Investigation of PVC Life at Sinusoidal Loading

M. NATOV, ST. VASSILEVA and P. TRIFONOV, *Higher Institute of Chemical Engineering, Sofia 1156, Blvd. K. Ochridsry 8, Bulgaria*

Synopsis

The durability of polyvinylchloride (PVC) at static and cyclic loads during establishing of tensile and flexural strength is studied. It is found out that bulk static and cyclic durability can be described by a kinetic equation assuming that the tension changes the temperature-energy factor. During testing of tensile strength it is established that the maximum deformation at break depends upon the tension of loading in an elaborate way with the existance of a peak at 32 MPa.

INTRODUCTION

Recent investigations of polymers life[1-7] have shown that it is a complex function of the stress applied. A number of equations have been suggested as to the relation between life and stress—the equations of Taylor, Büche, Zhourkov, Bartenev, Goule, etc.[1-5] According to those equations, life should depend linearly on the stress applied. However, the results obtained from tests have shown that the relationship between life and stress is more complex.[6] It is supposed,[7] that the relation between life τ and stress σ can be expressed by the following equation:

$$\tau = \tau_0 \exp \frac{U}{RT + \alpha\sigma^n} \tag{1}$$

where

U = destructive process activating energy

T = absolute temperature

R = *universal gas constant*

τ_0, α, n = constants

The majority of the investigations of (PVC) strength have been related to the determination of the effect of different factors such as loading frequency,[8] interval between different cycles, structure strengthening,[9] different additive (fillers) types and quantity, plasticizers,[10] and temperature,[11] on polymer cyclic durability. Generally it is shorter than static durability, but it is not still possible to draw the conclusion that the data related to static durability may be used as a basis for prognosticating life values in case of PVC cyclic loading.

Journal of Applied Polymer Science, Vol. 34, 785–792 (1987)

CCC 0021-8995/87/020785-08$04.00

TABLE I
Specification of PVC 64 Produced by Suspension Polymerization

Parameter	Value
Appearance	dusty(gypsum-like)
K value	64
Density	1.392 kg/m^3
Sulfate ashes	0.2%
Humidity and volatiles	0.5%
Tensile strength	56 MPa
Relative elongation	5–7%

It has been interesting to check whether on the basis of Eq. (1) it is possible to describe life at sinusoidal loading.

EXPERIMENTAL

Materials

PVC 64 produced by suspension polymerization, made in Bulgaria and having the specification shown in Table I has been used in the tests.

Preparation of Samples

When preparing polymer samples, 2% plastizer (diisooctilphtalate) and 1.5% stabilizer (lead stearate) were added. Samples for testing tensile strength have been made by cutting plates pressed in advance into the shape of a double blade of sizes determined by the standards related to measurements of tensile strength (i.e., 115 mm length, 25 mm width, and working section of 30 mm length and 6 mm width).

The samples used for tests of bonding strength represented a parallel pipe 115 mm long, 16.5 mm wide, and 9 mm thick.

Stress Measurements

The tests have been carried out on a stand designed especially for this purpose and allowing a cyclic loading with tension and stress or bending (pulsating mode) at a frequency of 0.05–1.2 c/s, without observing a self-heating of the samples.[12] Sample static durability has been also determined at the same time.

RESULTS AND DISCUSSION

The relation between life and tensile strength has been tested first at a large range of stresses. As is shown in Figure 1, the results obtained from the tests coincide with the results calculated as per Eq. (1).

On the basis of the relations established experimentally it has been possible to determine the following values of the constants in Eq. (1) for PVC, when testing its tensile strength:

$$U = 67810 \text{ J mol}^{-1} \qquad \alpha = 0.341 \times 10^{-18} \text{ J Pa}^{-3} \text{ mol}^{-1}$$

