DEVELOPMENT OF CIRCUMFERENTIAL HONEYCOMB IMPACT LIMITERS FOR A DEFENSE HIGH LEVEL WASTE SHIPPING CASK

A. Zimmer, M. A. Koploy, N. D. Rickard
GA Technologies Inc.*
San Diego, California

M.M. Madsen, W. L. Uncapher
Sandia National Laboratories**
Albuquerque, New Mexico

ABSTRACT

Circumferential honeycomb impact limiters provide lightweight, low-volume impact protection for nuclear waste shipping casks with circular cross sections. GA Technologies (GA) has developed an empirical procedure for designing circumferential honeycomb impact limiters to limit the impact g-level to a predetermined level. Sandia National Laboratories (SNL) has performed a series of tests demonstrating that the circumferential honeycomb impact limiters are effective and can be adequately designed using this empirical procedure. Circumferential honeycomb impact limiters are currently used on the Defense High Level Waste (DHLW) truck shipping cask and are planned for use on several new casks which are scheduled for development during the next few years. This paper describes the structural design of the circumferential honeycomb impact limiters, presents the emperical design procedure for predicting the impact g-level and required volume of honeycomb, and compares tests results with predicted results.

INTRODUCTION

Honeycomb is well known for its efficient and predictable energy absorbing capabilities. Honeycomb is frequently used to provide impact protection in cases where the loading is in one direction. Because the basic honeycomb structure is unidirectional and its energy absorbing efficiency is reduced when crushed at angles from the principal axis, it is not commonly used to protect the circumference of cylindrical casks. GA has found that by constructing the circumferential honeycomb limiters out of 15° segments, the overall impact limiter energy absorbing performance is nearly uniform for any circumferential drop orientation. Tests performed under the DHLW truck shipping cask program plus a study performed by Sandia, Livermore Laboratory (1) on cylindrically shaped honeycomb energy absorbers provide the basis for the development of the empirical design procedure described herein.

STRUCTURAL DESIGN

The following is a description of the basic design for circumferential honeycomb impact limiters. The basic design can be easily modified to fit the needs of other applications by applying the design procedure described below.

The basic circummferential honeycomb impact limiter consists of a honeycomb ring made up of twenty-four 15° segments as shown in Fig. 1. The cells of the centerline of each 15° segment line up radially like the center of the cask. Each segment is bonded directly to the cask body. 15° segments were chosen as a reasonable and practical approximation of an ideal honeycomb configuration where all honeycomb cell centerlines would be radial. Adjacent segments are bonded to a skin that separates them. This skin provides a surface to bond the honeycomb and a mechanism for transferring the load between segments. A stainless steel skin covers all exterior surfaces which facilitates decontamination.

DESIGN PROCEDURE

The cask designer must insure that the circumferential honeycomb impact limmiter can (a) absorb all of the impact energy without bottom-ing out and (b) will limit the impact g-level to a level at which the cask can meet the regulations.

The designer uses an iterative process to compute the volume honeycomb required to absorb all the impact energy. First, the designer assumes a value for the depth of crush and then computes the energy absorbed by crushing to that depth. Finally, if the energy absorbed by the honeycomb is

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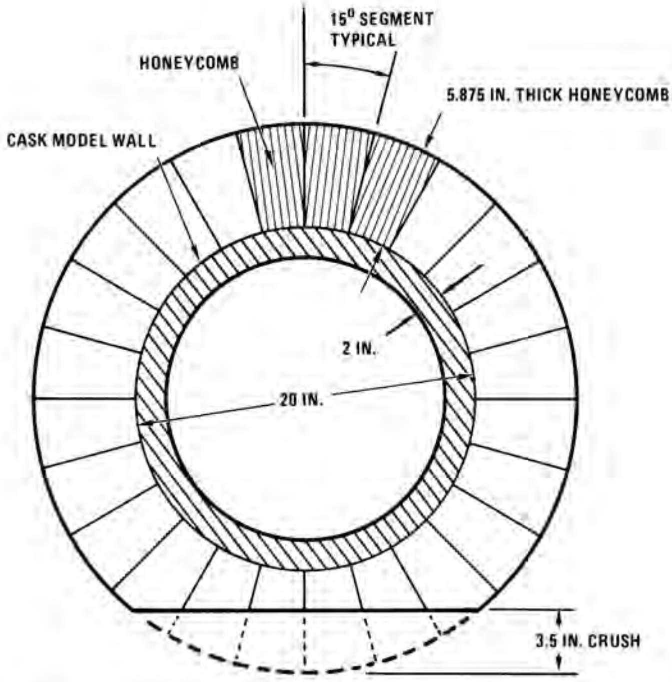

