UF_6 Cylinder Overpack Phenolic Foam Drop Testing

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INTRODUCTION

The types and quantities of materials to be used in the fire resistant phenolic foam for UF-6 cylinder protective overpacks are given in USDOE Material and Equipment Specification SP-9. Some of the specified materials and material grades used to make the foam have been unavailable or difficult to obtain since the late 1970's. Subsequently, overpack fabricators have found it necessary to substitute other materials or grades. With the requirements of SP-9 still applicable, it was necessary to determine if any property or quality of the phenolic foam was affected by the use of substituted materials in containers used to protect radioactive substances.

The purpose of this report is to compare the mechanical shock absorbing ability of phenolic foam made from reagent grade chemicals specified in SP-9 to that of foam made from substituted commercial grade chemicals. The testing reported here consisted of mechanical drop tests of overpack models using foams made from different grades of the same chemicals and at different temperatures. These test were performed to compare the mechanical properties of the foams.

The significant chemical and physical properties of the two foam types have been previously compared (DOE Report K/TL-729). No quality differences in the chemical and physical properties of the foams were noted.

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The method used for the comparisons was the drop testing of overpack models. The test models were made to dynamically and geometrically simulate a full UF-6 cylinder in a protective overpack. Fifteen models were made, five using foam with reagent grade chemicals and dropped at 75 F, five using foam with commercial grade chemicals and dropped at 75 F, and five using foam with commercial grade chemicals and dropped at -40 F.

The testing was conducted due to two primary concerns. One primary concern for this testing was the use of different grades of boric anhydride and oxalic acid. Foam containing reagent grade chemicals was compared to foam containing practical grade boric anhydride and technical grade oxalic acid. The practical and technical grade chemicals are referred to here as being commercial grade chemicals. The surfactant and the fiberglass specified are no longer available and were both replaced with the manufacturer's recommended equivalent materials in both foam types.

The other primary concern for this testing was the effect of temperature on the foam. It is well known that "Most material in common usage for package cushioning exhibit a marked increase in stiffness as the temperature decreases from 70 F (21 C)...". (Harris and Crede, 1976) This is particularly true for soft rubber or latex cushioning material and somewhat true for "hard, plastic" foams such as the phenolic foam used in these tests.

The primary factors involved in this comparison are maximum acceleration of the inner and outer components from a shock. Pulse shape is also considered in the form of rise times and pulse time length.

TEST MODELS

Test models were made to simulate a full UF-6 cylinder in a protective over-pack. Two test model types were made, one using foam with commercial grade chemicals and one using foam with reagent grade chemicals. Each test model was made from a small, five-gallon container, phenolic foam, and a short length of heavy-wall steel pipe.

Fifteen test models were used, five with the reagent grade chemicals and ten with the commercial grade chemicals. The foam ingredients were mixed in the same manner for all fifteen models. The foam density was restricted to 8 lb per cubic ft.

The models were constructed to have geometrical and dynamic similitude with a 12A UF-6 cylinder and its protective shipping overpack. The concept of similitude was used to assure that the foam was tested in a situation similar to that which would be experienced in an actual cylinder and overpack. Geometric similitude was achieved through designing a model with dimensionless ratios of linear length measurements (i.e., cylinder diameter, foam thickness, and container diameter) equal to those for a 12A cylinder/overpack. Geometric similitude was considered only on the diameter since the test consisted of "flat" drops.

Dynamic similitude was obtained by designing the dimensionless ratios from cylinder weight (mass), foam weight, and overall container weight for the model equal to the ratios for an actual 12A cylinder/overpack. Dynamic similitude assures that the force ratios would be the same in a model or 12A cylinder/overpack for drop testing. Static stresses on the model foam were maintained at or near the static stresses of the foam in a 12A overpack.

It should be noted that this testing was concerned with the comparison of two different foam types in identical models at two different temperatures. A direct comparison of the test model results to actual cylinder/overpack drop test results would be difficult due to the differences in overpack design and materials.

