Polymer Bulletin 21, 113–118 (1989)

Polymer Bulletin

The effect of electric field on the creep characteristics of low-density polyethylene (LDPE)

M. Amin[1], H.M. Osman[1], S.S. Hamza[1], N. El-Nashar[2], and S.F. Moghazy[2]

[1] Physics Department, Faculty of Science, Cairo University, Giza, Egypt
[2] Physics Department, Faculty of Science, Helwan University, Egypt

Summary
The effect of electric field on the creep characteristics and the corresponding parameters such as instantaneous strain, strain rate, activation energy, activation volume, stress-sensitivity parameter and viscosity was investigated.

1. Introduction

There is generally little information about the effect of electric field on the mechanical properties of polymers. Abasov et al.[1] have studied the effect of strong electric field on the mechanical long-term strength of polyethylene. They found that the field reduces this quantity through the dynamic perturbation of the molecular bonds by accelerated electron and thus reduces the activation energy of the process of polymer failure. In fact charges librated from traps may be displaced by the high external electric field from the Coulomb sphere of action of traps. They become accelerated in the field and thus dynamically disturb the bonds. This mechanism has the predominant effect on flexibility and fracture.

The end effect may help the polymer to gain some residual charges[2], which would be affected by the external field and could possibly perturb the chain structure and affect the mechanical properties. The application of the electric field may cause an appreciable internal strain as a result of electrostriction.[3]

In addition, residual polarity which may be produced in the polymer may also change chain flexibility.[4]

The best fit to experimental data has over a large range of fields been studied by Grine[5]. An exponential decrease of the activation energy, u, with the electric field, F, was found.

The aim of the present work is to study mechanical creep in the presence of an electric field, and to find the values of instantaneous strain, ε_0, strain rate, $\dot{\varepsilon}$, activation energy, u, activation volume, q, and viscosity η.

2. Experimental

A sheet of low density polyethylene LDPE of thickness 240 um manufactured by the National Plastic Company, Egypt, was used. Strips of 6 cm long and 0.5 cm width were cut out, annealed by heating to the required annealing temperature (40-80^{0}C) for an hour and allowed to cool slowly to room temperature.

The creep tensile apparatus used was described in a previous paper.[6]

A cyclindrical electric cell (6 cm long and 1.8 cm diameter) was designed to apply electric field on the sample during the creep test as shown in Fig.(1).

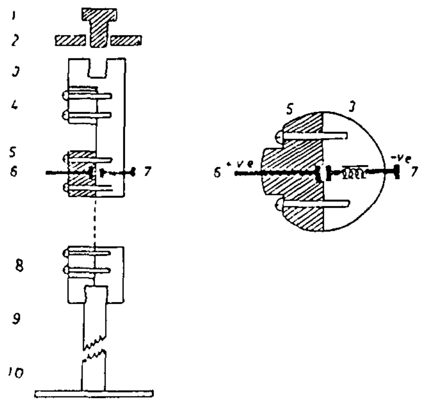
The applied electric field ranged between 0-1.6 x 10^{6} V/m. Care was taken to avoid electronic noise during measurements by applying shielding.

3. Results and Discussion

Figure (2) represents the effect of applied electric field on a set of creep curves of LDPE plotted at different temperatures and two values of stresses. The electric field has an appreciable effect represented in shifting the values of strains to higher values. Such behavior was observed with increasing the values of either stresses or temperatures. This means that the temperature (and/or) stress act in the same sense as the electric field.
In the presence of the electric field fracture takes place earlier especially at high temperature and stress.

It is clear from Fig. (2) that at low temperature and stress ε_o is a field independent quantity, while by increasing the temperature at low stress or increasing stress at low temperature, the instantaneous strain increases with the field. At high stresses and temperatures, the rate of increasing of ε_o with the field is also high. The temperature assists the electric field to

Fig. (1): Schematic diagram for the electric cell used in studying the electrical properties during tension
1. Teflon screw,
2. Teflon washer,
3. Brass, main body of the cell,
4. Upper grip,
5. Teflon part,
6. Brass electrode,
7. Brass electrode,
8. Lower grip,
9. Brass rod, and
10. Ebonite.



