Impact Limiter Tests of Four Commonly Used Materials and Establishment of an Impact Limiter Data Base*

W.M. McMurtry, G.F. Hohnstreiter
Sandia National Laboratories

INTRODUCTION

In designing a package for transporting hazardous or radioactive materials, there are a number of components whose design can lead to the success or failure to meet regulatory requirements for Type B packages as specified in Title 10 Code of Federal Regulations, Part 71 (10 CFR 71). One of these components is the impact limiter. The primary purpose of the impact limiter is to protect the package and its contents from sudden deceleration. It can also act as a thermal barrier. The package is protected by the impact limiter's ability to act as an energy absorber.

The crush strength of most impact limiting materials is determined by a standard quasi-static (QS) method. However, it has been observed that there are a number of factors that affect crush strength, in particular load rate and angle of impact. The material being used as an impact limiter in some cases may appear nearly incompressible because of one or more of these factors, giving the package almost no protection at all.

Factors that determine compressive strength of impact limiter materials are:

- The material density.
- The thickness of the impact limiter material. There must be adequate material to absorb the impact and not go into lockup; lockup occurs when the free volume of the material is eliminated and the crush strength sharply increases.
- The angle of impact.
- The loading rate.
- Operating temperature.

All of these are interactive and therefore difficult to model.

It is the intent of tests discussed in this paper to determine the dependency of crush strength to loading rate and angle of impact to the basic grain direction of two different densities of four impact limiting materials. The data gathered will be used to establish a World Wide Web home page accessible through Sandia's home page. The four materials are:

- Aluminum foam, Durocell®, ERG Materials and Areospace Corporation.

* This work was performed at Sandia National Laboratories, Albuquerque, New Mexico, supported by the U. S. Department of Energy under Contract No. DE-AC04-94 AL85000.

- Polyurethane, Last-A- Foam®, General Plastics Manufacturing Corporation.
- Aluminum honeycomb, manufactured by Alcore Inc.
- Trussgrid®, Alcore Inc., a material new to this application. Trussgrid is essentially honeycomb with alternating layers placed at 90 degrees rather than parallel.

The first three of these materials have been previously tested to some degree, and the results have been reported. In this test program they were tested more extensively with the intent of providing useful design data to package designers.

APPROACH

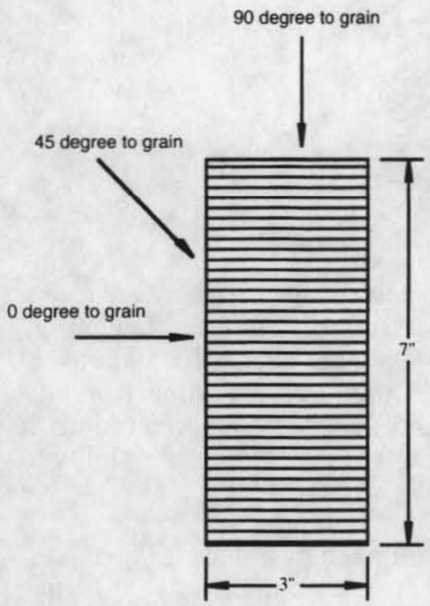

Figure 1.
Impact Direction to the Zero Grain Axis

The crush strength of four impact limiter materials was tested at four different load rates, quasi-statically, 44 feet per second (ft/s), (a 9-meter drop test per 10CF71), 33 ft/s and 22 ft/s. For each loading rate, the load was applied at three different angles (the impact direction) 0, 45, and 90 degrees to the axis (see Figure 1). For the aluminum and polyurethane foam, the zero axis is the rise direction (foams form vertically), and they ideally behave isotropically. For the aluminum honeycomb and trussgrid, the zero axis is parallel to the cell longitudinal axis.
All these tests were conducted at ambient temperature; tests at other temperatures are planned in the future.
The mass and velocity were calculated to take the impactor to approximately 10% of lockup of the test material.
In Table 1, the crush strength used for stress was from manufacturers' data and the Sandia Report "Characterization of Impact-Limiting Material" (Duffey et al 1992). The compressive distance was calculated based on the crush strength in psi and the area of the impactor. The masses at each velocity were calculated to deposit the same amount of energy into each sample of the material.

