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Effect of Radiation on Creep of Polyethylene

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PROPERTIES OF MATERIAL TESTED

The material investigated was an experimental linear polyethylene, Polyethylene 75, supplied by E. I. Du Pont de Nemours & Company. The unirradiated material has a density of 0.915 g./cc. at 20°C. and the crystallinity is 0.55%. The polyethylene had a number-average molecular weight of 25,000 and a weight-average molecular weight of 900,000.

EXPERIMENTAL RESULTS

Tension and compression specimens as represented in Figure 1 were machined and subjected to a predetermined amount of radiation. The radiation doses were applied by a swimming-pool type of reactor (available as a University facility). The creep experiments were conducted in a temperature (73° ± 2°F.) and humidity- (50 ± 2% R. H.) controlled laboratory. Tension and compression creep units, described previously,[1] were used for these experiments. Creep strains were measured with a micrometer microscope.

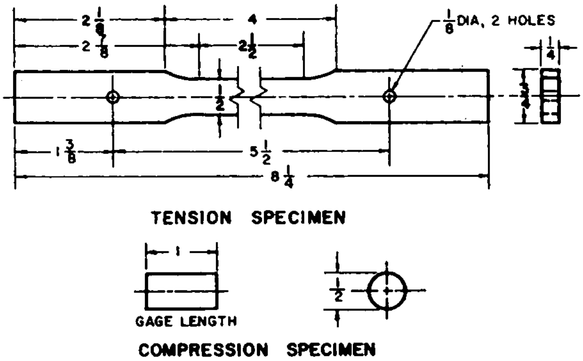

Fig. 1. Specimens.

The creep strains were measured at selected time intervals for periods of 100 hrs. Creep–time relations for the four radiation doses considered are shown in Figures 2 to 11 for both the tension and compression creep

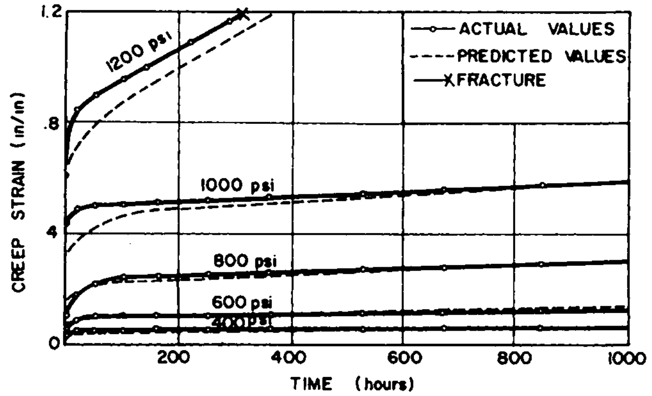

Fig. 2. Tension creep-strain–time curves for unirradiated Polyethylene 75.

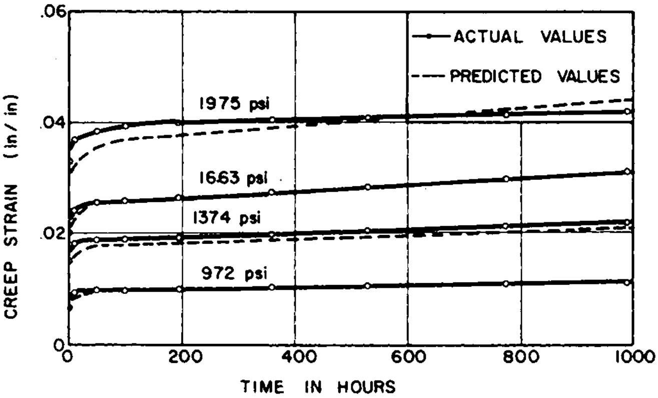

Fig. 3. Compression creep-strain–time curves for unirradiated Polyethylene 75.

