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PLASTIC AND SWELLING PROPERTIES OF ILLINOIS COALS

BY

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Introduction

For several years the plastic and swelling properties of Illinois coals have been studied in connection with research projects at the Illinois Geological Survey. Data have accumulated as a part of a fund of information on the characteristics of the reserves of coal of various ranks in Illinois, particularly from studies of the use of coal in underfeed stokers and the making of metallurgical coke. Similar properties of other coals, especially Eastern coals used in experimental blends for producing metallurgical coke, have been studied also. This report will summarize, classify, and compare the results accumulated from the various investigations.

Historical

Of the numerous types of equipment for measuring plastic properties of coal, three types have been tried in this laboratory: Agde-Damm, Davis, and Gieseler plastometers. The Agde-Damm apparatus gives reproductible results, but the data are not readily interpreted in terms of practical application. Illinois coals, in general, are of low plasticity, and the Davis plastometer has not been found to give good results with these coals. In our experience the Gieseler plastometer has given the most useful results, and consequently, the plasticity data discussed in this report were obtained by means of this equipment.

Apparatus

Our Gieseler plastometer was built in the Survey machine shop with minor changes from the description published by Soth and Russell.[1] The Survey instrument includes a modification in the plastometer head (see fig. 1) to permit a fixed position of the thrust bearings and provision for removal of decomposition gases by suction with a water aspiration pump.

The device for packing the sample in the plastometer (see fig. 2) was a modification of that described by Soth and Russell. We added more guides to insure proper packing and assembly of the plastometer, as this step in the determination is of primary importance.

A manually operated auto-transformer controls the temperature of the heating bath to give a steady rate of heat rise (3°C. per minute). Temperature readings are obtained by means of a chromel-alumel thermocouple in the heating bath immediately adjacent to the sample cup of the plastometer, which is connected to a Bristol pyrometer calibrated from 250°C. to 550°C. for direct reading.

The dial of the instrument is mounted with a ball bearing, and the pointer is counterbalanced. The frictional load of the plastometer has been found to be 0.9 grams at room temperature and at 400°C. This is determined by observing the minimum weight that will start and maintain movement of the dial under test conditions but without a sample. Frequent calibrations are made, after thoroughly cleaning and lubricating the bearings. The stirring shafts are replaced after approximately 100 determinations.

Free-swelling index determinations are made according to a modification of the standard British Swelling Index test, which was adopted in 1946 by the American Society for Testing Materials as its Standard Method of Test for Free-Swelling Index

[1]Soth, G. C., and Russell, C. C., Proceedings, Am. Soc. Testing Mats., vol. 43, p. 1176, 1943.

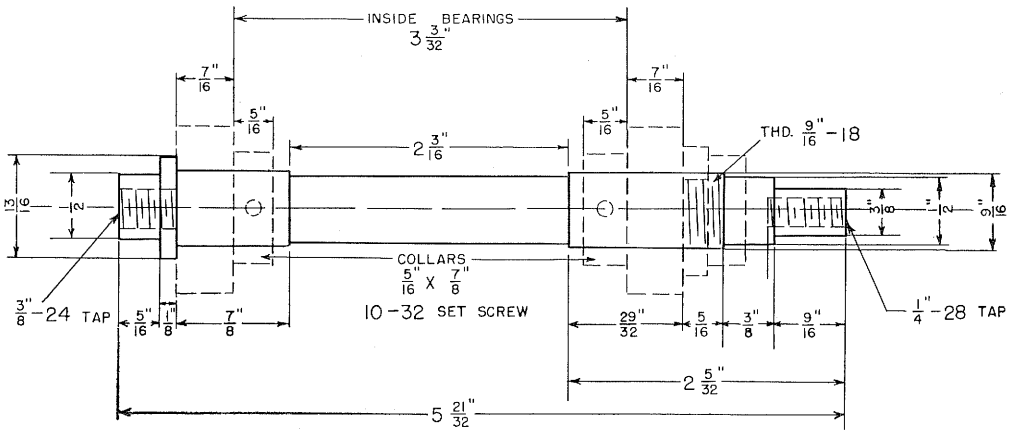

FIG. 1.—Gieseler plastometer shaft.

of Coal, D720-46.[2] In this laboratory it was necessary to use a blast type gas burner with flow meters in both the air and gas feed lines to obtain the proper rate of heating and final temperature.

