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Failure Loci for a Thermoplastic at Various Temperatures

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Synopsis

Corresponding flexural stress and strain data for polycarbonate failure (at yield or break when brittle), at various temperatures are reported. It is shown that a specific failure locus is obtained at each temperature examined and that the results provide a means of construction of an appropriate locus for any temperature within the range 77–373°K investigated.

INTRODUCTION

In a previous paper we reported[1] corresponding flexural stress and strain data obtained at yield, or break in the case of brittle specimens, for a polycarbonate. We showed that the results obtained for a range of molecular weights and over a range of strain rates formed a well defined failure locus. Little detailed information has been published[2–7] on the effect of temperature on the mechanical properties of polycarbonate and we have therefore extended the earlier study to cover a variety of temperatures in the range 77–373°K (−196° to +100°C). The results to be reported show that a specific failure locus can be constructed for any particular temperature in the range examined.

EXPERIMENTAL

Specimens

Bars (4 × 0.5 × 0.125 in.) were machined from extruded sheets of Makrolon Grade S (Farbenfabriken Bayer), poly[2,2-propane bis-4-(phenyl carbonate)]. The unannealed bars were irradiated in vacuum with the use of a 4-Mev electron beam (doses up to 320 Mrad) as previously described.[8] The molecular weights of the specimens were determined by solution viscometry.

Flexural Measurements

Strength and deformation were measured by three-point loading at a deformation rate of 20 in./min (corresponding to a maximum strain rate of

4 min^{-1}) at 77°K (−196°C) (liquid nitrogen); 135°K (−138°C) (pentane slush); 193°K (−80°C) (solid CO_2); 293°K (+20°C) (ambient), 373°K (+100°C) (boiling water). The results quoted in this paper refer to maximum stress and outer fiber strain at yield (or break in the absence of yield). Further details of the methods employed have been described previously.[1]

RESULTS

Corresponding flexural stress and strain data obtained at yield (or break in the case of brittle failures) for all molecular weights at the various temperatures examined are presented in Figure 1. The failure locus for each temperature is indicated by a solid curve; that for 293°K represents the results obtained previously[1] over a range of strain rates.

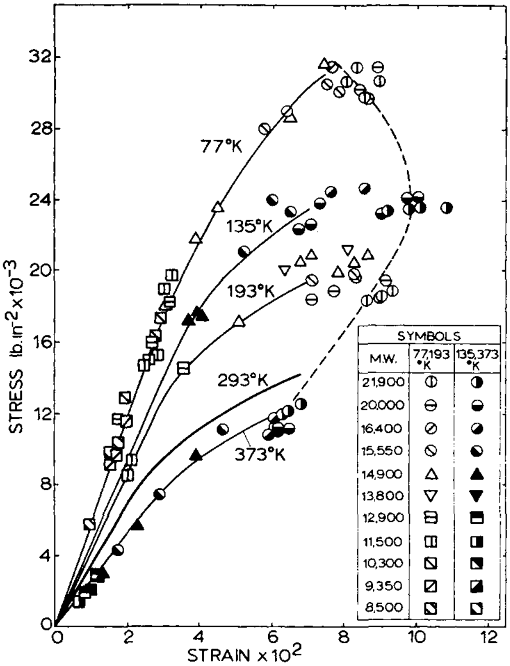

Fig. 1. Corresponding failure stress and strain data obtained for a range of molecular weights at a strain rate of 4 min^{-1} at the various temperatures indicated.

DISCUSSION

The corresponding flexural failure stress and strain data at each temperature give rise to a characteristic failure locus irrespective of the molecular weights of the specimens examined. From Figure 1 it can be seen that the initial portion of each locus is linear and may be represented by the equation

$$\sigma = A\,\epsilon \qquad (1)$$

where σ, ϵ, and A are the stress, strain, and secant modulus at failure. As the specimens are brittle and their behavior is essentially Hookean, the value of the secant modulus approximates to that of the tangent modulus in this region.

We have shown previously,[1] for one temperature, that the later curved region which represents specimens exhibiting transitional and ductile behavior could be described by the relationship

$$\sigma = k \log \epsilon + c \tag{2}$$

where k and c are constants. We have now found that eq. (2), which was established for a wide range of molecular weights and strain rates at 293°K, can also be used to describe the behavior of the material at a variety of temperatures and that specific values of k and c are obtained at each temperature.

TABLE I

Values of A, k, and c, [Eqs. (1) and (2)] at Various Temperatures

Temperature, °K	$A \times 10^{-5}$, lb/in.^{2}	$k \times 10^{-4}$, lb/in.^{2}	$c \times 10^{-4}$, lb/in.^{2}
77	5.89	3.48	7.05
135	4.68	2.31	5.03
193	4.32	1.71	3.93
293	3.60	1.40	3.00
373	2.61	1.39	2.90

Table I gives the values of A, k, and c, appropriate to the temperatures examined, which were used to construct the curves given in Figure 1. In all cases at strains in excess of 7%, eq. (2) appears to be invalid, and a considerably greater scatter of results is observed. Further extrapolation

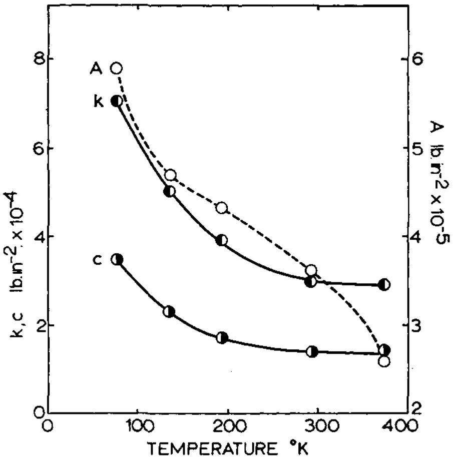

Fig. 2. Values of the constants A, k, and c [eqs. (1) and (2)] vs. absolute temperature.

of the curves is therefore of doubtful significance, although a study of higher molecular weight specimens might justify this. The limiting values of the molecular weight range examined are indicated by the broken curve in Figure 1. The shape of this curve is in accord with the tensile results of Ekvall and Low[5] and may reflect the ease of internal mobility of the polymer at the various temperatures.[9,10]

Plots of the constants A, k, and c versus temperature yield continuous curves (Fig. 2) which permit interpolation at intermediate temperatures within the range 77–373°K to provide appropriate failure loci. The information obtained thus provides failure stress and strain data for polycarbonate, up to a molecular weight of 22,000, over a range of temperatures and previous results suggest[1] that it is also valid over a range of strain rates of 0.0001 to 4 min^{-1}. We infer that the proposed approach could be applied to a wide range of thermoplastics given data similar to those shown in Figure 1.

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