Choosing Materials for Package Cushioning Applications

Here is how Mr. Eller and Mr. Stein tested foamed resilient elastomeric, plastic and rubberized hair materials for package cushioning: First, they determined all conditions package would encounter. From this information laboratory tests were devised. From data on stress, strain, hysteresis, shock mitigation, creep, density, package cushioning requirements were calculated.

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PACKAGE cushioning materials are necessary to protect equipment, particularly fragile electronic gear, from damage caused by shock during handling and shipment. The amount of protection required depends upon the fragility limit of the equipment. This refers to the magnitude of the shock expressed in the number of times the acceleration of gravity (G's) that the part can withstand and still function properly. Thus, a part having a low fragility limit requires the use of thicker, more shock absorbent packaging material than a part having a high fragility limit.

Krakover and Olevitch *(1)* aptly express the need for package cushioning materials. They point out that a falling part is subject to a high acceleration (which can exceed its fragility limit) when it hits the floor or other unyielding object. This occurs because of the short period of time during which the part comes to rest. This is due to the very small deformations of the part and the floor.

However, if there is a yielding cushioning material between the falling part and the floor, the length of time during which the acceleration (actually deceleration) occurs, increases. This reduces the maximum acceleration of the part.

Select Materials, Devise Tests

To protect equipment from shipping and handling hazards, a wide variety of packaging methods and materials are available. Those in use include mechanical springs in specially constructed boxes, loose granular materials, foamed resilient elastomeric and plastic materials, and rubberized hair.

This article concerns the investigation of foamed resilient elastomeric, plastic and rubberized-hair materials. From the wide variety of available materials the packaging engineer has to select the most economical material which performs satisfactorily in service.

Mindlin *(2)* notes that an empirical procedure to test types and thicknesses of package cushioning materials for the protection of fragile parts is impractical. Dropping the part from different heights to determine survival is not practical because of the possibility of breaking the part. Further, a large number of tests would be necessary.

Instead, the more logical approach is to devise laboratory procedures. These are to evaluate the suitability of package cushioning materials under simulated service conditions. They form a basis for scientific selection of the best material.

The samples of package cushioning materials this investigation involved consisted of representative foamed resilient polyester and polyether types of polyurethane, neoprene, a mixture of butadiene-styrene and natural rubber, polystyrene, polyethylene and rubberized hair. These materials came from manufacturers in the form of slabs measuring 12 x 12 x 1 in. thick.

Determine Service Conditions

In service, the cushioning material must protect the packaged part against all hazards encountered during shipment and storage. It must be capable of supporting the weight of the part for long periods

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of time. This must be without excessive creep while the package is subjected to the range of temperatures it may encounter in service. For Navy applications, the materials must be satisfactory over a temperature range of from –67° F. to +158° F.; as these temperatures are typical of an unheated airplane or the tropics, respectively.

The material must also: (1) be capable of absorbing energy to prevent the peak acceleration from exceeding the fragility limit of the part; (2) have high hysteresis, i.e. slow recovery after energy loading to prevent high rebound and also to dampen vibrations quickly after shock loading; and (3) be light in weight and suitable in thin thicknesses to minimize transportation charges.

Devise Laboratory Tests

In view of these expected service conditions, we selected the following test procedures to determine the suitability of package cushioning materials.

Stress Versus Strain

The stress versus strain properties of the material provide information as to the ability of the packaging material to support the weight of the packaged part. We measured this property under essentially static conditions using a Yerzley oscillograph operated in accordance with the procedures specified in Method 6111 of Federal Standard No. 601*(3)*. We determined the loading and unloading curves of specimens compresed 70 to 80 per cent of their original height. (Test results appear in Figs. 1-7.)

The Yerzley oscillograph was our choice because it is available in many laboratories and because it can be operated in a conditioning cabinet which can be maintained at temperatures of –67° F. to +158° F.

