PHYSICAL PROPERTIES OF RUBBER AND RUBBER SUBSTITUTES UNDER HEAT TREATMENT AND AT DIFFERENT TEMPERATURES

BY

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INTRODUCTION

This investigation was made to determine some of the physical properties of rubber and rubber substitutes at different temperatures and after prolonged heat treatment. Twenty samples were secured for this investigation. The investigation consisted of tests made upon these samples before and after a heat treatment of 1500 hours at a constant temperature of 100 degrees Centigrade and tests made at different temperatures between 0.0 degrees and 100 degrees Centigrade. These tests were hardness, elasticity, relative resilience, thermal conductivity, and shrinkage. The results of this investigation are to be used in industry to enable improvements and development. Due to this fact the samples will be designated by numbers as Sample No. 1, etc.

CHAPTER I

HARDNESS, ELASTICITY, AND RELATIVE RESILIENCE

A. CONSTANT TEMPERATURE OVEN

The samples named in the introduction were given a heat treatment consisting of 1500 hours at a constant temperature of 100 degrees Centigrade. A constant temperature oven was constructed to hold the temperature at 100 plus or minus 1 degree Centigrade. (See Fig. 1.) This heating test compares closely with the Greer Artificial Aging Test* which employs a constant temperature oven at 70 degrees Centigrade plus or minus 1 degree Centigrade. The samples were placed in the oven (Fig. 2) and tests made every two hours at the beginning of the treatment, the period gradually being extended to once a week. These tests consisted of hardness, elasticity, and relative resilience.

B. SHORE DUROMETER

The Shore Type "A" Durometer (Fig. 3) is an instrument to measure the hardness of semi-elastic rubbers and soft plastics. The Durometer is manufactured by the Shore Instrument and Mfg. Co. Inc., Jamaica, New York** This instrument

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*Davis, C. C. and J. T. Blake. 1937. Chemistry and Technology of Rubber. Reinhold Publishing Corporation, New York, N. Y. Page 819.

**Bulletin R-5. The Shore Instrument and Mfg. Co., Inc.; Jamaica, N. Y.

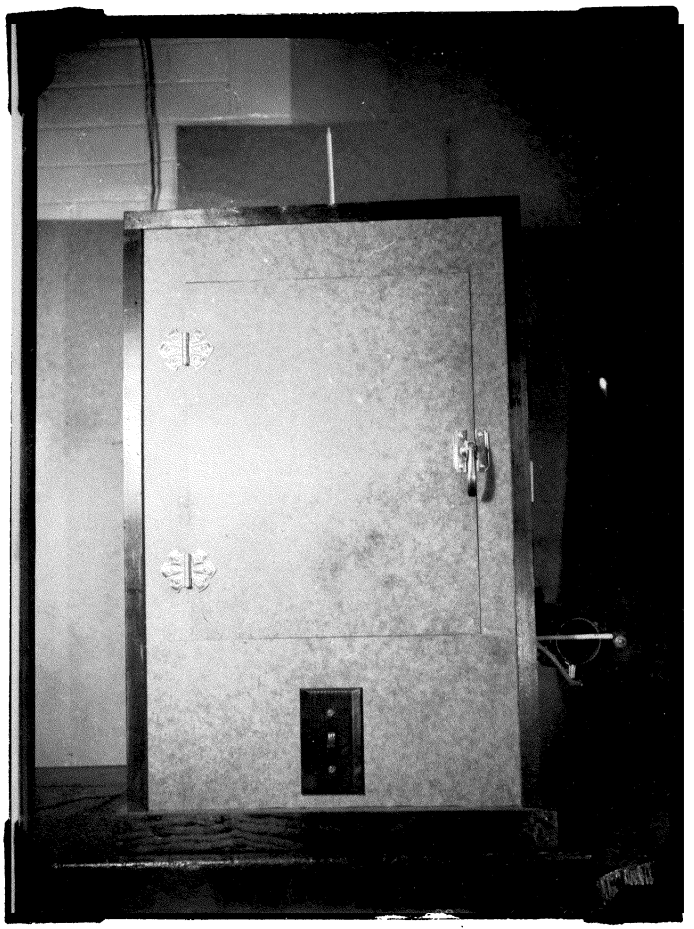

Figure 1.—Constant temperature oven.

Figure 2.—Arrangement of samples in constant temperature oven.

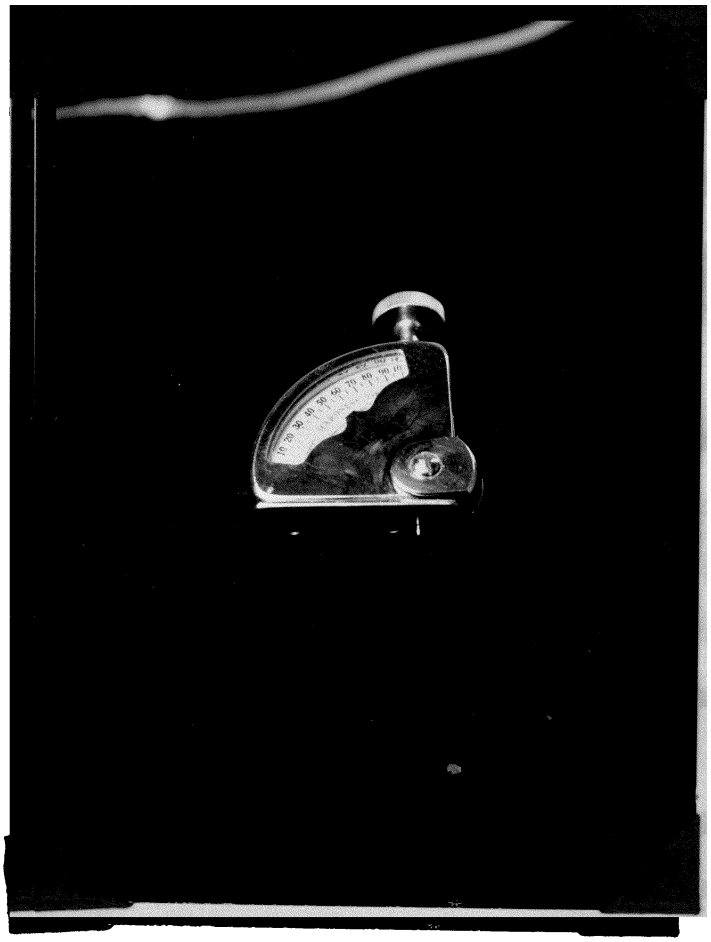

Figure 3.—Shore Type "A" Durometer.

has a small blunt pin or indentor which is placed against the sample. The instrument is pressed against the sample so that the axis of the pin is always perpendicular to the surface of the specimen. Enough pressure is exerted to seat the rest plate uniformly upon the sample. A standard spring presses the pin against the surface, indenting it according to the specimen. Geared to this pin is a small hand which indicates the hardness on a calibrated dial. The impressor pin is shaped like the frustum of a cone with a shank 3/64 inch in diameter and a flat tip 1/32 inch in diameter. When the pin begins to yield, the indicator hand departs from zero after a pressure of 2 ounces, then proceeding up to 29 ounces at which point 100 is indicated on the dial. The full stroke of the pin is 0.1 inch so that each division on the scale indicates 0.001 inch of depth traveled. While not regularly shown, the scale reads inversely as the depth of travel of the indicator; that is, the zero for depth travel would be at 100 on the scale, and 100 depth would be at zero on the scale*. The unit of hardness is called the "Durometer" and hardness specifications are written "65 Durometer" or whatever the numerical value might be. All hardness tests in the investigation were made with the Shore Durometer and performed in the manner prescribed above.

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*American Society for Testing Materials, Philadelphia, Pa. Symposium on Rubber. Page 92. March 9, 1932.

Davis, C. C. and J. T. Blake. 1937. Chemistry and Technology of Rubber. Reinhold Publishing Corporation, New York, N. Y. Page 810.

C. THE ELASTOMETER

The Elastometer (Fig. 4) also is made by the Shore Instrument and Mfg. Co., Inc.* It operates by a small pin which penetrates the sample with a cutting stress. This physical test compares closely with the standard stretch test used on very soft rubbers. The Elastometer is unlike the Durometer in that the penetrating pin of the Elastometer is sharp like a cone, whereas the indentor pin of the Durometer is blunt like the frustum of a cone. The penetrator pin is 0.1 inch in length and about 0.05 inch in diameter at the base of the instrument. This instrument unlike the Durometer has no spring attached to the penetrator. The dial of the instrument is calibrated like that of the Durometer except that the unit of elasticity is "percent" instead of "Durometer". To use the instrument, a small knob on the side is brought into the down position, locking the penetrator. The instrument is then pressed against the sample forcing the penetrator into the sample. The axis of the penetrator should always be perpendicular to the surface of the sample. When the point has penetrated its full length, so that the rest plate is in full contact with the sample, the penetrator is released by moving the locking knob upward. Then the indicating hand on the dial begins to move away from zero as the specimen forces

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*Bulletin R-5. The Shore Instrument and Mfg. Co., Inc., Jamaica, N. Y.

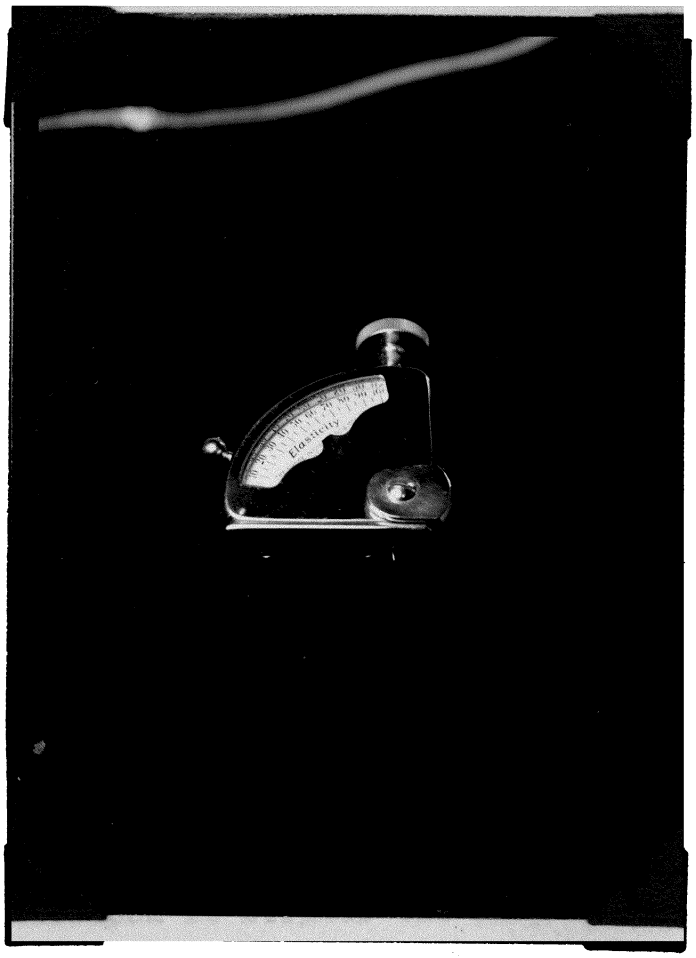

Figure 4.—Shore Elastometer.

the penetrating point out. When the hand stops, the elasticity is read, the unit being in percent of elasticity. All tests made with this instrument were performed as specified above.

D. RELATIVE RESILIENCE APPARATUS

An instrument was constructed (Fig. 5) to measure the relative resilience of the samples. These measurements were made by allowing a small steel sphere to drop from a given height upon a sample of rubber, or rubber substitute, and rebound, the height of rebound evaluating the relative resilience*. The relative resilience apparatus consists of two major parts; first, a system to control the freely falling steel sphere and measure its rebound; and second, the anvil and heating system to keep the specimen at constant temperature.

The steel sphere falls through a vertical glass tube 122 cm. long whereupon it strikes the sample and rebounds up the tube. The height of rebound is measured with the aid of a meter stick adjacent to the glass tube. The steel sphere weighs 8 grams and has a diameter of 1.25 cm. The relative resilience is the rebound in cm.

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*Davis, C. C and J. T. Blake. 1937. Chemistry and Technology of Rubber. Reinhold Publishing Corporation, New York, N. Y. Page 812.

Figure 5.—Relative resilience apparatus.

The anvil is a horizontal steel plate 2.1 cm. thick and 22.0 cm. in diameter. The steel plate is supported and kept in a horizontal position by three leveling screws. Beneath the plate is welded a water jacket allowing the water to come in contact with the bottom of the plate. This water jacket was kept at 100 degrees Centigrade by boiling the water with a gas burner. A copper constantan thermocouple was used to check the temperature of the anvil surface. This temperature was about 96 degrees Centigrade, which approximates the constant temperature of the sample.

E. DATA AND GRAPHS

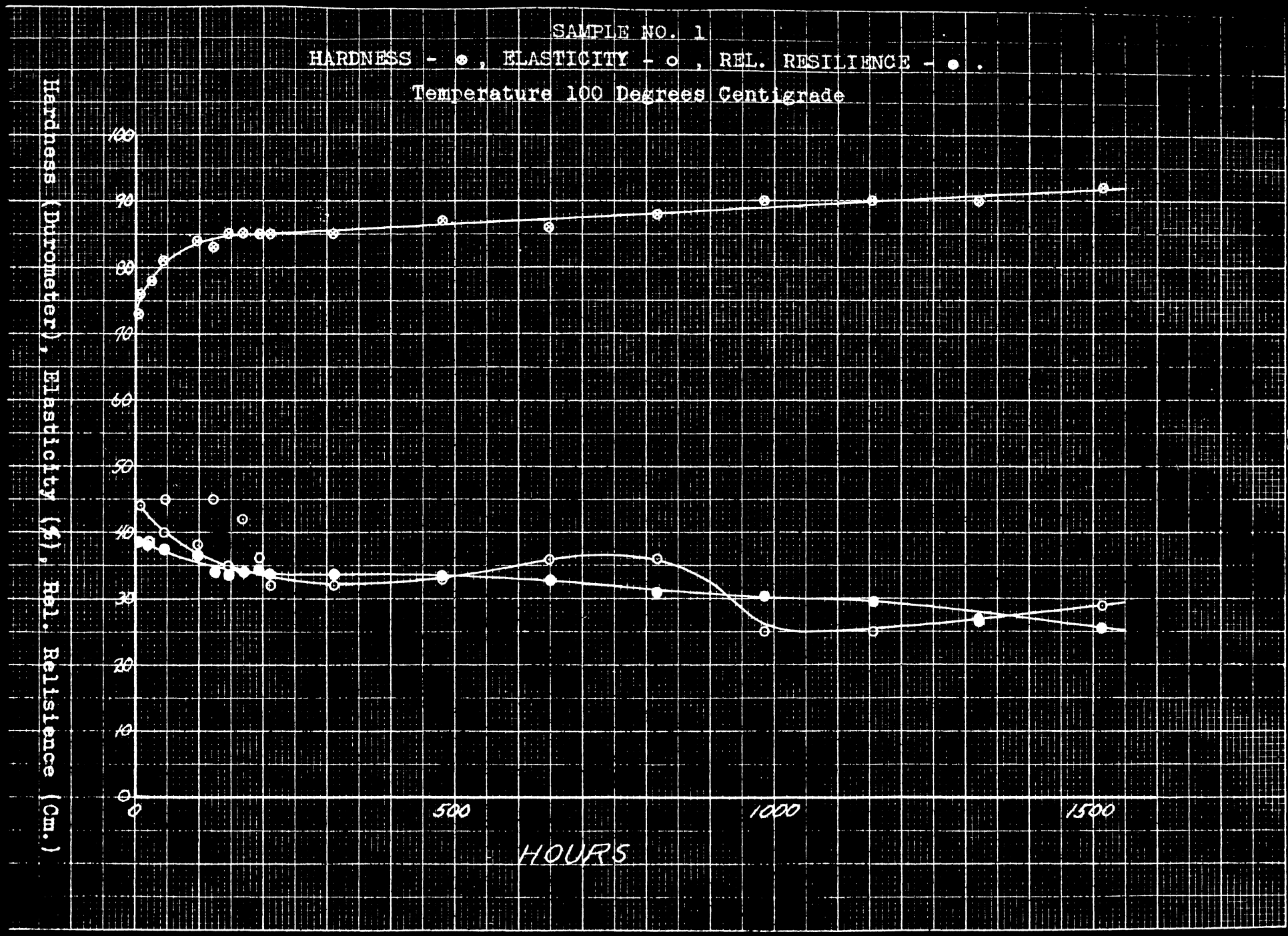
The following data was taken at the hour specified under (Hours) on the data sheets. The samples were taken from the oven and placed on the anvil of the resilience apparatus, the hardness, elasticity and relative resilience recorded. The 1500-hour period is equivalent to about 67 days or a little over two months.

For this particular phase of the investigation, the hardness, elasticity, and relative resilience curves for each sample were plotted on one sheet of graph paper. This was done so a comparison of properties might be made. Time in (hours) is plotted along the abscissa and the hardness (Hardness), elasticity (Elasticity), and relative resilience (Rel. Resilience) plotted along the ordinate.

Physical Properties of Rubber and Rubber Substitutes Over a Period of 1500 Hours at a Constant Temperature of 100 Degrees Centigrade.

Sample No. 1

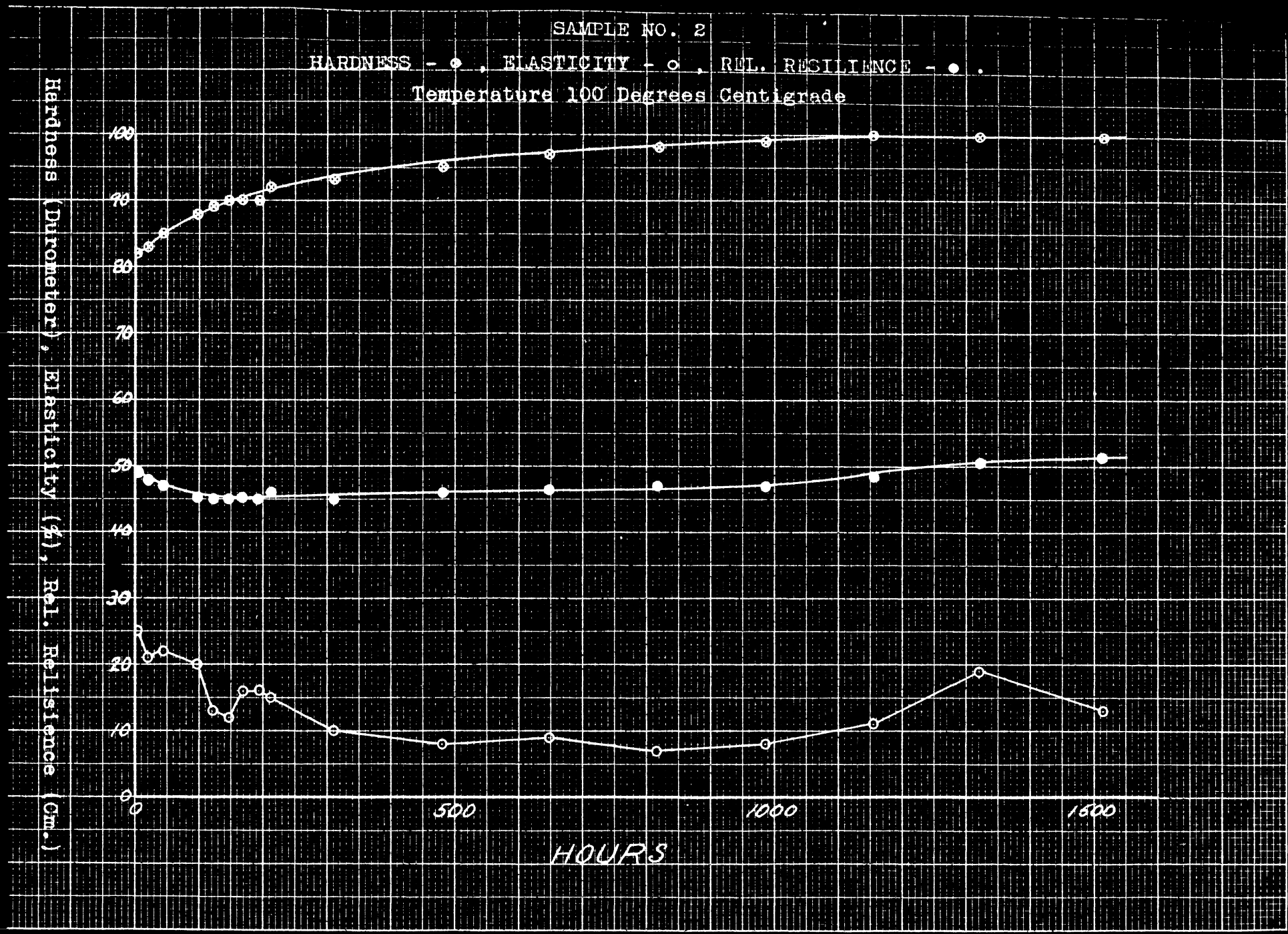
Test No.	Hours	Hardness (Durometer)	Elasticity (%)	Rel. Resilience (Rebound in Cm.)
1	2.0	76	73	38.5
2	4.5	77	52	38.5
3	6.5	75	55	38.0
4	8.5	76	44	38.0
5	20.5	80	38	38.0
6	25.5	78	46	37.5
7	44.0	81	45	37.2
8	97.5	84	38	36.6
9	121.0	83	45	34.0
10	145.0	85	35	33.5
11	169.0	85	42	34.0
12	193.0	85	36	34.2
13	211.0	85	32	33.8
14	310.0	85	32	33.8
15	480.5	87	33	33.2
16	648.0	86	36	32.8
17	817.0	88	36	31.0
18	984.0	90	25	30.2
19	1153.0	90	25	29.5
20	1320.0	90	27	26.5
21	1512.0	92	29	25.5


SAMPLE NO. 1
HARDNESS - ⊗ , ELASTICITY - o , REL. RESILIENCE - ● .
Temperature 100 Degrees Centigrade
Hardness (Durometer), Elasticity (%), Rel. Relisience (Cm.)
100
90
80
70
60
50
40
30
20
10
0
0
500
1000
1500
HOURS

Physical Properties of Rubber and Rubber Substitutes Over a Period of 1500 Hours at a Constant Temperature of 100 Degrees Centigrade.

Sample No. 2

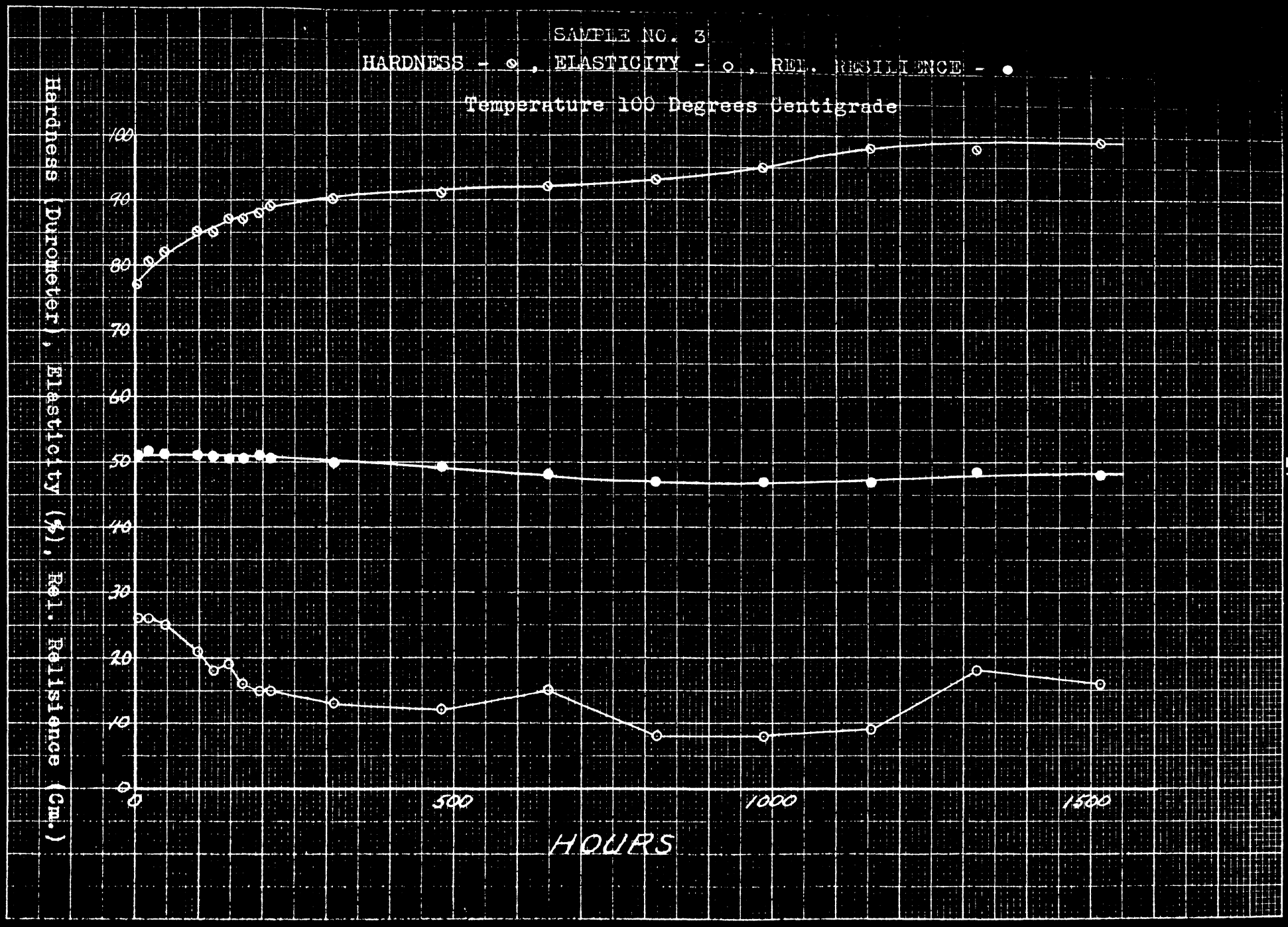
Test No.	Hours	Hardness (Durometer)	Elasticity (%)	Rel. Resilience (Rebound in Cm.)
1	2.0	82	25	49.0
2	4.5	83	24	49.0
3	6.5	81	22	49.0
4	8.5	82	26	48.5
5	20.5	83	21	48.0
6	25.5	84	20	47.5
7	44.0	85	22	47.0
8	97.5	88	20	40.2
9	121.0	89	13	40.0
10	145.0	90	12	40.0
11	169.0	90	16	40.2
12	193.0	90	16	40.0
13	211.0	92	15	41.0
14	310.0	93	10	40.0
15	480.5	95	8	41.0
16	648.0	97	9	41.4
17	817.0	98	7	42.0
18	984.0	99	8	42.0
19	1153.0	100	11	43.5
20	1320.0	100	19	45.5
21	1512.0	100	13	46.5


SAMPLE NO. 2
HARDNESS - ⊗ , ELASTICITY - o , REL. RESILIENCE - ● .
Temperature 100 Degrees Centigrade
Hardness (Durometer), Elasticity (%), Rel. Relisience (Cm.)
100
90
80
70
60
50
40
30
20
10
0
0
500
1000
1500
HOURS

Physical Properties of Rubber and Rubber Substitutes Over a Period of 1500 Hours at a Constant Temperature of 100 Degrees Centigrade.

Sample No. 3

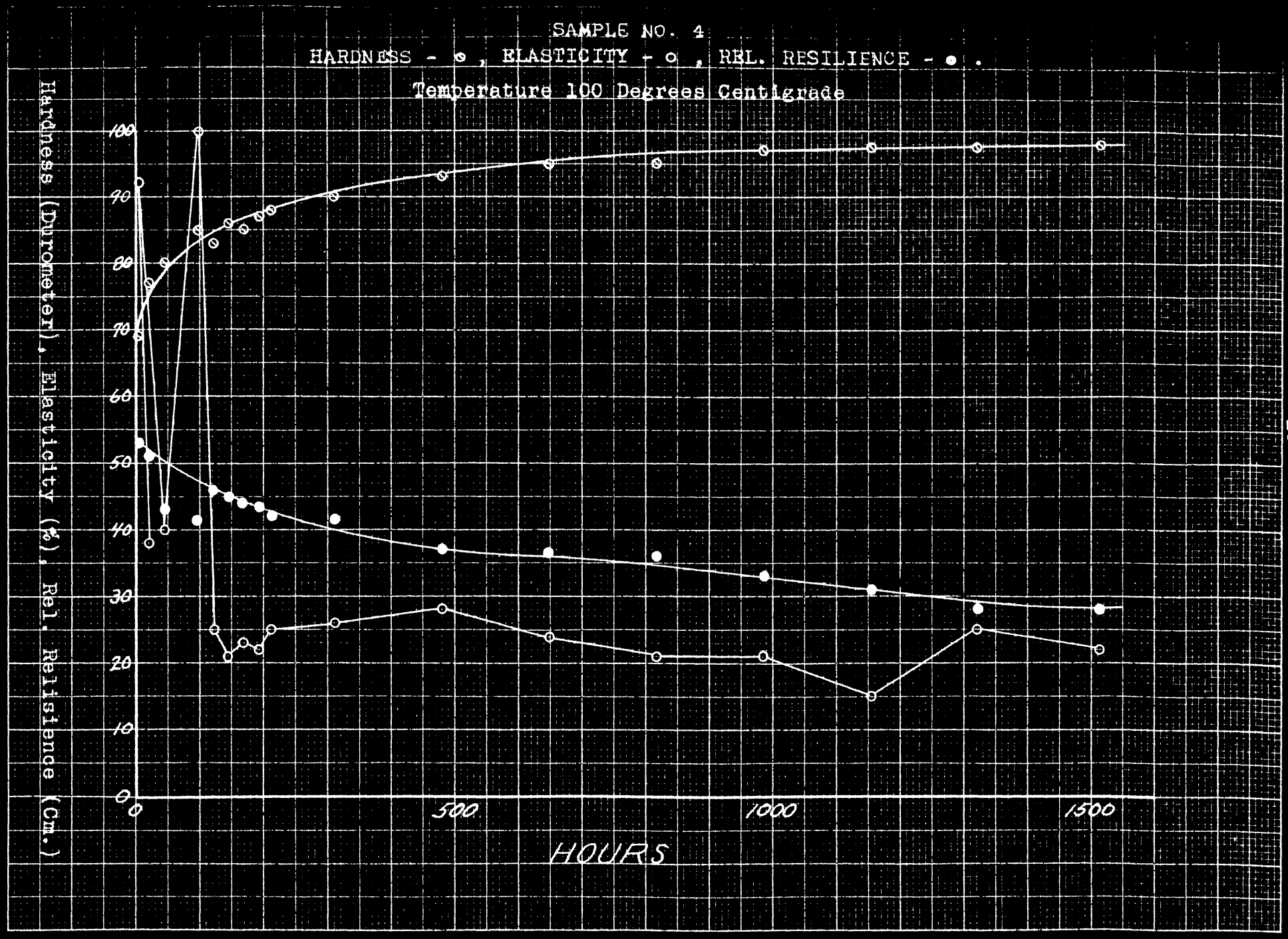
Test No.	Hours	Hardness (Durometer)	Elasticity (%)	Rel. Resilience (Rebound in Cm.)
1	2.0	77	26	51.0
2	4.5	78	28	51.2
3	6.5	78	28	51.3
4	8.5	78	25	52,0
5	20.5	80.5	26	51.8
6	25.5	80	21	51.0
7	44.0	82	25	51.2
8	97.5	85	21	51.0
9	121.0	85	18	51.0
10	145.0	87	19	50.5
11	169.0	87	16	50.5
12	193.0	88	15	51.0
13	211.0	89	15	50.5
14	310.0	90	13	50.0
15	480.5	91	17	49.5
16	648.0	92	15	48.0
17	817.0	93	8	47.0
18	984.0	95	8	47.0
19	1153.0	98	9	47.0
20	1320.0	98	18	48.4
21	1512.0	99	16	48.0


SAMPLE NO. 3
HARDNESS - ⊙ , ELASTICITY - ○ , REL. RESILIENCE - ●
Temperature 100 Degrees Centigrade
Hardness (Durometer), Elasticity (%), Rel. Relisience (Cm.)
100
90
80
70
60
50
40
30
20
10
0
0
500
1000
1500
HOURS

Physical Properties of Rubber and Rubber Substitutes Over a Period of 1500 Hours at a Constant Temperature of 100 Degrees Centigrade.

Sample No. 4

Test No.	Hours	Hardness (Durometer)	Elasticity (%)	Rel. Resilience (Rebound in Cm.)
1	2.0	69	74	53.0
2	4.5	72	92	52.0
3	6.5	70	100	53.5
4	8.5	74	30	53.0
5	20.5	77	28	51.0
6	25.5	77	25	51.4
7	44.0	80	30	43.0
8	97.5	85	100	41.5
9	121.0	83	25	46.0
10	145.0	86	21	45.0
11	169.0	85	23	44.0
12	193.0	87	22	43.5
13	211.0	88	25	42.0
14	310.0	90	26	41.5
15	480.5	93	28	37.0
16	648.0	95	24	36.5
17	817.0	95	21	36.0
18	984.0	97	21	33.0
19	1153.0	97.5	15	31.0
20	1320.0	97.5	25	28.0
21	1512.0	98	27	28.0


SAMPLE NO. 4
HARDNESS - ⊙ , ELASTICITY - ○ , REL. RESILIENCE - ● .
Temperature 100 Degrees Centigrade
Hardness (Durometer), Elasticity (%), Rel. Relisience (Cm.)
100
90
80
70
60
50
40
30
20
10
0
0
500
1000
1500
HOURS

Physical Properties of Rubber and Rubber Substitutes Over a Period of 1500 Hours at a Constant Temperature of 100 Degrees Centigrade.

Sample No. 5

Test No.	Hours	Hardness (Durometer)	Elasticity (%)	Rel. Resilience (Rebound in Cm.)
1	2.0	78	31	37.5
2	4.5	80	29	38.0
3	6.5	81	30	37.8
4	8.5	81	20	38.0
5	20.5	84	22	37.8
6	25.5	85	16	37.2
7	44.0	85	23	37.2
8	97.5	89	19	35.0
9	121.0	90	16	34.5
10	145.0	91	16	34.0
11	169.0	90	10	34.0
12	193.0	90	13	34.0
13	211.0	92	16	34.0
14	310.0	92	13	33.8
15	480.5	95	12	33.2
16	648.0	96	11	33.0
17	817.0	96	11	33.0
18	984.0	97	16	32.6
19	1153.0	97	19	33.0
20	1320.0	97	18	33.0
21	1512.0	98	15	33.0

SAMPLE NO. 5

HARDNESS - ⊙ , ELASTICITY - ○ , REL.RESILIENCE - ● .

Temperature 100 Degrees Centigrade

Hardness (Durometer), Elasticity (%), Rel. Resilience (Cm.)

100
90
80
70
60
50
40
30
20
10
0

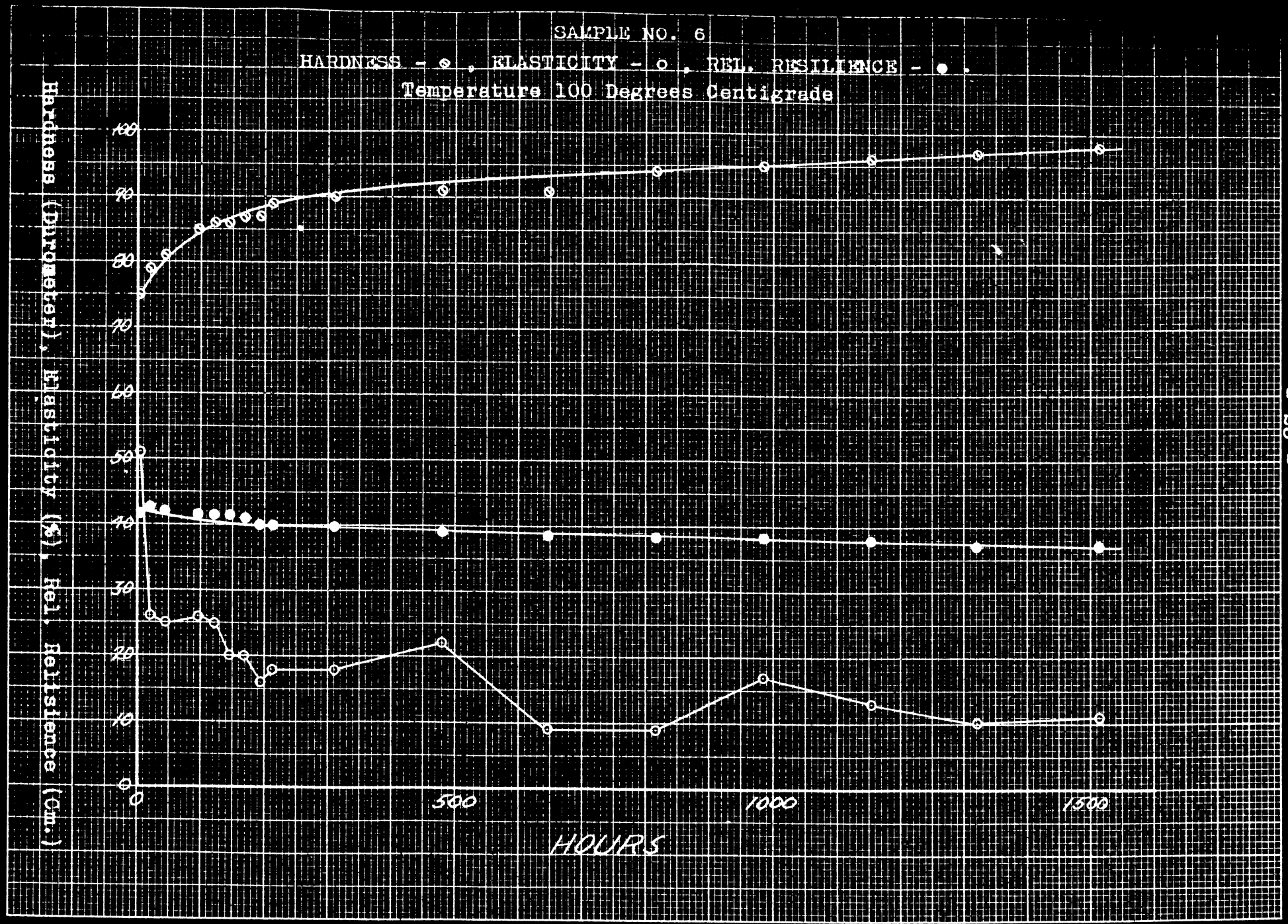
500
1000
1500

HOURS

Physical Properties of Rubber and Rubber Substitutes Over a Period of 1500 Hours at a Constant Temperature of 100 Degrees Centigrade.

