This is to certify that the

thesis entitled

THE EFFECT OF MULTIPLE IMPACTS ON THE
CUSHIONING PROPERTIES OF CLOSED CELL FOAM

presented by

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has been accepted towards fulfillment
of the requirements for

M.S. degree in Packaging

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Date May 11, 1989

THE EFFECT OF MULTIPLE IMPACTS ON THE CUSHIONING PROPERTIES OF CLOSED CELL FOAM

By

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

School of Packaging

1989

ABSTRACT

EFFECT OF MULTIPLE IMPACTS ON THE CUSHIONING PROPERTIES OF CLOSED CELL FOAM

By

Troy Leonard Totten

This study investigated the effect of multiple impacts on closed cell cushions. The goal of this research was to describe the change in the dampening characteristics of a closed cell foam due to multiple impacts and to quantify the mechanical property loss of closed cell cushions used for shock protection as it relates to reusable packaging. A trend towards cost effective reusable packaging has been observed within that part of the packaging community using cushion dunnage. Manufacturers of closed cell cushioning material traditionally publish cushion curves for a given material only for a limited number of impacts. The lack of published data describing cushion performance after repeated impacts is the basis for this study. Cushion curves and stress-strain curves for up to fifteen compressions were derived for three molded closed cell foams. The data demonstrated that although the mean percent increase in transmitted shock was greatest from the first impact to the fifth impact, the mechanical and structural properties continued to change with subsequent impacts. The cushion curves for a particular foam demonstrated increasing shock transmission due to multiple impacts and significant permanent deformation due to cellular rupture.

Dedicated to my parents, Ralph and Marie Totten, and to my grandmother, Elizabeth Heyboer, who have contributed in so many ways that to thank them for everything would double the size of this manuscript. Their enduring love, support, and frequent financial assistance sustained me during both happy and trying times. Not only have they helped me complete my formal education, but they have taught me, by example, values that I shall strive for throughout my personal and professional life. I hope that in some small way these words convey the love, respect, and appreciation I have for them.

And to my brother, Tracy Totten, who has taught me by example to be committed and dedicated to my work.

ACKNOWLEDGMENTS

I wish to express my deepest gratitude to Dr. Paul Singh, who served as my major professor, for his assistance in the completion of this thesis. I would also like to express my sincere appreciation to Dr. Gary Burgess who took the time to thoroughly discuss my concerns and questions and whose supervision and technical assistance was invaluable in the completion of this thesis. Special thanks to Dr. George E. Mase for his assistance as a member of my graduate committee and for raising some questions I had not considered. I am particularly grateful to Jorge Marcondes for his laboratory equipment assistance.

I would also like to thank Jim Sheppard, Building Manager of the Student Union, for the opportunity to work as a student manager for the past year and a half. This employment experience has greatly enhanced my education and has provided the necessary financial support to complete my graduate work.

I am also greatly indebted to the ARCO Chemical Company and the Dow Chemical Company for their generous donation of test materials.

I would also like to thank my dear friends Tony, Paula, George, and Dave who helped celebrate my triumphs and soften my defeats.

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbol	Notation
ASTM	American Standard Testing Method
β	Ratio of Strut Diameter to length
g	Acceleration of Gravity
G	Shock Transmission(Peak Acceleration)
h	Drop Height
m	mass
mv	millivolt
MHz	Megahertz
pcf	Pounds per cubic foot
t	thickness
b	Width of Trigger Blade
σ	Stress
ε	Strain

1.0 INTRODUCTION

In the handling and distribution of a package, there always exists the hazard of shock. A shock is created when a moving object strikes a rigid surface. The rate at which the object's kinetic energy is dissipated determines the deceleration of the object and thus the magnitude of the shock. The damage done to a product is dependent on the transmitted shock, the velocity change, and the number of impacts. The purpose of a cushion is to reduce the shock by extending the distance over which the packaged product is brought to rest in an impact. The traditional method for quantifying the shock dampening characteristics of a closed cell foam is the cushion curve. Derived specifically for a particular material type, density and thickness, the cushion curve relates the transmitted shock under dynamic compression to various static loads. In the design of cushioned package, one must determine not only the type and density of the material to be used but the necessary size parameters such as thickness and bearing area needed to protect the packaged object under specific dynamic conditions.

In the past, static tests were conducted prior to dynamic testing to determine the dampening characteristics of foam (Kerstner, 1957). Static tests produce the load versus deflection relationship for a cushion while dynamic tests describe the shock transmitted under free fall conditions. The reason for the initial interest in static measurements was to avoid the time consuming and costly testing necessary to generate a family of dynamic cushion curves for a specific material. The Kerstner study began by outlining statically derived cushion factors used to describe the mechanical properties of a cushion but then clearly states that, "Unfortunately this procedure is subject to serious errors. The strain rate effect on the stress-strain response of the cushion can be significant at the strain rates experienced in drop impacts." Kerstner found that the stress-strain curves vary significantly with the rate of deformation and therefore admits that "when there is a choice between using cushioning information determined statically or dynamically for absorbing the shock of a drop, the dynamic information is preferred." The dynamic data is preferred because the materials have inertia and exhibit internal damping.

A static compression test reveals the resilience of the foam material. A cushion sample is placed into a compression testing machine and the force required to compress the cushion a given amount is recorded. From this information, the energy stored in the cushion at a given compression can be determined. Typically, the energy absorbed during loading is greater than the energy released during unloading. This effect is described as hysteresis and is caused by a portion of the kinetic energy being converted into heat energy due to air compression and friction. The cushion is said to behave inelastically.

In this study several static compression tests were conducted on the Dow Chemical product Ethafoam™ 220 and three ARCO Chemical products, ARPRO™, ARCEL™, and ARPAK™ using a Lansmont model number 76-5K compression tester in order to establish at the outset that the properties of closed cell cushioning material continue to change due to multiple compressions. The stress-strain curves generated demonstrate the marked change in resilience after each successive compression. The greatest loss in resilience occurred after the first compression but additional smaller losses occurred with each successive compression. The stress-strain curves became progressively more linear in the low deflection range due to multiple compressions Region(C). A typical stress-strain curve is displayed in Figure (1). During the first compression, the cushioning material deforms elastically up to Region (A) in Figure (1). Region (A) in the first compression stress-strain curve represents the initial buckling of the cushion cell walls which effectively eliminates the contribution of the cell wall structure to the overall compressive resistance of the cushion. The bulk of the compressive resistance thereafter is due primarily to the compression of trapped air once all the cells have buckled. The stress-strain curves for the fifth, tenth and fifteenth compressions demonstrate that the cell walls are permanently deformed and offer very little resistance to compression as they hinge at their buckle points. At strains above 0.4 (in/in) the multiple compression stress-strain curves in Figure (1) appear to indicate that the cushion gets stiffer with repeated compressions (Region B). This in fact is not the case and is due to the calculation of strain based on the true thickness prior to compression. The stress-strain curves for all of the closed cell cushion samples obtained during this study are presented in Appendix C.

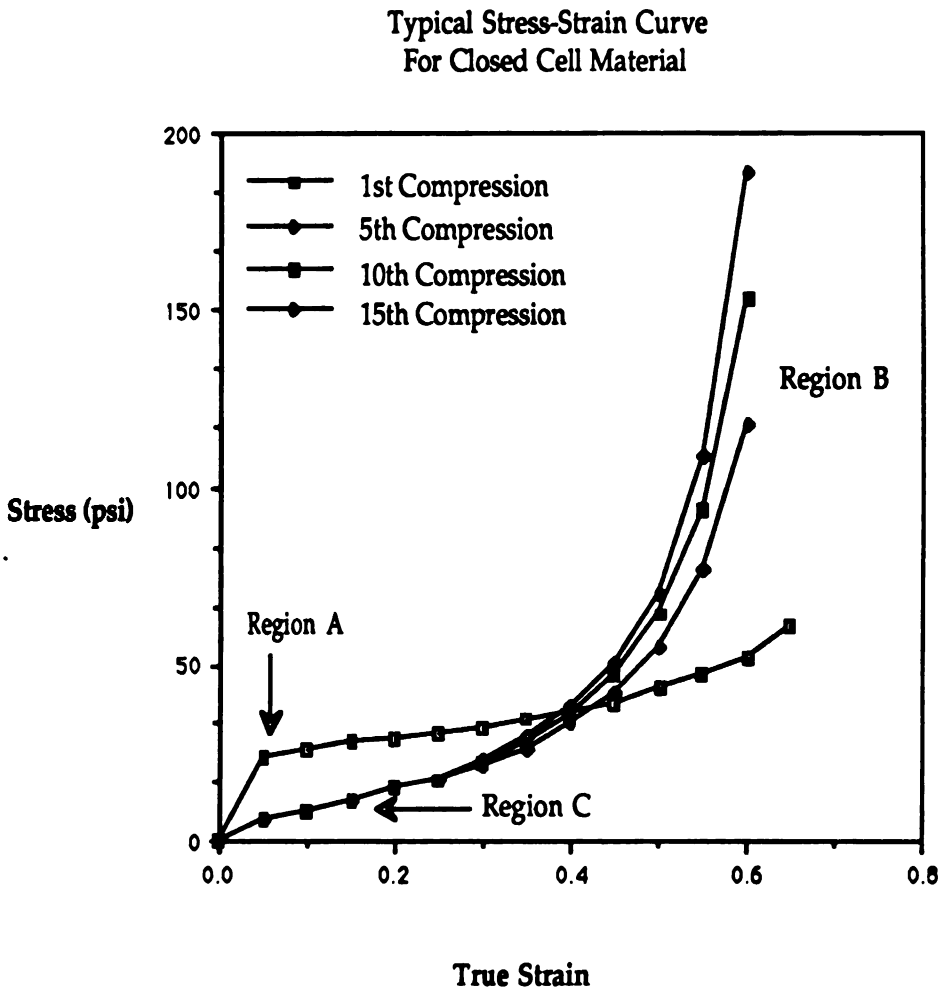

Figure 1. MECHANICAL PROPERTY LOSS OBSERVED DUE TO MULTIPLE COMPRESSIONS OF ARCEL™

The compression of a closed cell foam can be modeled as the isothermal compression of trapped air. The gas law for this process states that the product of pressure and volume of the trapped air remains constant. For a cushion plank under load W then,

$$P_a A t = (Pa + W/A) A (t - z) \qquad (1-1)$$

where: P_a = standard air pressure
A = cushion's bearing area
W = force on the bearing area
t = initial thickness of the foam
z = deflection due to the compressive force

Dividing Equation (1-1) by t and assigning W/A as the static stress and z/t as the strain, the static stress-strain curve for the closed cell cushion becomes,

$$\sigma = P_a \, \epsilon / (1 - \epsilon) \qquad (1-2)$$

where: σ = static stress
ϵ = strain

While the surrounding air pressure remains constant, the corresponding internal cell pressure increases to $P = P_a + \sigma$ as the cell is compressed. This means that cells near the edge of the cushion experience a significant pressure differential across the cell wall which sets up a tensile stress in the material. If a cell is considered to be spherical then the stress is the pressure differential multiplied by the radius of that cell and divided by twice the thickness of the cell wall. If the cell is nonspherical, the stress may be subsequently higher than this. If the stress in the cell wall exceeds the yield point for the material, then the cell will rupture. As the cells near the edge of a cushion rupture, the pressure differential progresses toward the center and therefore as a cushion is repeatedly compressed, the number of ruptured cells increases.

One of the earlier models of a foam which attempted to describe the stress versus strain curve was the the Gent - Thomas model which considers a foamed rubber cushion as a "thin thread" or "girder and beam" structure, where all of the cushion material resided in cylindrical struts (A. N. Gent, A. G. Thomas, 1963). The stress-strain curve was described by,

$$\sigma(\epsilon) = \frac{E_o \beta^4 f(\epsilon)}{(1+\beta)^2} \qquad (1\text{-}3)$$

where: E_o = Young's modulus of elasticity
$\sigma(\epsilon)$ = stress as a function of strain
β = ratio of strut diameter to length
$f(\epsilon)$ = function of strain

Upon initial compression, the "strut" or cell wall buckled allowing the foam to deform. Upon relaxation, the cell structure will nearly return to its initial shape but a flex point in the cell wall will be established. Figure (1) shows that once the cell wall buckles, the stiffness of the cushion is thereafter diminished. Also demonstrated by the difference between the first compression and the fifth compression in Figure (1). The cell membranes therefore provide initial resistance to compression but only act to contain the cell gas thereafter. After the cell wall bends, the force required to continue compression is determined mainly by the resistance of air compression. As the cushion is repeatedly compressed, the destruction of cellular integrity propagates from the surface of the cushion inward. In addition to the changes in the mechanical properties, structural changes were observed in the form of permanent deformation. This permanent deformation, attributed to the destruction of cellular integrity as cells rupture, suggests that the response of the foam to multiple impacts will also change.

It has also been shown that in extruded foams, the cell membranes do not yield uniformly because of cell size and dimensional variations (Throne, J.L., 1984). In extruded foams, the surface layers are subjected to greater constraining forces than the center during formation which could cause the cellular characteristics to change depending on thickness. Foams with an average cell size of 500 -

1500μ exhibit compression of the outer cells first while the cells in the center distort very little. As compression continues the lines of collapsed cells propagate toward the center. In foams with an average cell size of 25 - 50μ, all cells appear to distort uniformly under compression. The study concluded that the stress-strain compression of closed cell low density polyethylene foam is dependent on the cell size.

In addition to cell size, the orientation of the cushion during compression is important. As observed during compression testing, the orientation of cells aligned elliptically is of importance (Benning, C. J., 1969). It was shown that the compressive strength of a foam containing orientated cells was higher in the direction of orientation than the strength of the foam perpendicular to this orientation. An additional study was conducted in this thesis to identify any mechanical property variations due to cell geometry. The study revealed that at low deflections, Ethafoam™ 220 demonstrated a stress-strain variation relative to cushion orientation during compression. The compression tests indicate that in an extruded foam, cellular orientations with the major axis parallel to the direction of extrusion gives the greatest compressive strength (Figure 2).

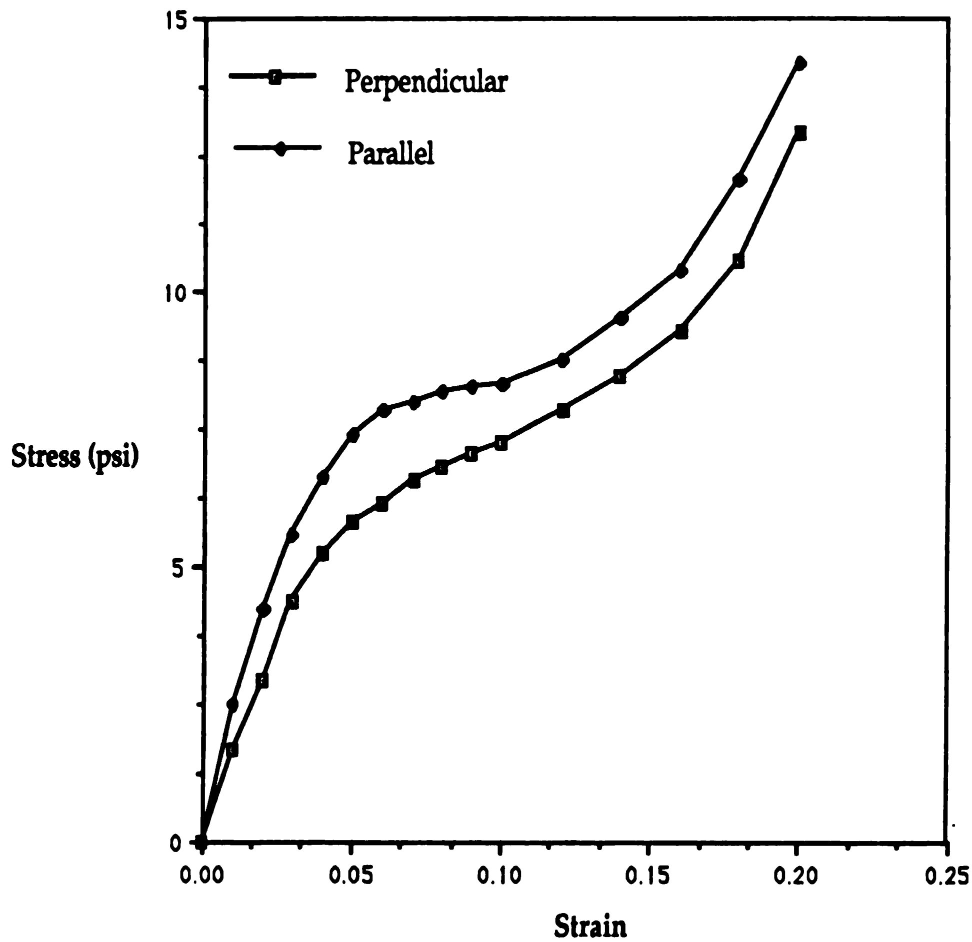

Figure 2. MECHANICAL PROPERTY VARIATION OBSERVED DURING COMPRESSION TEST DUE TO CELL ORIENTATION

The orientation of the cells is therefore expected to be of great importance in the performance of a cushioning system since the dampening characteristics differ depending on the cell structure and orientation. One should therefore consider this when an end or side face of a container is lined with closed cell cushioning material.

