Characteristics of Flexible Foams Under Impact Conditions—Density Variation, Analysis and Experiments

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INTRODUCTION

In Part I (Yossifon and Szanto 1987) the authors have fomulated the mathematical model, based on dimensional similarity parameters, to describe the characteristics of flexible plastic foams under impact conditions. The model assumes that the foam is a rate-dependent material. By using this model one can predict the maximum deformation, the maximum deceleration, and the time-pulse period for a wide range of drop heights and masses by conducting a few drop tests.

The designer of a protective packaging should choose the proper foam for specific needs. This means choosing the shape and the density of the foam for absorbing the shock of a known mass, while ensuring maximum permissible deceleration and deformation.

The characteristics of flexible foams under impact conditions are strongly dependent on their initial density for the same material and technology processes. The variation of the density of the flexible foam for the same geometrical dimensions affects the dynamic response, i.e., the cushioning parameters.

It is clear that the geometrical and the cell size parameters, affect the foam characteristics, but for foams made by this process and with the same technology, the density parameter has a special significance.

The aim of the present work, is to predict the maximum deformation, maximum deceleration and the time pulse period under test conditions for a wide range of foam densities. In the present work, we have extended the similarity model by including the density of the foam in the analysis.

By using the similarity parameters (Yossifon and Szanto 1987), only a few experiments should be needed to plot work-curves for various densities and drop conditions for the same geometrical dimensions. (It is proved that it is not necessary to vary the geometrical dimensions, for predicting the characteristics of the foam).

THEORY

A body of mass M is dropped from height H on foam of initial uniform density ρ_o, thickness h, and cross-sectional area A as shown in Figure 1. The force F that mass M exerts on the foam, at the time of impact, is:

$$F = M \frac{d^2y}{dt^2} + Mg \qquad (1)$$

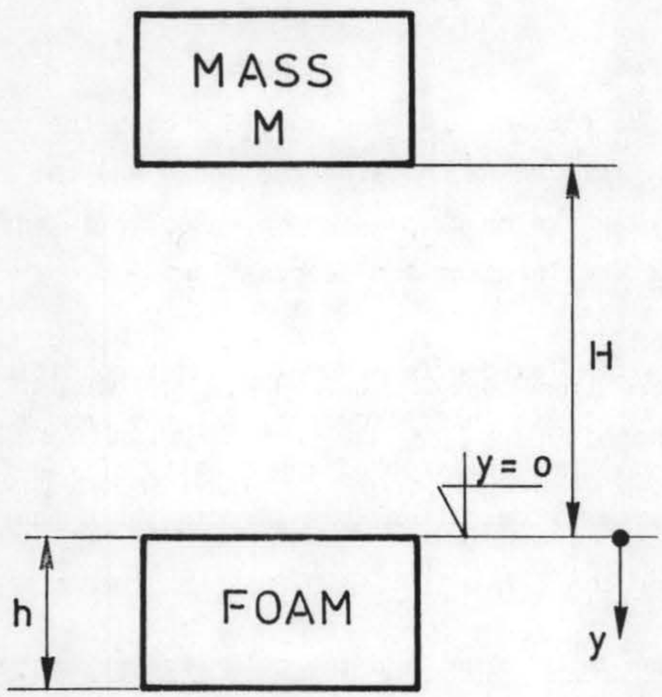

Fig. 1 A mass M dropped from height H on the foam of initial thickness h.