Sample No. 6

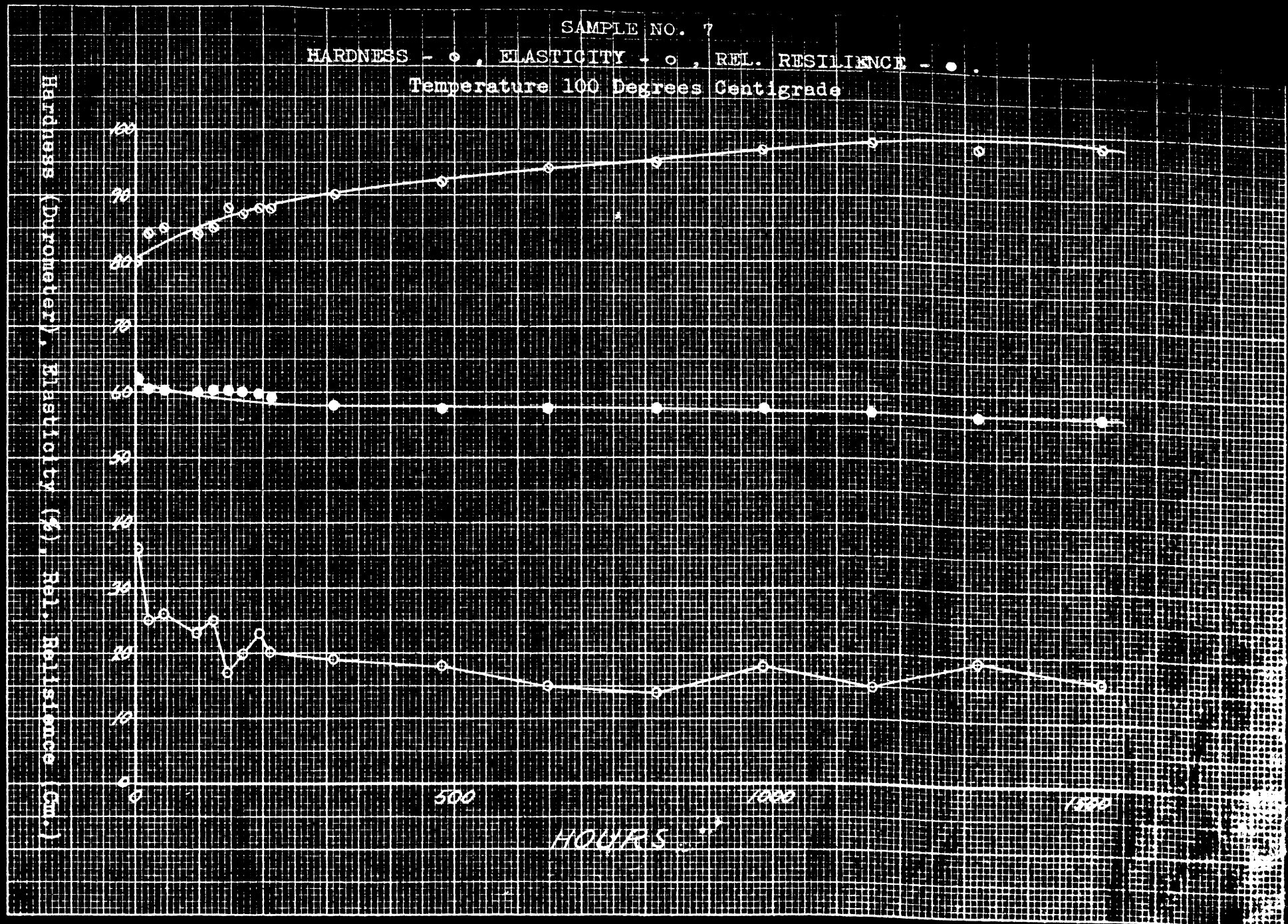
Test No.	Hours	Hardness (Durometer)	Elasticity (%)	Rel. Resilience (Rebound in Cm.)
1	2.0	75	40	41.5
2	4.5	76	51	41.5
3	6.5	76	37	42.0
4	8.5	78	32	42.3
5	20.5	79	26	42.6
6	25.5	80	26	42.8
7	44.0	81	25	42.0
8	97.5	85	26	41.6
9	121.0	86	25	41.5
10	145.0	86	20	41.5
11	169.0	87	20	41.0
12	193.0	87	16	40.0
13	211.0	89	18	40.0
14	310.0	90	18	39.8
15	480.5	91	22	39.0
16	648.0	91	9	38.5
17	817.0	94	9	38.5
18	984.0	95	17	38.2
19	1153.0	96	13	38.0
20	1320.0	97	10	37.0
21	1512.0	98	11	37.0


SAMPLE NO. 6
HARDNESS - ⊗ , ELASTICITY - o , REL. RESILIENCE - ● .
Temperature 100 Degrees Centigrade
Hardness (Durometer), Elasticity (%), Rel. Resilience (Cm.)
100
90
80
70
60
50
40
30
20
10
0
500
1000
1500
HOURS

Physical Properties of Rubber and Rubber Substitutes Over a Period of 1500 Hours at a Constant Temperature of 100 Degrees Centigrade.

Sample No. 7

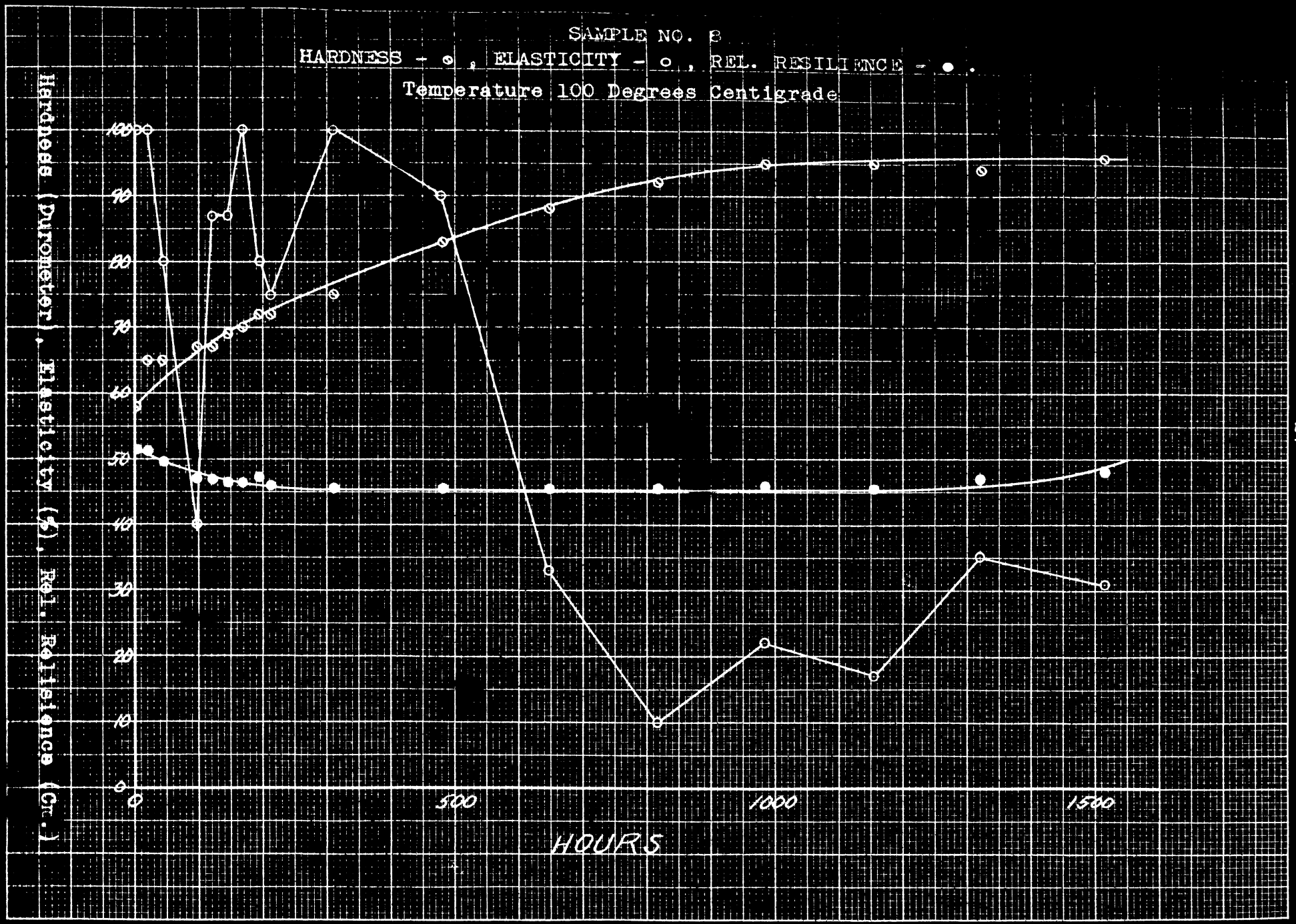
Test No.	Hours	Hardness (Durometer)	Elasticity (%)	Rel. Resilience (Rebound in Cm.)
1	2.0	80	36	62.0
2	4.5	81	34	61.0
3	6.5	82	39	61.0
4	8.5	83	30	60.8
5	20.5	84	25	60.4
6	25.5	84	34	60.2
7	44.0	85	26	60.2
8	97.5	84	23	60.0
9	121.0	85	25	60.2
10	145.0	86	17	60.2
11	169.0	87	20	60.0
12	193.0	88	23	59.8
13	211.0	88	20	59.0
14	310.0	90	19	58.0
15	480.5	92	18	57.5
16	646.0	94	15	57.5
17	817.0	95	14	57.5
18	984.0	97	18	57.5
19	1153.0	98	15	57.0
20	1320.0	97.5	19-	56.6
21	1512.0	98	16	56.5


SAMPLE NO. 7
HARDNESS - o , ELASTICITY - o , REL. RESILIENCE - ● .
Temperature 100 Degrees Centigrade
Hardness (Durometer), Elasticity (%), Rel. Resilience (%)
100
90
80
70
60
50
40
30
20
10
0
500
1000
1500
HOURS

Physical Properties of Rubber and Rubber Substitutes Over a Period of 1500 Hours at a Constant Temperature of 100 Degrees Centigrade.

Sample No. 8

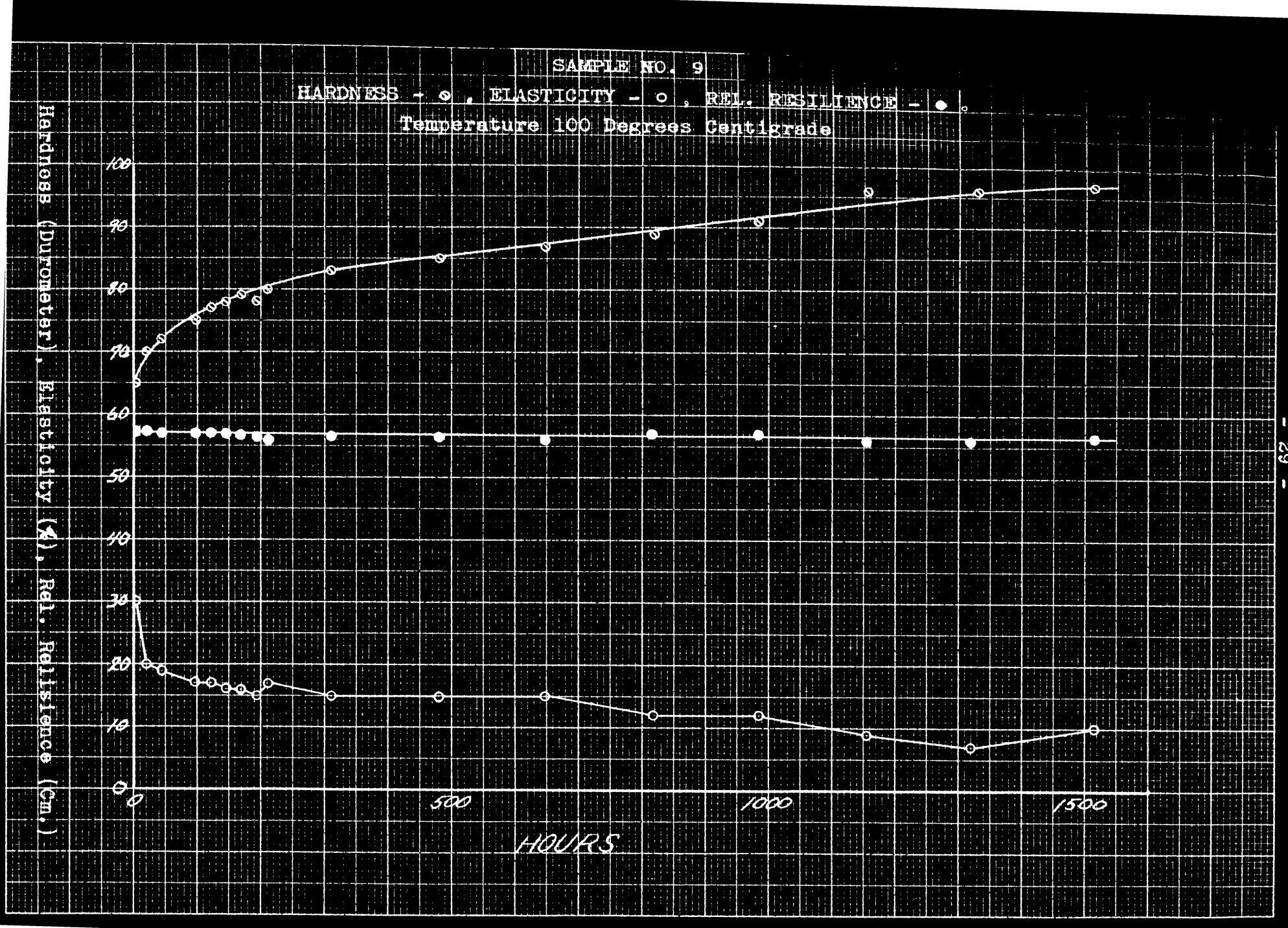
Test No.	Hours	Hardness (Durometer)	Elasticity (%)	Rel. Resilience (Rebound in Cm.)
1	2.0	58	100	51.5
2	4.5	60	100	51.0
3	6.5	60	100	51.2
4	8.5	60	100	51.0
5	20.5	65	100	51.2
6	25.5	64	95	50.2
7	44.0	65	80	49.6
8	97.5	67	40	47.0
9	121.0	67	87	47.0
10	145.0	69	87	46.6
11	169.0	70	100	46.4
12	193.0	72	80	47.2
13	211.0	72	75	46.0
14	310.0	75	100	45.5
15	480.5	83	90	45.5
16	648.0	88	33	45.5
17	817.0	92	10	45.5
18	984.0	95	22	46.0
19	1153.0	95	17	45.5
20	1320.0	94	35	47.0
21	1512.0	93	31	46.0


SAMPLE NO. 8
HARDNESS - ⊙ , ELASTICITY - o , REL. RESILIENCE - ● .
Temperature 100 Degrees Centigrade
Hardness (Durometer), Elasticity (%), Rel. Resilience (Ct.)
100
90
80
70
60
50
40
30
20
10
0
500
1000
1500
HOURS

Physical Properties of Rubber and Rubber Substitutes Over a Period of 1500 Hours at a Constant Temperature of 100 Degrees Centigrade.

Sample No. 9

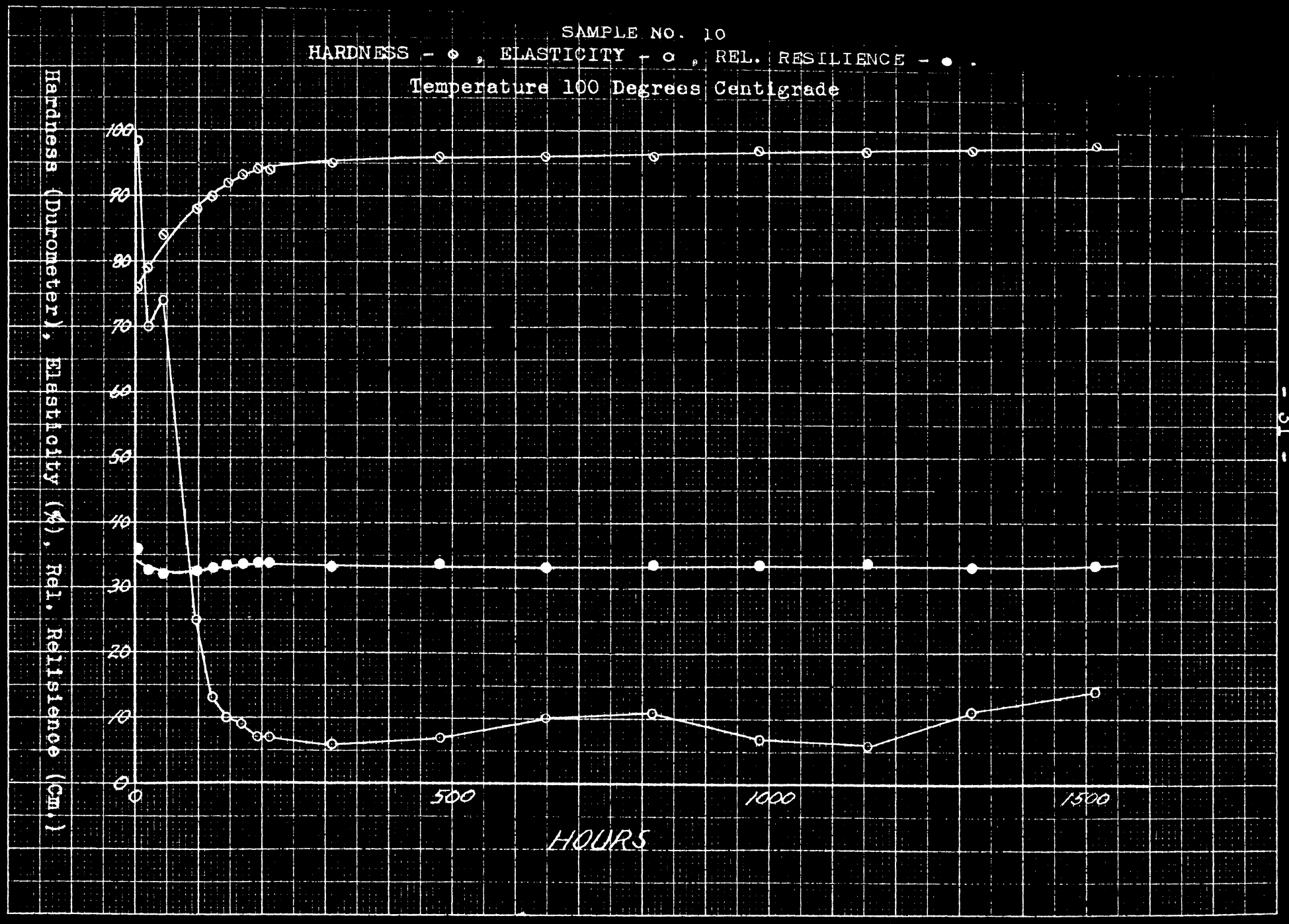
Test No.	Hours	Hardness (Durometer)	Elasticity (%)	Rel. Resilience (Rebound in Cm.)
1	2.0	65	30	57.5
2	4.5	65	28	57.3
3	6.5	66	26	57.3
4	8.5	67	20	57.5
5	20.5	70	20	57.2
6	25.5	70	22	57.0
7	44.0	72	19	57.0
8	97.5	75	17	57.0
9	121.0	77	17	57.0
10	145.0	78	16	57.0
11	169.0	79	16	56.8
12	193.0	78	15	56.4
13	211.0	80	17	56.0
14	310.0	83	15	56.5
15	480.5	85	15	56.5
16	648.0	87	15	56.0
17	817.0	89	12	57.0
18	984.0	91	12	57.0
19	1153.0	96	9	56.0
20	1320.0	96	7	56.0
21	1512.0	97	10	56.5


SAMPLE NO. 9
HARDNESS - ⊙ , ELASTICITY - ○ , REL. RESILIENCE - ● .
Temperature 100 Degrees Centigrade
Hardness (Durometer), Elasticity (%), Rel. Resilience (Cm.)
100
90
80
70
60
50
40
30
20
10
0
0
500
1000
1500
HOURS

Physical Properties of Rubber and Rubber Substitutes Over a Period of 1500 Hours at a Constant Temperature of 100 Degrees Centigrade.

Sample No. 10

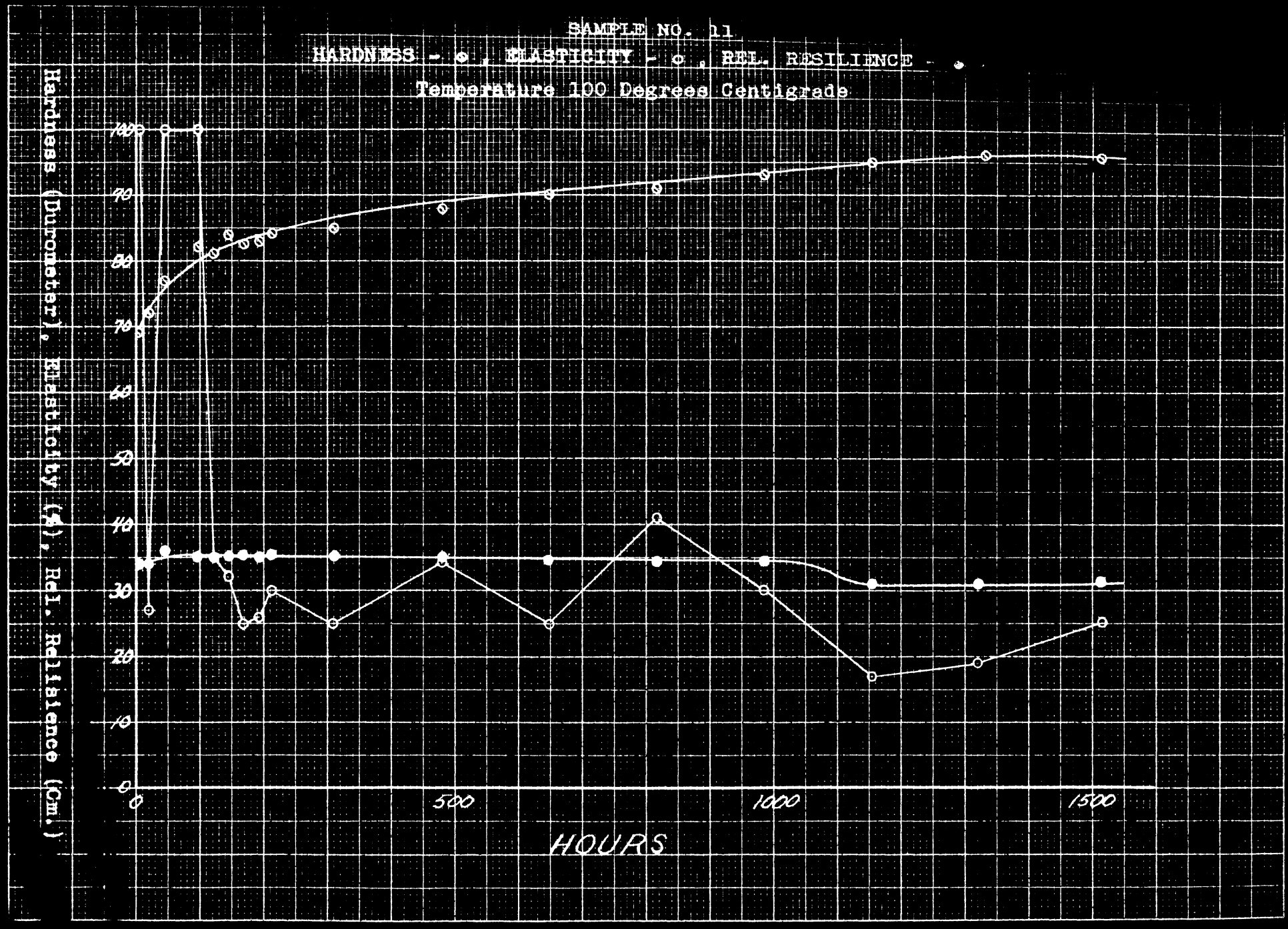
Test No.	Hours	Hardness (Durometer)	Elasticity (%)	Rel. Resilience (Rebound in Cm.)
1	2.0	76	98	36.0
2	4.5	75	97	35.0
3	6.5	76	30	34.0
4	8.5	77	25	33.7
5	20.5	79	70	32.5
6	25.5	79	71	32.2
7	44.0	84	74	32.0
8	97.5	88	25	32.6
9	121.0	90	13	33.0
10	145.0	92	10	33.5
11	169.0	93	9	33.6
12	193.0	94	7	33.8
13	211.0	94	7	33.8
14	310.0	95	6	33.2
15	480.5	96	7	33.8
16	648.0	96	10	33.2
17	817.0	96	11	33.5
18	984.0	97	7	33.5
19	1153.0	97	6	33.8
20	1320.0	97	11	33.0
21	1512.0	98	14	33.2


SAMPLE NO. 10
HARDNESS - ⊕ , ELASTICITY - o , REL. RESILIENCE - ● .
Temperature 100 Degrees Centigrade
Hardness (Durometer), Elasticity (%), Rel. Resilience (Cm.)
100
90
80
70
60
50
40
30
20
10
0
0
500
1000
1500
HOURS

Physical Properties of Rubber and Rubber Substitutes Over a Period of 1500 Hours at a Constant Temperature of 100 Degrees Centigrade.

Sample No. 11

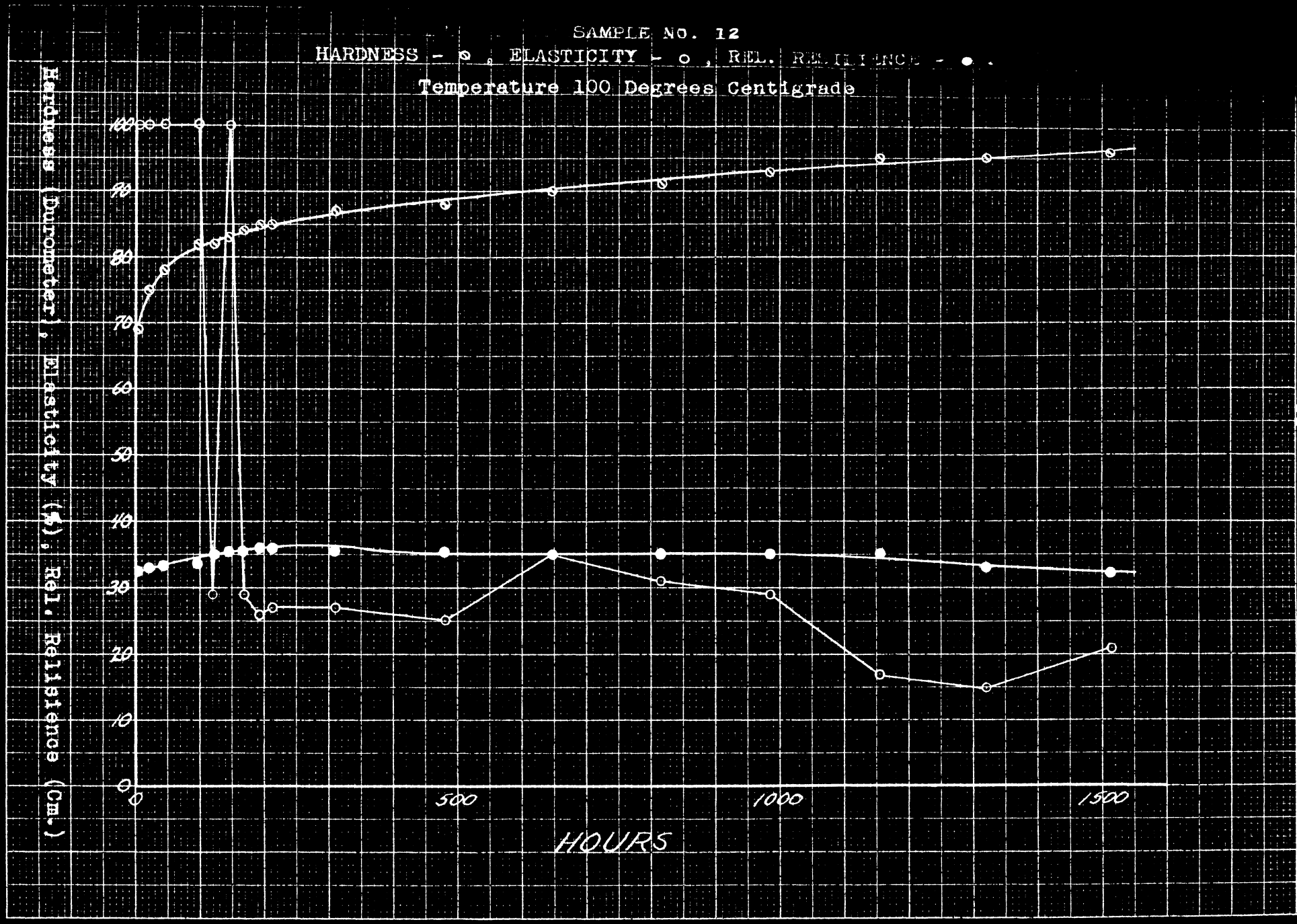
Test No.	Hours	Hardness (Durometer)	Elasticity (%)	Rel. Resilience (Rebound in Cm.)
1	2.0	69	64	34.0
2	4.5	70	100	34.0
3	6.5	70	100	34.0
4	8.5	71	100	34.5
5	20.5	72	27	34.0
6	25.5	75	38	34.2
7	44.0	77	100	36.0
8	97.5	82	100	35.0
9	121.0	81	35	35.0
10	145.0	84	32	35.0
11	169.0	82.5	25	35.2
12	193.0	83	26	35.0
13	211.0	84	30	35.4
14	310.0	85	25	35.0
15	480.5	88	34	35.0
16	648.0	90	25	34.5
17	817.0	91	41	34.5
18	984.0	93	30	34.5
19	1153.0	95	17	31.0
20	1320.0	96	19	31.0
21	1512.0	96	25	31.2


SAMPLE NO. 11
HARDNESS - ⊙ , ELASTICITY - ○ , REL. RESILIENCE - •
Temperature 100 Degrees Centigrade
Hardness (Durometer), Elasticity (%), Rdl. Reliience (Cm.)
100
90
80
70
60
50
40
30
20
10
0
0
500
1000
1500
HOURS

Physical Properties of Rubber and Rubber Substitutes Over a Period of 1500 Hours at a Constant Temperature of 100 Degrees Centigrade.

Sample No. 12

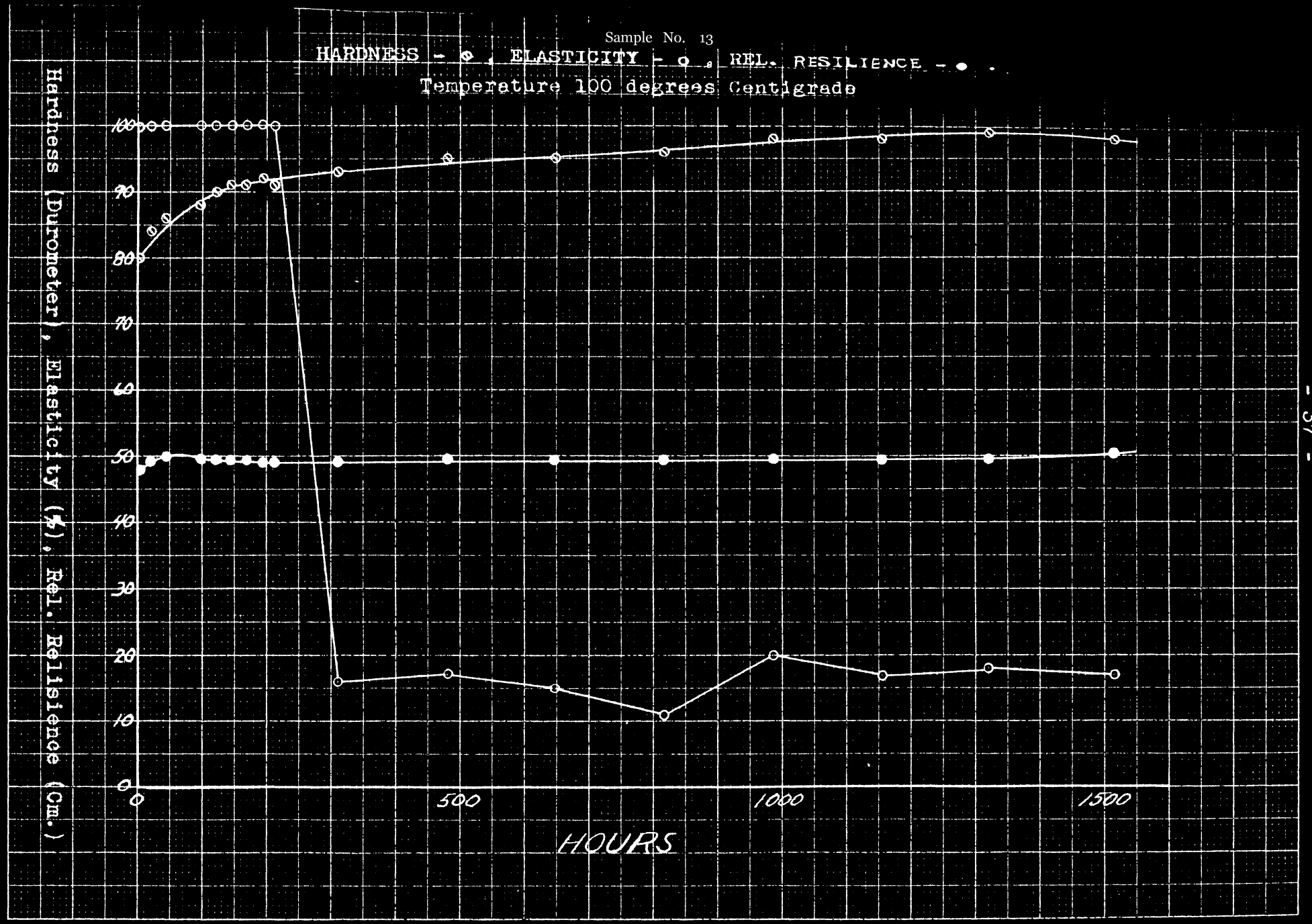
Test No.	Hours	Hardness (Durometer)	Elasticity (%)	Rel. Resilience (Rebound in Cm.)
1	2.0	69	70	32.5
2	4.5	69	100	33.5
3	6.5	74	30	33.5
4	8.5	71	31	33.0
5	20.5	75	100	33.0
6	25.5	74	100	33.0
7	44.0	78	100	33.5
8	97.5	82	100	33.5
9	121.0	82	29	35.0
10	145.0	83	100	35.5
11	169.0	84	29	35.5
12	193.0	85	26	36.0
13	211.0	85	27	36.0
14	310.0	87	27	35.6
15	480.5	88	25	35.5
16	648.0	90	35	35.5
17	817.0	91	31	35.0
18	984.0	93	29	35.0
19	1153.0	95	17	35.0
20	1320.0	95	15	33.0
21	1512.0	96	21	32.5


SAMPLE NO. 12
HARDNESS - ⊙ , ELASTICITY - ○ , REL. RESILIENCE - ● .
Temperature 100 Degrees Centigrade
Hardness (Durometer), Elasticity (%), Rel. Resilience (Cm.)
100
90
80
70
60
50
40
30
20
10
0
0
500
1000
1500
HOURS

Physical Properties of Rubber and Rubber Substitutes Over a Period of 1500 Hours at a Constant Temperature of 100 Degrees Centigrade.

Sample No. 13

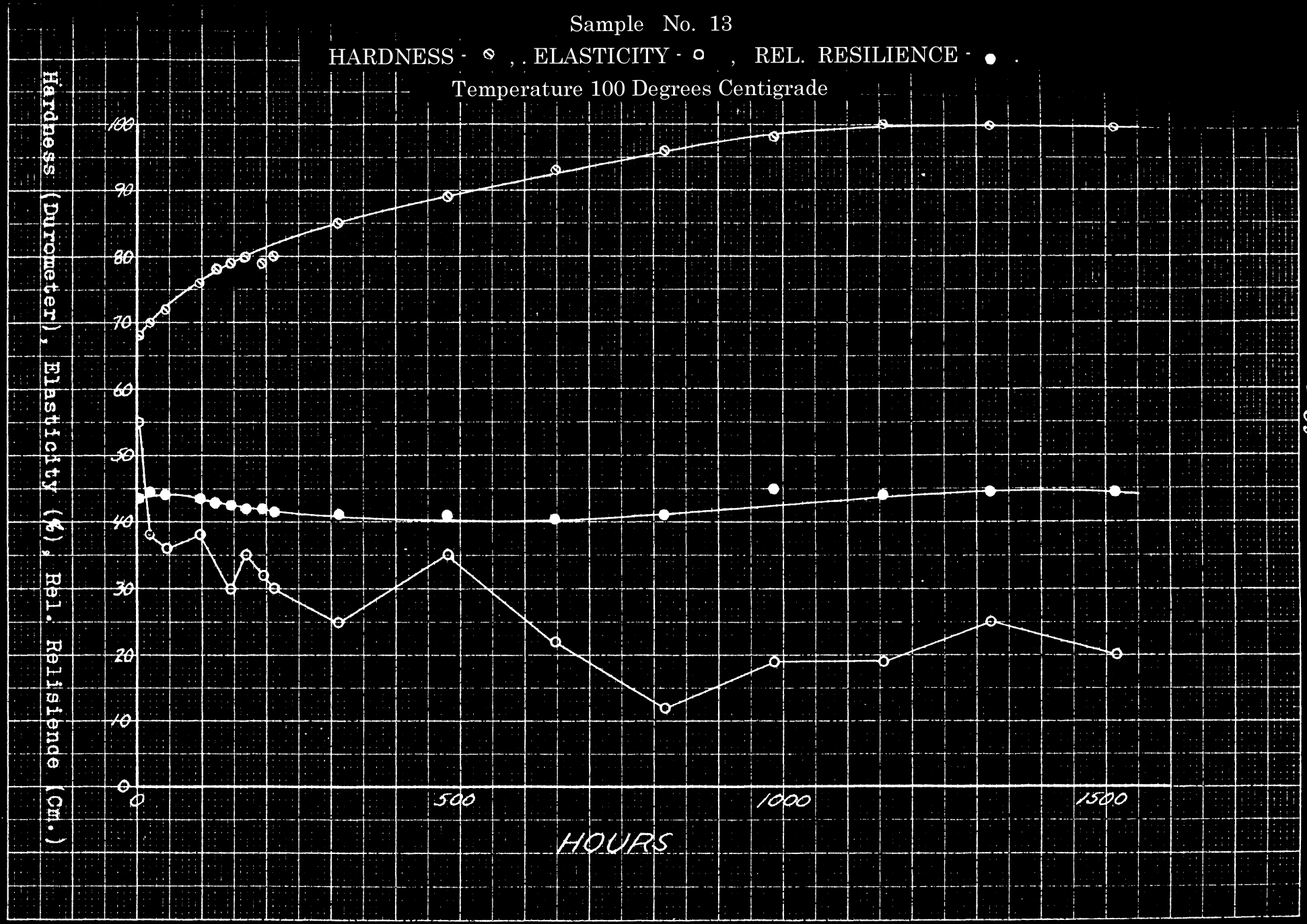
Test No.	Hours	Hardness (Durometer)	Elasticity (%)	Rel. Resilience (Rebound in Cm.)
1	2.0	80	100	48.0
2	4.5	80	100	49.0
3	6.5	82	100	49.0
4	8.5	82.5	100	49.4
5	20.5	84	100	49.5
6	25.5	83	100	49.5
7	44.0	86	100	50.0
8	97.5	88	100	49.6
9	121.0	90	100	49.5
10	145.0	91	100	49.5
11	169.0	91	100	49.5
12	193.0	92	100	49.0
13	211.0	91	100	48.8
14	310.0	93	16	49.0
15	480.5	95	17	49.5
16	648.0	95	15	49.4
17	817.0	96	11	49.5
18	984.0	98	20	49.4
19	1153.0	98	17	49.5
20	1320.0	99	18	49.5
21	1512.0	98	17	50.2


Sample No. 13
HARDNESS - ⊕ , ELASTICITY - ○ , REL. RESILIENCE - ● .
Temperature 100 degrees Centigrade
Hardness (Durometer), Elasticity (%), Rel. Relisience (Cm.)
100
90
80
70
60
50
40
30
20
10
0
0
500
1000
1500
HOURS

Physical Properties of Rubber and Rubber Substitutes Over a Period of 1500 Hours at a Constant Temperature of 100 Degrees Centigrade.