SAMPLES

For the most part the coal samples studied in this report were commercial products of mines rather than mine face samples. They include sized coals used in the carbonization research program and prepared stoker coals used in the stoker research studies. Some of the coals were washed and others were unwashed.

Laboratory samples were prepared from gross samples by standard methods. For the Gieseler plasticity tests the laboratory samples were air dried and pulverized to minus 40 mesh with a minimum of finer sizes. For the free-swelling index test, samples were air dried and pulverized to minus 60 mesh.

[2]Test for Free-Swelling Index of Coal, D720-46: ASTM Standards on Coal and Coke, p. 70, Sept. 1951.

DUPLICABILITY OF RESULTS

In order to expedite the study it has been necessary in most instances to make only single determinations of plastic characteristics with the Gieseler plastometer. However, some determinations have been made in duplicate (two or more determinations on identical samples made within a 24-hour period), which provide data, although meager, for a study of duplicability. Table 1 compares 35 duplicates (18 for fusion temperature) for individual coals. Average differences between duplicates for determined significant temperatures are of the order of 1.0% with ranges from a low of zero to high of 5.6% for softening temperature and zero to 2.5% for setting temperatures. Such duplicability seems to be reasonably satisfactory.

However, duplicability of maximum fluidity values is not nearly so satisfactory. The average difference is 20%; the range is wide—zero to 87.5%.

TABLE 1.—DUPLICABILITY OF GIESELER PLASTOMETER RESULTS

	Softening temperature	Fusion temperature	Max. fluidity temperature	Setting temperature	Max. fluidity (dial div. per min.)
Number of pairs	35	18	35	35	35
Average diff., %	1.3	0.8	1.0	0.7	20.0
Minimum diff., %	0.0	0.0	0.0	0.0	0.0
Maximum diff., %	5.6	2.7	3.4	2.5	87.5

