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Experimental Study of Stress-relaxation Behaviour of Polycarbonate After Yielding

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Summary

The viscoelastic behaviour of a bisphenol A polycarbonate after yielding is described by means of empirical superposition of coordinates along both time and stress axis, which allow collecting stress relaxation data, taken both in tension and in compression, into a master curve.

Introduction

Large information on the viscoelastic behaviour after compression yielding of a bisphenol A polycarbonate 4,4'-dioxydiphenyl 2-2 propane carbonate M_n=25000, Lexan (General Electric), was already collected in (4). In particular it was observed that both creep and stress relaxation in the plastic region depend separately on the test strain $e_t = l_{ot}/l_o$ (where l_o is the sample length in the unoriented configuration and l_{ot} is its value at the end of the sample loading) and on the strain rate α just prior to the test. The use of a dimensionless time θ proportional to both α and e_t allowed collecting the creep strains $\Delta l/l_{ot}$ (where Δl is the length variation during creep tests) into a single curve. Furthermore a master stress relaxation curve was obtained by plotting, in analogy to what suggested by Kubât et al. (1,2), the ratio between the relaxed and the relaxable stress versus θ.

The analysis of creep behaviour was then extended to some tensile tests (3). Creep data, taken both in tension and in compression, were plotted versus a dimensionless time θ' proportional both to α and to a strain measure which tends to e_t (thus reproducing θ) for small values of e_t and is a slightly decreasing function of e_t for e_t>1. The achievement of a good superposition of all data showed that the proper dimensionless time was identified.

Following the results reported in (3), both tensile and compressive stress relaxation data are considered in this work.

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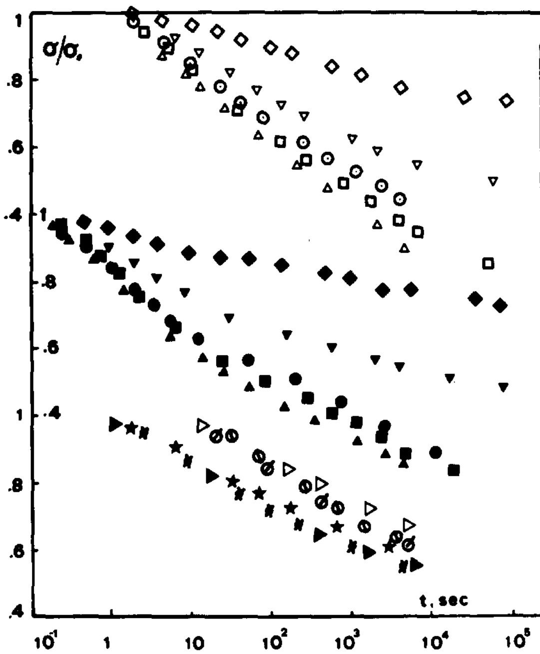
Experimental

The same material considered in (3,4) was here further investigated.

Stress-relaxation measurements were executed at room temperature (about 20°C) both in tension and in compression by an Instron testing machine. In all cases the samples were deformed beyond material yielding by means of constant velocity strain ramps. In order to enlarge the range of the test strain e_t , some compression tests were performed on samples which had been previously elongated at room temperature up to necking; this allowed values larger than one for e_t. Moreover tensile tests were made on the same material using strip samples cut from sheets prepared by compression molding and subsequent rolling, the latter being performed in order to avoid necking during the sample loading. Different types of strip samples were prepared having about the same initial strain (after rolling) e_1 along the testing direction and different deformations along the thickness and width directions.



	e_t	$d_t h^{-1}$	e_1	e_2
	compression			
◇	.35	9.5	1	1
▽	.7	4.8	1	1
○	1	7.3	1.7	.77
□	1.2	6.1	1.7	.77
△	1.4	5.2	1.7	.77
◆	.35	9.5	1	1
▼	.7	4.8	1	1
●	1	7.3	1.7	.77
■	1.2	6.1	1.7	.77
▲	1.4	5.2	1.7	.77
	tension			
⊗	1.4	.51	1.16	1.31
ø	1.4	.52	1.2	1.01
▷	1.7	.44	1.21	1.02
▶	1.4	5.1	1.16	1.31
✱	1.4	5.2	1.2	1.01
★	1.7	4.4	1.21	1.02

Fig.1 Stress relaxation data. e_i are initial (after rolling or necking) strains.