Fig. 1. Section Through Test Model Circumferential Honeycomb Impact Limiter.

not equal to the impact energy of the cask, the designer selects a new depth of crush and the process is repeated until the desired accuracy is achieved.

The energy absorbed by the impact limiter is the sum of the energy absorbed by each segment,

$$E = \sum_{i=1}^{n} \sigma_{n_i} V_i \qquad \text{Eq. (1)}$$

where E = energy absorbed,

σ_{n_i} = stress normal to the plane of crushing in the ith honeycomb segment.

V_i = volume of crush in the ith honey comb segment,

n = number of crushed honeycomb segments.

The volume of crush can be computed by simple geometry. The stress normal to the plane of crushing is a function of (a) the type of honeycomb and (b) the angle of crush. Manufacturers ordinarily only give honeycomb properties that are normal to or in the direction of the honeycomb cells. GA has developed an empirical prodcedure for calculating σ_n, which is the stress normal to the plane of crushing, for loads applied at angles off from the axis parallel to the honeycomb cells. This method is based on the following criteria: (a) the combination of stress components in the honeycomb cannot exceed the crush strength of the honeycomb,

$$\sigma_{cr} = \sqrt{\sigma_y^2 + 4\sigma_x^2} \qquad \text{Eq. (2)}$$

where σ_{cr} = manufacturer's crush strength of honeycomb, in direction of cells,

σ_y = compressive stress in the direction of the honeycomb cells,

= $\sigma_n \sin \alpha$,

σ_x = stress normal to the direction of the honeycomb cells,

σ_n = honeycomb stress normal to the plane of crushing,

α = angle between the normal to the plane of crushing and cell direction,

and (b) the stress normal to the direction of the honeycomb cells cannot exceed the plate shear strength of the honeycomb provided by the manufacturer,

$$\tau_f = \sigma_x = \sigma_n \sin \alpha \qquad \text{Eq. (3)}$$

where τ_f = plate shear strength of the honeycomb.

Therefore, the effective crush stress is equal to the minimum normal stress found by solving Eqs. (2) and (3) for σ_n or

$$\sigma_n = \text{Minimum of} \quad \frac{\sigma_{cr}}{\sqrt{\cos^2\alpha + 4\sin^2\alpha}}, \quad \frac{\tau_f}{\sin \alpha} \qquad \text{Eq. (4)}$$

The maximum force exerted by the circumferential honeycomb impact limiter is equal to the sum of the forces exerted by each honeycomb segment,

$$F = \sum_{i=1}^{n} \sigma_{n_i} A_i \qquad \text{Eq. (5)}$$

where F = total force exerted by the impact limiter,
σ_{ni} = stress normal to the plane of crushing in the ith honeycomb segment.
A_i = crush area of the ith honeycomb segmemt.
n = number of crushed honeycomb number of crushed honeycomb segments.

The crush area can be computed using simple geometry, and σ_n is computed using Eq. (4). Honeycomb crushing at an angle greater than 30° from the drop direction contributes very little to energy absorption and is, therefore, conservatively ignored.

TESTING

The series of tests of the circumferential honeycomb impact limiters were performed. First, a single half-scale impact limiter attached to a steel cylinder, as shown in Figs. 2 and 3, was dropped from both 15 ft. and 22 ft. Next, a half-scale model of the DHLW cask was drop tested from 30 ft.

