Effect of Fillers in Polyethylene

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Bakelite Company, A Division of
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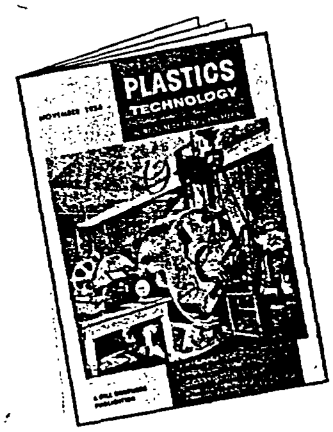

November, 1956

BAKELITE COMPANY

A DIVISION OF UNION CARBIDE AND CARBON CORPORATION

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PLASTICS
TECHNOLOGY

Effect of Fillers in Polyethylene

A study of the effects of 26 fillers on the physical properties of a medium molecular weight polyethylene resin.

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PREVIOUS work in this laboratory by Bostwick and Carey* has shown that inorganic fillers have a reinforcing effect in polyethylene, just as they do in other plastic resins. There are a number of attractive applications for filled polyethylene, such as hot water pipe, thermos bottle caps, electrical insulation, molded articles, kitchenware, and floor tile. Reduction of cost through the use of fillers should also be feasible in some applications.

The object of this study was to define the effects of a range of filler types on the properties of polyethylene. Primary emphasis was placed on physical properties, but effects on compound color and light stability were given only cursory examination.

Test Procedure

The resin used for this evaluation was Bakelite polyethylene resin DYNH, a medium molecular weight material with a melt index of 1.5-2.4 grams/10 minutes.

A list of the 26 fillers evaluated is given in Table 1, along with their respective compositions and suppliers. All of the fillers are commercially available, except the

* Bostwick, R., and Carey, R.H., Ind. Eng. Chem., 42, 848 (1950).

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Table I. Fillers Tested in Polyethylene.

No.	Name	Composition	Supplier
1.	Aluminum Hydrate C-741	Aluminum trihydrate, surface coated.	Aluminum Co. of America.
2.	Asbestos fibers	Mixed fibers (South Africa).	———
3.	Asbestos Shorts 7R	Short asbestos fibers.	Johns-Manville Corp.
4.	Atomite	Wet-ground calcium carbonate.	Thompson, Weinman & Co.
5.	Bentone 34	Basic clay.	National Lead Co.
6.	Cab-O-Sil	Very fine (0.020-micron) collodial silica.	Godfrey L. Cabot, Inc.
7.	Dicalite Super-Aid	Diatomaceous earth.	Dicalite Div., Great Lakes Carbon Corp.
8.	Fibrous Magnesium Silicate #380	———	Whittaker, Clark & Daniels, Inc.
9.	Fibrous Talc 6N	Fibrous talc.	International Talc Co., Inc.
10.	Glass Fibers: "A"	½-In. chopped strand, Silane treated.	Owens-Corning Fiberglas Corp.
11.	"B"	½-In. chopped strand, heat cleaned.	Owens-Corning Fiberglas Corp.
12.	"C"	⅛-In. milled fibers, Silane treated.	Owens-Corning Fiberglas Corp.
13.	"D"	⅛-In. chopped strand, Silane treated.	Pittsburgh Plate Glass Co.
14.	Glass Film: "A"	Double flakes 8-microns thick, untreated.	Owens-Corning Fiberglas Corp.
15.	"B"	Same as film "A," but treated with polyisobutylene.	Owens-Corning Fiberglas Corp.
16.	"C"	Same as film "A," but treated with compatible phenolic.	Owens-Corning Fiberglas Corp.
17.	"D"	Same as film "A," but treated with phenyl silane.	Owens-Corning Fiberglas Corp.
18.	"E"	Same as film "A," but treated with vinyl silane.	Owens-Corning Fiberglas Corp.
19.	Hi-Sil 110	Precipitated hydrous silica (0.025 micron).	Columbia-Southern Chemical Corp.
20.	Iceberg pigment	Calcined clay.	Burgess Pigment Co.
21.	Micronex W-6	Beaded channel black.	Binney & Smith, Inc.
22.	Multiflex MM	Precipitated calcium carbonate.	Diamond Alkali Co.
23.	Santocel C	Hydrated silica.	Monsanto Chemical Co.
24.	Satintone	Calcined clay.	Minerals & Chemicals Corp.
25.	Silene EF	Precipitated calcium silicate.	Pittsburgh Plate Glass Co.
26.	Sno-Brite	Uncalcined clay.	Thompson, Weinman & Co.

asbestos fibers from South Africa and the glass film. The latter is a development-scale product of Owens-Corning Fiberglas Corp.

