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TECHNICAL REPORT 3629

APPLICATION OF REACTION RATE
ANALYSIS TO THE MECHANICAL
PROPERTIES OF POLYMERS. II.

E. MCABEE
D. W. LEVI

FEBRUARY 1968

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APPLICATION OF REACTION RATE ANALYSIS
TO THE MECHANICAL PROPERTIES
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by

E. McAbee
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OBJECTIVE

To use reaction rate concepts to predict mechanical property data from a limited number of tests.

SUMMARY

Tensile strength data for nylon-6, polypropylene and polysulfone were analyzed according to a modified rate equation. The agreement of the test results with the theory was excellent. It appeared that the polypropylene material used was an impure mixture.

With the data now available it would be desirable to determine whether the parameters obtained could be related to molecular structure.

INTRODUCTION

Wolstenholme and Stark (Ref 1) suggested that the lifetime (or time to failure), t_f , of a material under mechanical restraint may follow a process according to a rate equation:

$$R_t = \frac{dN}{dt} = 2 \frac{kT}{h} e^{-\Delta F^\ddagger/RT} \sinh \frac{\lambda f}{2kT}$$

where

- R_t is the rate of the process
- N is the total volume of elements that must yield for failure
- k is Boltzmann's constant
- h is Planck's constant
- T is absolute temperature
- $e^{-\Delta F^\ddagger/RT}$ is the activation energy term
- λ is the average distance an element is moved by mechanical force f .

McAbee and Levi (Ref 2) applied a slightly modified version of the above equation to solid rocket propellant data at two rates of load application over a range of temperatures from -60°C to $+80^\circ\text{C}$. The same authors also showed that this approach was useful in describing the tensile behavior of five thermoplastics (Ref 3) and glass-cloth-reinforced epoxy and polyester resins (Ref 4). The thermoplastic data were also treated by temperature-time superposition and by the Bueche theory. It was shown that for the materials examined the reaction rate method described the data much more satisfactorily than did either of the other methods.

Since the reaction rate analysis method showed the greatest promise for prediction of tensile behavior it was decided to extend this investigation to other types of thermoplastics.

DISCUSSION OF RESULTS

The materials examined were nylon 6, polypropylene, and polysulfone. In those instances where there was a marked change in slope of the load-time curve, or a yield point was noted, this was taken as the failure as opposed to the actual separation of the specimen. Such separation may occur after considerable localized necking has taken place and beyond the useful life of the material for most applications. The results obtained are shown in Tables 1-4 and in Figures 1, 2, 4, 5, 7, and 8. The apparent activation energy plots are shown in Figures 3, 6, and 9, and a summary of the parameters is given in Table 5.

Examination of the nylon-6 isothermal data (Fig 1) shows that both the high rate and static data for any given temperature may be represented by the same straight line. In the vicinity of 323°K there is considerable scatter while above and below this the data are more reproducible, indicating a transition region at this temperature. Literature values of the second-order transition of nylon-6 are listed as 323-348°K (Ref 6). Figure 2 shows good agreement with theory for the temperatures above the transition represented by a line of slope -2.5 while below the transition the data may be described by a line of slope -.263. Figure 3 shows the Arrhenius plot for activation energy. The values obtained in this manner are 38 kilocalories/mol at the lower temperatures and 260 kilocalories/mol at the higher temperatures.

The polypropylene data (Table 2) are plotted in Figure 4. It may be noted that there is considerable scatter in the static data, especially in the vicinity of 233-243°K. The best parallel isothermal lines were drawn. Lines of slope -.715 were found to represent the static data above 243°K and the high rate data above 288°K, while lines of slope -.111 represented the static data below 213°K and the high rate data below 253°K. Both of these parameters were used for the static data at 233°K and the high rate data at 273°K. Another point which should be noted is that the 353°K high rate intercept is less than that for the static, the 323°K is the same, and the 296°K higher.

Literature values for T_g of this material (Ref 6) indicate a transition at 298°K , for the atactic form at 253°K , and the isotactic at 263°K . It would appear that the particular material used in this investigation was a mixture of polypropylenes. Figure 5 shows the $\log t_f - \log t_f$ (at $S/T = 0$) vs S/T plot for these data. Reasonably good agreement is shown except for the scatter in the vicinity of the transition. For the values calculated by both parameters the value of $b = -.111$ gives a better fit in both instances.

Figure 6 shows an Arrhenius plot for the activation energy. Values of 9 kilocalories/mol and 48 kilocalories/mol are indicated from these data.

The isothermal plot for polysulfone data (Table 3) is shown in Figure 7. It may be noted that all of the high rate data may be represented by parallel lines of slope $-.25$, as may the static data at temperatures above 338°K . It should be noted that while the static data above 338°K are represented by parallel lines of the same slope, as are the high rate data, the S/T intercept of the static isothermal is higher than those of the high rate data for a given temperature. At 338°K there is considerable scatter of the data, and lines of slope $-.25$ and $-.714$ represent the data equally well. The static data below 338°K are represented by lines of slope $-.714$. Plotting the data using both parameters (Fig 8) it appears that the value of $b = -.25$ gives a somewhat better fit than does the value $b = -.714$.

The value of T_g in the literature (Ref 7) is given as 374°F (463°K), which is well above the temperature of 338°K where the discontinuity in these data is noted. It would appear that there is a transition below the glass transition temperature for this material and that this is indicated by the scatter of data and change of slope of the static isothermal lines at 338°K .

The Arrhenius plot for activation energy is shown in Figure 9. The high rate data show a reasonably good straight line, as do the static data below 338°K . The static data above 338°K appear to describe a straight line of the same slope as that described by the high rate data. The apparent activation energies calculated in this way are 67 kilocalories/mol for the static data and 41 kilocalories/mol for the high rate data.

The results described in this report and in References 3 and 5 indicate that reaction rate analysis methods may be used to describe the mechanical behavior of a variety of polymeric materials and that for at least 5 materials they are more reliable than other approaches (Ref 4).

With the data now available on a reasonably wide range of materials an examination of the results should be made to determine a possible correlation with molecular structure.

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TABLE 1

Experimental and calculated values for nylon

T ^{OK}	t _f (sec)	Stress (psi)	Log t _f	S/T	Log (t _f at S/T = 0)	-[Log t _f - Log (t _f at S/T = 0)]
373	2386	3010	3.37	8.1	26.50	23.13
	2069	3460	3.32	9.3	26.50	23.18
	2770	4480	3.44	12.0	26.50	23.06
	1286	4110	3.11	11.0	26.50	23.39
	743	3770	2.87	10.1	26.50	23.63
	514	3690	2.71	9.9	26.50	23.79
	86	3450	1.93	9.3	26.50	24.57
	64	3600	1.81	9.7	26.50	24.69
	63	3670	1.80	9.8	26.50	24.70
	888	4020	2.95	11.4	32.00	29.05
	952	4870	2.98	13.8	32.00	29.02
	1195	5060	3.08	14.3	32.00	28.92
	2358	5530	3.37	15.7	32.00	28.63
353	2029	5090	3.31	14.4	32.00	28.69
	1174	5430	3.06	15.4	32.00	28.94
	668	4010	2.82	11.4	32.00	29.18
	1052	4670	3.02	13.2	32.00	28.98
	53	4260	1.72	12.1	32.00	30.28
	66	4010	1.82	11.4	32.00	30.18
	76	4210	1.88	11.9	32.00	30.18
	66	4480	1.82	12.7	32.00	30.12
	0.038	4650	-1.42	13.2	32.00	33.42
	0.038	4730	-1.42	13.4	32.00	33.42

Table 1 continued

T ^{OK}	t _f (sec)	Stress (psi)	Log t _f	S/T	Log (t _f at S/T = 0)	-[Log t _f - Log (t _f at S/T = 0)]
	0.036	4710	-1.44	13.3	32.00	33.44
	0.044	4180	-1.36	11.8	32.00	33.36
	0.046	3990	-1.34	11.3	32.00	33.34
	0.048	4560	-1.32	12.9	32.00	33.31
	0.031	4980	-1.51	14.1	32.00	33.51
	0.011	4790	-1.96	13.6	32.00	33.96
	0.01	4810	-2.00	13.6	32.00	34.00
323	1120	6490	3.05	20.1	49.30	46.25
	1375	4840	3.14	15.0	49.30	46.16
	1670	5350	3.22	16.6	49.30	46.08
	1164	4600	3.06	14.3	49.30	46.24
	709	5340	2.85	16.5	49.30	46.45
	449	5870	2.65	18.2	49.30	46.65
	352	4790	2.55	14.8	49.30	46.75
	1156	5890	3.06	18.2	49.30	46.24
	54	5870	1.73	18.2	49.30	47.57
	53	5950	1.72	13.4	49.30	47.58
	55	5480	1.74	17.0	49.30	47.56
	54	5890	1.73	18.2	49.30	47.57
	0.011	7380	-1.96	22.8	49.30	51.26
	0.008	6290	-2.10	19.5	49.30	51.40
	0.010	7280	-2.00	22.5	49.30	51.30
	0.040	6090	-1.40	18.9	49.30	50.70
	0.040	7060	-1.40	21.8	49.30	50.70
	0.060	6300	-1.22	19.5	49.30	50.52
	0.046	6990	-1.34	21.6	49.30	50.64