$$n = 3 \qquad \ln \tau_0 = -7$$

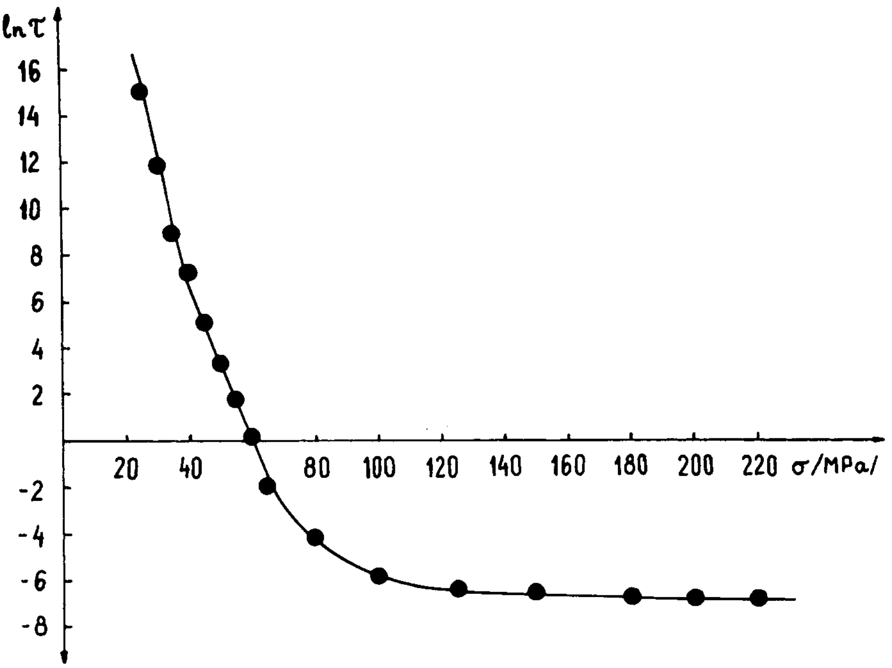

Fig. 1. Relation between life at static loading and tension applied.

at

$$R = 8.3143 \text{ kJ kmol}^{-1}\text{deg}^{-1} \qquad T = 298°\text{K}$$

When testing cyclic durability, stresses at which life is within the range of several seconds to several days have been used. The Bailey integral[13] should be valid for the ideal case of variable loads. According to this integral, irreversible partial destructions accumulating with time occur in materials under the effect of mechanical stresses. The Bailey integral for PVC, when using Eq. (1), will be as follows:

$$\int_0^{\infty} \frac{dt}{\tau_0 \exp \dfrac{U}{RT + \alpha\left[\dfrac{\sigma_0}{2}(1 - \cos wt)\right]^n}} = 1 \tag{2}$$

where

σ_0 = stress amplitude
w = circular frequency

If Bailey's premises related to partial destructions irreversibility and linear accumulation are valid for PVC, the Bailey integral in case of static loading will be represented as follows:

$$\int_0^{\infty} \frac{dt}{\tau_0 \exp \dfrac{U}{RT + \alpha \tau_0^n}} = 1 \tag{3}$$

The constants in Eqs. (2) and (3) are the same as in Eq. (1). However, it is known that in case of periodic loading partial destructive processes which are partially reversible take place in polymers.[14] If reversible partial destructions occur in PVC, the relation between Eq. (2) and Eq. (3) will be a real value characterizing partial destruction reversibility:

$$K = \frac{\displaystyle\int_0^{\tau_\mu} \frac{dt}{\tau_0 \exp \dfrac{U}{RT + \alpha \left[\dfrac{\sigma_0}{2}(1 - \cos wt) \right]^n}}}{\displaystyle\int_0^{\tau_\mu} \frac{dt}{\tau_0 \exp \dfrac{U}{RT + \alpha \sigma_0^n}}} \tag{4}$$

Integral limits in Eq. (4) are substituted from 0 to $\tau\mu$ for which there is good reason, since it is not possible to establish a relation for $\tau\mu$. The integrals in Eq. (4) have been calculated by means of a program (QSF of SSP). As is shown on Table II, K is the range of 0.15 to 0.26, the average value being Ka = 0.186.