Sample No. 14

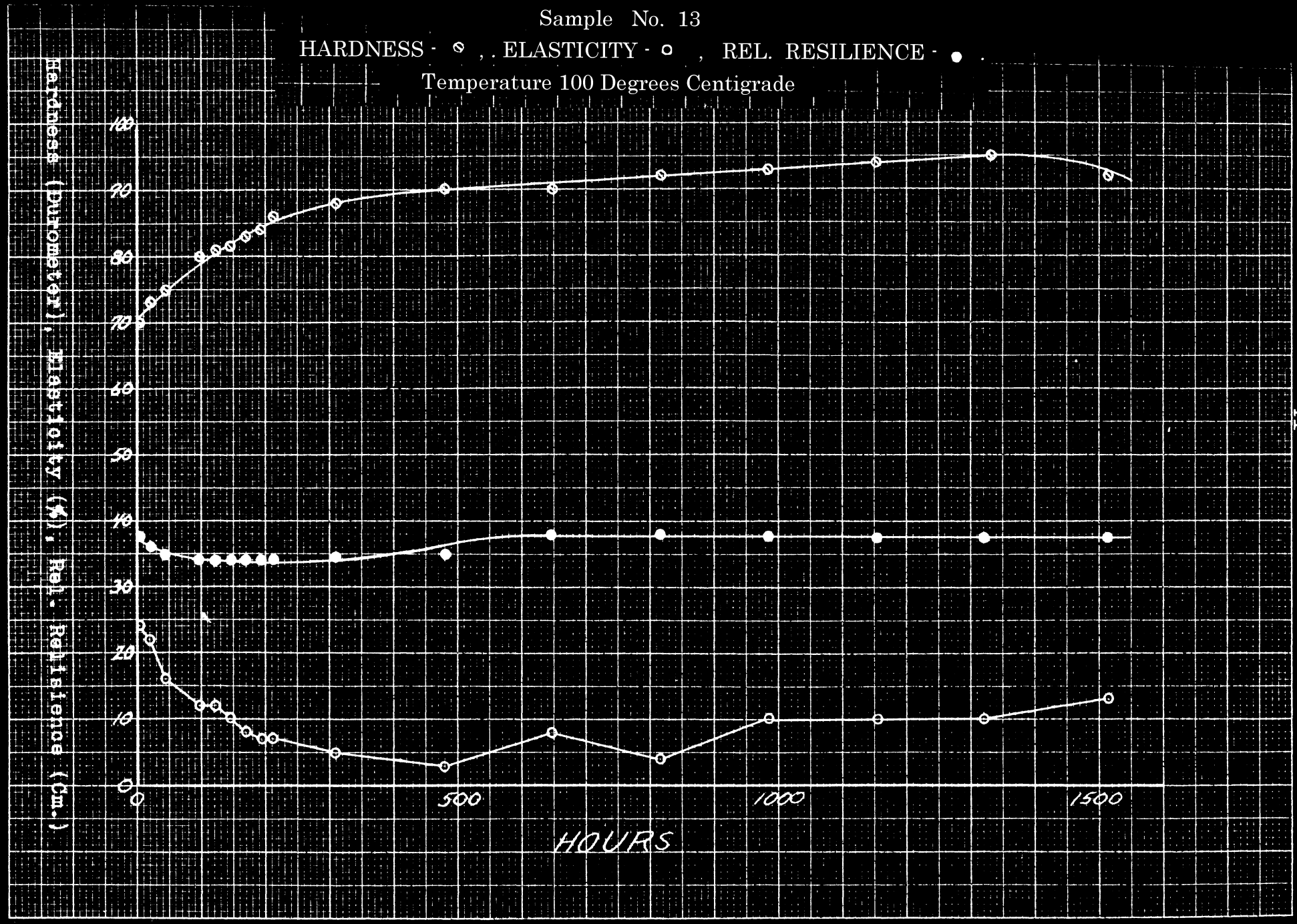
Test No.	Hours	Hardness (Durometer)	Elasticity (%)	Rel. Resilience (Rebound in Cm.)
1	2.0	68	55	43.5
2	4.5	68	63	44.5
3	6.5	67	55	44.5
4	8.5	68	36	44.6
5	20.5	70	38	44.5
6	25.5	69	60	44.0
7	44.0	72	36	44.0
8	97.5	76	38	43.5
9	121.0	78	43	43.0
10	145.0	79	30	42.5
11	169.0	80	35	42.0
12	193.0	79	32	42.0
13	211.0	80	30	41.5
14	310.0	85	25	41.0
15	480.5	89	35	41.0
16	648.0	93	22	40.2
17	817.0	96	12	41.0
18	984.0	98	19	45.0
19	1153.0	100	19	44.0
20	1320.0	100	25	44.6
21	1512.0	100	20	44.5


Sample No. 13
HARDNESS - ⊗ , . ELASTICITY - o , REL. RESILIENCE - ● .
Temperature 100 Degrees Centigrade
Hardness (Durometer), Elasticity (%), Rel. Relisience (Cm.)
100
90
80
70
60
50
40
30
20
10
0
0
500
1000
1500
HOURS

Physical Properties of Rubber and Rubber Substitutes Over a Period of 1500 Hours at a Constant Temperature of 100 Degrees Centigrade.

Sample No. 15

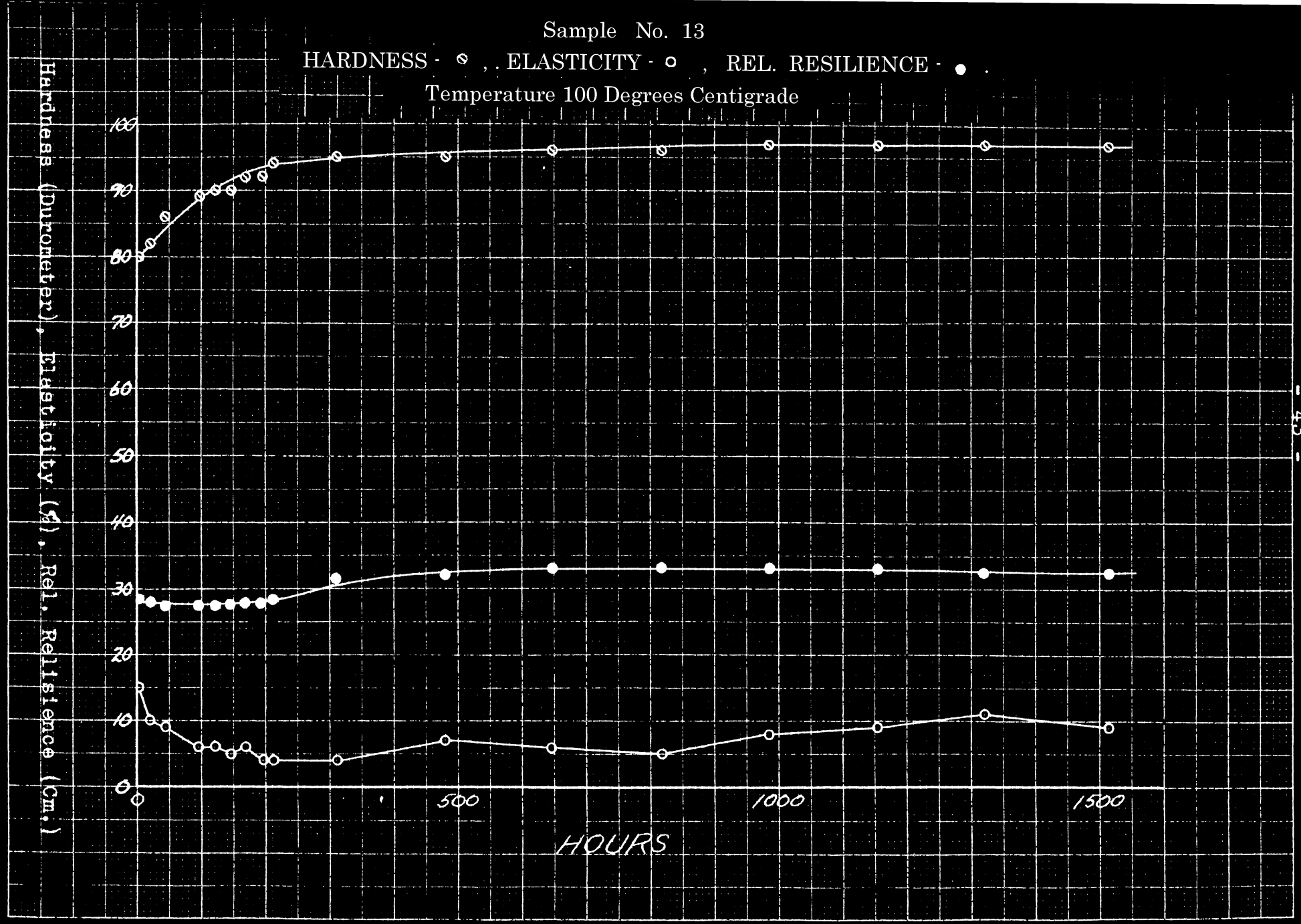
Test No.	Hours	Hardness (Durometer)	Elasticity (%)	Rel. Resilience (Rebound in Cm.)
1	2.0	70	24	37.5
2	4.5	70	15	38.0
3	6.5	72	22	37.5
4	8.5	71	21	37.0
5	20.5	73	22	36.0
6	25.5	72.5	24	35.8
7	44.0	75	16	35.0
8	97.5	80	12	34.0
9	121.0	81	12	34.0
10	145.0	81.5	10	34.0
11	169.0	83	8	34.0
12	193.0	84	7	34.0
13	211.0	86	7	34.2
14	310.0	88	5	34.5
15	480.5	90	3	35.0
16	648.0	90	8	38.0
17	817.0	92	4	38.0
18	984.0	93	10	37.8
19	1153.0	94	10	37.5
20	1320.0	95	10	37.4
21	1512.0	92	13	37.6


Sample No. 13
HARDNESS - ⊗ , . ELASTICITY - o , REL. RESILIENCE - ● .
Temperature 100 Degrees Centigrade
Hardness (Durometer), Elasticity (%), Rel. Resilience (Cm.)
100
90
80
70
60
50
40
30
20
10
0
500
1000
1500
HOURS

Physical Properties of Rubber and Rubber Substitutes Over a Period of 1500 Hours at a Constant Temperature of 100 Degrees Centigrade.

Sample No. 16

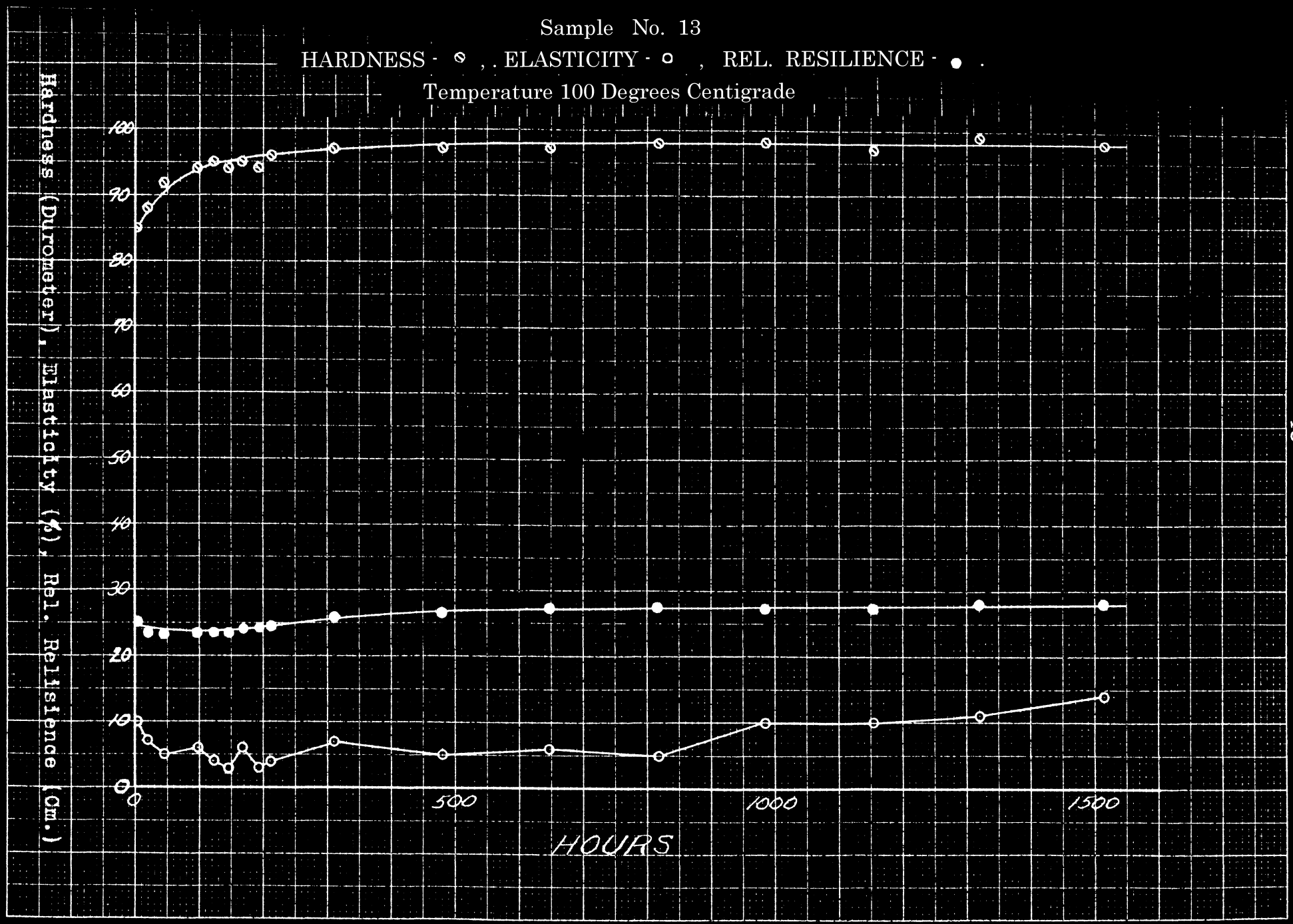
Test No.	Hours	Hardness (Durometer)	Elasticity (%)	Rel. Resilience (Rebound in Cm.)
1	2.0	80	15	28.5
2	4.5	80	14	28.5
3	6.5	80	15	28.5
4	8.5	81	11	28.6
5	20.5	82	10	28.0
6	25.5	84	10	27.8
7	44.0	86	9	27.5
8	97.5	89	6	27.5
9	121.0	90	6	27.6
10	145.0	90	5	27.8
11	169.0	92	6	28.0
12	193.0	92	4	28.0
13	211.0	94	4	28.2
14	310.0	95	4	31.5
15	480.5	95	7	32.0
16	648.0	96	6	33.0
17	817.0	96	5	33.0
18	984.0	97	8	33.0
19	1153.0	97	9	33.0
20	1320.0	97	11	32.5
21	1512.0	97	9	32.5


Sample No. 13
HARDNESS - ⊗ , . ELASTICITY - o , REL. RESILIENCE - ● .
Temperature 100 Degrees Centigrade
Hardness (Durometer), Elasticity (%), Rel. Relisience (Cm.)
100
90
80
70
60
50
40
30
20
10
0
0
500
1000
1500
HOURS

Physical Properties of Rubber and Rubber Substitutes Over a Period of 1500 Hours at a Constant Temperature of 100 Degrees Centigrade.

Sample No. 17

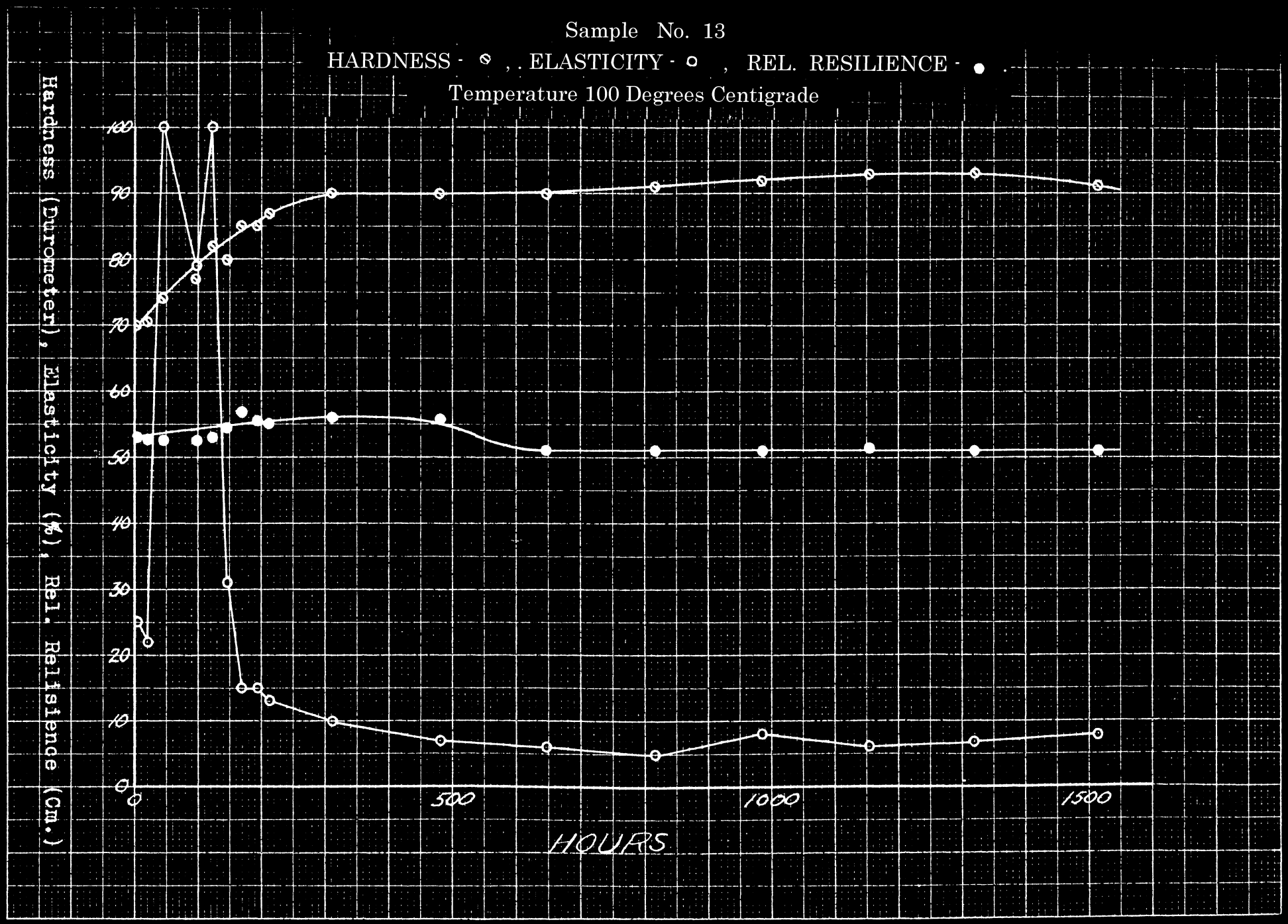
Test No.	Hours	Hardness (Durometer)	Elasticity (%)	Rel. Resilience (Rebound in Cm.)
1	2.0	85	10	25.0
2	4.5	86	9	25.0
3	6.5	86	8	25.2
4	8.5	86	7	24.0
5	20.5	88	7	23.5
6	25.5	89	7.5	23.0
7	44.0	92	5	23.2
8	97.5	94	6	23.4
9	121.0	95	4	23.5
10	145.0	94	3	23.5
11	169.0	95	6	24.0
12	193.0	94	3	24.2
13	211.0	96	4	24.5
14	310.0	97	7	26.0
15	480.5	97	5	26.5
16	648.0	97	6	27.2
17	817.0	98	5	27.5
18	984.0	98	10	27.2
19	1153.0	97	10	27.6
20	1320.0	99	11	28.0
21	1512.0	98	14	28.0


Sample No. 13
HARDNESS - ⊗ , . ELASTICITY - o , REL. RESILIENCE - ● .
Temperature 100 Degrees Centigrade
Hardness (Durometer), Elasticity (%), Rel. Relisience (Cm.)
100
90
80
70
60
50
40
30
20
10
0
0
500
1000
1500
HOURS

Physical Properties of Rubber and Rubber Substitutes Over a Period of 1500 Hours at a Constant Temperature of 100 Degrees Centigrade.

Sample No. 18

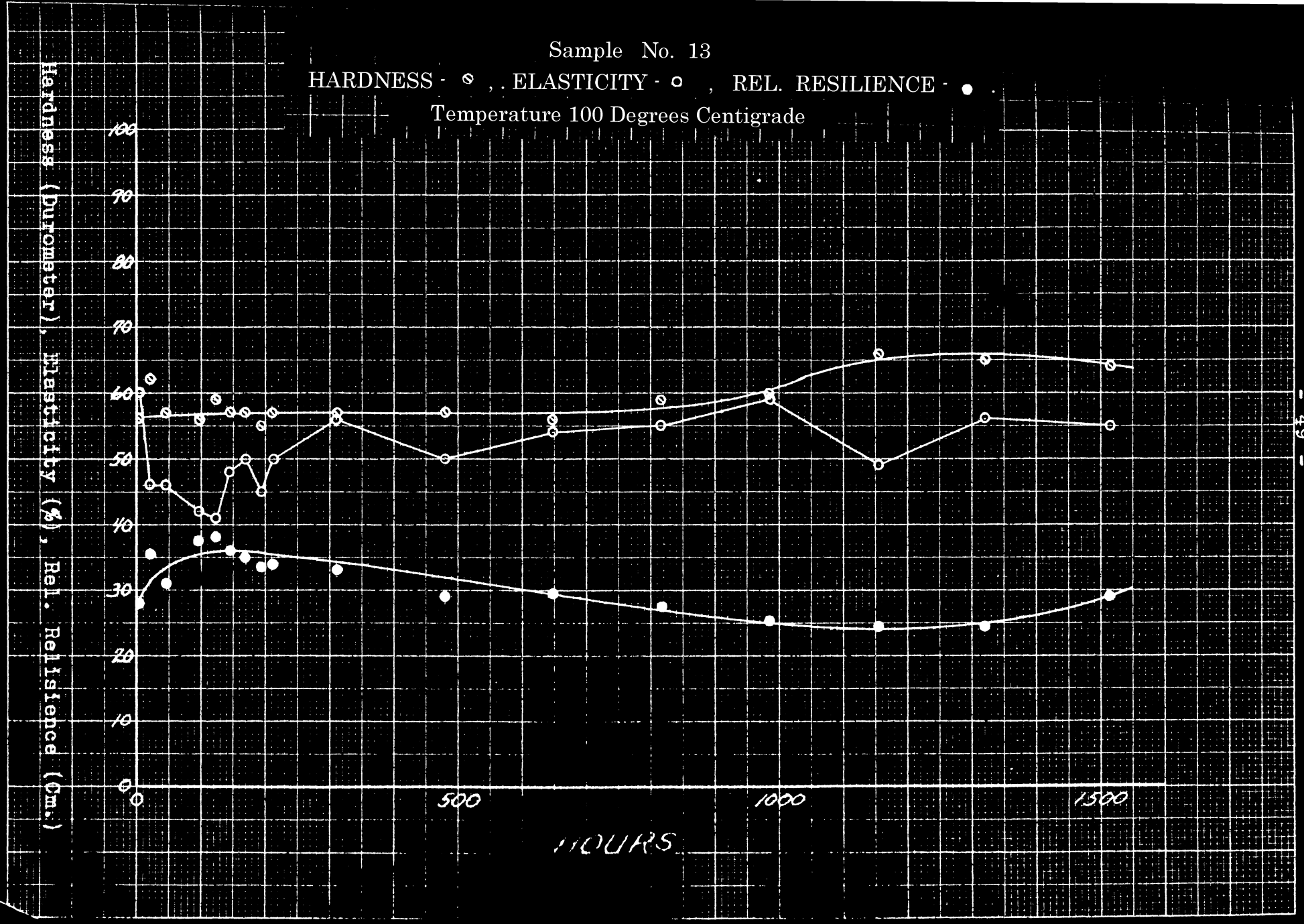
Test No.	Hours	Hardness (Durometer)	Elasticity (%)	Rel. Resilience (Rebound in Cm.)
1	2.0	70	25	53.0
2	4.5	70	22	52.8
3	6.5	70	25	53.2
4	8.5	71	22	52.8
5	20.5	70.5	22	52.4
6	25.5	73	20	52.5
7	44.0	74	100	52.5
8	97.5	77	84	52.6
9	121.0	83	100	53.0
10	145.0	80	31	54.5
11	169.0	85	15	57.0
12	193.0	85	15	55.5
13	211.0	87	13	55.0
14	310.0	90	10	56.0
15	480.5	90	7	55.8
16	648.0	90	6	51.0
17	817.0	91	5	51.0
18	984.0	92	8	51.0
19	1153.0	93	6	51.5
20	1320.0	93	7	51.0
21	1512.0	91	8	51.0


Sample No. 13
HARDNESS - ⊗ , . ELASTICITY - o , REL. RESILIENCE - ● .
Temperature 100 Degrees Centigrade
Hardness (Durometer), Elasticity (%), Rel. Relsience (Cm.)
100
90
80
70
60
50
40
30
20
10
0
0
500
1000
1500
HOURS

Physical Properties of Rubber and Rubber Substitutes Over a Period of 1500 Hours at a Constant Temperature of 100 Degrees Centigrade.

Sample No. 19

Test No.	Hours	Hardness (Durometer)	Elasticity (%)	Rel. Resilience (Rebound in Cm.)
1	2.0	56	60	28.0
2	4.5	56	60	30.5
3	6.5	56	55	31.0
4	8.5	57	45	32.0
5	20.5	62	46	35.5
6	25.5	56	52	32.0
7	44.0	57	46	31.0
8	97.5	56	42	37.5
9	121.0	59	38	41.0
10	145.0	57	48	36.0
11	169.0	57	50	35.0
12	193.0	55	45	33.6
13	211.0	57	50	34.0
14	310.0	57	56	33.0
15	480.5	57	50	29.0
16	648.0	56	54	29.5
17	817.0	59	55	27.5
18	984.0	60	59	25.5
19	1153.0	66	49	24.5
20	1320.0	65	56	24.5
21	1512.0	64	55	29.0


Sample No. 13
HARDNESS - ⊗ , . ELASTICITY - o , REL. RESILIENCE - ● .
Temperature 100 Degrees Centigrade
Hardness (Durometer), Elasticity (%), Rel. Relisience (Cm.)
100
90
80
70
60
50
40
30
20
10
0
500
1000
1500
HOURS

Physical Properties of Rubber and Rubber Substitutes Over a Period of 1500 Hours at a Constant Temperature of 100 Degrees Centigrade.

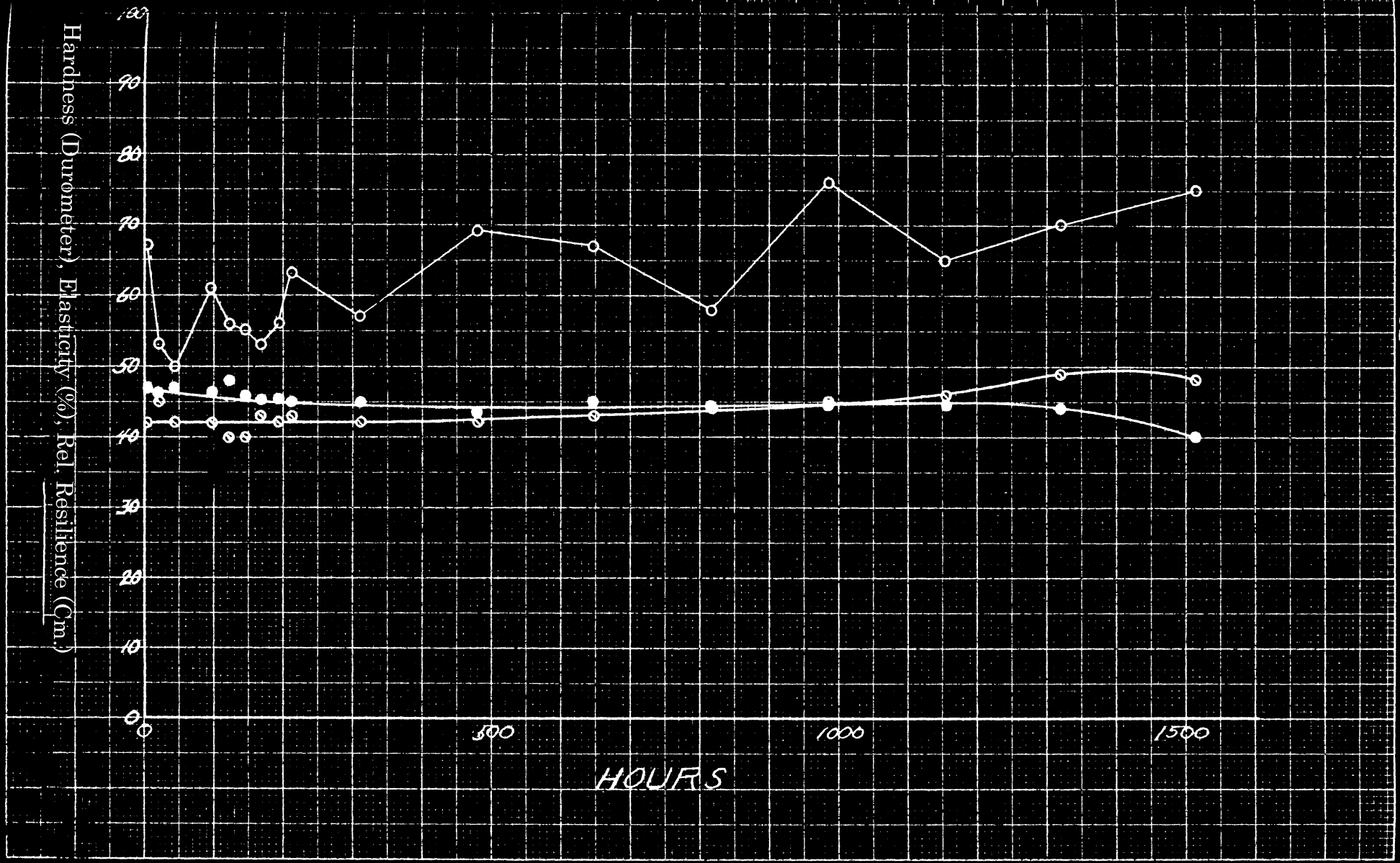
Sample No. 20

Test No.	Hours	Hardness (Durometer)	Elasticity (%)	Rel. Resilience (Rebound in Cm.)
1	2.0	42	67	47.0
2	4.5	42	70	47.0
3	6.5	42	55	46.2
4	8.5	42	61	46.4
5	20.5	45	53	46.2
6	25.5	42	58	46.2
7	44.0	42	50	47.0
8	97.5	42	61	46.5
9	121.0	40	56	46.0
10	145.0	40	55	46.0
11	169.0	43	53	45.2
12	193.0	42	56	45.2
13	211.0	43	63	45.0
14	310.0	42	57	45.0
15	480.5	42	69	43.5
16	648.0	43	67	45.0
17	817.0	44	58	44.5
18	984.0	45	77	44.5
19	1153.0	46	65	44.5
20	1320.0	49	70	44.0
21	1512.0	48	75	40.0

Sample No. 13

HARDNESS - ⊗ , . ELASTICITY - o , REL. RESILIENCE - ● . .

Temperature 100 Degrees Centigrade



F. INTERPRETATION OF GRAPHS AND DATA

1. Hardness

The hardening produced by the heat treatment of the samples was confined to the outer surface of the samples. This was observed by cutting a cross section from the sample and placing it under the microscope. It was also observed in the comparison of indentor holes made with the Elastometer before and after heating 1500 hours.

Each of the hardness curves shows a tendency to increase with the increase of time at the temperature of 100 degrees Centigrade. The sharpest increase took place in most of the samples during the first three hundred hours of heating. After this time the increase became more gradual, The exceptions to this increased hardness with time are Sample No. 19 and Sample No. 20. Sample No. 19 and Sample No. 20 show the least change of hardness of the whole group of samples. These two samples increase only a few points. A visual comparison of these curves gives far greater explanation of their properties than any description in this paragraph.

2. Elasticity

At the beginning of the 1500 hour period the elasticity was very eratic in its behavior, first jumping from a high to a low percentage of elasticity. This is not true in all cases.

Some of the graphs were regular and fell on a smooth curve. Possibly the reason for the eratic behavior was a change in molecular structure of the outer surface of the sample as a shifting from a higher to a lower polymer. In every case the graph smoothed out into a fairly smooth curve after 500 hours heating.

3. Relative Resilience

The relative resilience curves were very uniform, showing only a slight inclination to decline. This was probably due to the fact that the effect of the rebound was caused by the whole thickness of the sample and not the hardened surface alone.

G. PHYSICAL TESTS MADE AT DIFFERENT TEMPERATURES

Tests were run on the samples for hardness, elasticity and relative resilience at temperatures of 0, 25, and 100 degrees Centigrade. These tests were made so that a comparison of properties could be made at different temperatures. These tests were made before the 1500-hour heat treatment. The hardness was from 2 to 43 points higher on the 0 degree Centigrade test than the 100 degree Centigrade test. The elasticity was consistently lower per sample at a temperature

of 0 degrees Centigrade than 100 degrees Centigrade. Dr. R. Houwink states, in his book on Elasticity, Plasticity and Structure of Matter*, that

> "As might be expected, the consequence of the weakening of the secondary coherence by increase of temperature is a great capacity of stretching at high temperatures."

The relative resilience was consistently higher in the test at 100 degrees Centigrade than that made at 0 degrees Centigrade. This was with the exception of one sample, Sample No. 19, which had a rebound of 28.0 cm. at 100 degrees Centigrade and a rebound of 62.0 cm. at 0.0 degrees Centigrade.

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*Houwink, Dr. R. 1940. Elasticity, Plasticity and Structure of Matter. Cambridge University Press, London, England. Page 181.

Tests of Rubber and Rubber Substitutes at a Temperature of 0 Degrees Centigrade.

Sample No.	Hardness Durometer	Elasticity %	Rel. Resilience Rebound in Cm.
1	85	42	23.0
2	86	18	11.0
3	84	26	11.0
4	75	30	20.5
5	93	14	15.5
6	85	27	10.5
7	86	34	11.5
8	65	65	21.2
9	67	57	7.0
10	87	34	17.0
11	84	38	6.0
12	82	52	7.0
13	86	100	8.5
14	73	68	11.5
15	76	40	9.5
16	91	20	11.0
17	95	16	10.3
18	78	35	21.2
19	99	30	62.0
20			

Tests of Rubber and Rubber Substitutes at a Temperature of 25 Degrees Centigrade.

Sample No.	Hardness Durometer	Elasticity %	Rel. Resilience Rebound in Cm.
1	82	50	8.0
2	85	21	22.5
3	83	30	23.5
4	83	38	10.2
5	87	28	8.5
6	83	33	18.1
7	85	35	21.4
8	66	80	35.4
9	67	43	16.9
10	86	30	21.8
11	75	55	9.5
12	77	56	9.6
13	84	100	21.4
14	72	60	17.5
15	75	28	15.0
16	87	19	13.5
17	94	15	13.0
18	75	25	37.7
19	96	13	42.5
20	75	39	6.8

Test of Rubber and Rubber Substitutes at a Temperature of 100 Degrees Centigrade.

Sample No.	Hardness Durometer	Elasticity %	Rel. Resilience Rebound in Cm.
1	76	73	38.5
2	82	25	49.0
3	77	26	51.0
4	69	74	53.0
5	78	31	37.5
6	75	40	41.5
7	80	36	62.0
8	58	100	51.5
9	65	30	57.5
10	76	98	36.0
11	69	64	34.0
12	69	70	32.5
13	80	100	48.0
14	68	55	43.5
15	70	24	37.5
16	80	15	28.5
17	85	10	25.0
18	70	25	53.0
19	56	60	28.0
20	42	67	47.0

CHAPTER II

THERMAL CONDUCTIVITY

A. THEORY OF THERMAL CONDUCTIVITY

Conduction is the flow of heat upon contact of two bodies or from molecule to molecule in the same body. This flow of heat always passes from the region of higher to the region of lower temperature. The heat (H) transmitted by conduction varies directly as the cross-sectional area (A) of the mass, the difference of temperature $(t_2 - t_1)$ between the two cross-sectional areas, and the time of flow (T); and inversely as the distance (d) between the two cross sections.

$$H \propto \frac{A(t_2 - t_1)T}{d}$$

Putting a constant (K) into the equation:

$$H = \frac{KA(t_2 - t_1)T}{d} \quad \ldots\ldots\ldots \quad (1).$$

This constant (K) is called the thermal conductivity. By using the C. G. S. System and setting all the quantities in the equation, except K, at unity, a definition of K is established.

$$1(\text{cal.}) = \frac{K\ 1\ \text{cm.}^2\ 1^{\circ}\ \text{C.}\ 1\ \text{Sec.}}{1\ \text{cm.}}$$

Thus the thermal conductivity (K) of a material is the number of calories transmitted in one second between the opposite faces of a centimeter cubed of the material when the temperature difference between the faces is one degree Centigrade.

The materials dealt with in this thesis all come under the class of poor conductors. For determining the thermal conductivity of poor conductors an apparatus designed by Albert Lewis Fitch* and known as the Fitch thermal conductivity apparatus was used.

The Fitch conductivity apparatus (Fig. 6) consists of a heat source and a receiver. The source is a vessel with a copper plate in the bottom which is kept at a constant temperature by boiling water. The receiver is a polished copper plug of known mass embedded in thermally insulating surroundings. Embedded in the copper plate of the source and the plug of the receiver are copper-constantan thermocouples. When a uniform piece of material whose thermal conductivity is to be measured is placed between the upper vessel and the copper plug, of known thermal capacity, the heat conducted through the material raises the temperature of the copper plug. The temperature difference between the source and receiver is measured by the thermocouples and a galvanometer.

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*Fitch, Albert Lewis. 1938. American Men of Science. Science Press, New York, N. Y.

Figure 6.— Fitch thermal conductivity apparatus.

To derive the equation for (K) the following symbols will be used:

R = Rate of flow of heat - (Cal./Sec.).

t_2 = Constant temperature of the source (^{o}C.).

t_1 = Temperature of receiver (^{o}C.).

T = Time (Sec.)

d = Thickness of sample (Cm.)

A = Area of the exposed surface of the plug $(Cm.)^2$.

c = Specific heat of the copper plug, Cal./Gm. ^{o}C.

M = Mass of copper plug (Gm.).

m = Slope of (T vs. log i - log i_o) (Sec.).

K = Thermal conductivity. Cal./Cm. ^{o}C. Sec.

i = Current.

If R is the rate of flow of heat through the sample, then from equation (1):

$$R = \frac{K A (t_2 - t_1)}{d} \quad \ldots\ldots\ldots \quad (2).$$

If the upper face of the sample is at constant temperature t_2 and the temperature of the lower face slowly changing, then it can be said that in a small interval of time dT the temperature of the copper receiver changes by a small amount dt_1 where t_1 is the instantaneous temperature of the copper receiver. Then $\frac{dt_1}{dT}$ is the rate of increase in temperature of the copper plug.

Thus the rate of flow is:

$$R = M c \frac{dt_1}{dt} \quad \ldots\ldots\ldots\ldots\ldots \quad (3).$$

Since the block is well insulated, the heat conducted through the sample per unit time is the same as the number of calories per second received by the copper plug.

By combining equations (1) and (2):

$$\frac{K A (t_2 - t_1)}{d} = M c \frac{dt_1}{dT} \quad \ldots\ldots\ldots\ldots \quad (4).$$

If the temperature difference $(t_2 - t_1)$ is measured by the copper-constantan thermocouples, placed respectively in the source and the receiver, then the current produced by the thermocouples will be approximately proportional to the temperature difference for low temperatures.

$$\text{or} \qquad i = C(t_2 - t_1) \quad \ldots\ldots\ldots\ldots \quad (5),$$

where C is the constant of proportionality. This is a linear equation and thus a linear scaled galvanometer may be used to measure the temperature difference.

Differentiating with respect to T:

$$\frac{di}{dT} = - C \frac{dt_1}{dT} \quad \ldots\ldots\ldots\ldots\ldots \quad (6).$$

Substituting equation (5) and (6) in equation (4):

$$\frac{K A i}{d} = - M c \frac{di}{dT}$$

$$dT = - \frac{M c d}{K A} \frac{di}{i} \quad \ldots\ldots\ldots \quad (7).$$

Integrating dT between the limits of T and 0; and $\frac{di}{i}$ between the limits of i and i_o:

$$\int_o^T dT = \int_{i_o}^{i} - \frac{M c d}{K A} \frac{di}{i}$$

$$T = - \frac{M c d}{K A} (\ln i - \ln i_o) \quad \ldots\ldots \quad (8).$$

Changing logarithm to the base e to logarithm to the base 10:

$$T = - \frac{2.303 M c d}{K A} (\log i - \log i_o) \quad \ldots \quad (9).$$

If T is plotted versus i on semi-log paper, the points will fall on a straight line. The slope (m) of this line is equal to:

$$m = \frac{T}{\log i - \log i_o} \quad \ldots\ldots \quad (10)$$

Substituting m in equation (9):

$$m = - \frac{2.303 M c d}{K A} *$$

---

*Weber, Robert L. 1941. Temperature Measurement. Edwards Brothers, Inc., Ann Arbor, Mich.

or

$$K = - \frac{2.303 M \, e \, d}{A \, m} \quad \ldots\ldots \quad (11).$$

Thus an equation has been derived by which (K) may be calculated for any given sample tested with the thermal conductivity apparatus.

B. CALCULATION OF THERMAL CONDUCTIVITY

The sample whose thermal conductivity was to be measured was placed on the receiving plug of the Fitch thermal conductivity apparatus. The receiving plug was at room temperature and the constant temperature source was being heated by an extermal boiler and a steam tube (Fig. 8). The electrical connections of the constant temperature source and receiver thermocouples was a differential connection of the Copper-Constantan thermocouples and a linear scale galvanometer in series, as shown in Fig. 7.