Table 1 continued

$T^{\circ}K$	t_f (sec)	Stress (psi)	$\log t_f$	S/T	$\log (t_f \text{ at } S/T = 0)$	$-[\log t_f - \log (t_f \text{ at } S/T = 0)]$
303	0.036	6210	-1.44	19.2	49.30	50.74
	0.035	6350	-1.46	19.7	49.30	50.76
	1770	5060	3.25	16.7	7.71	4.46
	1731	5590	3.24	18.5	7.71	4.47
	1637	5930	3.21	19.6	7.71	4.50
	531	6050	3.73	20.0	7.71	4.98
	427	6000	2.63	19.8	7.71	5.08
	455	6070	2.66	20.0	7.71	5.05
	42	6640	1.62	21.9	7.71	6.09
	44	6880	1.64	22.7	7.71	6.07
	42	6570	1.62	21.7	7.71	6.09
	759	6820	2.88	23.0	8.68	5.80
	654	6630	2.82	22.4	8.68	5.86
	523	6270	2.72	21.2	8.68	5.96
296	552	6820	2.74	23.0	8.68	5.94
	109	7780	2.04	26.3	8.68	6.64
	100	7290	2.00	24.6	8.68	6.68
	106	7370	2.03	24.9	8.68	6.65
	111	7680	2.05	25.9	8.68	6.63
	19	8980	1.28	30.3	8.68	7.40
	19	8690	1.28	29.3	8.68	7.40
	15	8330	1.18	28.1	8.68	7.50
	17	8620	1.23	29.1	8.68	7.45
	0.095	10830	-1.02	36.6	8.68	9.70
	0.095	10750	-1.02	36.3	8.68	9.70
	0.035	8110	-1.46	27.4	8.68	10.14

Table 1 continued

TOK	t_f (sec)	Stress (psi)	Log t_f	S/T	Log (t_f at $S/T = 0$)	-[Log t_f - Log (t_f at $S/T = 0$)]
	0.089	10080	-1.05	34.0	8.68	9.73
	0.077	11410	-1.11	38.5	8.68	9.79
	0.076	11150	-1.12	37.7	8.68	9.80
	0.010	12720	-2.00	43.0	8.68	10.68
	0.009	12370	-2.05	41.8	8.68	10.70
	0.008	10240	-2.10	34.6	8.68	10.78
273	642	8900	2.81	32.6	11.02	8.21
	633	9490	2.80	34.8	11.02	8.22
	645	8570	2.81	31.4	11.02	8.21
	319	8350	2.50	30.6	11.02	8.52
	114	9920	2.06	36.3	11.02	8.96
	78	8390	1.89	30.7	11.02	9.13
	105	9630	2.02	35.3	11.02	9.00
	106	9920	2.03	36.3	11.02	8.99
	17	10580	1.23	38.8	11.02	9.79
	16	10740	1.20	39.3	11.02	9.82
	13	9380	1.11	34.4	11.02	9.91
	13	10110	1.11	37.0	11.02	9.91
	0.03	12470	-1.52	45.7	11.02	15.54
	0.045	14610	-1.35	53.5	11.02	12.37
	0.038	10320	-1.42	37.8	11.02	12.44
	0.034	10730	-1.47	39.3	11.02	12.49
	0.029	12530	-1.54	45.9	11.02	12.56
	0.043	16100	-1.37	59.0	11.02	12.39
	0.008	15900	-2.10	58.2	11.02	13.12
	0.007	10960	-2.15	40.1	11.02	13.17
	0.01	13900	-2.00	50.9	11.02	13.02

Table 1 continued

TOK	t_f (sec)	Stress (psi)	Log t_f	S/T	Log (t_f at S/T = 0)	-[Log t_f - Log (t_f at S/T = 0)]
253	317	12200	2.50	48.2	14.41	11.91
	304	12690	2.48	50.2	14.41	11.93
	352	12100	2.55	47.8	14.41	11.86
	322	12710	2.51	50.2	14.41	11.90
	95	11400	1.98	45.0	14.41	12.43
	100	13060	2.00	51.6	14.41	12.41
	116	12630	2.06	49.9	14.41	12.35
	125	13960	2.10	55.2	14.41	12.31
	16	11180	1.20	44.2	14.41	13.21
	23	12510	1.36	49.4	14.41	13.15
	16	12510	1.20	49.4	14.41	13.21
	14	10430	1.15	41.2	14.41	13.26
	0.009	16070	-2.05	63.5	14.41	16.46
	0.008	14580	-2.10	57.6	14.41	16.51
	0.009	15600	-2.05	61.3	14.41	16.46
	0.037	12330	-1.43	48.7	14.41	15.84
	0.052	17950	-1.28	71.0	14.41	15.69
	0.054	16850	-1.27	66.6	14.41	15.68
	0.051	14670	-1.29	58.0	14.41	15.70
	0.068	16850	-1.17	66.6	14.41	15.58
	0.066	17150	-1.18	67.8	14.41	15.59
233	245	10670	2.39	45.8	16.36	13.97
	353	13300	2.55	57.1	16.36	13.81
	391	12510	2.59	53.7	16.36	13.77
	280	11920	2.45	51.2	16.36	13.91
	89	12690	1.95	54.5	16.36	14.41
	107	15140	2.03	65.0	16.36	14.33

Table 1 continued

TOK	t _f (sec)	Stress (psi)	Log t _f	S/T	Log (t _f at S/T = 0)	-[Log t _f - Log (t _f at S/T = 0)]
233	116	14890	2.06	63.9	16.36	14.30
	109	13890	2.04	59.6	16.36	14.32
	13	11280	1.11	48.4	16.36	15.25
	20	17050	1.30	73.2	16.36	15.06
	20	16080	1.30	69.0	16.36	15.06
	16	15400	1.20	66.1	16.36	15.16
	0.044	13870	-1.36	59.5	16.36	17.72
	0.069	17810	-1.16	76.4	16.36	17.52
	0.078	17730	-1.11	80.4	16.36	17.46
	0.028	11440	-1.55	49.1	16.36	17.91
	0.064	15310	-1.19	65.7	16.36	17.55
	0.046	13700	-1.34	58.8	16.36	17.70
	0.014	15040	-1.85	64.6	16.36	18.21
	0.008	14090	-2.10	60.5	16.36	18.46
213	0.011	15870	-1.96	68.1	16.36	18.32
	297	14540	2.47	68.3	19.99	17.52
	359	14890	2.56	69.9	19.99	17.43
	404	15580	2.61	73.1	19.99	17.38
	343	15000	2.54	70.4	19.99	17.45
	127	16050	2.10	75.4	19.99	17.80
	92	13590	1.96	63.8	19.99	18.03
	113	15160	2.05	71.2	19.99	17.94
	153	15910	2.18	74.7	19.99	17.81
	15	14160	1.18	66.5	19.99	18.81
	17	15250	1.23	71.6	19.99	18.76
	13	11070	1.11	52.0	19.99	18.88
	16	13620	1.20	63.9	19.99	18.79

Table 1 continued

T ^{OK}	t _f (sec)	Stress (psi)	Log t _f	S/T	Log (t _f at S/T = 0)	-[Log t _f - Log (t _f at S/T = 0)]
	0.056	17840	-1.25	83.8	19.99	21.24
	0.050	17000	-1.30	79.8	19.99	21.29
	0.050	15540	-1.30	73.0	19.99	21.29
	0.050	15060	-1.30	70.7	19.99	21.29
	0.054	16130	-1.27	75.7	19.99	21.26
	0.056	16131	-1.25	75.7	19.99	21.24
	0.010	17340	-2.00	81.4	19.99	21.99
	0.007	14120	-2.15	66.3	19.99	22.14
	0.009	18180	-2.05	85.4	19.99	22.04
193	279	13310	2.44	69.0	22.64	20.20
	374	14810	2.57	76.7	22.64	20.07
	350	15030	2.54	77.9	22.64	20.10
	158	14950	2.20	77.4	22.64	20.44
	92	13640	1.96	70.7	22.64	20.68
	109	15550	2.04	80.5	22.64	20.60
	15	15320	1.18	79.4	22.64	21.46
	15	15580	1.18	80.7	22.64	21.46
	18	17620	1.26	91.3	22.64	21.39

TABLE 2

Experimental and calculated values for polypropylene

T _{OK}	t _f (sec)	Stress (psi)	Log t _f	S/T	Log (t _f at S/T = 0)	-[Log t _f - Log (t _f at S/T = 0)]
353	378	1500	2.58	4.2	6.65	4.07
	434	1970	2.64	5.6	6.65	4.01
	368	1430	2.57	4.0	6.65	4.08
	440	1540	2.64	4.4	6.65	4.01
	145	1710	2.16	4.8	6.65	4.49
	145	1800	2.16	5.1	6.65	4.49
	153	1970	2.18	5.6	6.65	4.47
	23	2650	1.36	7.5	6.65	5.29
	25	2440	1.40	6.9	6.65	5.25
	23	2750	1.36	7.8	6.65	5.29
	24	2730	1.38	7.7	6.65	5.27
	0.012	3470	-1.92	9.8	5.15	7.07
	0.012	3550	-1.92	10.1	5.15	7.07
	0.013	3440	-1.89	9.7	5.15	7.04
	0.068	3350	-1.17	9.5	5.15	6.32
	0.086	3320	-1.07	9.4	5.15	6.22
323	0.070	3240	-1.15	9.2	5.15	6.30
	0.062	3240	-1.21	9.2	5.15	6.36
	0.056	3080	-1.25	8.7	5.15	6.40
	0.078	3460	-1.11	9.8	5.15	6.26
	416	2310	2.62	7.1	8.15	5.53
	329	2190	2.52	6.8	8.15	5.63
	434	2670	2.64	8.3	8.15	5.51
	386	2100	2.59	6.5	8.15	5.56
	153	2370	2.18	7.3	8.15	5.97