Figure 2 shows the durability at static load (curve 1) and the relationship at cyclic load τ_μ (curve 2) within the range of stresses applied during the tests. Curve 3, τ_T corresponds to the theoretically calculated value of cyclic durability obtained by multiplying τ_μ values by constant K:

$$\tau_T = K \cdot \tau_\mu \tag{5}$$

It is obvious that the course of both relations (experimental and theoretical) is the same. Their difference is due to partial destruction reversibility observed repeatedly.[15]

TABLE II

Values of τ_μ, τ_T and K Established by a Tensile (Strength) Test of PVC

σ (MPa)	τ_μ (s)	τ_T (s)	K
20	5.15×10^4	1.28×10^4	0.25
25	9.41×10^3	2.07×10^3	0.22
30	3.13×10^3	6.26×10^2	0.20
35	9.07×10^2	1.57×10^2	0.17
40	3.24×10^2	5.00×10	0.16
45	1.48×10^2	2.20×10	0.15
50	7.40×10	1.10×10	0.15
55	2.30×10	0.52×10	0.22
60	0.70×10	0.12×10	0.16

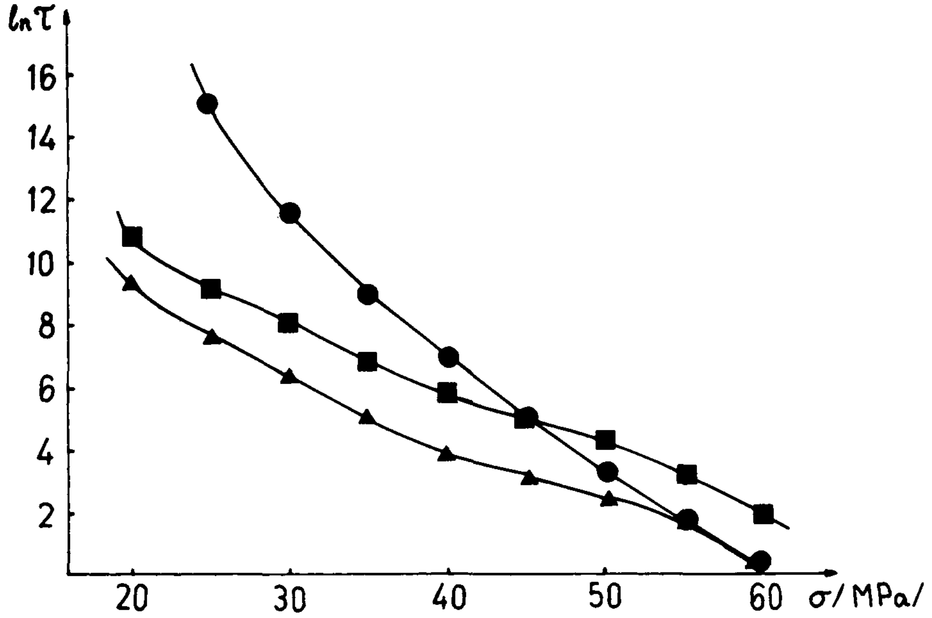

Fig. 2. Relation between life at cyclic loading and tension applied: (●) Relation between life and stress applied by static loading; (■) Relation between life and stress applied by cyclic loading; (▲) Relation between life and stress applied calculated as per Eq. (5).

It is known that PVC life depends on the type of stress applied—tension, twisting, etc. Therefore PVC static and cyclic life have been tested by bending after fixing the samples at both sides. Curve 1 on Figure 3 represents PVC life at static load, and curve 2 represents PVC life calculated as per Eq. (1), the constants for PVC subject to bending being

$$U = 67810\ \mathrm{J\ mol}^{-1} \qquad \ln \tau_0 = -5 \qquad n = 6$$

$$\alpha = 1.08 \times 10^{-43}\ \mathrm{J\ Pa}^{-6}\ \mathrm{mol}^{-1} \qquad \text{at } T = 293°\mathrm{K}$$

Figure 4 shows the relationship established during tests by sinusoidal loading sampley at 24 cycles/min (curve 1). Curve 2 represents life value calculated by means of equations (4) and (5) and by using the constants indicated above for loading PVC by bending. It is evident that the course of the relation is similar to that of the tests. The relationship between the two is shown on Table III. K values vary from 0.09 to 0.20, the average value being about 0.1, which is about twice less than Ka related to PVC loading by tension, i.e., τ_T and τ_μ values in case of tension are twice closer to those of τ_T and τ_μ in case of bending, which is proof that bending is more unfavorable than tension for PVC samples and the difference between static and cyclic life values in case of bending is greater than that between both life values in case of tension.