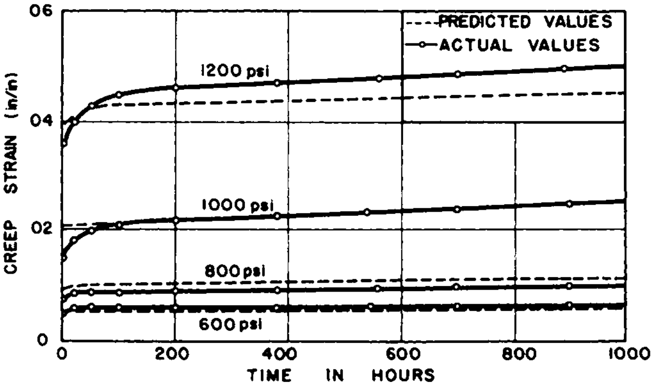

Fig. 4. Tension creep-strain–time curves for Polyethylene 75 irradiated at 1.0 × 10^{17} nvt.

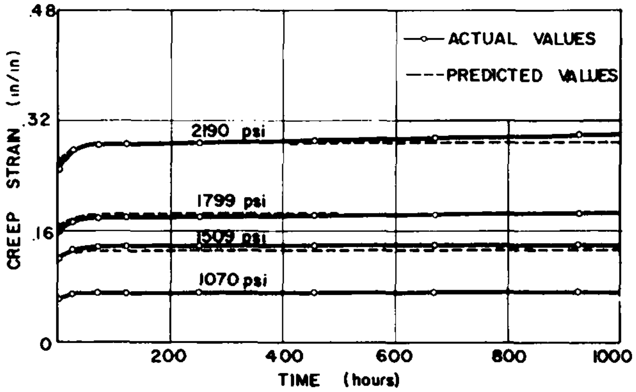

Fig. 5. Compression creep-strain-time curves for Polyethylene 75 irradiated at 1.0 × 10^{17} nvt.

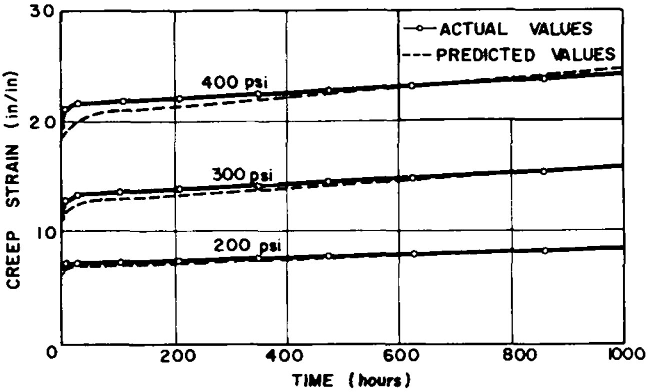

Fig. 6. Tension creep-strain-time curves for Polyethylene 75 irradiated at 2.5 × 10^{17} nvt.

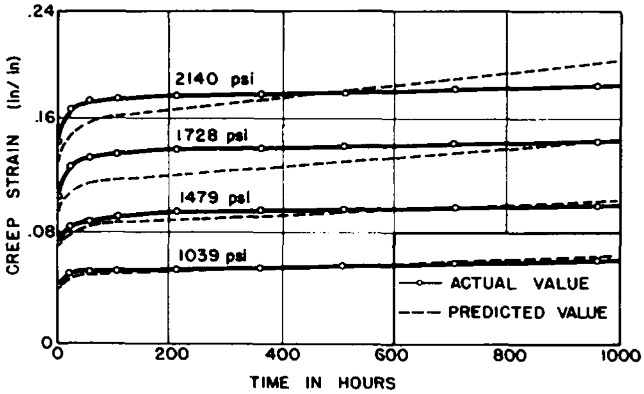

Fig. 7. Compression creep-strain-time relation for Polyethylene 75 irradiated at 2.5 × 10^{17} nvt.

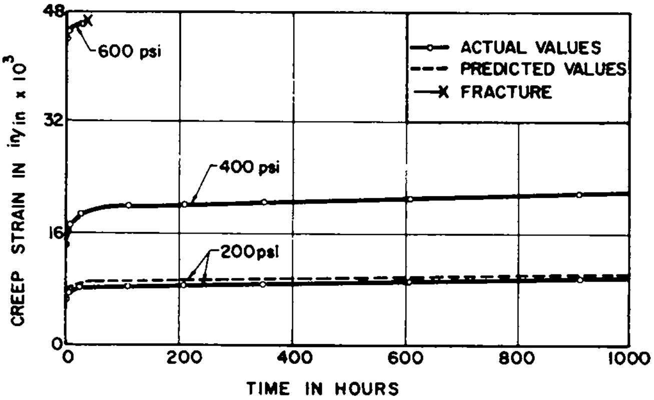

Fig. 8. Tension creep-strain-time curves for Polyethylene 75 irradiated at 5 × 10^{17} nvt.

