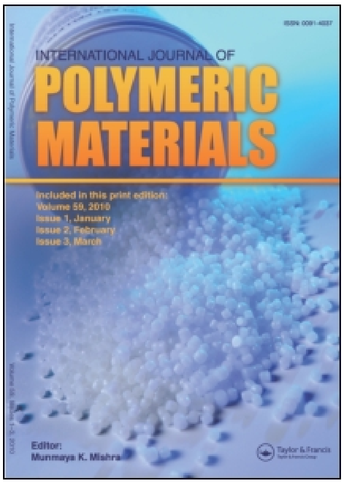

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Shape Index to Describe Stress—Strain Curves of Filled Elastomers

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Shape Index to Describe Stress–Strain Curves of Filled Elastomers

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Simple mechanical models illustrating the behavior of viscoelastic material which exhibit yield, were used to define a shape index to describe the stress–strain curve of filled elastomers. Thus a numerical index was found to be useful to characterize relatively small changes in the shape of stress–strain curves of the above materials. It can be also used as a measure of the linearity of the material response in the whole range of deformation.

1. INTRODUCTION

Stress–strain curves, obtained from the deformation of various shapes of specimens and from different modes of loading, are one of the common results used to characterize the mechanical behavior of materials. From this curve several mechanical properties such as the modulus, the ultimate strength and strain are obtained. Although these properties are usually assumed to be sufficient to characterize the material, a knowledge of the general shape of the curve can contribute greatly to the understanding of the material behavior and of the changes which occur in it during deformation, such as crystallization, chemical degradation and dewetting. Such changes are of great importance particularly in case of the material having to withstand large deformations or repeated loading.

In material development laboratories, where large numbers of specimens are tested for the purpose of comparison of different materials or different conditions of preparation, the task of drawing and comparing stress–strain curves is very time consuming and tedious. Even if a computer is used to plot the results, the comparison of the curves is difficult, because in most cases the changes in the shape of the curves are small. Efforts were therefore made in this study to characterize numerical indexes that will describe the salient features of the stress–strain curve, particularly for filled elastomers in their rubbery region. These indexes might then help in determining the most appropriate ultimate properties of the material to be used for design.

Typical stress–strain curves of filled polymers in their rubbery region, are illustrated in Figure 1. For practical uses the range of deformations beyond the maximum strength (curve 3 in Figure 1) is of minor importance; thus the following discussion will be limited to stress–strain curves similar to curves 1 and 2 in Figure 1. These stress–strain curves describe viscoelastic material which exhibit yield. A few mechanical models, using Bingham type element,[1]

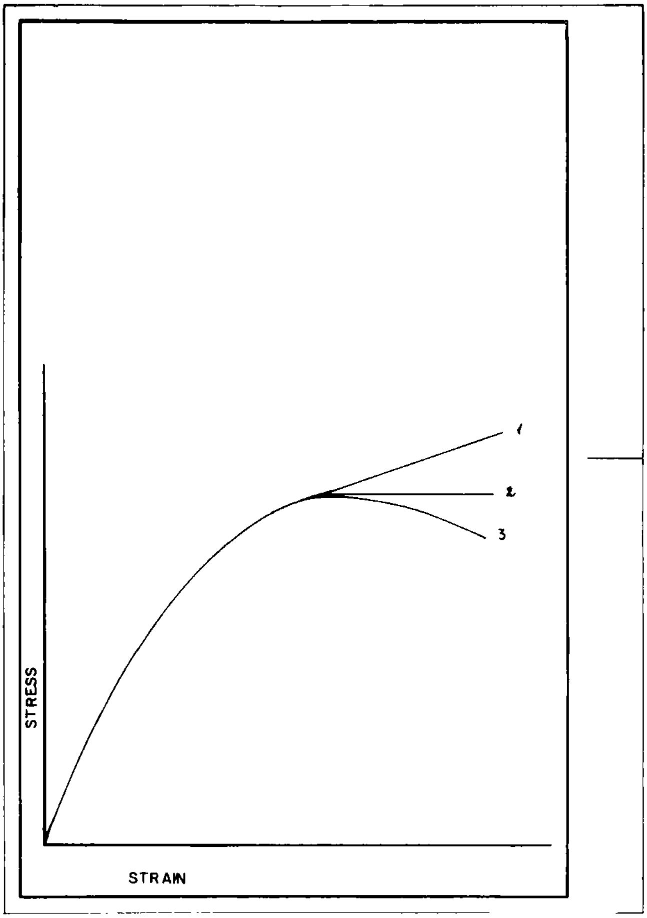

FIGURE 1 Schematic typical stress–strain curves of filled elastomers.