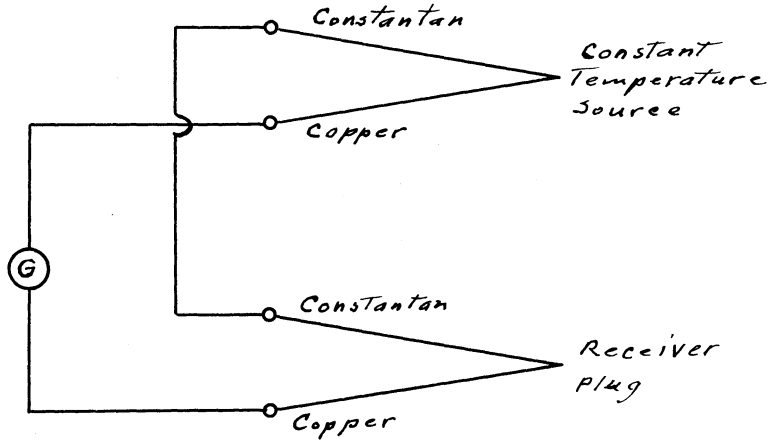


Figure 7.—Connection of Copper-Constantan Thermocouples.

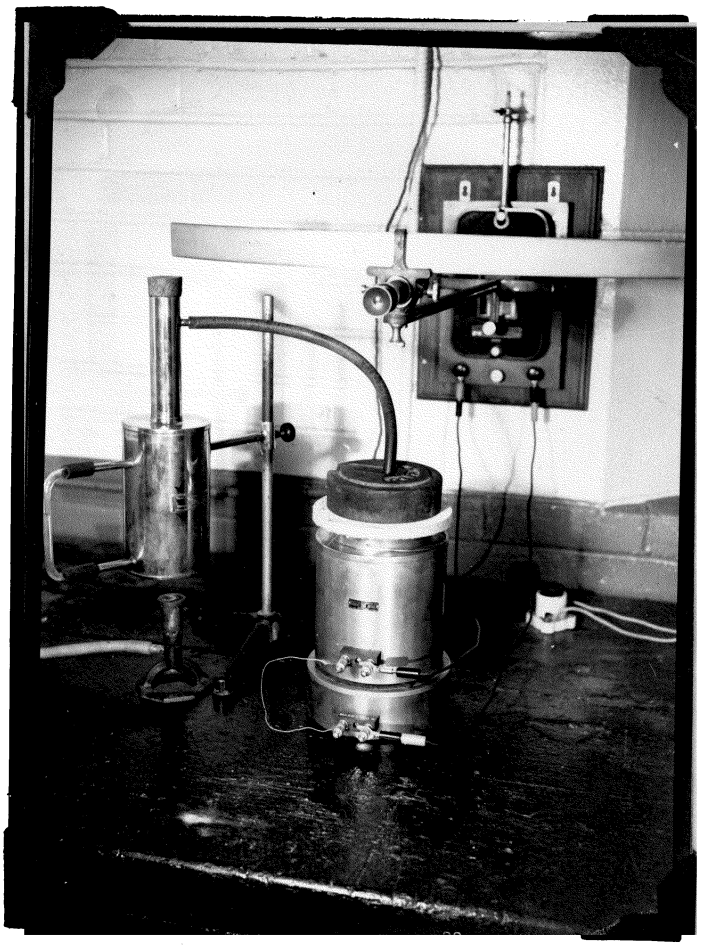


Figure 8.—Connection of Fitch thermal conductivity apparatus.

The constant temperature vessel was then placed upon the sample so that the source plate was directly over the receiver plug. When the vessel was thus placed, a two-K.G. weight was placed on top of the vessel to insure good contact of the source and receiver with the sample. A stop watch was started and readings of the galvanometer recorded at minute intervals.

To derive a working equation for (K) the constants of the apparatus were substituted in equation (11).

The Constants of the apparatus are:

$$M - 340.0 \text{ Gm.}$$

$$A - 15.48 \text{ (Cm.)}^2$$

$$c - 0.093 \text{ Cal./Gm. } ^{o}\text{C.}$$

Substituting these constants in equation (11):

$$K = - \frac{2.303 \times 340.0 \times 0.093 \times d}{15.48 \times m} \quad \ldots\ldots (12)$$

$$K = - 4.704 \frac{d}{m} \quad \ldots\ldots\ldots\ldots\ldots (13)$$

For a specific example, the data of Sample No. 18, before it was heated 1500 hours at 100 degrees Centigrade, will be used and a complete calculation made.

(d) for Sample No. 18 was 0.670 Cm.

The Time vs. Current data for Sample No. 18 was:

T (Min.)	i
1	24.88
2	24.36
3	23.75
4	23.14
5	22.58
6	22.00
7	21.45
8	20.90
9	20.40
10	19.88

This data was plotted on semi-log paper (Time (T) vs. i on log scale). The curve fell on a straight line (Graph on page 69). The slope of the curve is the value of (m) in equation (13).

Letting OX be the abscissa and OY be the ordinate,

$$m = \frac{O\,Y}{O\,X} \quad \ldots\ldots\ldots\ldots \quad (14).$$

Evaluating OY:

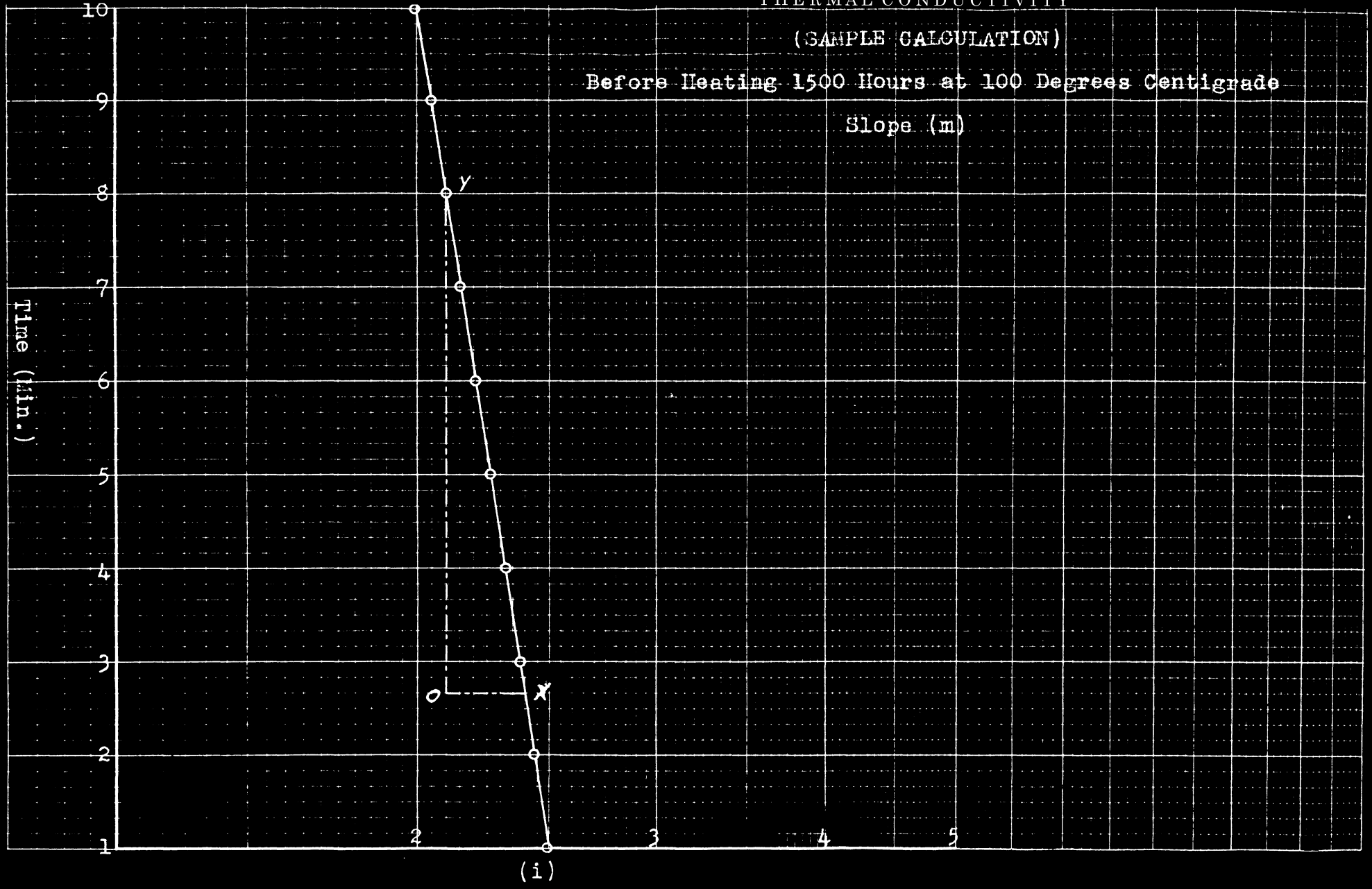
$$O\,Y = 5 \text{ minutes } 20 \text{ seconds.}$$

Changing OY to seconds:

$$O\,Y = 320 \text{ seconds.}$$

Evaluating OX:

$$O\,X = \log 2.1 - \log 2.4$$
$$= 0.32222 - 0.38021$$
$$= -0.05977.$$


(SAMPLE CALCULATION)
Before Heating 1500 Hours at 100 Degrees Centigrade
Slope (m)
Time (min.)
10
9
8
7
6
5
4
3
2
1
y
o
x
2
3
4
5
(i)

Substituting these values for OX and OY in equation (14),

$$m = -\frac{320.0}{0.05977}$$

$$= -5518.19 \text{ seconds.}$$

Going back to equation (13) and substituting the values of (d) and (m) we get:

$$K = 0.000571 \text{ Cal./Sec. Cm. } ^{o}C.$$

Thus the thermal conductivity has been evaluated for Sample No. 18. All the values of (K) were evaluated in this manner.

Thermal Conductivity Before Heating 1500 Hours at 100 Degrees Centigrade.
Time vs. Current

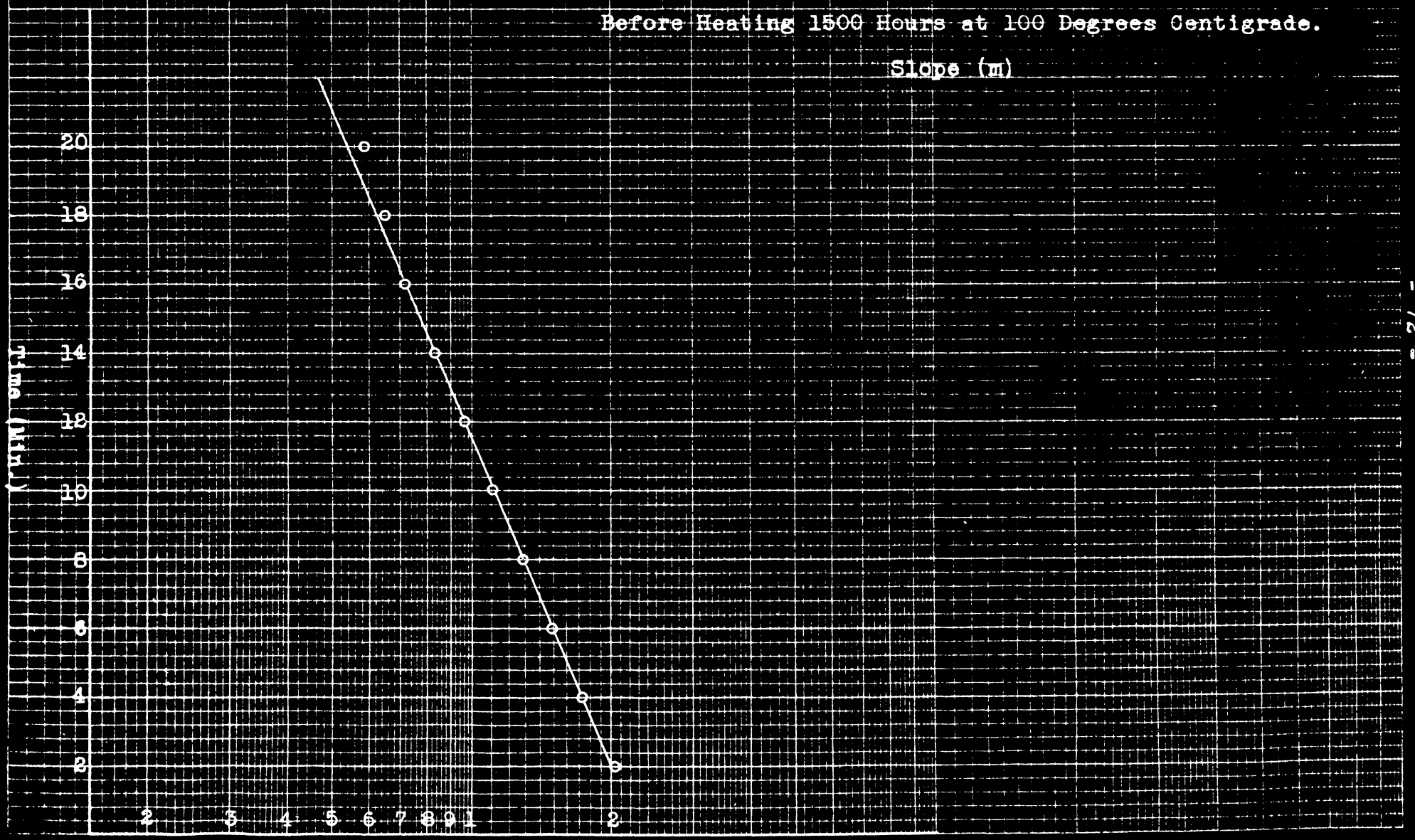
Time (Minute)	Sample No. 1 (i)	Sample No. 2 (i)	Sample No. 3 (i)	Sample No. 4 (i)	Sample No. 5 (i)
2	20.50	23.30	24.30	24.40	23.60
4	17.20	21.10	22.80	23.00	21.90
6	14.80	19.40	21.10	21.40	20.00
8	12.80	17.90	19.50	20.05	18.40
10	11.00	16.40	18.00	18.90	17.00
12	9.60	15.10	16.70	17.60	15.60
14	8.30	14.00	15.50	16.70	14.40
16	7.20	13.15	14.50	15.60	13.30
18	6.50	12.20	13.70	14.70	12.40
20	5.90	11.40	12.80	13.90	11.60

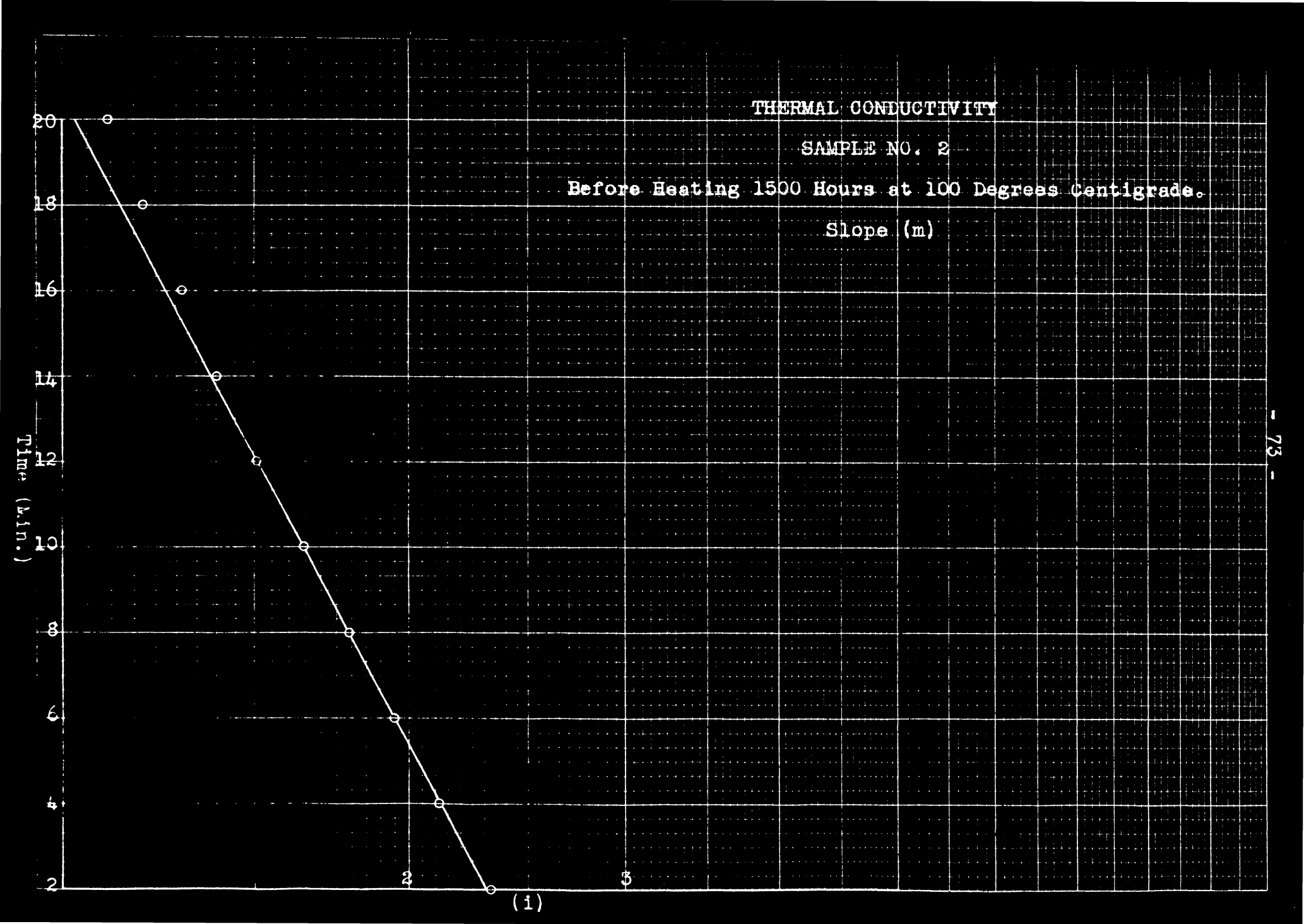
THERMAL CONDUCTIVITY

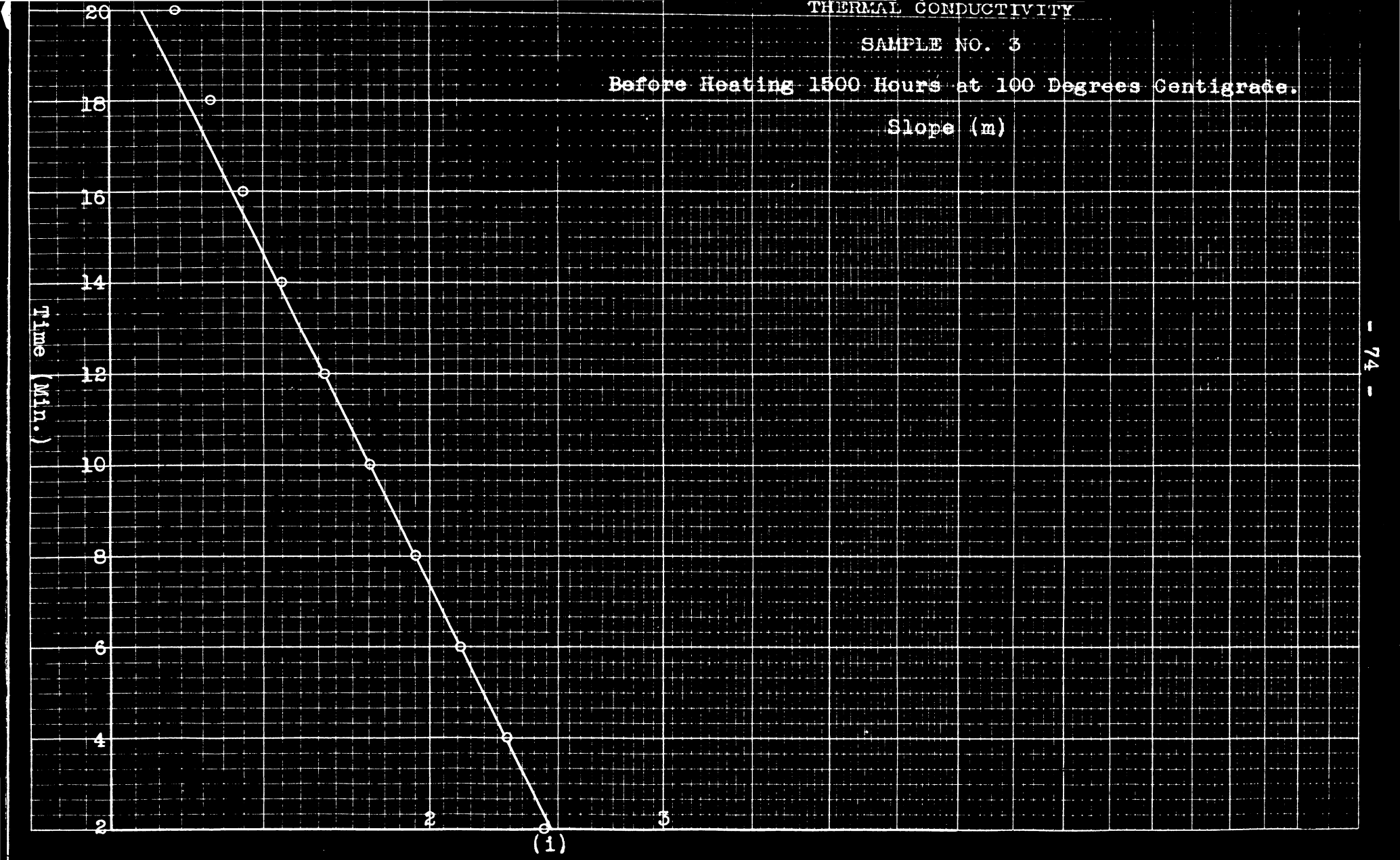
SAMPLE NO. 1

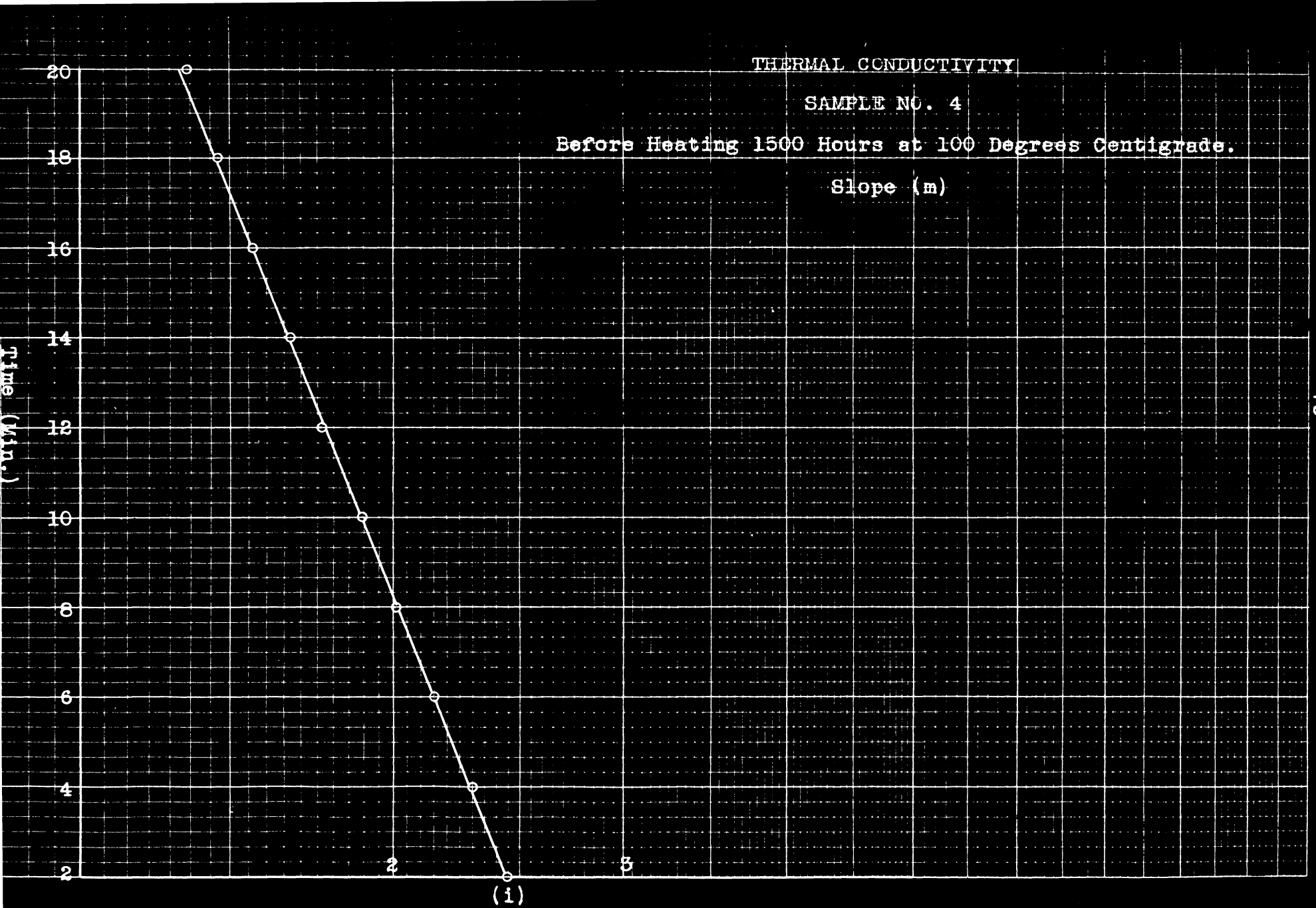
Before Heating 1500 Hours at 100 Degrees Centigrade.

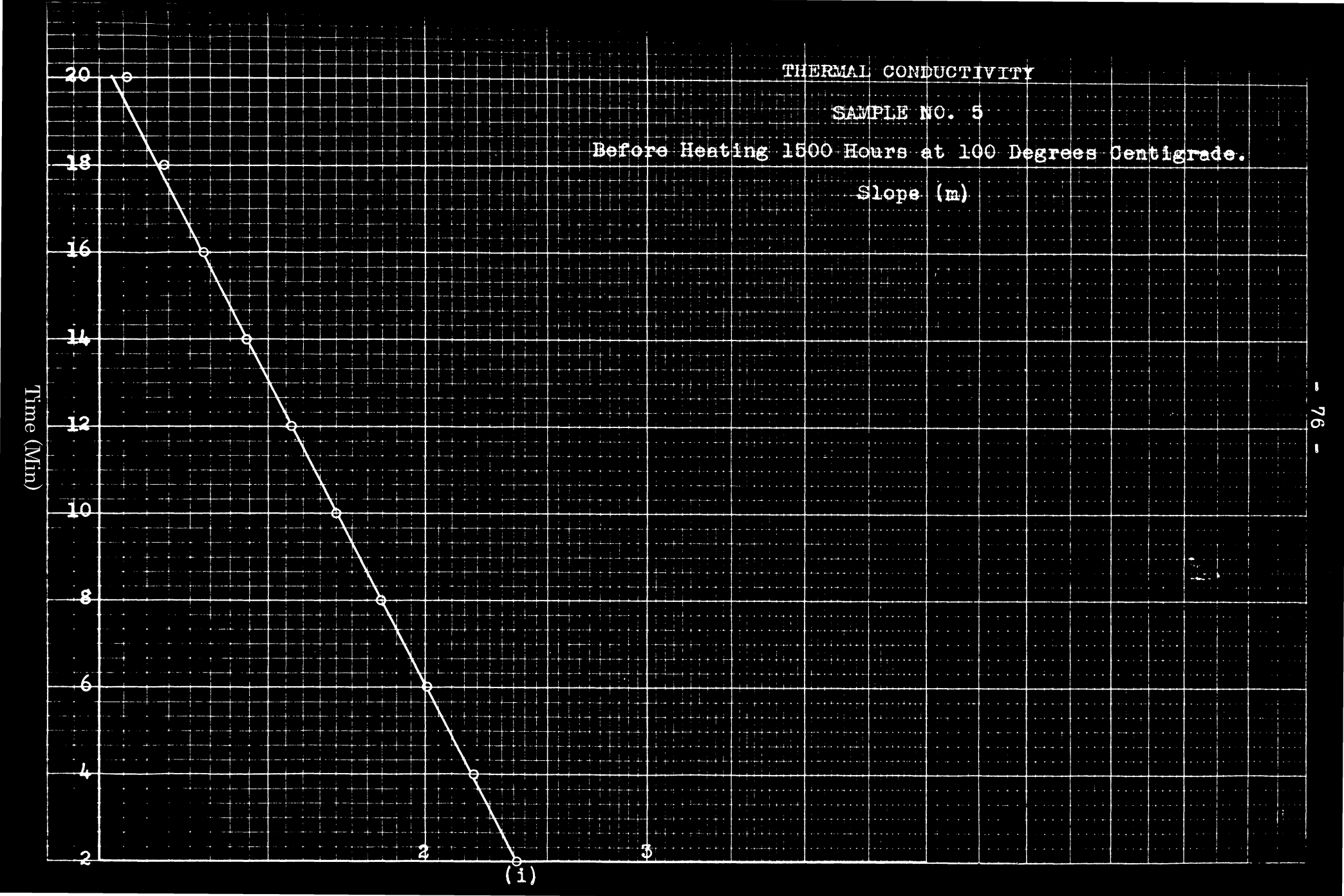
Slope (m)




THERMAL CONDUCTIVITY
SAMPLE NO. 2
Before Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
20
18
16
14
12
10
8
6
4
2
2
3
(i)

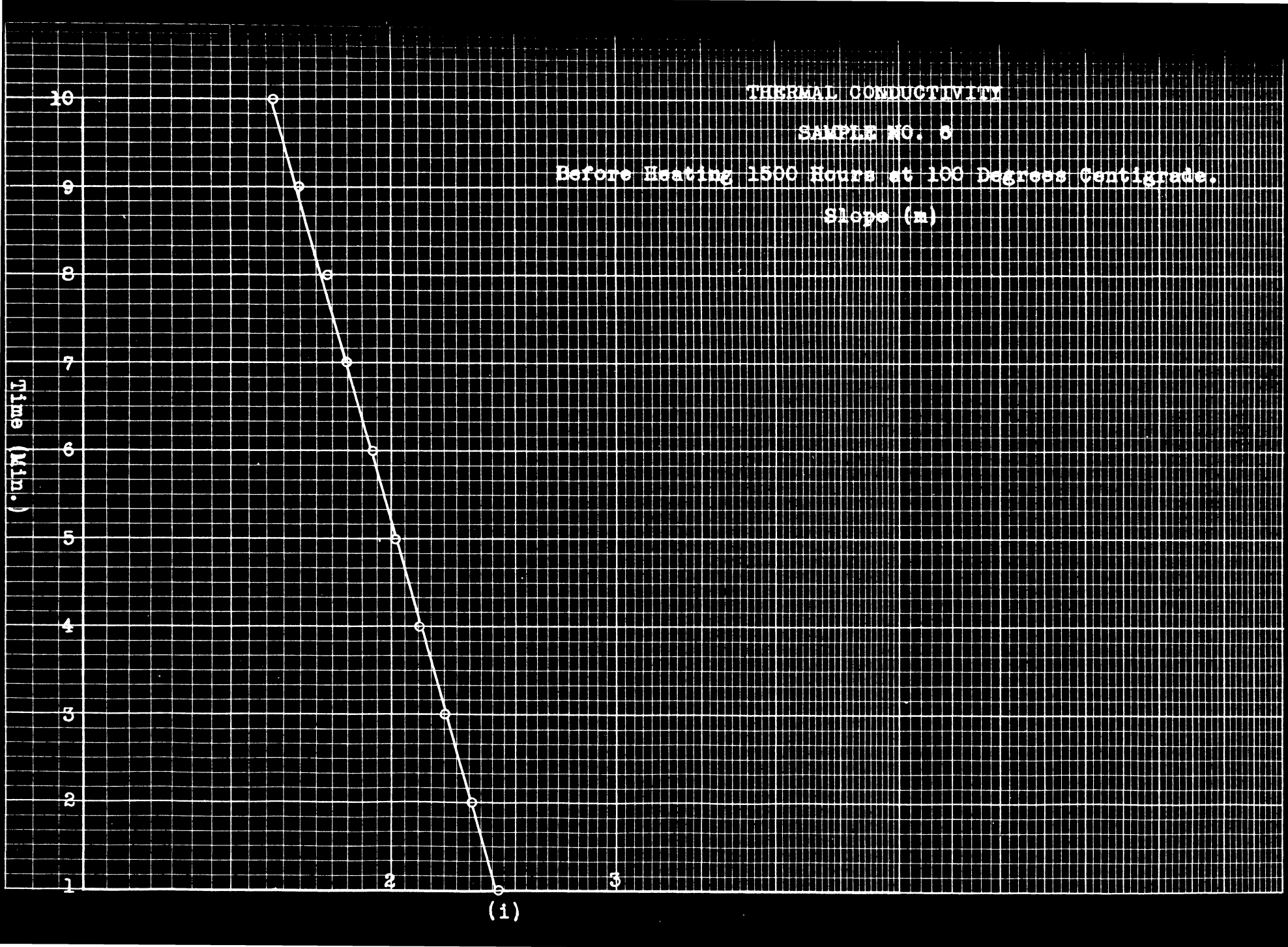

THERMAL CONDUCTIVITY
SAMPLE NO. 3
Before Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
20
18
16
14
12
10
8
6
4
2
2
3
(i)

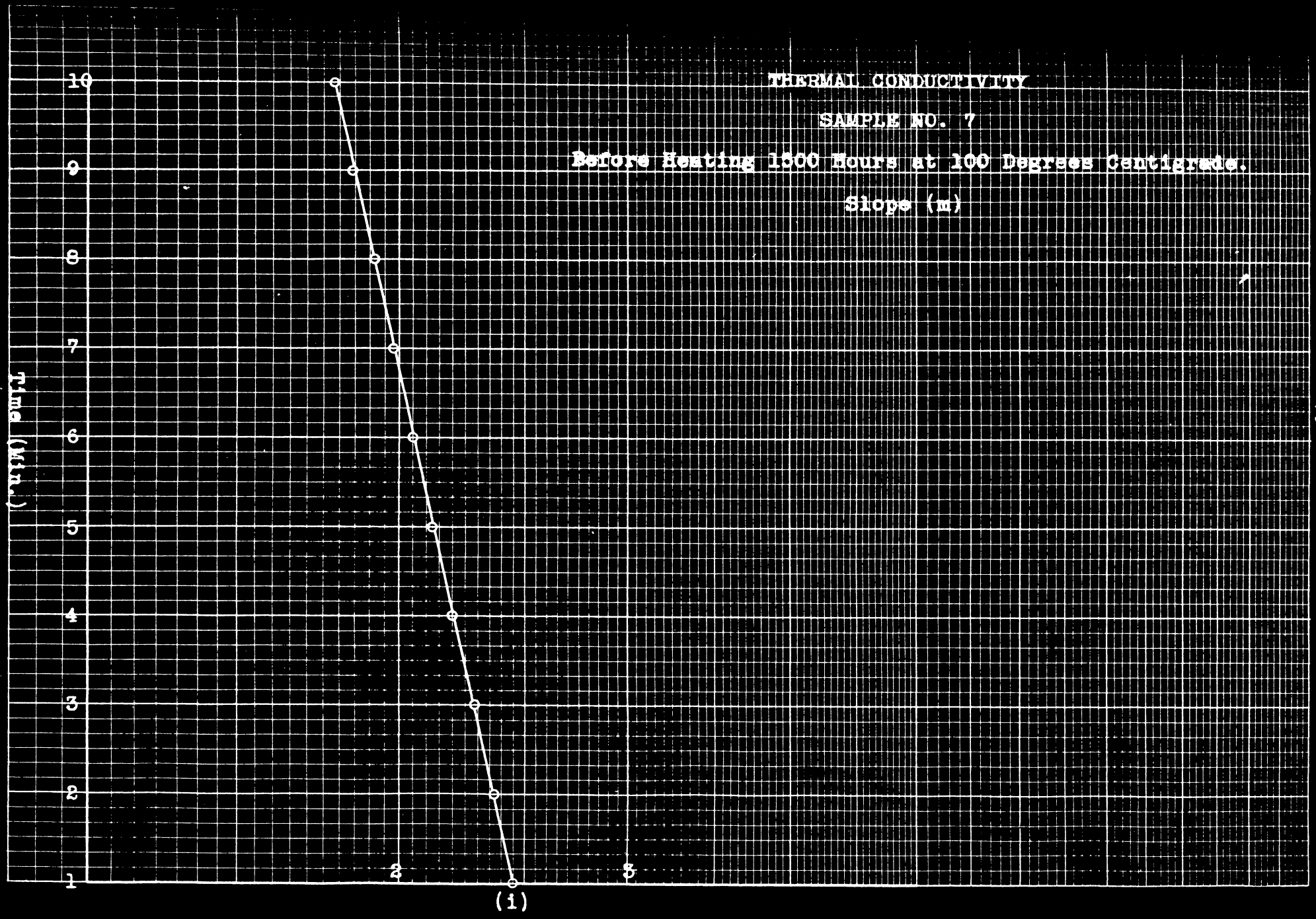

THERMAL CONDUCTIVITY
SAMPLE NO. 4
Before Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
20
18
16
14
12
10
8
6
4
2
2
3
(i)

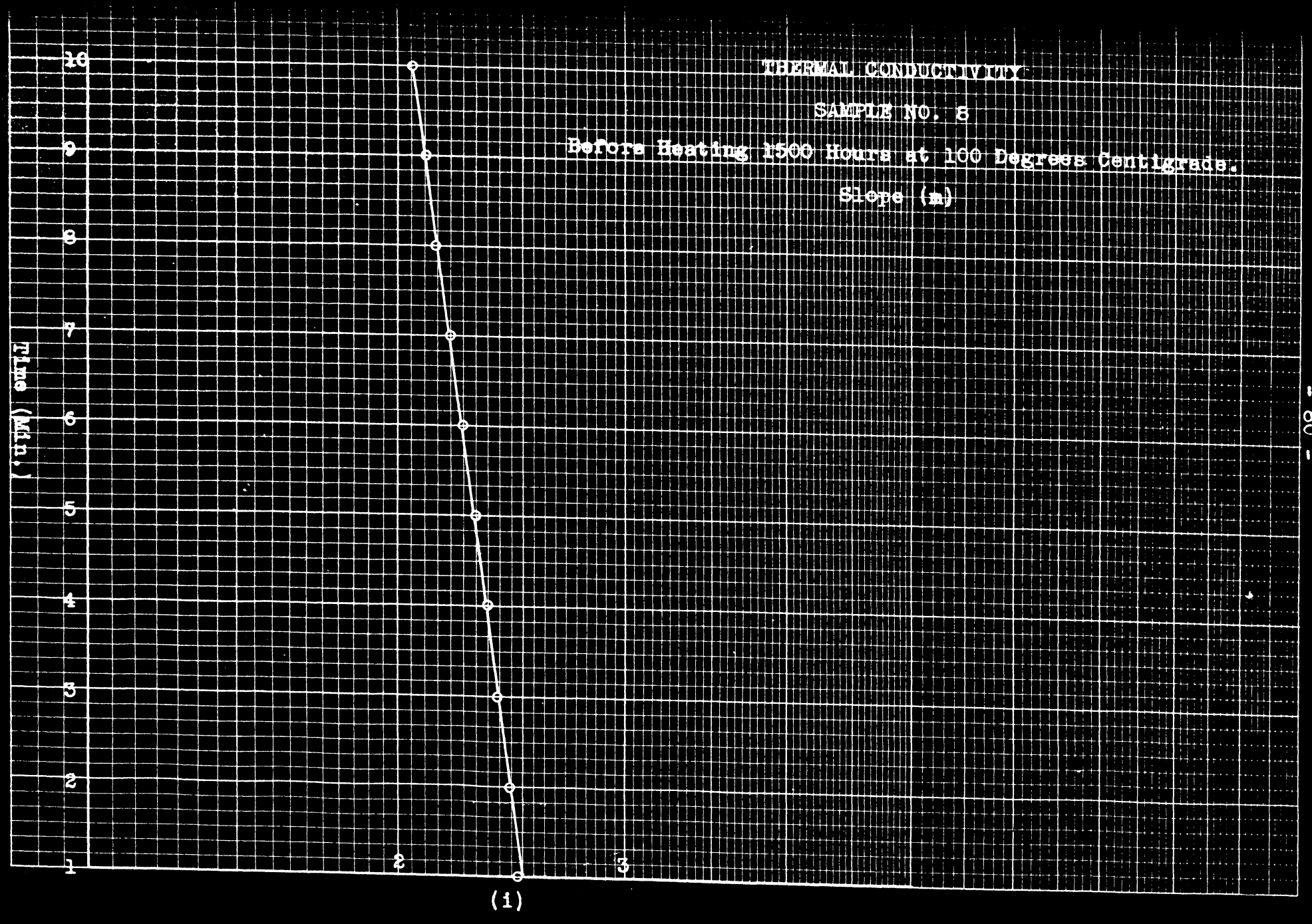

THERMAL CONDUCTIVITY
SAMPLE NO. 5
Before Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min)
20
18
16
14
12
10
8
6
4
2
2
3
(i)