The relationship between stress and the corresponding strain of the various package cushioning materials appears in Figs. 1-7. The upper and lower curves are for the loading and unloading conditions, respectively.

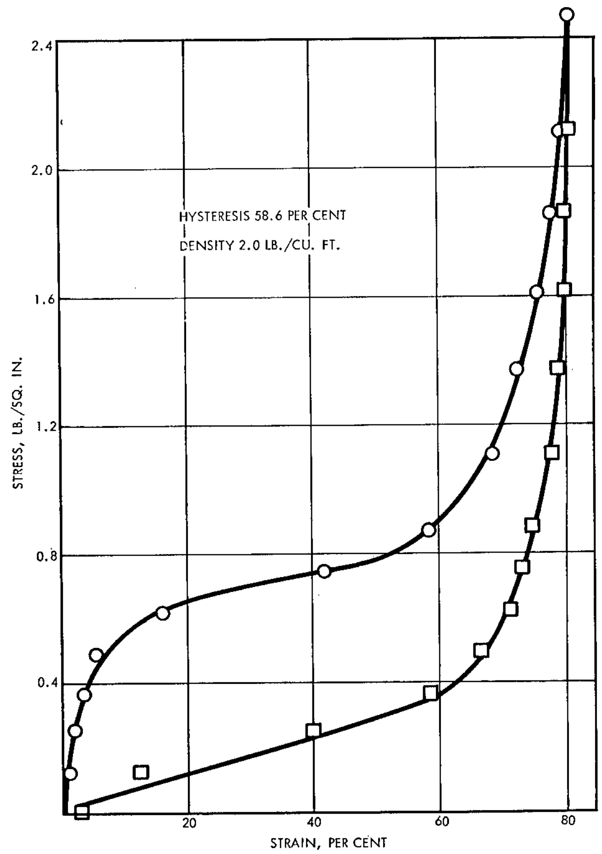
Hysteresis

Hysteresis is a measure of the sluggishness of recovery after deformation. We calculated this property of the packaging materials from the equation:

$$\text{Hysteresis, per cent} = \frac{A_1 - A_u}{A_1} \times 100$$

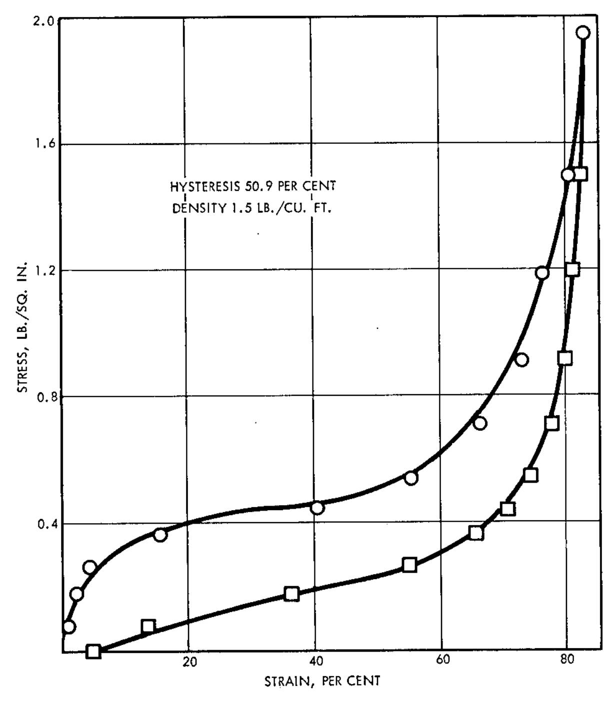
where A_1 equals the area beneath the loading portion of the stress versus strain and curve A_u is the area beneath the unloading portion.