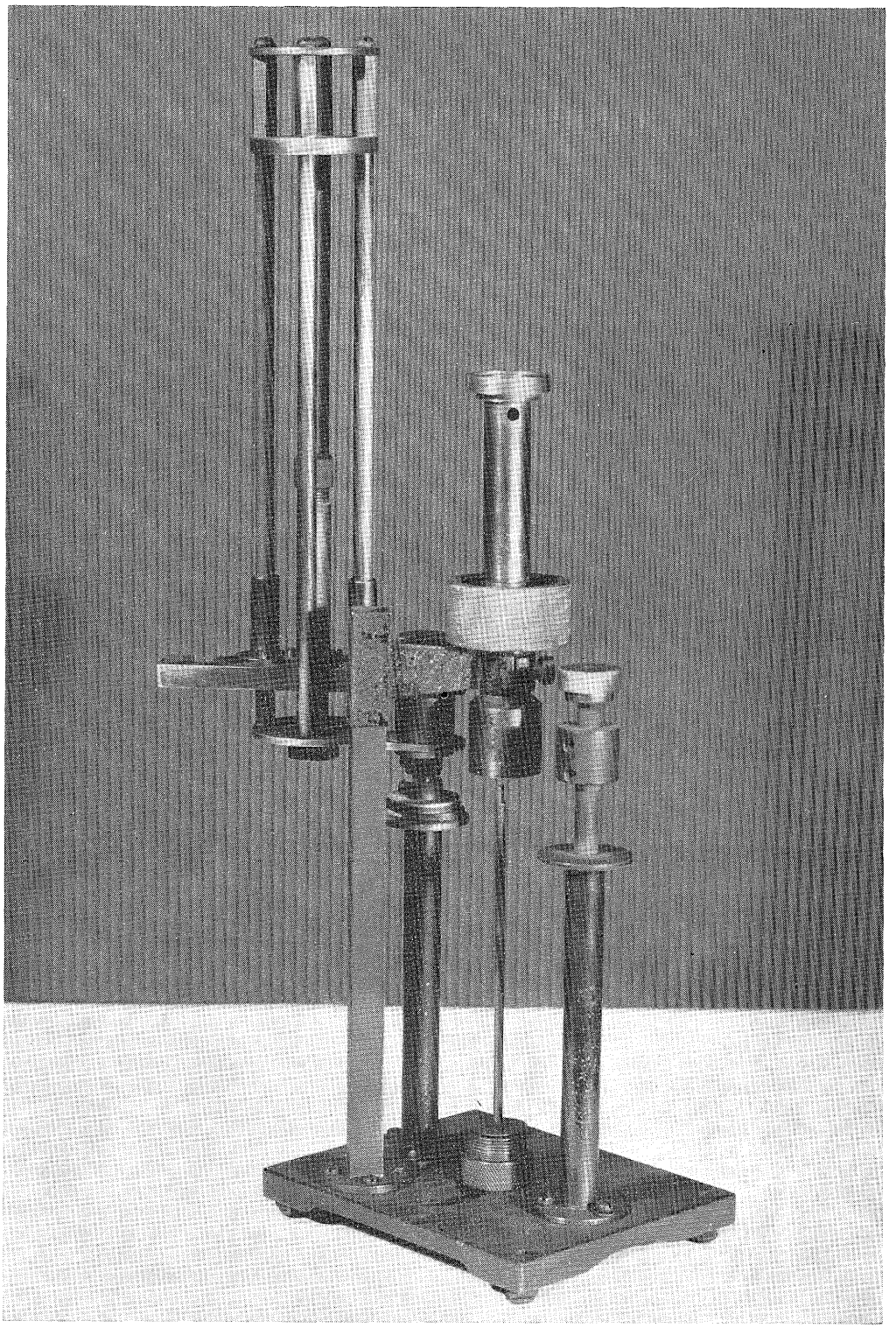

FIG. 2.—Packing device for Gieseler plastometer.

Discussion

The various values determined with the Gieseler plastometer are defined as follows:

Softening Temperature.—The temperature at which dial pointer movement reaches 0.5 dial divisions per minute.

Fusion Temperature.—The temperature at which dial pointer movement reaches 5.0 dial divisions per minute.

Maximum Fluid Temperature.—The temperature at which the dial pointer movement reaches maximum rate.

Setting Temperature.—The temperature at which dial pointer movement stops.

Maximum Fluidity.—The maximum rate of dial pointer movement in dial divisions per minute.

Plastic Range.—The temperature range, from the Softening Temperature to the Setting Temperature, in which the coal is plastic.

Maximum fluidity values are reported to the nearest unit where ten or greater. Free-swelling index values are reported to the nearest 0.5 unit.

Table 2 gives average Gieseler plasticity and free-swelling index results for Illinois coals arranged according to county, rank, and seam. Table 3 and figure 3 present average values for the various plasticity and swelling characteristics of U. S. coals arranged according to rank of coal from the low-volatile bituminous coals through the high volatile bituminous C coals.

The data shown in table 2 cover three ranks of coal found in Illinois: high-volatile bituminous A, B, and C. As far as possible, tabulated values are averages of two or more determinations made on different samples of coal within the same group. High and low values are included to show the wide differences, particularly in maximum fluidity, for coals within a given group. The fact that both maximum fluidity and free-swelling index values are definitely influenced by oxidation of the coal samples may contribute, at least in part, to these differences. It seems wise to place more confidence in averages for several coals than in individual determinations. Furthermore, such data should be considered more qualitatively than quantitatively in making comparisons.

Referring again to table 2, it will be seen that the high-volatile bituminous A coals of the No. 5 seam in Gallatin County show the highest maximum fluidity of the Illinois coals for which data are available. The high-volatile bituminous B coals of the No. 5 seam show the next highest maximum fluidity, whereas coals of this same rank in the No. 6 seam show the lowest maximum fluidity of any group of Illinois coals. Considering all high-volatile bituminous C coals together regardless of county or seam, it will be seen that, on an average, they appear to be somewhat more fluid than those of the next higher rank.

Free-swelling index values decrease with decreasing rank except for the high-volatile bituminous A coal, whose average is shown as one unit lower than that for the next lower rank. However, only two values for high-volatile bituminous A coal were available for averaging, one of which was the highest shown in table 2.