TEST METHOD

Shock testing is a classical method for determining the integrity of packaging material by dropping the package from a characteristic height onto a rigid surface. (Harris and Crede, 1976) A general concept from packaging and shock testing technology is that the damage potential of any shock motion to a packaged item is dependent upon the nature of the item and the package, as well as the nature and intensity of the measured motion, or shock pulse. The nature of the item and the package refer to the cylinder/overpack geometry and the associated material properties. The nature and intensity of the measured motion refer to the properties of the shock pulse. Since the models were identical, the mechanical shock absorbing ability of the foams was determined solely by measuring the properties of the shock pulse itself. (Doebelin, 1975)

A single test consisted of a model being turned on its side, parallel to the concrete drop surface, and dropped from a height of 10 feet. Test data was acquired from accelerometers mounted on the outside of the container and on the inside of the pipe. The accelerometers were mounted perpendicular to the projected plane of impact. The accelerometer signals were recorded for analysis on an instrumentation tape recorder. The test configuration, including the model position and accelerometer locations, are shown in Figure 1. A sketch of the test instrumentation is shown in Figure 2.

TEST PARAMETERS

The measured parameters (or properties) for this study were single-value measurements of the pulses taken from the recorded acceleration time histories of both the inside and the outside accelerometers. These measurements were: maximum and minimum (greatest negative) acceleration; time duration that the signal is positive (or positive pulse length); and time duration to the first maxima and to the positive maximum (or rise times). The measured characteristics are shown in Figure 3. The use of single amplitudes of duration values for shock data analysis is sufficient when a well defined empirical relationship exists between the measured value and the known performance of the system, provided that the pulse shapes are approximately the same. Both of these requirements were met for this study.

Damage to a packaged item tends to be directly proportional to the peak acceleration experienced by the item. This empirical relationship applies only when, as in this study, the lowest and most predominate natural frequency of the packaged item is much greater than the lowest and most predominate natural frequency of the package. A linear extrapolation of foam behavior under load has not been done since, upon impact, the phenolic foam exhibits a complex, difficult to predict, non-linear stress-strain behavior typical of crushing. The crushing, of course, allows maximum energy absorption by the foam.

In order to assure the consistency of the shock test drops and test pulses, the external acceleration (outside) time histories were observed and those not demonstrating the same general pulse shape characteristics were discarded. This eliminated the use of pulses from models with minor inconsistencies in model construction and test method. After the models were dropped, the containers were deformed up to 3/8-inch on the radius, while the foams were crushed up to 3/4-inch on the radius. This observation, along with the information from the external acceleration time histories, tended to discount the potential of having the test results significantly biased by the strength of the container walls.

RESULTS

The results of the testing are given in Table 1. This table compares the averages of the measured parameters from the tests of the five models containing commercial grade chemicals at room temperature (70 F), five models containing reagent grade chemicals at room temperature (70 F), and five models containing commercial grade chemicals at -40 F. The accelerations shown as being positive are actually the deceleration experienced by the model.

From Table 1, the outside maximum positive accelerations for both types of foam are essentially equal within the accuracy limits of the measurements. The inside maximum positive accelerations are also essentially equal for both foam types, graphically demonstrating the attenuation of the shock pulse. The ratios of outside to inside maximum positive acceleration show that, within the accuracy limits of the measurements, the two foam types are equal in their shock absorbability. The difference in the ratios indicate that the commercial foam is the slightly better shock absorber, but the accuracy limits of the data restrict the confidence level of such a statement.

The pulse lengths and rise times show the further similarity between the commercial and reagent grade test pulses. The outside positive pulse lengths are equal for both foam types, as are both rise time measurements. The outside rise times are quite short and are typical for a metal container striking a rigid object. The inside positive pulse lengths were the only measurements between the two foam types that were not equal within the accuracy limits, even though they were approximately the same. This is most likely due to the difficulty of measuring this length since a 1,700 Hz resonance ringing of the pipe was present which left the crossover point difficult to define. The ratio of the outside to inside positive maximum to negative minimum peak accelerations further demonstrate the equivalence of the shock absorbing ability of the two foam types.

The data from the -40 F testing shows a reduction in shock absorbing ability of approximately 20 to 25 percent. Increases in both the inside acceleration values and outside acceleration values were seen, consistent with the fact that the entire package stiffness has increased. The reduction in acceleration ratios was expected, since most commercially available cushioning material exhibits marked increases is stiffness below 70 F. Although the pulse lengths are remarkably similar, the rise times demonstrated an increase rather than the expected decrease. It is suspected that this is evidence of a slight mounting difference or temperature shock of the accelerometers, but no errors in the acceleration values are suspected.

Comparison of the outside to inside pulses show the attenuation and lengthening of the shock pulse by the foam, as indicated by the Table 1 values. The small oscillations on the inside time histories show the previously mentioned pipe resonant frequency at 1,700 Hz.