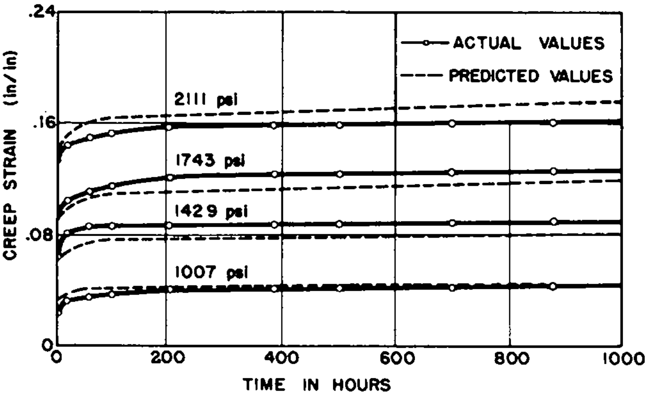

Fig. 9. Compression creep-strain-time curves for Polyethylene 75 irradiated at 5 × 10^{17} nvt.

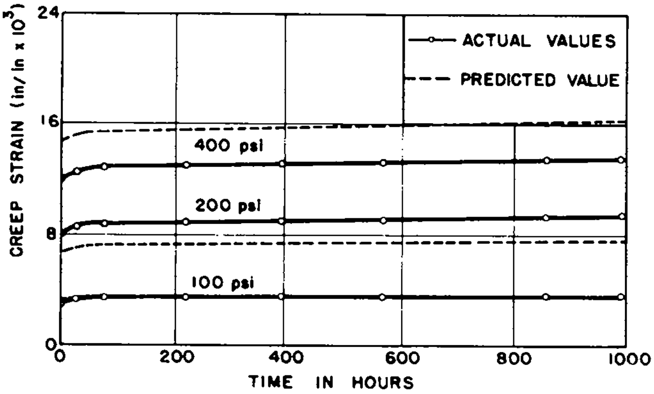

Fig. 10. Tension creep-strain-time curves for Polyethylene 75 irradiated at 7.5 × 10^{17} nvt.

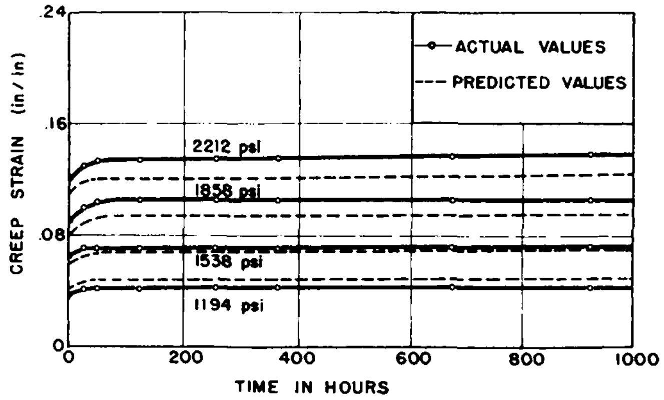

Fig. 11. Compression creep-strain-time curves for Polyethylene 75 irradiated at 7.5 × 10^{17} nvt.

tests. The radiation doses indicated on these figures are the number of neutrons of velocity v which cross one square centimeter of material per second.

The gamma-dose rate applied to the material corresponding to each of the nvt dosages are listed below:

Dose, nvt units	Dose, r/hr.
1.0×10^{17}	5×10^{6}
2.5×10^{17}	12.5×10^{6}
5.0×10^{17}	25×10^{6}
7.5×10^{17}	37.5×10^{6}

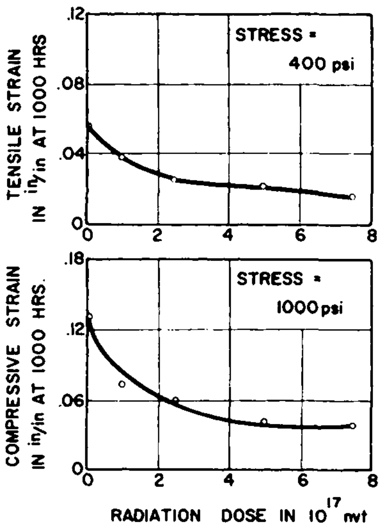

Fig. 12. Variation in creep strain for different doses of irradiation at 1000 hrs.

