# *Correlation of Flexural Modulus and Apparent Density of Extruded Polystyrene Foam Sheets*

Due to the broad applications of low-density polymer foam sheet for end uses such as food packaging and insulation, the market for extruded polystyrene (PS) foams has grown considerably in recent years. In a typical low-density rigid PS foam, the actual volume of polymer present is less than 10% and is distributed in the form of fibrils and thin membranes with voids in cellular structure. The fibrillar structure is responsible for the strength properties of rigid foams; thus an immediate and simple method of altering the strength of a foam is to alter the apparent density of the sample. This method is widely used in the manufacturing industry for product property control.

As the density is increased, the mechanical properties of the foam, such as resistance to compression, tension, shear, and flexure are also increased. Conflicting reports concerning the dependence of strength properties on the density of polymer rigid foams were found in the literature. Doherty et al.[1] and Stengard[2] have shown that the change in strength properties with density for polyurethane foams can be expressed as a straight line on a log–log plot, i.e.,

$$\log P = A + S \log \rho \tag{1}$$

where $P$ is the strength property and $\rho$ the apparent density and $A$ and $S$ are constants which are characteristic for each property and foam system. On the other hand, Frisch and Saunders have reported that the strength properties of the polymer foams are linearly dependent on the density.[3] Correlations of mechanical properties, e.g., tensile, shear, and compressive strength to density of PS foams exhibit a linear relationship.[3,4]

The flexural modulus reflects the toughness and rigidity of the material and thus is an important parameter used for designing applications of the polymer foam sheets. In view of the uncertainty of quantitatively relating density to strength properties of the extruded polymer foams, we have measured the flexural moduli of a series of commercially available extruded polystyrene foam sheets of different density. The measurements were conducted according to ASTM procedure D790-IA in which a three-point loading system with central loading on a supported beam is employed. The instrument used for measurement was an UTI Instron Model 1122. Two types of cutting were done to each specimen: one along the machine direction (of extrusion) and the other in the cross direction. For each sample twelve specimens were cut along each direction, with a dimension of 6.16 × 1.27 cm. All specimens were conditioned at 23°C and 50% relative humidity for 24 h before testing. The identical condition was maintained during the measurement of the flexural modulus. The apparent density of the bulk foam sheets was determined by measuring the weight and the volume of the specimen. The reported mean value was an average of results from twelve specimens.

The flexural moduli of six commercial PS foam sheets of different densities are given in Table I. Variations of the flexural modulus in the machine ($E_{\parallel}$) and in the cross direction ($E_{\perp}$) are shown. The dependence of $E_{\parallel}$ and $E_{\perp}$ on the apparent density of the specimens is shown in Figure 1.

It is seen from Figure 1 that the extruded PS foams are anisotropic in the strength characteristics. The flexural modulus along the machine direction, i.e., the direction of the melt flow during processing, is greater than that in the cross direction. However, the anisotropy due to direction of flow in these PS foams tends to vanish at higher densities. At the apparent density of 0.085 g/cc, $E_{\parallel}$ is 70% higher than $E_{\perp}$, but at $\rho = 0.16$ g/cc, there is only 4% difference in $E_{\parallel}$ and $E_{\perp}$.

It is obvious in Figure 1 that both $E_{\parallel}$ and $E_{\perp}$ correlate linearly with the apparent density of the PS foam sheets. In both cases the correlation coefficient is better than 0.997. These

Journal of Applied Polymer Science, Vol. 30, 3515–3517 (1985)
 CCC 0021-8995/85/083515-03$04.00

TABLE I
Flexural Moduli of PS Foams of Different Density

| | Apparent density (g/cc) | | Flexural modulus ($\times 10^6$ N/m$^2$) | | |
|---|---|---|---|---|---|
| Sample | Machine direction | Cross direction | Machine direction ($E_{\parallel}$) | Cross direction ($E_{\perp}$) | Remarks |
| A | 0.1643 | 0.1597 | 3.857 | 3.707 | Taiwan HDPS foam sheet, white. |
| B | 0.1130 | 0.1150 | 2.581 | 2.201 | Taiwan PS foam sheet, yellow |
| C | 0.1110 | 0.113 | 2.527 | 2.117 | Dow (HK) PS foam L2-HK |
| D | 0.1064 | 0.09936 | 2.317 | 1.710 | Dow (DEP) PS foam sheet |
| E | 0.1061 | 0.1033 | 2.293 | 1.659 | ditto |
| F | 0.08557 | 0.08506 | 1.728 | 1.016 | Dolco (USA) PS foam sheet |

observations are in agreement with previous results on other strength properties of PS foams reported by Frisch and Saunders[3] and are important for application purposes of the extruded rigid PS foam sheets.

We wish to thank Dr. Conway Yip of Dow Chemical (H. K.) Ltd for his suggestions and technical assistance on this project.

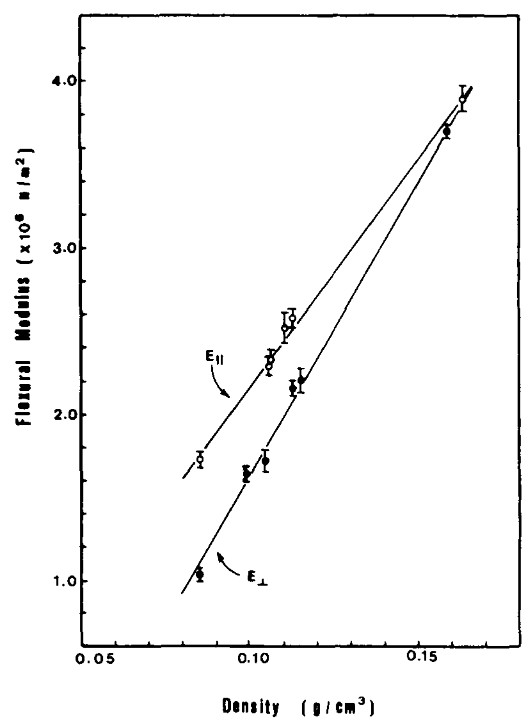


Fig. 1. Dependence of flexural modulus on apparent density of polystyrene foam sheets.

## References

1. D. J. Doherty, R. Hurd, and G. R. Lester, *Chem. Ind.*, **30**, 1340 (1962).
2. R. A. Stengard, *Urethane Foam Bulletin,* E. I. DuPont de Nemours and Co., June 21, 1963.
3. K. C. Frisch and J. H. Saunders, in *Plastic Foams,* Marcel Dekker, New York, 1972, Parts I, II.
4. *Properties of Foam Dylite Polystyrene,* Sinclair-Koppers Co. Bulletin, Pittsburgh, PA, 1969.

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Received October 24, 1984
Accepted December 17, 1984