Material	Density	Stress Crush Strength to 10% Lockup Acr in psi	Compressive Distance in 3" of Material		Energy Dissipation E = Acr(Area in inches)"B"			Weight required for constant Energy at certain velocity. $E = 1/2\ mv^2$ or $W = 2Eg/v^2$		
			Strain in/in	"B" Dist in inches	Area = $Pi*r^2$	E in lb inches Acr*"B"*Area	E in ft.lb E/12	for 44'/sec W in pounds	for 33'/sec W in pounds	for 22'/sec W in pounds
Aluminum	12.1 pcf	350.00	0.76	2.29	5.41	4330	361	11.93	21.21	47.71
Foam	18.5 pcf	752.00	0.71	2.12	5.41	8644	720	23.81	42.33	95.25
Poly	10.7 pcf	750.00	0.53	1.59	5.41	6454	538	17.78	31.61	71.11
Foam	18.1 pcf	2,260.00	0.52	1.55	5.41	18897	1575	52.06	92.55	208.23
Honey-	5.7 pcf	500.00	0.78	2.33	5.41	6291	524	17.33	30.81	69.33
comb	9.0 pcf	960.00	0.75	2.24	5.41	11612	968	31.99	56.87	127.95
Trussgrid	7.9 pcf	350.00	0.78	2.33	5.41	4404	367	12.13	21.57	48.53
	10.8 pcf	700.00	0.75	2.24	5.41	8467	706	23.32	41.47	93.30

Table 1.
Impact Limiter Test Matrix with Calculated Values of Energy and Impactor Weights

TEST SETUP

The static testing was conducted in Sandia's Force and Pressure laboratory using the 20,000 pound MTS™ test machine. The tests at 44, 33, and 22 ft/s were conducted using a horizontal 3-inch ID Air gun in the Sandia Mechanical Shock Lab. Figures 2, 3, and 4 show the air gun, impactor, impactor mass, impact limiter material, material retainer, and load cell.

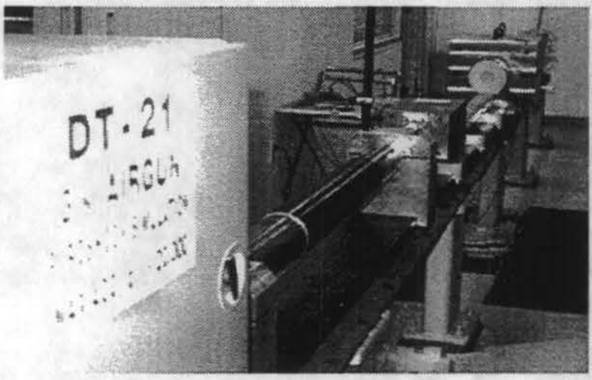

Figure 2.
3-Inch Air gun

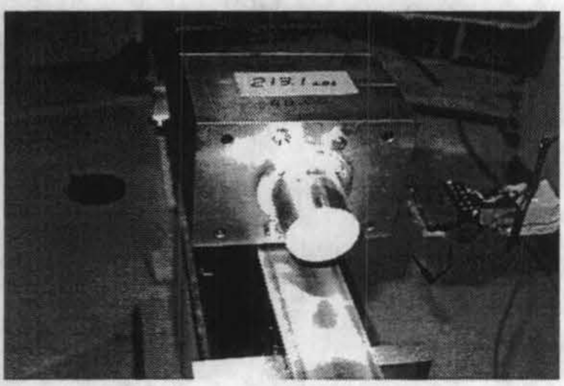

Figure 3.
Impactor and Impactor Mass

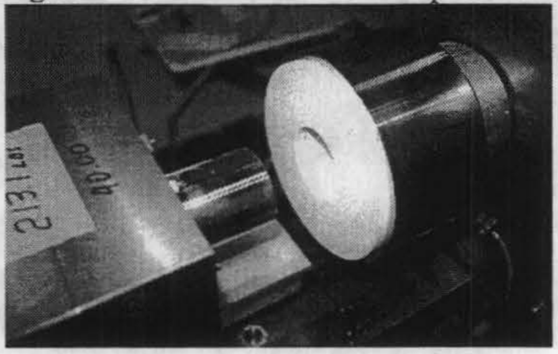

Figure 4.
Impactor Mass, Impactor, Impact Limiter Material, Material Retainer, and Load Cell