Results for the various materials appear on the stress versus strain graphs, Figs. 1-7. *(Turn Page)*



1 *Stress versus strain of polyester type polyurethane foam.*

2 *Stress versus strain of polyether type polyurethane foam.*



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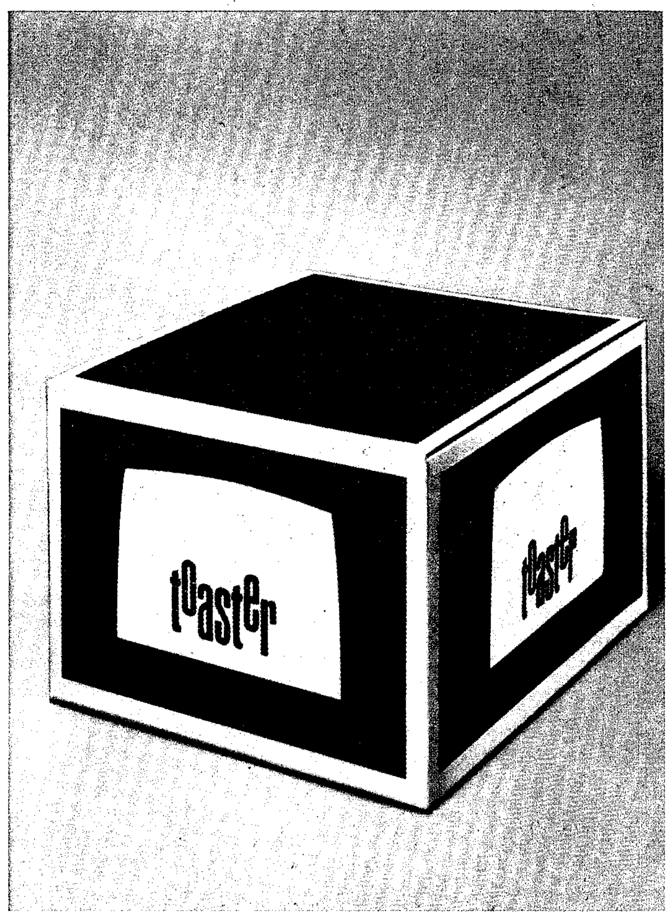

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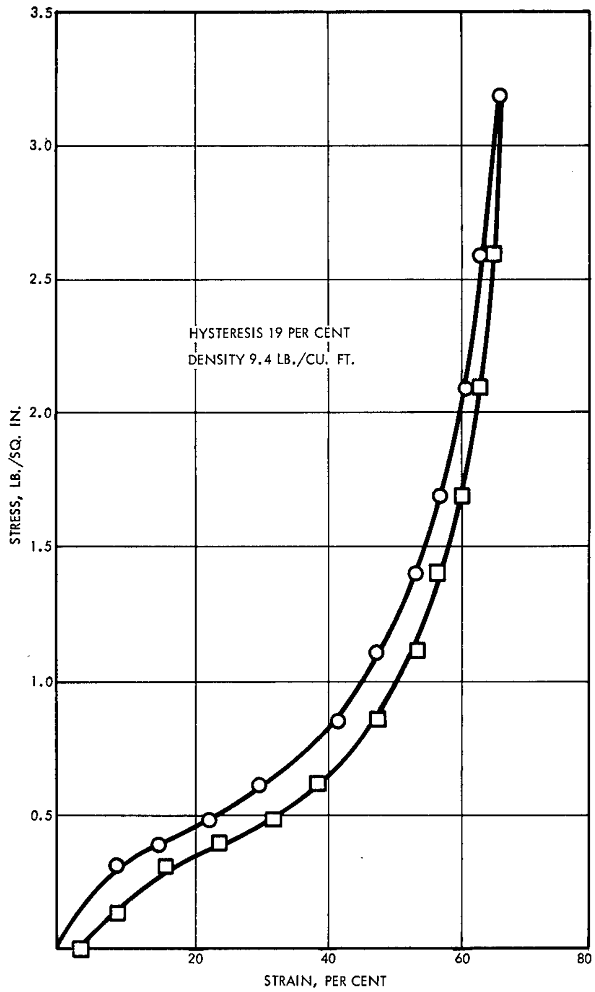