The cylinder for the half-scale tests of the single impact limiter was fabricated from a 1018 steel cylinder with 2-in. thick walls. Steel plates were welded to the interior. A honeycomb ring was attached at the mid-length circumference of the cylinder. The thickness and width of the honeycomb were 5.875 and 10.00 in., respectively. Twenty-four segments of 4000 psi crush strength aluminum honeycomb were bonded to the cylinder with the 0.125 in. cells perpendicular to the circumference. The exterior surfaces were covered with 0.063 in. thick 304 stainless steel. The weight of the test unit was 5695 lb. Instrumentation included two Endevco 2264, 10,000-g accelerometers mounted on the cylinder circumference.

Testing was conducted at the Sandia National Laboratories 2500-ft. aerial cable facility in Coyote Test Field. The model was suspended above the unyielding target at a height of first 22 ft., then 15 ft. The model was positioned with the axial centerline of the cylinder parallel to the unyielding target for each impact.

The honeycomb crushed 3.4 to 3.6 in. at the centerline of the impact for the 22 ft. drop. The peak accelerations, measured on the two accelerometers, filtered at 1000 Hz, were 135 g and 120 g. The maximum mean value of the acceleration was approximately 90 g.

For the 15 ft. impact, the model was rotated 180° . The honeycomb crushed 2.6 to 2.8 in. at the centerline of the impact. The peak accelerations, filtered at 1000 Hz, were below 160 g and 120 g. The maximum mean value of the acceleration was approximately 85 g.

The DHLW cask has two circumferential honeycomb impact limiters, one at each end of the cask. The design procedure described in this paper was used in their design. The DHLW half-scale testing program was conducted at SNL.

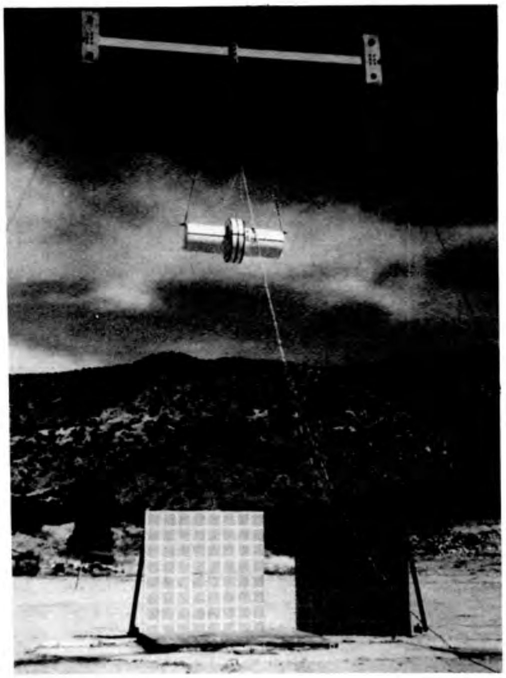

Fig. 2. Test Model in Position to be Drop Tested.