The development of a procedure for determining the shock mitigating properties of a closed cell cushioning material is based on energy conservation principles and experimentally determined material deformation relationships. The basic theoretical approach used to describe the impact loading of a cushion involves an energy balance between the impacting object and the cushion and a force balance based on Newton's law. In order for this procedure to be carried out, it must be assumed that the static stress-strain curve is a sufficiently accurate representation of the dynamic stress-strain relationship during impact.

The dynamic deflection is first determined as the point on the stress-strain curve where the area under the curve (the absorbed energy) equals the weight multiplied by the drop height (the object's potential energy). Integration of Equation (1-2) gives the area under the stress-strain curve and the energy balance becomes Equation (1-4).

$$\ln(1 - \varepsilon_m) + \varepsilon_m = -(SL/P_a)(h/t) \qquad (1\text{-}4)$$

where: ε_m = dynamic strain
SL = static load = W/A
h = drop height
t = cushion thickness

The transmitted shock G from Newton's law is G = force/weight or

$$G = (P_a/SL)\varepsilon_m/(1 - \varepsilon_m) \qquad (1\text{-}5)$$

For a given static loading, drop height, and thickness, Equation (1-4) gives the dynamic strain and Equation (1-5) gives the corresponding shock. Unfortunately, Equation (1-5) is difficult to solve for ε_m in general. An approximate solution to equation (1-4) for higher compressions(as ε_m approaches one) can be obtained by noting that the $\ln(1 - \varepsilon_m)$ term dominates ε_m. Ignoring ε_m then leads to

$$\varepsilon_m = 1 - e^{-(SL \bullet h / P_a \bullet t)}$$

The transmitted shock is now obtained from Equation (1-5) by again using the fact that ε_m is nearly one is,

$$G = (P_a/SL)\, e^{-(SL \bullet h/P_a \bullet t)} \qquad (1\text{-}7)$$

Equation (1-7) represents the entire set of cushion curves for closed cell foams. It can be shown by direct comparison that Equation(1-7) agrees fairly well with many of the sets of published cushion curves for low density foams. Still, there are points of disagreement most likely attributed to the model used. The strain energy that a cushion must absorb in a drop is determined by the material's dynamic stress-strain curve. The basic energy approach above fails to account for this strain-rate dependency of the material's stress-strain curve by using the static stress-strain curve. Bigg(1980) refined the energy balance approach to include strain-rate on foam behavior but unfortunately, strain-rate stress-strain curves are not available to confirm this approach.

Another problem with the basic energy approach is the overly simplistic treatment of the compression of the cell gas. When a cushion undergoes compression, the internal gas pressure and temperature increase due to the reduced volume. This causes heat to be irreversibly transferred from the gas to the cell walls which ultimately shows up as a strain rate dependent effect (Burgess, 1988). As the cushion rebounds, some of the heat will remain in the cell wall and therefore the cell gas will be at a lower temperature causing the volume of the cushion immediately after impact to be less than that before impact. As heat moves back into the cell gas, the cell pressure increases and the cushion expands. It has been shown that a delay of three minutes allows sufficient time for a normal cushion to recover thermodynamically.

Although many of the mathematical models described above do develop a major portion of the dynamic properties of a cushion, none have addressed the main concern of this study which is to describe the change in a cushion's dampening characteristics due to multiple impacts. Since there is presently no mathematical basis for answering this question, this study experimentally develops fatigue properties using the cushion curve approach.

The concept behind the cushion curve is to describe the actual cushion dampening characteristics under a specific set of drop conditions. The construction of a cushion curve requires a large number of data points gathered from dynamic tests. This process is quite expensive and tedious, but the expected G levels predicted by the cushion curves are quite accurate when compared to actual test results. However, the cushion curves currently published by closed cell foam manufacturers only provide information for up to five impacts which leads the user to believe that a closed cell cushion only deteriorates up to five impacts. The preliminary compression test dispute this assumption. Since a package system in a reusable mode may receive more than five impacts on any surface, it becomes necessary to quantify the fatigue life of the cushion with respect to repeated impacts. The goal of this study is to investigate the continued loss of mechanical properties due to multiple impacts for closed cell cushions.

2.0 Experimental Design

The design of this experiment followed the accepted norm for testing cushions in a dynamic setting. (ASTM standard D-1596-78a) The equipment used was a Kikusui CO55020-ST 20 MHz Storage Oscilloscope which received the shock output from a 2.00 mv/g PCB accelerometer model number 305 A05. The accelerometer output cable was patched through a Kistler Piezotron Coupler 5116 which amplified the signal to a measurable level. The output from the coupler was also fed into the Lansmont Digital Velocity Change Indicator. The Digital Velocity Change Indicator calculated the area under the shock pulse which then represents the velocity change encountered in the impact. The impacts were generated using a Lansmont Cushion Tester model 23 affixed with a GHI System VS200 Velocimeter and a photoelectric sensor. The Velocimeter sensor was set just above the impact surface and measured the velocity of the falling platen using a metal blade which passed through a photoelectric sensor. Weights were bolted to the platen to achieve the desired static loading. In addition, the platen was connected to a pneumatic brake which was activated by a rebound trigger. The platen signaled the trigger twice, once on the way down and again on rebound.

The three cushioning materials chosen for the drop tests were molded closed cell planks of ARCO foam.

ARPRO™ 3319	1.9 pcf Expanded Polypropylene Beads
ARCEL™ 512	2.0 pcf Moldable Polyethylene Copolymer
ARPAK™4322	2.2 pcf Expanded Polyethylene Beads

These materials were chosen because of their small average cell size, the consistent material thickness from sample to sample and the nearly spherical cell dimensions. The test materials were stored in controlled atmospheric conditions at 50% RH and 70° F for at least twenty-four hours prior to testing in order to reach equilibrium.

The test procedure was as follows. Two inch thick cushions were first cut into six inch squares and stored in a controlled atmospheric room. During this time, the test equipment was calibrated. Just prior to the drop test, weights were bolted to the platen to achieve the desired static loading. The required platen drop height for a specific impact velocity was then established using the gate time. In this way, the equivalent free fall drop height could be established. Friction between the platen and the guide rods of the Lansmont Cushion Tester cause the velocity of the falling platen to be lower than it would in free fall and therefore the platen drop height must be somewhat higher than the desired free fall drop height. The impact velocity of an object in a free fall is shown in Equation (2-1).

$$V_i = \sqrt{2gh} \tag{2-1}$$

where: V_i = impact velocity
g = acceleration of gravity
h = drop height

The required gate time corresponding to the equivalent free fall must then be,

$$t_g = {}^{b}/\, V_i \tag{3-2}$$

where: t_g = desired gate time
b = width of trigger blade
V_i = impact velocity for free fall drop

Table 1 illistrates the relationship between the desired drop height, the corresponding free fall velocity at that drop height, and the gate time.

Table 1. DROP HEIGHT, IMPACT VELOCITY & GATE TIME

Desired Drop Height	Equivalent Free Fall Velocity	Gate Time
24 Inch	136.2 Inches/sec	3.67 ms
30 Inch	152.3 Inches/sec	3.28 ms
36 Inch	166.8 Inches/sec	3.00 ms

The three materials were tested at three different drop heights (based on desired impact velocity) and four different static loadings. This study deviated from the ASTM standard in that only four static loadings were used due to the limited supply of test materials, cost constraints, and time restrictions. The experimental test conditions are listed in Tables 2, 3, and 4.

The dynamic test was broken down so that all three materials were evaluated at one particular drop height and one static loading. Fifteen impacts were recorded for each test specimen and two replicates were tested for each material at the twelve different parameters for a total of 1080 impacts. A three minute interval was allowed between each successive cushion impact in accordance with ASTM standard 1596-78a. The three minute time delay between drops was established to allow the cushion to recover thermodynamically and to allow air to flow back into the cushion through the ruptured cells.

Table 2. EXPERIMENTAL TEST CONDITIONS FOR ARPRO™

MATERIAL	DROP HEIGHT	STATIC LOAD	SAMPLE
ARPRO	24 Inches	0.71 psi	Test One* Replicate*
	30 Inches	0.71 psi	Test One* Replicate*
	36 Inches	0.71 psi	Test One* Replicate*
ARPRO	24 Inches	1.20 psi	Test One* Replicate*
	30 Inches	1.20 psi	Test One* Replicate*
	36 Inches	1.20 psi	Test One* Replicate*
ARPRO	24 Inches	1.70 psi	Test One* Replicate*
	30 Inches	1.70 psi	Test One* Replicate*
	36 Inches	1.70 psi	Test One* Replicate*
ARPRO	24 Inches	2.23 psi	Test One* Replicate*
	30 Inches	2.23 psi	Test One* Replicate*
	36 Inches	2.23 psi	Test One* Replicate*

* INDICATES FIFTEEN IMPACTS PER TEST

Table 3. EXPERIMENTAL TEST CONDITIONS FOR ARCEL™

MATERIAL	DROP HEIGHT	STATIC LOAD	SAMPLE
ARCEL	24 Inches	0.71 psi	Test One* Replicate*
	30 Inches	0.71 psi	Test One* Replicate*
	36 Inches	0.71 psi	Test One* Replicate*
ARCEL	24 Inches	1.20 psi	Test One* Replicate*
	30 Inches	1.20 psi	Test One* Replicate*
	36 Inches	1.20 psi	Test One* Replicate*
ARCEL	24 Inches	1.70 psi	Test One* Replicate*
	30 Inches	1.70 psi	Test One* Replicate*
	36 Inches	1.70 psi	Test One* Replicate*
ARCEL	24 Inches	2.23 psi	Test One* Replicate*
	30 Inches	2.23 psi	Test One* Replicate*
	36 Inches	2.23 psi	Test One* Replicate*

* INDICATES FIFTEEN IMPACTS PER TEST

Table 4. EXPERIMENTAL TEST CONDITIONS FOR ARPAK™

MATERIAL	DROP HEIGHT	STATIC LOAD	SAMPLE
ARPAK	24 Inches	0.71 psi	Test One* Replicate*
	30 Inches	0.71 psi	Test One* Replicate*
	36 Inches	0.71 psi	Test One* Replicate*
ARPAK	24 Inches	1.20 psi	Test One* Replicate*
	30 Inches	1.20 psi	Test One* Replicate*
	36 Inches	1.20 psi	Test One* Replicate*
ARPAK	24 Inches	1.70 psi	Test One* Replicate*
	30 Inches	1.70 psi	Test One* Replicate*
	36 Inches	1.70 psi	Test One* Replicate*
ARPAK	24 Inches	2.23 psi	Test One* Replicate*
	30 Inches	2.23 psi	Test One* Replicate*
	36 Inches	2.23 psi	Test One* Replicate*

* INDICATES FIFTEEN IMPACTS PER TEST

3.0 RESULTS

The raw test data off the oscilloscope listed in Appendix A, Tables A-1 through A-12, were used to calculate shock duration and peak G's for the test conditions described. The calculated values mentioned above are listed in Appendix B, Tables B-1 through B-12. The averaged G level data from Appendix B were used to present the cushion curves which follow.

The averaged peak shock responses from Appendix B are plotted as cushion curves with the peak deceleration level on the ordinate and the static load on the abscissa. The peak shock responses observed in this study are presented in Figures 3 through 8. Figure 3 describes the observed dynamic response of ARPRO™ after 1, 5, and 15 impacts from drops of 24, 30, and 36 inches. Figures 4 and 5 show the dynamic response after 1, 5, and 15 impacts for drops heights of 24, 30, and 36 inches for ARPAK™ and ARCEL™ respectively. Figure 6 shows a material comparison between ARPRO™, ARPAK™, and ARCEL™ after the first impact from 24, 30, and 36 inches. Figures 7 and 8 compare ARPRO™, ARPAK™, and ARCEL™ after 5 impacts and 15 impacts respectively. In addition, a comparison between the first impact cushion curve data found in this study and those presented by ARCO Chemical Company are presented in Table 5. The comparison revealed an average difference of 14.3 percent.