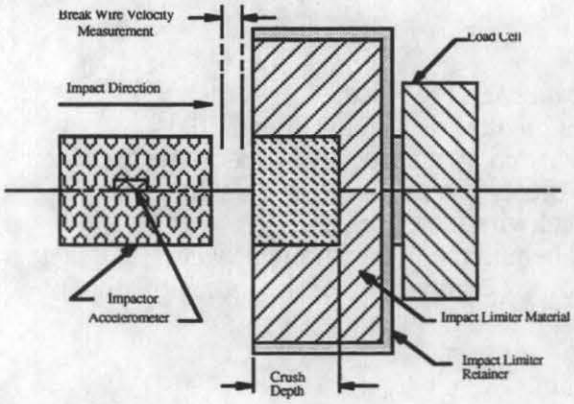

Figure 5.
Schematic of Test Setup

As shown in Figure 5, the impactor, which was the desired weight, was accelerated to a specified velocity. The weight and velocity were specified in the test matrix (Table 1), but the actual test weight was adjusted during the testing. The impactor velocity was measured by a break wire velocity measurement system. The energy in the impactor = $1/2mv^2$) was sufficient to crush the impact limiter material into approximately 10% of lockup. The load cell measured the load applied to the impact limiter material in pounds and so was divided by the area of the impactor (5.42 square inches) to give pounds per square inch (psi). The load cell was mounted on a

1,500 pound reaction mass. An accelerometer measured the deceleration of the impactor. From the accelerometer data the velocity and crush depth were determined.

Figures 6 through 9 are samples of each material after testing.