Table 2 continued

TOK	t_f (sec)	Stress (psi)	Log t_f	S/T	Log $(t_f \text{ at } S/T = 0)$	$-\left[\text{Log } t_f - \text{Log } (t_f \text{ at } S/T = 0)\right]$
296	141	2370	2.15	7.3	8.15	6.00
	151	2465	2.18	7.6	8.15	5.97
	143	2700	2.16	8.4	8.15	5.99
	18	2890	1.26	8.9	8.15	6.89
	23	3070	1.36	9.5	8.15	6.79
	22	3060	1.34	9.5	8.15	6.81
	24	3170	1.38	9.8	8.15	6.77
	0.05	4100	-1.30	12.7	8.15	9.45
	0.048	4030	-1.32	12.5	8.15	9.47
	0.058	4310	-1.24	13.3	8.15	9.39
	0.066	4120	-1.18	12.8	8.15	9.33
	0.061	4430	-1.21	13.7	8.15	9.36
	0.06	4330	-1.22	13.4	8.15	9.37
	0.011	4820	-1.96	14.9	8.15	10.11
	0.013	4710	-1.89	14.6	8.15	10.04
	0.011	4870	-1.96	15.1	8.15	10.11
	430	3270	2.63	11.0	10.87	8.24
	463	3250	2.67	11.0	10.87	8.20
	337	3310	2.53	11.2	10.87	8.34
	340	3070	2.53	10.4	10.87	8.34
	121	3550	2.08	12.0	10.87	8.79
	120	3560	2.08	12.0	10.87	8.79
	122	3340	2.08	11.3	10.87	8.78
	130	3570	2.11	12.1	10.87	8.76
	17	3990	1.23	13.5	10.87	9.64
	19	3920	1.28	13.3	10.87	9.59
	19	3850	1.28	13.0	10.87	9.59

Table 2 continued

TOK	t_f (sec)	Stress (psi)	Log t_f	S/T	Log (t_f at S/T = 0)	-[Log t_f - Log (t_f at S/T = 0)]
	20	3930	1.30	13.3	10.87	9.57
	0.079	5560	-1.10	18.8	11.58	12.68
	0.057	5640	-1.24	19.1	11.58	12.82
	0.060	5740	-1.22	19.4	11.58	12.80
	0.061	5530	-1.21	18.7	11.58	12.79
	0.068	5280	-1.17	17.8	11.58	12.75
	0.045	5360	-1.35	18.1	11.58	12.93
	0.012	5760	-1.92	19.5	11.58	13.50
	0.010	5650	-2.00	19.1	11.58	13.58
	0.012	5840	-1.92	19.7	11.58	13.50
	214	3330	2.33	11.6	11.73	9.40
	534	4000	2.73	13.9	11.73	9.00
	334	3630	2.52	12.6	11.73	9.21
	92	3950	1.96	13.7	11.73	9.77
	102	3830	2.01	13.3	11.73	9.72
	107	3920	2.03	13.6	11.73	9.70
	19	4180	1.28	14.5	11.73	10.45
	19	3980	1.28	13.8	11.73	10.45
	18	3760	1.26	13.0	11.73	10.47
	0.006	5060	-2.22	17.6	11.73	13.95
	0.007	6060	-2.15	21.0	11.73	13.88
	0.007	6140	-2.15	21.3	11.73	13.88
	0.044	5290	-1.36	18.4	11.73	13.09
	0.047	4980	-1.33	17.3	11.73	13.06
	0.046	5330	-1.34	18.5	11.73	13.07
	0.059	5550	-1.23	19.3	11.73	12.96
	0.062	5063	-1.21	17.6	11.73	12.94
	0.064	5281	-1.19	18.3	11.73	12.92

Table 2 continued

TOK	t_f (sec)	Stress (psi)	Log t_f	S/T	Log (t_f at S/T = 0)	-[Log t_f - Log (t_f at S/T = 0)]
273	272	4640	2.43	17.0	13.94	11.51
	251	4630	2.40	17.0	13.94	11.54
	267	4540	2.43	16.6	13.94	11.51
	269	4530	2.43	16.6	13.94	11.51
	89	4520	1.95	16.6	13.94	11.99
	95	4680	1.98	17.2	13.94	11.96
	94	4480	1.97	16.4	13.94	11.97
	96	4420	1.98	16.2	13.94	11.96
	17	4530	1.23	16.6	13.94	12.71
	17	4600	1.23	16.8	13.94	12.71
	17	4390	1.23	16.1	13.94	12.71
	18	4630	1.26	16.9	13.94	12.68
	0.008	8070	-2.10	29.6	18.59	20.69
	0.009	8690	-2.05	31.8	1.55	3.65
	0.009	8500	-2.05	31.1	18.59	20.65
	0.060	7060	-1.22	25.9	1.55	3.60
	0.062	7550	-1.21	27.6	18.59	19.81
	0.063	7560	-1.20	27.7	1.55	2.77
	0.054	7370	-1.27	27.0	18.59	19.80
	0.044	7440	-1.36	27.3	1.55	2.76
					18.59	19.79
					1.55	2.75
					18.59	19.86
					1.55	2.82
					18.59	19.95
					1.55	2.91

Table 2 continued

T ^{OK}	t _f (sec)	Stress (psi)	Log t _f	S/T	Log (t _f at S/T = 0)	-[Log t _f - Log (t _f at S/T = 0)]
253	0.052	7180	-1.28	26.3	18.59	19.87
	295	4940	2.34	19.5	1.55	2.83
	297	4880	2.34	19.3	16.23	13.89
	295	4900	2.36	19.3	16.23	13.89
	295	4950	2.41	19.5	16.23	13.87
	300	4970	1.92	19.6	16.23	13.82
	291	4910	1.97	19.4	16.23	14.31
	293	4810	1.90	19.0	16.23	14.26
	87	4890	1.94	19.3	16.23	14.33
	15	5150	1.18	20.4	16.23	14.29
	14	5160	1.15	20.4	16.23	15.05
	14	5000	1.15	19.7	16.23	15.08
	15	5090	1.18	20.1	16.23	15.08
	0.044	8910	-1.36	35.2	2.58	15.05
	0.042	8670	-1.38	34.3	2.58	3.94
	0.040	9180	-1.40	36.3	2.58	3.96
	0.046	9090	-1.34	35.9	2.58	3.98
	0.044	8940	-1.36	35.3	2.58	3.92
	0.042	9070	-1.38	35.8	2.58	3.94
	0.008	11300	-2.10	44.7	2.58	3.96
243	0.008	10750	-2.05	42.5	2.58	4.68
	0.008	9960	-2.10	39.4	2.58	4.63
	258	4970	2.41	20.5	2.58	4.68
	264	5580	2.42	23.0	19.02	16.61
	246	5210	2.39	21.4	19.02	16.60
	96	5390	1.98	22.2	19.02	16.63
					19.02	17.04

Table 2 continued

T ^{OK}	t _f (sec)	Stress (psi)	Log t _f	S/T	Log (t _f at S/T = 0)	-[Log t _f - Log (t _f at S/T = 0)]
233	66	5240	1.82	21.6	19.02	17.20
	93	6260	1.97	25.8	19.02	17.05
	13	5990	1.11	24.6	19.02	17.91
	13	6780	1.11	27.9	19.02	17.91
	239	6960	2.38	29.9	22.52	20.14
	238	6790	2.38	29.2	5.06	2.68
					22.52	20.14
	242	6630	2.38	28.5	5.06	2.68
					22.52	20.14
	233	6430	2.37	27.6	5.06	2.68
					22.52	20.15
	76	6360	1.88	27.3	5.06	2.69
	79	6260	1.90	26.9	22.52	20.64
	83	5950	1.92	25.5	5.06	3.18
	84	5740	1.92	24.6	22.50	20.62
	12	7350	1.08	31.5	5.06	3.16
	12	7530	1.08	32.3	22.50	20.60
	12	7770	1.08	33.3	5.06	3.14
	11	8130	1.04	34.9	22.50	21.44
					5.06	3.98
					22.50	21.44
					5.06	3.98
					22.50	21.44
					5.06	4.02

Table 2 continued

T ^{OK}	t _f (sec)	Stress (psi)	Log t _f	S/T	Log (t _f at S/T = 0)	-[Log t _f - Log (t _f at S/T = 0)]
	0.007	13000	-2.15	55.8	3.64	5.79
	0.009	13880	-2.05	59.6	3.64	5.69
	0.009	11560	-2.05	49.6	3.64	5.69
	0.049	10570	-1.31	45.4	3.64	4.95
	0.048	10100	-1.32	43.3	3.64	4.96
	0.05	10510	-1.30	45.1	3.64	4.94
	0.045	10940	-1.35	46.9	3.64	4.99
	0.042	9960	-1.38	42.7	3.64	5.02
	0.044	10130	-1.36	43.5	3.64	5.00
213	247	6480	2.39	30.4	5.84	3.45
	78	7500	1.89	35.2	5.84	3.95
	87	7050	1.94	33.1	5.84	3.90
	81	7340	1.91	34.4	5.84	3.93
	77	7440	1.89	34.9	5.84	3.95
	208	6640	2.32	31.2	5.84	3.52
	209	6850	2.32	32.2	5.84	3.52
	190	6450	2.28	30.3	5.84	3.56
	12	8780	1.08	41.2	5.84	4.76
	14	9100	1.15	42.7	5.84	4.69
	13	9110	1.11	42.8	5.84	4.73
	16	9780	1.20	45.9	5.84	4.64
	0.048	12520	-1.32	58.8	4.66	5.98
	0.029	10340	-1.54	48.5	4.66	6.20
	0.034	10640	-1.47	50.0	4.66	6.13
	0.044	12670	-1.36	59.5	4.66	6.02
	0.026	7060	-1.59	33.2	4.66	6.25
	0.050	12200	-1.30	57.3	4.66	5.96