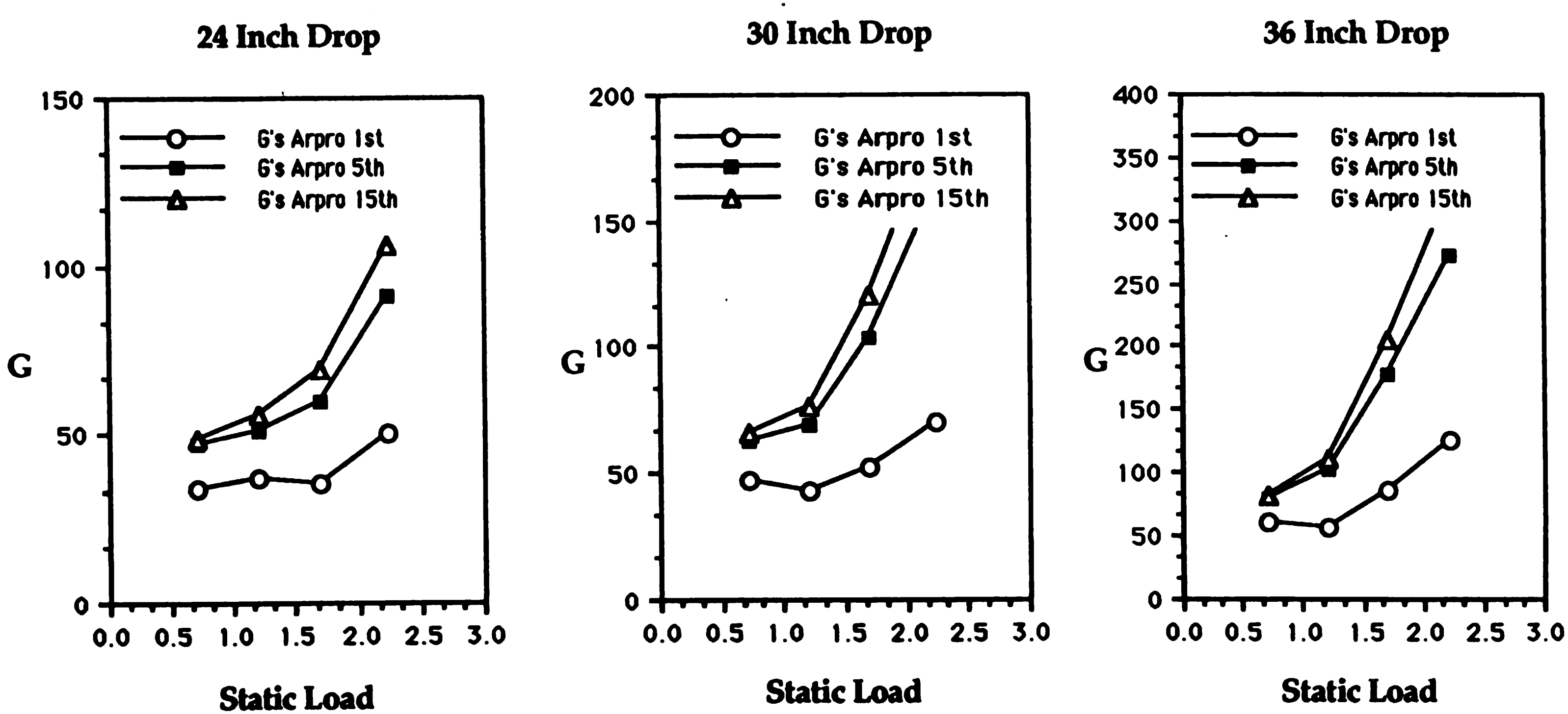

Figure 3. CUSHION CURVE FOR ARPRO™ AFTER 1, 5, & 15 IMPACTS FROM 24, 30, & 36 INCH DROPS

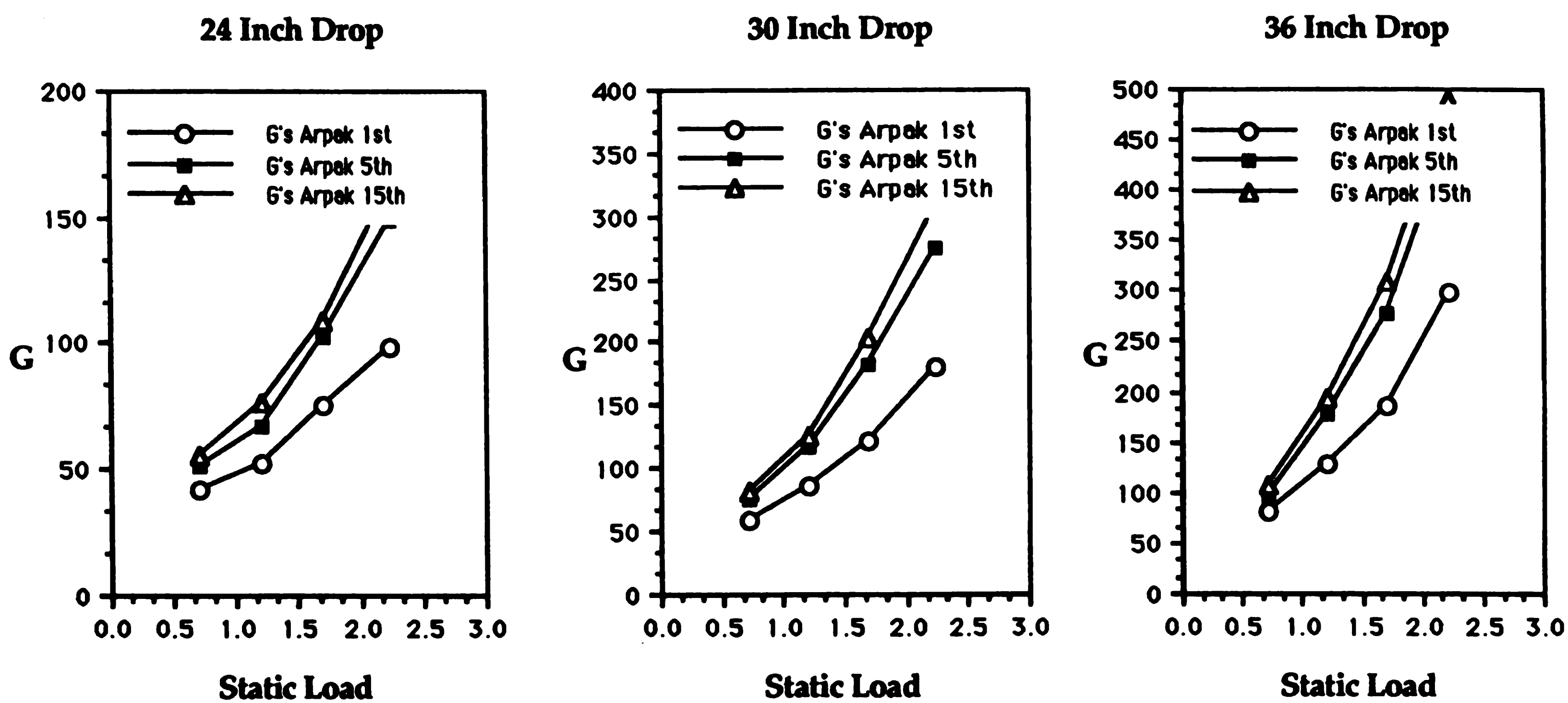

Figure 4. CUSHION CURVE FOR ARPAK™ AFTER 1, 5, & 15 IMPACTS FROM 24, 30, & 36 INCH DROPS

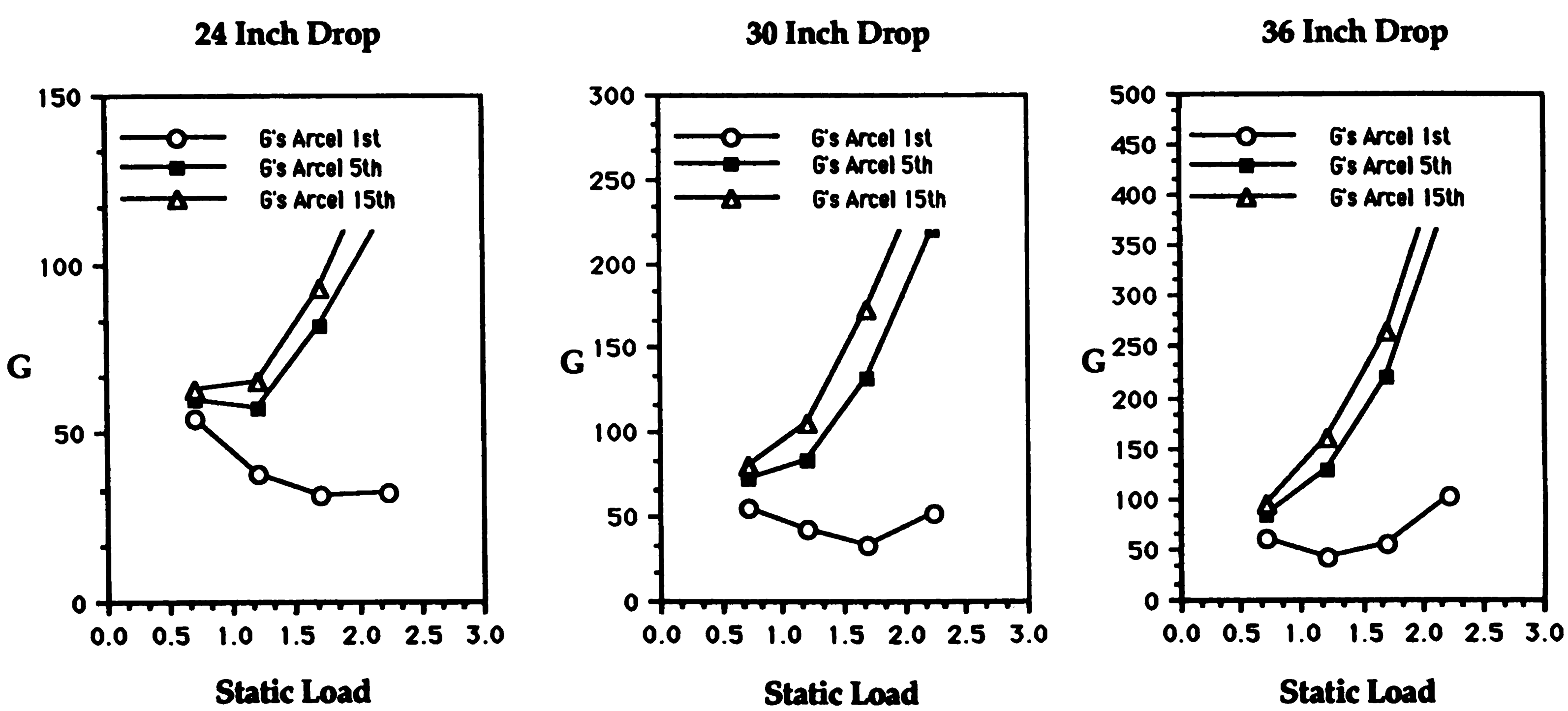

Figure 5. CUSHION CURVE FOR ARCEL™ AFTER 1, 5, & 15 IMPACTS FROM 24, 30, & 36 INCH DROPS

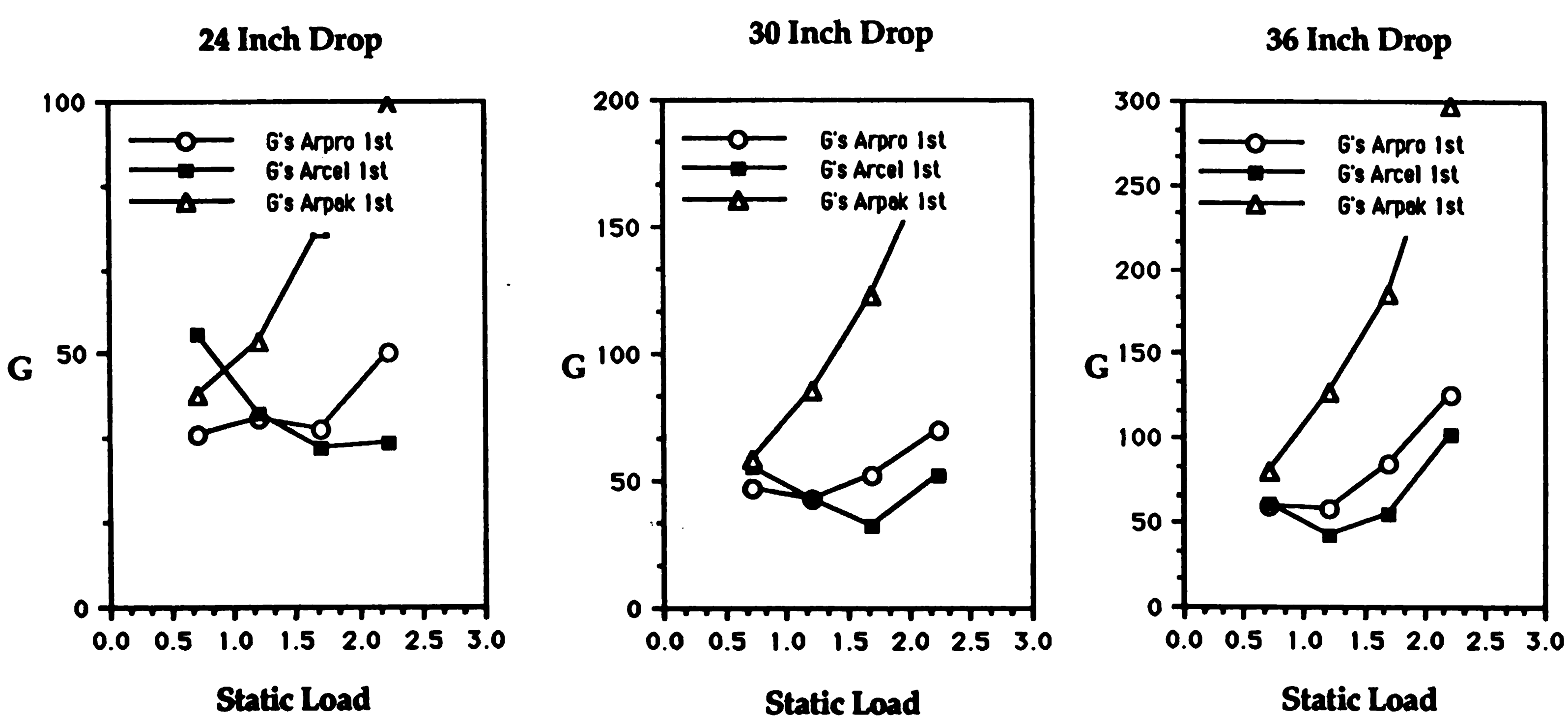

Figure 6. A COMPARISON OF ARPRO™, ARPAK™ & ARCEL™ FIRST IMPACT CUSHION CURVES @ 24, 30 & 36 INCH DROPS

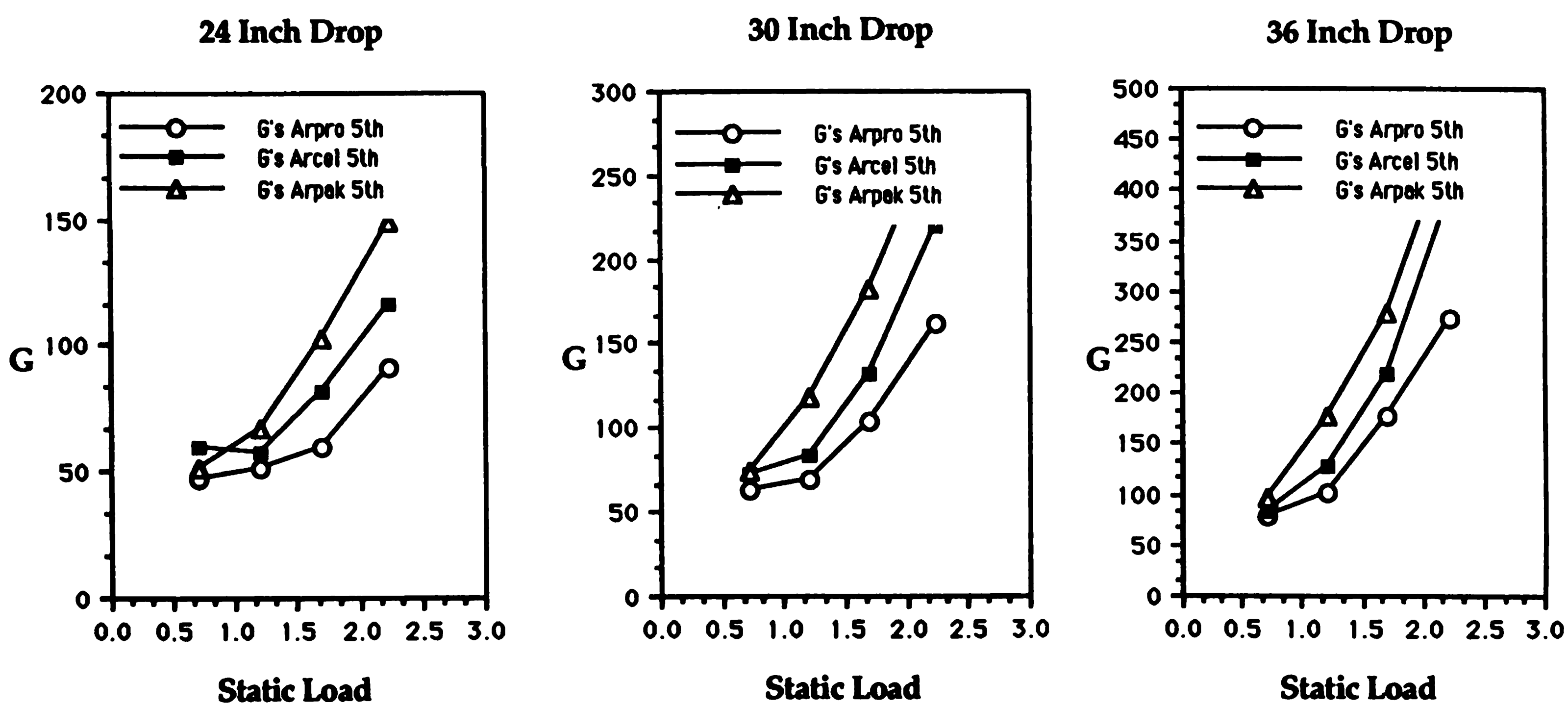

Figure 7. A COMPARISON OF ARPRO™, ARPAK™ & ARCEL™ FIFTH IMPACT CUSHION CURVES @ 24, 30 & 36 INCH DROPS

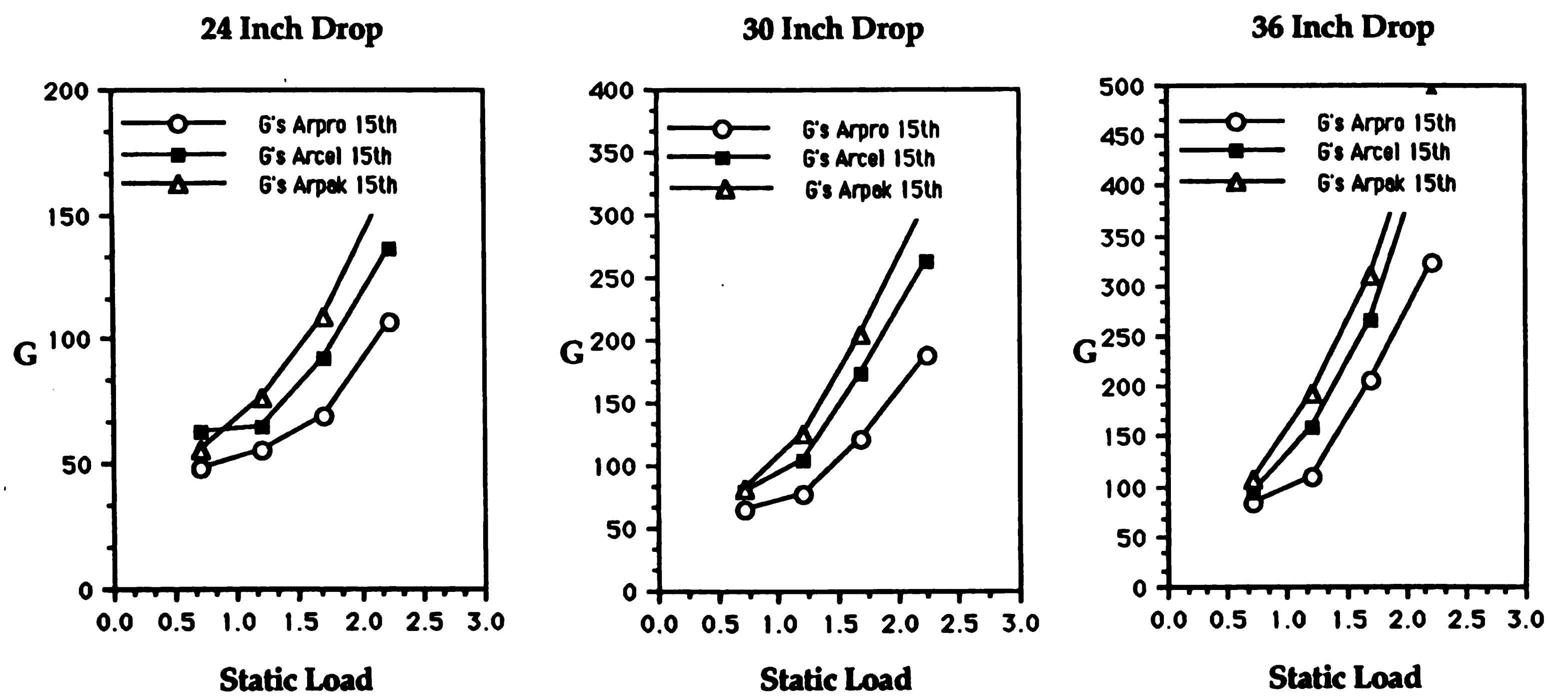

Figure 8. A COMPARISON OF ARPRO™, ARPAK™ & ARCEL™ FIFTEENTH IMPACT CUSHION CURVES @ 24, 30 & 36 INCH DROPS

Table 5. PUBLISHED CUSHION CURVE DATA vs. EMPIRICAL DATA OBSERVED IN THIS STUDY

Material	Drop Ht.	Static Load	Published G	Observed G	Percent Difference
ARPRO	24 Inches	0.71	47	34	38.2%
ARPRO	24 Inches	1.2	35	37	5.7%
ARPRO	24 Inches	1.7	32	35	9.4%
ARPRO	24 Inches	2.23	34	50	47.1%
ARPRO	30 Inches	0.71	50	47	6.4%
ARPRO	30 Inches	1.2	43	43	0.0%
ARPRO	30 Inches	1.7	41	53	29.3%
ARPRO	30 Inches	2.23	46	70	52.2%
ARPRO	36 Inches	0.71	54	60	11.1%
ARPRO	36 Inches	1.2	47	58	23.4%
ARPRO	36 Inches	1.7	52	85	63.5%
ARPRO	36 Inches	2.23	59	125	111.9%
ARCEL	24 Inches	0.71	42	54	28.6%
ARCEL	24 Inches	1.2	34	38	11.8%
ARCEL	24 Inches	1.7	32	31	3.2%
ARCEL	24 Inches	2.23	36	33	9.1%
ARCEL	30 Inches	0.71	48	56	16.7%
ARCEL	30 Inches	1.2	42	43	2.4%
ARCEL	30 Inches	1.7	46	33	39.4%
ARCEL	30 Inches	2.23	53	53	0.0%
ARCEL	36 Inches	0.71	53	61	15.1%
ARCEL	36 Inches	1.2	49	43	14.0%
ARCEL	36 Inches	1.7	58	55	5.5%
ARCEL	36 Inches	2.23	73	103	41.1%
ARPAK	24 Inches	0.71	38	42	10.5%
ARPAK	24 Inches	1.2	38	53	39.5%
ARPAK	24 Inches	1.7	48	75	56.3%
ARPAK	24 Inches	2.23	N.A.	99	N.A.
ARPAK	30 Inches	0.71	48	59	22.9%
ARPAK	30 Inches	1.2	54	85	57.4%
ARPAK	30 Inches	1.7	N.A.	123	N.A.
ARPAK	30 Inches	2.23	N.A.	180	N.A.
ARPAK	36 Inches	0.71	56	80	42.9%
ARPAK	36 Inches	1.2	75	128	70.7%
ARPAK	36 Inches	1.7	N.A.	185	N.A.
ARPAK	36 Inches	2.23	N.A.	298	N.A.

4.0 DISCUSSION

This study examined the effects of multiple impacts on closed cell cushioning material. The results of the study were presented as cushion curves based on the data observed. The cushion curves demonstrate that as the number of impacts increases, the amount of energy needed to compress the cushion decreases. One can then say that, as the cushion is repeatedly compressed, the mechanical properties continue to diminish.

The results of this study as presented in Tables 6, 7, and 8 indicate that the percent increase in the transmitted shock continues to be significant after five, ten, and fifteen impacts. From Table 6 the mean percent increase in the transmitted shock for the population of ARPRO™ samples between the first impact and the fifth impact was 74.4 percent. The mean percent increase between the fifth impact and the tenth impact was 7.8 percent and the mean percent increase between the tenth impact and the fifteenth impact was 3.2 percent. The net result is an increase in transmitted shock between the fifth impact and the fifteenth impact of 11.3 percent with a standard deviation of 5.22 percent.

From Table 7, the mean percent increase in the transmitted shock for the population of ARCEL™ samples between the first impact and the fifth impact was 171.2 percent. The mean percent increase between the fifth impact and the tenth impact was 11.4 percent and the mean percent increase between the tenth impact and the fifteenth impact was 5.3 percent. The net result is an increase in transmitted shock between the fifth impact and the fifteenth impact of 17.3 percent with a standard deviation of 7.0 percent.

From Table 8, the mean percent increase in the transmitted shock for the population of ARPAK™ samples between the first impact and the fifth impact was 38.9 percent. The mean percent increase between the fifth impact and the tenth impact was 5.3 percent and the mean percent increase between the tenth impact and the fifteenth impact was 4.1 percent. The net result is an increase in transmitted shock between the fifth impact and the fifteenth impact of 9.6 percent with a standard deviation of 2.0 percent.

The trends observed in the dynamic cushion study were consistent with every test condition and material. Each material demonstrated degradation beyond five impacts, however, the accumulated error in measuring G's due to instrument error was greater than the measured changes observed for some test conditions. A two population one-sided t-test has been conducted to provide statistical validity to the trends observed. This test compares the transmitted shock between the fifth impact and the fifteenth impact. The results of the statistical test group all three materials in the same population and measures the degree of confidence relative to static loading and drop height. The results of this statistical verification are presented in Table 9.

Appendix C presents additional information on the changes that a closed cell cushion undergoes during compression testing. Permanent deformation of the cushion was often substantial. From Table C-1, ARPRO™ demonstrated a 5 percent permanent deformation after five compressions. From the fifth compression to the tenth compression an additional permanent deformation of 2.6 percent was observed and from the tenth to the fifteenth compression, a 2.2 percent permanent deformation.