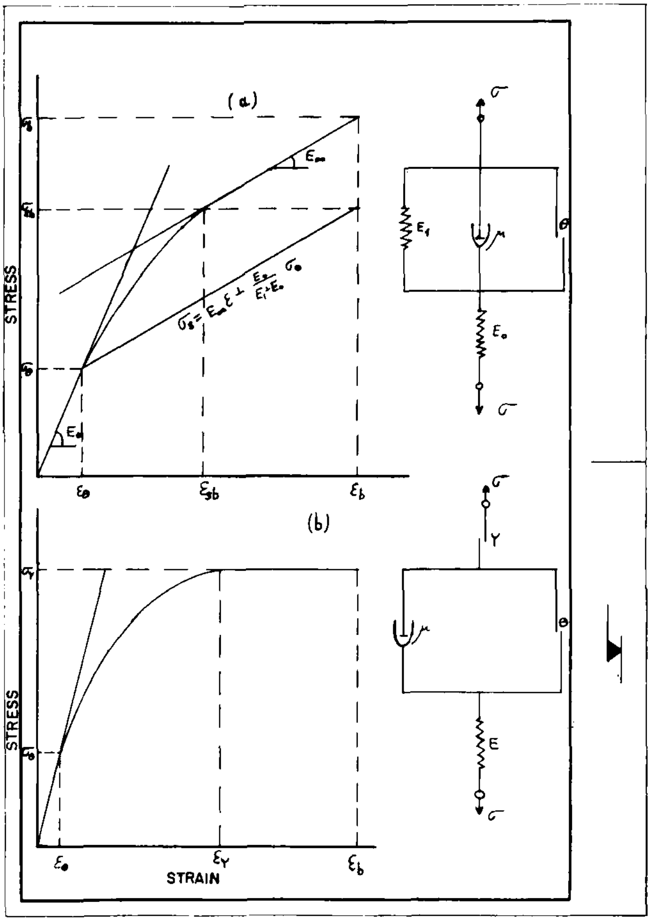

FIGURE 2 The Chase and Goldsmith model (a) and Brinson model (b) for describing visco-elastic materials which exhibit yielding.

have been used to model this kind of behavior. The Chase–Goldsmith model[2] and the Brinson model[3] were found to be useful in describing materials whose mechanical response is illustrated by curves 1 and 2 respectively. The Chase–Goldsmith model (Figure 2a) exhibits a linear behavior below the yield point (σ_θ) which is described by the spring $-E_0$. Above the yield point the material response is described by a Voigt element in series with a spring $-E_0$. The Brinson model (Figure 2b) describes an elastic response for $\sigma \leqslant \sigma_\theta$ which is given by the spring E, a viscoelastic response described by a Maxwell element for $\sigma_\theta \leqslant \sigma \leqslant \sigma_y$ and a range of plastic flow for $\varepsilon \geqslant \varepsilon_y$. By substituting $E_1 = 0$ the Chase–Goldsmith model can be used also to describe the behavior illustrated by curve b in Figure 2. Therefore this model was used here.