Results and discussion

The stress relaxation data are reported in Fig.1. In presence of internal stresses arising from material orientation only a part of the stress, that exceeding the internal stress, undergoes relaxation (1,2). Consistently, the ratio $\underline{\sigma}$ between the relaxed stress $\sigma_o-\sigma$ and the relaxable one $\sigma_o-\sigma_\infty$ was identified in (4) as a significant stress measure. σ_∞ is the asymptote of the stress relaxation curve and has the meaning of the opposite of the internal stress. In order to obtain $\underline{\sigma}$, σ_∞ has been here evaluated as follows.

Values of $y = 1 - \sigma_c/\sigma_{oc}$, obtained from the compression curves of Fig.1, are reported in Fig.2 versus e_t for two different values of the dimensionless time θ', already defined in (3) as:

$$\theta' = t.\alpha.\frac{1}{\sqrt{II_{\underline{C}_u}-1}} \tag{1}$$

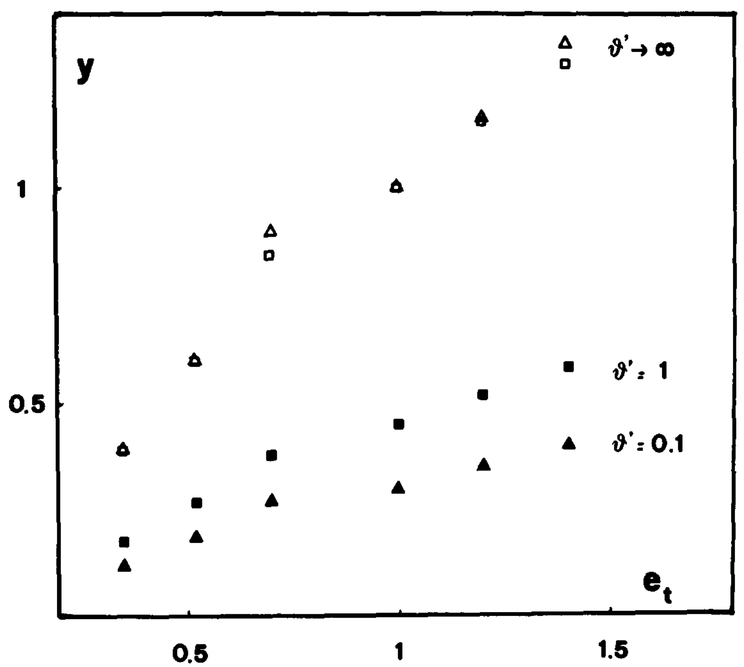


Fig.2 Dimensionless measure of relaxed stress y versus the strain e_t. θ' is the dimensionless time. ▲ ■ were evaluated from compression curves shown in Fig.1. △ □ were obtained from the corresponding full points by means of a scale factor.

$\sqrt{II}_{C_u^{-1}}$ is the magnitude of the tensor $\underline{C}_u^{-1}$, where $\underline{C}_u$ indicates the Cauchy strain tensor of the present material configuration with respect to the unoriented one.

The ratio between the ordinates of the two resultant curves shown in Fig.2 is to a good approximation constant over the whole range of e_t considered. This suggests that $y(\theta', e_t)$ can be factorized into the product of two functions, one of θ' and the other of the strain e_t:

$$y(\theta', e_t) = 1- \sigma_c/\sigma_{oc} = A(\theta').g(e_t) \qquad (2)$$

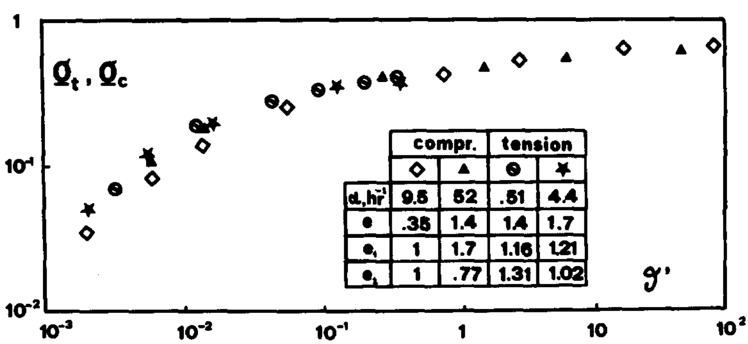
where the subscript c is to remember that Eq.1 refers to compression tests.