For ready comparison of plastic and swelling characteristics of Illinois coals with higher-rank Eastern coals, average values for the ranks from low-volatile bituminous through high-volatile bituminous C are tabulated in table 3 and shown graphically in figure 3. Maximum fluidities of Illinois coals are shown to be lower than those of Eastern high-volatile bituminous coals. In addition, significant temperature values for the Illinois coals are lower. Free-swelling index values decrease with decrease of rank throughout the range of ranks shown.

TABLE 2.—COUNTY AVERAGE GIESELER PLASTICITY AND FREE-SWELLING INDEX VALUES FOR ILLINOIS COALS

County	Soft temp. °C.	Fusion temp. °C.	Max. fluid. temp. °C.	Setting temp. °C.	Max. fluid. div./min.	Free-swelling index
No. 5 Seam Coals (Rank HVAB)						
Gallatin						
Average	375	399	428	474	3098	5.0
No. Averaged	3	3	3	3	3	2
High	377	401	435	487	4500	6.5
Low	373	396	424	461	1579	3.5
No. 5 Seam Coals (Rank HVBB)						
Jackson						
Average	366	404	433	466	192	6.0
No. Averaged	2	2	2	2	2	2
High	368	404	434	468	238	6.0
Low	364	404	432	463	146	5.5
Saline						
Average	388	415	433	463	49	5.0
No. Averaged	16	16	16	16	16	11
High	416	442	457	485	150	5.5
Low	357	392	417	449	14	4.0
Williamson						
Average	389	413	432	464	86	4.0
No. Averaged	10	10	10	10	10	2
High	404	431	443	474	345	4.0
Low	363	390	414	456	12	4.0
No. 6 Seam Coals (Rank HVBB)						
Douglas						
Average	362	414	429	460	12	4.0
No. Averaged	1	1	1	1	1	1
High	—	—	—	—	—	—
Low	—	—	—	—	—	—
Franklin						
Average	386	417	423	454	6.4	4.5
No. Averaged	40	15	40	40	40	64
High	413	430	441	468	42	6.0
Low	355	406	404	442	1.8	2.5
Jefferson						
Average	391	424	430	457	7.0	5.5
No. Averaged	3	3	3	3	3	1
High	393	425	431	457	7.3	—
Low	390	422	428	457	6.8	—
Perry						
Average	379	417	426	456	8.5	4.0
No. Averaged	5	4	5	5	5	6
High	391	431	432	465	18	5.0
Low	369	407	420	445	3.1	2.5
Williamson						
Average	393	418	433	461	13	5.0
No. Averaged	9	6	9	9	9	8
High	406	420	440	466	34.0	6.0
Low	386	417	425	452	2.4	4.0

TABLE 2—Continued

County	Soft temp. °C.	Fusion temp. °C.	Max. fluid. temp. °C.	Setting temp. °C.	Max. fluid. div./min.	Free-swelling index
No. 1 Seam Coals (Rank HVCB)						
Henry						
Average	—	—	—	—	—	4.5
No. Averaged	—	—	—	—	—	1
High	—	—	—	—	—	—
Low	—	—	—	—	—	—
Knox						
Average	—	—	—	—	—	3.5
No. Averaged	—	—	—	—	—	1
High	—	—	—	—	—	—
Low	—	—	—	—	—	—
No. 2 Seam Coals (Rank HVCB)						
Grundy						
Average	374	432	432	456	5.0	2.0
No. Averaged	1	1	1	1	1	1
High	—	—	—	—	—	—
Low	—	—	—	—	—	—
Hancock						
Average	—	—	—	—	—	4.0
No. Averaged	—	—	—	—	—	2
High	—	—	—	—	—	4.0
Low	—	—	—	—	—	3.5
LaSalle						
Average	326	401	417	446	19	4.0
No. Averaged	2	1	2	2	2	7
High	340	—	418	449	34	4.5
Low	312	—	416	442	4.6	3.5
Will						
Average	373	416	425	455	13	2.0
No. Averaged	9	5	9	9	9	7
High	392	421	437	464	49	3.0
Low	338	408	399	441	1.2	1.5
No. 5 Seam Coals (Rank HVCB)						
Peoria						
Average	—	—	—	—	—	3.0
No. Averaged	—	—	—	—	—	2
High	—	—	—	—	—	4.0
Low	—	—	—	—	—	2.0
Sangamon						
Average	—	—		—	—	3.0
No. Averaged	—		—	—	—	3
High	—	—	—	—	—	4.0
Low	—	—	—	—	—	3.0
Woodford						
Average	—	—	—	—	—	5.5
No. Averaged	—	—	—	—	—	2
High	—	—	—	—	—	5.5
Low	—	—	—	—	—	5.5

