch thick EPS 100% recycled content from 36 inch drop height.

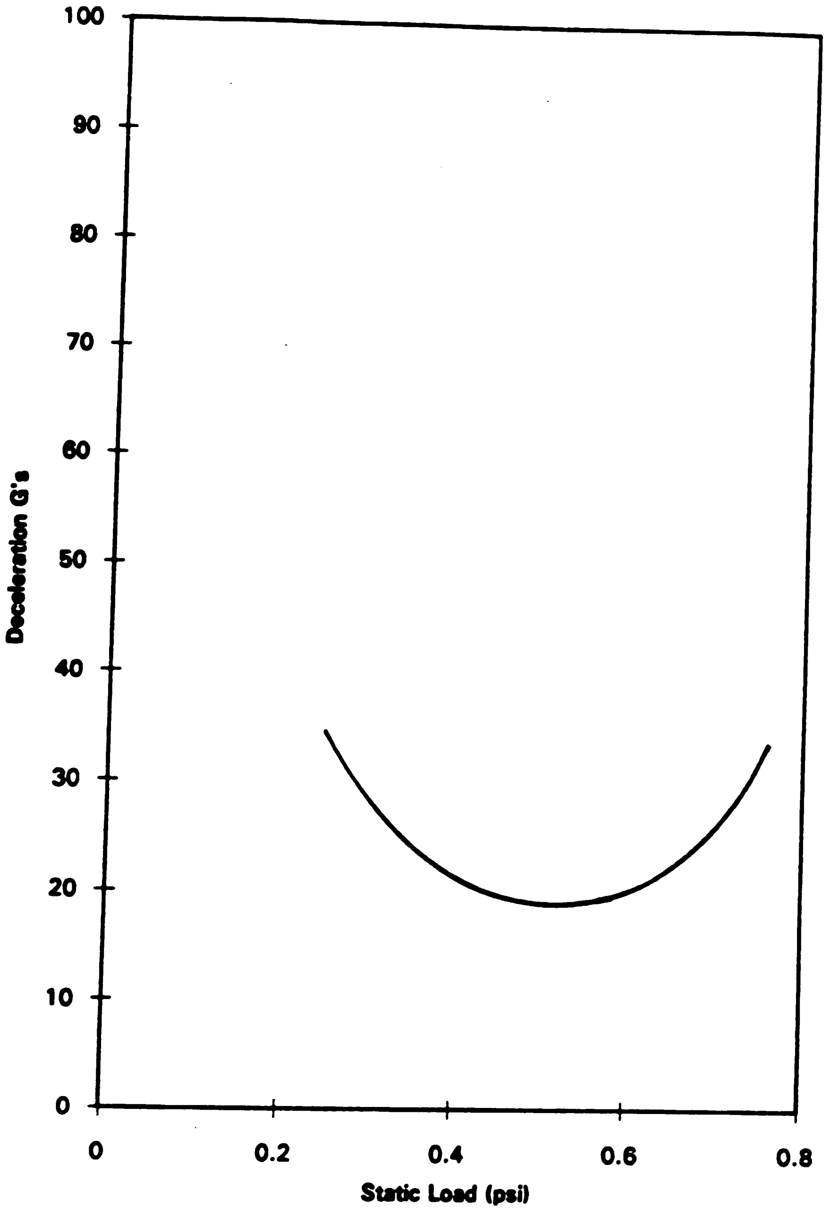


Figure B4: Cushion Curve for 3 inch thick Eco Foam from 24 inch drop height.

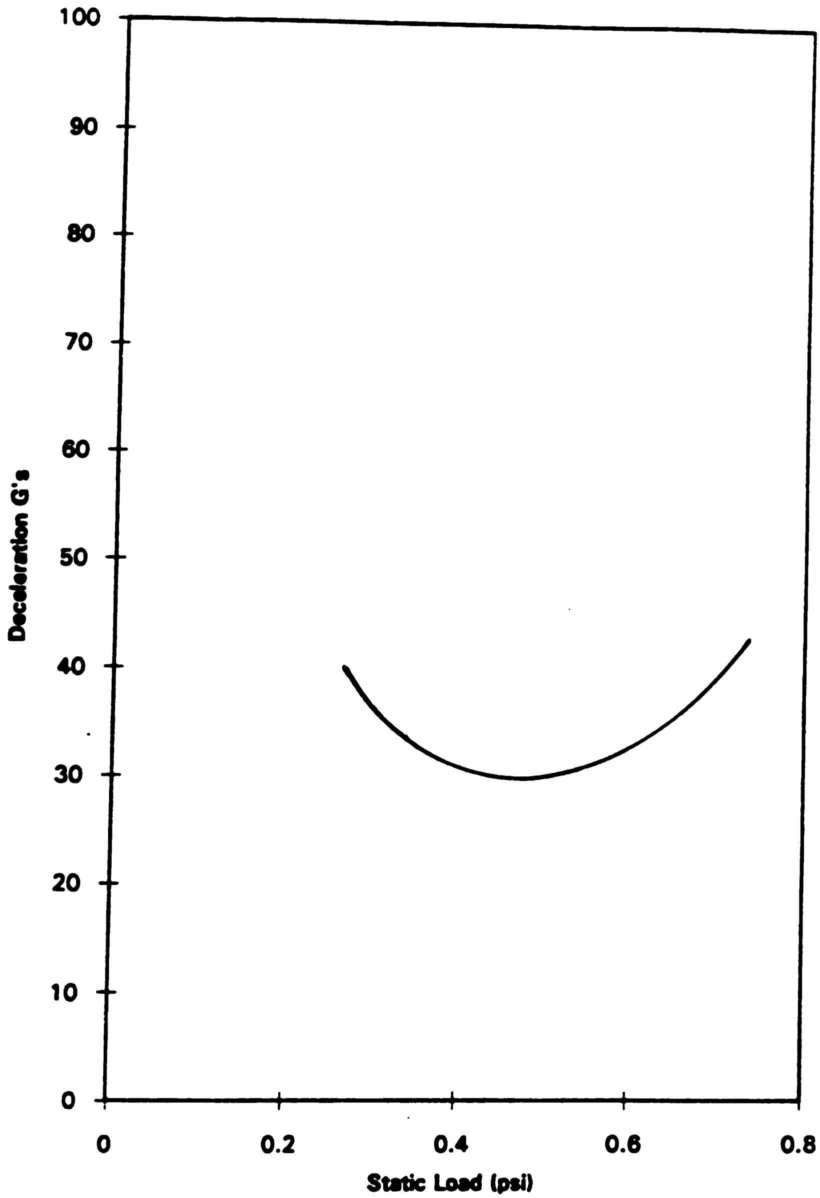


Figure B5: Cushion Curve for 3 inch thick Eco Foam from 30 inch drop height.