3 *Stress versus strain of neoprene foam.*

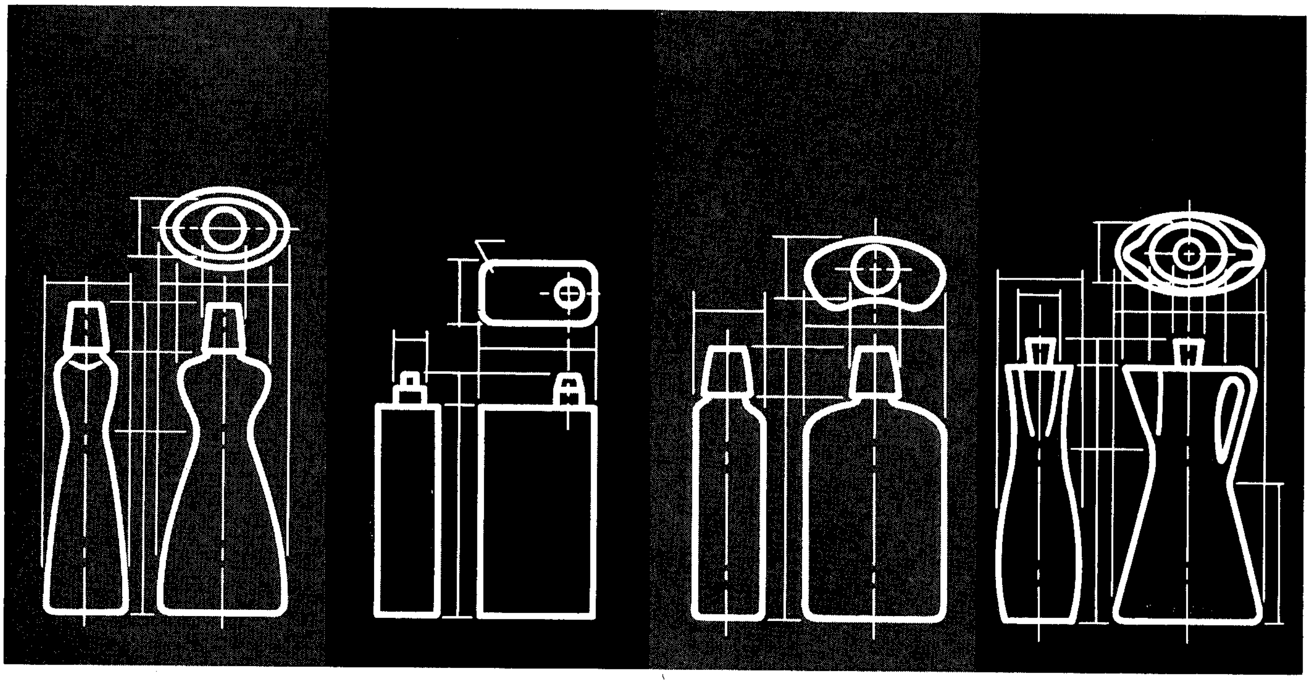
Shock Mitigation

This concerns the maximum acceleration versus static stress that occurs when parts are packaged in different thicknesses of material and dropped from a specified height. We presently determine it in accord with U. S. Air Force Specification MIL-C-26861*(4)*. Manufacturers of the various package cushioning materials can also furnish this information.

A typical set of acceleration versus static load (lb./sq. in.) curves for different thicknesses of a polyester type of polyurethane appears in Fig. 8. This information is from Krakover and Olevitch *(1)*.