Table 2 continued

T ^{OK}	t _f (sec)	Stress (psi)	Log t _f	S/T	Log (t _f at S/T = 0)	-[Log t _f - Log (t _f at S/T = 0)]
	0.008	13580	-2.10	63.7	4.66	6.76
	0.009	13440	-2.05	63.1	4.66	6.71
	0.007	12830	-2.15	60.2	4.66	6.81
193	207	8000	2.32	41.4	7.24	4.92
	225	8500	2.35	44.0	7.24	4.99
	232	8670	2.37	44.9	7.24	4.87
	74	8760	1.87	45.4	7.24	5.37
	80	9660	1.90	50.1	7.24	5.34
	86	10100	1.93	52.3	7.24	5.31

TABLE 3

Experimental and calculated values for polysulfone

TOK	t_f (sec)	Stress (psi)	Log t_f	S/T	Log (t_f at S/T = 0)	-[Log t_f - Log (t_f at S/T = 0)]
373	239	8110	2.38	21.7	7.81	5.43
	250	8110	2.40	21.7	7.81	5.41
	251	8650	2.40	23.2	7.81	5.41
	79	8790	1.90	23.6	7.81	5.91
	83	8770	1.92	23.5	7.81	5.89
	84	8760	1.92	23.5	7.81	5.89
	15	9380	1.18	25.1	7.81	6.63
	15	9450	1.18	25.3	7.81	6.63
	15	9440	1.18	25.3	7.81	6.63
	238	8960	2.38	25.4	8.95	6.57
353	249	9210	2.40	26.1	8.95	6.55
	281	9760	2.45	27.6	8.95	6.50
	250	9040	2.40	25.6	8.95	6.55
	85	9660	1.93	27.4	8.95	7.02
	88	9690	1.94	27.5	8.95	7.01
	94	9610	1.97	27.2	8.95	6.98
	94	9830	1.97	27.8	8.95	6.98
	17	10940	1.23	31.0	8.95	7.72
	15	10740	1.18	30.4	8.95	7.77
	15	10480	1.18	29.7	8.95	7.77
	15	10590	1.18	30.0	8.95	7.77
	0.008	14280	-2.10	40.4	6.9	9.00
	0.008	12300	-2.10	34.8	6.9	9.00
	0.008	12270	-2.10	34.8	6.9	9.00
	0.063	11060	-1.20	31.3	6.9	8.10

Table 3 continued

T ^o K	t _f (sec)	Stress (psi)	Log t _f	S/T	Log (t _f at S/T = 0)	-[Log t _f - Log (t _f at S/T = 0)]
338	0.057	11860	-1.24	33.6	6.9	8.14
	0.062	11870	-1.21	30.8	6.9	8.11
	0.050	9220	-1.30	6.1	6.9	8.20
	0.052	9500	-1.28	26.9	6.9	8.18
	0.058	12710	-1.24	36.0	6.9	8.14
	297	9610	2.47	28.4	22.99	20.52
	282	9260	2.45	27.4	9.25	6.78
	279	8700	2.45	25.7	22.99	20.54
	85	9610	1.93	28.4	9.25	6.80
	93	10010	1.97	29.6	22.99	20.54
338	93	10060	1.97	29.8	9.25	6.81
	13	10620	1.11	31.4	22.99	21.06
	16	10460	1.20	30.9	9.25	7.32
	16	10310	1.20	30.5	22.99	21.02
					9.25	7.28
					22.99	21.88
					9.25	8.14
					22.99	21.79
					9.25	8.05
					22.99	21.79
					9.25	8.05

Table 3 continued

T ^{OK}	t _f (sec)	Stress (psi)	Log t _f	S/T	Log (t _f at S/T = 0)	-[Log t _f - Log (t _f at S/T = 0)]
323	242	10240	2.38	31.7	25.56	23.18
	260	10270	2.42	31.8	25.56	23.14
	275	10830	2.44	33.5	25.56	23.12
	259	9970	2.41	30.9	25.56	23.15
	96	10310	1.98	31.9	25.56	23.58
	92	10440	1.96	32.3	25.56	23.60
	100	10610	2.00	32.8	25.56	23.56
	103	10660	2.01	33.0	25.56	23.55
	16	10940	1.20	33.9	25.56	24.36
	16	10980	1.20	34.0	25.56	24.36
	15	11150	1.18	34.5	25.56	24.38
	16	11060	1.20	34.2	25.56	24.36
	0.050	12040	-1.30	37.3	8.25	9.55
	0.048	12090	-1.32	37.4	8.25	9.57
	0.048	12460	-1.32	38.6	8.25	9.57
	0.054	12710	-1.27	39.3	8.25	9.52
	0.055	13060	-1.26	40.4	8.25	9.51
	0.057	13130	-1.24	40.7	8.25	9.49
	0.008	13150	-2.10	40.7	8.25	10.35
	0.008	13050	-2.10	40.4	8.25	10.35
	0.008	13840	-2.10	42.9	8.25	10.35
296	343	11410	2.54	38.5	30.00	27.46
	393	11230	2.59	37.9	30.00	27.41
	363	11300	2.56	38.2	30.00	27.44
	372	11290	2.57	38.1	30.00	27.43
	123	11520	2.09	38.9	30.00	27.91

Table 3 continued

TOK	t_f (sec)	Stress (psi)	Log t_f	S/T	Log (t_f at $S/T = 0$)	-[Log t_f - Log (t_f at $S/T = 0$)]
273	120	11490	2.08	38.8	30.00	27.92
	117	11480	2.07	38.8	30.00	27.93
	115	11520	2.06	38.9	30.00	27.94
	18	11940	1.26	40.3	30.00	28.74
	18	11780	1.26	39.8	30.00	28.74
	18	11820	1.26	39.9	30.00	28.74
	17	11970	1.23	40.4	30.00	28.77
	0.01	13800	-2.00	46.6	30.00	12.43
	0.008	16240	-2.10	54.9	10.43	12.53
	0.009	15080	-2.05	50.9	10.43	12.48
	0.056	14760	-1.25	49.9	10.43	11.68
	0.056	13930	-1.25	47.1	10.43	11.68
	0.058	14000	-1.24	47.3	10.43	11.67
	0.052	14330	-1.28	48.4	10.43	11.71
	0.057	13560	-1.24	45.8	10.43	11.67
	0.067	13480	-1.17	45.5	10.43	11.60
	368	12260	2.57	44.9	33.34	30.77
	375	12040	2.57	44.1	33.34	30.77
	357	11830	2.55	43.3	33.34	30.79
	340	11770	2.53	43.1	33.34	30.81
	119	11990	2.08	43.9	33.34	28.26
	113	11930	2.05	43.7	33.34	28.29
	121	11650	2.08	42.7	33.34	28.26
	116	11780	2.06	43.1	33.34	28.28
	17	12180	1.23	44.6	33.34	29.11
	17	12210	1.23	44.7	33.34	29.11
	17	12300	1.23	45.1	33.34	29.11
	17	12310	1.23	45.1	33.34	29.11

Table 3 continued

TOK	t_f (sec)	Stress (psi)	Log t_f	S/T	Log t_f at $S/T = 0$	$-\left[\text{Log } t_f - \text{Log } (t_f \text{ at } S/T = 0)\right]$
	0.072	15890	-1.14	58.2	13.72	14.86
	0.072	15790	-1.14	57.8	13.72	14.86
	0.073	15970	-1.14	58.5	13.72	14.86
	0.082	16300	-1.09	59.7	13.72	14.81
	0.085	16570	-1.07	60.7	13.72	14.79
	0.084	16500	-1.08	60.4	13.72	14.80
	0.009	17430	-2.05	63.9	13.72	15.77
	0.009	17600	-2.05	64.5	13.72	15.77
	0.009	17830	-2.05	65.3	13.72	15.77
253	351	12630	2.55	49.9	38.27	35.72
	372	12720	2.57	50.3	38.27	35.70
	381	12380	2.58	48.9	38.27	35.69
	412	12660	2.61	50.0	38.27	35.66
	131	12880	2.12	50.9	38.27	36.15
	127	12400	2.10	49.0	38.27	36.17
	125	12070	2.10	47.7	38.27	36.17
	139	12970	2.14	51.2	38.27	36.13
	21	13080	1.32	51.7	38.27	36.95
	20	13290	1.30	52.5	38.27	36.97
	19	12510	1.28	49.4	38.27	37.00
	20	13150	1.30	52.0	38.27	36.97
	0.010	18130	-2.00	71.7	16.50	18.50
	0.009	18460	-2.05	73.0	16.50	18.55
	0.009	19700	-2.05	77.9	16.50	18.55
	0.088	17690	-1.06	69.9	16.50	17.56
	0.096	18740	-1.02	74.1	16.50	17.52