where y is a displacement of the contact surface between the foam and the mass, and g is a gravity acceleration. We assume a constant foam cross-sectional area during impact. This assumption was shown experimentlly to be quite accurate for a wide range of drop tests. Introducing the displacement-strain relationship and its derivations as (Yossifon and Szanto, 1989):

$$y = h \cdot \epsilon, \quad dy/dt = h \cdot d\epsilon/dt, \quad d^2y/dt^2 = h \cdot d^2\epsilon/dt^2 \qquad (2)$$

where ϵ is the strain in the foam.
Combining eq. (2) with eq. (1) gives:

$$\sigma(\epsilon, d\epsilon/dt, \rho) = (\sigma_{st} \cdot h)(d^2\epsilon/dt^2/g) + \sigma_{st} \qquad (3)$$

where the static stress σ_{st} = M.g/A
where, the normal dynamic compression stress σ is a function of the strain (ϵ) strain-rate ($d\epsilon/dt$, and the foam density (ρ).
The initial conditions, at the time of impact, which satisfy eq. (3) are:

a) The initial displacement is zero, $y\big|_{t=0} = 0$

b) The initial velocity (Vo) is equal to the velocity of the mass M at impact time.

$$V_0 = dy/dt\Big|_{t=0}$$

Actually, in severe impact conditions, the second term of the right member can be ignored in eq.(3)*, because the dynamic stress to static stress ratio $\sigma(\epsilon, d\epsilon/dt, \rho)/\sigma_{st}$, is much higher than unity. Therefore, maintaining the same initial conditions and keeping a constant value for the term $\sigma_{st} \cdot h$, from eq.(3), yields one possible solution only.

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* to predict the characteristics of the foam for constant thickness h, It is not necessary to ignore the right term in eq.(3).

Mathematically, one can write:

$$\sigma(\epsilon,\ d\epsilon/dt,\rho\ ) = C_1 \cdot (d^2\epsilon/dt^2/g) \qquad (4)$$

Where: $C_1 = \sigma_{st}h$

With initial conditions:

a) $d\epsilon/dt\Big|_{t=0} = C_2 \qquad (C_2 = V_0/h)$

b) $\epsilon\Big|_{t=o} = C_3 \qquad (C_3 = 0)$

c) $\rho\Big|_{t=o} = C_4 \qquad (C_4 = \rho_o)$

were, C_2, C_3, C_4 are initial parameters.
and ρ_o is the initial foam density.

The similarity parameters are: a) $\sigma_{st}h$, b)V_o/h and c) ρ_o for the same numerical values, for similarity parameters, one can expect to obtain the same solution for eq.(4), that is, the same impact response in the drop-test for the same flexible foam material.

As a result, one can assume that for the same numerical values for similarity parameters in the impact conditions, the same values may be obtained for a) maximum deceleration, b) maximum deformation and c) time pulse period, for the same flexible foam.
These three parameters are the most important dynamic compression characteristics of the foam (Shuttleworth et al. 1985). Prediction of these parameters for specific design is very usefull for proper choice of the dimensions and the density of the foam.
One can apply this model by making several drop-tests with various masses and drop heights, for the same plastic foam material and geometrical dimensions, (It is not necessary to use various geometrical dimensions to predict the dynamic characteristics of the foam (Yossifon and Szanto 1987).

EXPERIMENT

A total of five locally-manufactured polyurethan flexible foam were tested. Each had a thickness of 0.2m, and cross-section area of $0.272m^2$, but each had a different initial density. The production of different density foams is achieved by glueing together pieces of the same open-cell size (average cell size 0.5mm) whilst applying different pressures.

The initial tested foam densities are: 100, 120, 150 and $240 kg/m^3$. The experimental apparatus, shown schematically in figure 2, consisted of a changeable mass A(of up to 60 kg) guided by eight rollers on a vertical guiding rod, which was 50mm diameter and 4.5m long. The mass is positioned at the desired height H by an electrical winch and the foam is positioned at the bottom of the rod.