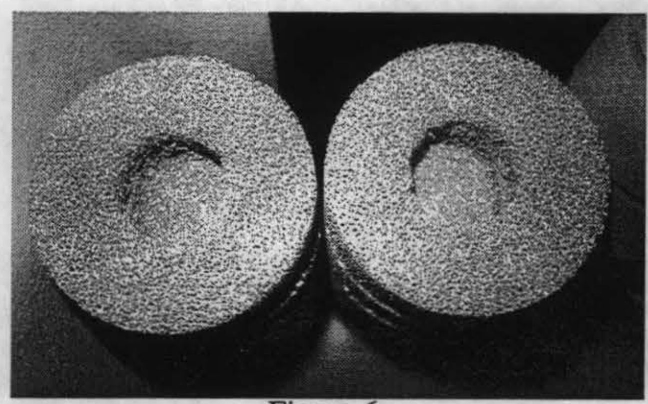

Figure 6.
Aluminum Foam

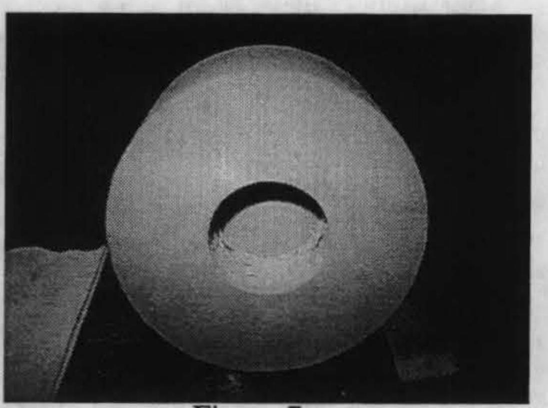

Figure 7.
Polyurethane Foam

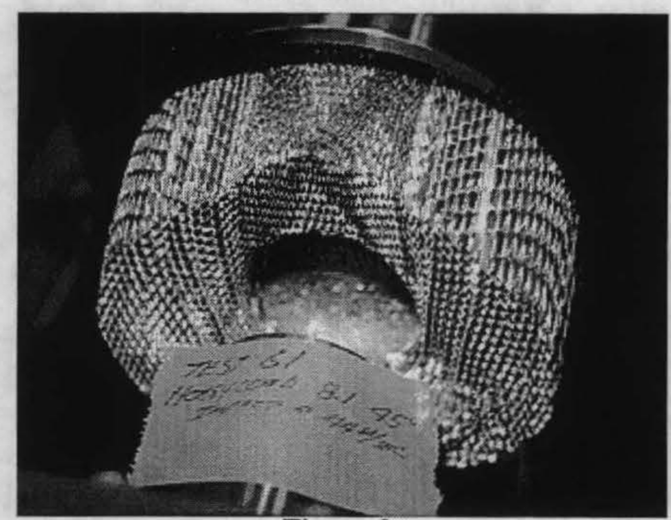

Figure 8.
Aluminum Honeycomb

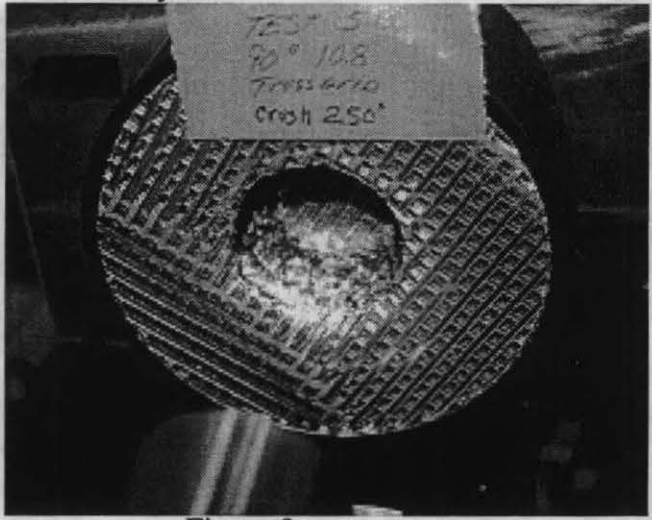

Figure 9.
Trussgrid

DATA DISCUSSION

As discussed in the Test Setup, three types of data were recorded:

1. Velocity of the impactor was measured by a breakwire system (Figure 10).
2. Acceleration (actually deceleration) was measured by an accelerometer on the impactor (Figure 11). From those data, velocity and crush distance were calculated. The velocity in all cases agreed well with the breakwire measurement.
3. Load was measured using a load cell placed behind the impact limiter material retainer; this provided crush strength. Figure 12 shows a comparison of the load plots for 0, 45, and 90 degree tests at 33 ft/sec.

Note that all of these plots are for aluminum foam.

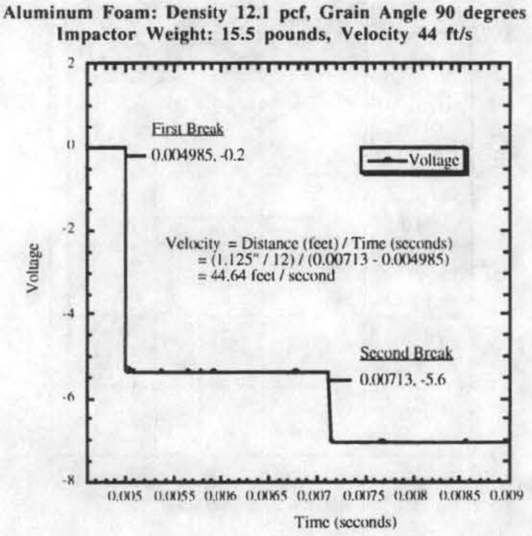

Figure 10.
Breakwire Velocity Measurement

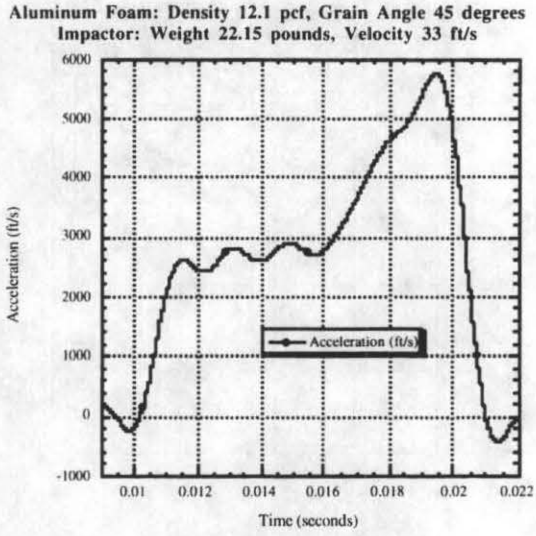

Figure 11.
Accelerometer Trace

The measured crush strength was from plots the same as shown in Figure 12. The energy was calculated from integral of the measured crush distance and measured load.