The deformation of the samples destroyed by tension during the tests is of a particular interest. When increasing tension in case of static loading it varies, its maximum values at 32 MPa (curve 1, Fig. 5). This maximum value does not

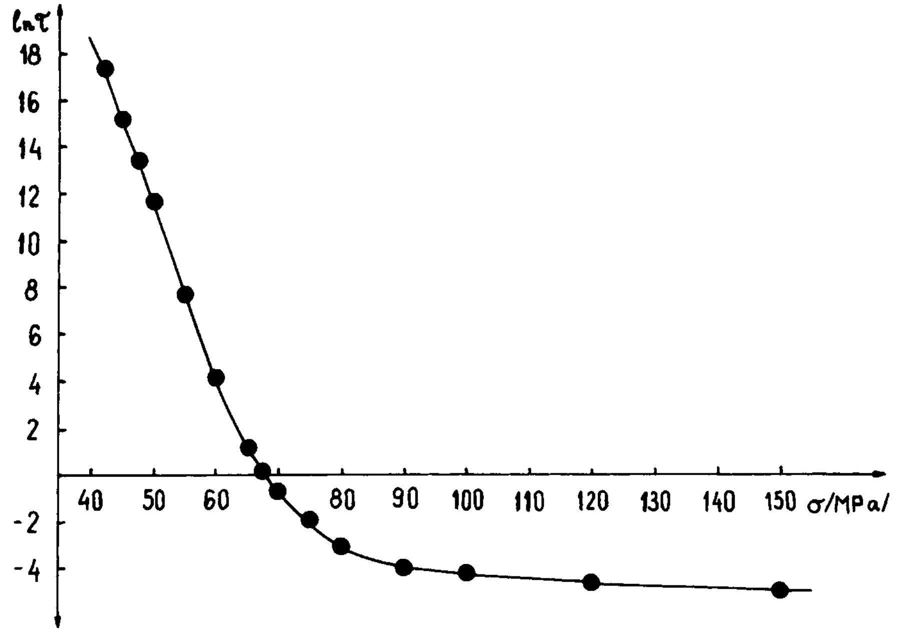

Fig. 3. Relation between life and bending by static loading.

correspond to any variation in the course of the relation between life and stress (Fig. 1). Probably this maximum value is related to the fact that PVC deformation and destruction represent two independent processes. Deformation in case of destruction increases in case of larger tensions, but sample life is shorter. After 32 MPa the deformation should have been greater than at 32

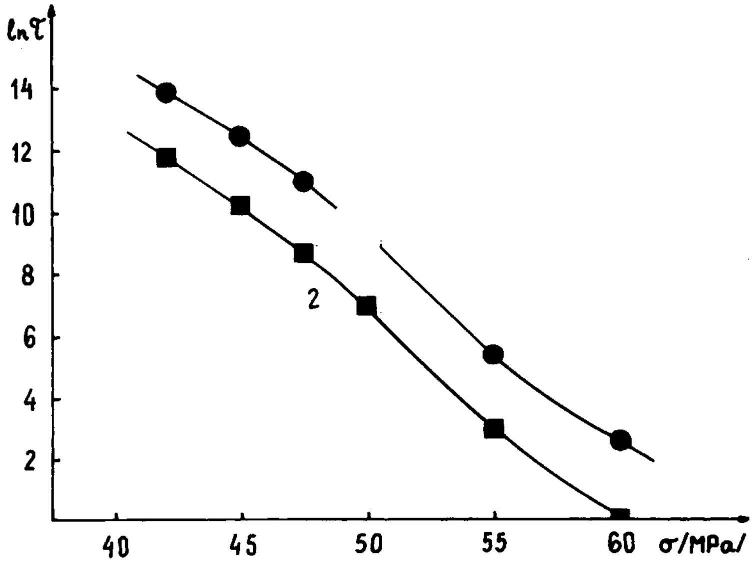

Fig. 4. Relation between life and bending by cyclic loading: (●) Relation between life and stress by cyclic loading; (■) Relation between life and stress calculated as per Eq. (5).