Table 3 continued

TOX	t_f (sec)	Stress (psi)	Log t_f	S/T	Log (t_f at S/T = 0)	-[Log t_f - Log (t_f at S/T = 0)]
233	0.091	18880	-1.04	74.6	16.50	17.54
	0.088	17830	-1.06	70.5	16.50	17.56
	0.086	17230	-1.07	68.1	16.50	17.57
	0.090	18130	-1.05	71.7	16.50	17.55
	825	12740	2.61	54.7	42.70	40.09
	835	13050	2.66	56.0	42.70	40.05
	820	12470	2.56	53.5	42.70	40.14
	845	13210	2.56	56.7	42.70	40.14
	878	13410	2.16	57.6	42.70	40.54
	868	13260	2.13	56.9	42.70	40.57
	808	12730	2.11	54.6	42.70	40.59
	840	13360	2.16	57.3	42.70	40.54
	930	14180	1.34	60.8	42.70	41.36
	839	13040	1.30	56.0	42.70	41.40
	0.100	18770	-1.00	80.5	19.55	20.55
	0.104	19920	-0.98	85.5	19.55	20.53
213	0.100	18910	-1.00	81.2	19.55	20.55
	0.118	19800	-0.93	85.0	19.55	20.48
	0.122	18700	-0.91	80.3	19.55	20.46
	0.120	19070	-0.92	81.8	19.55	20.47
	0.010	20600	-2.00	88.4	19.55	21.55
	0.009	20550	-2.05	88.2	19.55	21.60
	0.010	20250	-2.00	86.9	19.55	21.55
	412	13830	2.62	64.9	49.55	46.94
	438	14000	2.64	65.7	49.55	46.91
	467	14000	2.67	65.7	49.55	46.88
	479	13980	2.68	65.6	49.55	46.87

Table 3 continued

T ^{OK}	t _f (sec)	Stress (psi)	Log t _f	S/T	Log (t _f at S/T = 0)	-[Log t _f - Log (t _f at S/T = 0)]
	149	14650	2.17	68.8	49.55	47.38
	155	14420	2.19	67.7	49.55	47.36
	145	14100	2.16	66.2	49.55	47.39
	143	13640	2.16	64.0	49.55	47.39
	23	14650	1.36	68.8	49.55	48.19
	22	14640	1.34	68.7	49.55	48.21
	22	14860	1.34	69.8	49.55	48.21
	21	14420	1.32	67.7	49.55	48.23
	0.009	21160	-2.05	99.4	22.13	24.18
	0.009	21330	-2.05	100.1	22.13	24.18
	0.008	20570	-2.10	96.6	22.13	24.23
	0.132	19570	-0.88	91.9	22.13	23.01
	0.140	19570	-0.85	91.9	22.13	22.98
	0.140	19570	-0.85	91.9	22.13	22.98
	0.128	19470	-0.89	91.4	22.13	23.02
	0.076	20120	-1.12	94.5	22.13	23.25
	0.076	19280	-1.12	90.5	22.13	23.25

TABLE 4
Summary of Parameters

	-b	Apparent Activation Energy	T _g
Nylon			323-348
Static			
193-303°	.263	38	
323-373°	2.5	260	
High Rate			
213-303°	.263	38	
323-353°	2.5	260	
Polypropylene			253-263
Static			298
193-233°	.111	9	
233-353°	.715	48	
High Rate			
213-273°	.111	9	
273-353°	.715	48	
Polysulfone			463
Static			
213-338°	.714	67	
338-373°	.25		
High Rate			
213-353°	.25	41	