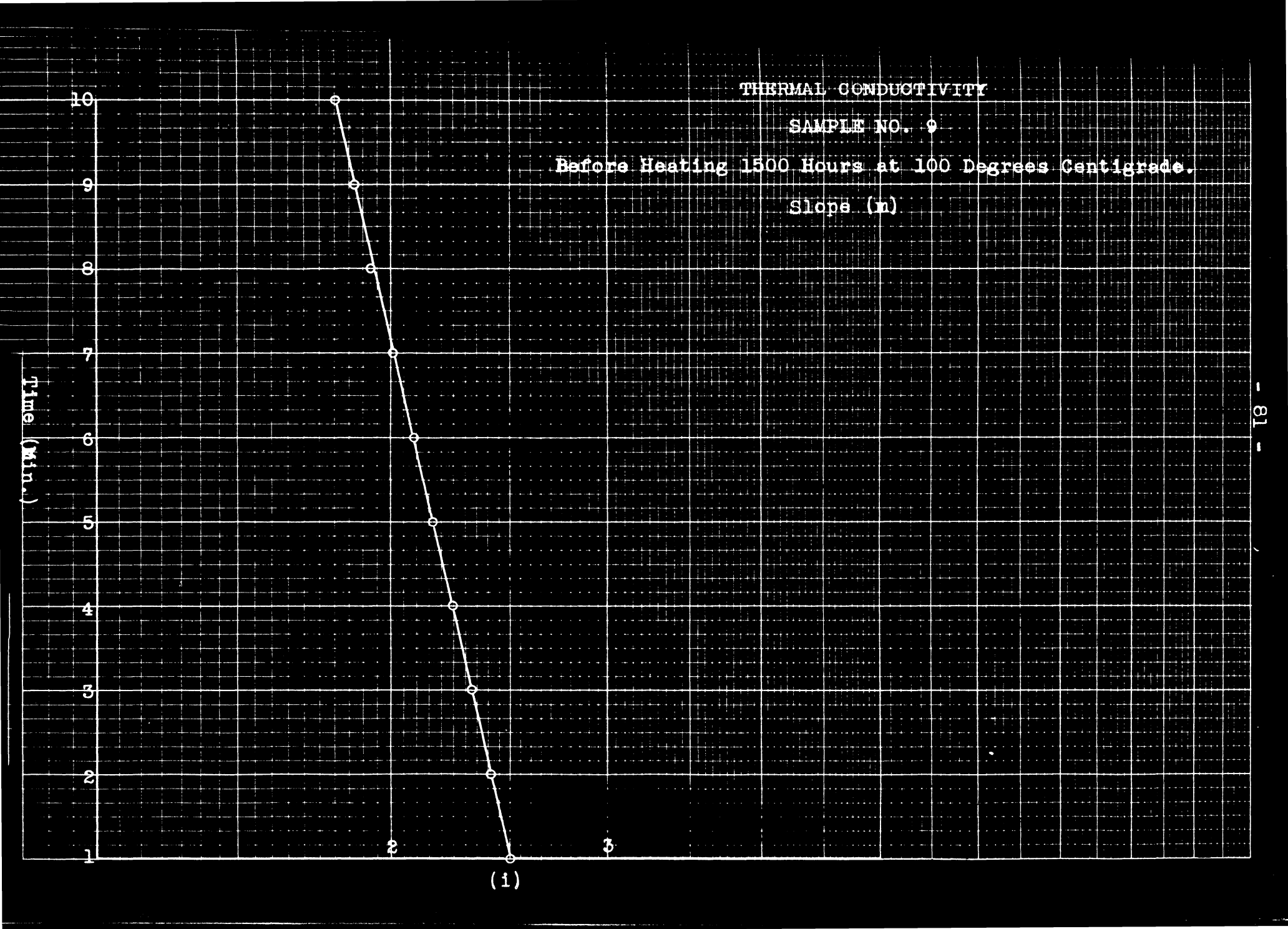
Thermal Conductivity Before Heating 1500 Hours at 100 Degrees Centigrade.
Time vs. Current

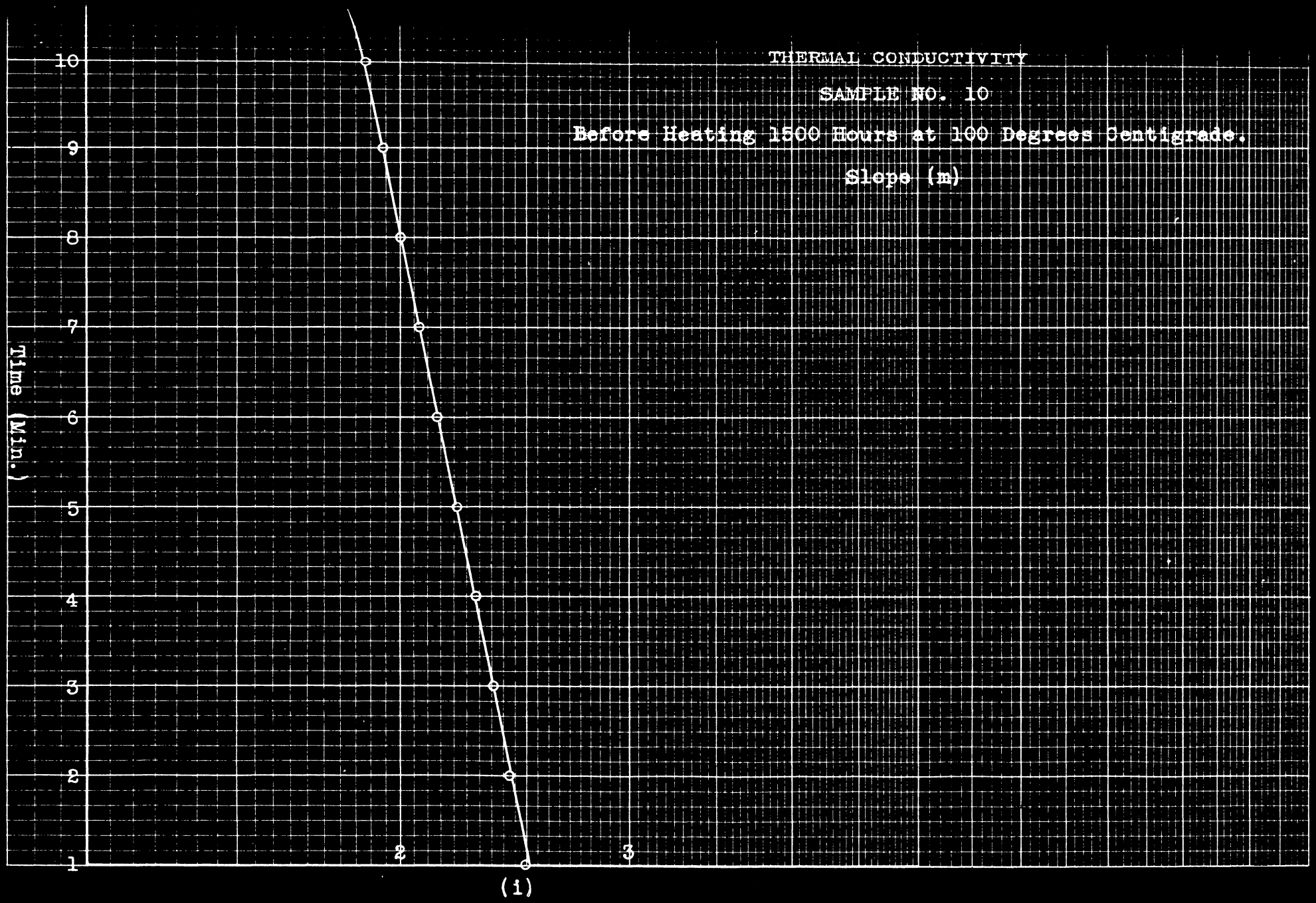
Time (Minutes)	Sample No. 6 (i)	Sample No. 7 (i)	Sample No. 8 (i)	Sample No. 9 (i)	Sample No. 10 (i)
1	24.30	24.40	24.70	25.00	24.90
2	23.10	23.70	24.30	24.10	24.20
3	22.00	22.90	23.90	23.25	23.60
4	21.00	22.00	23.40	22.40	22.90
5	20.10	21.20	23.00	21.70	22.10
6	19.30	20.40	22.50	20.90	21.30
7	18.40	19.80	22.00	20.00	20.70
8	17.80	19.10	21.30	19.20	20.00
9	17.00	18.30	21.00	18.70	19.30
10	16.20	17.80	20.50	18.00	18.80


THERMAL CONDUCTIVITY
SAMPLE NO. 8
Before Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
1
2
3
(i)


THERMAL CONDUCTIVITY
SAMPLE NO. 7
Before Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)

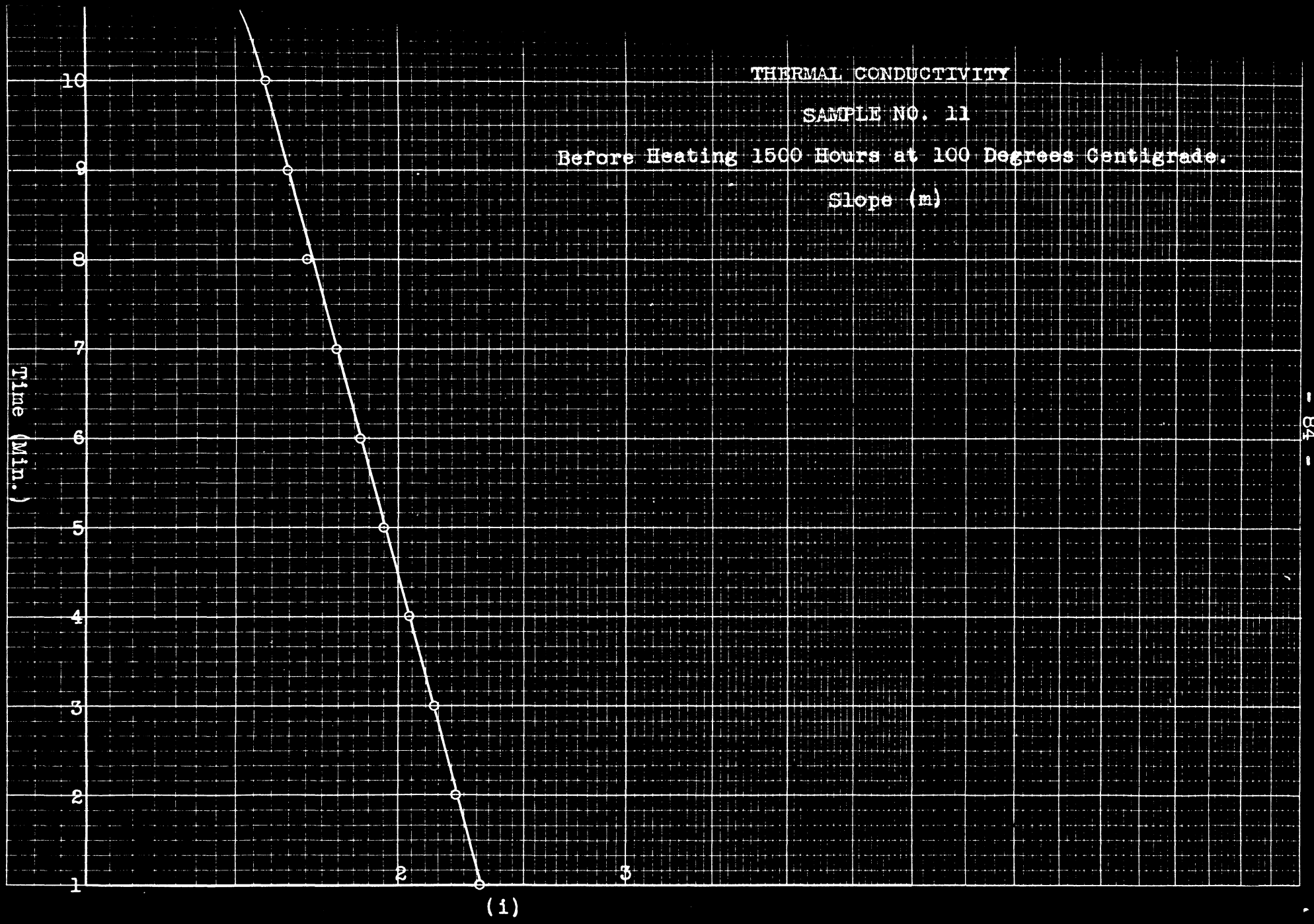

THERMAL CONDUCTIVITY
SAMPLE NO. 8
Before Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)

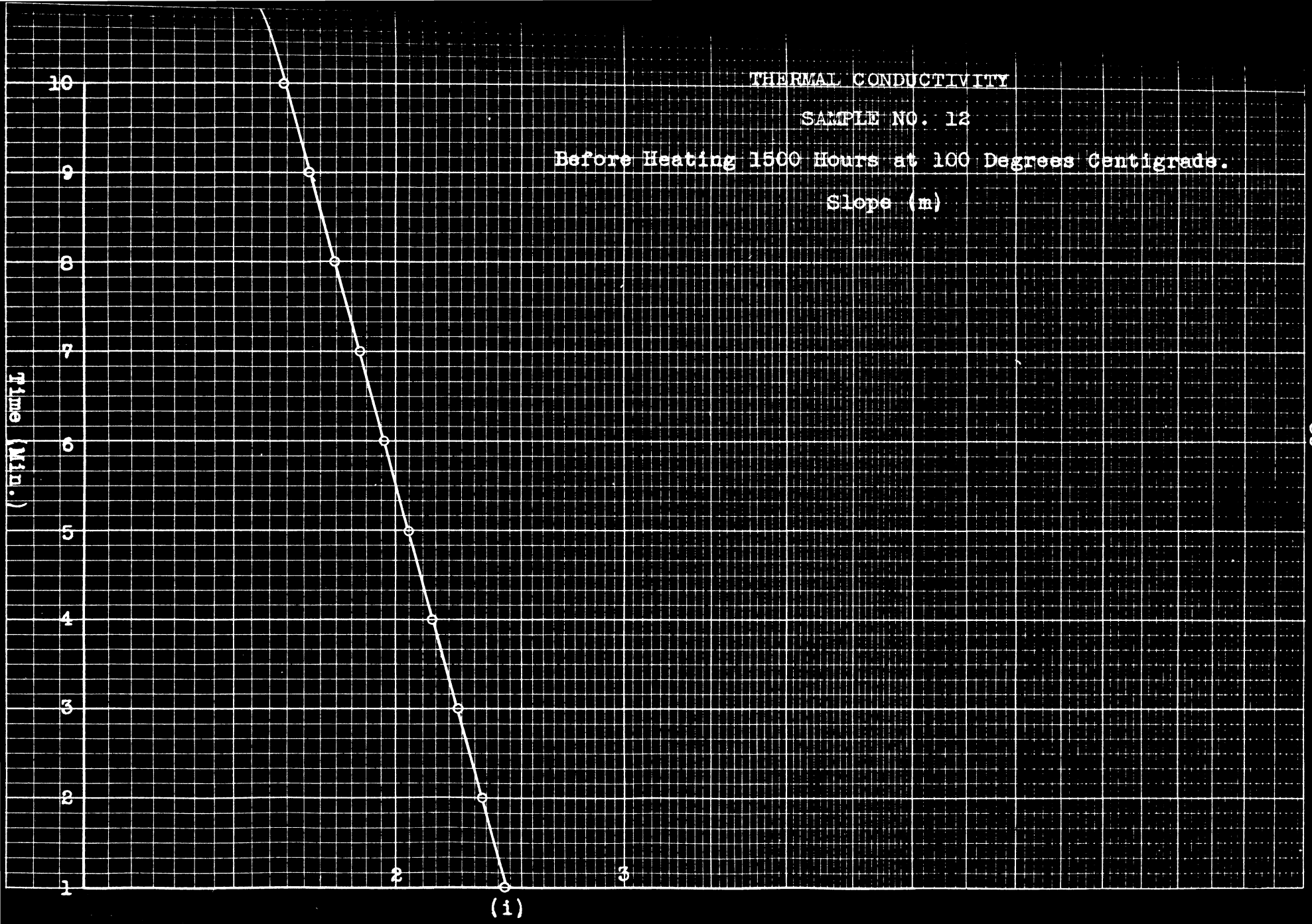

THERMAL CONDUCTIVITY
SAMPLE NO. 9
Before Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)

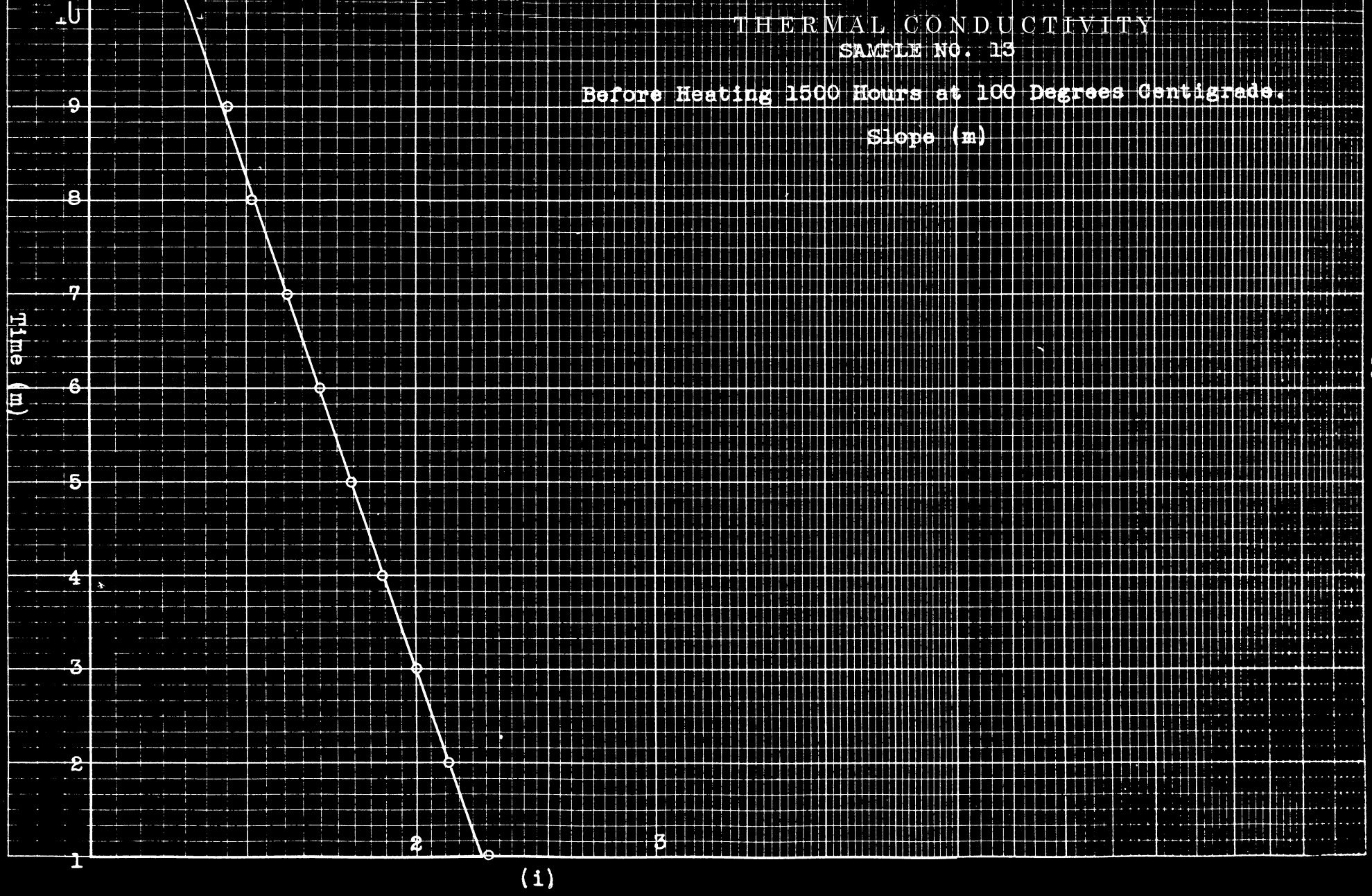

THERMAL CONDUCTIVITY
SAMPLE NO. 10
Before Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)

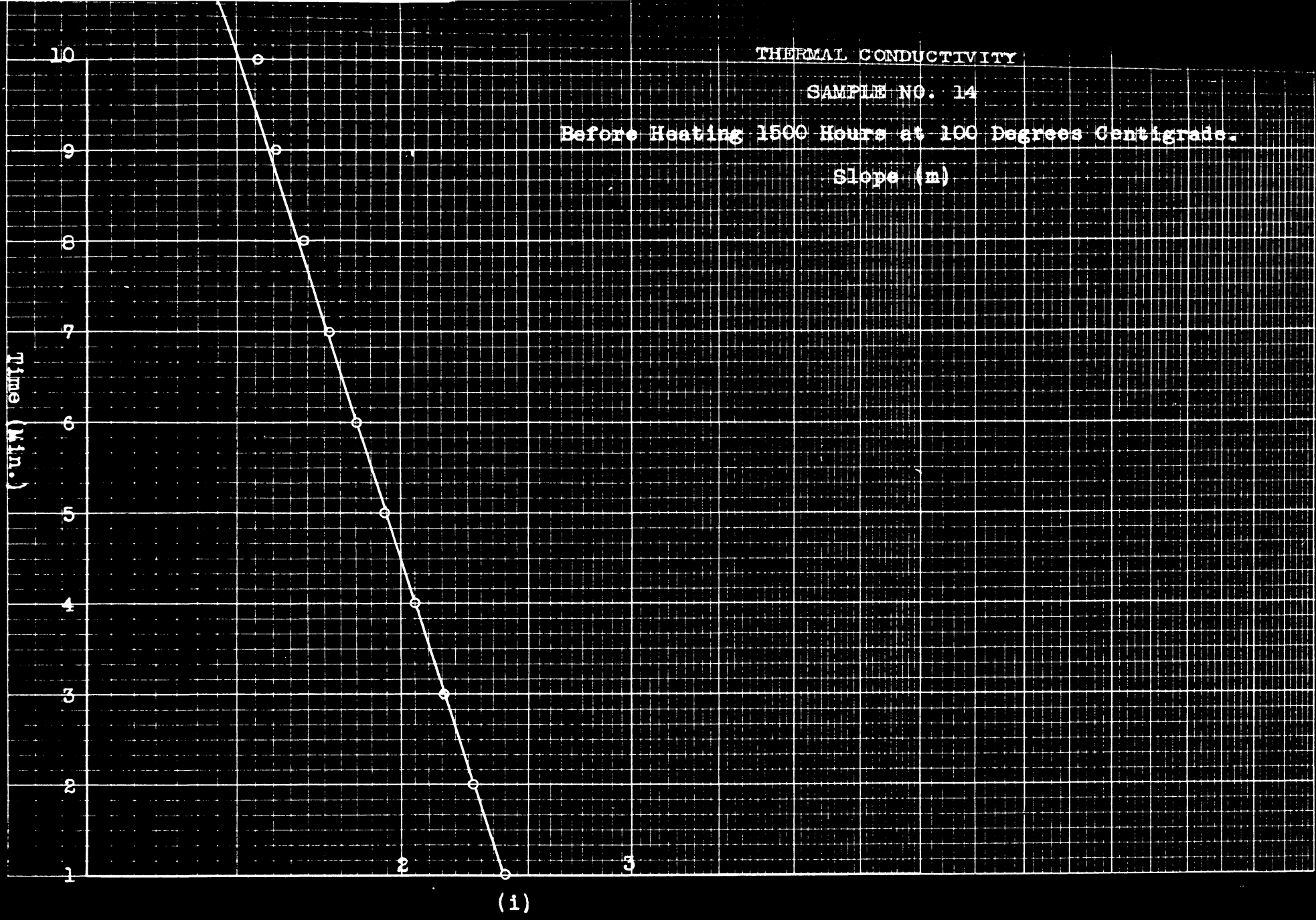
Thermal Conductivity Before Heating 1500 Hours at 100 Degrees Centigrade
Time vs. Current

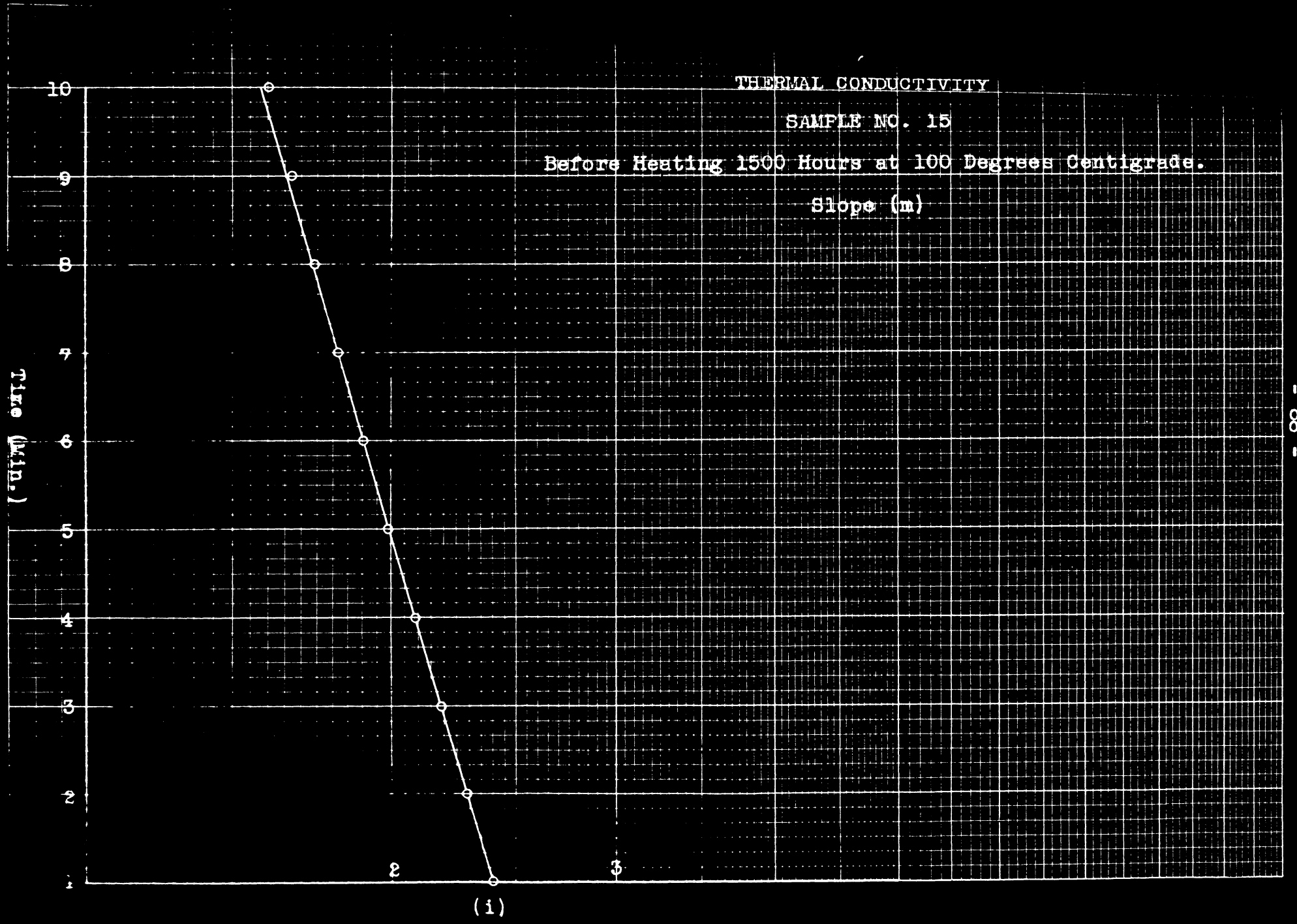
Time (Minutes)	Sample No. 11 (i)	Sample No. 12 (i)	Sample No. 13 (i)	Sample No. 14 (i)	Sample No. 15 (i)
1	23.20	24.20	22.60	23.89	24.00
2	22.20	23.30	21.20	22.65	22.92
3	21.30	22.30	20.00	21.50	21.86
4	20.40	21.30	18.90	20.44	20.85
5	19.50	20.40	17.90	19.40	19.90
6	18.70	19.50	17.00	18.50	19.00
7	17.90	18.70	16.10	17.70	18.20
8	17.00	17.90	15.10	16.90	17.42
9	16.40	17.10	14.50	16.22	16.72
10	15.80	16.40	13.90	15.60	16.08


THERMAL CONDUCTIVITY
SAMPLE NO. 11
Before Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)


THERMAL CONDUCTIVITY
SAMPLE NO. 12
Before Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)

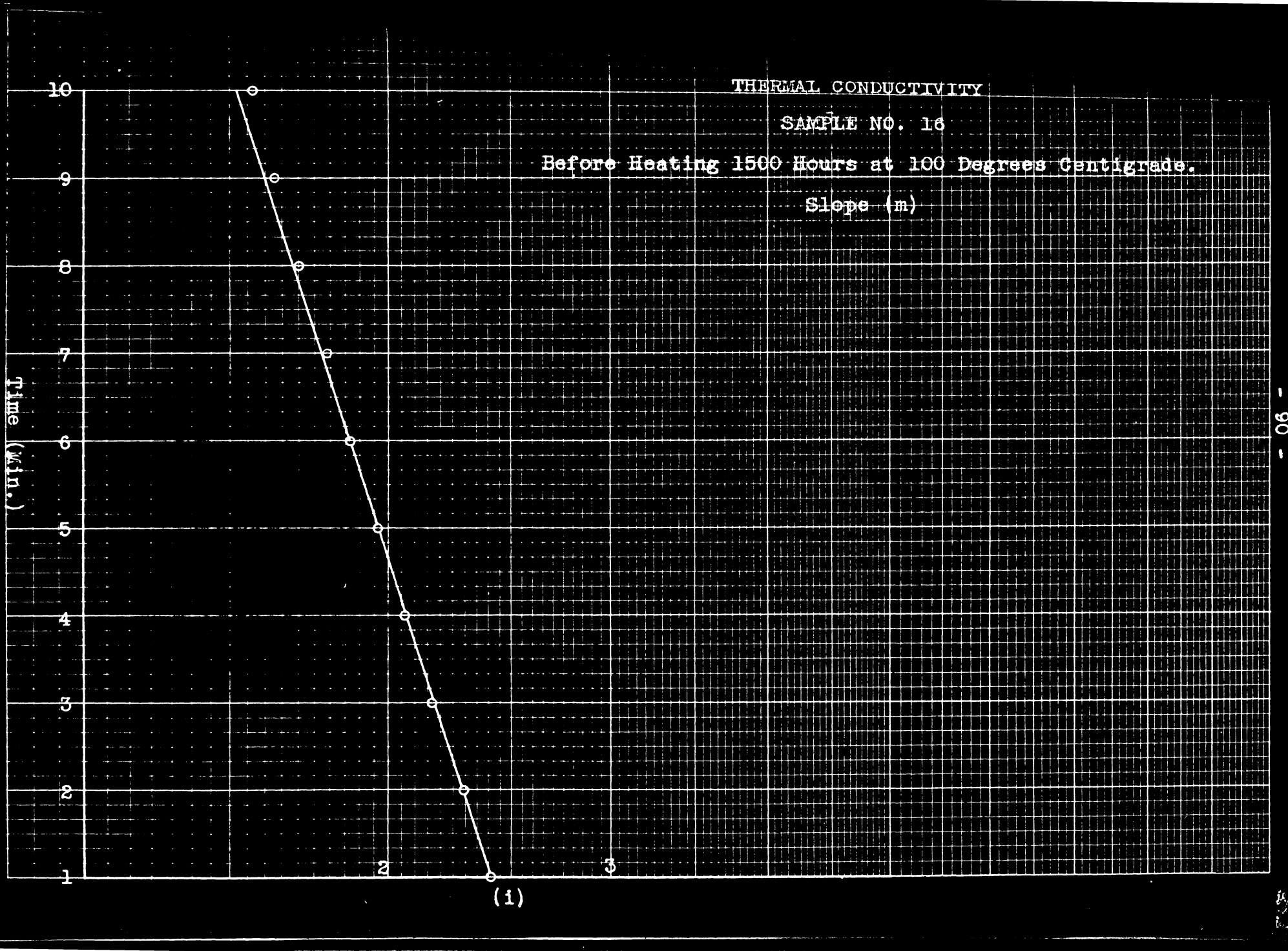

THERMAL CONDUCTIVITY
SAMPLE NO. 13
Before Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (m)
10
9
8
7
6
5
4
3
2
1
2
3
(i)

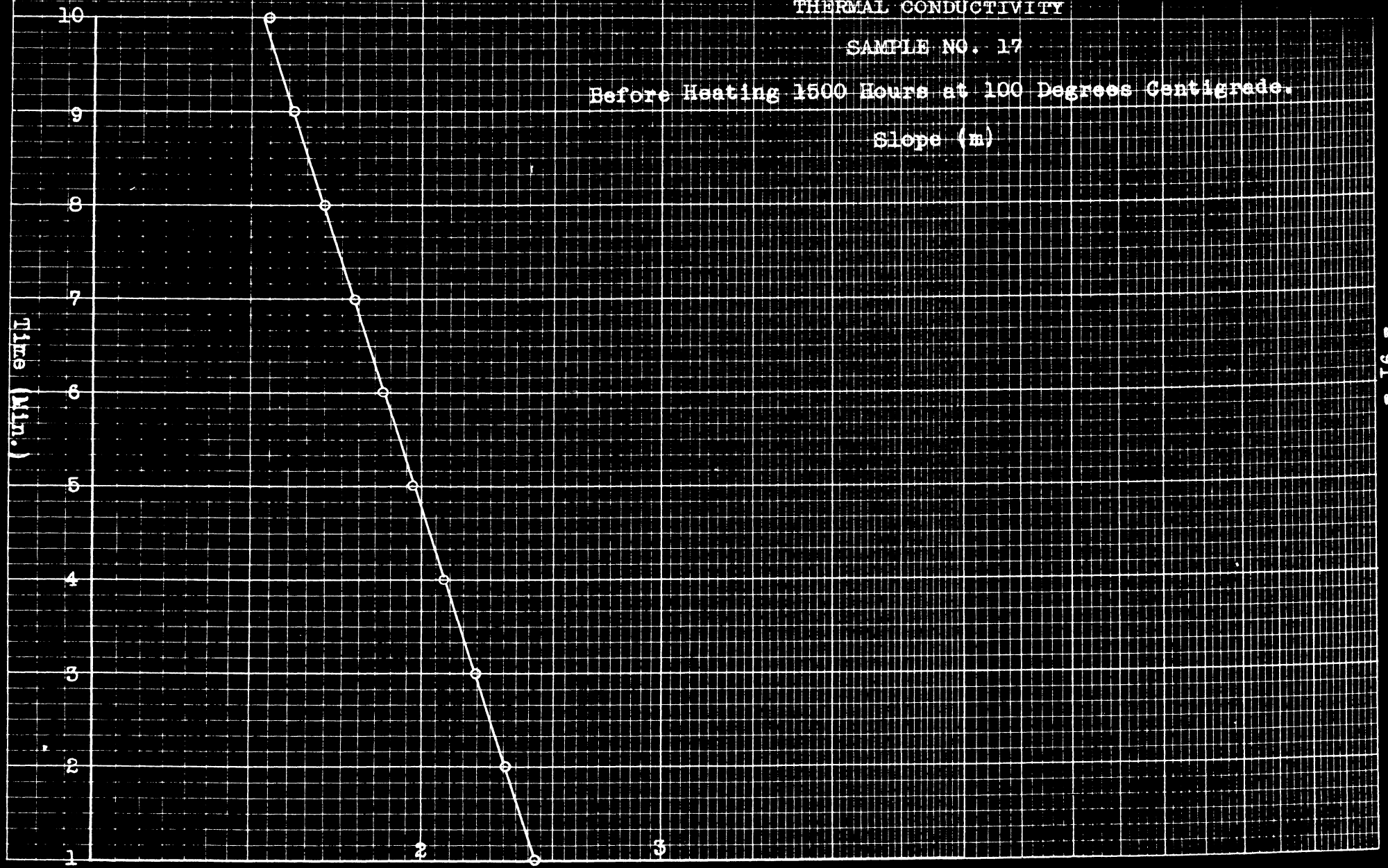

THERMAL CONDUCTIVITY
SAMPLE NO. 14
Before Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)

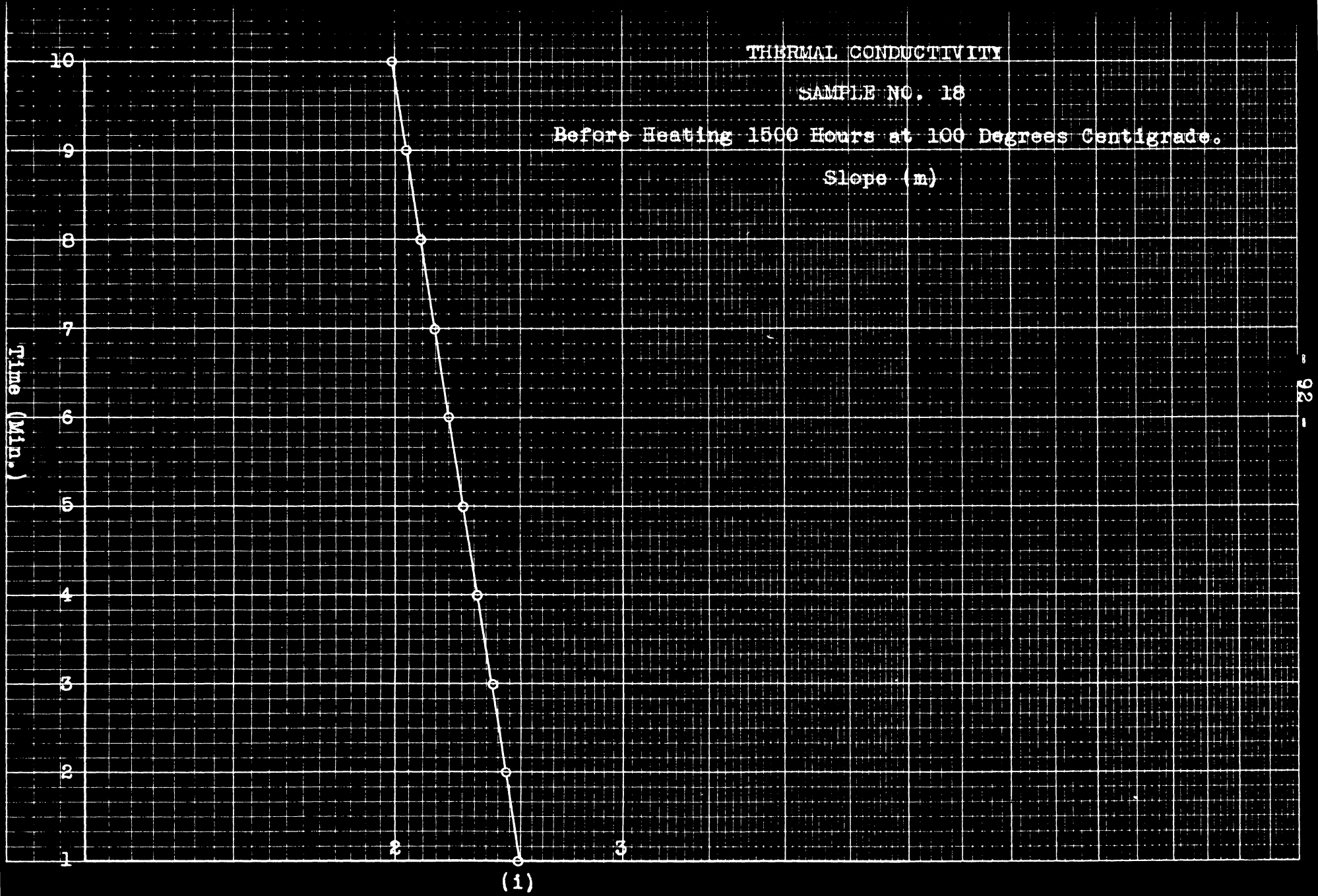

THERMAL CONDUCTIVITY
SAMPLE NO. 15
Before Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)