CONCLUSIONS

The numerical and graphical results presented here vividly demonstrate the similarity in the shock absorbability of the two foam types. It is concluded that, within the accuracy of these test, the two foams are equal in their shock absorbing ability, and, therefore, can be considered to be equal in all mechanical properties. Therefore, the use of commercial grade boric anhydride and oxalic acid is not detrimental to the shock absorbability of the phenolic foam.

It has also been demonstrated that foam exhibits an expected increase in stiffness at low temperature (-40 F). This increase in stiffness, while evident, is not seriously detrimental to the ability of the foam to absorb shock.

REFERENCES

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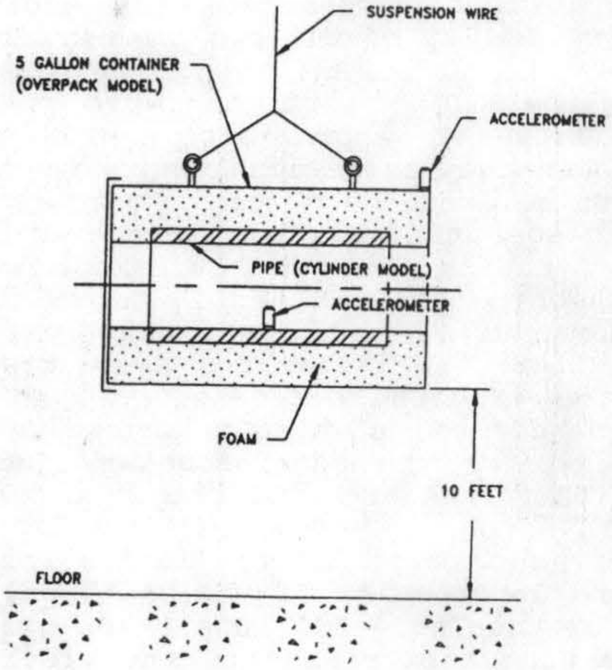
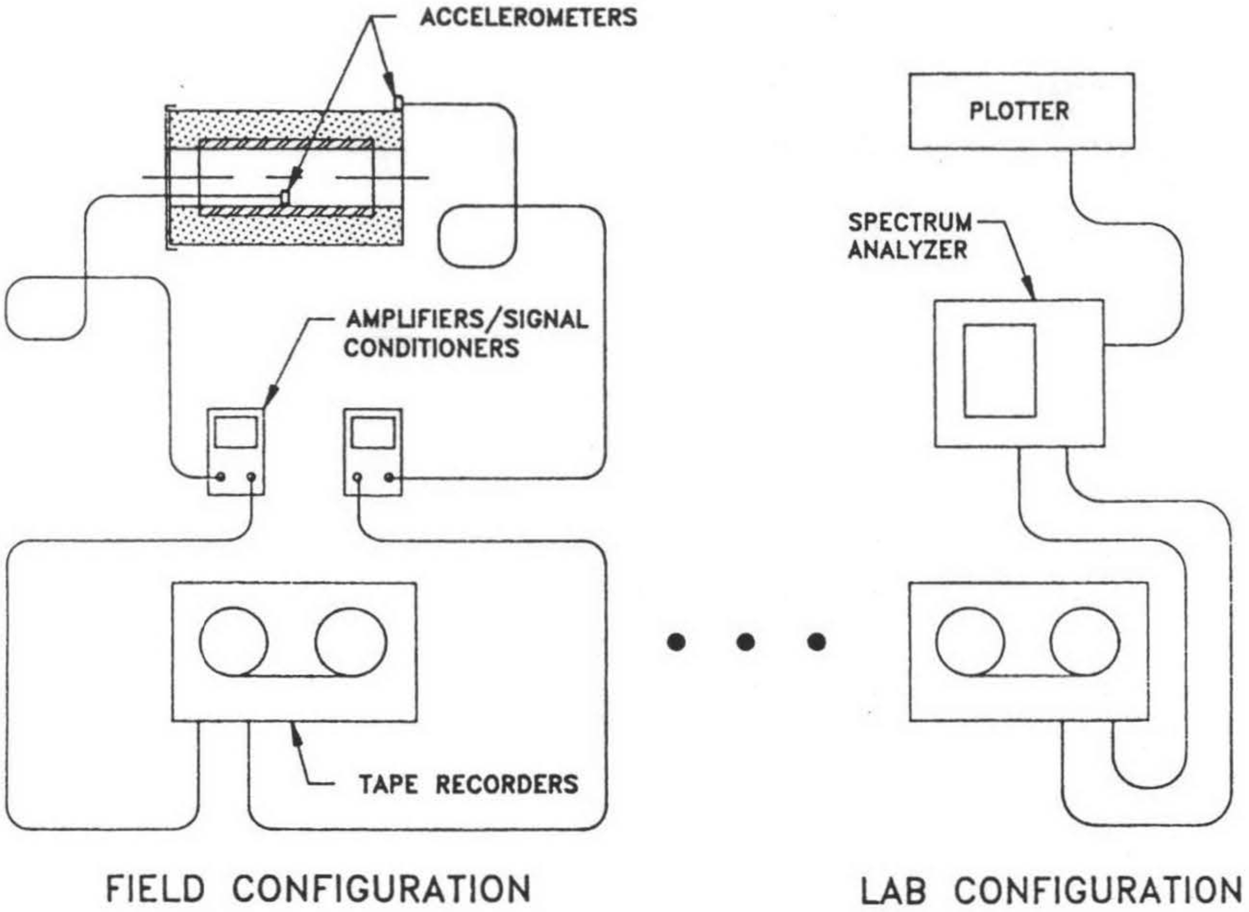
Doebelin, E. O., MEASUREMENT SYSTEMS - APPLICATION AND DESIGN, McGraw-Hill Book Company, New York, New York, 1975.