The influence of radiation on the creep deformations in tension and compression is represented in Figures 12 and 13. Figure 12 shows the variation in creep strain at 1000 hrs. with increase in radiation dosage. Variations for selected tensile and compressive stresses are shown in this figure. For both types of stress, Figure 12 shows that there is considerable improvement in creep resistance (or decrease in strain) with increase in radiation dosage.

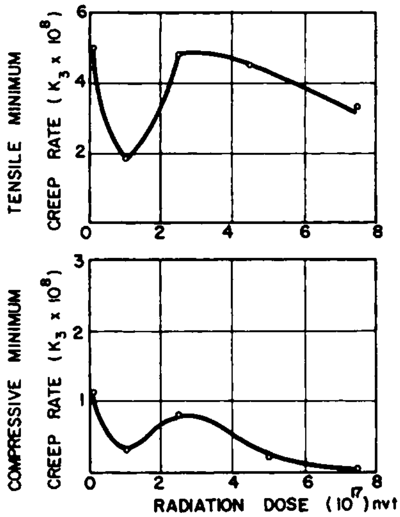

Fig. 13. Variation of the minimum creep rate with the radiation dose for Polyethylene 75.

Figure 13 shows the influence of radiation on the minimal creep rate for both tension and compression. An examination of Figure 13 shows that there is a decrease in minimum creep rate or improvement in creep resistance with increase in radiation.

INTERPRETATION OF CREEP TEST RESULTS

For purposes of creep analysis and design, it is desirable to interpret the creep–time data and find a stress–time–creep–strain relation representing the experimental results. Several relations were investigated; the relation that gave the best approximation to the experimental results was the following assumption, where ϵ is creep strain:

$$\epsilon = f(t)\sigma e^{\beta\sigma} \tag{1}$$

where σ is the stress, e is the base of natural logs, β is a material constant, and $f(t)$ is a time function.

In the interpretation of the results, a time function $f(t)$ in Eq. (1) of the following form was assumed

$$f(t) = k_1 + k_2 (1 - e^{-qt}) + k_3 t \tag{2}$$

where k, k_2, q, and k_3 are material constants and t is time.

If the term $e^{\beta\sigma}$ in eq. (1) is expanded into a series,

$$\epsilon = f(t)\ [\sigma + \beta\sigma^2 + \beta^2\,\sigma^3/2! + \beta^3\,\sigma^4/3!\ldots.]$$

or

$$\epsilon = f(t) \sum_{n=1}^{n=\alpha} [\beta^{n-1}\,\sigma^n/(n-1)!] \tag{3}$$

Equation (3) is a more general form of the creep relation used by Marin and Griffith,[2] as it represents a series of terms and the other corresponds to only one term in this series. The creep relation used in this paper, therefore, has both a physical and mechanistic basis as discussed in ref. 2.

Table I gives the values of the creep constants based on eqs. (1) and (2) while Table II shows the percentage differences between the actual creep strains and the predicted creep strains obtained with eqs. (1) and (2). In Figures 2 to 11, the theoretical creep–time relations based on eqs. (1) and (2) are also shown, for purposes of comparison. An examination of the comparison between theoretical and experimental results given in Figures 2 to 11 and Table II indicates that the creep relation proposed gives a good interpretation of the test results.