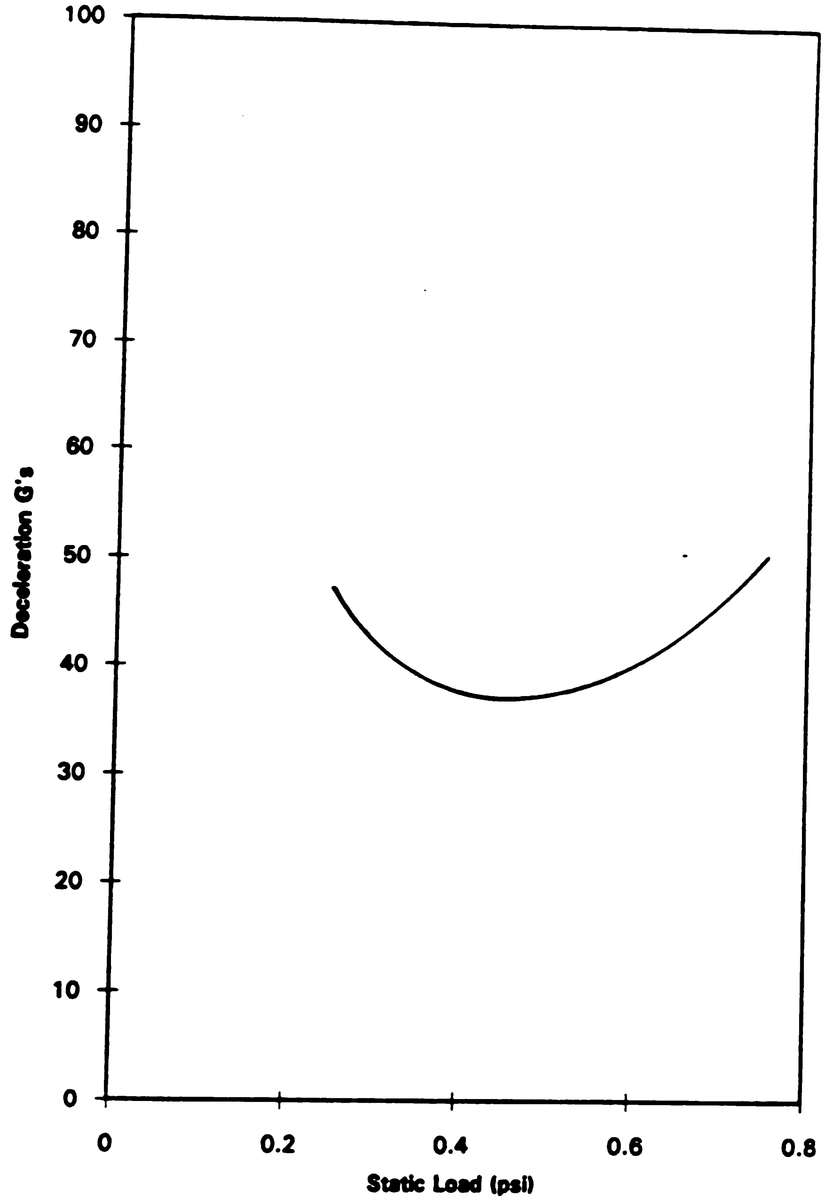


Figure B6: Cushion Curve for 3 inch thick Eco Foam from 36 inch drop height.

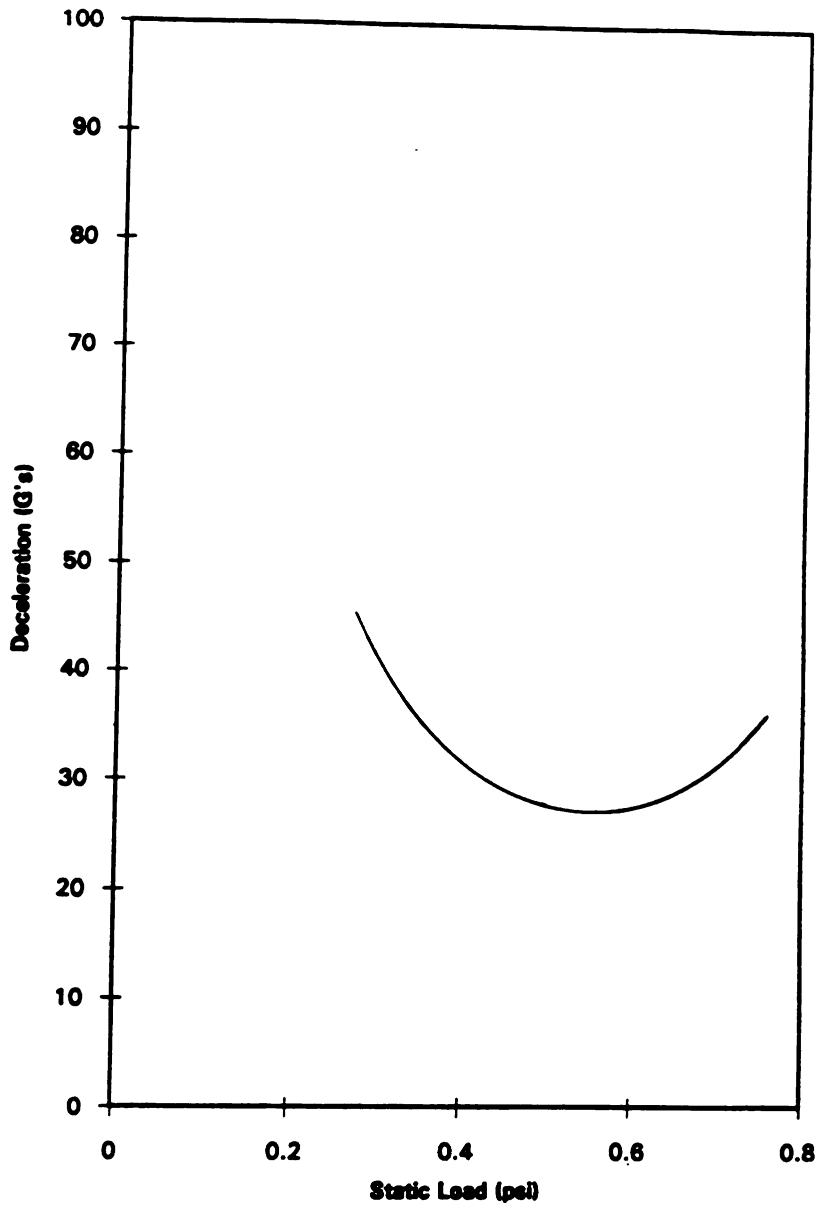


Figure B7: Cushion Curve for 3 inch thick Naturpack from 24 inch drop height.