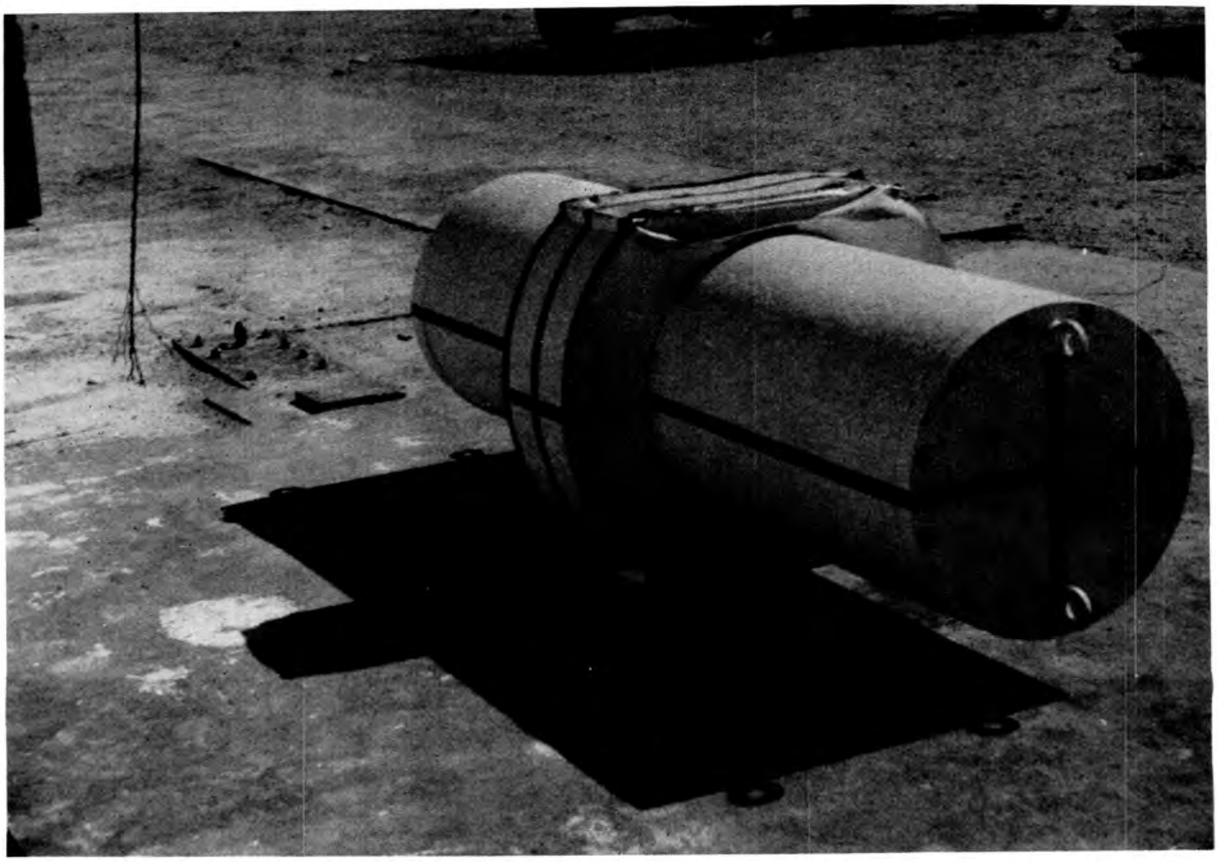

Fig. 3. Model After Both 15 ft. and 22 ft. Drop Tests.

TABLE I

Test and Analysis Results

	22 Ft. Drop		15 Ft. Drop	
	Predicted by Analysis	Test Results	Predicted by Analysis	Test Results
Depth of Impact Limiter Crush	3.6 in.	3.5 in.	2.6 in.	2.7 in.
G Level	90*	90	90*	85

* Predicted g level is constant for drop height more than 13 ft. because of the 30° angle limit assumed for effectiveness of honeycomb.

A 30-ft. side-drop onto the two circumferential honeycomb impact limiters was conducted. The results of the test showed that the circumferential honeycomb impact limiters crushed less than predicted by the design procedure. This shows the approach is conservative.

COMPARISON OF TEST AND ANALYSIS

Comparisons between test results from the first series of tests and analysis showned below in Table I that the analytical procedure predicted both the volume of crush and g-level very accurately when the nominal honeycomb crush strength was used.

CONCLUSIONS

Circumferential honeycomb impact limiters provide lightweight, low-volume impact protection for nuclear waste shipping casks. The design procedure presented in this paper provides a simple procedure for sizing circumferential honeycomb impact limiters and for predeter-mining the impact g-level. The test work performed by SNL demonstrates the effectiveness of circumferential honeycomb impact limiters and verifies the accuracy of the design procedure.

REFERENCE

1. R. W. Weaver and A. S. Rivenes, "Expandable Metal Honeycombs For High-Temperature, Load-Bearing Structures", SCL-DC-66-107, Sandia Corporation, Livermore Laboratory (1967).