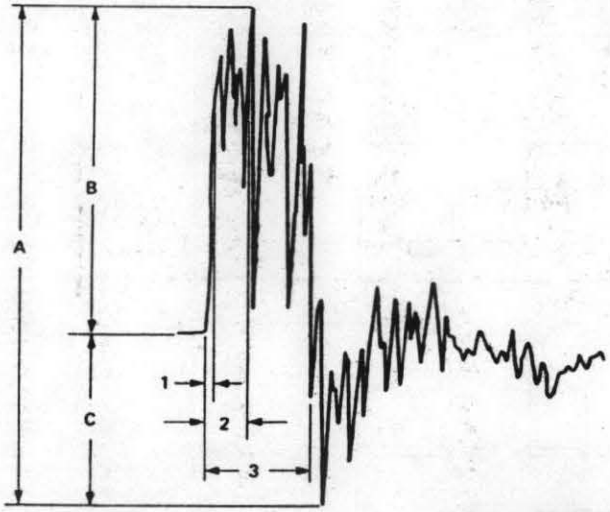
TEST APPARATUS

Figure 1.



TEST INSTRUMENTATION

Figure 2.



TIME

1. RISE TIME TO FIRST POSITIVE MAXIMA
2. RISE TIME TO POSITIVE MAXIMUM
3. POSITIVE PULSE LENGTH

ACCELERATION

A. POSITIVE MAXIMUM PEAK TO MINIMUM NEGATIVE PEAK
B. POSITIVE MAXIMUM
C. NEGATIVE MINIMUM

MEASURED CHARACTERISTICS OF SHOCK PULSES

Figure 3.

Table 1. Average Values for Shock Pulse Time Histories

	Reagent Grade Test	Commercial Grade Test	-40F,Com. Grade Test
1. Maximum Positive Acceleration of Pulse, Outside (±10g), g	555	552.5	698
2. Maximum Positive Acceleration of Pulse, Inside (±5g), g	135	130	195
3. Ratio of Outside to Inside Max. Positive Acceleration(±0.24)	4.11	4.25	3.58
4. Positive Pulse Length, Outside (±0.0001 sec), sec	0.0030	0.0028	0.0031
5. Rise Time to Positive Maximum, Outside (±0.0001 sec), sec	0.0010	0.0011	0.0024
6. Rise Time to 1st Positive Maxima, Outside (±0.0001 sec), sec	0.0001	0.0001	0.0004
7. Positive Pulse Length, Inside (±0.0001 sec), sec	0.0100	0.0095	0.0092
8. Positive Maximum Peak to Negative Minimum Peak Acceleration, Outside (±20g), g	800	790	910
9. Positive Maximum Peak to Negative Minimum Peak Acceleration, Inside (±10g), g	195	190	279
10. Ratio of Outside to Inside Peak Accelerations (±0.32)	4.10	4.16	3.26

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