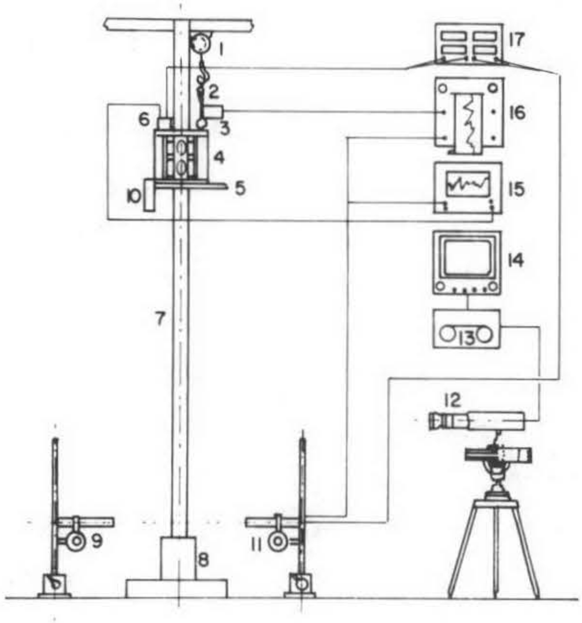

Fig. 2 Experimental setup.

1) Electrical Winch 2) Release Mechanism 3) Micro-Switch
4) Sliding Mass 5) Marking knife 6) Accelerometer 7) Guiding rod
8) Foam 9) Light Source 10) Photo-Slide 11) Photocell detector
12) T.V. camera 13) Videotape 14) Monitor 15) Storage oscilloscope
16) X-T Recorder 17) D-C Power Supply.

The deceleration pulse is measured by a piezoresistive accelerometer, and the deformation is measured by a photo-sensor with 0.5mm resolution. The impact velocity V_0 is measured at the moment of impact contact time at y=0 state by the photo-sensor. The measurement of the velocity V_0 is preferred to the drop height H, to eliminate the friction forces between mass and the guides.

In the present experiments, a T.V. camera was used to display the shape of the foam at impact time and occasionally, to check the foam-mass contact time (in addition to the impact time being obtained from the output of the photo-sensors). The tests were conducted with different masses and drop heights for each foam.

RESULTS AND DISCUSSIONS

In figure 3 is shown, typical plot of (a) maximum deceleration $d^2\epsilon/dt^2/g$, b) maximum deformation ϵ_{max}, and c) time pulse duration Δt versus V_o/h for diffferent initial foam density (from 100 to 240 kg/m^3), for constant value of $\sigma_{st} \cdot h$. The experiment results were obtained for different drop-heights H, and masses M.

From the plots one can see, that as the foam density increases, all the three dynamic characteristic values decrease consistently, for the same impact conditions. It is a very interesting point, that for those specific tested density ranges, the results show that, as the foam density increases the foam cushioning effeciency also increases, i.e., the maximum deceleration, maximum deformation and the time-pulse period decrease. The typical plot of deceleration versus time, under an impact condition, is different when the foam density varies. As the foam density increases the peak pulse zone is more moderate.