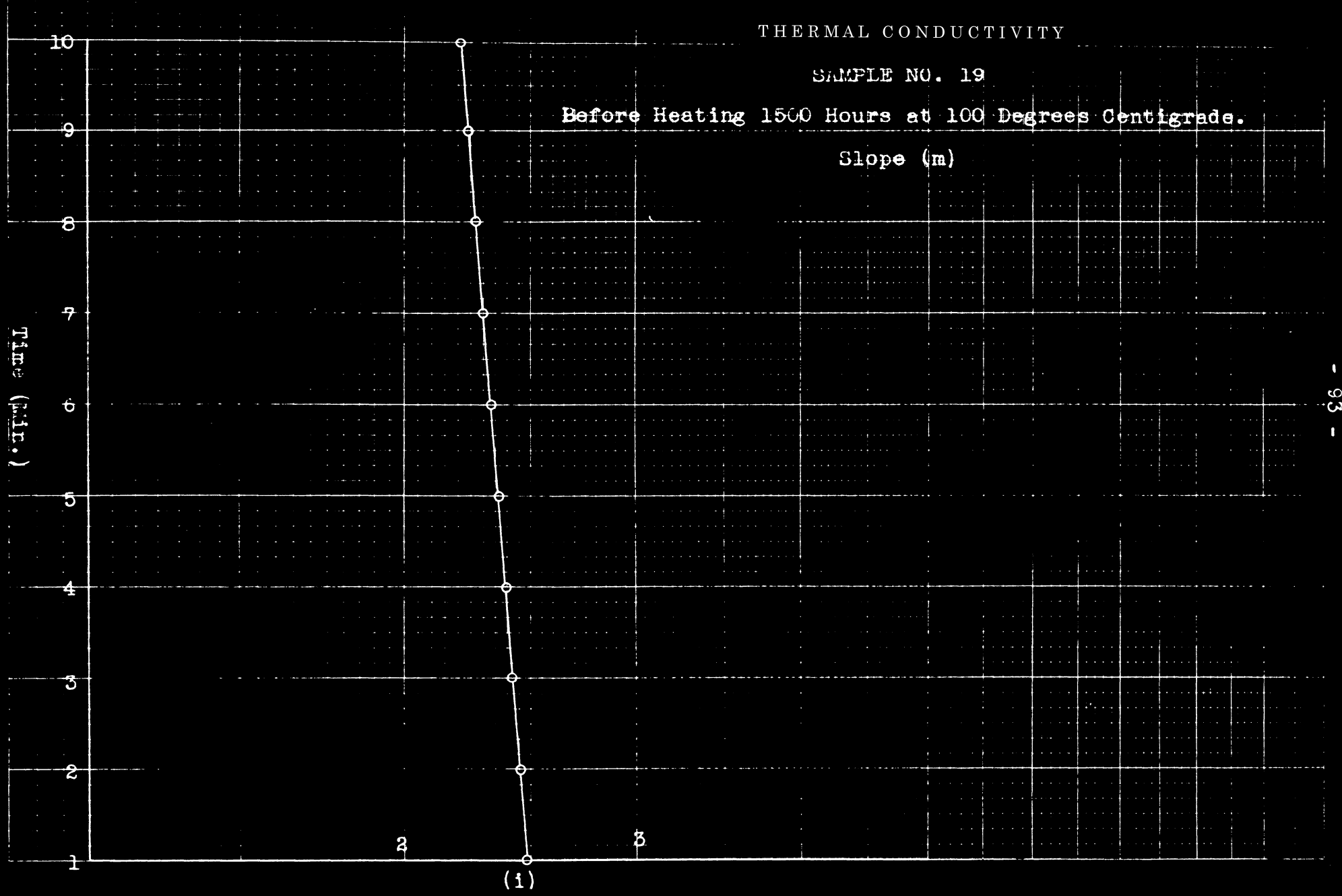
Thermal Conductivity Before Heating 1500 Hours at 100 Degrees Centigrade
Time vs. Current

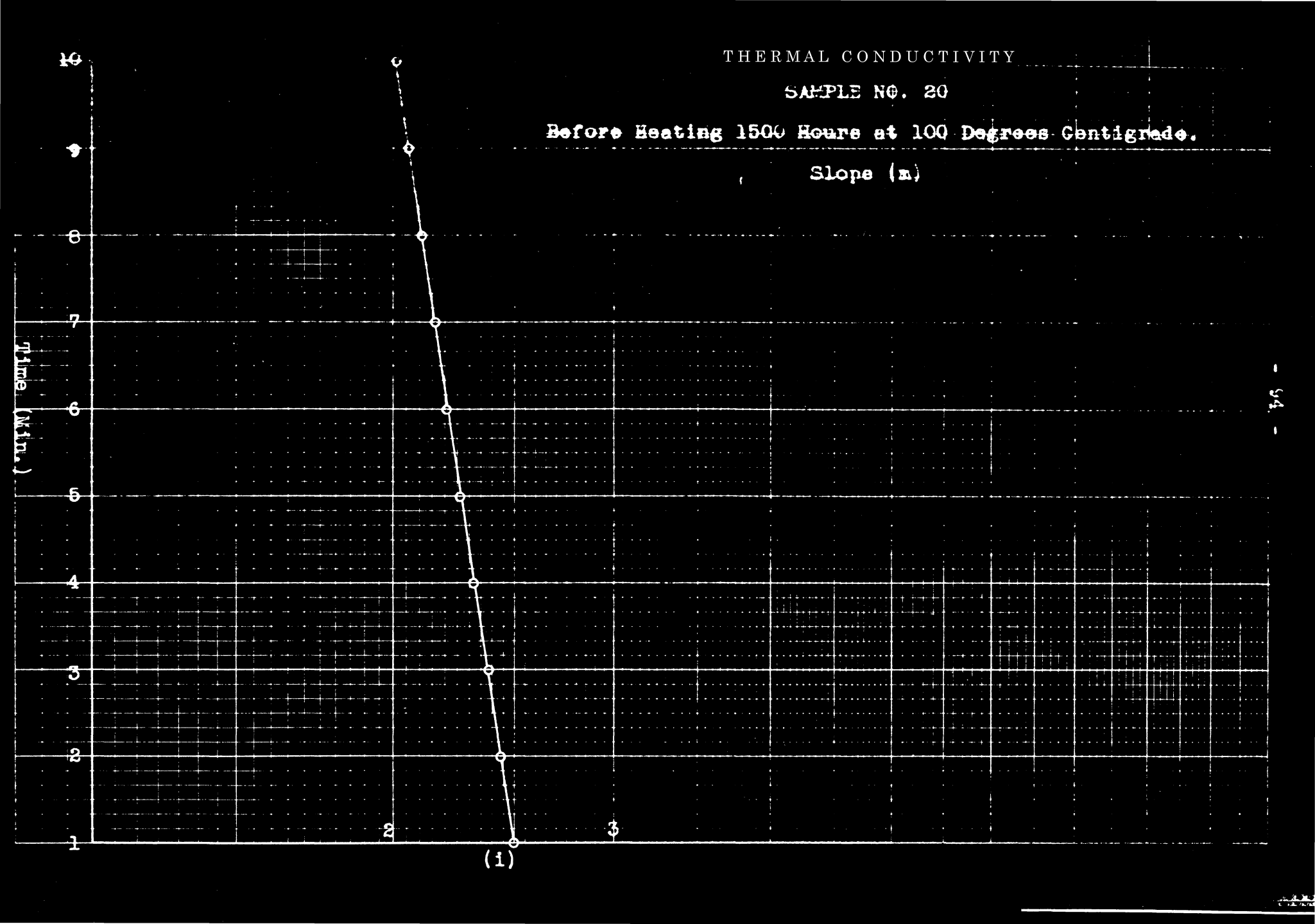
Time (Minutes)	Sample No. 16 (i)	Sample No. 17 (i)	Sample No. 18 (i)	Sample No. 19 (i)	Sample No. 20 (i)
1	24.06	24.25	24.68	24.80	24.98
2	22.84	23.05	24.36	24.50	24.37
3	21.70	21.90	23.75	24.22	23.80
4	20.60	20.74	23.14	23.91	23.20
5	19.60	19.67	22.58	23.62	22.62
6	18.65	18.70	22.00	23.30	22.10
7	17.80	17.80	21.45	23.00	21.60
8	17.00	16.95	20.90	22.70	21.10
9	16.25	16.18	20.40	22.37	20.60
10	15.68	15.45	19.88	22.03	20.15


THERMAL CONDUCTIVITY
SAMPLE NO. 16
Before Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)


THERMAL CONDUCTIVITY
SAMPLE NO. 17
Before Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)


THERMAL CONDUCTIVITY
SAMPLE NO. 18
Before Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
2
3
(1)


THERMAL CONDUCTIVITY
SAMPLE NO. 19
Before Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)

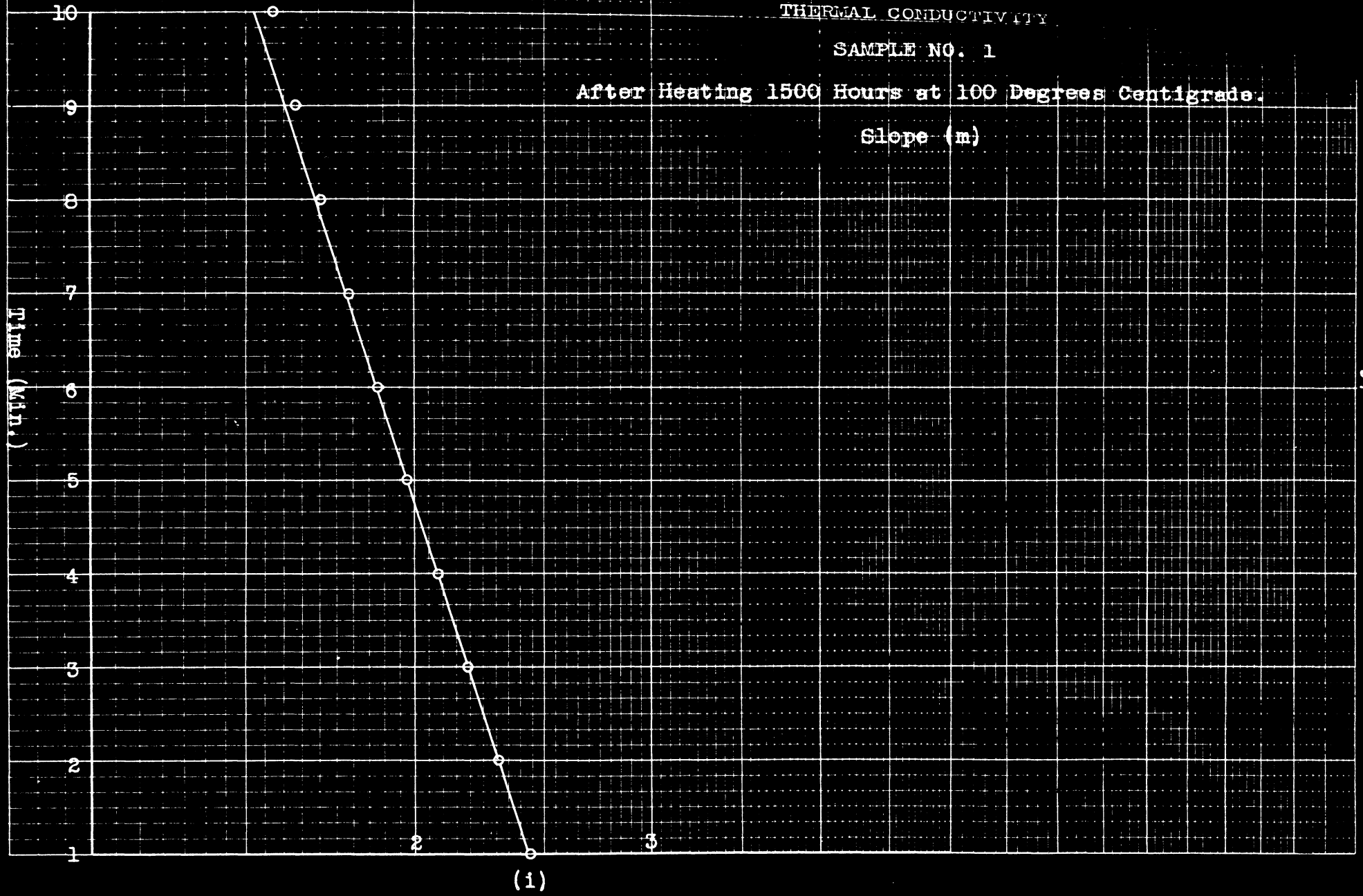

THERMAL CONDUCTIVITY
SAMPLE NO. 20
Before Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)

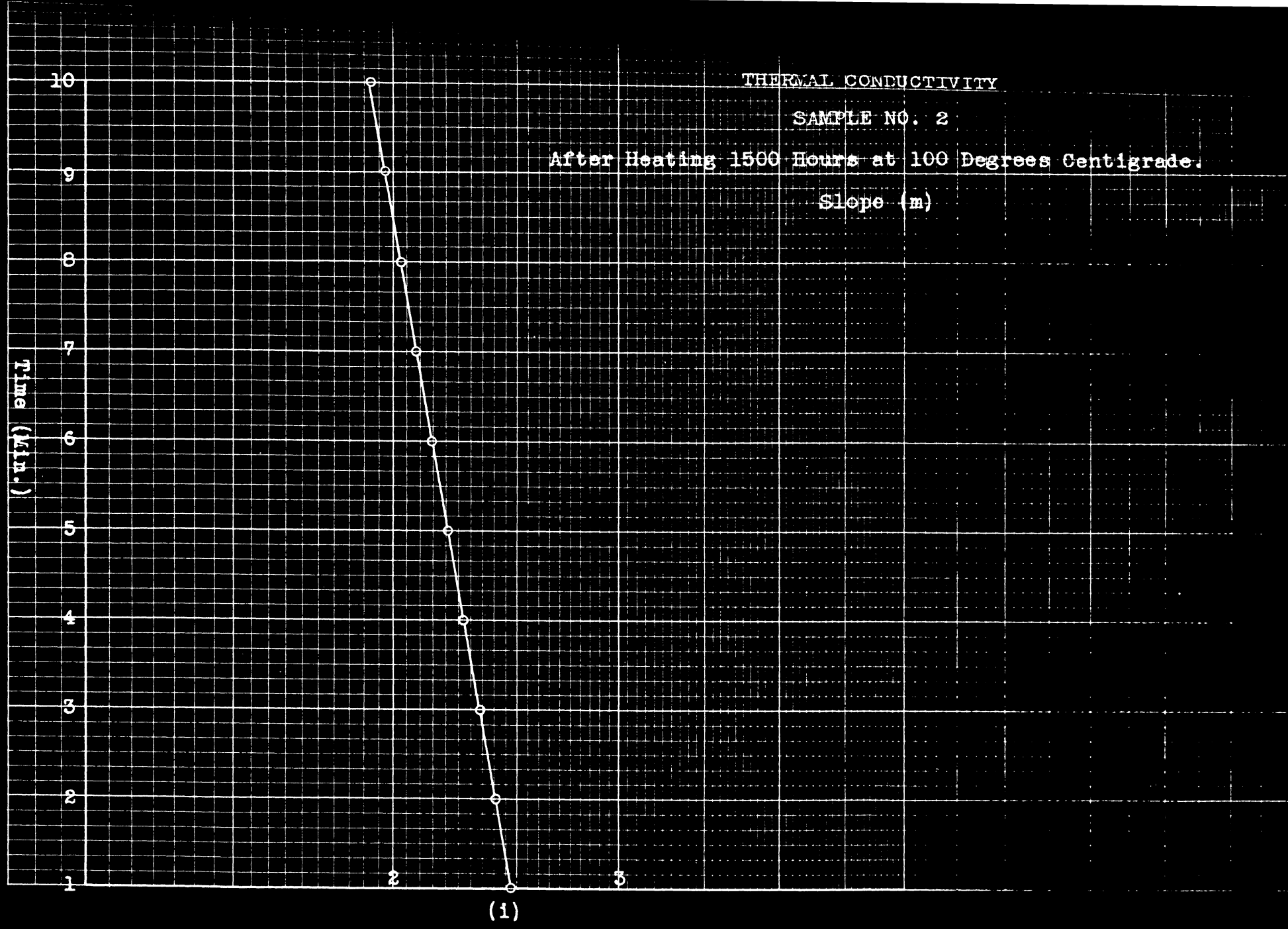
Thermal Conductivity Before Heating 1500 Hours at 100 Degrees Centigrade.

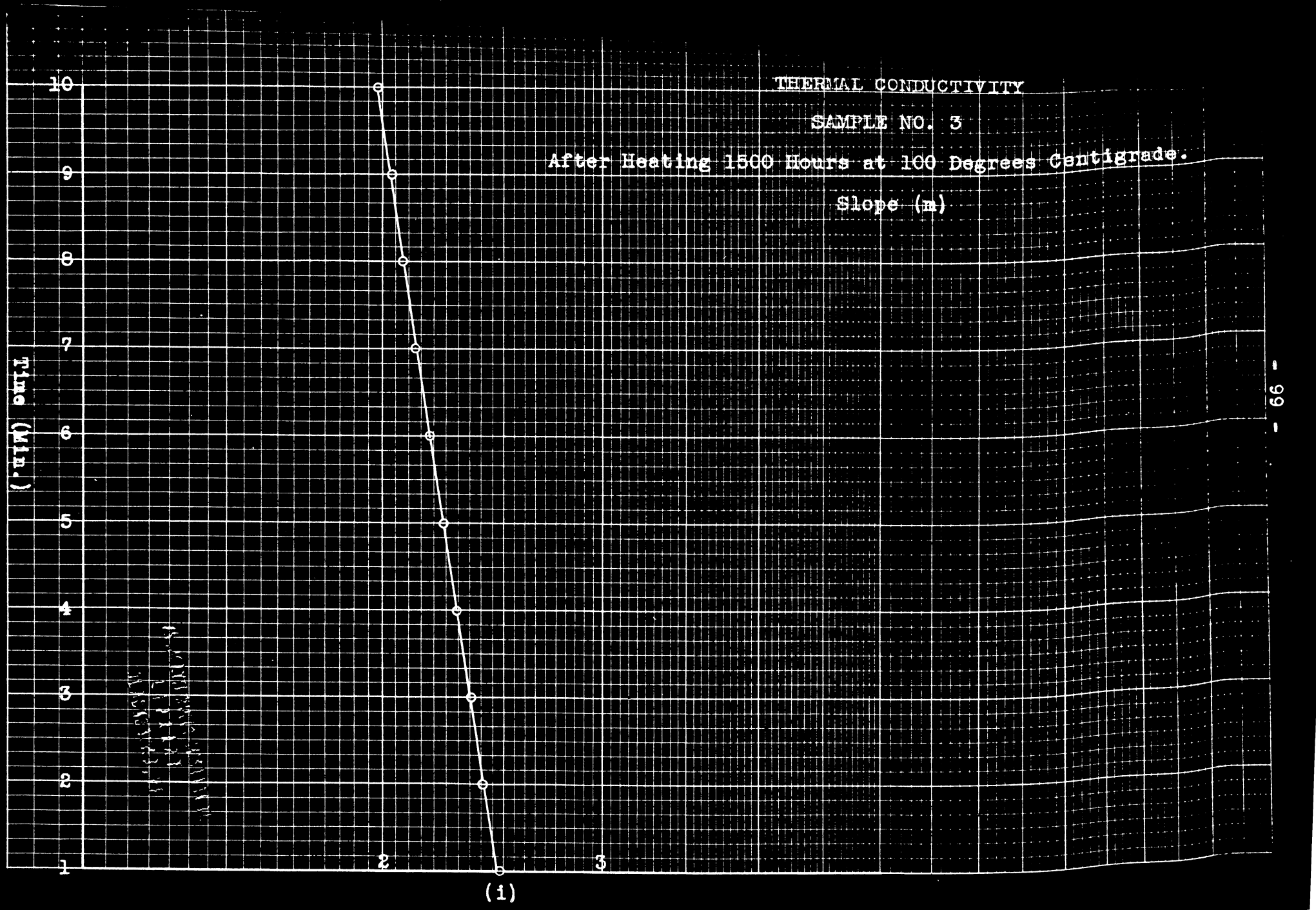
Sample No.	m (Sec.)	4.704 x (d) (Cal./Cm. ^{o}C.)	K (Cal./Cm. ^{o}C.Sec.)
1	1870.16	1.0584	.000566
2	3202.78	2.9635	.000925
3	3646.86	3.4810	.000955
4	4118.74	2.8224	.000685
5	3409.76	3.2928	.000966
6	3075.87	3.0576	.000994
7	3816.23	3.2928	.000863
8	6397.69	3.1987	.000500
9	3817.98	3.0576	.000801
10	3701.71	3.3398	.000902
11	3276.50	2.8224	.000861
12	3166.94	2.8694	.000606
13	2450.98	2.5872	.001056
14	2682.90	0.9408	.000351
15	3036.87	1.5288	.000503
16	2668.85	1.5053	.000564
17	2612.30	1.5053	.000576
18	5518.19	3.1517	.000571
19	9740.25	2.3134	.000238
20	5690.63	1.3877	.000244

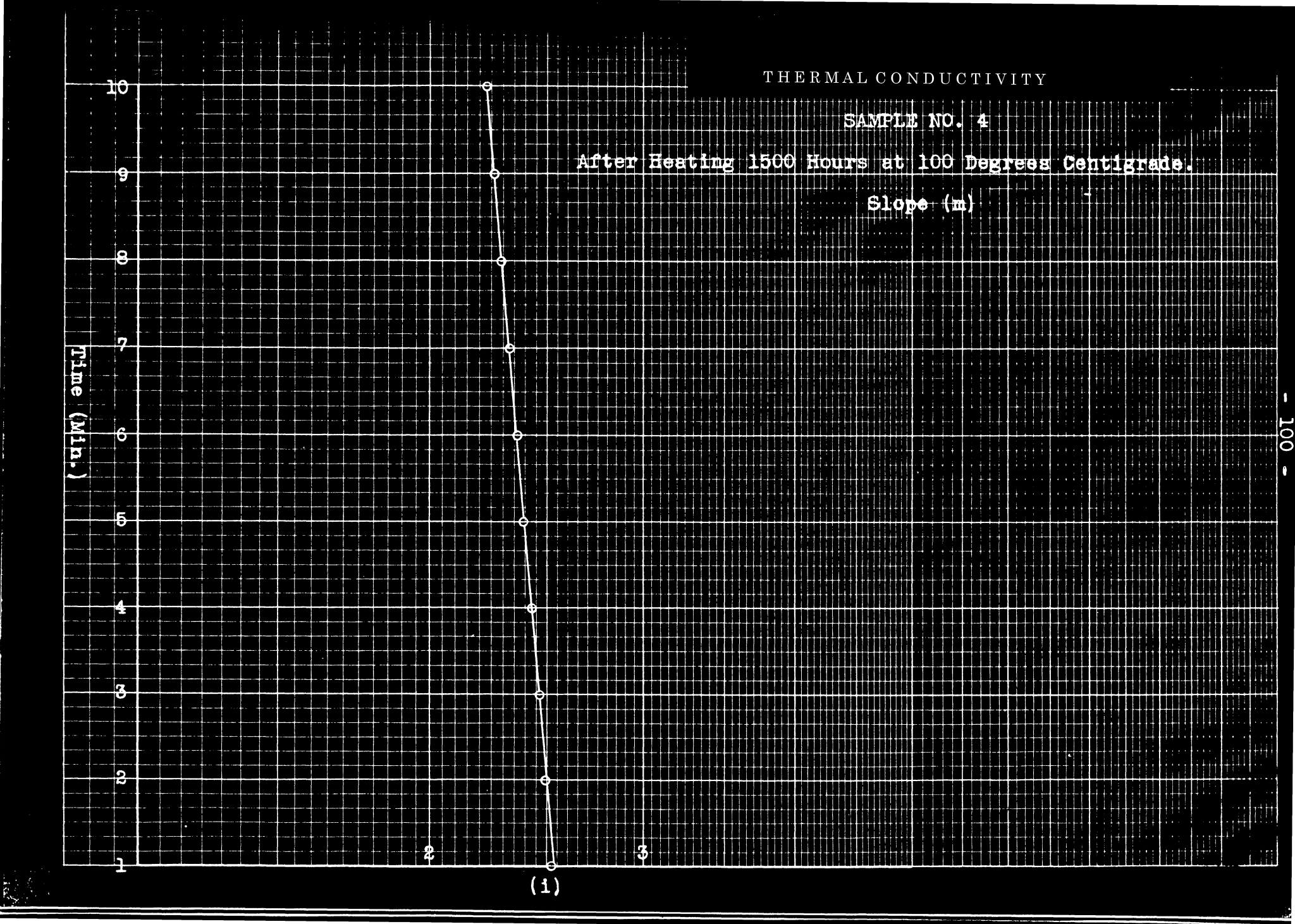
Thermal Conductivity After Heating 1500 Hours at 100 Degrees Centigrade.
Time vs. Current

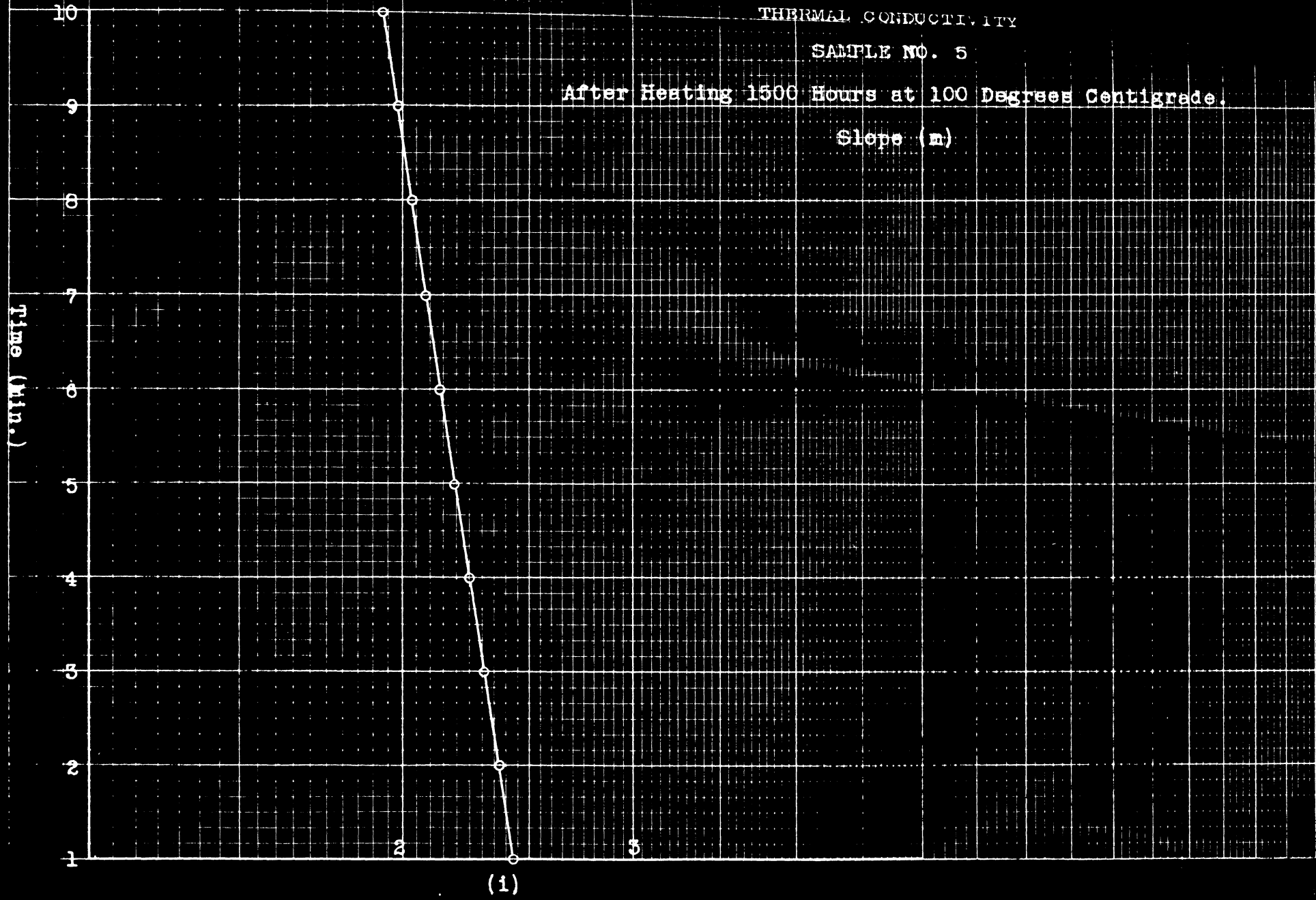
Time (Minutes)	Sample No. 1 (i)	Sample No. 2 (i)	Sample No. 3 (i)	Sample No. 4 (i)	Sample No. 5 (i)
1	24.44	24.74	24.85	25.20	24.28
2	23.10	24.07	24.18	24.92	23.72
3	21.88	23.26	23.55	24.62	23.10
4	20.74	22.70	22.92	24.30	22.50
5	19.70	22.05	22.35	23.95	21.92
6	18.74	21.43	21.80	23.60	21.38
7	17.85	20.88	21.25	23.25	20.80
8	17.02	20.28	20.74	22.90	20.30
9	16.30	19.75	20.27	22.59	19.79
10	15.72	19.25	19.80	22.25	19.30


THERMAL CONDUCTIVITY
SAMPLE NO. 1
After Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)


THERMAL CONDUCTIVITY
SAMPLE NO. 2
After Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)

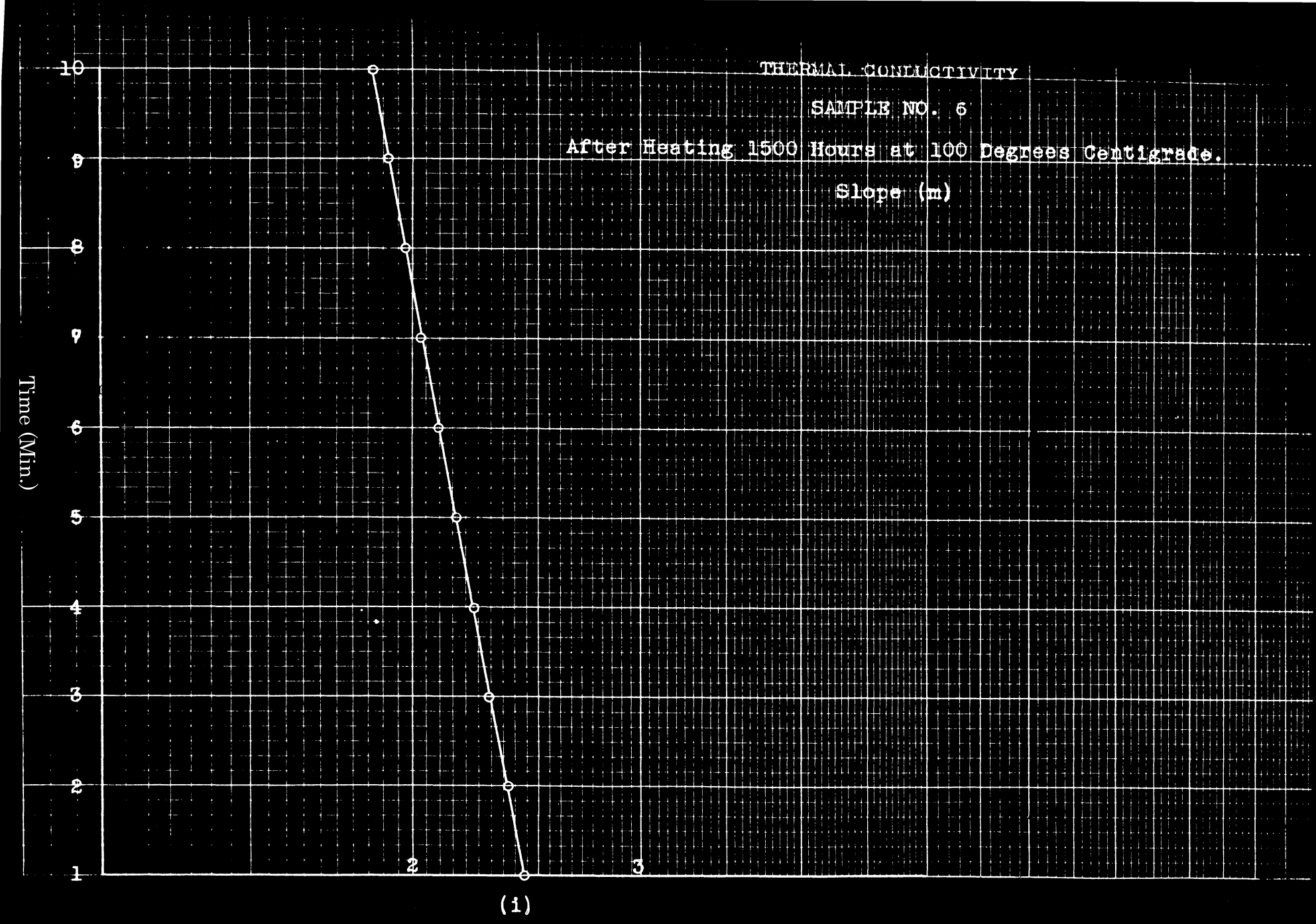

THERMAL CONDUCTIVITY
SAMPLE NO. 3
After Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)
- 99 -

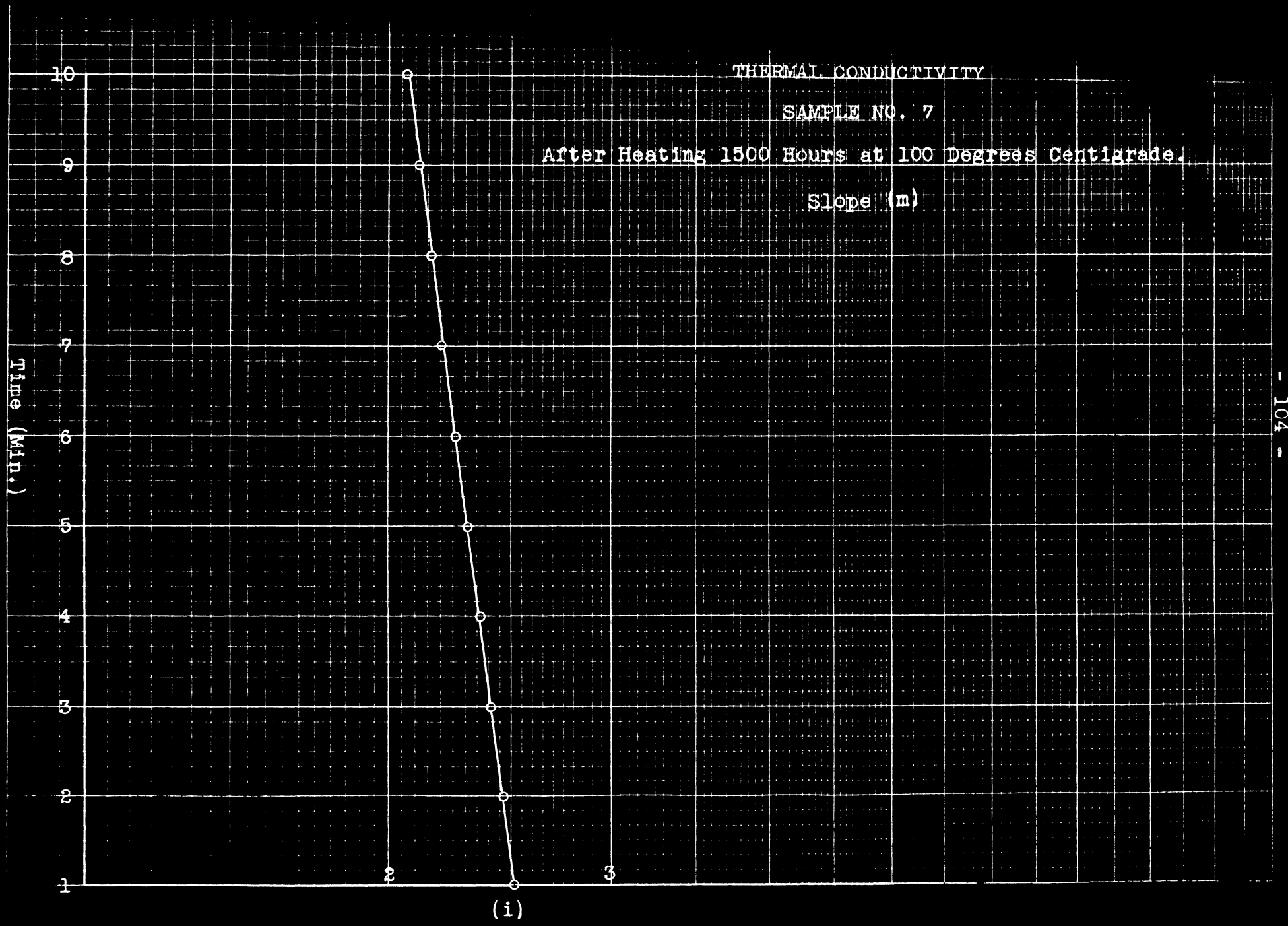

THERMAL CONDUCTIVITY
SAMPLE NO. 4
After Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)

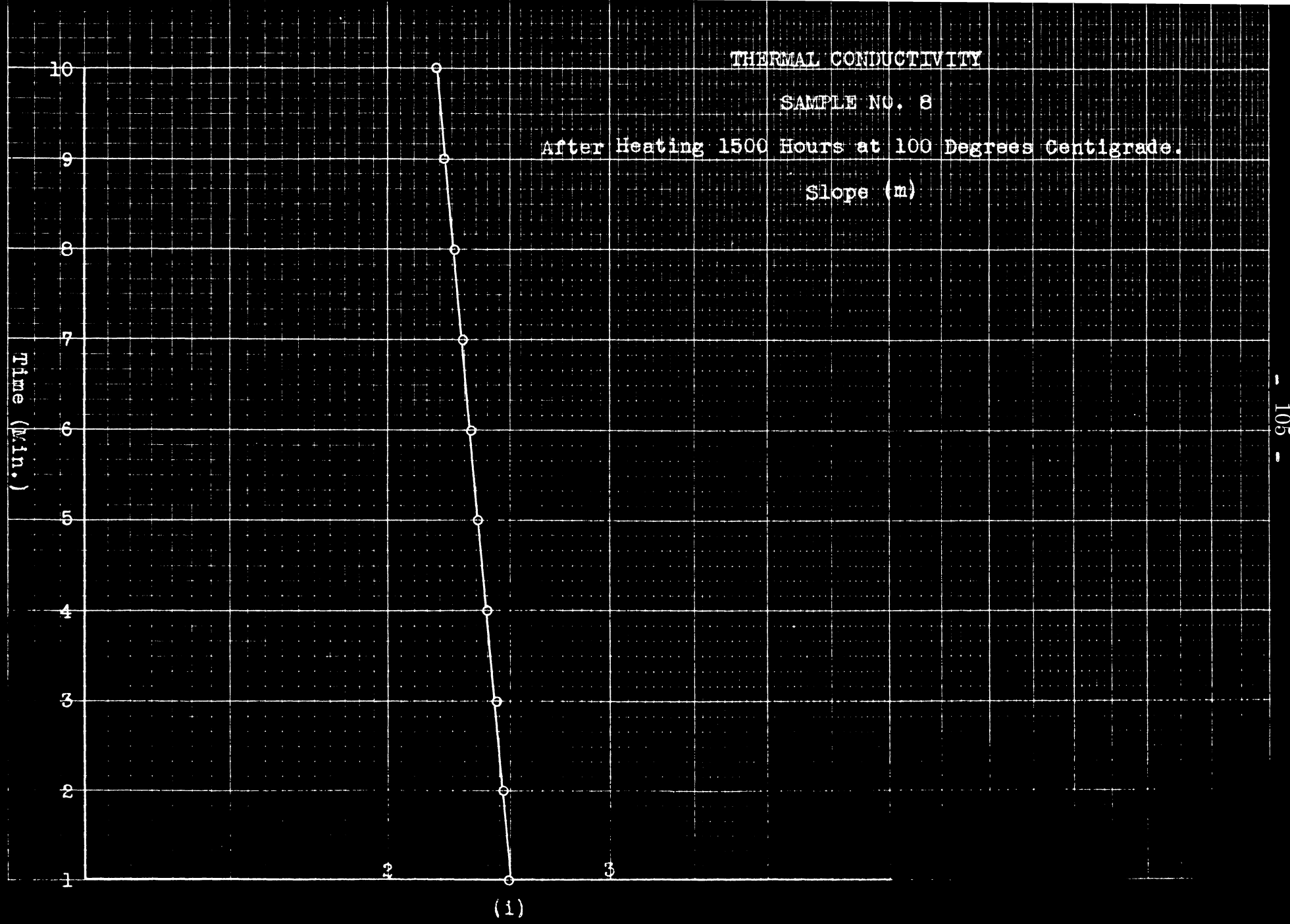

THERMAL CONDUCTIVITY
SAMPLE NO. 5
After Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)