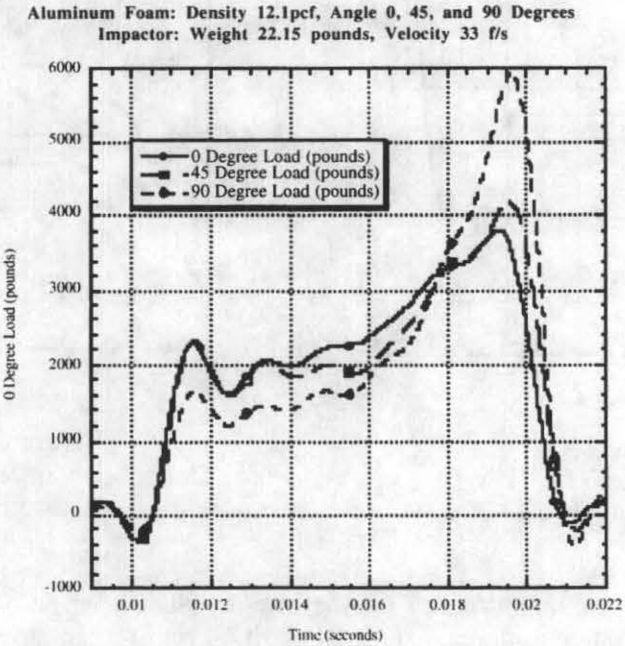

Figure 12.
Load Comparison for 0, 45, and 90 Degree 12.1 pcf Aluminum Foam at 33 ft/s

Shown in Figures 13, 14, 15, and 16 are sample force deflection curves for the low-density materials. All these tests were done at 0 degrees and 44 ft/s.