Creep

This is the tendency of the packaging material to flow under load. We measured it by applying a dead weight load onto the packaging material sufficient to cause an initial compression of 20 per cent as determined from the stress versus strain curve. We applied this load onto four specimens, each



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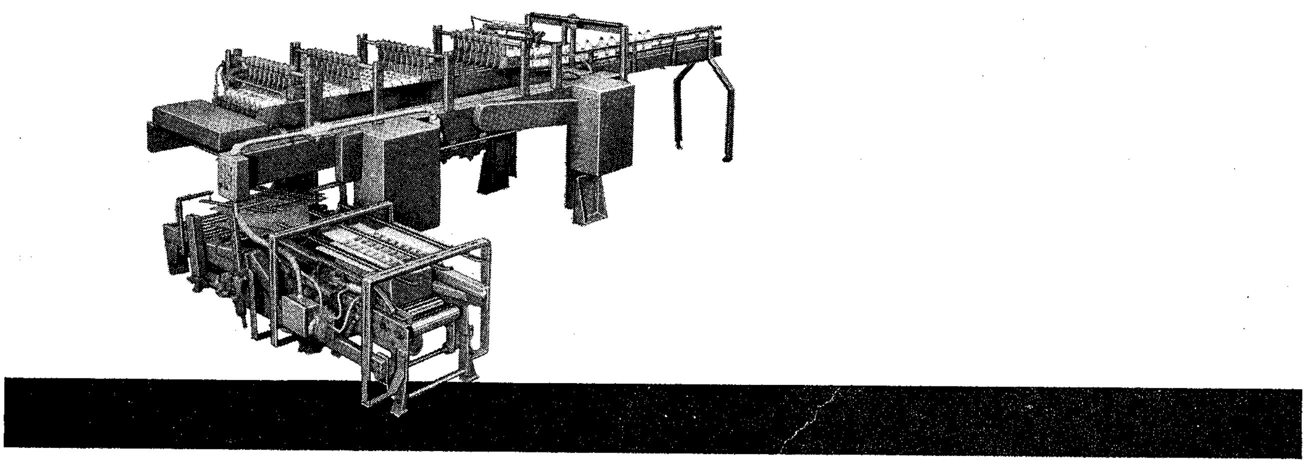

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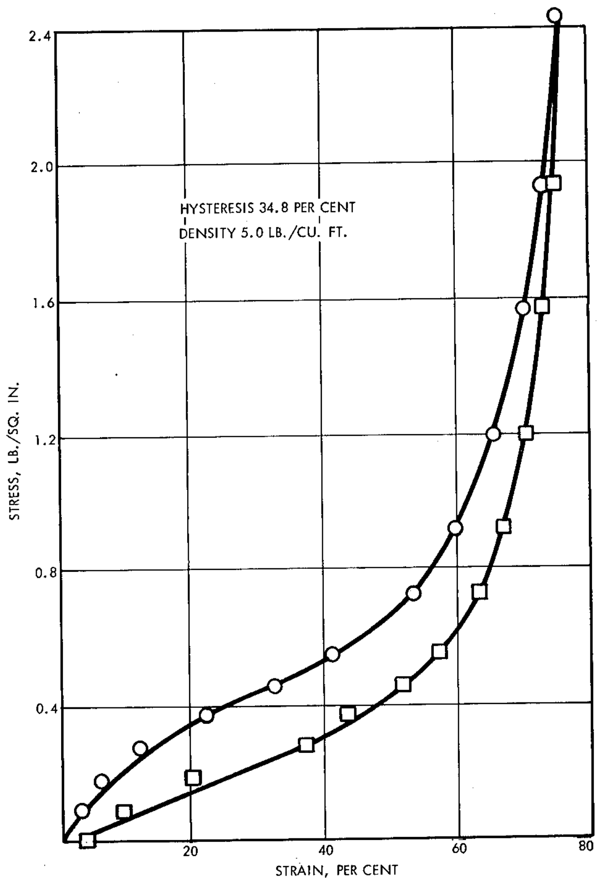


4 *Stress versus strain of butadiene-styrene foam.*

1-5/8 in. diameter by 1 in. thick, and positioned the specimens beneath the corners of a metal plate. We measured the height of the specimens before loading and at appropriate periods up to 14 days after loading.