TABLE 2—Concluded

County	Soft temp. °C.	Fusion temp. °C.	Max. fluid. temp. °C.	Setting temp. °C.	Max. fluid. div./min.	Free-swelling index
			No. 6 Seam Coals (Rank HVCB)			
Macoupin						
Average	—	—	—	—	—	4.0
No. Averaged	—	—	—	—	—	4
High	—	—	—	—	—	4.5
Low	—	—	—	—	—	3.0
Madison						
Average	345	392	408	439	20	3.0
No. Averaged	2	1	2	2	2	3
High	349	—	409	439	36	3.5
Low	341	—	407	438	4.9	3.0
Perry						
Average	385	417	423	439	4.0	4.5
No. Averaged	2	1	2	2	2	9
High	388	—	425	445	5.8	5.0
Low	381	—	420	432	2.1	3.5
Randolph						
Average	—	—	—	—	—	4.0
No. Averaged	—	—	—	—	—	2
High	—	—	—	—	—	4.0
Low	—	—	—	—	—	3.5
St. Clair						
Average	—	—	—	—	—	4.0
No. Averaged	—	—	—	—	—	3
High	—	—	—	—	—	4.5
Low	—	—	—	—	—	3.5
Vermilion						
Average	374	—	408	442	2.1	4.0
No. Averaged	1	—	1	1	1	6
High	—	—	—	—	—	4.0
Low	—	—	—	—	—	3.5
Washington						
Average	—	—	—	—	—	4.5
No. Averaged	—	—	—	—	—	1
High	—	—	—	—	—	—
Low	—	—	—	—	—	—
			No. 7 Seam Coals (Rank HVCB)			
Will						
Average	333	401	425	465	158	2.5
No. Averaged	1	1	1	1	1	1
High	—	—	—	—	—	—
Low	—	—	—	—	—	—

TABLE 3.—GIESELER AND FREE-SWELLING INDEX DATA FOR UNITED STATES COALS. RANK AVERAGE VALUES

Rank	Softening temp. °C.[1]	Fusion temp. °C.[2]	Maximum fluid temp. °C.	Setting temp. °C.	Maximum fluidity dial div./min.	Free-swelling index[3]
Low-Vol. Bituminous						
Average	447	472	483	511	12	8.5
No. Averaged	39	31	39	39	39	45
High	467	488	499	526	40	9.5
Low	412	451	464	487	1.8	6.0
Medium-Vol. Bituminous						
Average	390	423	463	504	2991	8.5
No. Averaged	5	5	5	5	5	12
High	397	431	483	511	10,000	9.0
Low	377	412	444	499	723	5.5
High-Vol. A Bit. (Eastern)						
Average	388	414	442	481	5004	6.0
No. Averaged	73	74	74	74	74	72
High	433	456	463	504	15,000	9.0
Low	343	388	420	456	22	2.5
High-Vol. A Bituminous Illinois No. 5 Seam						
Average	375	399	428	474	3098	5.0
No. Averaged	3	3	3	3	3	2
High	377	401	435	487	4500	6.5
Low	373	396	424	461	1579	3.5
High-Vol. B Bituminous Illinois No. 5 Seam						
Average	387	414	433	464	73	5.0
No. Averaged	28	28	28	28	28	16
High	416	442	457	485	345	6.0
Low	357	390	414	449	12	4.0
High-Vol. B Bituminous Illinois No. 6 Seam						
Average	386	418	425	456	8.5	4.5
No. Averaged	58	29	58	58	58	80
High	413	431	441	468	42	6.0
Low	362	406	404	442	1.8	2.5
High-Vol. C Bituminous Illinois Coals						
Average	364	413	421	450	20	3.5
No. Averaged	18	10	18	18	18	54
High	392	432	437	465	158	5.5
Low	312	392	399	432	1.2	1.5

[1]Temperature at 0.5 dial divisions per minute.
[2]Temperature at 5.0 dial divisions per minute.
[3]Values to nearest 0.5 unit.