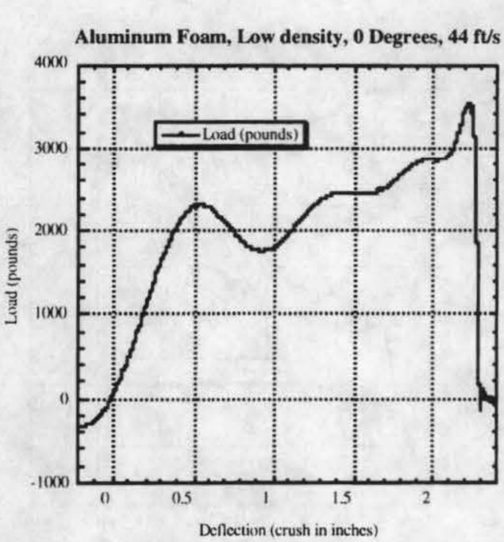

Figure 13.
Force Deflection Curve for Low-Density Aluminum Foam

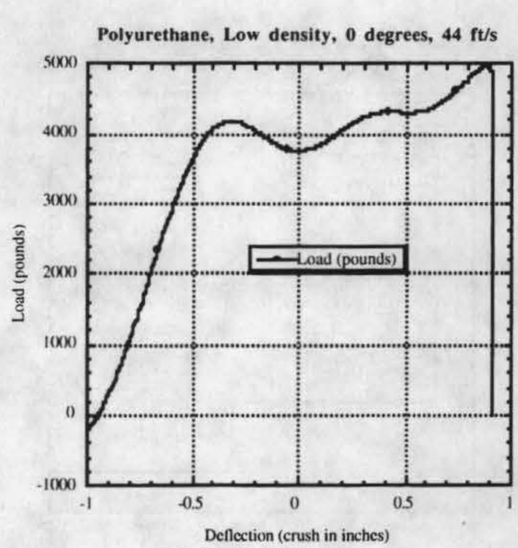

Figure 14
Force Deflection Curve for Low-Density Polyurethane

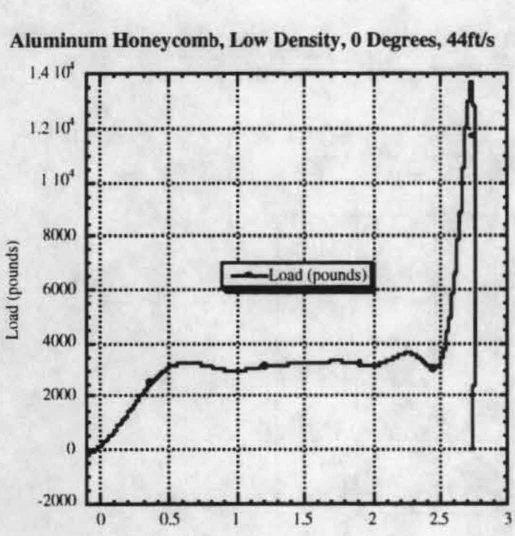

Figure 15.
Force Deflection Curve for Low Density Honeycomb

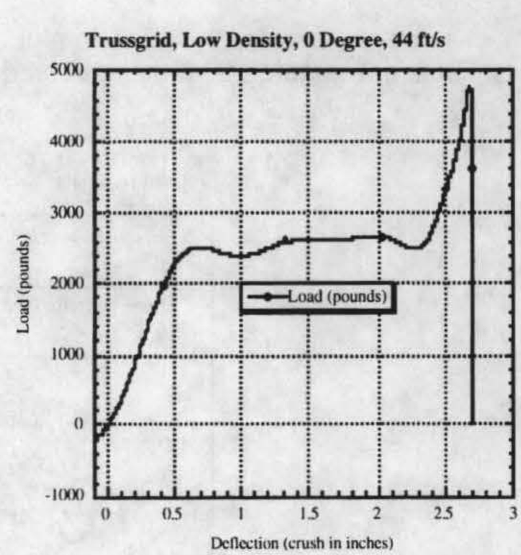

Figure 16.
Force Deflection Curve for Low Density Trussgrid

Table 2 shows a sample data summary for the low-density and high-density impact limiter materials tested at 0 degree and quasi-static through 44 ft/s. Crush strengths in pounds per square inch (psi) and energy absorption in joules (newton.metres [N.m]) were measured. The other test parameters are shown for information. In some instances there are crush data but no energy data, because no accelerometer data were recorded. The impactor was broken during the 45 degree test at 33 ft/sec test of the 8.10 pound per cubic foot (pcf) test of the aluminum honeycomb. No further tests were done on this material.

Impact Limiter Material	Density lb/cuft	Impactor Weight pounds	Velocity ft/sec	Impact Angle to 0 Grain direction	Given Crush Strength psi	Measured Crush Strength psi	Energy= $1/2mv^2$ ft.lbf	Calculated Energy Joules N.m	Measured Energy Absorbed Joules N.m
Aluminum Foam	12.10	11.95	44.00	0	350	591	361	490	470
	12.10	22.15	32.80	0	350	684	372	505	no data
	12.10	50.75	22.00	0	350	702	384	520	610
	12.10	NA	QS	0	350	314-635	NA	NA	NA
	18.50	24.20	43.40	0	752	1441	712	966	1180
	18.50	43.25	33.00	0	752	1552	736	998	1062
	18.50	96.50	22.30	0	752	1552	750	1017	1110
	18.50	NA	QS	0	752	490-1019	NA	NA	NA
Polyurethane Foam	10.70	18.35	44.00	0	750	735-809	555	753	1010
	10.70	35.24	33.00	0	750	680-824	600	813	1045
	10.70	77.24	22.00	0	750	no data	584	792	no data
	10.70	NA	QS	0	750	400-1064	NA	NA	NA
	18.10	18.35	44.00	0	2260	698-772	555	753	1150
	18.10	35.24	33.00	0	2260	1848-1863	600	813	2980
	18.10	77.24	22.00	0	2260	1478-1667	584	792	3000
	18.10	NA	QS	0	2260	1196-2325	NA	NA	NA
Aluminum Honeycomb	5.70	25.73	44.00	0	500	558	778	1055	1250
	5.70	45.79	33.00	0	500	558	779	1056	1200
	5.70	101.60	22.00	0	500	869	768	1042	no data
	5.70	NA	QS	0	500	283	NA	NA	NA
	8.10	38.83	44.00	0	960	928	1175	1593	1790
	8.10	70.77	33.00	0	960	933	1204	1633	1700
	8.10	162.27	22.00	0	960	no data	1227	1664	no data
	8.10	NA	QS	0	960	458-509	NA	NA	NA
Trussgrid	7.90	17.78	44.00	0	350	462	538	729	810
	7.90	30.38	33.00	0	350	462	517	701	825
	7.90	70.78	22.00	0	350	479	535	726	805
	7.90	NA	QS	0	350	209-311	NA	NA	NA
	10.80	30.38	44.00	0	700	924	919	1246	1420
	10.80	71.10	33.00	0	700	832	1210	1640	1500
	10.80	162.20	22.00	0	700	832	1227	1663	1410
	10.80	NA	QS	0	700	498	NA	NA	NA