Preparation of Samples

Filler and resin were blended for five minutes in a Hobart kitchen-type mixer. A total batch weight of 400 grams was used. The blend was fluxed on an 8 by 16-inch two-roll laboratory mill at 120° C. (steam outlet temperature), and rolled for 15 minutes. The resulting sheet was molded into appropriate plaques for the various tests.

Test Methods

Tensile properties at 23 and 80° C. were measured using a Baldwin-Tate-Emery Universal Testing Machine. Specimens were cut with die "A" of ASTM D412-51T. A strain rate of 1.0 inch/minute was used until the yield point was passed, then the rate was increased to 20 inches/minute until the specimen broke. The properties reported from this test are tensile strength, yield strength, ultimate elongation at yield point.

Secant modulus at 23° C. was measured with the same test method, but at a strain rate of 0.1 inch/minute. The secant modulus was taken as the slope of the line intersecting the stress-strain curve at the origin and 1.0% strain.

Heat distortion temperature was determined in accordance with ASTM method D648-45T using a stress of 66 psi.

Durometer "D" hardness was determined by the method of ASTM D676-49 using a 3.2-pound weight and taking the reading after 15 seconds contact.

Brittle temperature (50% index) was run by modification of ASTM method D746-44T intended for use with materials having a wide transition range.

X1A failure was determined in the Atlas X1A Weatherometer.

Zero-strength time is a type of creep test run above the softening point of the polymer. For this study, it was run at a temperature of 127° C. and a stress of 5.6 psi. The time to failure, in seconds, is recorded.

The guillotine test was developed by Worthington Ball Co. to test the cutting resistance of golf ball covers. The apparatus is essentially a miniature guillotine. Depth of cut edgewise into a 0.125-inch thick sample is measured.

Stress rupture was measured by loading a ⅛-inch thick specimen in tension at a stress of 600 psi. and a temperature of 60° C. Time to failure, in days, and approximate per cent strain at failure were recorded.

Table 2. Tensile and Yield Properties at 23° C. of Filled Polyethylene at Various Loadings.

Filler No.	Filler concentration, phr.:	Tensile Strength at 23° C., Psi.				Yield Strength at 23° C., Psi.				Ultimate Elongation at 23° C., %				Elongation at Yield Point at 23° C., %			
		5	20	50	100	5	20	50	100	5	20	50	100	5	20	50	100
1.		1680	1460	1460	1380	1340	1370	1410	1380	565	360	65	2	76	60	20	12
2.		—	1860	2530	2390	—	1770	2530	2390	—	22	15	5	—	12	12	1
3.		1480	1520	1660	1760	1340	1360	1660	1760	355	140	25	6	67	20	10	2
4.		1870	1480	1450	1510	1340	1350	1450	1510	590	630	110	30	65	50	20	10
5.		1790	1560	1530	1440	1280	1380	1530	1440	590	160	36	0	65	10	8	0
6.		—	1740	1900	—	—	1540	1900	—	—	102	7	—	—	35	6	—
7.		1540	1650	1840	2170	1360	1530	1840	2170	600	130	26	9	57	40	17	5
8.		1450	1540	1790	1980	1350	1430	1790	1980	440	110	22	4	60	22	15	3
9.		—	1730	1910	2110	—	1520	1720	2050	—	98	49	19	—	40	17	10
10.		—	1890	2680	3050	—	1890	2680	3050	—	28	16	5	—	12	10	5
11.		—	1580	1820	1790	—	1410	1790	1790	—	65	15	3	—	10	6	2
12.		—	1880	1980	2100	—	1860	1970	2100	—	22	13	5	—	7	7	1
13.		—	1490	1510	1510	—	1260	1510	1510	—	270	16	3	—	12	4	2
14.		—	1550	1770	—	—	1450	1770	—	—	34	8	—	—	6	3	—
15.		—	1600	1820	1540	—	1430	1790	1540	—	169	23	0	—	8	5	0
16.		—	1610	2060	2300	—	1520	1970	2300	—	43	27	0	—	20	8	0
17.		—	1750	1760	1600	—	1730	1710	1600	—	14	15	0	—	2	2	0
18.		—	1710	1980	2270	—	1540	1900	2270	—	41	19	0	—	12	2	0
19.		1690	1630	1930	1150	1350	1540	1920	1150	545	185	15	0	65	40	10	0
20.		—	1750	1690	1950	—	1550	1640	1950	—	169	45	10	—	50	24	9
21.		1350	1690	1810	1390	1310	1500	1810	1390	99	460	14	0	40	50	7	0
22.		1890	1430	1310	1390	1330	1330	1310	1390	585	585	55	15	70	60	20	15
23.		—	1600	1800	—	—	1450	1800	—	—	87	12	—	—	18	11	—
24.		1710	1550	1730	1840	1350	1460	1650	1840	630	195	100	20	70	65	40	10
25.		1460	1560	1670	1730	1330	1430	1670	1730	380	87	13	5	55	20	12	5
26.		—	1640	1650	2150	—	1450	1650	2150	—	197	16	10	—	53	7	8
	None (control)	1670	—	—	—	1310	—	—	—	560	—	—	—	72	—	—	—