TABLE I

Values of Creep Constants

Radiation dose, 10^{17} nvt	$k_1 \times 10^6$	$k_2 \times 10^5$	$k_3 \times 10^8$	$q \times 10^2$	$\beta \times 10^3$
Tension Creep Constants					
0	2.8782	1.8647	0.5117	0.9433	2.4349
1.0	2.0000	0.3233	0.1726	0.3443	2.2640
2.5	2.1944	0.3360	0.4859	2.3875	1.9071
5.0	2.9359	0.4683	0.4598	1.2946	0.8876
7.5	3.1657	0.1333	0.1734	0.5022	0.4143
Compression Creep Constants					
0	4.4886	0.8556	1.0971	0.4431	0.6327
1.0	3.2022	0.3387	0.0314	0.4601	0.6000
2.5	2.3299	0.7335	0.8023	0.2730	0.4290
5.0	1.8897	0.3699	0.1732	1.4935	0.5911
7.5	2.5431	0.3983	0.0342	3.1998	0.2775

CONCLUSION

This paper shows that creep resistance of polyethylene is increased with increase in radiation dosage. This increased resistance applies for both tension and compression. A creep-stress–time relation for both tension and compression creep is proposed, which gives a good interpretation of the experimental results.

TABLE II
Percentages of Error between Experimental and Predicted Values of Tension and Compression Creep at 1000 Hrs.

Radiation dose, 10^{17} nvt	Tensile stress, psi	Error, %	Compressive stress, psi	Error, %
Unirradiated	400	−5.0	972	−12.2
	600	+9.1	1374	−5.1
	800	−5.5	1663	+0.6
	1000	+2.2	1975	+5.7
1	600	−14.2	1070	−0.1
	800	+19.1	1509	−6.5
	1000	−7.3	1799	+0.3
	1200	−10.0	2190	−3.7
2.5	200	+3.2	1039	+4.3
	300	−1.6	1479	+6.2
	400	+6.4	1782	−0.2
			2140	+10.3
5.0	200	+6.0	1007	+2.5
	400	+2.7	1429	−8.9
			1743	−5.6
			2111	+11.2
7.5	100	−0.2	1194	+14.9
	200	−18.6	1538	−3.0
	400	+20.9	1858	−13.1
			2212	−13.0

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References

1. Marin, J., A. C. Webber, and G. F. Weissmann, *Proc. ASTM*, Vol. 54, 17 pp., 1954.

2. Marin, J., and J. E. Griffith, *Proc. Ninth Intern. Cong. Appl. Mech.*, September 1956.

Synopsis

This paper describes an investigation of the influence of radiation on the creep of polyethylene in tension and compression. The influence of five radiation doses and four stress levels were considered in this study. The tests were conducted for periods of 1000 hr. Even for small doses of radiation, it was found that the creep resistance of the material was increased. However, it should be noted that with decrease in creep deformations, the time to rupture for a given stress will very likely be decreased. In addition, the short-time properties may be adversely influenced by radiation. It is

therefore necessary to select the optimum radiation dose based upon a consideration of all the properties.

Résumé

Ce texte décrit une étude sur l'influence de la radiation sur le retrait du polyéthylène soumis á la tension et á la compression. L'influence de cinq doses de radiation et de quatre niveaux de tension a été considérée dans cette étude. Les tests ont été effectués pendant des périodes de 1000 heures. Même pour de faibles doses de radiation, on a trouvé que la résistance au retriat du matériau était augmentée. Toutefois, on peut noter qu'en même temps que la diminution de la deformation due au retrait le temps de rupture pour une tension donnée est très probablement diminué. De plus, les propriétés instantanées peuvent être influencées différemment par radiation. Il est, dès lors, nécessatire de sélectionner la quantité de radiation optimum en tenant compte de toutes les propriétés.

Zusammenfassung

In der vorliegenden Mitteilung wird eine Untersuchung des Einflusses der Bestrahlung auf das Kriechen von Polyäthylen unter Zugund Druckbeanspruchung beschrieben. Es wurden dabei fünf verschiedene Bestrahlungsdosen und vier Beanspruch ungsniveaus angewendet. Die Tests erstreckten sich über Zieträume von 1000 Stunden. Auch bei kleinen Bestrahlungsdosen zeigte sich eine Zunahme der Kriechbeständigkeit des Materials. Es muss jedoch festgehalten werden, dass mit abnehmender Kriechverformung die Bruchdauer für eine gegebene Spannung sehr wahrscheinlich abnehmen wird. Zusätzlich können auch die Eigenschaften für kyrzzeitige Beanspruchung durch Bestrahlung ungünstig beeinflusst werden. Es ist daher notwendig die optimale Bestrahlungsdosis auf Grund einer Betrachtung aller Eigenschaften auszuwählen.

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