We calculated the total percentage compression (initial plus creep) of the specimens in accord with this equation:

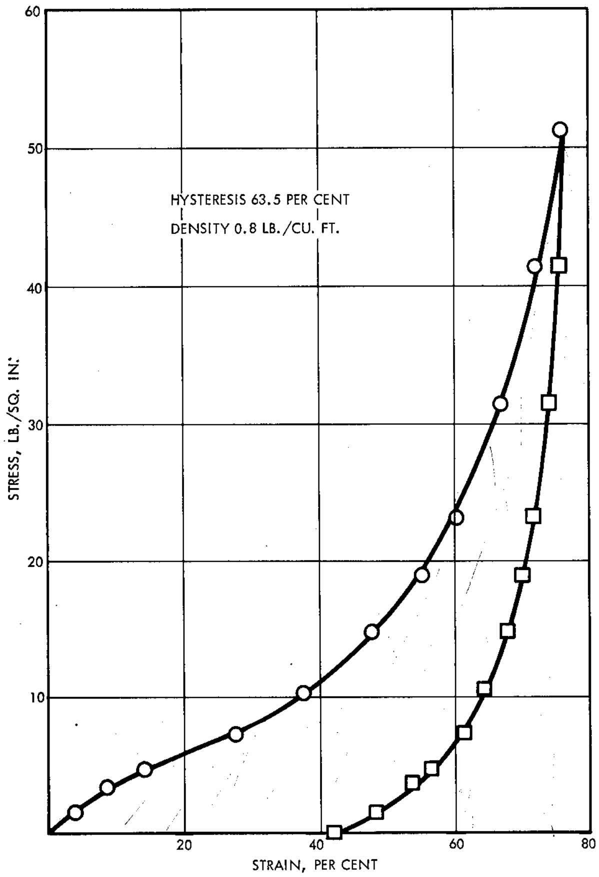
$$\text{Total compression (initial plus creep), per cent} = \frac{H_o - H_i}{H_o} \times 100$$

where H_o equals initial height of the specimen in in. and H_i equals the height of the specimen after the aging period in in.

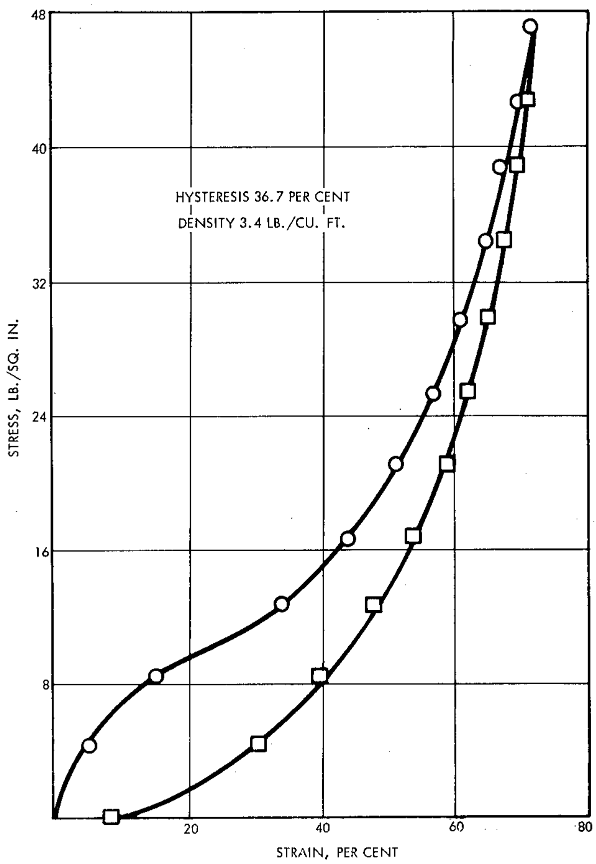
The total percentage compression (initial plus creep) of the materials appears in Fig. 9.