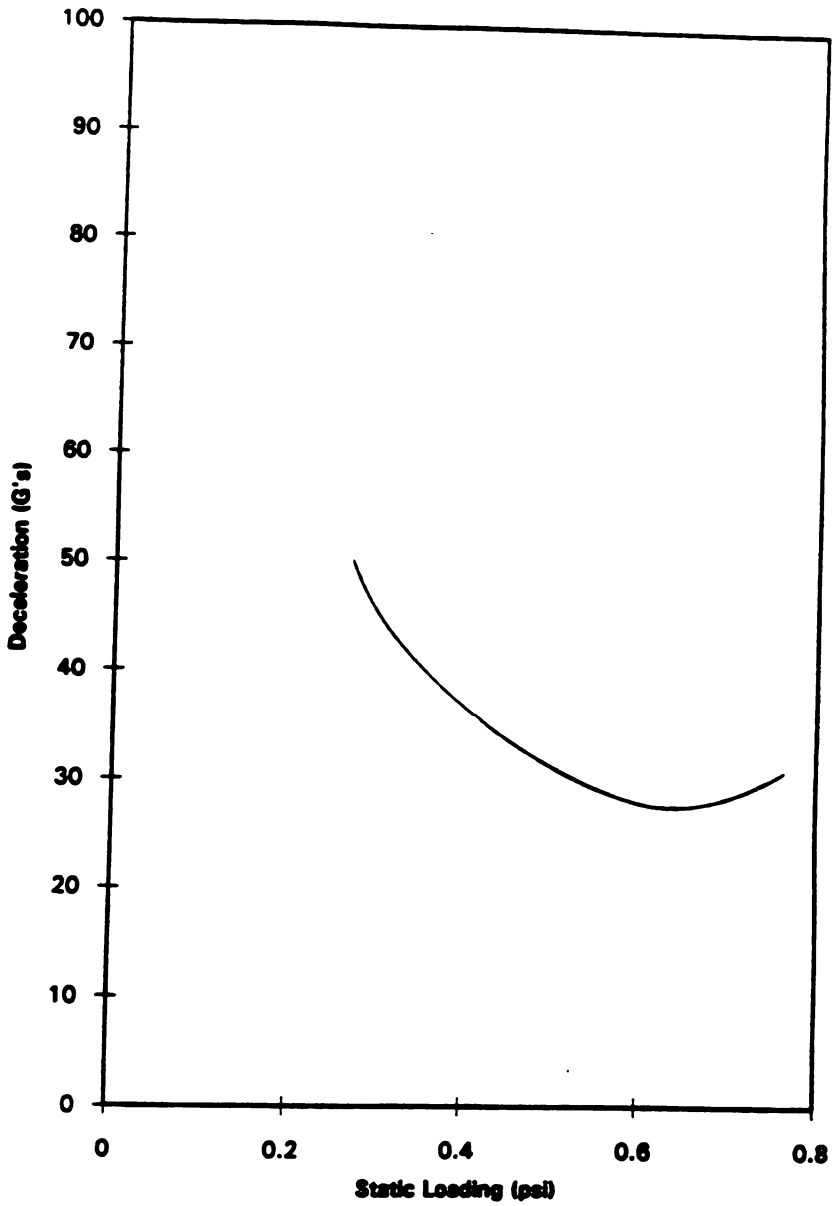


Figure B8: Cushion Curve for 3 inch thick Naturpack from 30 inch drop height.

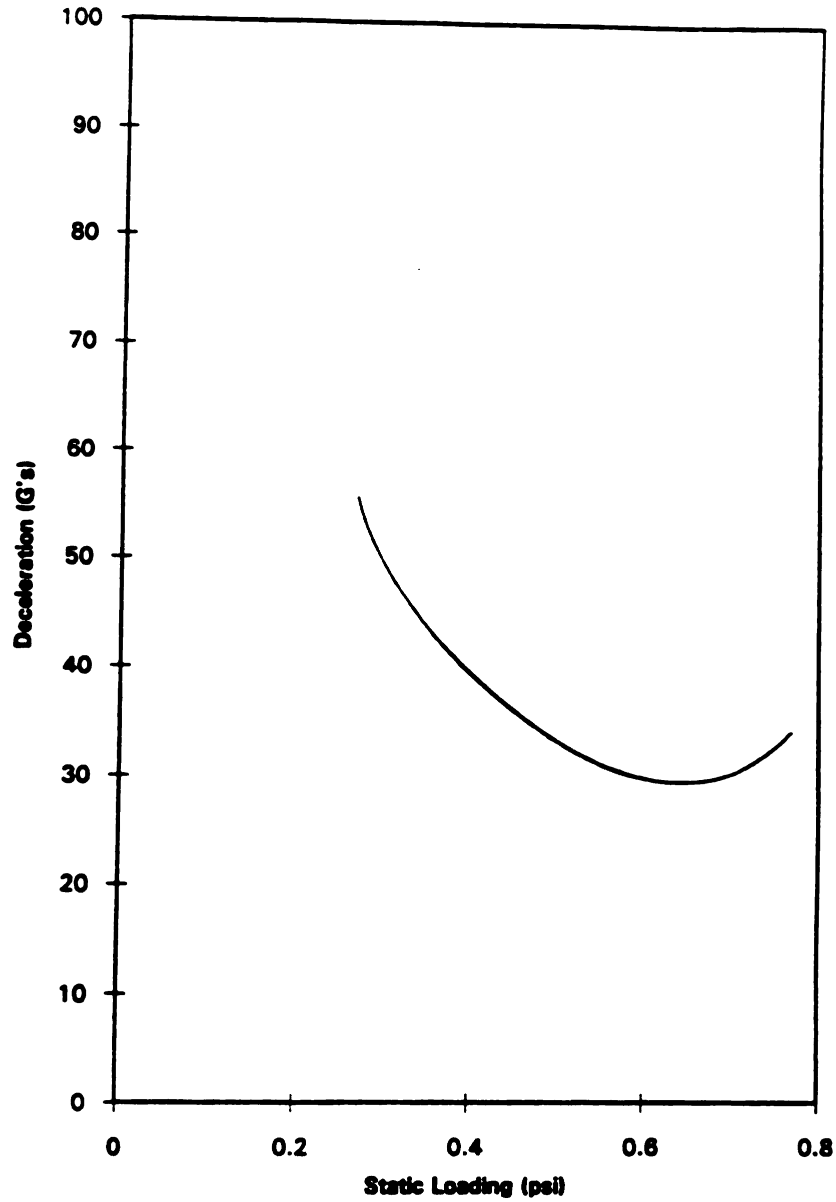


Figure B9: Cushion Curve for 3 inch thick Naturpack from 36 inch drop height.

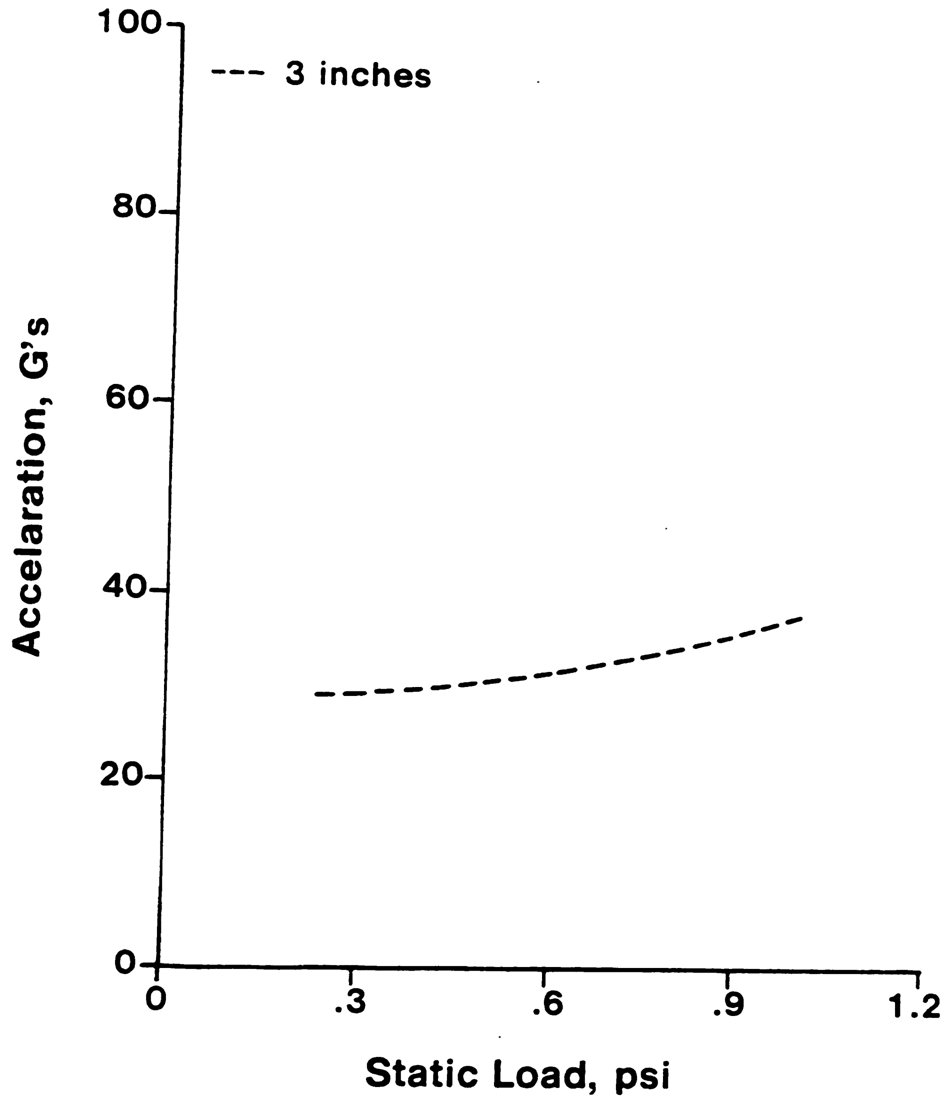


Figure B10: Cushion Curve for 3 inch thick loose fill corrugated from 24 inch drop height.