Table 3. Tensile and Yield Properties at 80° C. of Filled Polyethylene at Various Loadings.

Filler No.	Filler concentration, phr.:	Tensile Strength at 80° C., Psi.				Yield Strength at 80° C., Psi.				Ulimate Elongation at 80° C., %				Elongation at Yield Point at 80° C., %			
		5	20	50	100	5	20	50	100	5	20	50	100	5	20	50	100
1.		590	520	415	330	545	485	415	330	636	197	57	20	75	57	52	16
2.		—	600	715	825	—	600	715	825	—	44	14	8	—	40	15	8
3.		505	470	555	570	485	455	550	570	201	104	51	23	83	62	45	23
4.		610	595	590	505	575	595	590	505	398	192	63	14	67	60	53	11
5.		505	485	430	350	475	460	420	350	440	275	110	15	95	85	80	15
6.		—	630	660	—	—	630	660	—	—	81	18	—	—	65	12	—
7.		470	510	580	615	435	480	580	615	188	108	31	12	65	65	31	12
8.		520	555	685	675	485	535	685	675	285	83	33	11	77	53	33	11
9.		—	600	650	750	—	600	650	750	—	94	54	18	—	62	30	15
10.		—	615	795	890	—	580	790	890	—	80	10	4	—	8	7	4
11.		—	580	680	570	—	550	680	570	—	125	14	10	—	70	9	7
12.		—	620	745	825	—	600	745	825	—	98	15	17	—	13	15	8
13.		—	530	450	360	—	520	450	360	—	167	52	36	—	110	13	5
14.		—	540	645	—	—	525	645	—	—	54	26	—	—	30	20	—
15.		—	525	605	620	—	525	605	620	—	38	23	8	—	33	17	8
16.		—	635	705	815	—	615	705	815	—	86	21	9	—	50	16	9
17.		—	640	605	630	—	630	595	630	—	35	31	7	—	20	15	7
18.		—	630	700	945	—	600	700	945	—	79	21	11	—	42	20	11
19.		545	670	705	345	515	635	705	345	303	100	25	0	90	58	25	0
20.		—	730	760	850	—	670	710	850	—	187	96	32	—	60	50	28
21.		490	635	715	595	455	545	680	595	290	770	203	13	70	87	62	13
22.		610	610	540	445	575	580	515	445	351	170	80	8	77	60	37	8
23.		—	585	590	—	—	580	590	—	—	61	10	—	—	52	9	—
24.		600	575	635	650	570	540	635	650	528	191	61	22	90	75	60	22
25.		605	520	540	570	580	520	540	570	153	74	25	5	77	65	25	5
26.		—	645	700	805	—	605	675	805	—	208	107	50	—	80	60	45
	None (control)	635	—	—	—	545	—	—	—	540	—	—	—	81	—	—	—

Table 4. Secant Modulus, Heat Distortion, and ZST Values for Filled Polyethylene at Various Loadings.