Table 2.
Data Sample for the Low Density of Each Impact Limiter Material

DISCUSSION OF THE MATERIALS

Aluminum Foam

For the static tests, the crush strength appeared to be higher than previously reported and is not a plateau but rather a slope up from the beginning of crush to start of lockup. The material does not appear to be fully isotropic. For the dynamic tests, the crush strength for the high velocity 44 ft/s is relatively close to the static result but is higher at the lower velocities. The energy absorbed and the calculated energy for both the low-density and high-density material are within less than 10 percent.

Polyurethane

For the static tests, the crush strength of the low-density and high-density material starts out below the given crush strength, but slopes up to the start of lockup to above the given. The average is close to the given and is isotropic. The dynamic tests show the measured crush strength to be very close to the given for the 44 and 33 ft/s in the low-density material but nearly double for the 22 ft/s. In the high-density material, both the 33 and 22 ft/s are high but not as high as the given.

Aluminum Honeycomb

In the static tests for the low-density material, the crush strength for the 0 and 90 degree material appeared low. For the dynamic tests, this material behaved as expected for the tests run. Due to lack of tests, very little can be determined.

Trussgrid

The static tests for both densities appear to be the opposite to what would be expected. The crush strength for the 90 degree material is higher than the 0 degree material, starting with a lower initial crush strength and increases to above at start of lockup. The dynamic tests appear normal, and the material looks reasonably isotropic.

CONCLUSIONS

Tests were conducted on four impact limiter materials, aluminum foam, polyurethane, aluminum honeycomb, and Trussgrid. The tests were conducted to determine the dependency of the crush strength and energy absorption on: (1) density, (2) loading rate, and (3) impact angle. The tests were conducted using a free-flying impactor maintaining the same energy for each density of material The data collected can be used by designers of transportation packages to:

- Determine a crush strength of the four materials and two densities of each to use in their design.
- Determine the density dependency.
- See if material is isotropic and, if not, what is the angular dependency.
- Determine load rate dependency.

More testing needs to be done using a different method of testing to correlate the data and prepare a test plan with a quality assurance level 1, which will be acceptable by other organizations designing transportation packages. The beginning of this testing is scheduled in fiscal 1996. A complete data summary table is available on request.

ACKNOWLEDGMENTS

The support of the U. S. Department of Energy, Office Transportation, Emergency Management, and Analytical Services, Transportation Division. I also wish to thank D.L. Bolton for technical assistance and F.A. Brown and N.T. Davies of Department 2742 Sandia National Laboratories for test operations.

REFERENCES

1. Title 10, Code of Federal Regulations, Part 71, Nuclear Regulatory Commission, Washington, DC, January 1988.
2. T.A. Duffey, R.E. Glass, P. McConnell, "Characterization of Impact-Limiting Material", Sandia National Laboratories, Albuquerque, New Mexico, May 1992.

Session V-4: Risk Assessment