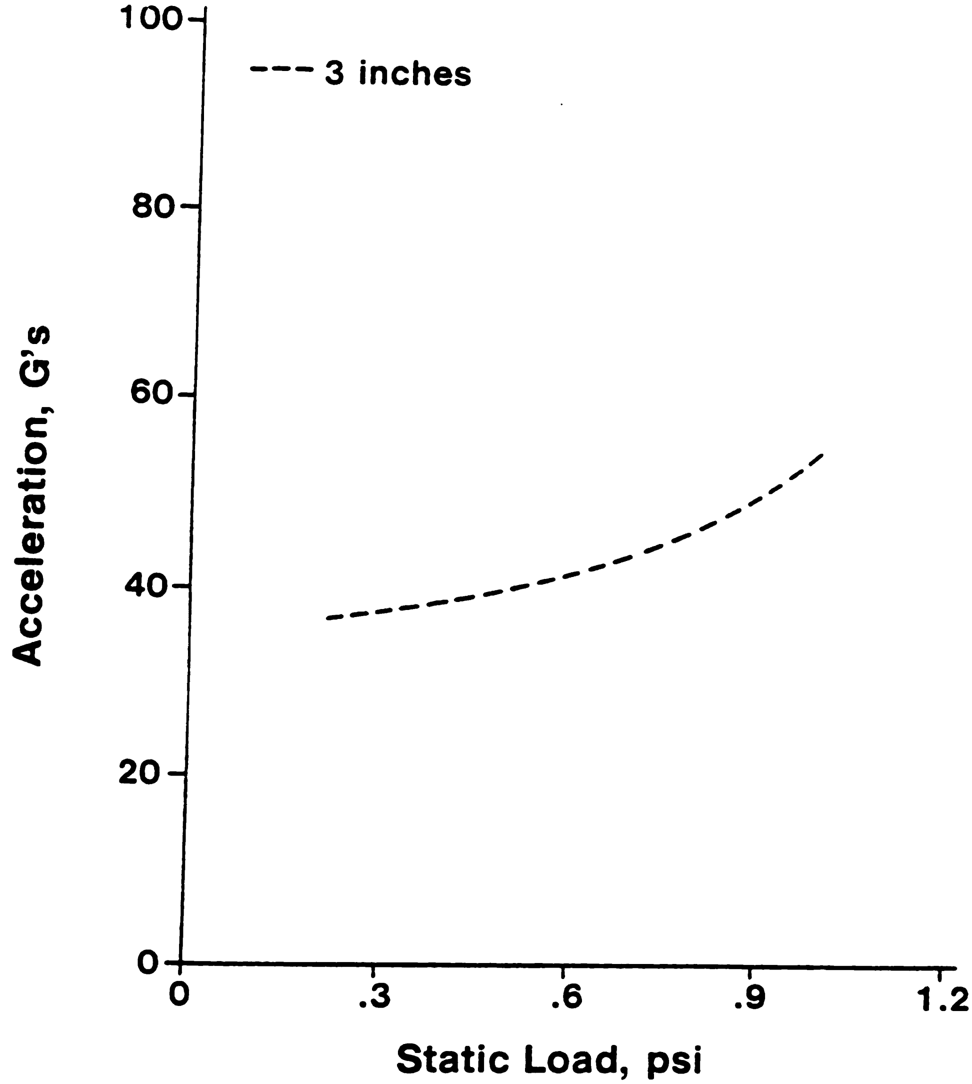


Figure B11: Cushion Curve for 3 inch thick loose fill corrugated from 30 inch drop height.

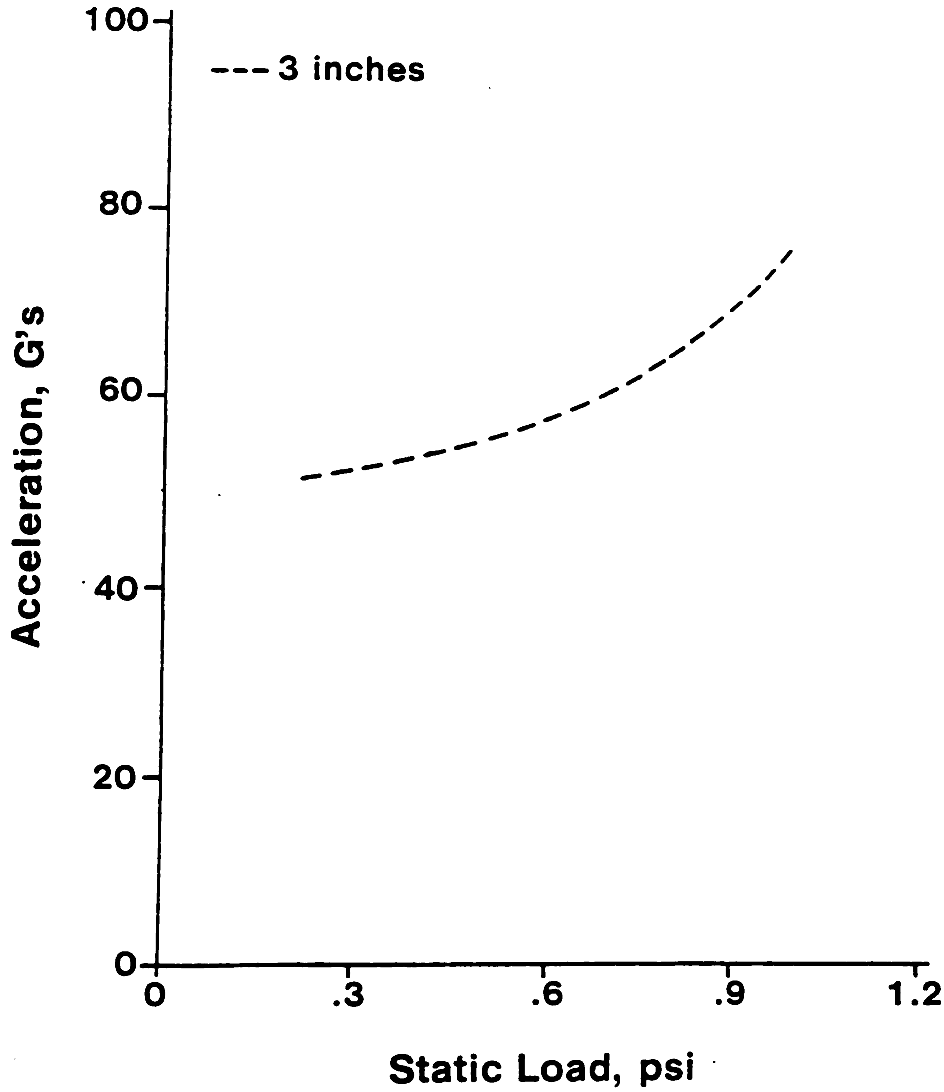


Figure B12: Cushion Curve for 3 inch thick loose fill corrugated from 36 inch drop height.