The differential equation of the Chase–Goldsmith model can be easily derived and are:

$$\left.\begin{aligned} \sigma &= E_0\varepsilon \\ \dot{\varepsilon} &= \frac{\dot{\sigma}}{E_0} - \frac{1}{\bar{\mu}}(\sigma - \sigma_s) \end{aligned}\right\} \begin{aligned} &(\sigma \leqslant \sigma_\theta) \\ &(\sigma \geqslant \sigma_\theta) \end{aligned} \tag{1}$$

where

$$\begin{aligned} \sigma_s &= \frac{E_0}{E_0 + E_1}(\sigma_\theta + E_1\varepsilon) \\ \bar{\mu} &= \frac{E_0}{E_0 + E_1}\mu \end{aligned} \tag{2}$$

and

$$E_\infty = \frac{E_0 E_1}{E_0 + E_1} \tag{3}$$

The solution of Eq. (1) for the case of a constant strain rate is:

$$\sigma = E_0\varepsilon(\sigma \leqslant \sigma_\theta)$$

$$\sigma = \left[\sigma_s + \frac{E_0\bar{\mu}\dot{\varepsilon}}{E_0 + E_1}\right]\{1 - \exp[-\alpha(\varepsilon - \varepsilon_0)]\}(\sigma \geqslant \sigma_\theta) \tag{4}$$

where

$$\begin{aligned} \varepsilon_\theta &= \sigma_\theta / E_0 \\ \alpha &= \frac{E_0}{\bar{\mu}\dot{\varepsilon}} \end{aligned} \tag{5}$$

Using the Chase–Goldsmith model a non-dimensional index was defined:

$$F_1 = \frac{\varepsilon_{sb} - \varepsilon_\theta}{\varepsilon_b - \varepsilon_\theta} \tag{6}$$

This index was found to be useful as a measure of shape changes in the stress–strain curves (curve 1 in Figure 1) where the strains used in Eq. (6) are defined in Figure 2b. For a curve of type 2 in Figure 1 a similar index can be defined:

$$F_2 = \frac{\varepsilon_y - \varepsilon_\theta}{\varepsilon_b - \varepsilon_\theta} \tag{7}$$

When an on line computer is used to evaluate the mechanical properties from the experimental data, the shape index is calculated as follows:

After determining of the ultimate properties (σ_b, ε_b), E_∞, the limit where the stress–strain curve deviates from linearity (σ_θ, ε_θ) are evaluated. If E_∞ is positive, Eq. (6) is used to calculate the shape index, and if $E_\infty \leqslant 0$, Eq. (7)

is used. In the first case the point $(\sigma_\theta, \varepsilon_\theta)$ and E_∞ are used to derive $\sigma_s(\varepsilon)$ by means of Eq. (2). Then by calculating $\sigma_s(\varepsilon_b)$, ε_{sb} can be determined. In the second case, ε_y is derived from the smallest strain, for which its corresponding stress is equal to σ_b.

2. EXPERIMENTAL

Two series of filled elastomers with different amounts of curing agent were investigated. The standard dumbbell shape specimens were tested at room temperature and at a constant crosshead speed of 5 cm/min using an Instron Machine. The obtained stress–stress curves are illustrated in Figures 3 and 4, and the calculated shape indexes are listed in Table I.