The data from Appendix C indicates that ARCEL™ demonstrated the greatest permanent deformation. After 15 compressions, ARCEL™ lost 33 percent of its original thickness, ETHAFOAM™ lost 24 percent, ARPAK™ lost 16 percent, and ARPRO™ lost 12 percent. The permanent deformation observed is attributed to the cell rupture and partial collapse due to the buckled and bent cellular structures.

As the stress level increases in the wall of a cell due to compression, the concentrated stresses will cause the cell to rupture. This rupture is very often a pin hole or small crack which allows the cell air to escape from the cell under compression. During the slow compression of closed cell foam, the pressure differential drives the cell air from the ruptured cells. If the rate of compression is slow, the cell air has time to flow out of the cushion and the foam behaves like a quasi-open cell foam. However, during dynamic compression, the air does not have time to escape from the cells and therefore even though the cellular structure has been fatigued and ruptured, the cushion still performs dynamically as a closed cell foam.

Table 6. PERCENT INCREASE IN G LEVEL FOR ARPRO™

		AVERAGE G LEVEL				PERCENT INCREASE		
Drop Ht.	Static Load	1st	5th	10th	15th	1st - 5th	5th - 10th	10th - 15th
24 Inch	0.71	33.8	47	48	48.5	39.1	2.1	1.0
24 Inch	1.2	37	51	54	55.5	37.8	5.9	2.8
24 Inch	1.7	35	60	67.5	68.8	71.4	12.5	1.9
24 Inch	2.23	50	91.3	97.5	106	82.6	6.8	9.0
30 Inch	0.71	47	63	63.5	65.5	34.0	0.8	3.1
30 Inch	1.2	42.5	68.8	76.3	76.3	61.9	10.9	0.0
30 Inch	1.7	52.5	104	114	120	97.7	9.6	5.4
30 Inch	2.23	70	163	180	188	132.1	10.8	4.2
36 Inch	0.71	60	78.8	81.3	82.5	31.3	3.2	1.5
36 Inch	1.2	57.5	103	110	110	78.3	7.3	0.0
36 Inch	1.7	85	178	198	205	108.8	11.3	3.8
36 Inch	2.23	125	273	305	323	118.0	11.9	5.9

Standard Deviation Population =	34.8	3.9	2.6
Mean for Population =	74.4	7.8	3.2

Range	Static load	Mean	Standard Deviation
1st - 5th	0.71	34.8	3.2
1st - 5th	1.2	59.3	16.6
1st - 5th	1.7	92.6	15.7
1st - 5th	2.23	110.9	20.8
5th - 10th	0.71	2.0	1.0
5th - 10th	1.2	8.0	2.1
5th - 10th	1.7	11.1	1.2
5th - 10th	2.23	8.8	2.0
10th - 15th	0.71	1.9	0.9
10th - 15th	1.2	0.9	1.3
10th - 15th	1.7	3.7	1.4
10th - 15th	2.23	6.3	2.0

Table 7. PERCENT INCREASE IN G LEVEL FOR ARCEL™

		AVERAGE G LEVEL				PERCENT INCREASE		
Drop Ht.	Static Load	1st	5th	10th	15th	1st - 5th	5th - 10th	10th - 15th
24 Inch	0.71	54	60	61	63	11.1	1.7	3.3
24 Inch	1.2	38	57.5	62.5	65	51.3	8.7	4.0
24 Inch	1.7	31.3	81.3	87.5	92.5	159.7	7.6	5.7
24 Inch	2.23	32.5	116	131	136	257.8	12.9	3.8
30 Inch	0.71	55.5	72	77.5	79.5	29.7	7.6	2.6
30 Inch	1.2	42.5	83.8	100	105	97.2	19.3	5.0
30 Inch	1.7	32.5	131	149	173	304.0	13.3	15.9
30 Inch	2.23	52.5	220	253	263	319.0	14.8	4.0
36 Inch	0.71	61.6	83.8	91.3	95	36.0	8.9	4.1
36 Inch	1.2	42.5	129	150	160	203.1	16.5	6.7
36 Inch	1.7	55	220	253	265	300.0	14.8	5.0
36 Inch	2.23	103	395	435	450	285.4	10.1	3.4

Standard Deviation Population =	116.0	4.6	3.4
Mean for Population =	171.2	11.4	5.3

Range	Static load	Mean	Standard Deviation
1st - 5th	0.71	25.6	10.6
1st - 5th	1.2	117.2	63.6
1st - 5th	1.7	254.6	67.1
1st - 5th	2.23	287.4	25.0
5th - 10th	0.71	6.1	3.1
5th - 10th	1.2	14.9	4.5
5th - 10th	1.7	11.9	3.1
5th - 10th	2.23	12.6	1.9
10th - 15th	0.71	3.4	0.6
10th - 15th	1.2	5.2	1.1
10th - 15th	1.7	8.9	5.0
10th - 15th	2.23	3.7	0.3

Table 8. PERCENT INCREASE IN G LEVEL FOR ARPAK™

		AVERAGE G LEVEL				PERCENT INCREASE		
Drop Ht.	Static Load	1st	5th	10th	15th	1st - 5th	5th - 10th	10th - 15th
24 Inch	0.71	42	51.5	53.5	56	22.6	3.9	4.7
24 Inch	1.2	52.5	67.5	74.5	76	28.6	10.4	2.0
24 Inch	1.7	75	103	108	109	36.7	4.9	1.4
24 Inch	2.23	98.8	149	156	163	50.8	4.9	4.0
30 Inch	0.71	58.5	74.5	74.5	81	27.4	0.0	8.7
30 Inch	1.2	85	118	123	125	38.2	4.3	2.0
30 Inch	1.7	123	183	196	204	49.0	7.6	3.8
30 Inch	2.23	180	275	293	308	52.8	6.4	5.1
36 Inch	0.71	80	96.3	100	106	20.4	3.8	6.3
36 Inch	1.2	128	178	186	194	39.2	5.0	4.0
36 Inch	1.7	185	278	298	310	50.0	7.2	4.2
36 Inch	2.23	298	450	475	490	51.3	5.6	3.2

Standard Deviation Population =		
11.4	2.4	1.9

Standard Deviation Population = 11.4 2.4 1.9

Mean for Population = 38.9 5.3 4.1

Range	Static load	Mean	Standard Deviation
1st - 5th	0.71	23.5	2.9
1st - 5th	1.2	35.3	4.9
1st - 5th	1.7	45.2	6.1
1st - 5th	2.23	51.6	0.9
5th - 10th	0.71	2.6	1.8
5th - 10th	1.2	6.6	2.7
5th - 10th	1.7	6.6	1.2
5th - 10th	2.23	5.6	0.6
10th - 15th	0.71	6.6	1.6
10th - 15th	1.2	2.7	0.9
10th - 15th	1.7	3.1	1.2
10th - 15th	2.23	4.1	0.8

Table 9. DEGREE OF CONFIDENCE "t - TEST" VERIFICATION

Drop Height	Static Load	Degree of Confidence
24 Inches	0.71	85%
24 Inches	1.20	93%
24 Inches	1.70	84%
24 Inches	2.23	90%
30 Inches	0.71	93%
30 Inches	1.20	87%
30 Inches	1.70	92%
30 Inches	2.23	91%
36 Inches	0.71	96%
36 Inches	1.20	86%
36 Inches	1.70	94%
36 Inches	2.23	89%

5.0 CONCLUSIONS

Cushion curves were constructed for three closed cell foams to determine the change in the actual dampening characteristics due to multiple impacts. The results revealed significant mechanical and structural changes in the closed cell foam matrix. The cell structures were ruptured and permanently deformed as the foam was repeatedly compressed either statically or dynamically.