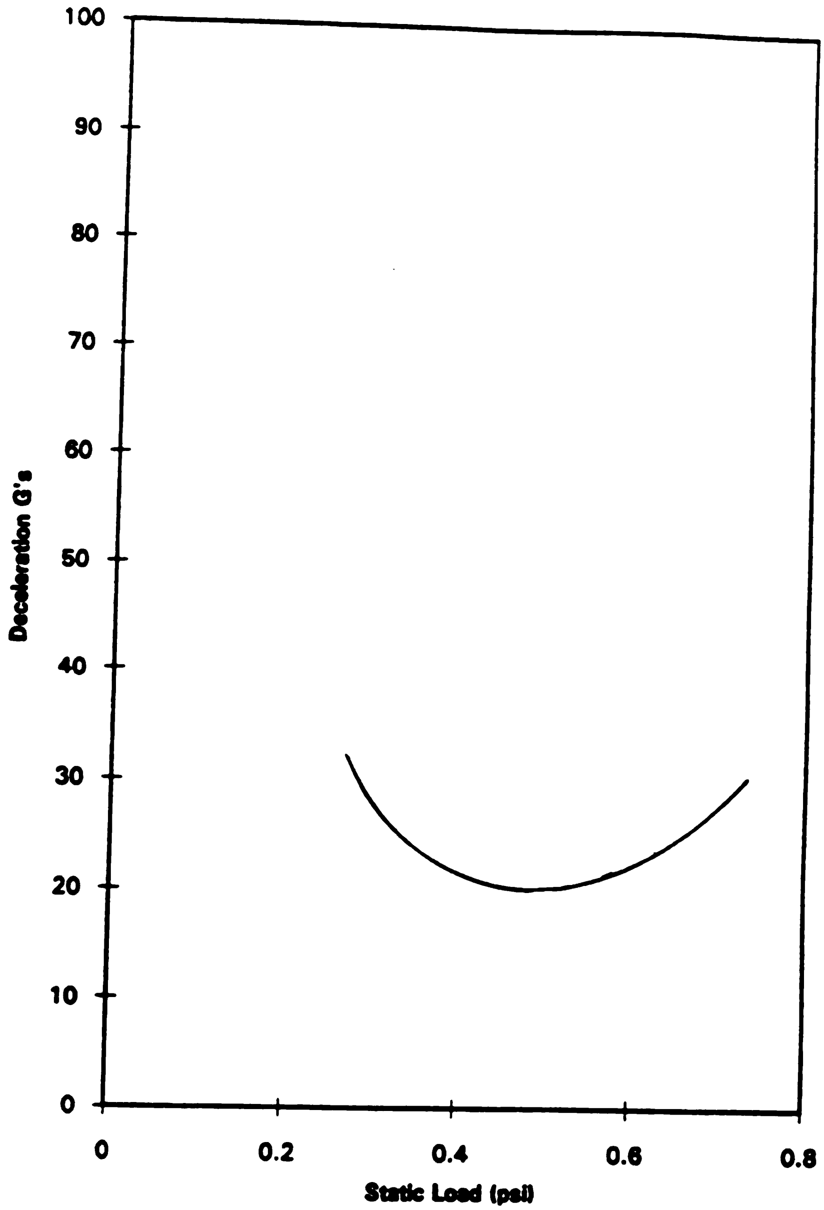


Figure B13: Cushion Curve for 3 inch thick Fiberflow from 24 inch drop height.

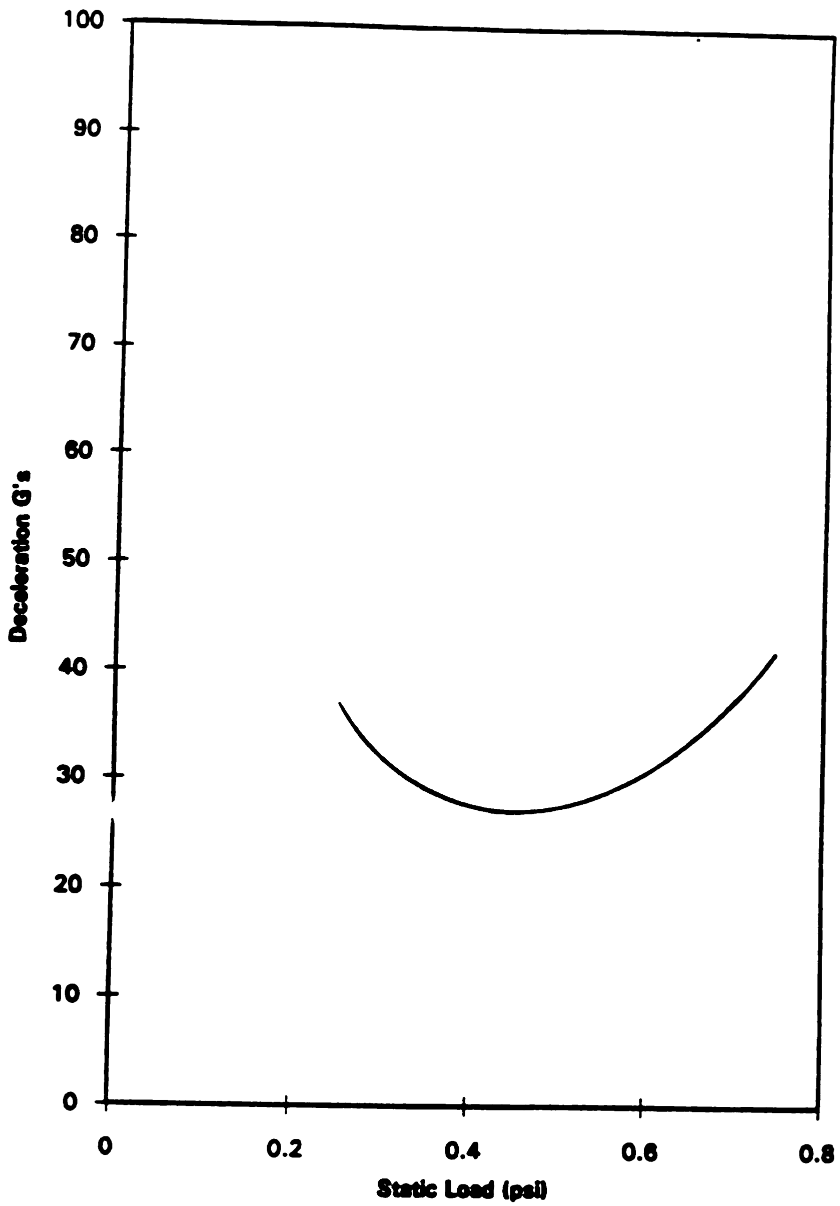


Figure B14: Cushion Curve for 3 inch thick Fiberflow from 30 inch drop height.