σ_∞ can be obtained from Eq.2 for $\theta' \to \infty$; the curve $y(\infty, e_t)$, see Fig.2, was determined after evaluation of the scale factor $A(\infty)$ so as to satisfy the condition that for $e_t=1$ the internal stress $\sigma_\infty=0$, and thus $y(\infty,1)=1$. This curve is satisfactorily described by the equation $y(\infty,e_t)= 1-0.6 \ln e_t$, which for σ_∞ gives:

$$\sigma_\infty = - \sigma_{oc}\ 0.6 \cdot \ln e_t \qquad (3)$$

As it could have been expected, σ_∞ has the same sign as σ_{oc} when $e_t<1$ and viceversa; with reference to compression tests internal and external stresses act together when $e_t>1$ whereas they act in the opposite direction when $e_t<1$. Substitution of Eq.3 into $\underline{\sigma}$ gives:

$$\underline{\sigma}_c = (1-\sigma_c/\sigma_{oc})/(1+ 0.6 \cdot \ln e_t) \qquad (4)$$



	compr.		tension	
	◇	▲	⊖	✶
d, hr^{-1}	9.5	52	.51	4.4
e	.35	1.4	1.4	1.7
e_1	1	1.7	1.16	1.21
e_t	1	.77	1.31	1.02

Fig.3 Stress relaxation master curve. Key for symbols as in Fig.1.

This equation determines the stress measure for compression tests.

In order to have an analogous expression for tensile tests one should identify also for them a relation between σ_∞ and the test strain. According to our picture the internal stresses, and thus σ_∞, depend only on the strain with respect to the unoriented configuration, regardless the test is performed in tension or in compression. Neglecting the effect of the strains along the directions normal to the load, one may use Eq.3 also in tension; obviously σ_{oc} holds the meaning of the stress corresponding to e_t during a compression test. This gives for the stress measure in tension:

$$\underline{\sigma}_t = (\sigma_{ot} - \sigma_t)/(\sigma_{ot} + \sigma_{oc} \cdot 0.6 \cdot \ln e_t) \qquad (5)$$

It is worth pointing out that σ_{ot} and σ_{oc} have different sign. Then for $e_t > 1$ the external stress σ_{ot} and the internal stress act in the opposite direction, the latter tending to restore the unoriented configuration which corresponds to $e=1$.

Four curves from Fig.1, corresponding to very different operating conditions, are plotted in Fig.3 as $\underline{\sigma}_t$ and $\underline{\sigma}_c$ versus θ' obtaining a satisfactory superposition. The values of the stresses σ_{ot} and σ_{oc} used for calculating $\underline{\sigma}_t$ have been taken from the stress strain curves shown in Fig.4.

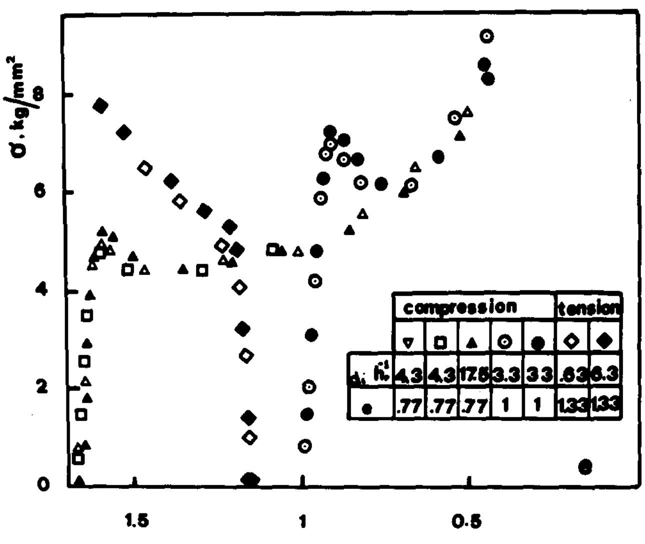


Fig.4 Stress σ versus strain e for constant velocity deformation. α_i is initial deformation rate.

Conclusions

The stress-relaxation behavior of a polycarbonate after yielding has been described by means of a master curve collecting both tensile and compressive data.

This curve was obtained by the following steps: i) time shift superposition was achieved by use of a dimensionless time θ' proportional both to the strain rate α just prior to the test and to a strain measure, so as defined by Eq.1; ii) because of the presence of a stress σ_∞ at infinite time, the stress measure was taken as $(\sigma_0-\sigma)/(\sigma_0-\sigma_\infty)$ and the value of σ_∞ was obtained by extrapolation of experimental data, according to Eq.3.

The fact that, in spite of the very different operating conditions (e_t, α, e_i, tension, compression), a satisfactory superposition of all the data was obtained, shows that the chosen dimensionless stress and time measures account correctly for most of the phenomena involved.

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