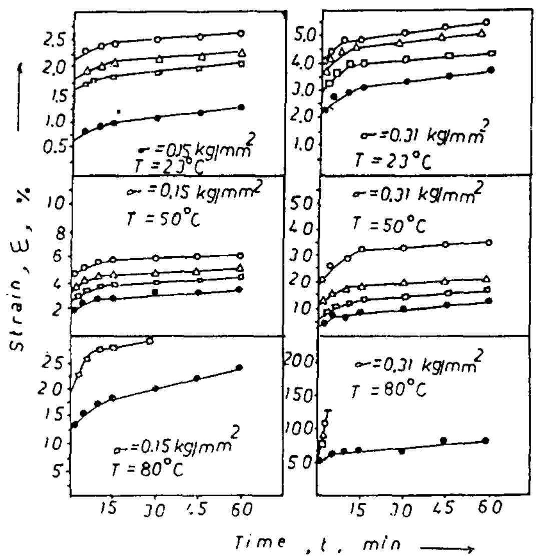


Fig. (2): The creep curves for LDPE at different values of applied electrical potential and temperature (stress = 0.15 kg/mm^2 and 0.31 kg/mm^2).
zero Vol., 200 Vol.,
300 Vol., o 400 Vol.

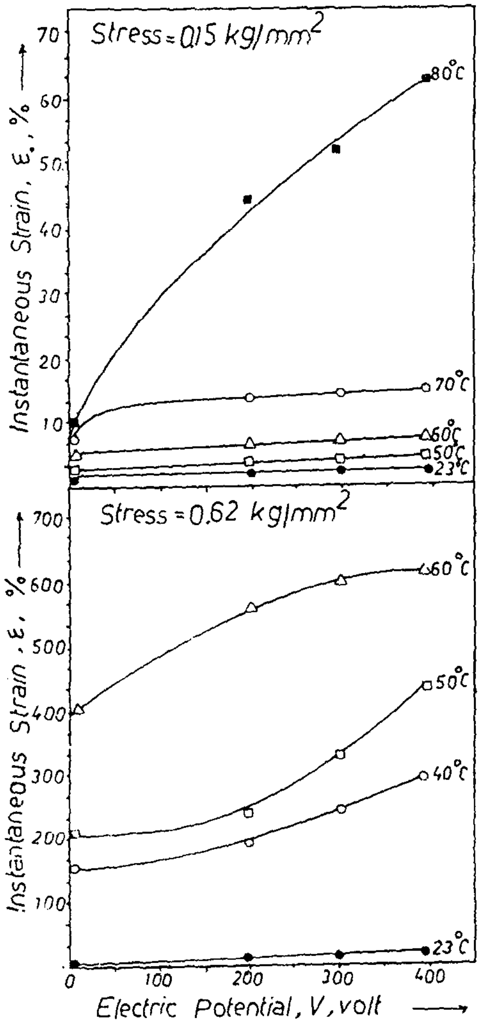


Fig. (3): The dependence of instantaneous strain on the applied electrical potential at different temperature, (stress = 0.15 kg/mm^2 and 0.62 kg/mm^2).

produce perturbation of the macromolecular bonds. The heating of LDPE during the application of the electric field may release various types of molecular motions which favor the liberation of more charges from traps.

Figure (4) illustrates the temperature dependence of η at different applied electric fields. The field lowers the values of strain rate keeping the general behavior unchanged. There is also a kink at about 50^oC, i.e. two activation energies exist, one at low temperature (< 50^oC) and the other at a higher temperature (>50^oC), where, 50^oC is the temperature of the crystallized phase.

The dependence of the value of activation energy for creep on the electric field is shown in Fig. (5). At low temperatures the activation energy decreases with the field. The stress acts as a differentiating factor between the curves.

However, at high temperatures the stress is nearly ineffective. The lowering in activation energy implies that the field has hindered the barriers against the motion of the macromolecules and accelerated the charged particles to assist the motion of macromolecules.