This implies that the effect of multiple impacts has a continuing and cumulative effect on the mechanical and structural characteristics of a closed cell foam. Therefore, it can be concluded that the cushion curves developed for the first impact and the second through the fifth impacts averaged are inadequate to describe cushion behavior under conditions where multiple impacts will be observed.

The objective of this study was to determine, if at some point, the mechanical properties of a closed cell foam become constant. The results indicate that the percent loss in cushioning properties, between the tenth impact and the fifteen impact, is relatively small as compared to the percent lost after one impact. Assuming that this trend would continue with subsequent compressions, one could then speculate that the cushioning properties would eventually become nearly constant. However, since the rate of loading affects the response of the closed cell foam with respect to the ruptured cells and the subsequent fatigue of the material, the resulting performance would continue to degrade.

Future studies could concentrate on the porosity of the resulting cell structure and quantifying the dampening characteristics of a precompressed closed cell cushion.

APPENDICES

The raw data accumulated from the dynamic cushion testing is presented in Appendix A. This data describes the impact velocity, velocity change, duration of the pulse measured by the oscilloscope, and the peak of the pulse under varying test conditions. The half sine wave represents the shock transmitted due to the dissipation of kinetic energy. The severity of the shock is quantified by the duration and the peak height of the pulse. The raw data, measured by the oscilloscope, is converted and presented in Appendix B. The conversion procedures are as follows:

$$\mathrm{Dur} = \mathrm{Div} \bullet (\mathrm{ms}/\mathrm{Div}) \tag{A-1}$$

Variables:	Dur	=	duration of the transmitted shock
	Div	=	number of divisions
	ms	=	number of milliseconds*

* the oscilloscope was set at 10 ms/Div throughout the experiment

$$G = \frac{\mathrm{Div} \bullet (\mathrm{mv}/\mathrm{Div})}{(2\,\mathrm{mv}/g)} \tag{A-2}$$

Variables:	G	=	level of transmitted shock
	Div	=	number of divisions
	mv	=	number of millivolts*
	2 mv/g	=	sensitivity of the accelerometer

* the oscilloscope settings are shown in Table A-1.

APPENDIX A RECORDED DYNAMIC DATA

Table A-1. ARPRO 1.9 DENSITY @ 0.71 PSI & DROPS OF 24", 30", & 36"

		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
	1ST test #1	3.64	223	1.7	3.4
	test#2	3.64	227	1.7	3.4
	2ND test#1	3.70	224	1.7	4.3
	test#2	3.70	223	1.7	4.3
24"	3RD test#1	3.64	234	1.7	4.6
DROP	test#2	3.65	224	1.7	4.5
	5TH test#1	3.64	231	1.7	4.7
	test#2	3.64	230	1.7	4.7
	10TH test#1	3.65	232	1.8	4.8
	test#2	3.64	222	1.8	4.8
	15TH test#1	3.64	222	1.8	4.8
	test#2	3.64	232	1.8	4.9
		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
	1ST test #1	3.24	261	1.6	4.7
	test#2	3.24	258	1.6	4.7
	2ND test#1	3.28	270	1.6	5.8
	test#2	3.24	264	1.6	5.6
30"	3RD test#1	3.24	273	1.6	6.0
DROP	test#2	3.24	265	1.6	5.9
	5TH test#1	3.24	277	1.5	6.3
	test#2	3.24	274	1.6	6.3
	10TH test#1	3.24	273	1.6	6.4
	test#2	3.24	274	1.6	6.3
	15TH test#1	3.23	280	1.6	6.8
	test#2	3.29	271	1.6	6.3
		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
	1ST test #1	3.02	293	1.7	2.5
	test#2	3.02	288	1.7	2.3
	2ND test#1	3.02	293	1.7	2.9
	test#2	3.03	269	1.7	2.8
36"	3RD test#1	3.02	294	1.6	3.0
DROP	test#2	3.02	298	1.6	3.0
	5TH test#1	3.02	292	1.6	3.1
	test#2	3.02	299	1.6	3.2
	10TH test#1	3.03	303	1.6	3.3
	test#2	3.02	305	1.6	3.2
	15TH test#1	3.02	296	1.6	3.3
	test#2	3.03	306	1.6	3.3

Appendix A (Continued)

Table A-2. ARCEL 2.0 DENSITY @ 0.71 PSI & DROPS OF 24", 30", & 36"

		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
	1ST test #1	3.65	220	1.2	5.4
	test#2	3.64	219	1.2	5.4
	2ND test#1	3.70	228	1.2	5.7
	test#2	3.64	230	1.2	5.8
24" DROP	3RD test#1	3.64	235	1.4	5.9
	test#2	3.64	236	1.4	5.9
	5TH test#1	3.64	238	1.4	6.0
	test#2	3.64	238	1.4	6.0
	10TH test#1	3.64	241	1.4	6.1
	test#2	3.64	239	1.4	6.1
	15TH test#1	3.64	238	1.4	6.3
	test#2	3.65	243	1.4	6.3
		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
	1ST test #1	3.24	247	1.1	5.7
	test#2	3.24	248	1.1	5.4
	2ND test#1	3.24	260	1.2	6.3
	test#2	3.23	264	1.3	6.1
30" DROP	3RD test#1	3.23	270	1.2	6.6
	test#2	3.24	272	1.2	6.5
	5TH test#1	3.24	275	1.2	7.0
	test#2	3.23	278	1.2	7.4
	10TH test#1	3.23	276	1.2	7.7
	test#2	3.24	282	1.2	7.8
	15TH test#1	3.25	278	1.2	7.8
	test#2	3.23	283	1.2	8.1
		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
	1ST test #1	3.02	264	1.3	2.3
	test#2	3.02	265	1.2	2.6
	2ND test#1	3.03	279	1.3	2.7
	test#2	3.03	280	1.3	2.9
36" DROP	3RD test#1	3.02	293	1.4	3.3
	test#2	3.02	292	1.3	3.1
	5TH test#1	3.02	300	1.3	3.4
	test#2	3.02	297	1.3	3.3
	10TH test#1	3.02	299	1.2	3.6
	test#2	3.03	305	1.3	3.7
	15TH test#1	3.06	295	1.2	3.8
	test#2	3.02	298	1.3	3.8

Appendix A (Continued)

Table A-3. ARPAK 2.2 DENSITY @ 0.71 PSI & DROPS OF 24", 30", & 36"

		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
	1ST test #1	3.64	222	1.8	4.6
	test#2	3.71	211	1.8	3.8
	2ND test#1	3.65	223	1.7	5.2
	test#2	3.64	221	1.8	4.6
24"	3RD test#1	3.65	226	1.7	5.4
DROP	test#2	3.65	215	1.8	4.7
	5TH test#1	3.64	227	1.6	5.5
	test#2	3.64	214	1.7	4.8
	10TH test#1	3.65	227	1.7	5.7
	test#2	3.65	224	1.7	5.0
	15TH test#1	3.64	229	1.7	5.9
	test#2	3.66	217	1.7	5.3
		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
	1ST test #1	3.24	257	1.6	5.9
	test#2	3.24	258	1.6	5.8
	2ND test#1	3.24	270	1.6	6.9
	test#2	3.24	273	1.6	7.0
30"	3RD test#1	3.24	278	1.5	7.1
DROP	test#2	3.23	278	1.6	7.3
	5TH test#1	3.24	274	1.5	7.4
	test#2	3.23	282	1.6	7.5
	10TH test#1	3.28	275	1.6	7.5
	test#2	3.28	273	1.6	7.4
	15TH test#1	3.23	280	1.5	8.1
	test#2	3.23	284	1.5	8.1
		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
	1ST test #1	3.02	304	1.5	3.3
	test#2	3.03	297	1.5	3.1
	2ND test#1	3.02	297	1.5	3.6
	test#2	3.02	307	1.5	3.7
36"	3RD test#1	3.02	307	1.5	3.8
DROP	test#2	3.02	306	1.5	3.8
	5TH test#1	3.02	309	1.4	3.9
	test#2	3.04	292	1.4	3.8
	10TH test#1	3.02	3017	1.4	4.0
	test#2	3.02	307	1.4	4.0
	15TH test#1	3.03	312	1.4	4.2
	test#2	3.02	316	1.4	4.3

Appendix A (Continued)

Table A-4. ARPRO 1.9 DENSITY @ 1.2 PSI & DROPS OF 24", 30", & 36"

		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
24" DROP	1ST test #1	3.66	217	1.9	3.6
	test#2	3.67	220	1.9	3.8
	2ND test#1	3.65	227	1.9	4.7
	test#2	3.66	222	1.9	4.6
	3RD test#1	3.66	230	2.0	4.9
	test#2	3.66	229	2.0	4.7
	5TH test#1	3.66	227	2.0	4.9
	test#2	3.66	236	2.0	5.3
	10TH test#1	3.66	229	2.0	5.4
	test#2	3.67	237	2.0	5.4
	15TH test#1	3.66	230	1.9	5.4
	test#2	3.67	237	2.0	5.7
		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
30" DROP	1ST test #1	3.28	243	1.7	1.7
	test#2	3.27	238	1.7	1.7
	2ND test#1	3.28	258	1.7	2.3
	test#2	3.27	253	1.7	2.2
	3RD test#1	3.27	264	1.7	2.6
	test#2	3.27	266	1.7	2.7
	5TH test#1	3.27	269	1.7	2.8
	test#2	3.26	265	1.7	2.7
	10TH test#1	3.28	274	1.7	3.0
	test#2	3.27	267	1.7	3.1
	15TH test#1	3.27	271	1.7	3.1
	test#2	3.27	273	1.7	3.0
		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
36" DROP	1ST test #1	3.00	281	1.6	2.3
	test#2	3.00	278	1.6	2.3
	2ND test#1	3.00	302	1.6	3.3
	test#2	3.00	293	1.6	3.2
	3RD test#1	3.00	304	1.6	3.6
	test#2	3.01	308	1.6	3.9
	5TH test#1	3.00	313	1.5	3.9
	test#2	3.00	310	1.5	4.3
	10TH test#1	3.00	311	1.5	4.4
	test#2	3.00	316	1.5	4.4
	15TH test#1	3.00	312	1.5	4.4
	test#2	3.00	319	1.5	4.4

Appendix A (Continued)

Table A-5. ARCEL 2.0 DENSITY @ 1.2 PSI & DROPS OF 24", 30", & 36"

		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
24" DROP	1ST test #1	3.66	210	1.5	3.8
	test#2	3.67	210	1.6	3.8
	2ND test#1	3.67	226	1.6	4.0
	test#2	3.67	226	1.5	4.1
	3RD test#1	3.66	229	1.6	4.8
	test#2	3.65	230	1.6	4.9
	5TH test#1	3.66	239	1.5	5.7
	test#2	3.66	239	1.5	5.8
	10TH test#1	3.67	242	1.5	6.3
	test#2	3.66	234	1.5	6.2
	15TH test#1	3.67	244	1.5	6.4
	test#2	3.67	246	1.5	6.6
		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
30" DROP	1ST test #1	3.27	232	1.6	1.7
	test#2	3.27	235	1.6	1.7
	2ND test#1	3.28	258	1.6	2.4
	test#2	3.27	256	1.6	2.3
	3RD test#1	3.27	271	1.6	3.0
	test#2	3.27	265	1.6	2.9
	5TH test#1	3.28	273	1.6	3.5
	test#2	3.28	270	1.6	3.2
	10TH test#1	3.27	281	1.6	4.2
	test#2	3.27	281	1.6	3.8
	15TH test#1	3.27	285	1.6	4.4
	test#2	3.28	280	1.6	4.0
		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
36" DROP	1ST test #1	3.00	262	1.5	1.7
	test#2	3.00	261	1.5	1.7
	2ND test#1	3.00	295	1.5	3.4
	test#2	3.00	293	1.5	3.1
	3RD test#1	3.00	310	1.4	4.5
	test#2	3.01	308	1.4	4.1
	5TH test#1	3.00	319	1.3	5.3
	test#2	3.00	318	1.3	5.0
	10TH test#1	3.00	323	1.3	6.3
	test#2	3.00	321	1.3	5.7
	15TH test#1	3.00	328	1.3	6.6
	test#2	3.01	325	1.3	6.2

Appendix A (Continued)

Table A-6. ARPAK 2.2 DENSITY @ 1.2 PSI & DROPS OF 24", 30", & 36"

		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
	1ST test #1	3.67	234	1.9	5.3
	test#2	3.67	228	1.8	5.2
	2ND test#1	3.67	234	1.8	6.2
	test#2	3.66	237	1.8	6.1
24"	3RD test#1	3.66	240	1.8	6.8
DROP	test#2	3.67	233	1.9	6.4
	5TH test#1	3.65	246	1.8	6.9
	test#2	3.66	244	1.8	6.6
	10TH test#1	3.66	252	1.8	7.7
	test#2	3.65	236	1.8	7.2
	15TH test#1	3.67	253	1.7	7.7
	test#2	3.66	247	1.8	7.5
		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
	1ST test #1	3.28	272	1.7	3.4
	test#2	3.27	275	1.7	3.4
	2ND test#1	3.27	286	1.7	4.1
	test#2	3.27	289	1.7	4.3
30"	3RD test#1	3.27	292	1.7	4.5
DROP	test#2	3.28	286	1.7	4.5
	5TH test#1	3.27	293	1.7	4.6
	test#2	3.27	295	1.7	4.8
	10TH test#1	3.27	294	1.7	4.8
	test#2	3.27	294	1.7	5.0
	15TH test#1	3.27	298	1.7	5.0
	test#2	3.28	293	1.7	5.0
		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
	1ST test #1	3.00	315	1.5	5.0
	test#2	3.01	322	1.5	5.2
	2ND test#1	3.00	325	1.4	6.3
	test#2	3.00	333	1.4	6.5
36"	3RD test#1	3.00	327	1.4	6.7
DROP	test#2	3.00	334	1.4	6.8
	5TH test#1	3.00	335	1.4	7.0
	test#2	3.00	338	1.4	7.2
	10TH test#1	3.00	335	1.4	7.4
	test#2	3.00	333	1.4	7.5
	15TH test#1	3.00	337	1.4	7.7
	test#2	3.01	342	1.4	7.8

Appendix A (Continued)

Table A-7. ARPRO 1.9 DENSITY @ 1.7 PSI & DROPS OF 24", 30", & 36"

		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
	1ST test #1	3.67	175	2.0	1.4
	test#2	3.67	180	2.0	1.4
	2ND test#1	3.67	194	1.9	2.0
	test#2	3.70	191	1.9	1.9
24" DROP	3RD test#1	3.67	203	1.9	2.3
	test#2	3.66	200	1.9	2.4
	5TH test#1	3.67	206	1.9	2.4
	test#2	3.66	199	1.9	2.4
	10TH test#1	3.66	211	1.9	2.7
	test#2	3.67	203	1.9	2.7
	15TH test#1	3.66	211	1.9	2.7
	test#2	3.67	197	1.9	2.8
		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
	1ST test #1	3.28	241	1.9	2.1
	test#2	3.27	241	1.9	2.1
	2ND test#1	3.26	264	1.9	3.3
	test#2	3.27	259	1.8	3.2
30" DROP	3RD test#1	3.27	269	1.7	3.7
	test#2	3.27	268	1.8	3.7
	5TH test#1	3.26	276	1.7	4.1
	test#2	3.27	279	1.7	4.2
	10TH test#1	3.26	282	1.7	4.6
	test#2	3.26	278	1.7	4.5
	15TH test#1	3.26	287	1.7	4.9
	test#2	3.26	286	1.7	4.7
		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
	1ST test #1	3.00	292	1.7	1.7
	test#2	2.99	294	1.7	1.7
	2ND test#1	2.98	314	1.6	2.7
	test#2	2.99	307	1.6	2.8
36" DROP	3RD test#1	2.99	316	1.5	3.2
	test#2	2.99	317	1.5	3.2
	5TH test#1	3.00	324	1.5	3.5
	test#2	2.99	324	1.5	3.6
	10TH test#1	2.98	326	1.5	3.9
	test#2	2.99	328	1.5	4.0
	15TH test#1	2.99	329	1.5	4.2
	test#2	2.99	333	1.5	4.0