Filler No.	Filler concentration, phr.:	Secan Modulus at 23° C., Psi. x 10^{-3}				Heat Distortion Temp. at 66 Psi., °C.				Zero Strength Time at 127° C., Sec.			
		5	20	50	100	5	20	50	100	5	20	50	100
1.		26	28	34	44	40	39	40	45	250	250	240	780
2.		—	48	83	108	—	53	72	69	—	260	280	310
3.		31	40	58	81	44	46	56	62	220	220	270	>860
4.		29	33	38	56	38	38	43	48	280	270	270	260
5.		30	—	47	112	46	46	54	63	210	240	360	—
6.		—	39	76	—	—	64	77	—	—	240	>600	—
7.		—	42	64	92	44	44	57	69	220	230	220	230
8.		—	39	58	91	42	46	59	67	220	230	240	240
9.		—	36	50	78	—	59	60	72	—	200	190	200
10.		—	64	108	166	—	61	84	94	—	240	330	360
11.		—	44	76	93	—	68	85	82	—	210	220	230
12.		—	55	77	125	—	54	85	88	—	270	280	300
13.		—	44	69	89	—	56	70	88	—	220	210	230
14.		—	46	78	—	—	58	68	—	—	240	250	—
15.		—	58	92	123	—	59	71	80	—	250	230	250
16.		—	55	89	137	—	56	70	81	—	240	230	250
17.		—	76	80	108	—	65	66	78	—	250	250	250
18.		—	52	83	132	—	57	69	83	—	250	260	250
19.		28	38	70	129	45	49	62	85	240	260	>860	>860
20.		—	33	43	72	—	53	60	67	—	200	200	190
21.		31	40	67	94	47	50	54	68	210	240	>860	>860
22.		29	33	43	66	39	42	46	56	260	260	260	250
23.		—	41	66	—	—	49	61	—	—	320	>860	—
24.		25	33	48	71	40	43	49	62	260	260	250	240
25.		30	39	60	132	44	50	59	86	210	220	240	>860
26.		—	35	56	90	—	49	60	72	—	250	260	400
	None (control)	26	—	—	—	43	—	—	—	260	—	—	—

Table 5. Hardness, Cut Resistance, and Color of Filled Polyethylene at Various Loadings.

Filler No.	Filler concentration, phr.:	Durometer "D" Hardness				Guillotine Test Depth of Cut, Mm.				Color Imparted by Filler
		5	20	50	100	5	20	50	100	
1.		49	49	51	54	13	12	11	11	White
2.		—	52	55	60	—	11	9	Split	Dark gray
3.		45	48	52	55	16	12	12	10	Dark gray
4.		48	49	51	55	12	12	11	11	Grayish white
5.		45	47	50	53	13	12	13	Split	Tan
6.		—	52	59	—	—	11	8	—	Very light tan
7.		44	[illegible]	54	60	12	13	10	9	Brown
8.		[illegible]	47	51	55	16	14	12	—	Gray
9.		—	48	51	57	—	13	12	10	Light gray
10.		—	54	59	61	—	11	10	9	Light gray
11.		—	49	54	57	—	13	12	11	Light gray
12.		—	52	56	60	—	11	10	Split	Light gray
13.		—	49	53	58	—	13	11	Split	Light gray
14.		—	50	54	—	—	12	11	—	Light gray
15.		—	48	51	59	—	12	11	Split	Light gray
16.		—	49	54	59	—	12	11	Split	Light gray
17.		—	52	54	59	—	11	11	Split	Light gray
18.		—	50	55	58	—	12	11	Split	Light gray
19.		48	53	57	67	12	10	8	6	Light gray
20.		—	49	52	56	—	13	11	10	White
21.		47	50	55	65	15	12	10	6	Black
22.		48	49	52	56	14	12	12	Split	Cream
23.		—	50	57	—	—	11	9	—	Light tan
24.		48	50	54	58	14	12	11	10	Light gray
25.		46	49	55	63	13	12	10	8	Light gray
26.		—	49	52	54	—	11	10	8	Cream
	None (control)	46	—	—	—	14	—	—	—	White

Test Results

Yield and Ultimate Tensile

Four properties were measured with the tensile test: ultimate tensile strength, ultimate elongation, yield strength, and elongation at yield point. Since the yield point for most applications is the point of failure, the yield properties are considered more significant than the ultimate tensile properties. Tensile tests were run at both 23 and 80° C., with the results shown in Tables 2 and 3. Concentration of filler is shown in parts per hundred of resin.

In general, the tensile properties at 23° C. were slightly affected by the addition of five parts of filler. Twenty parts of filler lowered the elongation, but had very little effect on tensile strength and yield strength. However, both 50 and 100 parts of filler reduced elongation sharply and, in most cases, raised the yield and tensile strengths. Glass fibers "A" (Filler No. 10) raised yield strength to almost twice that of unfilled resin at a concentration of 100 parts. Other fillers which were particularly good in raising yield strength were asbestos fibers (No. 2), Dicalite Super-Aid (No. 7), glass film samples "C" and "D" (Nos. 16 and 18), and Sno-Brite (No. 26).

With most of the fillers, increased concentration resulted in higher yield strength. However, in some cases, the yield strength was lower at 100 parts filler than at 50 parts. Two examples of the latter behavior occur with Hi-Sil 110 precipitated hydrous silica' (No. 19) and Micronex W-6 carbon black (No. 21). Apparently, in these cases, the surface area of the filler is so great that it cannot be wetted adequately by the resin. As a result, the compound is lacking in strength.