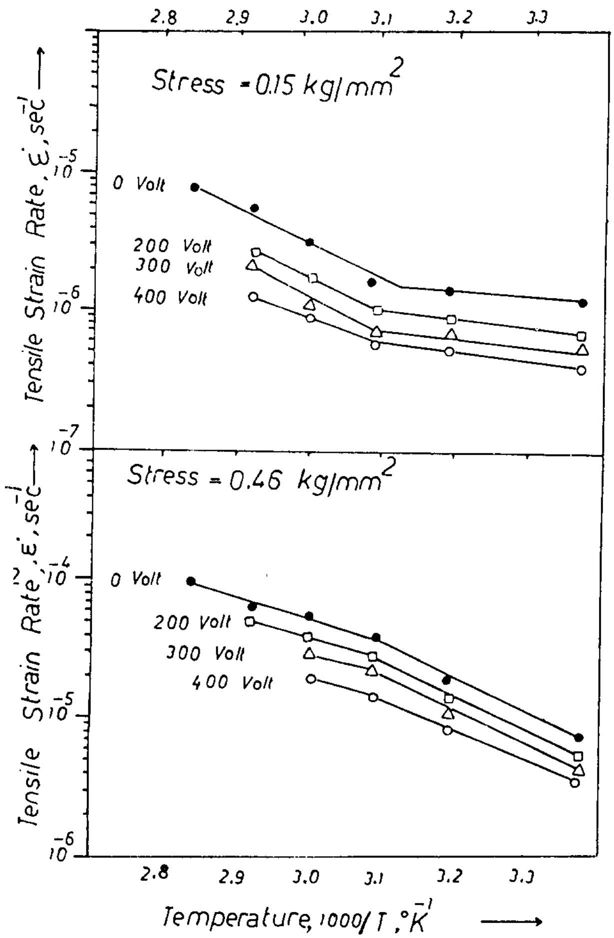


Fig. (4): The dependence of tensile strain on the reciprocal of temperature at different values of applied electric potential (stress = 0.15 kg/mm^2 and 0.46 kg/mm^2).

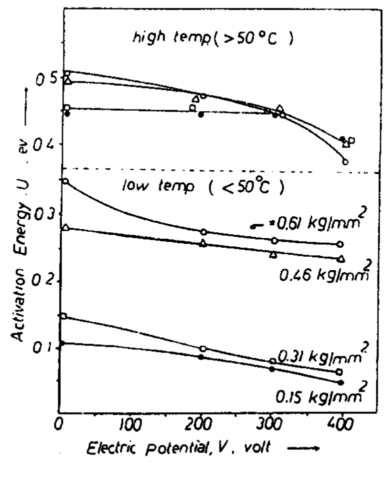


Fig. (5): The variation of activation energy with the applied electric potential at different values of stress (temperature < 50^{o}C and temperature > 50^{o}C).

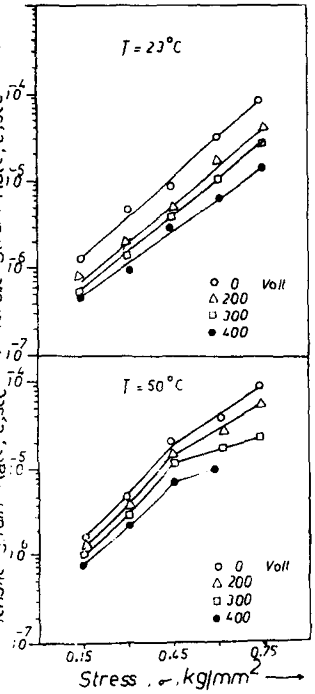


Fig. (6): The relation between the tensile strain rate and the applied stress at different values of the applied electric potential (temperature = 23^{0} and 50^{0}C).

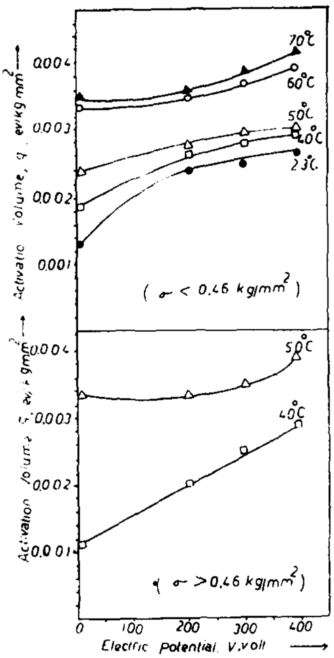


Fig. (7): The activation volume of steady creep dependence on the applied electric potential temperature is a parameter (stress is less than 0.46 kg/mm^2 and greater than 0.46 kg/mm^2).