TABLE III
Values of τ_μ, τ_T and K Established by a Bending (Strength) Test of PVC

σ (MPa)	τ_μ (s)	τ_T (s)	K
42	1.04×10^6	1.25×10^5	0.20
45	2.63×10^5	2.70×10^4	0.10
47.5	6.12×10^4	5.79×10^3	0.09
50	1.12×10^4	1.01×10^3	0.09
55	2.13×10^2	1.85×10	0.09
60	0.13×10	0.14×10	0.10

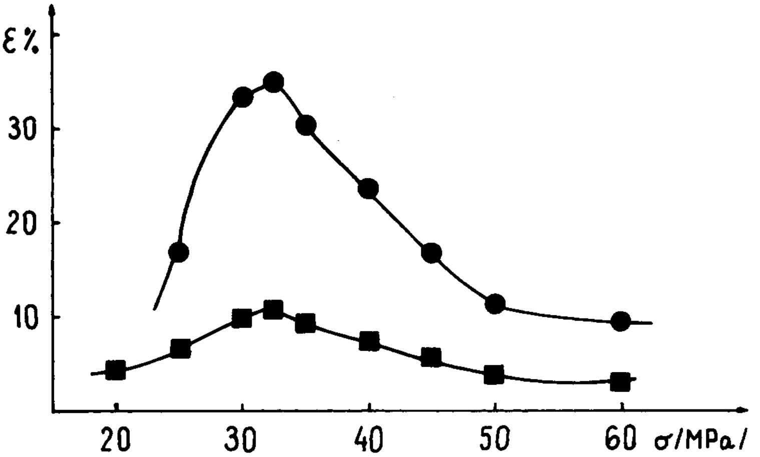

Fig. 5. Relation between maximum deformation and stress: (●) Relation between deformation and stress in case of static loading; (■) Relation between deformation and stress in case of cyclic loading.

MPa, but the time required for polymer creeping is shorter than its life, therefore the deformation in case of destruction starts to decrease. The relationship between deformation and tension in case of sinusoidal loading (curve 2 on Fig. 5) has the same course, but total deformation values are much smaller, which is proof that both partial destruction and partial deformation are reversible.

CONCLUSIONS

1. PVC life at static stresses by tension and bending has been investigated, and data related to the complex relation between life and stress have been confirmed. It is possible to describe this relation by means of a modified Arrhenius equation.

2. PVC life at sinusoidal loading at a frequency of 24 circ/min (0.4 Hz) and stresses by tension and bending of 20 to 60 MPa has been tested. It has been established that PVC life in the case of sinusoidal tension may be described by the equation suggested on the basis of Bailey's integral and taking into consideration partial destruction reversibility.

3. It has been established that maximum deformation until destruction depends on the tension in a complicated way, the peak appearing at about 32

MPa, which is an indication that PVC deformation and destruction are two independent processes.

References

1. N. Taylor, *J. Appl. Phys.*, **18**, 943 (1947).
2. F. Bueche, *J. Appl. Phys.*, **28**, 784 (1957).
3. S. N. Jurkov and E. E. Tomashevsky, "Some Problems about the Strength of Solids," Moscow, Ed. Academy of Science USSR, 1959, 68.
4. G. M. Bartenev and U. S. Zuev, "Strength and destruction of highelastic materials," Moscow-Leningrad, Chemistry, 1964, 388.
5. V. E. Gull, "Success of chemistry and technology of polymers," Moscow, Chemistry, 1957, pp. 202–223.
6. M. A. Natov and St. Vassileva, *Die Ang. Makromol. Chemie*, **20**, 181 (1971).
7. M. A. Natov and St. Vassileva, "Mechanics and technology of compositive materials," Sofia, Bulgarian Academy of Science, 1979, 863.
8. S. B. Ratner and S. S. Agamaljan, *Plastics*, **12**, 66 (1967).
9. A. V. Stinskas and S. B. Ratner, *Plastics*, **12**, 56 (1962).
10. Y. N. Van Gang, *Mech. Polym.*, **3**, 151 (1965).
11. N. G. Smotrin, *Mech. Polym.*, **3**, 81 (1965).
12. M. A. Natov, St. Vassileva, and P. I. Trifonov, *Mech. Compositive Mat.*, **2**, 202 (1985).
13. J. Bailey, *Glass Ind.*, **20**, 143 (1939).
14. M. A. Natov and M. Glushkov, *Mech. Polym.* **6**, 1003 (1970).
15. N. A. Natov, St. Vassileva, K. Popov, and V. Sidjopulu, *Mech. Polym.*, **4**, 735 (1974).

Received May 27, 1986
Accepted November 18, 1986