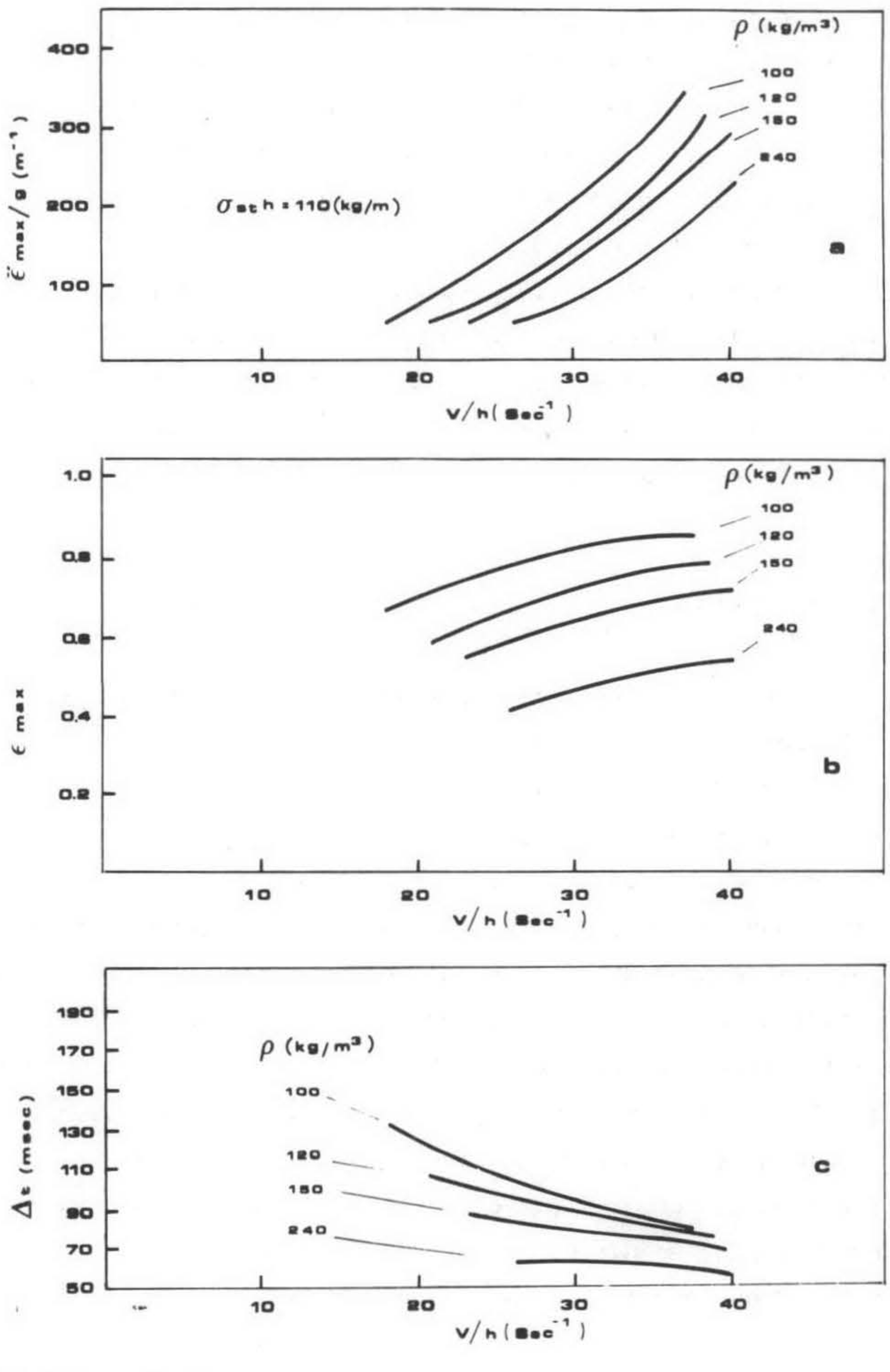

Fig. 3 Plot of a) maximum deceleration, b) maximum deformation, c) time pulse period, versus V_o/h,. for four different foam density, for σ_{st}·h = 110 kg/m.

Figure 4 shows a maximum deformation versus maximum deceleration for a) $\sigma_{st} \cdot h$ = 110kg/m, b) $\sigma_{st} \cdot h$ = 415kg/m. One can see, that as the deceleration rises sharply, the deformation increases moderately. The figure is a very useful plot for cushion designers, to choose the proper flexible plastic foam for maximum permissible deformation and deceleration for goods under impact conditions.

In our work, we used more tests than necessary to predict the typical plots, in order to verify the simple mathematical model.