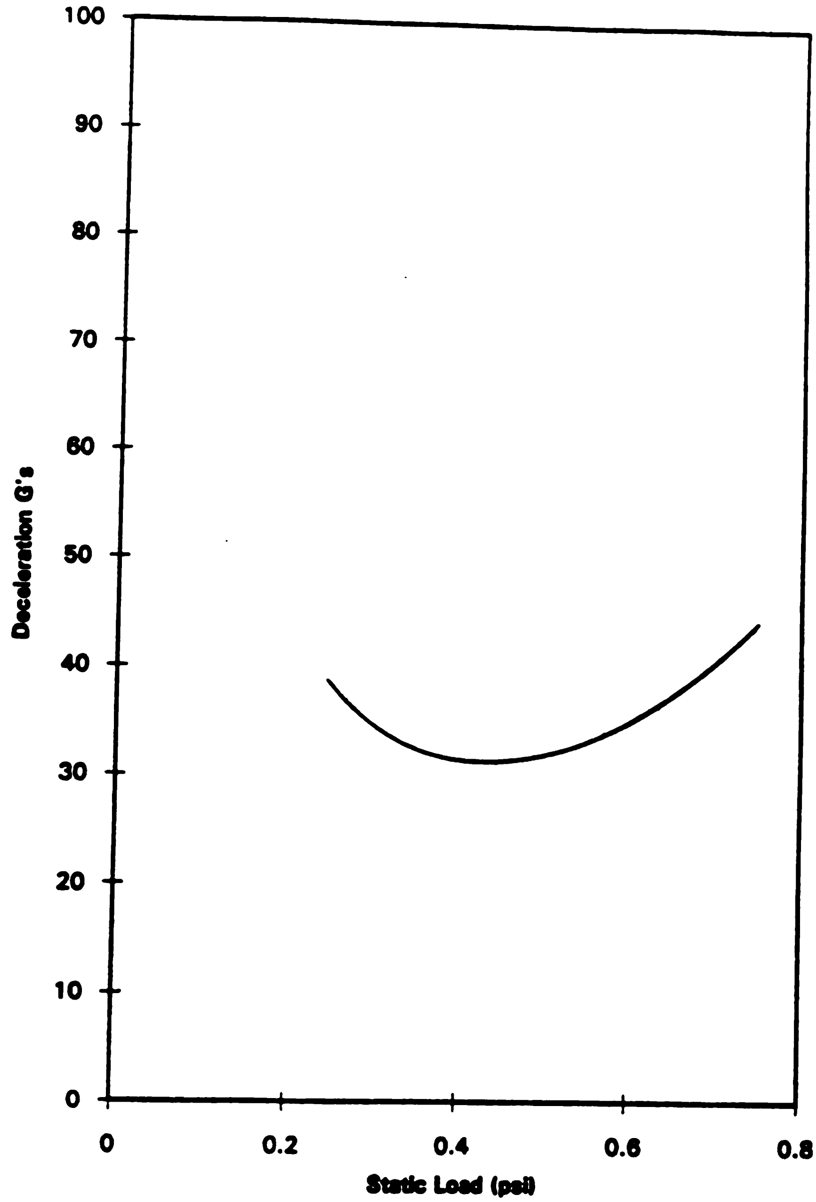


Figure B15: Cushion Curve for 3 inch thick Fiberflow from 36 inch drop height.

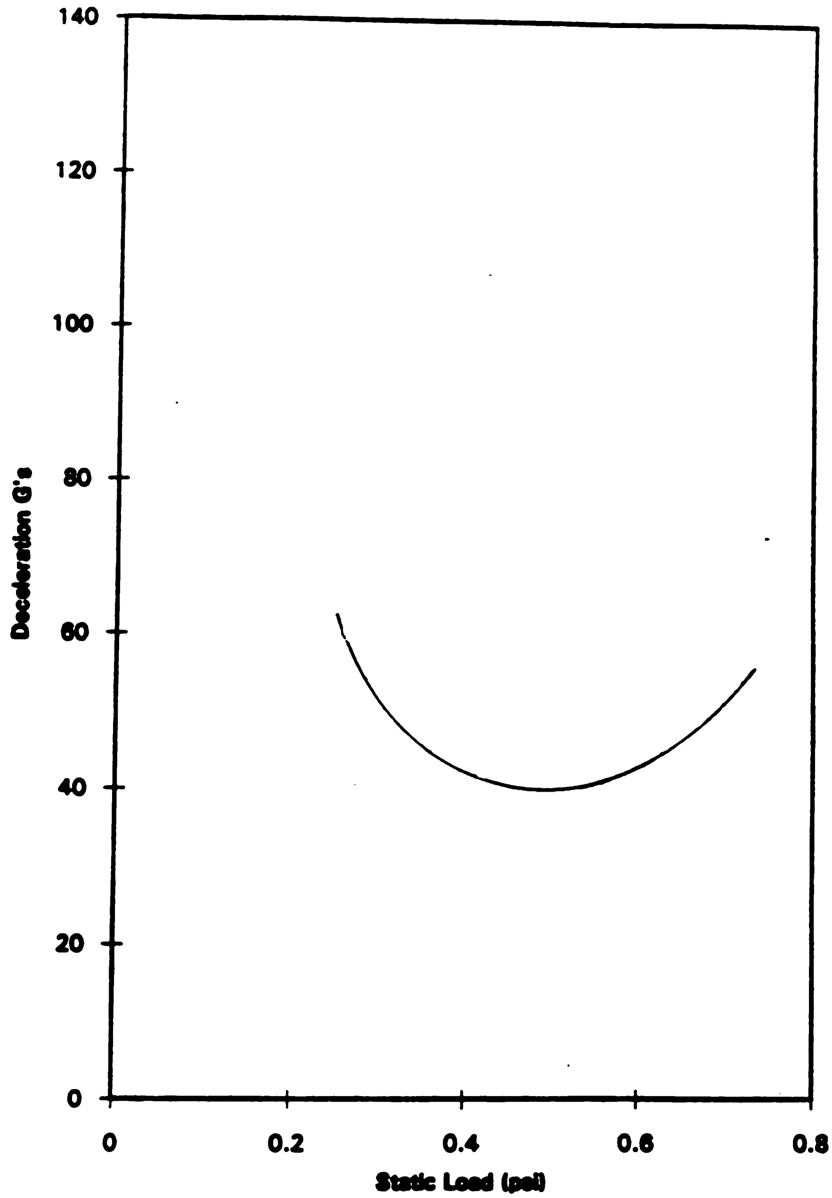


Figure B16: Cushion Curve for 3 inch thick Curl Pak from 24 inch drop height.