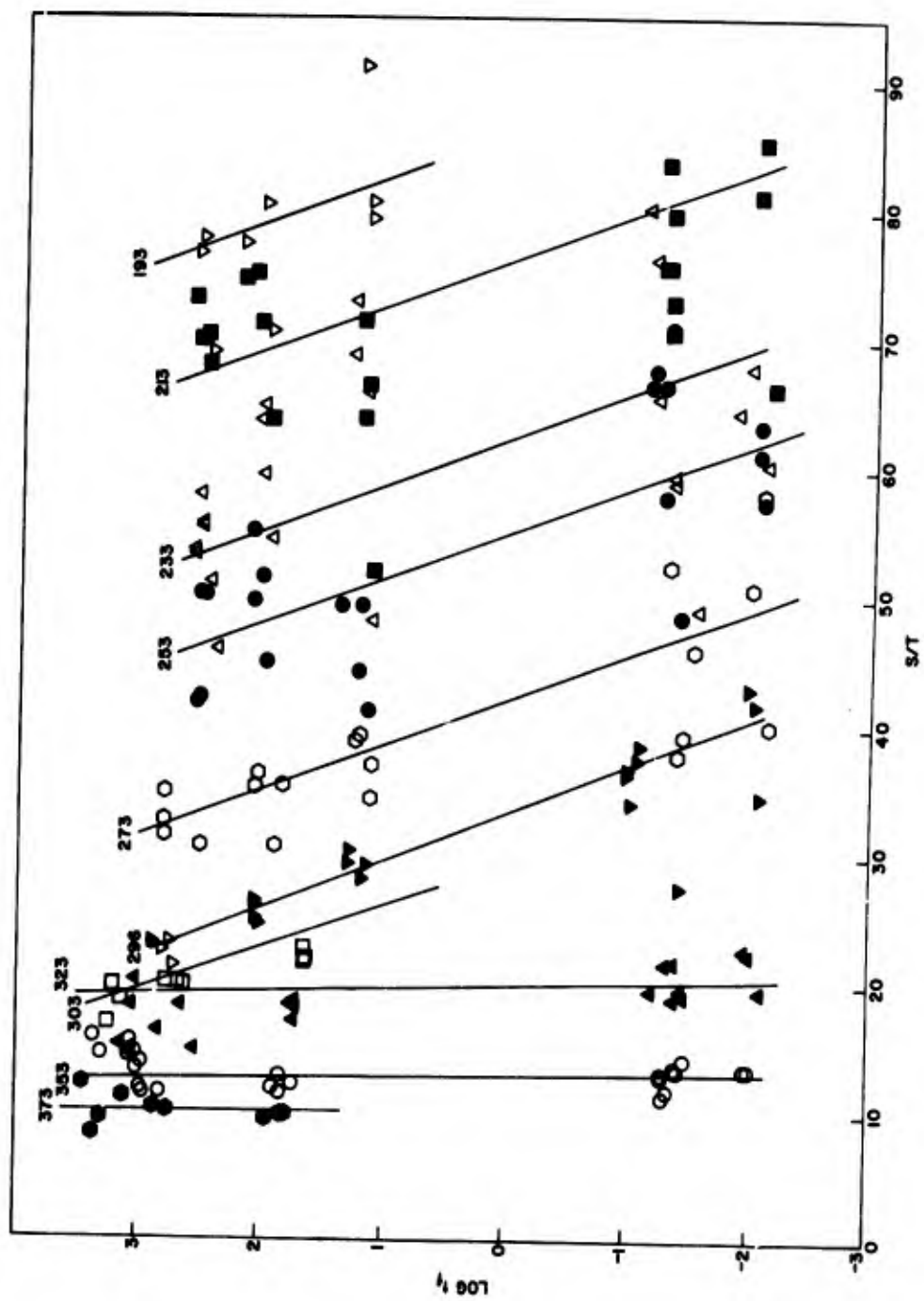


Fig 1 Isothermal stress rupture data for nylon

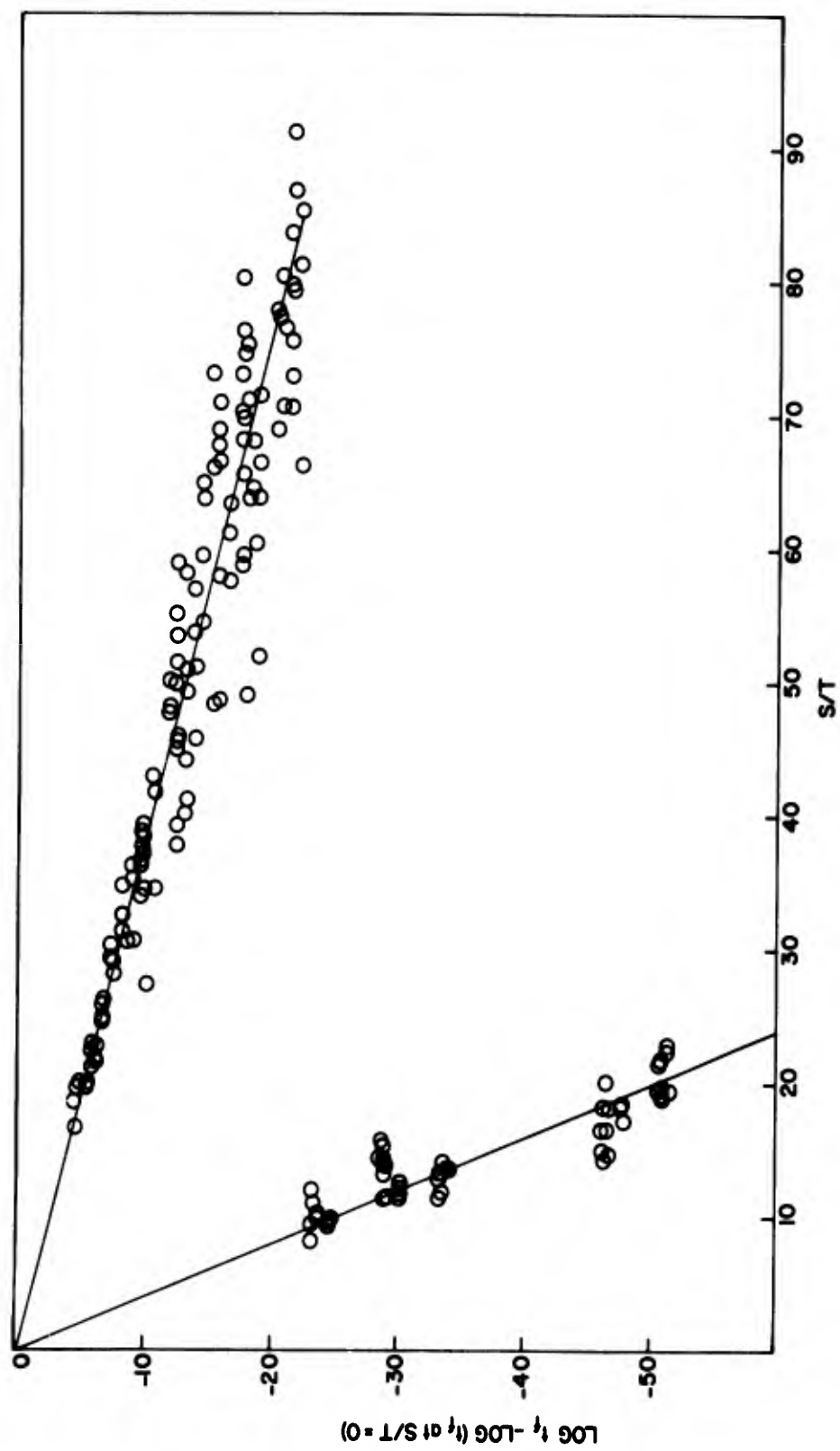


Fig 2 $\log t_f - \log (t_f \text{ at } S/T = 0)$ versus S/T for nylon

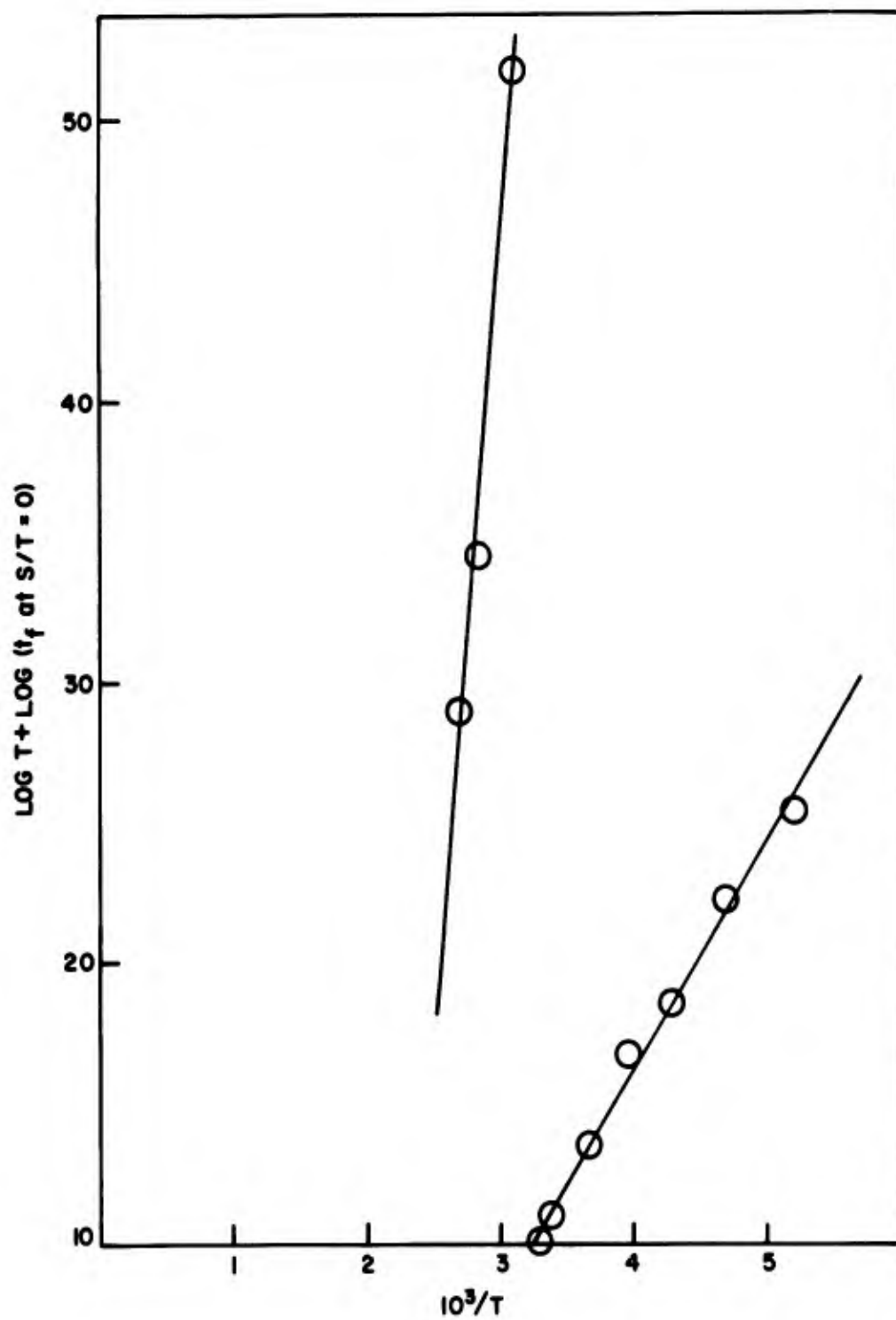