It is interesting to note that at filler concentrations of 50 and 100 parts, the yield strength and ultimate tensile strength are usually the same; the ductibility normally associated with polyethylene is missing; and the compound breaks very soon after it yields.

In general, the same behavior is found at 80° C. as at 23° C. Of course, the yield strength is much lower at 80° C. The elongation figures are of the same order, although at 100 parts of filler they are higher at 80° than at 23° C. At 80° C., the degree of increase in yield strength caused by the better fillers is not as great as at 23° C. The same fillers are generally good, with the exception of Dicalite Super-Aid (No. 7). The phenomenon of a lower yield strength at 100 parts than at 50 parts is also found at 80° C., notably with Hi-Sii 110 (No. 19).

Modulus of Elasticity

In all cases, the secant modulus at 23° C. showed a rise with increasing filler concentration (see Table 4). At five parts phr., the fillers had little effect, but 20 parts raised the modulus as much as 300% in one case. The highest modulus, 166,000 psi., was found with 100 parts of glass fibers (No. 10). The result for unfilled resin was 26,000 psi.

Other fillers which produced a high modulus were asbestos fibers (No. 2), Bentone 34 basic clay (No. 5), glass fibers "C" (No. 12), the glass films (Nos. 14-18), Hi-Sil 110 (No. 19), and Silene EF precipitated calcium silicate (No. 25). Atomite calcium carbonate (No. 4), and Aluminum Hydrate C-741 (No. 1) had the least effect on modulus.

Heat Distortion Temperature

Increases in heat distortion point ranged from 51° C. for glass fibers "A" (No. 10) to two degrees for Aluminum Hydrate C-741 (No. 1), as shown in Table 4. The most effective fillers here were the glass fibers (Nos. 10-13), the glass films (Nos. 14-18), Hi-Sil 110 (No. 19), and Silene EF (No. 25). It seems reasonable to expect a correlation between heat distortion temperature and yield strength at 80° C. This, along with other possible correlations, is discussed in a later section.

Zero-Strength Time (ZST)

Results of this test (see Table 4) fall into two categories. Most of the filled compounds were not significantly different from the unfilled resin, but a few showed comparatively long zero-strength times. These were Aluminum Hydrate C-741 (No. 1), Asbestos Shorts 7R (No. 3), Cab-O-Sil silica pigment (No. 6), Hi-Sil 110 (No. 19), Micronex W-6 (No. 21), Santocel C hydrated silica (No. 23), and Silene EF (No. 25). The longer ZST values were found only at 50 or 100 parts of filler.

Durometer Hardness

As shown in Table 5, the effect of fillers on Durometer "D" hardness was generally much less than effect on other properties. The highest hardness value found was 67 for a loading of 100 parts phr. of Hi-Sil 110 (No. 19), as compared with 46 for unfilled resin. The differences among fillers on the hardness properties also were smaller than with other properties. The high hardness value of 67 was somewhat below that of a rigid vinyl sheet which is around 80.

Guillotine Test

The resistance to cutting, as measured by this test, was approximately doubled by the most effective fillers, as shown in Table 5. These were Hi-Sil 110 (No. 19) and Micronex W-6 (No. 21). Many of the compounds containing 100 parts of filler actually split, showing a definite brittle fracture.

Brittle Temperature

As shown in Table 6, the test for brittle temperature at 50% index was run on only five fillers so no over-all comparisons can be made. However, it is obvious that the effect of any filler will be to raise the brittle temperature drastically, especially at the higher loadings. Of the fillers tested, Iceberg pigment (No. 20) had the least effect.

In connection with brittle temperature, it should be realized that the use of a filler changes polyethylene from a flexible material to one which is essentially rigid. The brittle temperatures of rigid plastics are usually above room temperature, and the brittle temperature test may be of questionable value.

Table 6. Brittle Temperature, Stress Rupture, and Weatherometer Values for Filled Polyethylene at Various Loadings.

Filler			Stress Rupture at 600 Psi. and 60° C.		X1A Weatherometer Failure	
No.	Concentration	Brittle Temp. 50% Index, °C.	Time to Failure, Days	Approx. Strain at Failure, %	Hours	Type
3	50	—	>274	>15.9	—	—
5	50	—	16	20.0	—	—
6	20	−18	—	—	500	Crazing
	50	>25	—	—	240	Crazing
7	50	—	59	7.5	—	—
8	50	—	3	7.0	—	—
9	20	−36	—	—	750	Crazing
	50	−14	—	—	750	Crazing
	100	>25	—	—	500	Crazing
11	20	−34	—	—	750*	Slight darkening, White streaks
	50	10	—	—	750	White streaks
	100	>25	—	—	500	White streaks
12	50	—	70	3.5	—	—
	100	—	105	1.0	—	—
13	20	−36	—	—	750*	Slight yellowing
	50	8	—	—	750	White streaks
	100	>25	—	—	750	White streaks
19	50	—	96	6.5	—	—
20	20	−64	—	—	500	Crazing
	50	−25	—	—	500	Crazing
	100	3	—	—	500	Crazing
21	50	—	0	—	—	—
24	100	—	2	5.0	—	—
Control	—	−98	2	39.1	750*	Slight darkening

* These samples are not considered to have failed.