Density

We calculated this property of the materials from weight and volume measurements. These results



5 *Stress versus strain of polystyrene foam.*



6 *Stress versus strain of polyethylene foam.*

appear on the respective graphs, Figs. 1-7.

Analyze Test Results

It is important to note that we obtained the results on the specific samples submitted and that manufacturers can supply materials having considerably different properties by making changes in their formulation.

The stress versus strain results indicate that foamed resilient elastomeric, plastic and rubberized-hair materials in common use differ markedly in their ability to support load. For example, the stress required to cause a strain of 20 per cent ranged from 0.15 lb./sq. in. for the rubberized hair to 10 lb./sq. in. for the polyethylene material.

The hysteresis of the materials when compressed to 70 to 80 per cent of their original height exhibited considerable variation, ranging from 19 to 63 per cent.

The flow under load, or creep of the materials when subjected to an initial stress designed to cause 20 per cent compression of the samples was excessive. (Note Fig. 9.) The total percentage compression (initial plus creep) of five samples was in the range of 50 to 70 per cent. This was after a conditioning period of two weeks at room temperature. Such excessively high creep indicates this: the maximum permissible stress that can be safely put on many types of packaging material may be limited by the amount of creep which will occur at that stress. Laboratory experience indicates the lower the design stress, the lower the creep.

Designing a Package

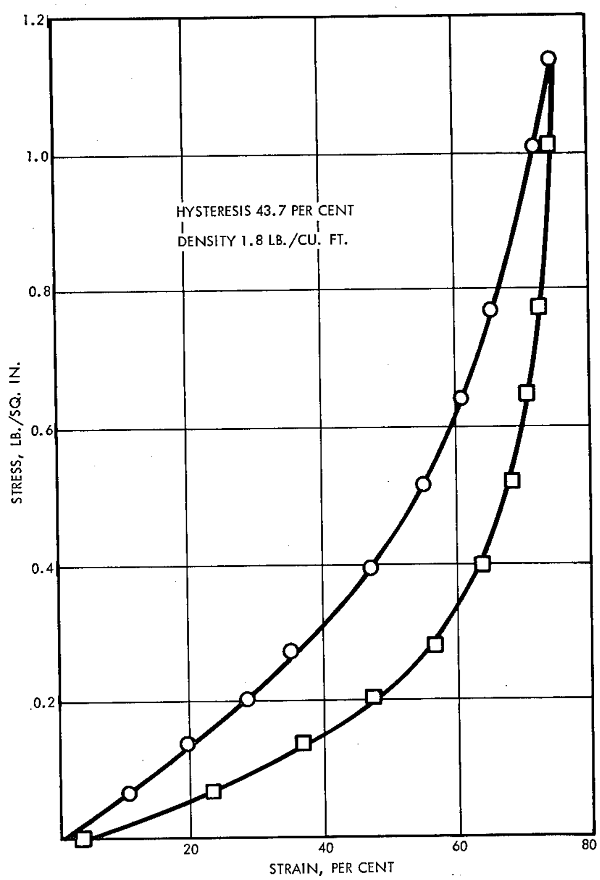
Krakover and Olevitch *(1)* use the following calculations to design a package for a rectangular object having dimensions of 20 x 10 x 5 in., weight of 20 lb. and fragility of 40 G's.