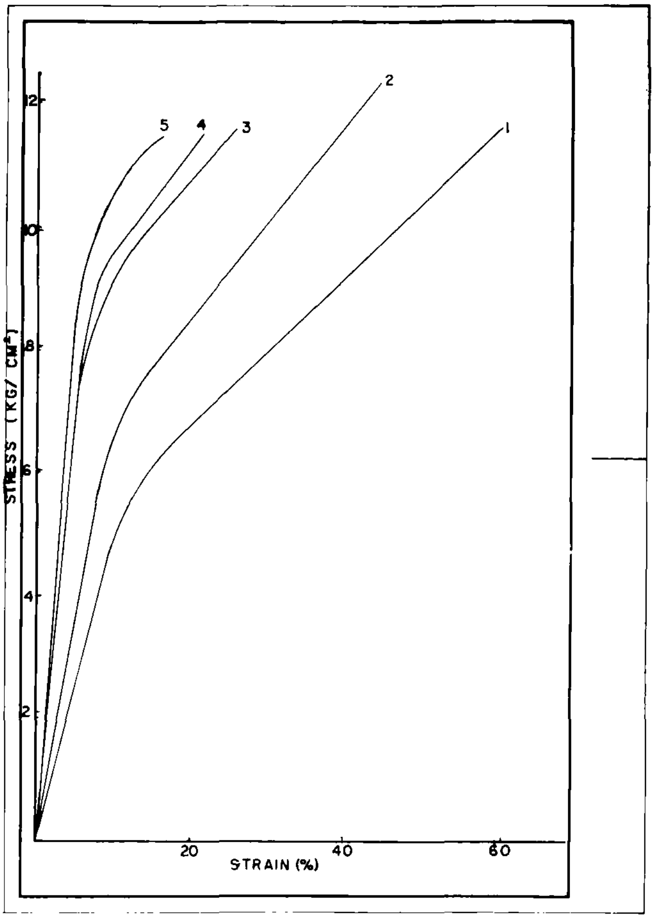

FIGURE 3 Stress–strain curves of Series I.

TABLE I

The shape index describing the stress–strain curves of Series I and II

No. of curve	Series I (Figure 3)	Series II (Figure 4)
1	0.882	0.400
2	0.833	0.475
3	0.737	0.500
4	0.625	0.692
5	0.273	0.792

3. DISCUSSION

Increasing the equivalent of the curing agent increases the stiffness of the material due to the higher crosslink density. On the other hand, ranges can be found in which changing the amount of the curing agent will not influence either the ultimate strength or the strain capacity. In the first Series (Figure 3) the strain capacity was changed while the ultimate strength remained constant and in the second series the ultimate strength was changed while the strain capacity remained constant (Figure 4). In the first case the shape index was calculated using Eq. (6) and in the second case Eq. (7) was used. The results indicate that improving the strain capacity or the strength increases the shape index which means that the stress–strain response is closer to linearity over the whole deformation range.

4. SUMMARY

While the general shape of the stress–strain curve can be easily characterized in most cases from the upper part of the curve, the shape index defined here was found to be useful for distinguishing between relatively small changes in the shape of the stress–strain curves. This shape index can also be used as a measure of the linearity of the mechanical response of the material investigated over the whole range of deformation. The main advantage of having a numerical measure of the linearity of the material's response is that it can be used for engineering purposes where the material has to withstand high deformation.

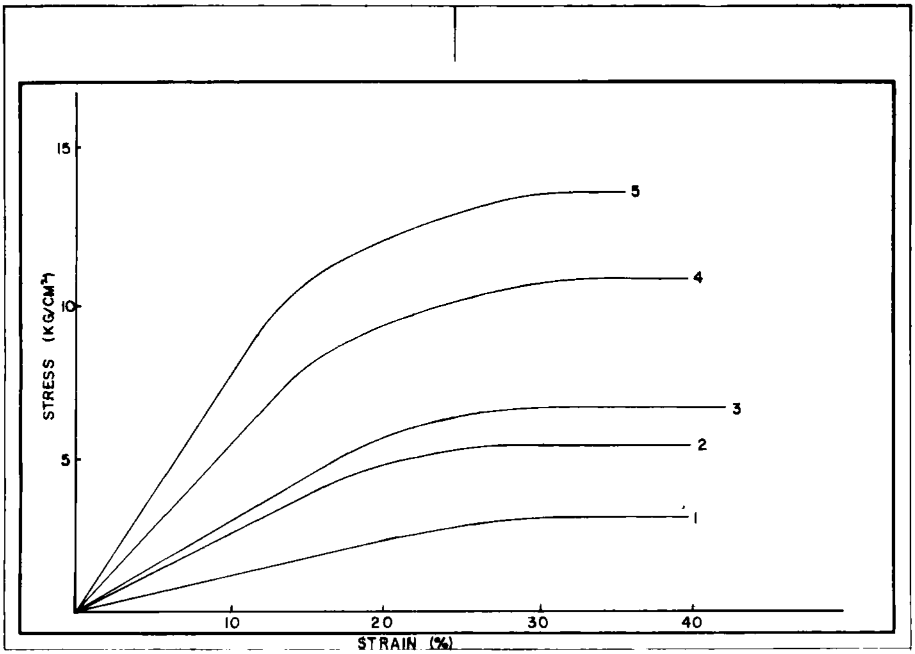

FIGURE 4 Stress–strain curves of Series II.

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