Stress Rupture

As shown in Table 6, straight resin shows the very short life of two days when tested for stress rupture at 600 psi. and 60° C. Three of the fillers, Satintone calcined clay (No. 24), Micronex W-6 (No. 21), and fibrous magnesium silicate (No. 8) did not improve this performance. Among the other fillers tested, Asbestos Shorts 7R (No. 3) was the best with a life of over 274 days at the comparatively low strain of 15.9%. Glass fibers "C" (No. 12) and Hi-Sil 110 (No. 19), which lasted 105 and 96 days respectively, also were very good.

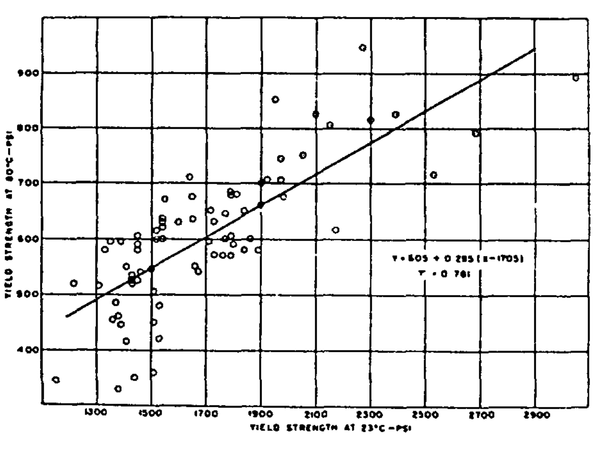

Fig. 1. Correlation between yield strengths at 23° C. and 80° C.

It is apparent that properly chosen fillers can greatly improve the long-time strength of polyethylene resin.

Light Stability

A cursory study of the effects of five different fillers on the light stability of the resin was made using the X1A Weatherometer (see Table 6). After 750 hours exposure, straight resin showed only a slight discoloration. All of the samples containing Cab-O-Sil (No. 6), Fibrous Talc 6N (No. 9), or Iceberg Pigment (No. 20) showed severe crazing at or before this exposure time.

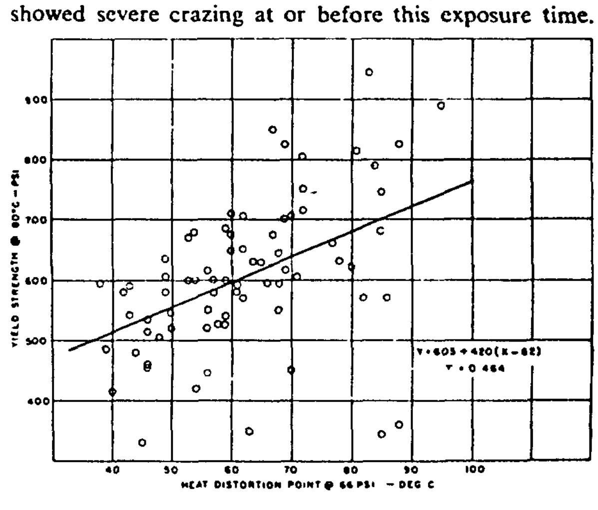

Fig. 2. Correlation between yield strength at 80° C. and heat distortion at 66 psi.

The samples containing either of the glass fibers (Nos. 12 and 13) showed a curious white streaking effect in the exposed area which seemed like an erosion of the surface. The use of the fillers tested was definitely detrimental to the light stability of the resin.

Color Imparted by Filler

Most of the fillers imparted comparatively little color to the polyethylene, as shown in Table 5. However, the coloring effect of such materials as Micronex W-6 carbon black (No. 21) and the asbestos fillers (Nos. 2 and 3) would definitely limit their use. Of the fillers tested, the glass fibers (Nos. 10-13) and glass films (Nos. 14-18) had the least opacifying effect.

Summary of Properties

To permit quick comparisons of fillers, a summary chart has been constructed and is shown in Table 7. A numerical rating system has been used as follows:

(1) The filler had no effect as compared with unfilled resin.
(2) Slight effect.
(3) Moderate effect.
(4) Large effect.
(5) Very large effect.