Appendix A (Continued)

Table A-8. ARCEL 2.0 DENSITY @ 1.7 PSI & DROPS OF 24", 30", & 36"

		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
	1ST test #1	3.68	181	1.9	1.2
	test#2	3.67	181	1.9	1.3
	2ND test#1	3.68	193	1.9	2.1
	test#2	3.69	200	1.8	2.0
24"	3RD test#1	3.67	214	1.8	2.8
DROP	test#2	3.67	213	1.8	2.6
	5TH test#1	3.67	217	1.8	3.3
	test#2	3.68	222	1.8	3.2
	10TH test#1	3.66	212	1.8	3.6
	test#2	3.66	221	1.8	3.4
	15TH test#1	3.66	231	1.8	3.8
	test#2	3.67	216	1.7	3.6
		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
	1ST test #1	3.27	224	1.8	1.3
	test#2	3.28	225	1.8	1.3
	2ND test#1	3.27	260	1.7	3.2
	test#2	3.27	261	1.7	3.0
30"	3RD test#1	3.27	273	1.6	4.2
DROP	test#2	3.27	273	1.6	4.1
	5TH test#1	3.26	284	1.6	5.3
	test#2	3.26	285	1.5	5.2
	10TH test#1	3.27	292	1.5	6.0
	test#2	3.26	292	1.5	5.9
	15TH test#1	3.27	296	1.5	6.5
	test#2	3.26	295	1.5	7.3
		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
	1ST test #1	2.99	268	1.6	1.1
	test#2	2.99	270	1.6	1.1
	2ND test#1	2.99	302	1.5	2.5
	test#2	3.00	305	1.5	2.7
36"	3RD test#1	2.99	318	1.4	3.4
DROP	test#2	2.99	320	1.4	3.7
	5TH test#1	2.99	324	1.4	4.3
	test#2	2.99	327	1.4	4.5
	10TH test#1	2.99	331	1.4	4.9
	test#2	2.99	333	1.4	5.2
	15TH test#1	2.99	336	1.4	5.2
	test#2	2.99	335	1.4	5.4

Appendix A (Continued)

Table A-9. ARPAK 2.2 DENSITY @ 1.7 PSI & DROPS OF 24", 30", & 36"

		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
24" DROP	1ST test #1	3.69	193	1.8	3.0
	test#2	3.68	195	1.8	3.0
	2ND test#1	3.67	226	1.7	3.6
	test#2	3.66	228	1.7	3.8
	3RD test#1	3.66	213	1.7	3.9
	test#2	3.68	210	1.7	3.7
	5TH test#1	3.67	216	1.7	4.0
	test#2	3.66	235	1.7	4.2
	10TH test#1	3.67	235	1.7	4.3
	test#2	3.67	233	1.7	4.3
	15TH test#1	3.67	236	1.7	4.4
	test#2	3.67	237	1.7	4.3
		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
30" DROP	1ST test #1	3.27	283	1.7	4.9
	test#2	3.27	281	1.7	4.9
	2ND test#1	3.27	290	1.6	6.2
	test#2	3.27	292	1.6	6.3
	3RD test#1	3.26	295	1.6	6.5
	test#2	3.26	296	1.6	6.7
	5TH test#1	3.26	305	1.5	7.3
	test#2	3.26	300	1.5	7.3
	10TH test#1	3.26	304	1.5	7.8
	test#2	3.26	306	1.5	7.9
	15TH test#1	3.26	305	1.5	8.0
	test#2	3.26	310	1.5	8.3
		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
36" DROP	1ST test #1	2.99	319	1.3	3.7
	test#2	2.99	324	1.4	3.7
	2ND test#1	2.99	331	1.3	4.8
	test#2	2.99	327	1.3	4.7
	3RD test#1	2.98	334	1.2	5.3
	test#2	2.99	328	1.3	5.1
	5TH test#1	2.99	335	1.3	5.7
	test#2	2.99	336	1.3	5.4
	10TH test#1	2.99	339	1.3	6.1
	test#2	2.99	339	1.3	5.8
	15TH test#1	3.00	342	1.3	6.3
	test#2	2.99	341	1.3	6.1

Appendix A (Continued)

Table A-10. ARPRO 1.9 DENSITY @ 2.23 PSI & DROPS OF 24", 30", & 36"

		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
24" DROP	1ST test #1	3.66	177	2.2	2.0
	test#2	3.66	180	2.2	2.0
	2ND test#1	3.67	201	2.0	2.7
	test#2	3.66	205	1.9	2.8
	3RD test#1	3.66	210	1.9	3.1
	test#2	3.66	209	1.8	3.2
	5TH test#1	3.66	219	1.8	3.6
	test#2	3.66	216	1.8	3.7
	10TH test#1	3.67	221	1.8	3.8
	test#2	3.67	221	1.8	4.0
	15TH test#1	3.66	225	1.8	4.2
	test#2	3.67	212	1.8	4.3
		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
30" DROP	1ST test #1	3.29	245	1.8	1.4
	test#2	3.28	246	1.8	1.4
	2ND test#1	3.29	272	1.7	2.3
	test#2	3.28	273	1.7	2.3
	3RD test#1	3.28	282	1.7	2.8
	test#2	3.28	281	1.7	2.9
	5TH test#1	3.27	289	1.7	3.2
	test#2	3.27	285	1.6	3.3
	10TH test#1	3.28	289	1.6	3.5
	test#2	3.27	291	1.6	3.7
	15TH test#1	3.29	292	1.6	3.7
	test#2	3.30	294	1.6	3.8
		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
36" DROP	1ST test #1	2.99	305	1.5	2.6
	test#2	2.99	298	1.5	2.4
	2ND test#1	2.99	322	1.4	4.3
	test#2	2.99	317	1.4	3.9
	3RD test#1	3.00	331	1.4	5.0
	test#2	2.99	322	1.4	4.6
	5TH test#1	2.99	331	1.3	5.6
	test#2	3.00	332	1.3	5.3
	10TH test#1	3.00	336	1.3	6.3
	test#2	3.00	331	1.3	5.9
	15TH test#1	3.00	338	1.3	6.6
	test#2	3.00	340	1.3	6.3

Appendix A (Continued)

Table A-11. ARCEL 2.0 DENSITY @ 2.23 PSI & DROPS OF 24", 30", & 36"

		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
24" DROP	1ST test #1	3.66	170	2.1	1.3
	test#2	3.67	174	2.1	1.3
	2ND test#1	3.66	209	1.9	2.8
	test#2	3.66	206	1.9	2.7
	3RD test#1	3.67	225	1.8	3.7
	test#2	3.66	219	1.8	3.7
	5TH test#1	3.67	231	1.8	4.6
	test#2	3.66	230	1.7	4.7
	10TH test#1	3.66	238	1.7	5.2
	test#2	3.66	239	1.7	5.3
	15TH test#1	3.67	242	1.7	5.4
	test#2	3.66	242	1.7	5.5
		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
30" DROP	1ST test #1	3.28	230	1.8	1.1
	test#2	3.28	226	1.8	1.0
	2ND test#1	3.28	277	1.7	2.7
	test#2	3.28	276	1.7	2.7
	3RD test#1	3.27	290	1.6	3.7
	test#2	3.28	285	1.6	3.6
	5TH test#1	3.28	298	1.5	4.4
	test#2	3.28	294	1.5	4.4
	10TH test#1	3.28	302	1.5	5.1
	test#2	3.28	298	1.5	5.0
	15TH test#1	3.30	297	1.5	5.2
	test#2	3.29	303	1.5	5.3
		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
36" DROP	1ST test #1	2.99	289	1.4	2.3
	test#2	3.00	284	1.4	1.8
	2ND test#1	3.00	326	1.3	5.6
	test#2	2.99	320	1.3	4.7
	3RD test#1	3.00	330	1.1	7.2
	test#2	3.00	329	1.0	6.0
	5TH test#1	3.00	338	1.0	4.2
	test#2	3.00	334	1.0	3.7
	10TH test#1	3.00	344	1.0	4.6
	test#2	2.99	340	1.0	4.1
	15TH test#1	3.00	346	1.0	4.8
	test#2	3.00	347	1.0	4.2

Appendix A (Continued)

Table A-12. ARPAK 2.2 DENSITY @ 2.23 PSI & DROPS OF 24", 30", & 36"

		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
24" DROP	1ST test #1	3.67	221	1.8	4.1
	test#2	3.66	218	1.8	3.8
	2ND test#1	3.66	233	1.7	5.1
	test#2	3.66	235	1.7	4.9
	3RD test#1	3.66	240	1.7	5.6
	test#2	3.67	239	1.7	5.3
	5TH test#1	3.66	238	1.7	6.1
	test#2	3.66	239	1.6	5.8
	10TH test#1	3.66	252	1.6	6.5
	test#2	3.66	247	1.6	6.0
	15TH test#1	3.66	251	1.6	6.7
	test#2	3.66	239	1.6	6.3
		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
30" DROP	1ST test #1	3.28	285	1.5	3.6
	test#2	3.28	289	1.5	3.6
	2ND test#1	3.28	300	1.5	4.8
	test#2	3.27	300	1.5	4.8
	3RD test#1	3.27	302	1.5	5.2
	test#2	3.27	300	1.5	5.2
	5TH test#1	3.27	308	1.4	5.5
	test#2	3.28	304	1.4	5.5
	10TH test#1	3.28	308	1.4	5.9
	test#2	3.27	306	1.4	5.8
	15TH test#1	3.30	308	1.4	6.1
	test#2	3.30	311	1.4	6.2
		Impact Vi	Δ V	Pulse Duration	Maximum Pulse
36" DROP	1ST test #1	2.99	328	1.3	5.9
	test#2	2.99	325	1.3	6.0
	2ND test#1	2.99	342	1.2	7.7
	test#2	2.99	336	1.1	7.9
	3RD test#1	3.00	340	1.0	4.2
	test#2	2.99	339	1.0	4.3
	5TH test#1	3.00	344	0.9	4.4
	test#2	2.99	345	0.9	4.6
	10TH test#1	2.99	347	0.9	4.7
	test#2	3.00	351	0.9	4.8
	15TH test#1	3.00	351	0.9	4.8
	test#2	3.00	350	0.9	5.0

APPENDIX B CONVERTED DYNAMIC DATA

Table B-1. ARPRO 1.9 DENSITY @ 0.71 PSI & DROPS OF 24", 30", & 36"

		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
24" DROP	1ST test #1	17.0	33.5	17.0	33.8
	test#2	17.0	34.0		
	2ND test#1	17.0	43.0	17.0	43.0
	test#2	17.0	43.0		
	3RD test#1	17.0	46.0	17.0	45.5
	test#2	17.0	45.0		
	5TH test#1	17.0	47.0	17.0	47.0
	test#2	17.0	47.0		
	10TH test#1	18.0	48.0	18.0	48.0
	test#2	18.0	48.0		
	15TH test#1	18.0	48.0	18.0	48.5
	test#2	18.0	49.0		
		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
30" DROP	1ST test #1	16.0	47.0	16.0	47.0
	test#2	16.0	47.0		
	2ND test#1	16.0	58.0	16.0	57.0
	test#2	16.0	56.0		
	3RD test#1	16.0	60.0	16.0	59.5
	test#2	16.0	59.0		
	5TH test#1	15.0	63.0	15.5	63.0
	test#2	16.0	63.0		
	10TH test#1	16.0	64.0	16.0	63.5
	test#2	16.0	63.0		
	15TH test#1	16.0	68.0	16.0	65.5
	test#2	16.0	63.0		
		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
36" DROP	1ST test #1	17.0	62.5	17.0	60.0
	test#2	17.0	57.5		
	2ND test#1	17.0	72.5	17.0	71.3
	test#2	17.0	70.0		
	3RD test#1	16.0	75.0	16.0	75.0
	test#2	16.0	75.0		
	5TH test#1	16.0	77.5	16.0	78.8
	test#2	16.0	80.0		
	10TH test#1	16.0	82.5	16.0	81.3
	test#2	16.0	80.0		
	15TH test#1	16.0	82.5	16.0	82.5
	test#2	16.0	82.5		

Appendix B (Continued)

Table B-2. ARCEL 2.0 DENSITY @ 0.71 PSI & DROPS OF 24", 30", & 36"

Drop	Test	Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
24" DROP	1ST test #1	12.0	54.0	12.0	54.0
	test#2	12.0	54.0		
	2ND test#1	12.0	57.0	12.0	57.5
	test#2	12.0	58.0		
	3RD test#1	14.0	59.0	14.0	59.0
	test#2	14.0	59.0		
	5TH test#1	14.0	60.0	14.0	60.0
	test#2	14.0	60.0		
	10TH test#1	14.0	61.0	14.0	61.0
	test#2	14.0	61.0		
	15TH test#1	14.0	63.0	14.0	63.0
	test#2	14.0	63.0		
		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
30" DROP	1ST test #1	11.0	57.0	11.0	55.5
	test#2	11.0	54.0		
	2ND test#1	12.0	63.0	12.5	62.0
	test#2	13.0	61.0		
	3RD test#1	12.0	66.0	12.0	65.5
	test#2	12.0	65.0		
	5TH test#1	12.0	70.0	12.0	72.0
	test#2	12.0	74.0		
	10TH test#1	12.0	77.0	12.0	77.5
	test#2	12.0	78.0		
	15TH test#1	12.0	78.0	12.0	79.5
	test#2	12.0	81.0		
		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
36" DROP	1ST test #1	13.0	57.5	12.5	61.3
	test#2	12.0	65.0		
	2ND test#1	13.0	67.5	13.0	70.0
	test#2	13.0	72.5		
	3RD test#1	14.0	82.5	13.5	80.0
	test#2	13.0	77.5		
	5TH test#1	13.0	85.0	13.0	83.8
	test#2	13.0	82.5		
	10TH test#1	12.0	90.0	12.5	91.3
	test#2	13.0	92.5		
	15TH test#1	12.0	95.0	12.5	95.0
	test#2	13.0	95.0		

Appendix B (Continued)

Table B-3. ARPAK 2.2 DENSITY @ 0.71 PSI & DROPS OF 24", 30", & 36"

		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
24" DROP	1ST test #1	18.0	46.0	18.0	42.0
	test#2	18.0	38.0		
	2ND test#1	17.0	52.0	17.5	49.0
	test#2	18.0	46.0		
	3RD test#1	17.0	54.0	17.5	50.5
	test#2	18.0	47.0		
	5TH test#1	16.0	55.0	16.5	51.5
	test#2	17.0	48.0		
	10TH test#1	17.0	57.0	17.0	53.5
	test#2	17.0	50.0		
	15TH test#1	17.0	59.0	17.0	56.0
	test#2	17.0	53.0		
		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
30" DROP	1ST test #1	16.0	59.0	16.0	58.5
	test#2	16.0	58.0		
	2ND test#1	16.0	69.0	16.0	69.5
	test#2	16.0	70.0		
	3RD test#1	15.0	71.0	15.5	72.0
	test#2	16.0	73.0		
	5TH test#1	15.0	74.0	15.5	74.5
	test#2	16.0	75.0		
	10TH test#1	16.0	75.0	16.0	74.5
	test#2	16.0	74.0		
	15TH test#1	15.0	81.0	15.0	81.0
	test#2	15.0	81.0		
		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
36" DROP	1ST test #1	15.0	82.5	15.0	80.0
	test#2	15.0	77.5		
	2ND test#1	15.0	90.0	15.0	91.3
	test#2	15.0	92.5		
	3RD test#1	15.0	95.0	15.0	95.0
	test#2	15.0	95.0		
	5TH test#1	14.0	97.5	14.0	96.3
	test#2	14.0	95.0		
	10TH test#1	14.0	100.0	14.0	100.0
	test#2	14.0	100.0		
	15TH test#1	14.0	105.0	14.0	106.3
	test#2	14.0	107.5		

Appendix B (Continued)

Table B-4. ARPRO 1.9 DENSITY @ 1.2 PSI & DROPS OF 24", 30", & 36"