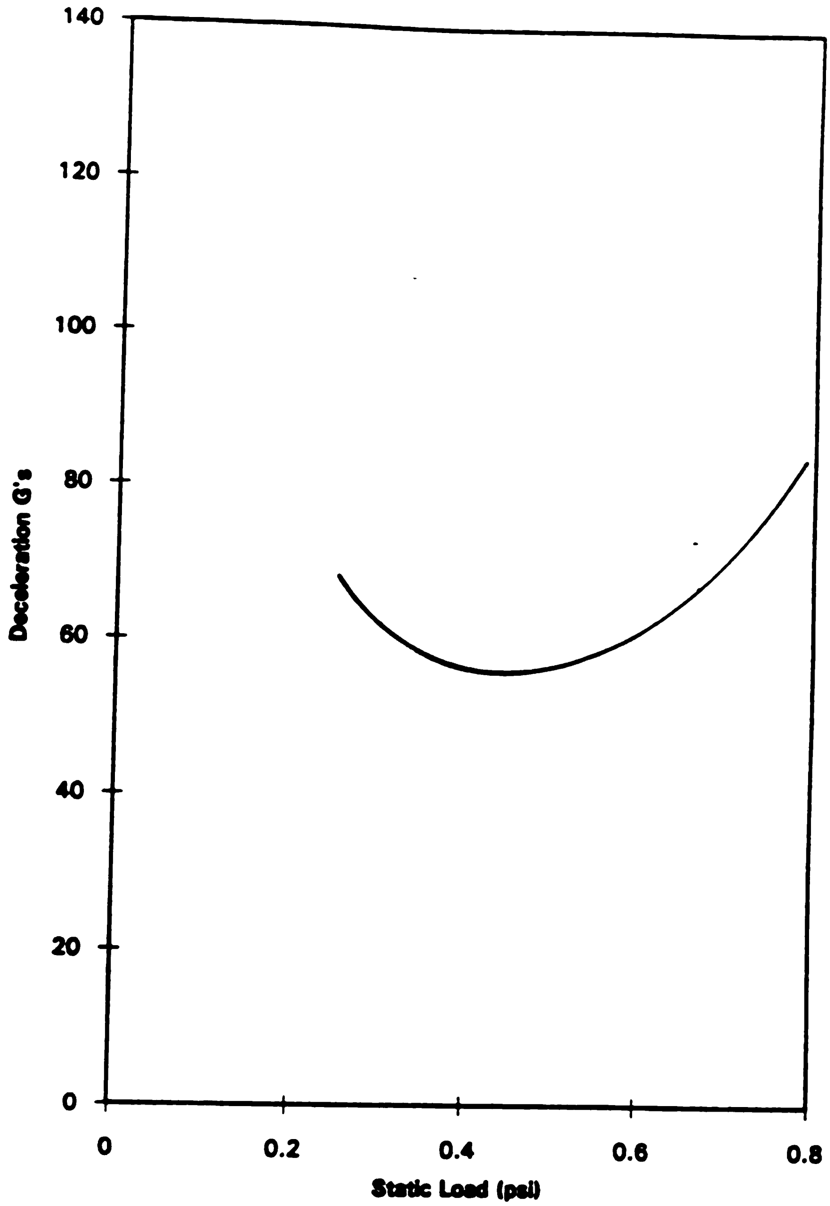


Figure B17: Cushion Curve for 3 inch thick Curl Pak from 30 inch drop height.

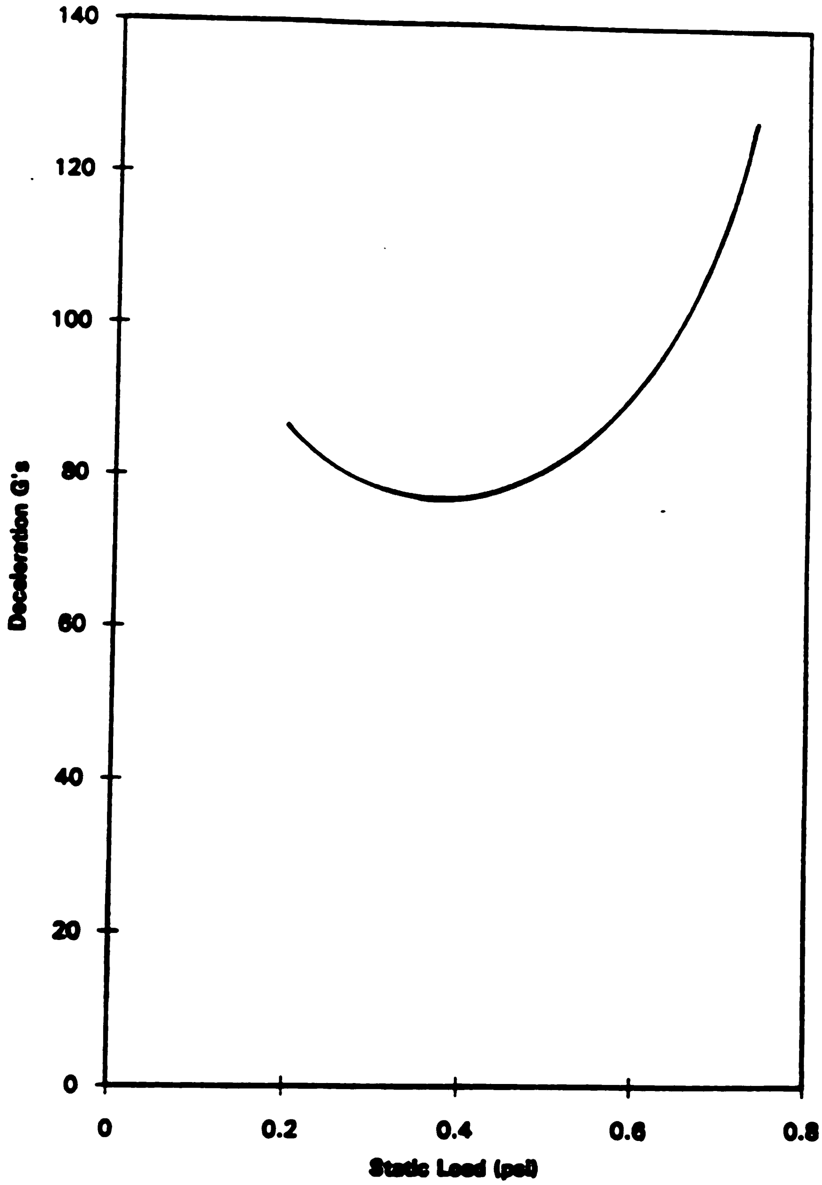


Figure B18: Cushion Curve for 3 inch thick Curl Pak from 36 inch drop height.

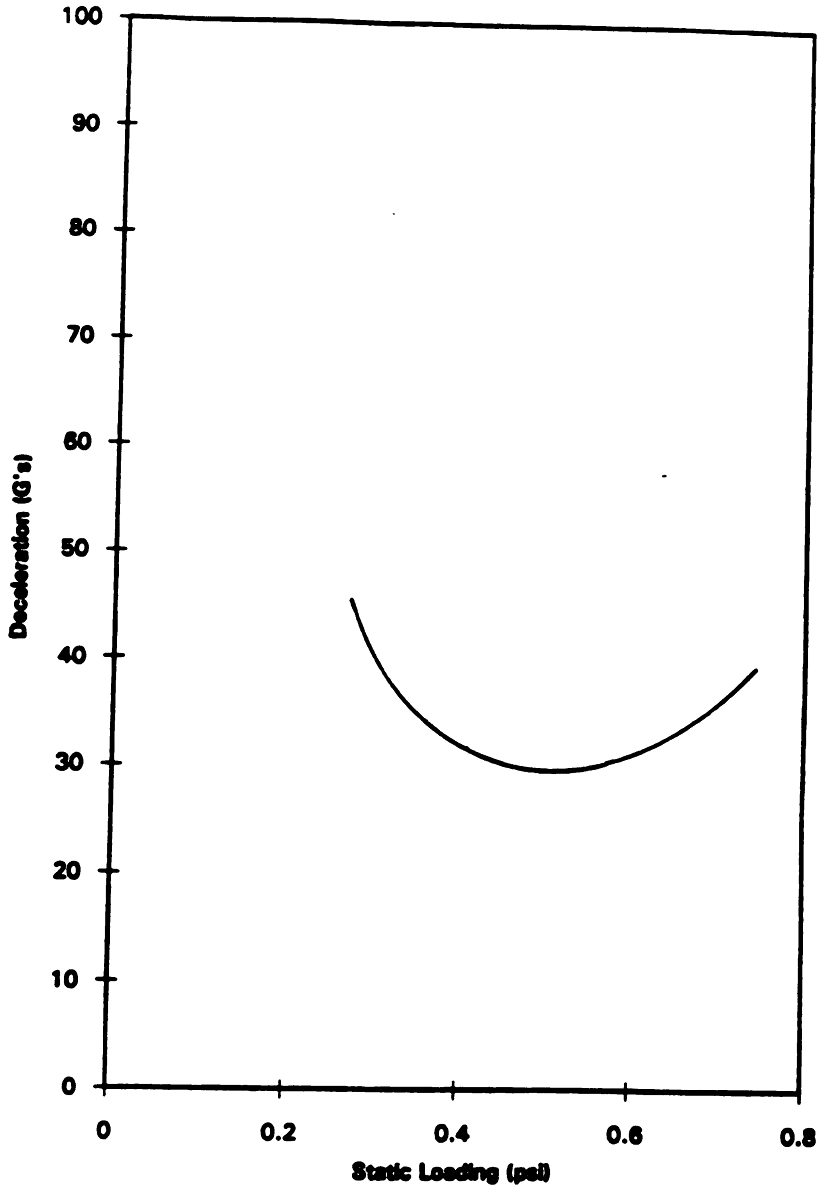


Figure B19: Cushion Curve for 3 inch thick Popcorn from 24 inch drop height.