Fig 3 Arrhenius plot for activation energy of nylon

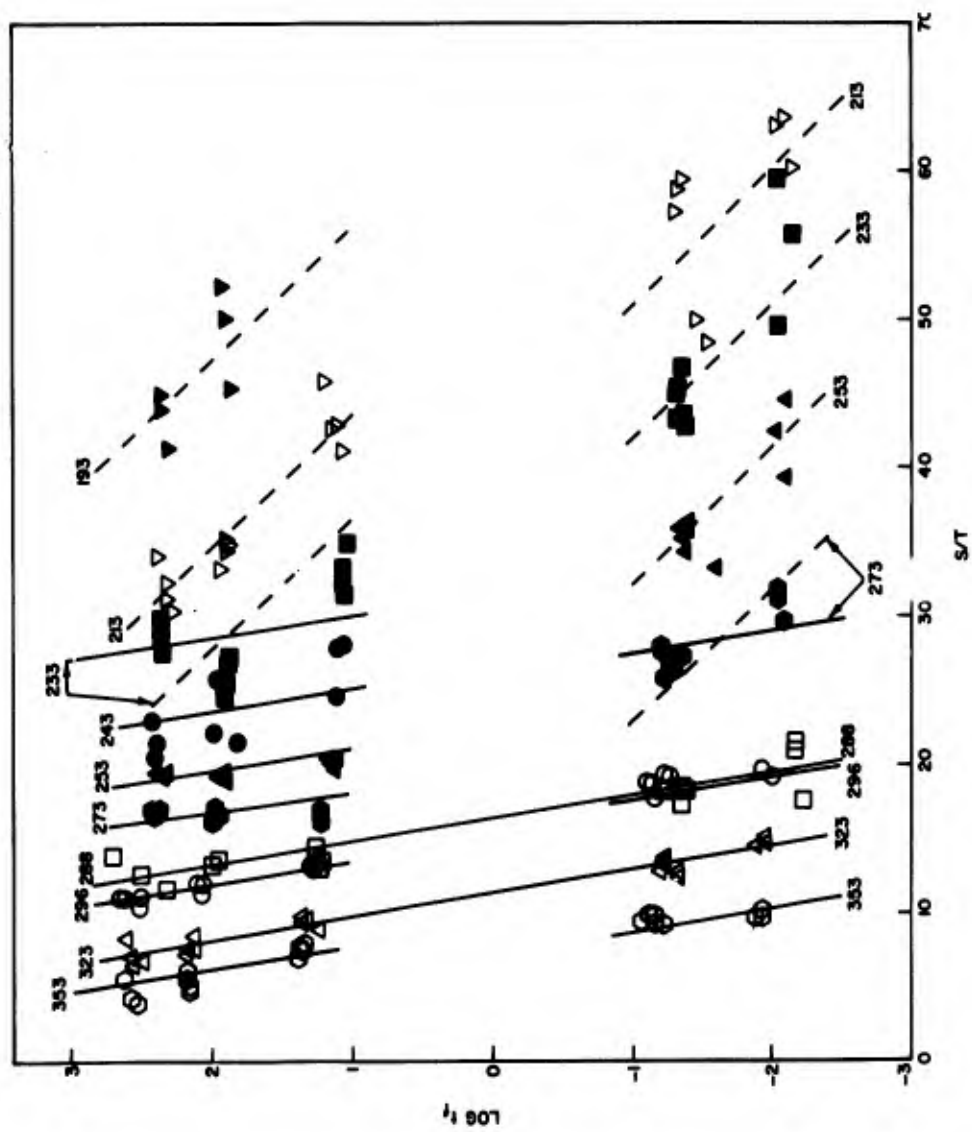


Fig 4 Isothermal stress rupture data for polypropylene

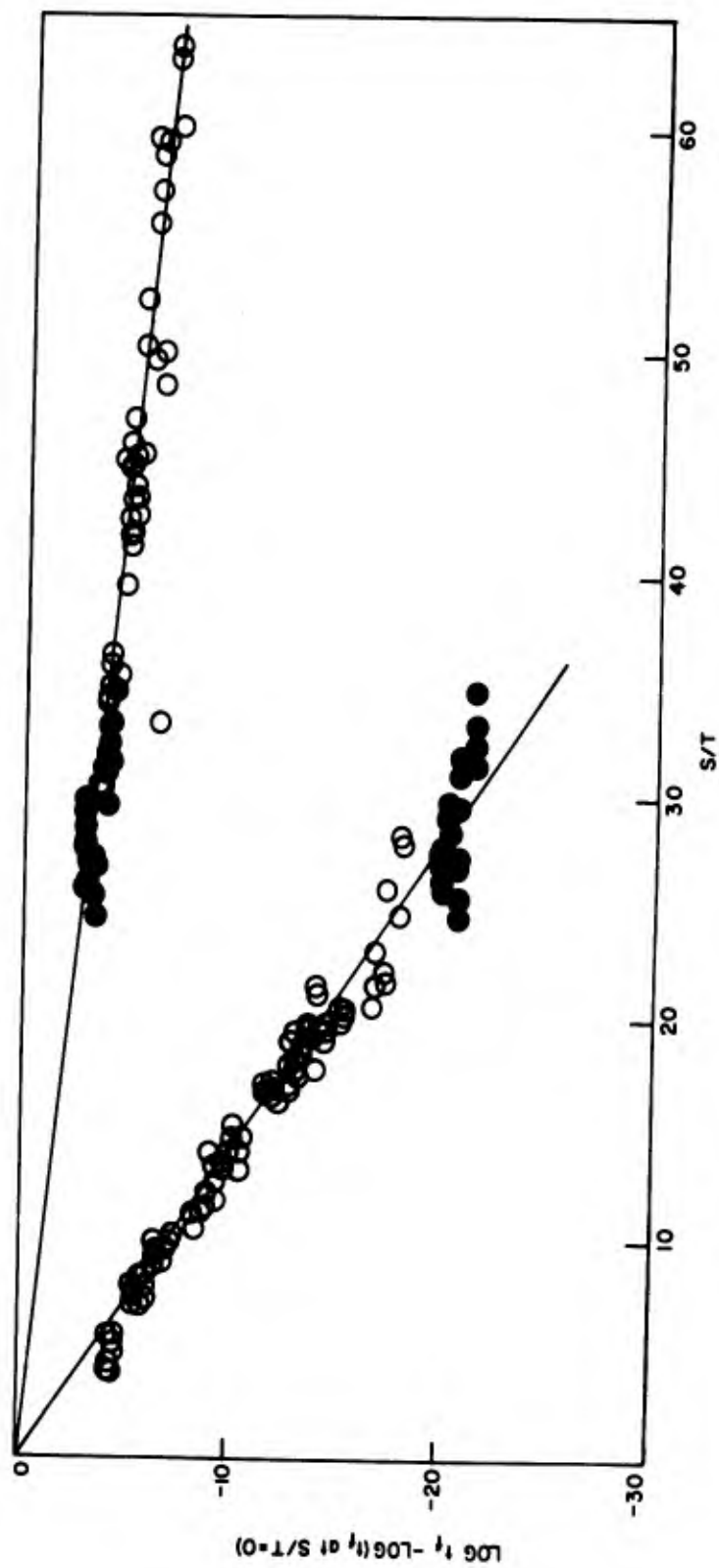


Fig 5 $\text{Log } t_f - \text{Log}(t_f \text{ at } S/T = 0)$ versus S/T for polypropylene