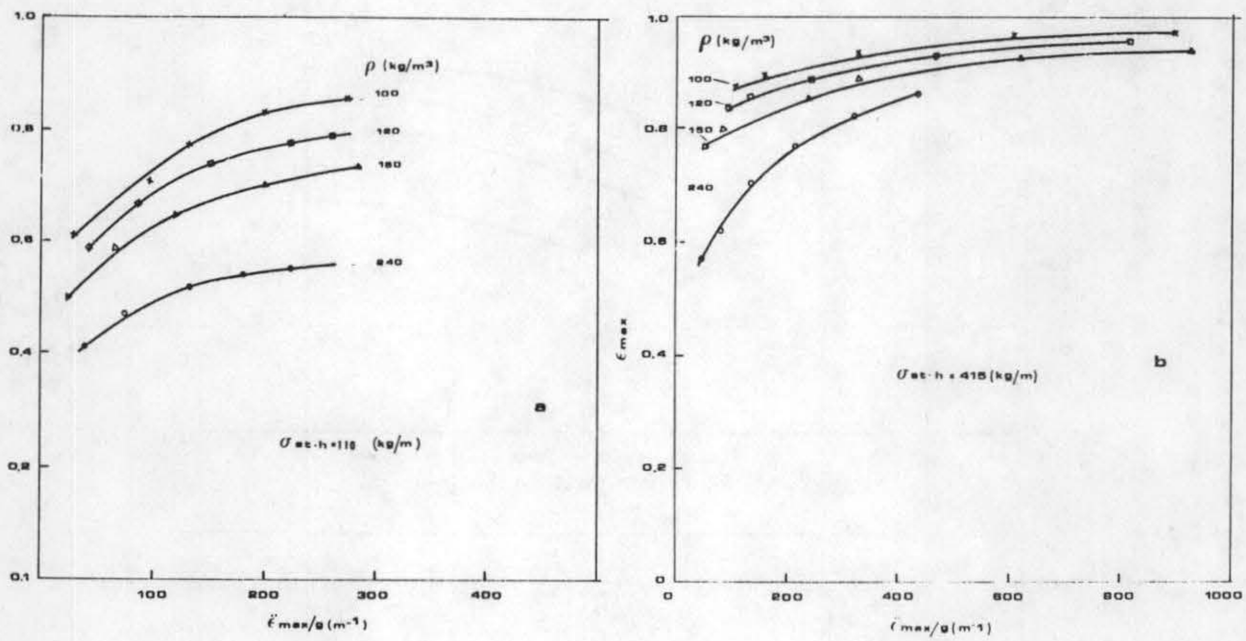

Fig. 4 Plots of maximum deformation versus maximum deceleration for four different foam density where:
a) $\sigma_{st} \cdot h$ = 110 kg/m. b) $\sigma_{st} \cdot h$ = 415 kg/m.

CONCLUSIONS

A model, based on dimensional similarity, include the plastic foam density in the similarity parameters in order, to enable more goods. flexibility for the designer to choose the proper foam for cushioning

The model was presented and examined by drop-tests with specially constructed apparatus. The results showed good correlation between the model and the experiments.
The results show that the plastic foam density parameter is very significant in predicting of the dynamic characteristics of the foam. This parameter makes available for more flexibility in the choice of foam.
For the whole range of foam densities tested the results show, that as the foam density increases, the maximum deformation, the maximum deceleration, and the time pulse duration decreases.
By using the mathematical model, the designer can predetermine the dimensions of the foam and its density for maximum permissible deformation and deceleration (figure 4) for goods under impact conditions.

REFERENCES

Shuttleworth, R.W., shestopal, V.O., Goss,P.C., Open-Cell Flexible Polyurethane Foams: Comparison of Static and Dynamic Compression Properties, Journal of Applied Polymer Science,30,333 (1985).

Yossifon, S. and Szanto, M. Dynamic Compression characteristics flexible Foams I. Similarity Model, Analysis, and Experiments, Journal of Applied Polymer Science,34,2025-2036(1987).

Yossifon, S. and Szanto, M. Dynamic Compression characteristics flexible Foams II. Density, Variation, Analysis, and Experiments, Journal of Applied Polymer Science (1989) (Accepted for publication).

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Waste Packagings