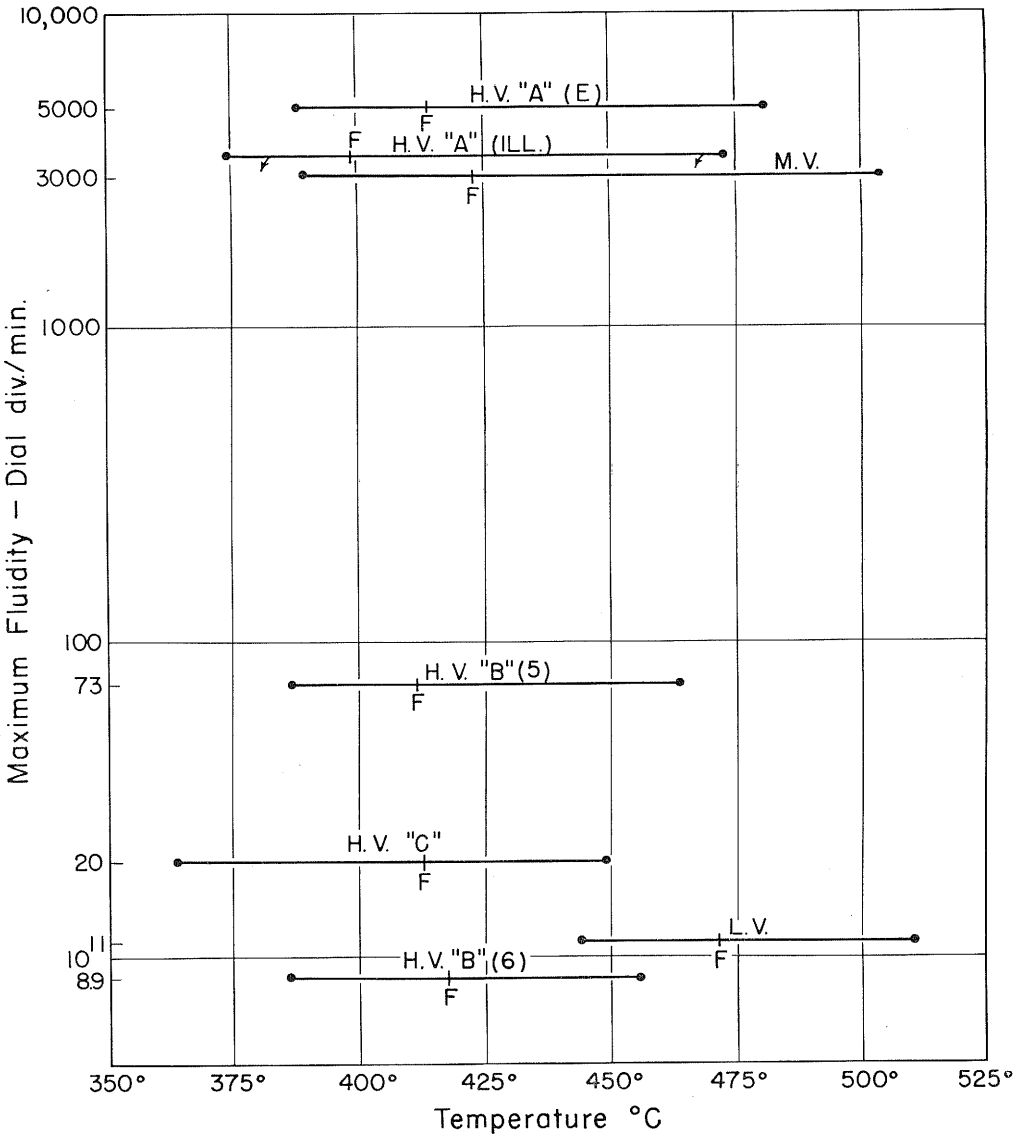

FIG. 3.—Gieseler fluidity and plastic range. The plastic range is the range between the softening temperature and the setting temperature. F is the fusion temperature.