		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
	1ST test #1	19.0	36.0	19.0	37.0
	test#2	19.0	38.0		
	2ND test#1	19.0	47.0	19.0	46.5
	test#2	19.0	46.0		
24"	3RD test#1	20.0	49.0	20.0	48.0
DROP	test#2	20.0	47.0		
	5TH test#1	20.0	49.0	20.0	51.0
	test#2	20.0	53.0		
	10TH test#1	20.0	54.0	20.0	54.0
	test#2	20.0	54.0		
	15TH test#1	19.0	54.0	19.5	55.5
	test#2	20.0	57.0		
		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
	1ST test #1	17.0	42.5	17.0	42.5
	test#2	17.0	42.5		
	2ND test#1	17.0	57.5	17.0	56.3
	test#2	17.0	55.0		
30"	3RD test#1	17.0	65.0	17.0	66.3
DROP	test#2	17.0	67.5		
	5TH test#1	17.0	70.0	17.0	68.8
	test#2	17.0	67.5		
	10TH test#1	17.0	75.0	17.0	76.3
	test#2	17.0	77.5		
	15TH test#1	17.0	77.5	17.0	76.3
	test#2	17.0	75.0		
		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
	1ST test #1	16.0	57.5	16.0	57.5
	test#2	16.0	57.5		
	2ND test#1	16.0	82.5	16.0	81.3
	test#2	16.0	80.0		
36"	3RD test#1	16.0	90.0	16.0	93.8
DROP	test#2	16.0	97.5		
	5TH test#1	15.0	97.5	15.0	102.5
	test#2	15.0	107.5		
	10TH test#1	15.0	110.0	15.0	110.0
	test#2	15.0	110.0		
	15TH test#1	15.0	110.0	15.0	110.0
	test#2	15.0	110.0		

Appendix B (Continued)

Table B-5. ARCEL 2.0 DENSITY @ 1.2 PSI & DROPS OF 24", 30", & 36"

		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
24" DROP	1ST test #1	15.0	38.0	15.5	38.0
	test#2	16.0	38.0		
	2ND test#1	16.0	40.0	15.5	40.5
	test#2	15.0	41.0		
	3RD test#1	16.0	48.0	16.0	48.5
	test#2	16.0	49.0		
	5TH test#1	15.0	57.0	15.0	57.5
	test#2	15.0	58.0		
	10TH test#1	15.0	63.0	15.0	62.5
	test#2	15.0	62.0		
	15TH test#1	15.0	64.0	15.0	65.0
	test#2	15.0	66.0		
		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
30" DROP	1ST test #1	16.0	42.5	16.0	42.5
	test#2	16.0	42.5		
	2ND test#1	16.0	60.0	16.0	58.8
	test#2	16.0	57.5		
	3RD test#1	16.0	75.0	16.0	73.1
	test#2	16.0	71.3		
	5TH test#1	16.0	87.5	16.0	83.8
	test#2	16.0	80.0		
	10TH test#1	16.0	105.0	16.0	100.0
	test#2	16.0	95.0		
	15TH test#1	16.0	110.0	16.0	105.0
	test#2	16.0	100.0		
		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
36" DROP	1ST test #1	15.0	42.5	15.0	42.5
	test#2	15.0	42.5		
	2ND test#1	15.0	85.0	15.0	81.3
	test#2	15.0	77.5		
	3RD test#1	14.0	112.5	14.0	107.5
	test#2	14.0	102.5		
	5TH test#1	13.0	132.5	13.0	128.8
	test#2	13.0	125.0		
	10TH test#1	13.0	157.5	13.0	150.0
	test#2	13.0	142.5		
	15TH test#1	13.0	165.0	13.0	160.0
	test#2	13.0	155.0		

Appendix B (Continued)

Table B-6. ARPAK 2.2 DENSITY @ 1.2 PSI & DROPS OF 24", 30", & 36"

		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
24" DROP	1ST test #1	19.0	53.0	18.5	52.5
	test#2	18.0	52.0		
	2ND test#1	18.0	62.0	18.0	61.5
	test#2	18.0	61.0		
	3RD test#1	18.0	68.0	18.5	66.0
	test#2	19.0	64.0		
	5TH test#1	18.0	69.0	18.0	67.5
	test#2	18.0	66.0		
	10TH test#1	18.0	77.0	18.0	74.5
	test#2	18.0	72.0		
	15TH test#1	17.0	77.0	17.5	76.0
	test#2	18.0	75.0		
		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
30" DROP	1ST test #1	17.0	85.0	17.0	85.0
	test#2	17.0	85.0		
	2ND test#1	17.0	102.5	17.0	105.0
	test#2	17.0	107.5		
	3RD test#1	17.0	112.5	17.0	112.5
	test#2	17.0	112.5		
	5TH test#1	17.0	115.0	17.0	117.5
	test#2	17.0	120.0		
	10TH test#1	17.0	120.0	17.0	122.5
	test#2	17.0	125.0		
	15TH test#1	17.0	125.0	17.0	125.0
	test#2	17.0	125.0		
		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
36" DROP	1ST test #1	15.0	125.0	15.0	127.5
	test#2	15.0	130.0		
	2ND test#1	14.0	157.5	14.0	160.0
	test#2	14.0	162.5		
	3RD test#1	14.0	167.5	14.0	168.8
	test#2	14.0	170.0		
	5TH test#1	14.0	175.0	14.0	177.5
	test#2	14.0	180.0		
	10TH test#1	14.0	185.0	14.0	186.3
	test#2	14.0	187.5		
	15TH test#1	14.0	192.5	14.0	193.8
	test#2	14.0	195.0		

Appendix B (Continued)

Table B-7 ARPRO 1.9 DENSITY @ 1.7 PSI & DROPS OF 24", 30", & 36"

		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
24" DROP	1ST test #1	20.0	35	20.0	35.0
	test#2	20.0	35		
	2ND test#1	19.0	50	19.0	48.8
	test#2	19.0	48		
	3RD test#1	19.0	58	19.0	58.8
	test#2	19.0	60		
	5TH test#1	19.0	60	19.0	60.0
	test#2	19.0	60		
	10TH test#1	19.0	68	19.0	67.5
	test#2	19.0	68		
	15TH test#1	19.0	68	19.0	68.8
	test#2	19.0	70		
		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
30" DROP	1ST test #1	19.0	53	19.0	52.5
	test#2	19.0	53		
	2ND test#1	19.0	83	18.5	81.3
	test#2	18.0	80		
	3RD test#1	17.0	93	17.5	92.5
	test#2	18.0	93		
	5TH test#1	17.0	103	17.0	103.8
	test#2	17.0	105		
	10TH test#1	17.0	115	17.0	113.8
	test#2	17.0	113		
	15TH test#1	17.0	123	17.0	120.0
	test#2	17.0	118		
		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
36" DROP	1ST test #1	17.0	85	17.0	85.0
	test#2	17.0	85		
	2ND test#1	16.0	135	16.0	137.5
	test#2	16.0	140		
	3RD test#1	15.0	160	15.0	160.0
	test#2	15.0	160		
	5TH test#1	15.0	175	15.0	177.5
	test#2	15.0	180		
	10TH test#1	15.0	195	15.0	197.5
	test#2	15.0	200		
	15TH test#1	15.0	210	15.0	205.0
	test#2	15.0	200		

Appendix B (Continued)

Table B-8. ARCEL 2.0 DENSITY @ 1.7 PSI & DROPS OF 24", 30", & 36"

		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
	1ST test #1	19.0	30	19.0	31.3
	test#2	19.0	33		
	2ND test#1	19.0	53	18.5	51.3
	test#2	18.0	50		
24"	3RD test#1	18.0	70	18.0	67.5
DROP	test#2	18.0	65		
	5TH test#1	18.0	83	18.0	81.3
	test#2	18.0	80		
	10TH test#1	18.0	90	18.0	87.5
	test#2	18.0	85		
	15TH test#1	18.0	95	17.5	92.5
	test#2	17.0	90		
		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
	1ST test #1	18.0	33	18.0	32.5
	test#2	18.0	33		
	2ND test#1	17.0	80	17.0	77.5
	test#2	17.0	75		
30"	3RD test#1	16.0	105	16.0	103.8
DROP	test#2	16.0	103		
	5TH test#1	16.0	133	15.5	131.3
	test#2	15.0	130		
	10TH test#1	15.0	150	15.0	148.8
	test#2	15.0	148		
	15TH test#1	15.0	163	15.0	172.5
	test#2	15.0	183		
		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
	1ST test #1	16.0	55	16.0	55.0
	test#2	16.0	55		
	2ND test#1	15.0	125	15.0	130.0
	test#2	15.0	135		
36"	3RD test#1	14.0	170	14.0	177.5
DROP	test#2	14.0	185		
	5TH test#1	14.0	215	14.0	220.0
	test#2	14.0	225		
	10TH test#1	14.0	245	14.0	252.5
	test#2	14.0	260		
	15TH test#1	14.0	260	14.0	265.0
	test#2	14.0	270		

Appendix B (Continued)

Table B-9. ARPAK 2.2 DENSITY @ 1.7 PSI & DROPS OF 24", 30", & 36"

		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
24" DROP	1ST test #1	18.0	75	18.0	75.0
	test#2	18.0	75		
	2ND test#1	17.0	90	17.0	92.5
	test#2	17.0	95		
	3RD test#1	17.0	98	17.0	95.0
	test#2	17.0	93		
	5TH test#1	17.0	100	17.0	102.5
	test#2	17.0	105		
	10TH test#1	17.0	108	17.0	107.5
	test#2	17.0	108		
	15TH test#1	17.0	110	17.0	108.8
	test#2	17.0	108		
		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
30" DROP	1ST test #1	17.0	123	17.0	122.5
	test#2	17.0	123		
	2ND test#1	16.0	155	16.0	156.3
	test#2	16.0	158		
	3RD test#1	16.0	163	16.0	165.0
	test#2	16.0	168		
	5TH test#1	15.0	183	15.0	182.5
	test#2	15.0	183		
	10TH test#1	15.0	195	15.0	196.3
	test#2	15.0	198		
	15TH test#1	15.0	200	15.0	203.8
	test#2	15.0	208		
		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
36" DROP	1ST test #1	13.0	185	13.5	185.0
	test#2	14.0	185		
	2ND test#1	13.0	240	13.0	237.5
	test#2	13.0	235		
	3RD test#1	12.0	265	12.5	260.5
	test#2	13.0	256		
	5TH test#1	13.0	285	13.0	277.5
	test#2	13.0	270		
	10TH test#1	13.0	305	13.0	297.5
	test#2	13.0	290		
	15TH test#1	13.0	315	13.0	310.0
	test#2	13.0	305		

Appendix B (Continued)

Table B-10. ARPRO 1.9 DENSITY @ 2.23 PSI & DROPS OF 24", 30", & 36"

		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
	1ST test #1	22.0	50	22.0	50.0
	test#2	22.0	50		
	2ND test#1	20.0	68	19.5	68.8
	test#2	19.0	70		
24"	3RD test#1	19.0	78	18.5	78.8
DROP	test#2	18.0	80		
	5TH test#1	18.0	90	18.0	91.3
	test#2	18.0	93		
	10TH test#1	18.0	95	18.0	97.5
	test#2	18.0	100		
	15TH test#1	18.0	105	18.0	106.3
	test#2	18.0	108		
		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
	1ST test #1	18.0	70	18.0	70.0
	test#2	18.0	70		
	2ND test#1	17.0	115	17.0	115.0
	test#2	17.0	115		
30"	3RD test#1	17.0	140	17.0	142.5
DROP	test#2	17.0	145		
	5TH test#1	17.0	160	16.5	162.5
	test#2	16.0	165		
	10TH test#1	16.0	175	16.0	180.0
	test#2	16.0	185		
	15TH test#1	16.0	185	16.0	187.5
	test#2	16.0	190		
		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
	1ST test #1	15.0	130	15.0	125.0
	test#2	15.0	120		
	2ND test#1	14.0	215	14.0	205.0
	test#2	14.0	195		
36"	3RD test#1	14.0	250	14.0	240.0
DROP	test#2	14.0	230		
	5TH test#1	13.0	280	13.0	272.5
	test#2	13.0	265		
	10TH test#1	13.1	315	13.1	305.0
	test#2	13.0	295		
	15TH test#1	13.0	330	13.0	322.5
	test#2	13.0	315		

Appendix B (Continued)

Table B-11. ARCEL 2.0 DENSITY @ 2.23 PSI & DROPS OF 24", 30", & 36"

		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
24" DROP	1ST test #1	21.0	33	21.0	32.5
	test#2	21.0	33		
	2ND test#1	19.0	70	19.0	68.8
	test#2	19.0	68		
	3RD test#1	18.0	93	18.0	92.5
	test#2	18.0	93		
	5TH test#1	18.0	115	17.5	116.3
	test#2	17.0	118		
	10TH test#1	17.0	130	17.0	131.3
	test#2	17.0	133		
	15TH test#1	17.0	135	17.0	136.3
	test#2	17.0	138		
		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
30" DROP	1ST test #1	18.0	55	18.0	52.5
	test#2	18.0	50		
	2ND test#1	17.0	135	17.0	135.0
	test#2	17.0	135		
	3RD test#1	16.0	185	16.0	182.5
	test#2	16.0	180		
	5TH test#1	15.0	220	15.0	220.0
	test#2	15.0	220		
	10TH test#1	15.0	255	15.0	252.5
	test#2	15.0	250		
	15TH test#1	15.0	260	15.0	262.5
	test#2	15.0	265		
		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
36" DROP	1ST test #1	14.0	115	14.0	102.5
	test#2	14.0	90		
	2ND test#1	13.0	280	13.0	257.5
	test#2	13.0	235		
	3RD test#1	11.0	360	10.5	330.0
	test#2	10.0	300		
	5TH test#1	10.0	420	10.0	395.0
	test#2	10.0	370		
	10TH test#1	10.0	460	10.0	435.0
	test#2	10.0	410		
	15TH test#1	10.0	480	10.0	450.0
	test#2	10.0	420		

Appendix B (Continued)

Table B-12. ARPAK 2.2 DENSITY @ 2.23 PSI & DROPS OF 24", 30", & 36"

		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
24" DROP	1ST test #1	18.0	103	18.0	98.8
	test#2	18.0	95		
	2ND test#1	17.0	128	17.0	125.0
	test#2	17.0	123		
	3RD test#1	17.0	140	17.0	136.3
	test#2	17.0	133		
	5TH test#1	17.0	153	16.5	148.8
	test#2	16.0	145		
	10TH test#1	16.0	163	16.0	156.3
	test#2	16.0	150		
	15TH test#1	16.0	168	16.0	162.5
	test#2	16.0	158		
		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
30" DROP	1ST test #1	15.0	180	15.0	180.0
	test#2	15.0	180		
	2ND test#1	15.0	240	15.0	240.0
	test#2	15.0	240		
	3RD test#1	15.0	260	15.0	260.0
	test#2	15.0	260		
	5TH test#1	14.0	275	14.0	275.0
	test#2	14.0	275		
	10TH test#1	14.0	295	14.0	292.5
	test#2	14.0	290		
	15TH test#1	14.0	305	14.0	307.5
	test#2	14.0	310		
		Shock Dur (ms)	Shock in G's	Avg. Dur (ms)	Avg. G's
36" DROP	1ST test #1	13.0	295	13.0	297.5
	test#2	13.0	300		
	2ND test#1	12.0	385	11.5	390.0
	test#2	11.0	395		
	3RD test#1	10.0	420	10.0	425.0
	test#2	10.0	430		
	5TH test#1	9.0	440	9.0	450.0
	test#2	9.0	460		
	10TH test#1	9.0	470	9.0	475.0
	test#2	9.0	480		
	15TH test#1	9.0	480	9.0	490.0
	test#2	9.0	500		

APPENDIX C RECORDED STATIC DATA

Table C -1. PERMANENT DEFORMATION ON MATERIAL THICKNESS

Material	Thickness in Inches			
		Compression		
	Average Initial	Average 5th	Average 10th	Average 15th
ARPRO™	2.00	1.90	1.85	1.79
ARCEL™	2.00	1.63	1.56	1.50
ARPAK™	1.92	1.76	1.70	1.65
ETHAFOAM™	2.00	1.75	1.63	1.61