In using a chart such as this, a specific application must be kept in mind. For example, if the modification of resin to make it suitable for boilable articles is being considered, an increase in modulus, heat distortion, and yield strength at 80° C. are required. The desired filler should have a large effect on these and related properties, combined with a small effect on other properties.

In a second case, it may be desired to simply lower the cost by addition of a filler. Here the least effect on all properties is required. For the first application, the chart shows glass fibers "A" (No. 10) to be a good choice. For the second application, Aluminum Hydrate C-741 (No. 1) Atomite (No. 4), or Satintone (No. 24) would be indicated.

Correlation Among Tests

A number of graphs of related properties plotted against one another have been made to check correlations. These graphs contain data on compounds with 20, 50 and 100 parts of filler, and are shown in Figures 1-4. Least square lines and correlation coefficients were calculated in each case. A correlation coefficient of 1.00 represents a perfect correlation.

Figure 1 shows yield strength at 23° C. vs. yield strength at 80° C. There is some scatter, but the correlation is fairly good throughout the graph. The correlation coefficient is 0.78. in Figure 2, yield strength at

Table 7. Numerical Ratings of Fillers by Effects on Polyethylene Properties at 50-Part Loading.

No.	Filler Name	At 23°C. Yield Strength	At 23°C. Yield Point Elongation at	At 80°C. Yield Strength	At 80°C. Elongation at Yield Point	Secant Modulus at 23° C.	Heat Distortion Temperature	Zero Strength Time	Durometer "D" Hardness	Guillotine Test	Brittle Temperature	X1A Weatherometer	Color Imparted	Stress Rupture at 600 Psi. and 60°
1.	Aluminum Hydrate C-741	1	4	1	2	2	1	1	3	3	—	—	1	—
2.	Asbestos Fibers	5	5	4	5	4	4	1	4	5	—	—	4	—
3.	Asbestos Shorts 7R	2	5	1	3	3	3	1	3	3	—	—	4	5
4.	Atomite	1	4	1	2	2	1	1	3	3	—	—	2	2
5.	Bentone 34	2	5	1	1	2	2	2	2	2	—	—	3	—
6.	Cab-O-Sil	3	5	3	5	4	5	5	5	5	5	4	2	—
7.	Dicalite Super-Aid	3	4	1	4	3	3	1	4	4	—	—	3	3
8.	Fibrous Magnesium Silicate #380	3	5	3	4	3	3	1	3	3	—	—	3	1
9.	Fibrous Talc 6N	2	4	3	4	3	3	1	3	3	4	2	2	—
10.	Glass Fibers "A"	5	5	5	5	5	5	2	5	4	—	—	2	—
11.	"B"	3	5	3	5	4	5	1	4	3	5	2	2	—
12.	"C"	3	5	5	5	4	5	1	4	4	—	—	2	4
13.	"D"	2	5	1	5	4	4	1	3	4	5	2	2	—
14.	Glass Film "A"	2	5	3	5	4	4	1	4	4	—	—	2	—
15.	"B"	3	5	2	5	5	4	1	3	4	—	—	2	—
16.	"C"	3	5	4	5	5	4	1	4	4	—	—	2	—
17.	"D"	2	5	2	5	4	4	1	4	4	—	—	2	—
18.	"E"	3	5	4	5	4	4	1	4	4	—	—	2	—
19.	Hi-Sil 110	3	5	4	4	4	3	5	5	5	—	—	2	4
20.	Iceberg Pigment	2	4	5	3	2	3	1	3	4	3	3	1	—
21.	Micronex W-6	3	5	4	2	3	2	5	4	4	—	—	5	1
22.	Multifex MM	1	4	1	3	2	2	1	3	3	—	—	2	—
23.	Santocel C	3	5	1	5	3	3	5	5	5	—	—	2	—
24.	Santintone	2	3	2	2	2	2	1	4	4	—	—	2	1
25.	Silene EF	2	5	1	4	3	3	1	4	4	—	—	2	—
26.	Sno-Brite	2	5	4	2	3	3	1	3	4	—	—	2	—