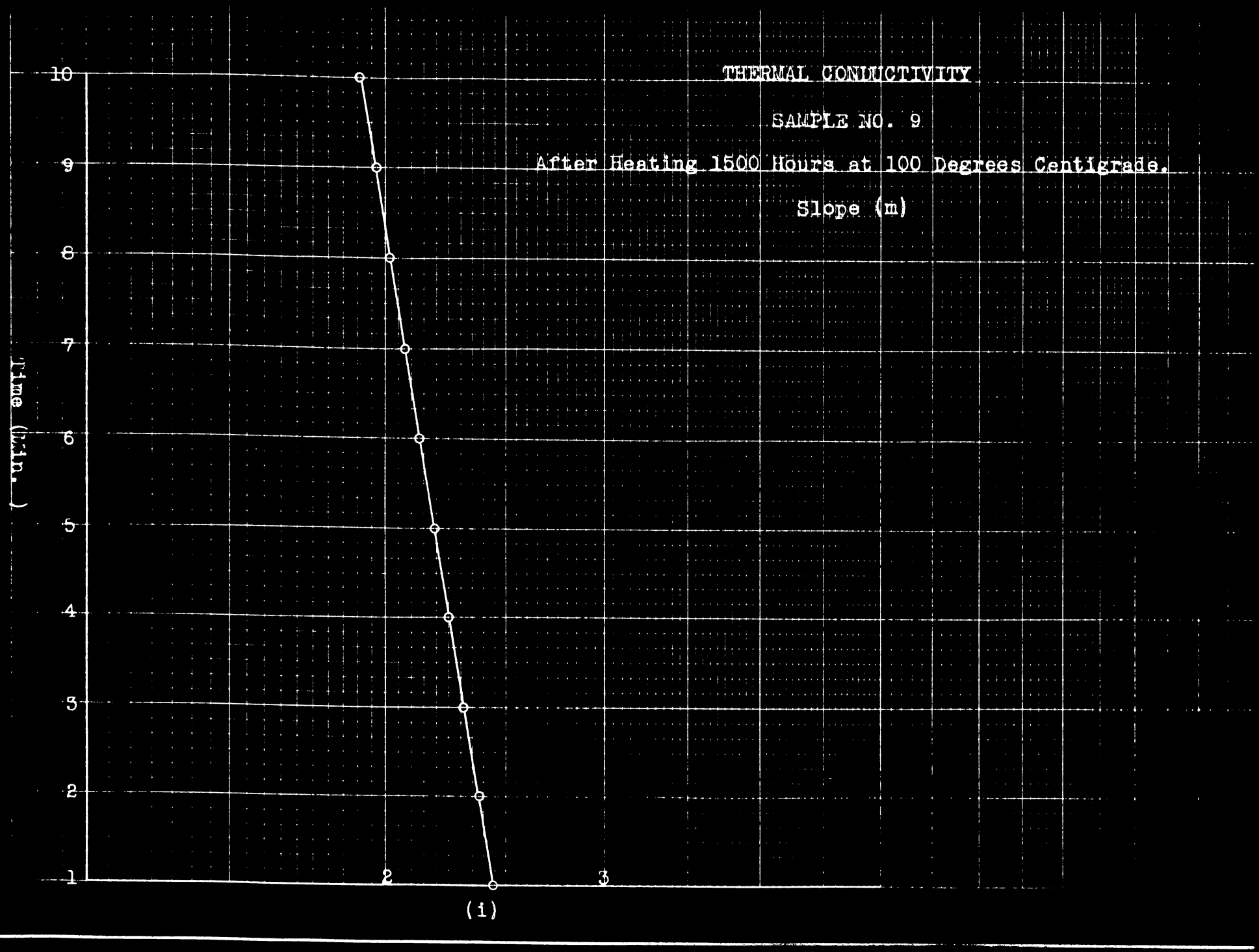
Thermal Conductivity After Heating 1500 Hours at 100 Degrees Centigrade.
Time vs. Current

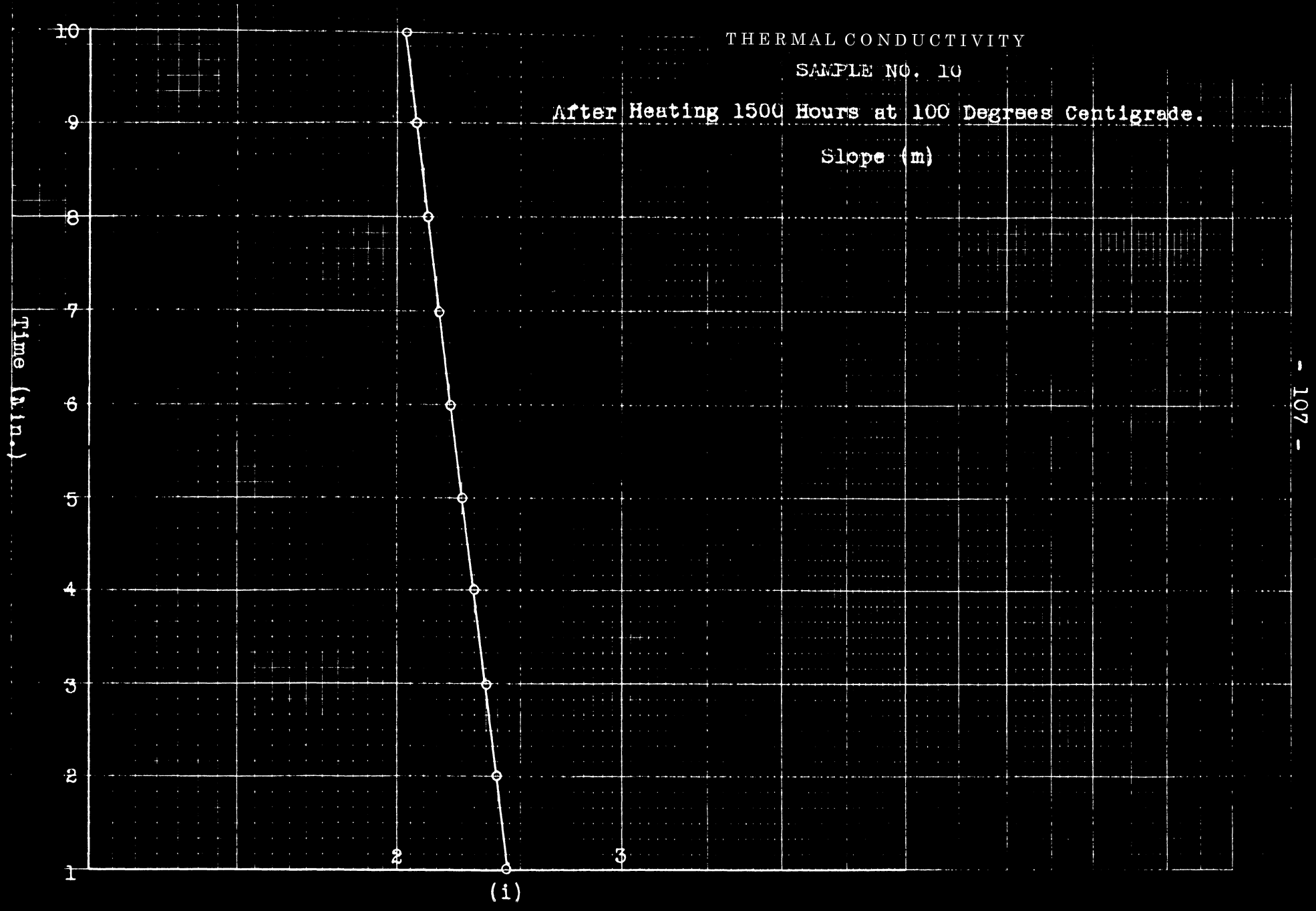
Time (Minutes)	Sample No. 6 (i)	Sample No. 7 (i)	Sample No. 8 (i)	Sample No. 9 (i)	Sample No. 10 (i)
1	24.38	25.03	24.87	24.40	24.35
2	23.70	24.65	24.68	23.80	23.96
3	22.98	24.16	24.34	23.14	23.50
4	22.27	23.63	23.98	22.50	23.00
5	21.60	23.10	23.62	21.90	22.50
6	20.95	22.67	23.28	21.30	22.05
7	20.31	22.05	22.94	20.75	21.60
8	19.74	21.58	22.58	20.20	21.15
9	19.15	21.10	22.18	19.70	20.70
10	18.65	20.66	21.85	19.18	20.30


THERMAL CONDUCTIVITY
SAMPLE NO. 6
After Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)


THERMAL CONDUCTIVITY
SAMPLE NO. 7
After Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)

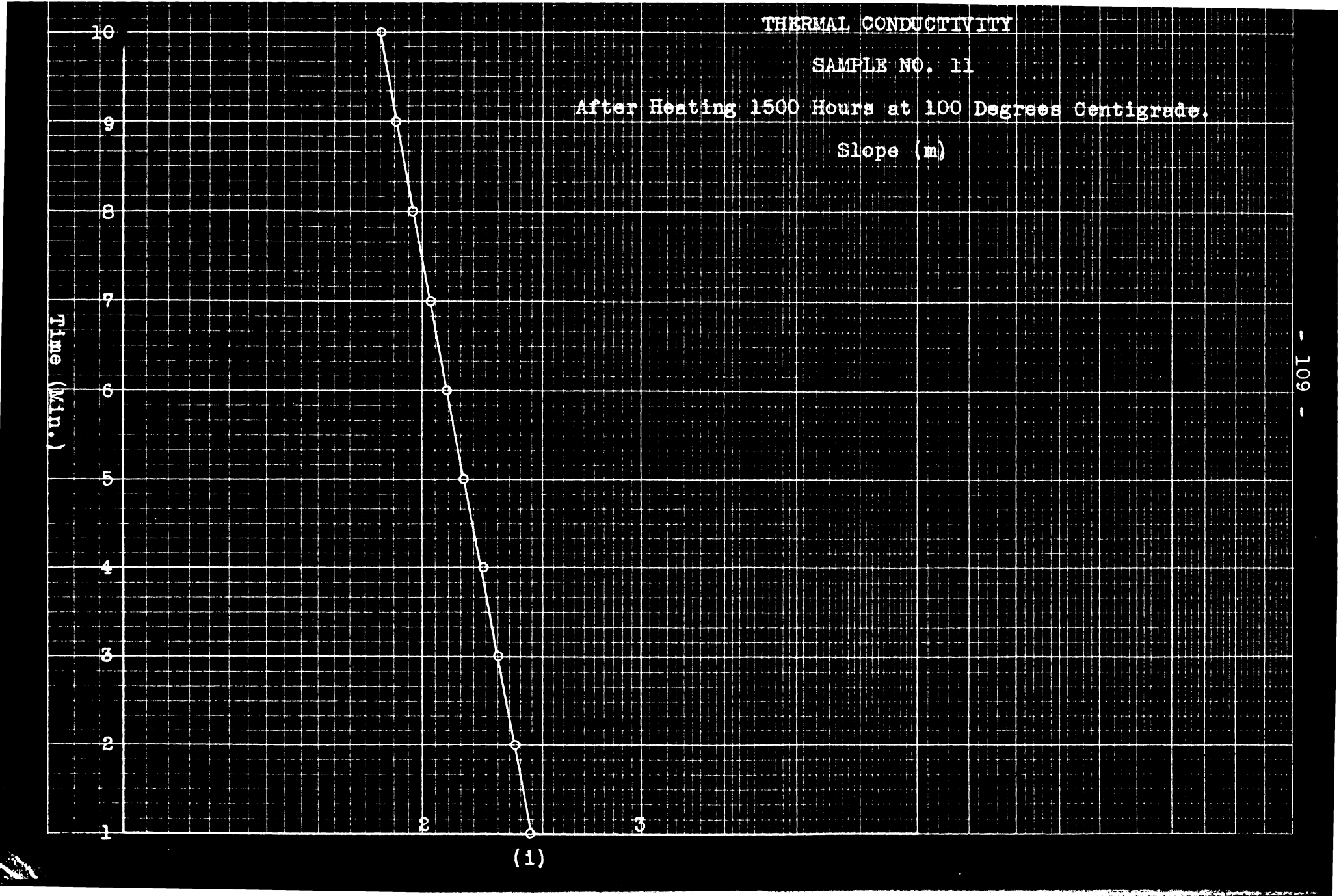

THERMAL CONDUCTIVITY
SAMPLE NO. 8
After Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)

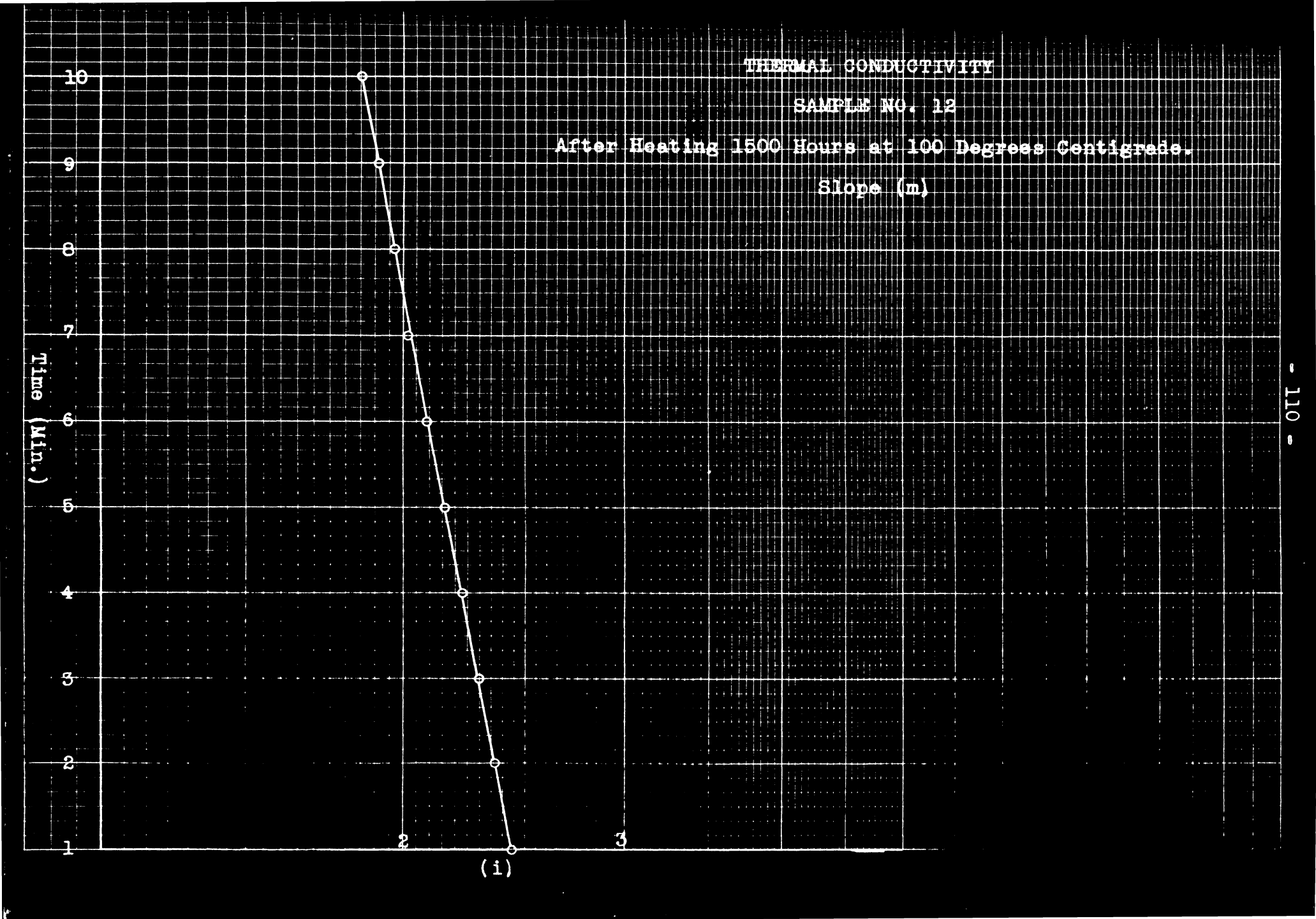

THERMAL CONDUCTIVITY
SAMPLE NO. 9
After Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)

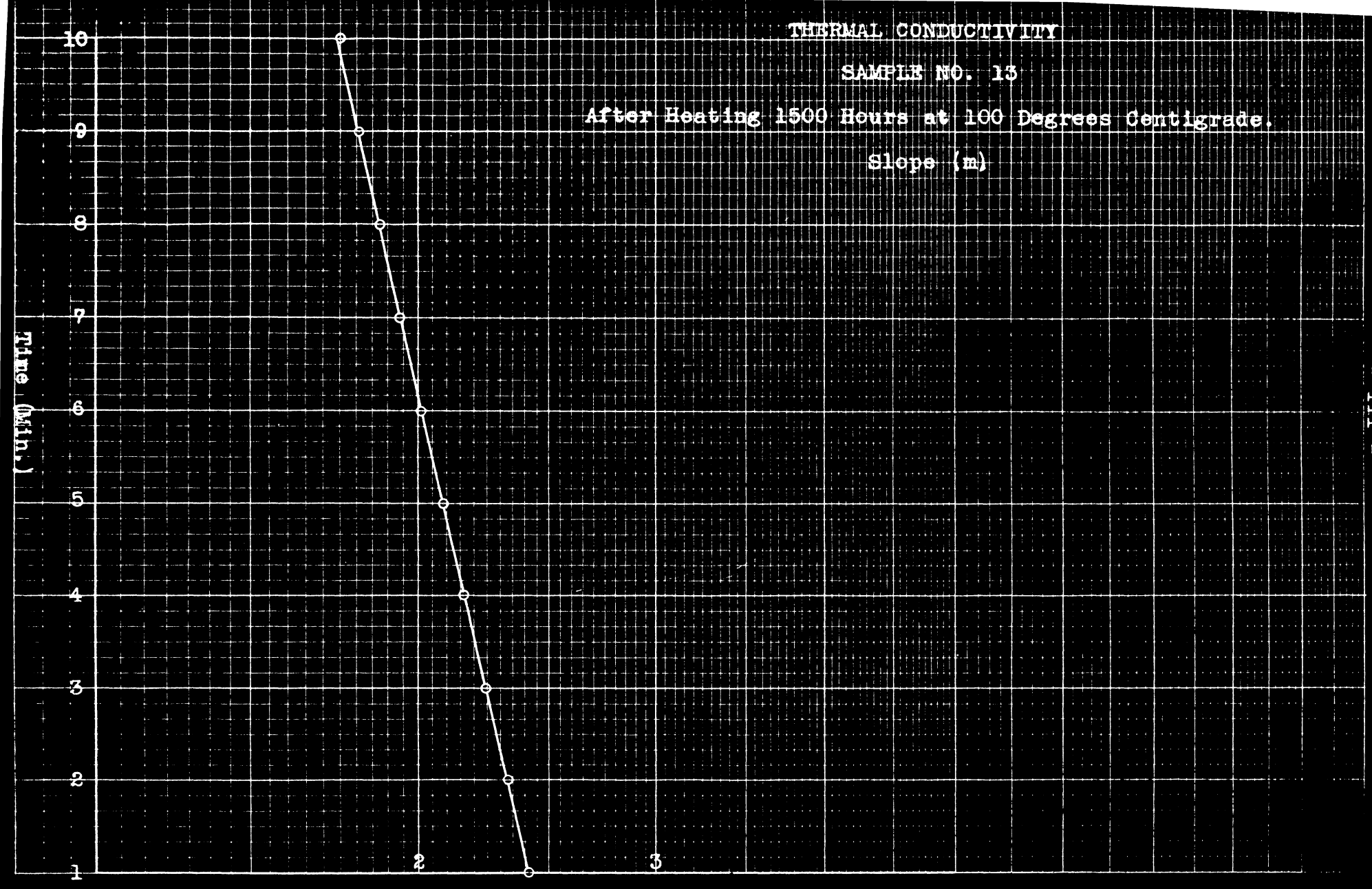

THERMAL CONDUCTIVITY
SAMPLE NO. 10
After Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)

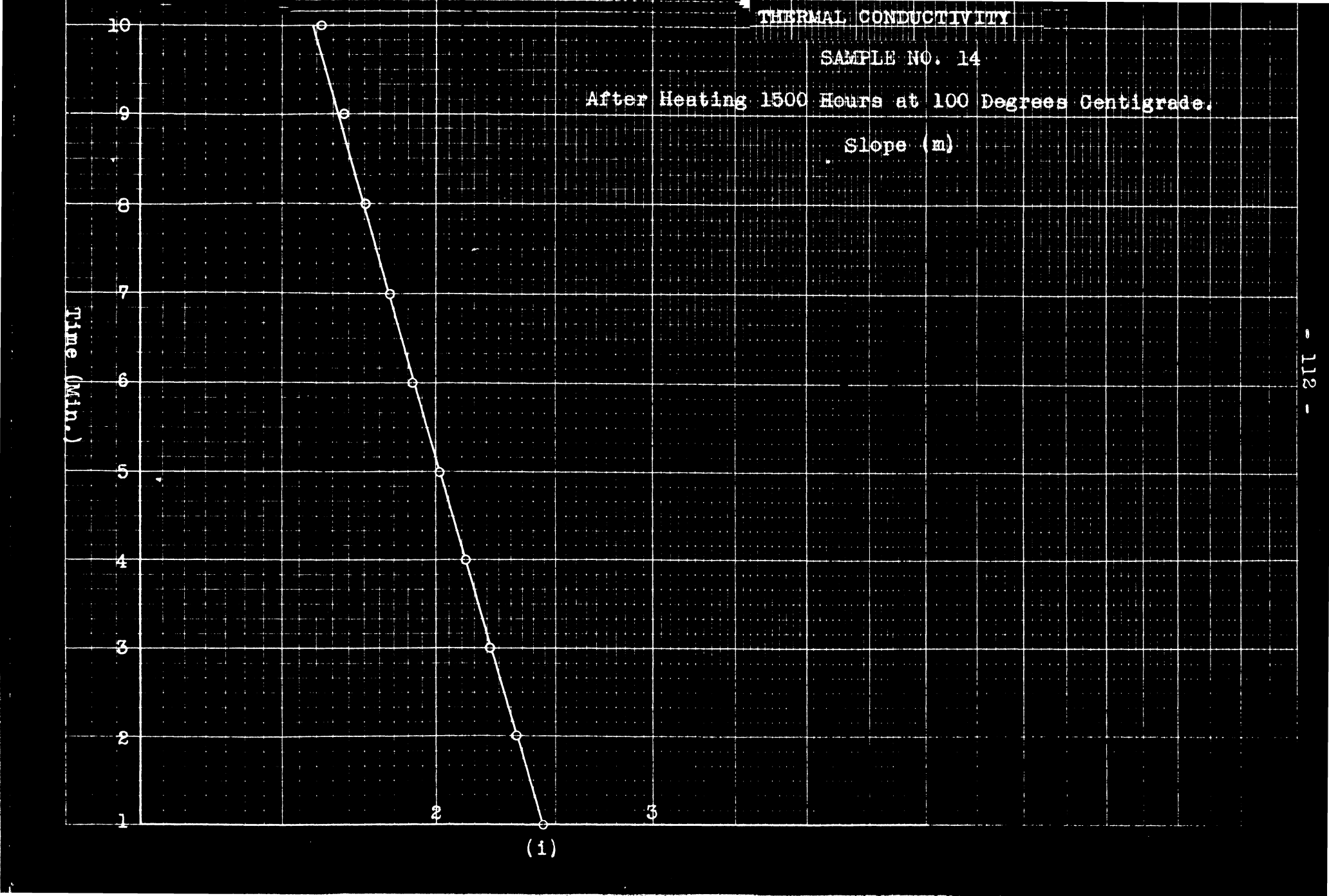
Thermal Conductivity After Heating 1500 Hours at 100 Degrees Centigrade.
Time vs. Current

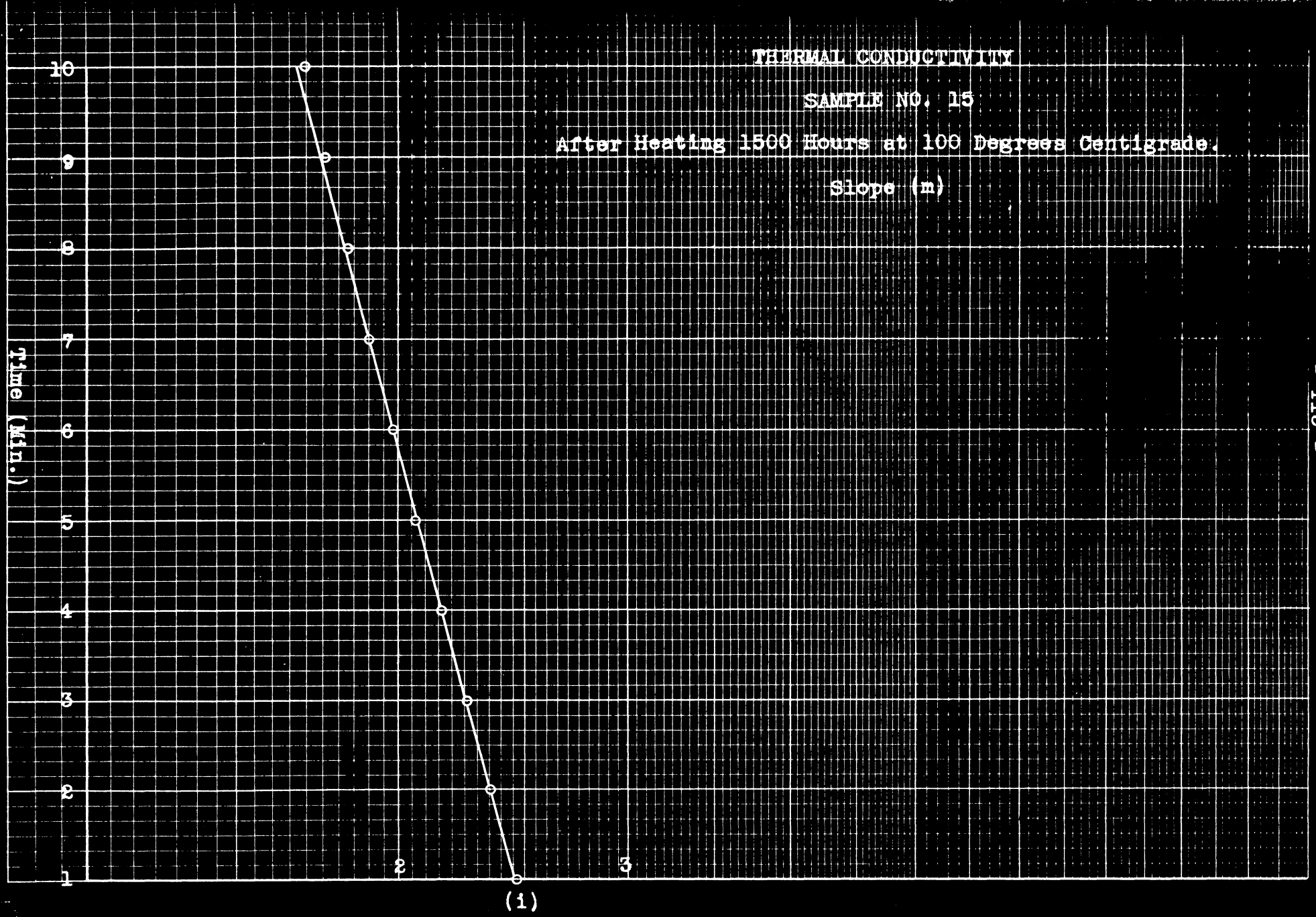
Time (Minutes)	Sample No. 11 (i)	Sample No. 12 (i)	Sample No. 13 (i)	Sample No. 14 (i)	Sample No. 15 (i)
1	24.35	24.27	24.15	24.38	24.60
2	23.73	23.65	23.30	23.25	23.50
3	23.00	22.99	22.47	22.15	22.50
4	22.30	22.34	21.65	21.08	21.53
5	21.60	21.60	20.83	20.10	20.61
6	20.92	20.78	20.10	19.15	19.78
7	20.28	20.18	19.37	18.30	19.00
8	19.67	19.65	18.70	17.52	18.30
9	19.10	19.12	18.10	16.80	17.64
10	18.50	18.60	17.50	16.14	17.00


THERMAL CONDUCTIVITY
SAMPLE NO. 11
After Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)


THERMAL CONDUCTIVITY
SAMPLE NO. 12
After Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)

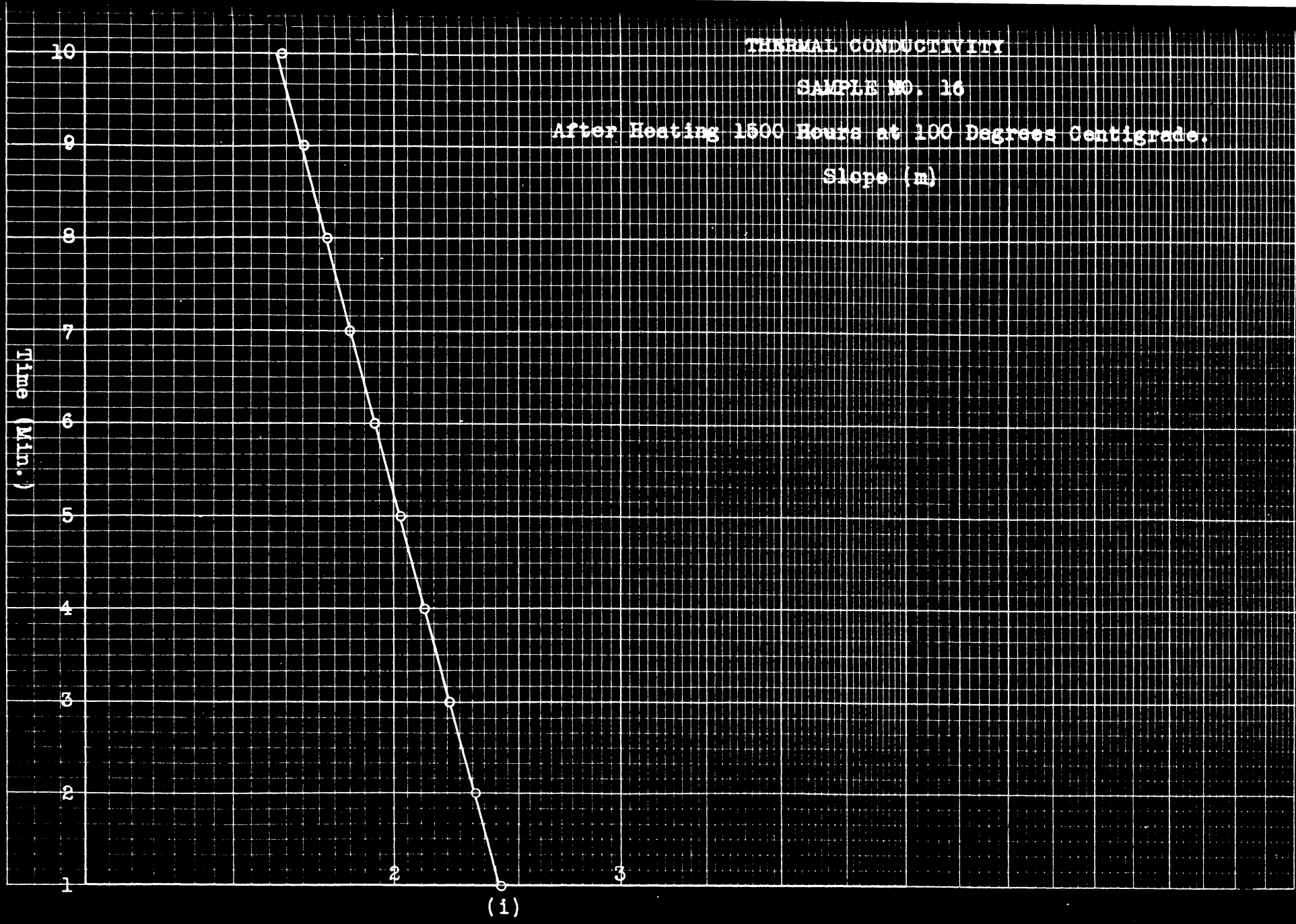

THERMAL CONDUCTIVITY
SAMPLE NO. 13
After Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
2
3

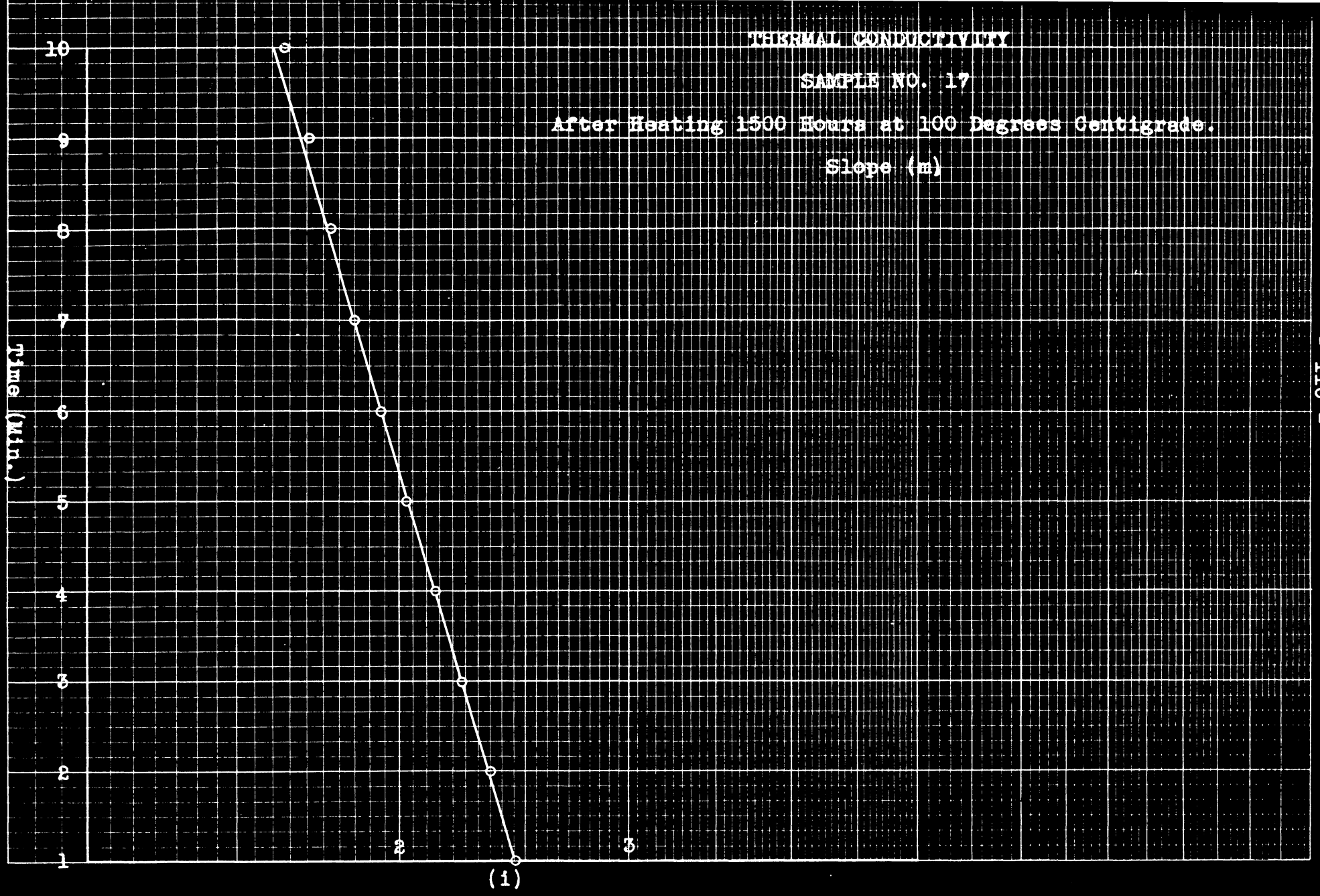

THERMAL CONDUCTIVITY
SAMPLE NO. 14
After Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)

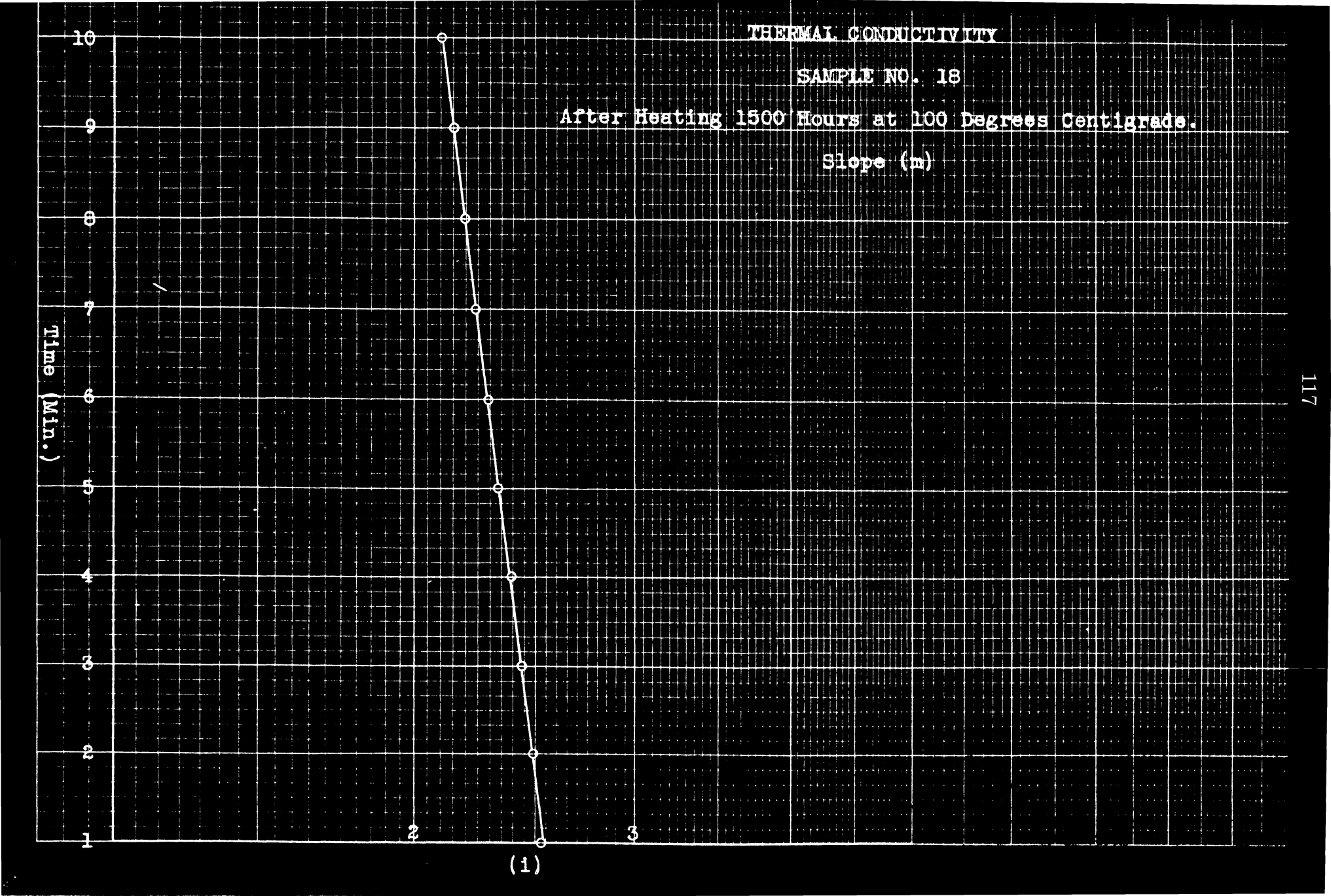

THERMAL CONDUCTIVITY
SAMPLE NO. 15
After Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)