Material	Percent decrease in thickness			
	Initial to 5th	5th to 10th	10th to 15th	Initial to 15th
ARPRO™	5.0%	2.6%	3.2%	11.7%
ARCEL™	18.5%	4.3%	3.8%	33.3%
ARPAK™	8.3%	3.4%	2.9%	16.4%
ETHAFOAM™	12.5%	6.9%	1.2%	24.2%

ARPRO

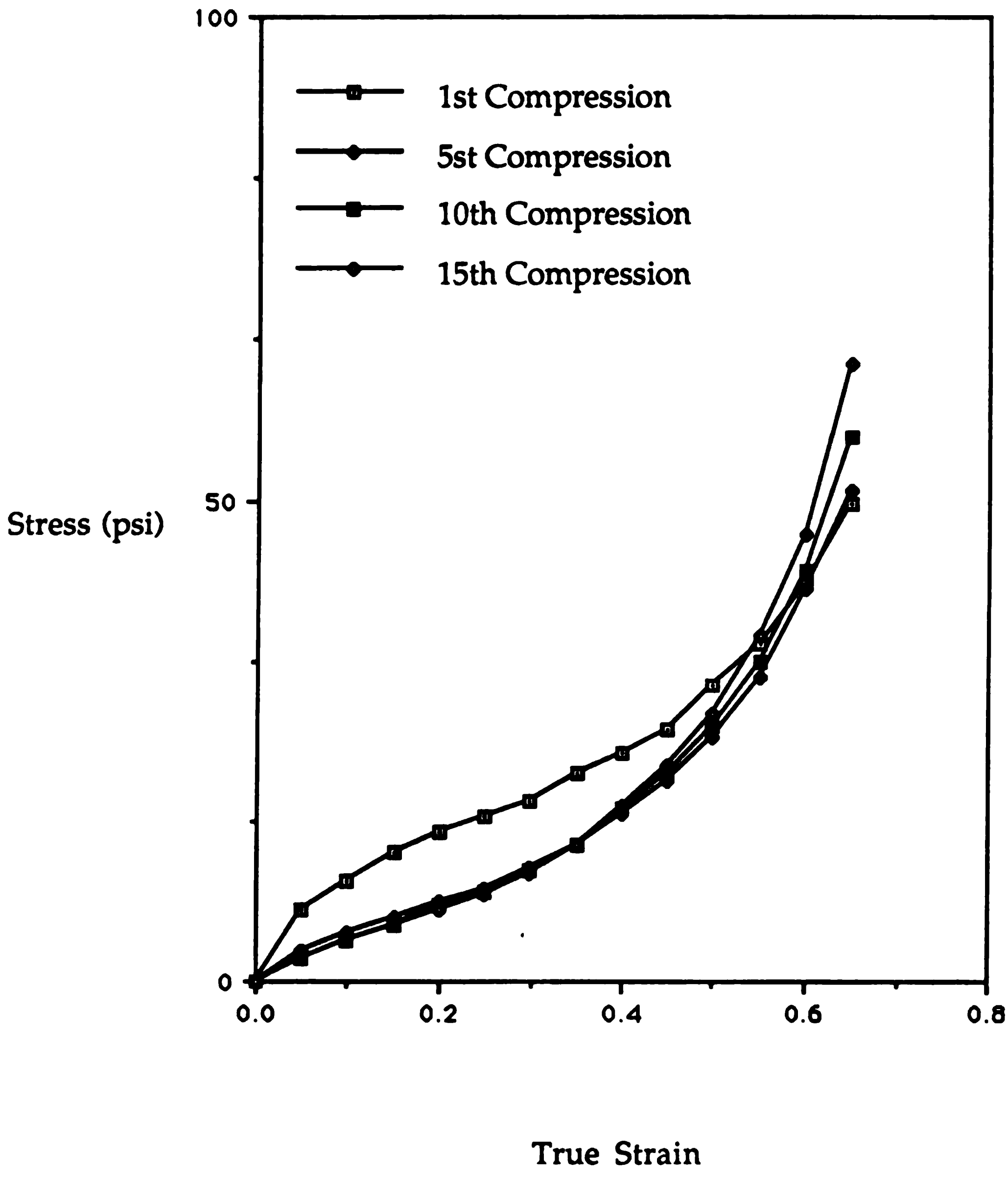

Figure C-1. RECORDED STRESS-STRAIN CURVE FOR ARPRO™

Appendix C (cont)
ARCEL

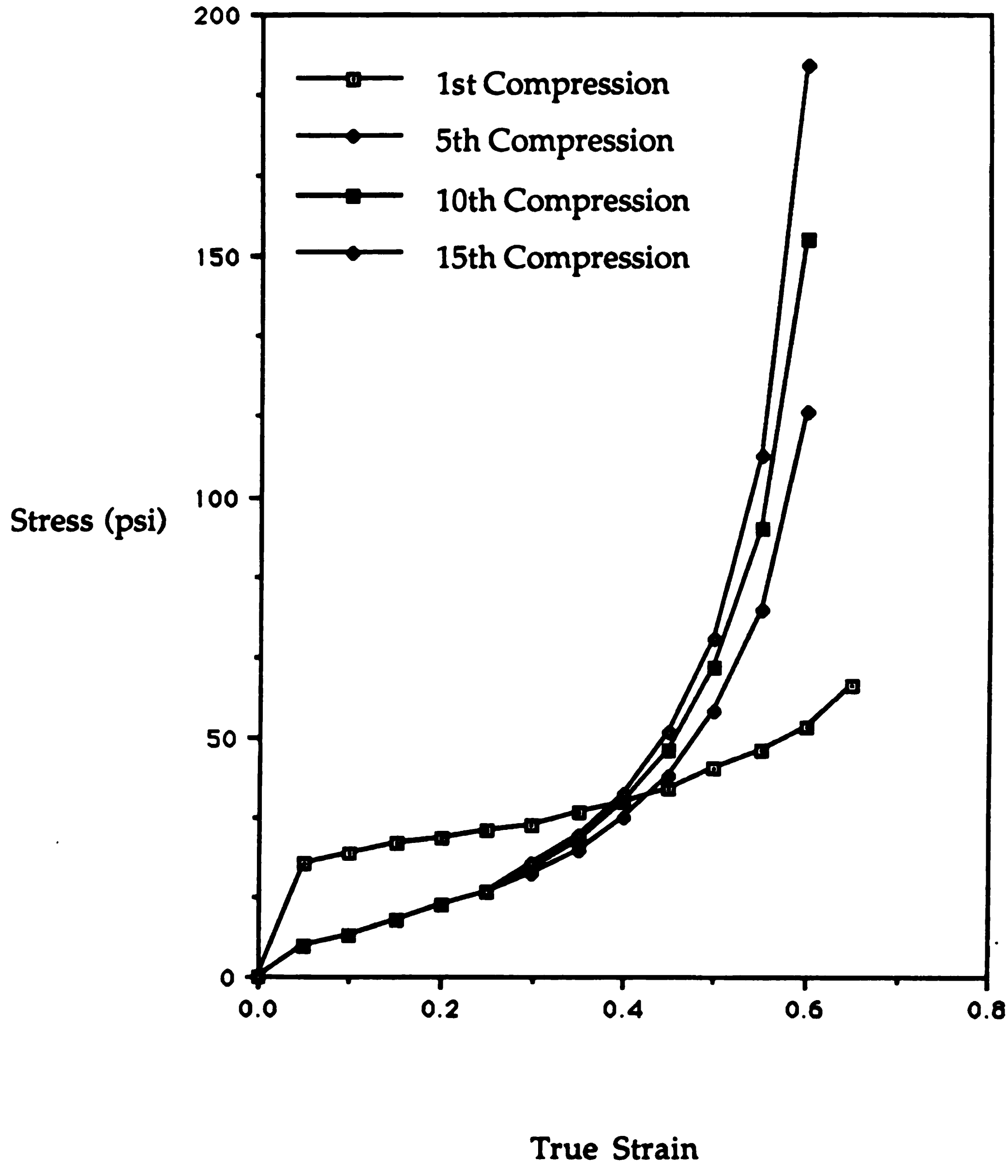

Figure C-2. RECORDED STRESS-STRAIN CURVE FOR ARCEL™

Appendix C (cont)
ARPAK

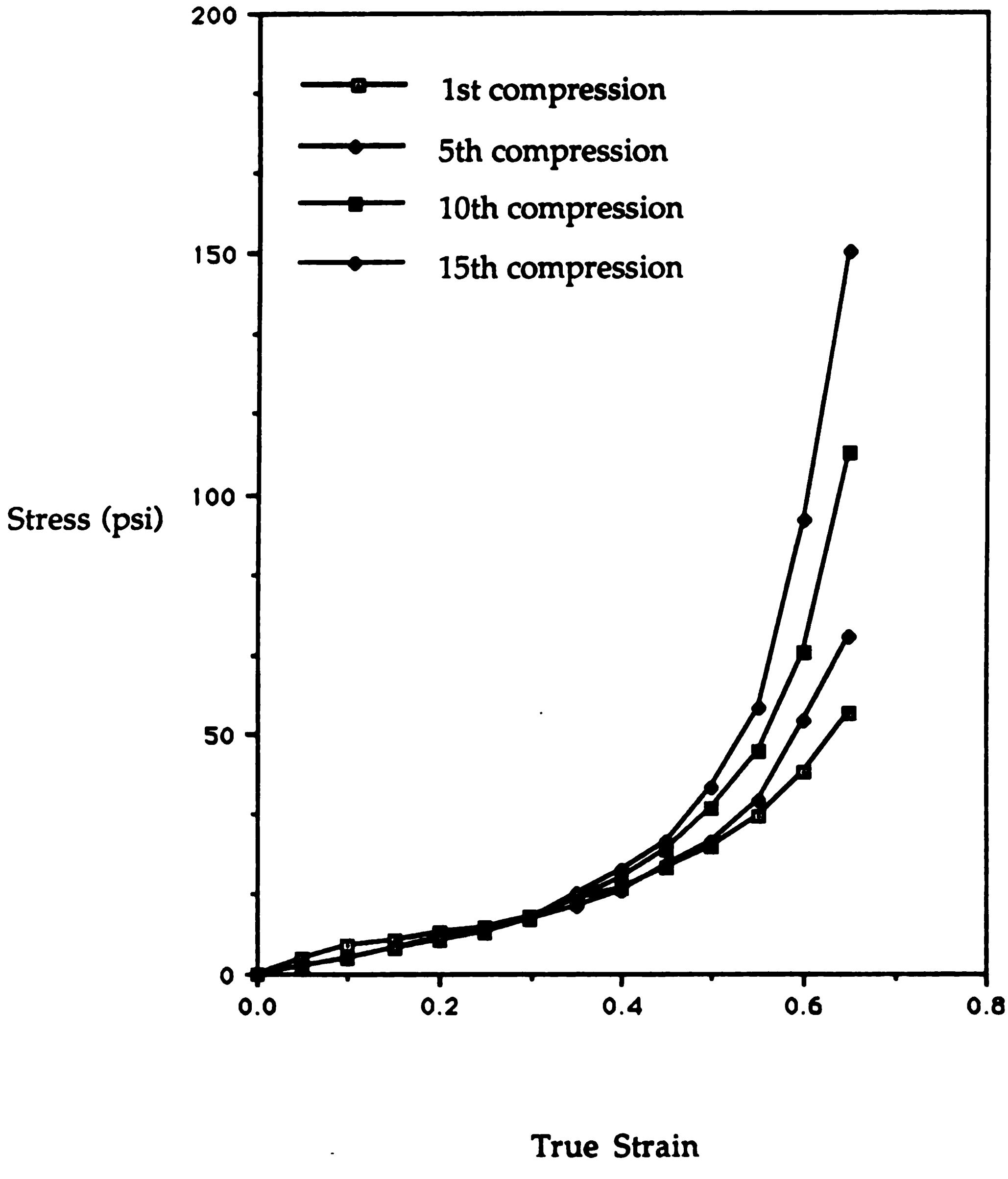

Figure C-3. RECORDED STRESS-STRAIN CURVE FOR ARPAK™

Appendix C (cont)
ETHAFOAM

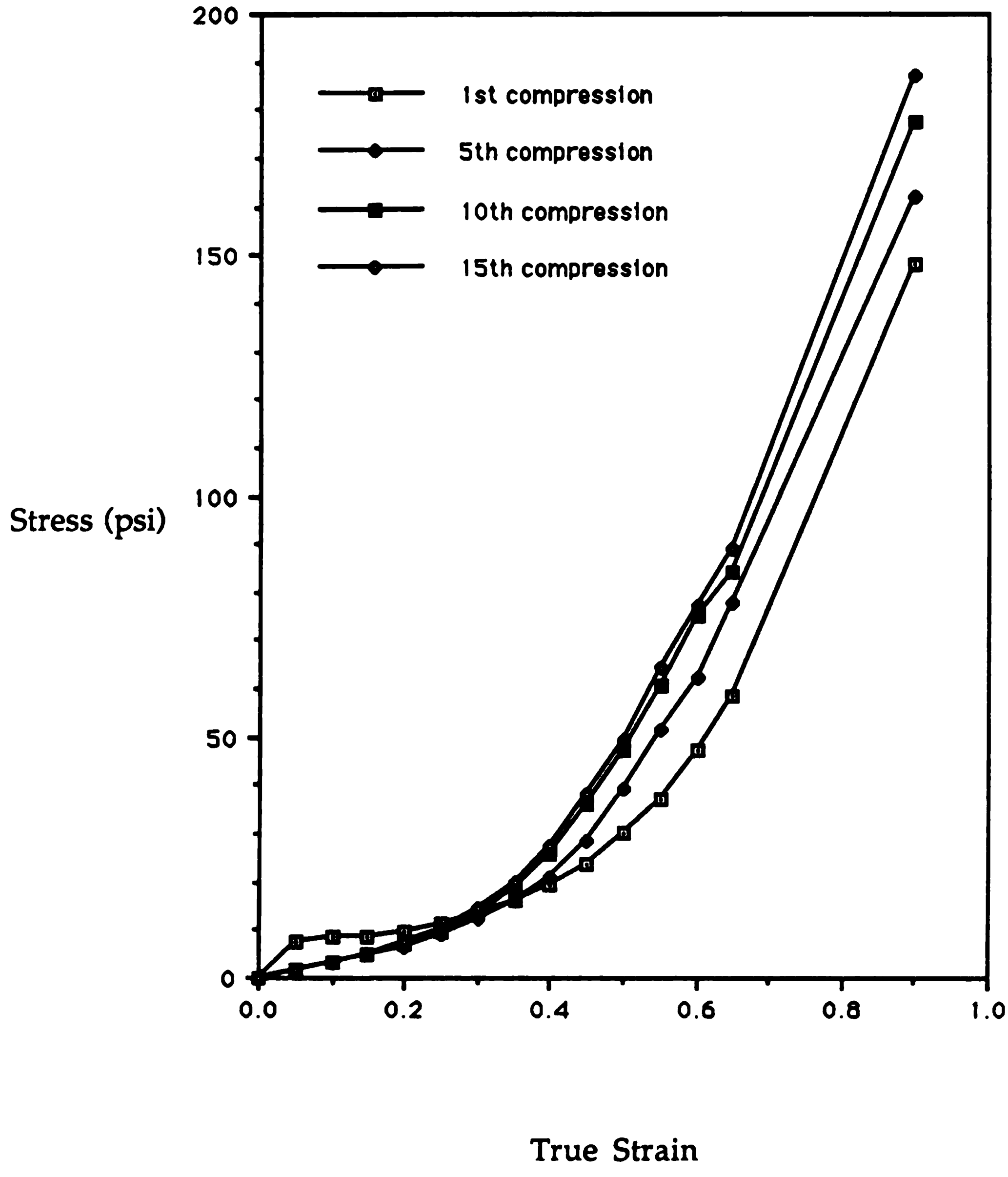

Figure C-4. RECORDED STRESS-STRAIN CURVE FOR ETHAFOAM 220™

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