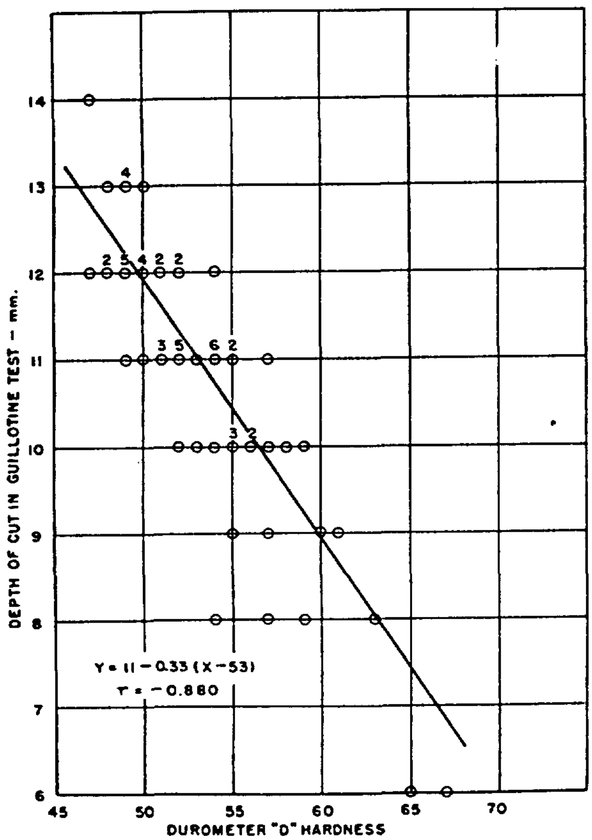

Fig. 3. Correlation between Durometer "D" hardness and secant modulus at 23° C.

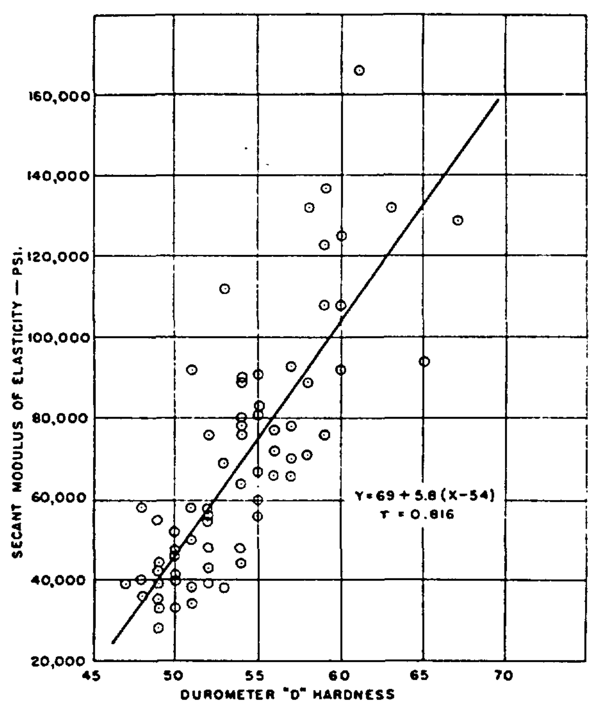

Fig. 4. Correlation betweel Durometer "D" hardness and depth of cut in guillotine test.

80° is plotted against heat distortion at 66 psi. This is the weakest of the group with a correlation coefficient of only 0.46.

Figure 3 is a plot of Durometer "D" hardness against secant modulus at 23° C. A correlation coefficient of 0.82 shows this to be a fairly good correlation. In Figure 4, Durometer "D" hardness is plotted against depth of cut in the guillotine test. This is the best correlation of the group with a coefficient of –0.88.

As a result of these correlations, several tests could possibly be dropped in screening evaluations of fillers in polyethylene. The yield strength at 80° C. and the guillotine test give essentially the same information as yield strength at 23° C. and Durometer "D" hardness, respectively, and thus are superfluous. Since Durometer "D" hardness and secant modulus correlate well, one of these tests also can be eliminated. These three tests may still be useful for the more comprehensive evaluations, since exceptions to the correlations do exist.

Summary and Conclusions

A study has been made of the effects of 26 different fillers on the properties of a medium molecular weight polyethylene resin. The fillers varied widely in the degree to which they changed such properties as tensile strength, yield strength, modulus of elasticity, brittle temperature, heat distortion temperature, and light stability.

One of the glass fiber samples caused the largest increases in yield strength and modulus. Asbestos shorts gave the greatest improvement in long-term strength. The least effect on all properties was found with either aluminum hydrate or Atomite wet-ground calcium carbonate. The results indicate that the addition of fillers to polyethylene may be used to broaden the applications of this already versatile resin.

Acknowledgements

The author wishes to express his appreciation to his colleagues in the Development Laboratories for their aid in the collection of data and the preparation of this paper, and to The Worthington Ball Co., Elyria, O., for permission to discuss their Guillotine Test. —The End

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March 1957
I-1003

Printed in U.S.A.