Figure (6) gives the stress dependence of η at different electric fields. The slope of these relations can be used to calculate q has two values, one at low stresses and the other at higher stresses.

The temperature dependence of activation volume at low and high stresses is illustrated in Fig. (7). The activation volume increases as the field increases, which means that the volume necessary for the macromolecules to translate increases, and that these values are high for low stress and vice versa. Apparently the field tends to increase the spacing between the macromolecules.

Another important parameter is the stress sensitivity parameter[7], m'. It was found that this parameter increases with increasing the electric field, as shown in Fig. (8), which is in good agreement with the data of the activation volume. This means that as the activation volume q increases the sample becomes more sensitive to creep with stress.

Figure (9) represents the field dependence of viscosity of steady state creep at different temperatures and stresses. The viscosity increases with the electric field, because the sample has rapidly reaches a more stable structure in the viscoelastic state by increasing the field. This behavior depends largely on both temperature and stress.

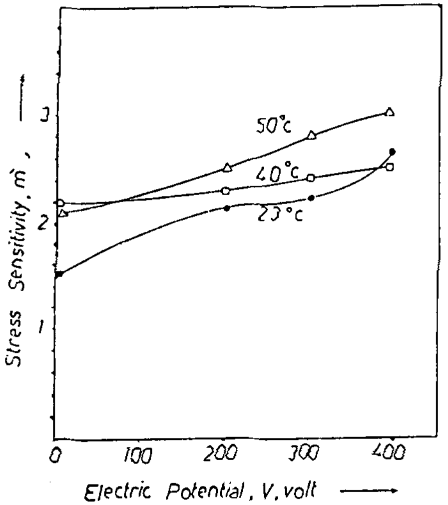


Fig. (8): The relation between stress sensitivity parameter and the applied electric field at various temperatures.

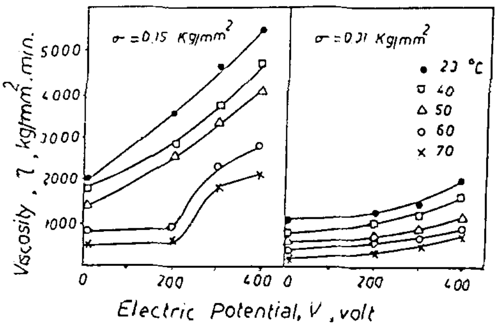


Fig. (9): The dependence of viscosity on the applied electric potential at different temperature and stresses.

4. Conclusion

An applied electric field raises the creep curves and results in earlier fracture, especially when temperature and stress are relatively high. It was found that the instantaneous strain is a field independent quantity. It increases as the field increases for high values of temperature and/or stress.
The activation energy decreases with the field at low temperature, whereas the activation volume has two values; one at low stresses and the other at higher stresses. The activation volume and the stress sensitivity parameter are linear functions of the applied field. Finally, the viscosity was found to increase with increasing the applied field.

5. References

[1] S.A. Abasov, M.A. Kurbanov and M.M. Kuliev, Sov. Phys. Solid State, 24, 3, 1982.

[2] S. Yamanaka, T. Fukuda, G. Sawa and M. Jeda, J. Appl. Phys. 23, 6, 741, 1984.

[3] Ennio Fatuzzo and Walter J. Merz, "Ferroelectricity", North Holland Pub., Amsterdam, 1967.

[4] A. Tager, "Physical Chemistry of Polymers", Mir. Pub., Moscow, 1972.

[5] J.P. Grine, Annual Report, IEEE, Conference of Electric Insulation and Dielectric Phenomena, P. 496-502, N.Y., USA, 1983.

[6] M. Amin, S.S. Hamza, H.M. Osman, N. El-Nashar and S.F. Moghazy, to be published.

[7] W.R. Cannon and O.D. Sherby, Metallurgy, Trans. 1, 1031, 1970.

Accepted December 8, 1988 K