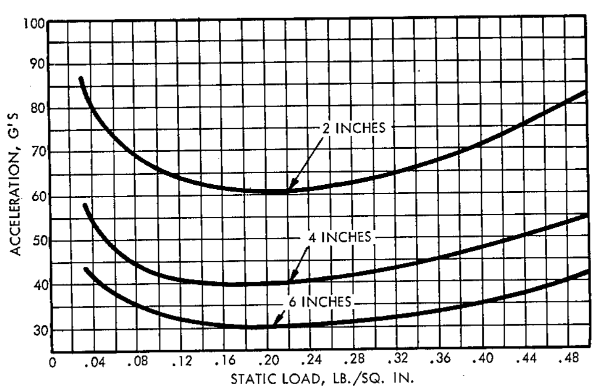
The static stress on the top and bottom surfaces is:

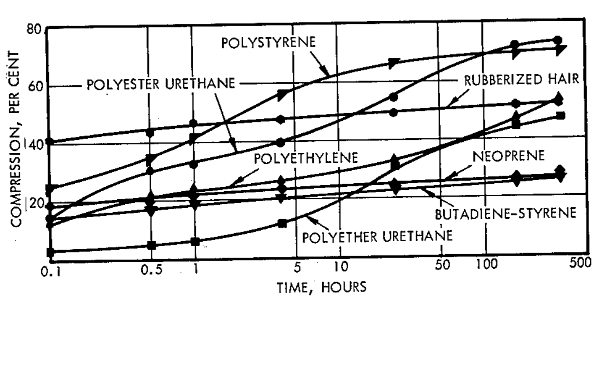
$$\frac{20 \text{ lb.}}{20 \times 10 \text{ in.}} = 0.1 \text{ lb./sq. in.}$$

Similarly, the static stress at the ends and sides are 0.2 and 0.4 lb./sq. in., respectively.

Let us assume that the packaging material we are considering is a polyester type of polyurethane: it has the maximum acceleration versus static stress







7 *Top: Stress versus strain of rubberized hair.*

8 *Middle: Maximum acceleration versus static stress versus thickness of a polyester type polyurethane.*

9 *Bottom: Total percentage compression (initial plus creep) of packaging materials when subjected to dead weight load calculated to cause initial compression of 20 per cent.*

versus thickness of material characteristics (See Fig. 8) when dropped from a specified height. It has the stress versus strain characteristics appearing in Fig. 1 and a creep of 20 per cent when subjected to a static stress of 0.4 lb./sq. in.

Using Fig. 9, the required thickness for the sides to keep the acceleration below 40 G's (when the static stress is 0.4 lb./sq.in.) is 5 in. (This is interpolated in Fig. 8.)

The required thickness of the packaging material is equal to:

$$\frac{5 \text{ in.}}{(1.00\text{-}0.20)} = 6.25 \text{ in.}$$

where (1.00-0.20) is the correction factor to compensate for creep.

As noted in Fig. 1, a stress of 0.4 lb./sq. in. will cause a strain of 5 per cent in the packaging material. Therefore,

$$5 \times (1.00\text{-}0.05) = 4.75 \text{ in.}$$

is the thickness to which the 5-in. thick packaging material will compress due to the load. This thickness of 4.75 in. must be available after creep takes place. We use this to calculate the inside dimension of the package.

You should calculate the required thicknesses for the other sides of the package in a similar manner. The package can rest or fall on any of its sides.

Job of Packaging Engineer

From the above, it is apparent that there is a wide variety of resilient, foamed elastomeric, plastic and rubberized-hair materials having a wide range of physical properties. These materials are superior to one another in some respects and inferior in others. It is the job of the packaging engineer to select the most economical packaging material for each part which best satisfies expected service condition.

Literature Cited

(1) Krakover, S. M. and Olevitch, A. "Investigation of Design Criteria for Cushioning Material", Wright Air Development Center Technical Report 58-639, March 1959.

(2) Mindlin, R. D. "Dynamics of Package Cushioning", The Bell System Technical Journal, July-October 1945.

(3) Federal Test Method Standard No. 601, 12 April 1955, "Rubber: Sampling and Testing".

(4) Specification MIL-C-26861 (USAL) of 1 May 1959, "Cushioning Material, Elastic Type, General". *(End)*