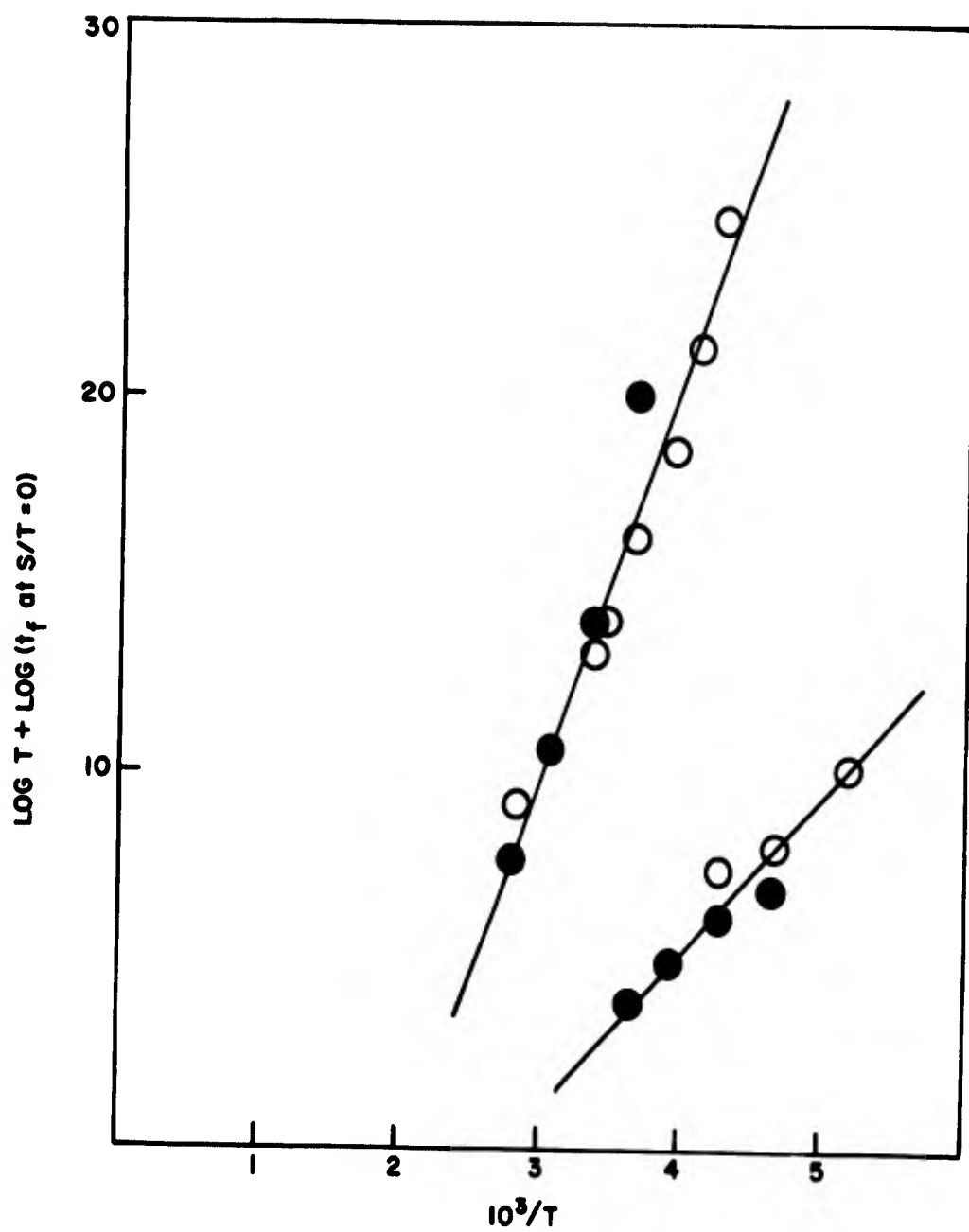


Fig 6 Arrhenius plot for activation energy of polypropylene

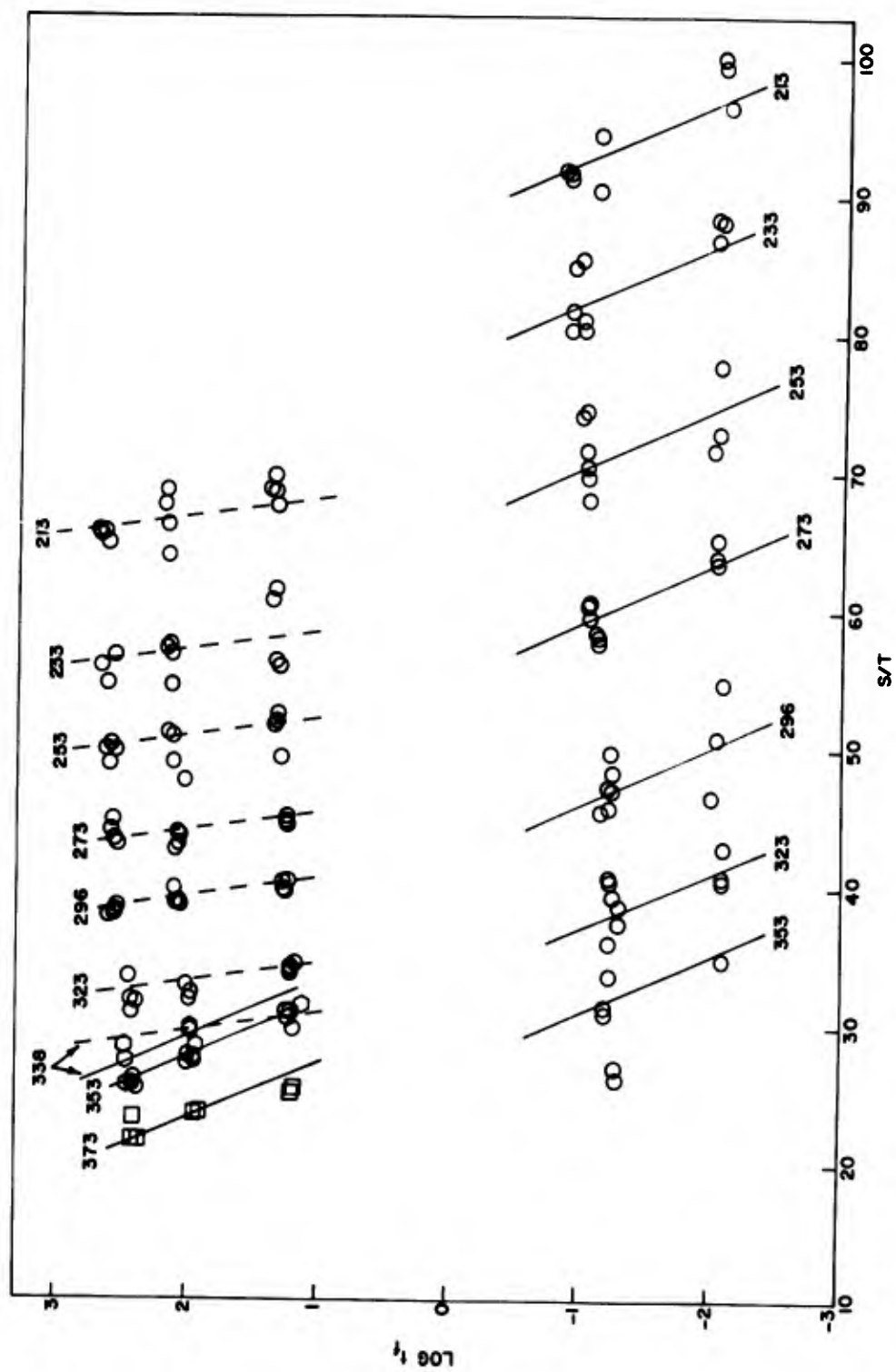


Fig 7 Isothermal stress rupture data for polysulfone

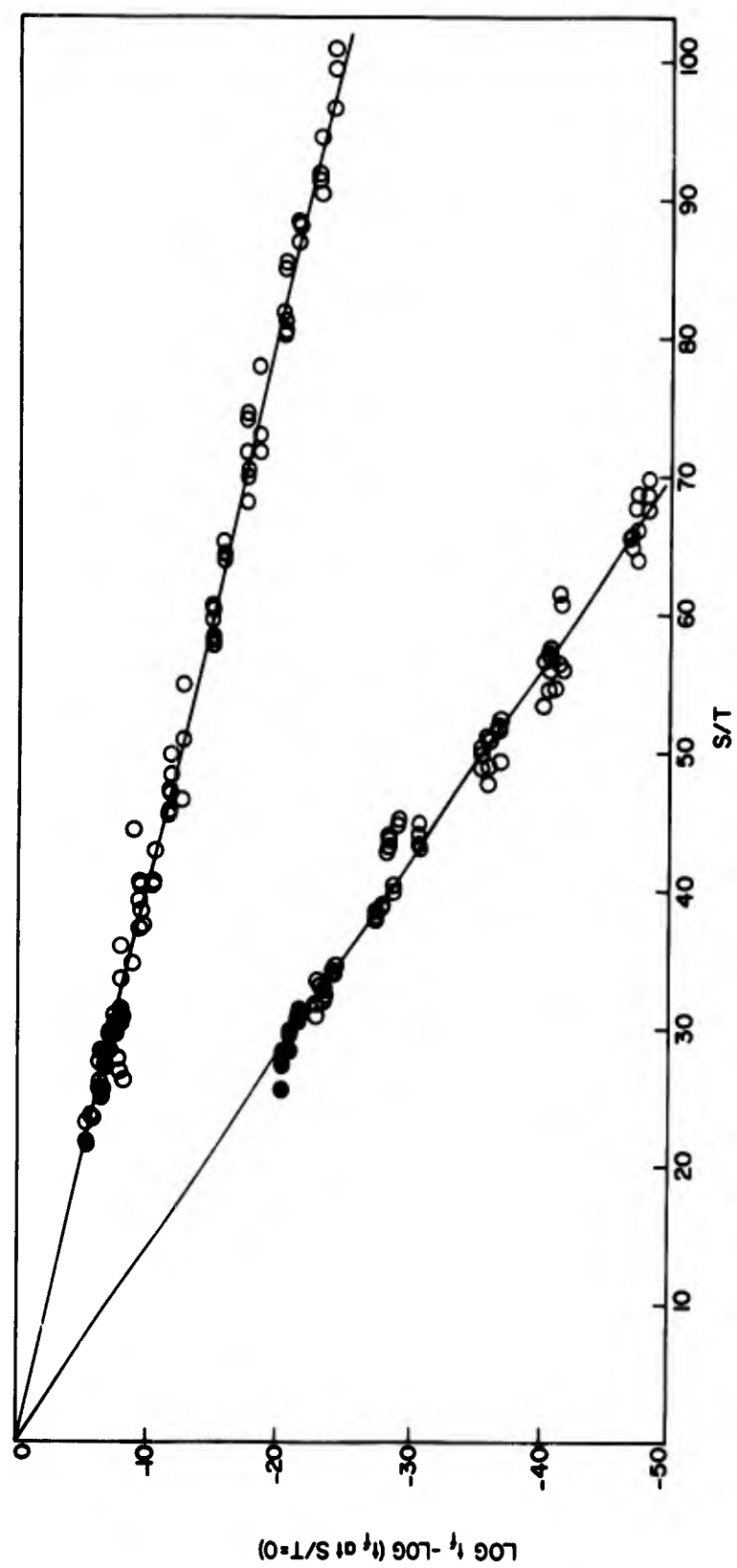


Fig 8 $\log t_f - \log(t_f \text{ at } S/T = 0)$ versus S/T for polysulfone

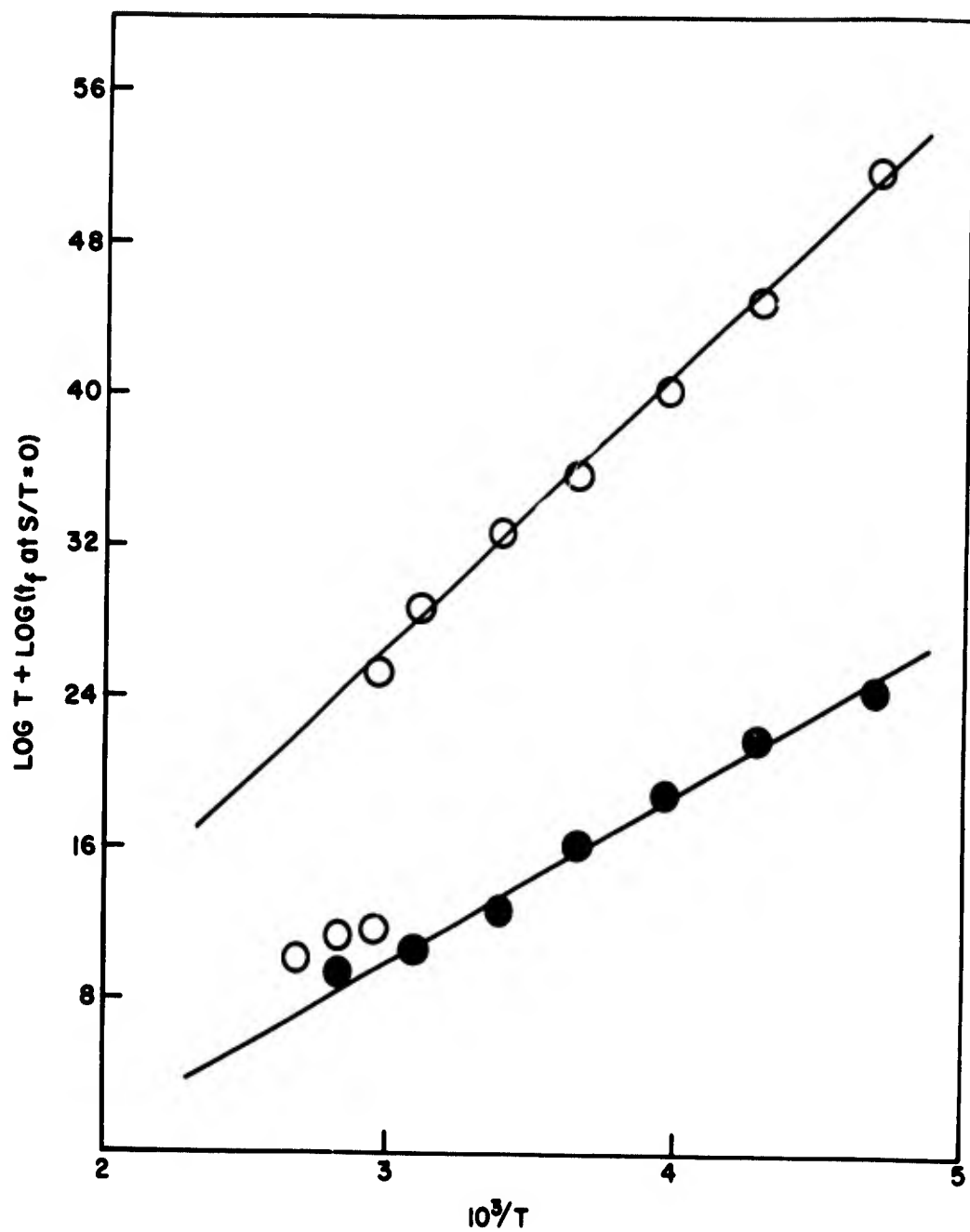


Fig 9 Arrhenius plot for activation energy of polysulfone

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Tensile strength data for nylon-6, polypropylene and polysulfone were analyzed according to a modified rate equation. The agreement of the test results with the theory was excellent. It appeared that the polypropylene material used was an impure mixture. With the data now available it would be desirable to determine whether the parameters obtained could be related to molecular structure.		

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