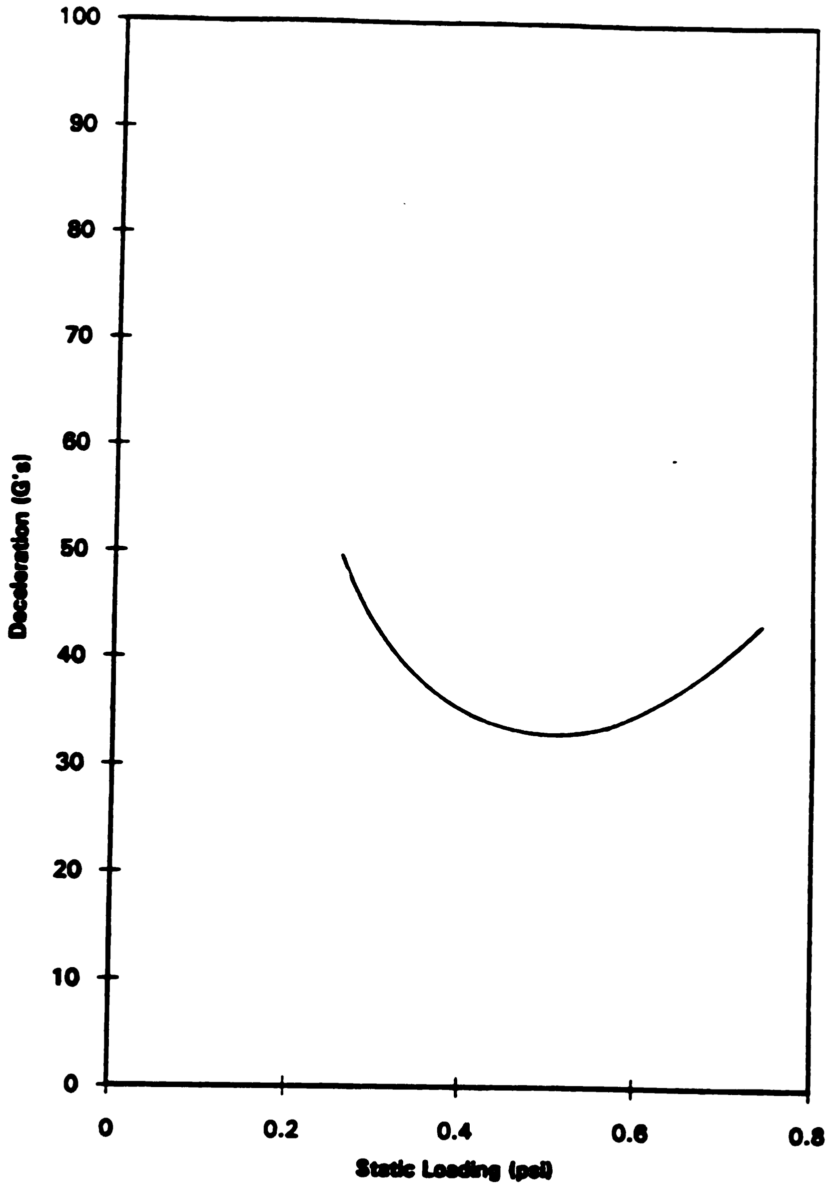


Figure B20: Cushion Curve for 3 inch thick Popcorn from 30 inch drop height.

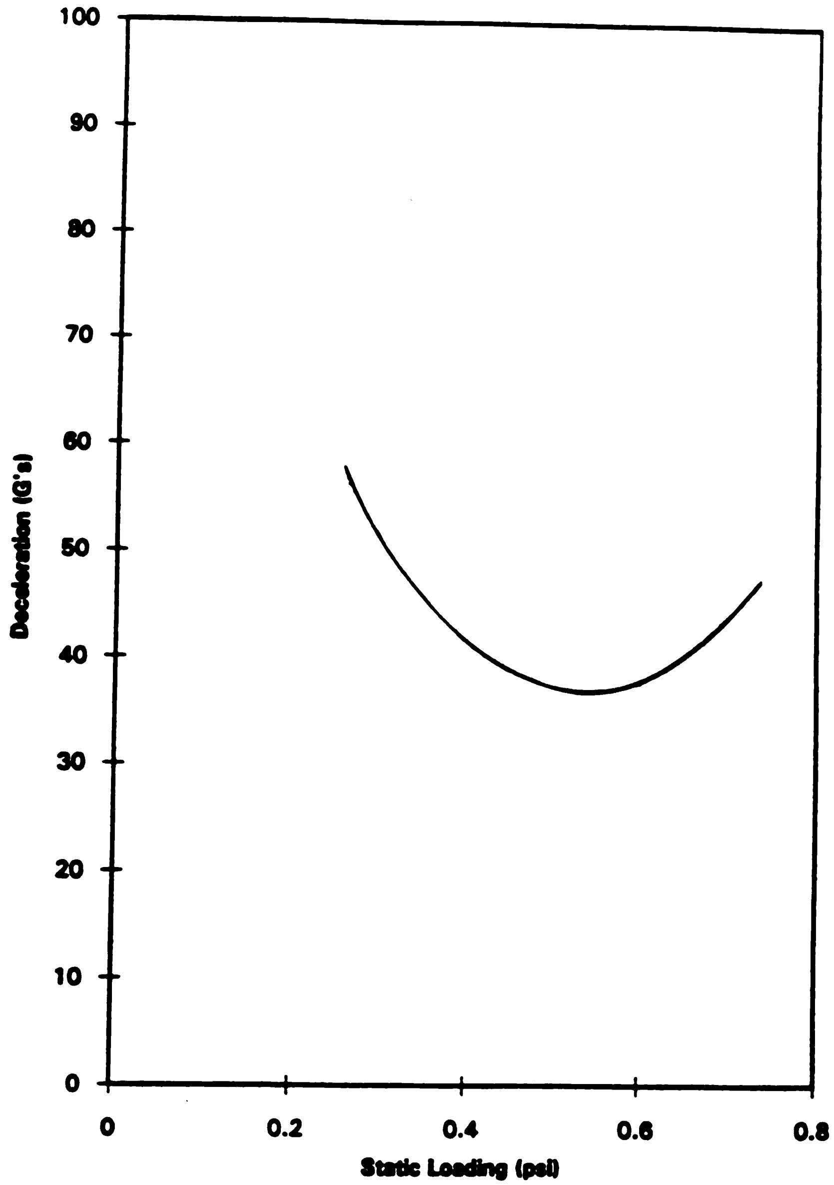


Figure B21: Cushion Curve for 3 inch thick Popcorn from 36 inch drop height.

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