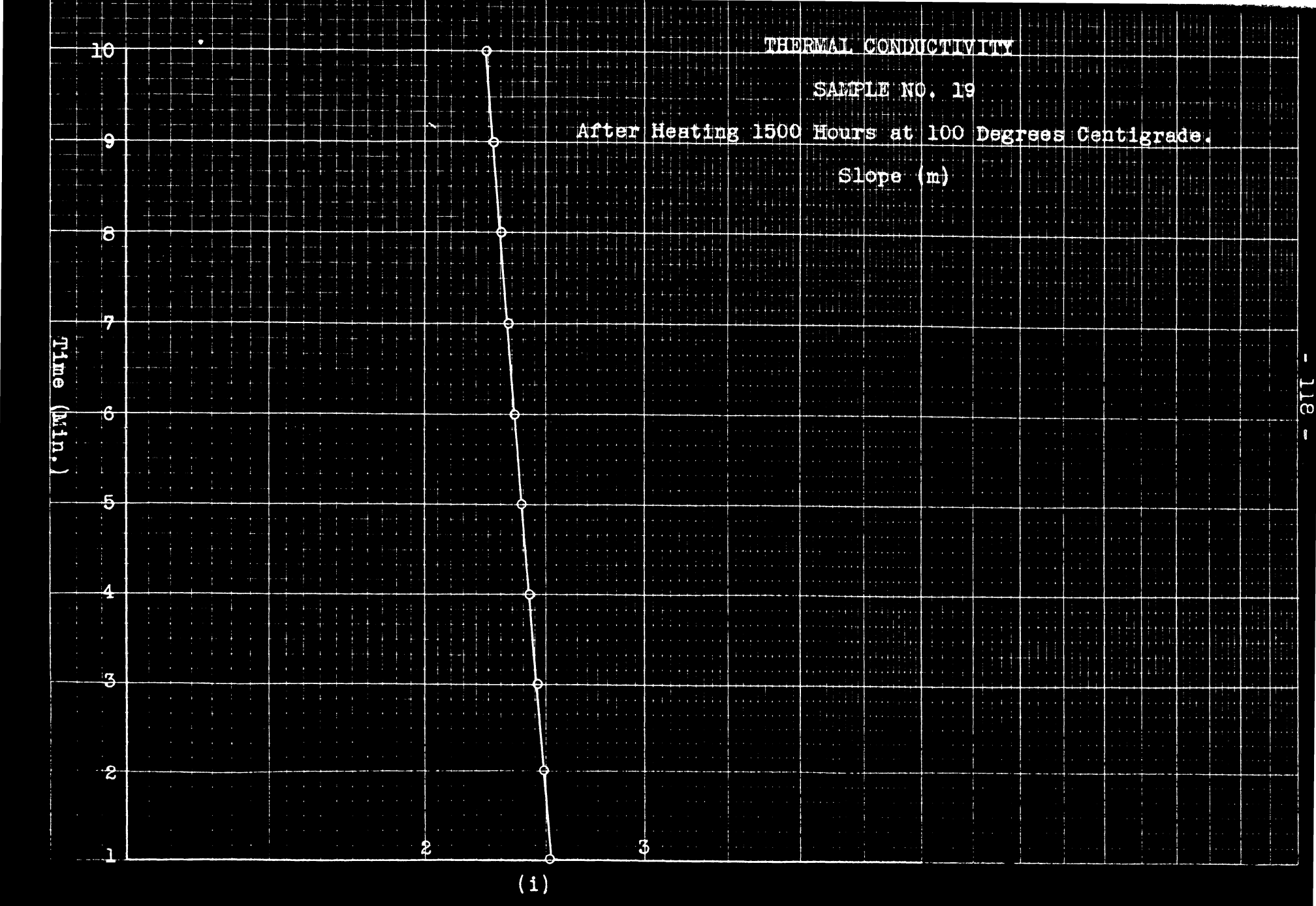
Thermal Conductivity After Heating 1500 Hours at 100 Degrees Centigrade.
Time vs. Current

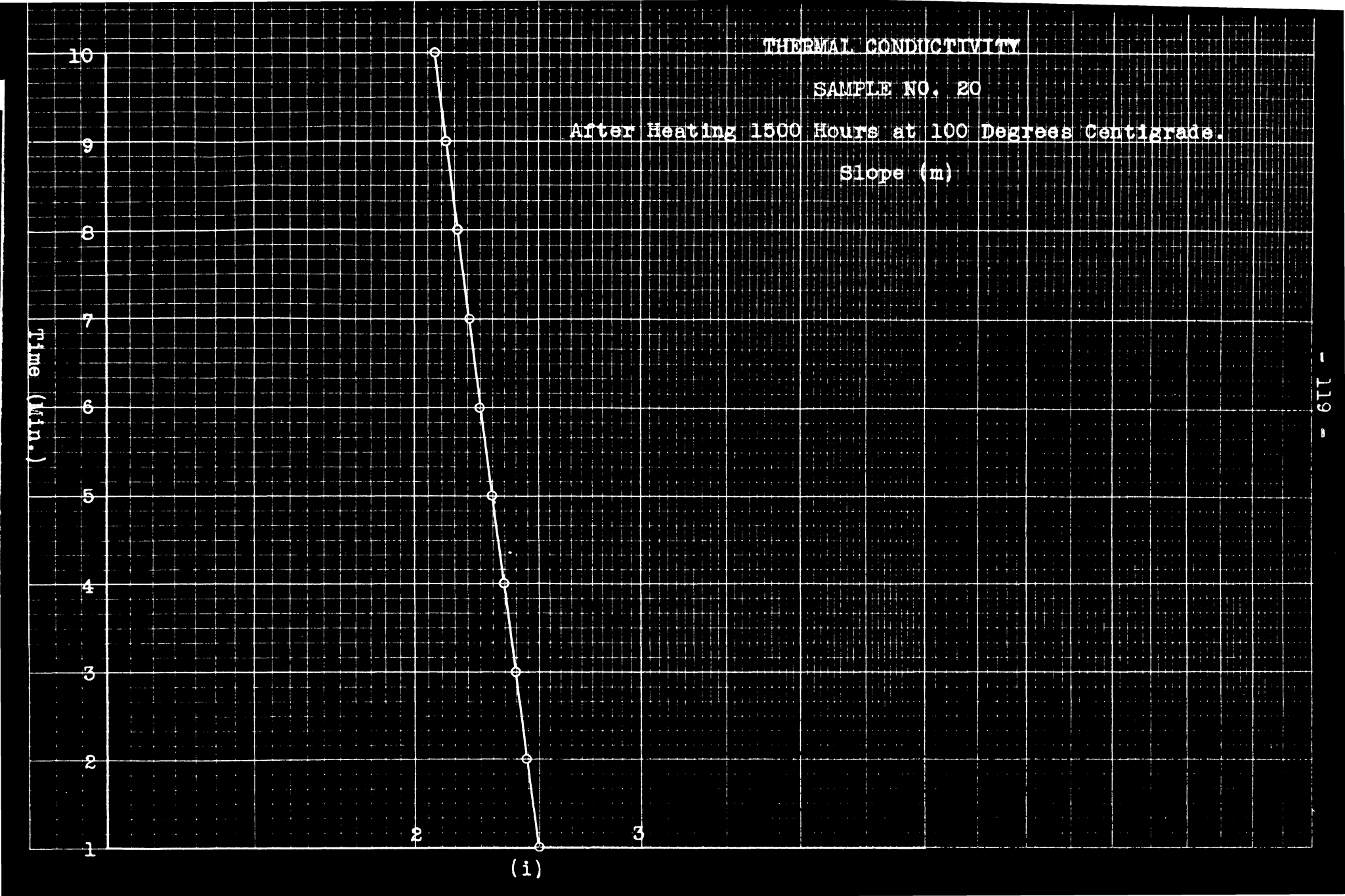
Time (Minutes)	Sample No. 16 (1)	Sample No. 17 (1)	Sample No. 18 (1)	Sample No. 19 (1)	Sample No. 20 (1)
1	24.15	24.50	25.20	25.10	24.87
2	23.08	23.40	24.85	24.85	24.38
3	22.05	22.25	24.36	24.55	23.89
4	21.04	21.25	23.85	24.25	23.40
5	20.10	20.26	23.35	23.93	22.93
6	19.25	19.35	22.90	23.60	22.49
7	18.45	18.50	22.41	23.29	22.03
8	17.70	17.75	21.92	22.98	21.60
9	17.03	17.05	21.50	22.68	21.20
10	16.40	16.35	21.08	22.40	20.80


THERMAL CONDUCTIVITY
SAMPLE NO. 16
After Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)


THERMAL CONDUCTIVITY
SAMPLE NO. 17
After Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)


THERMAL CONDUCTIVITY
SAMPLE NO. 18
After Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
2
3
(1)


THERMAL CONDUCTIVITY
SAMPLE NO. 19
After Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)


THERMAL CONDUCTIVITY
SAMPLE NO. 20
After Heating 1500 Hours at 100 Degrees Centigrade.
Slope (m)
Time (Min.)
10
9
8
7
6
5
4
3
2
1
2
3
(i)

Thermal Conductivity After Heating 1500 Hours at 100 Degrees Centigrade.

Sample No.	m (Sec.)	4.704 x (d) (Cal./Cm.^{o}C.)	K (Cal./Cm.^{o}C.Sec.)
1	2668.86	1.0855	.000384
2	4829.49	2.9588	.000613
3	5315.11	3.0482	.000574
4	9665.84	2.7283	.000282
5	5322.29	3.3163	.000623
6	4579.42	3.0106	.000657
7	6339.14	3.1564	.000498
8	9526.33	3.1093	.000326
9	5271.83	3.0764	.000584
10	7070.18	3.1470	.000445
11	4435.25	2.7095	.000611
12	4632.37	2.8036	.000605
13	3786.57	2.4790	.000655
14	2970.75	0.9408	.000317
15	3361.61	1.5053	.000448
16	3172.39	1.5147	.000478
17	3009.82	1.4724	.000489
18	6897.74	3.1611	.000458
19	9822.51	2.4742	.000252
20	7086.81	1.5288	.000216

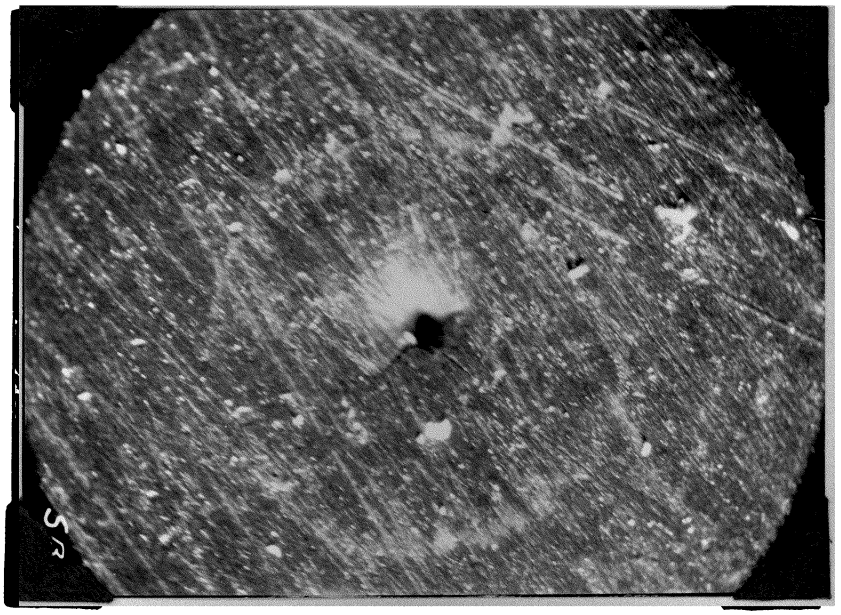
CHAPTER III

PHYSICAL EFFECTS OF HEAT TREATMENT UPON THE SAMPLES.

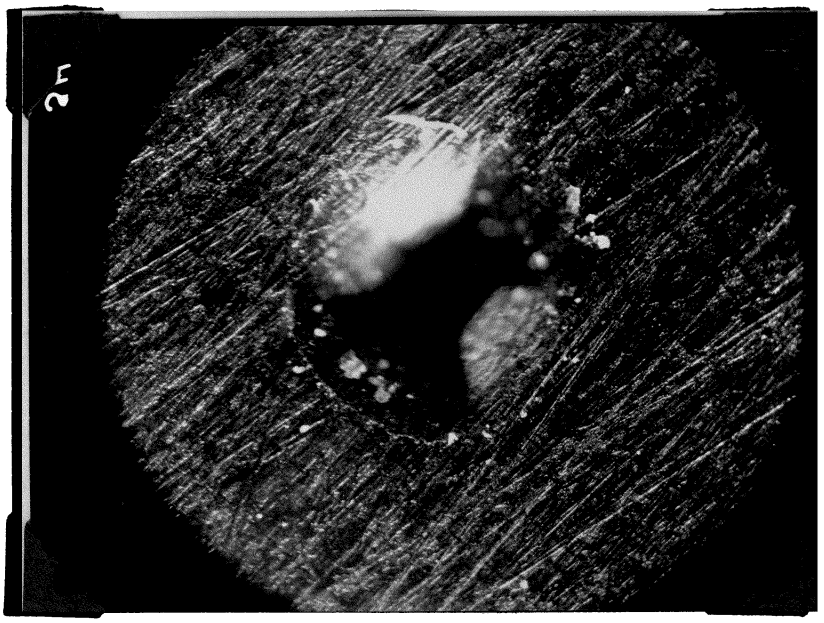
A. EFFECTS OF ELASTOMETER PENETRATOR UPON THE SURFACE OF THE SAMPLES BEFORE AND AFTER HEAT TREATMENT.

A microphotograph of the impression of the Elastometer penetrator was made for each of the samples before and after heating 1500 hours at 100 degrees Centigrade. The magnification of these microphotographs was about 75 diameters. The microphotographs were made with a Bausch and Lomb microscope and a plate camera (Fig. 9). Surface illumination was produced by a slide projector with the aid of a focusing lens.

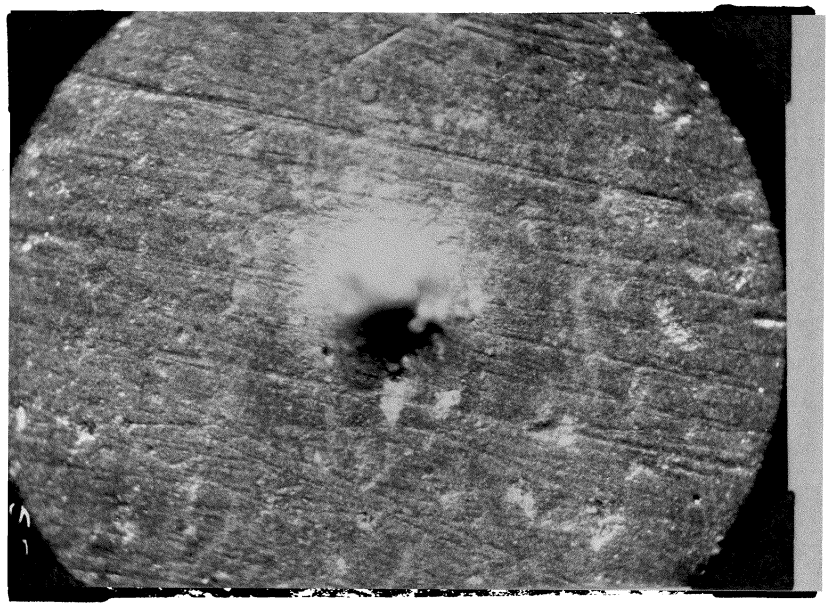
Figure 9.—Microphotographic apparatus.



Sample No. 1.—Penetrator hole made before heating 1500 hours at 100 degrees Centigrade.



Sample No. 1.—Penetrator hole made after heating 1500 hours at 100 degrees Centigrade.



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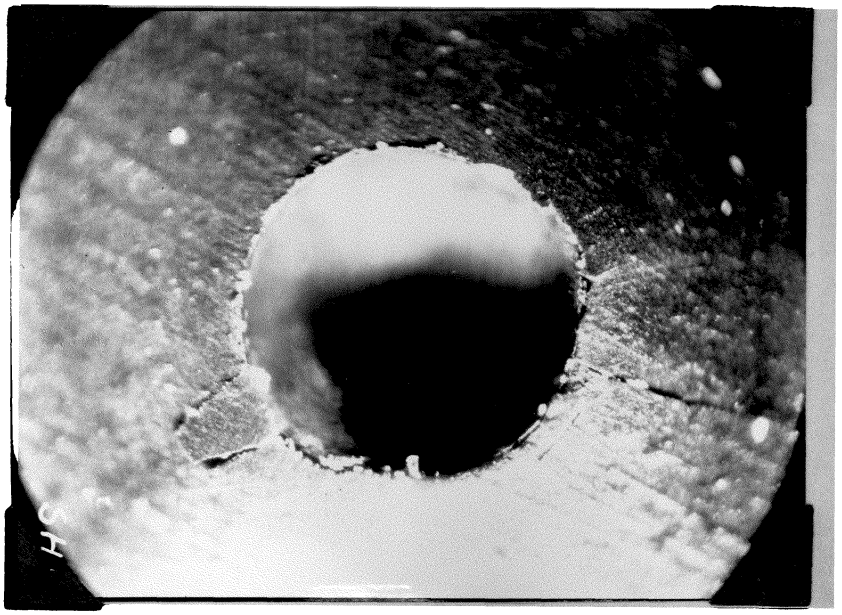
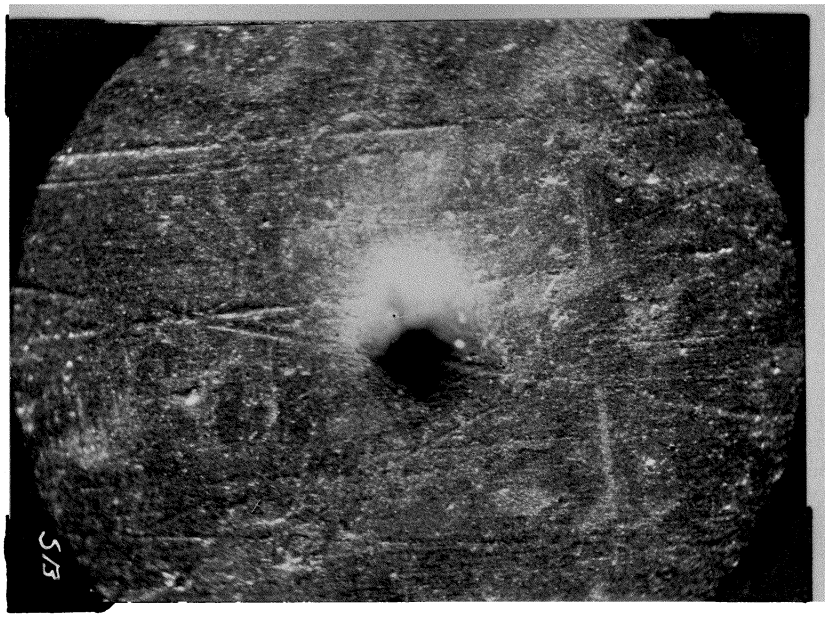
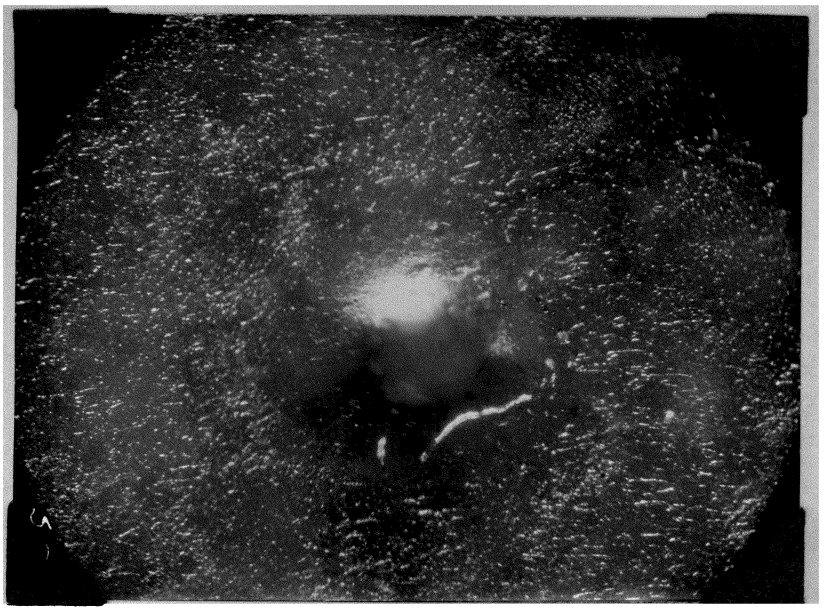


Sample No. 2.—Penetrator hole made after heating 1500 hours at 100 degrees Centigrade.



Sample No. 3.—Penetrator hole made before heating 1500 hours at 100 degrees Centigrade.

Sample No. 3.—Penetrator hole made after heating 1500 hours at 100 degrees Centigrade.



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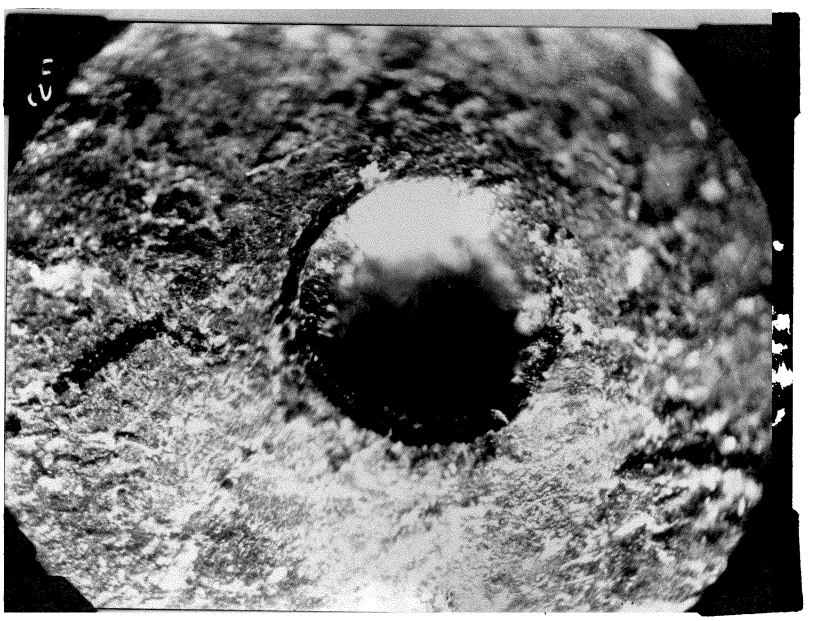
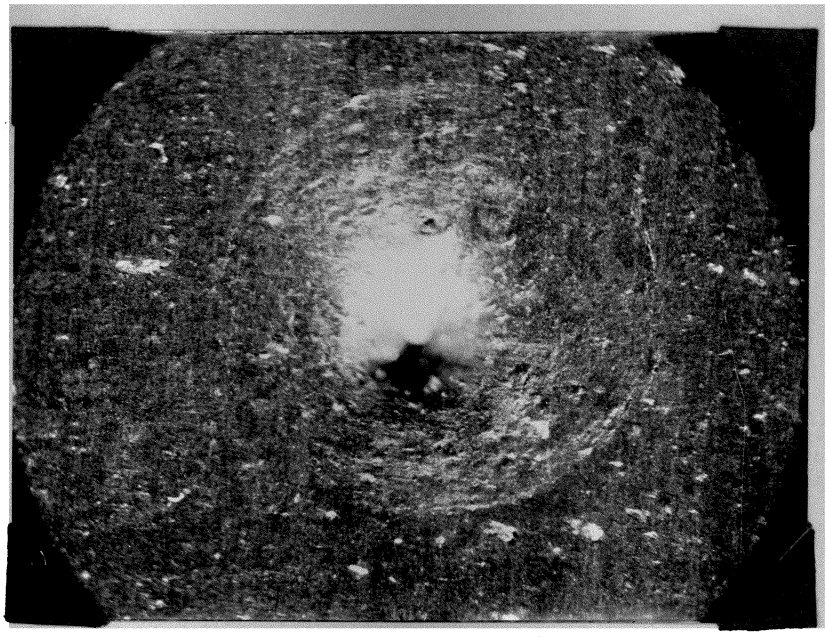


Sample No. 4.—Penetrator hole made after heating 1500 hours at 100 degrees Centigrade.



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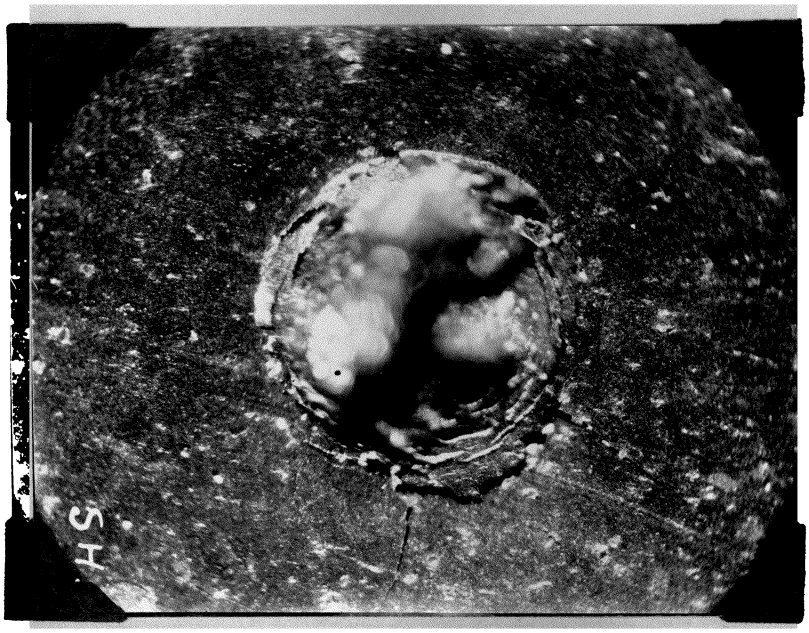
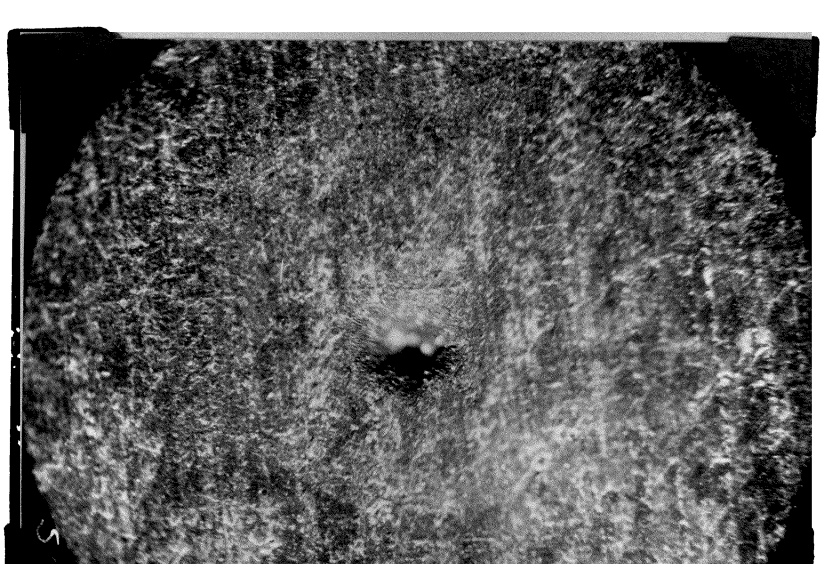
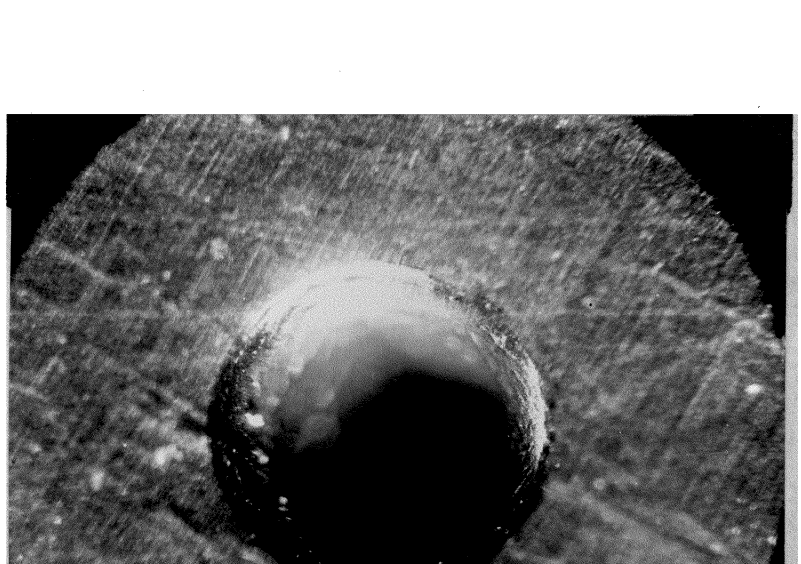


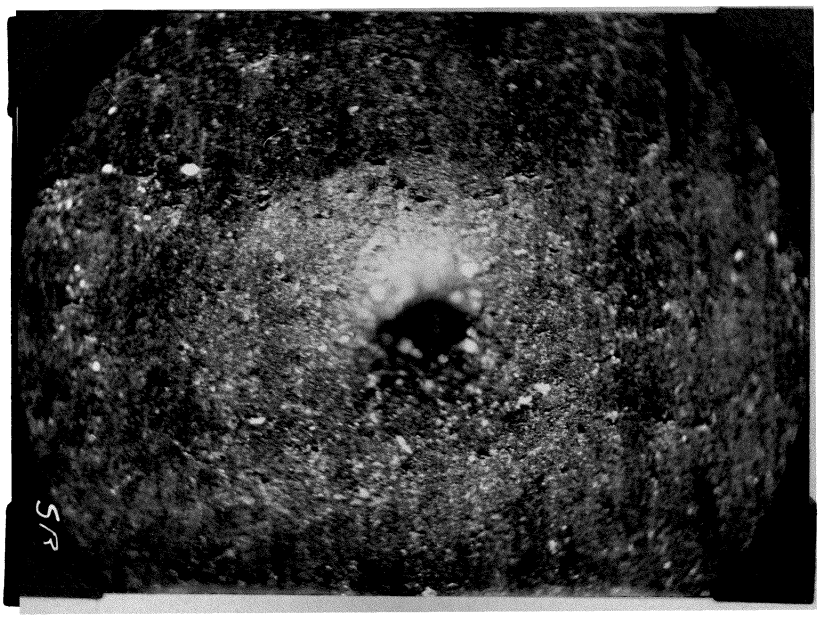
Sample No. 5.—Penetrator hole made after heating 1500 hours at 100 degrees Centigrade.



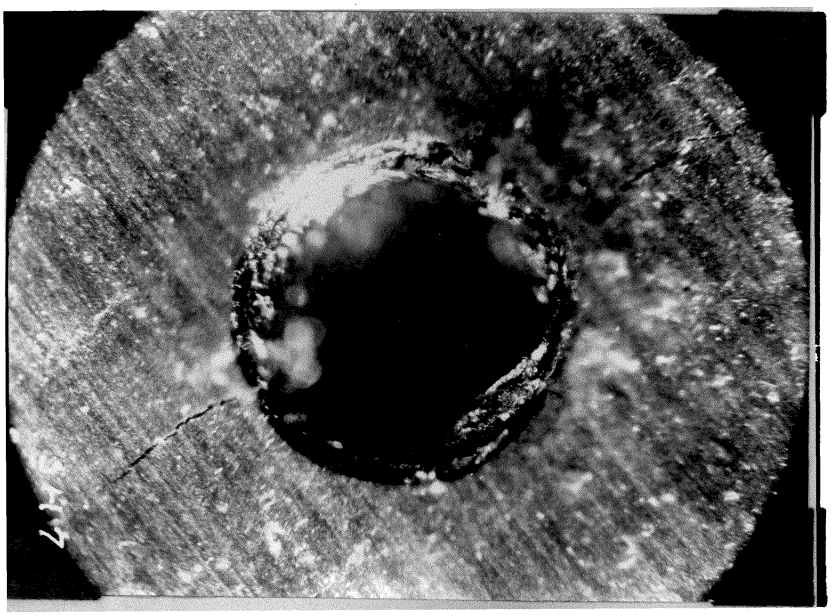
Sample No. 6.—Penetrator hole made before heating 1500 hours at 100 degrees Centigrade.



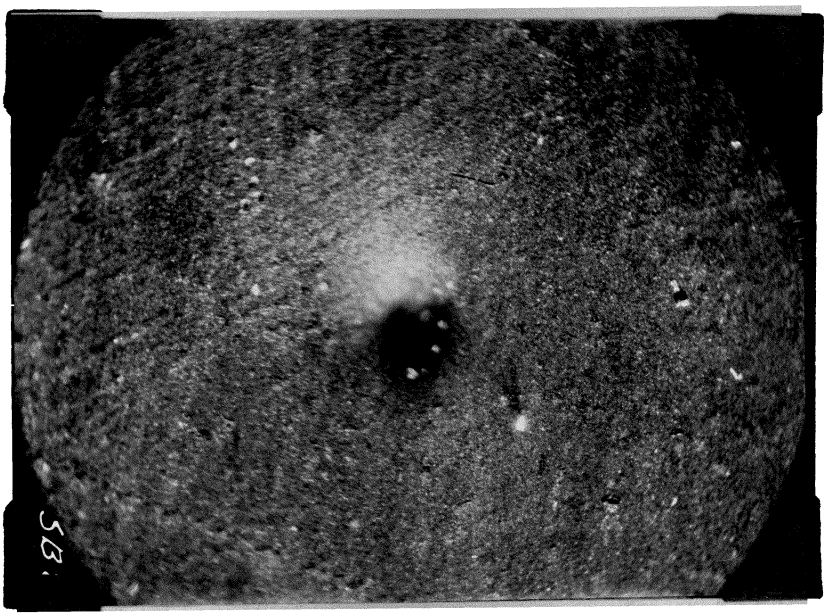
Sample No. 6.—Penetrator hole made after heating 1500 hours at 100 degrees Centigrade.



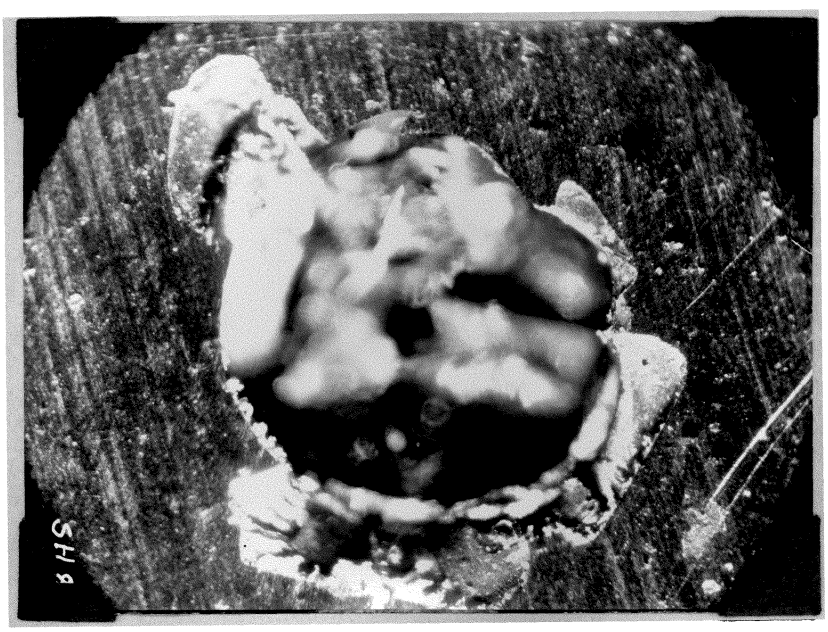
Sample No. 7.—Penetrator hole made before heating 1500 hours at 100 degrees Centigrade.



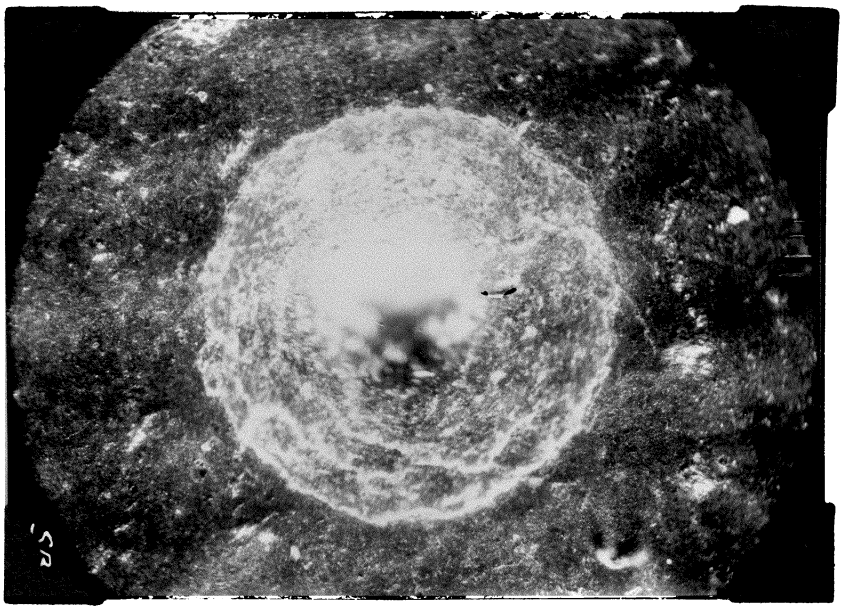
Sample No. 7.—Penetrator hole made after heating 1500 hours at 100 degrees Centigrade.



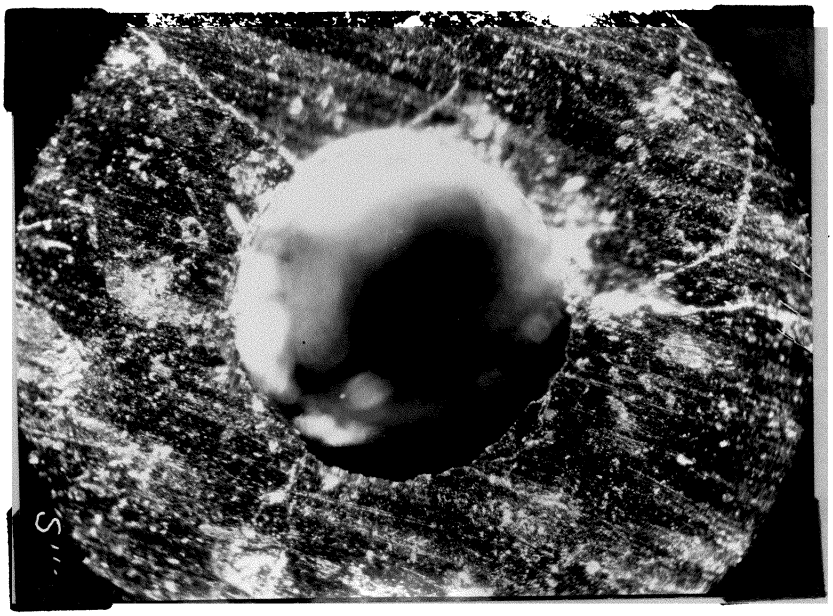
Sample No. 8.—Penetrator hole made before heating 1500 hours at 100 degrees Centigrade.



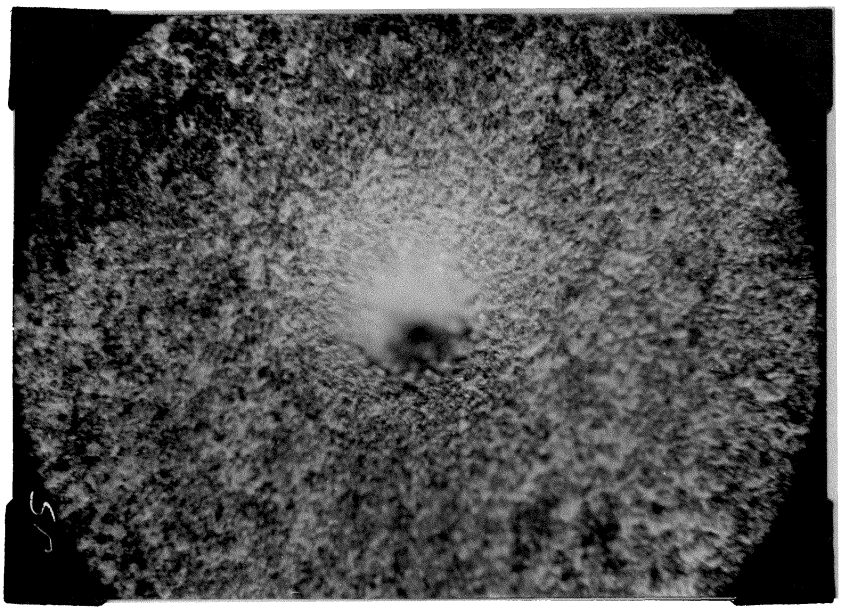
Sample No. 8.—Penetrator hole made after heating 1500 hours at 100 degrees Centigrade.



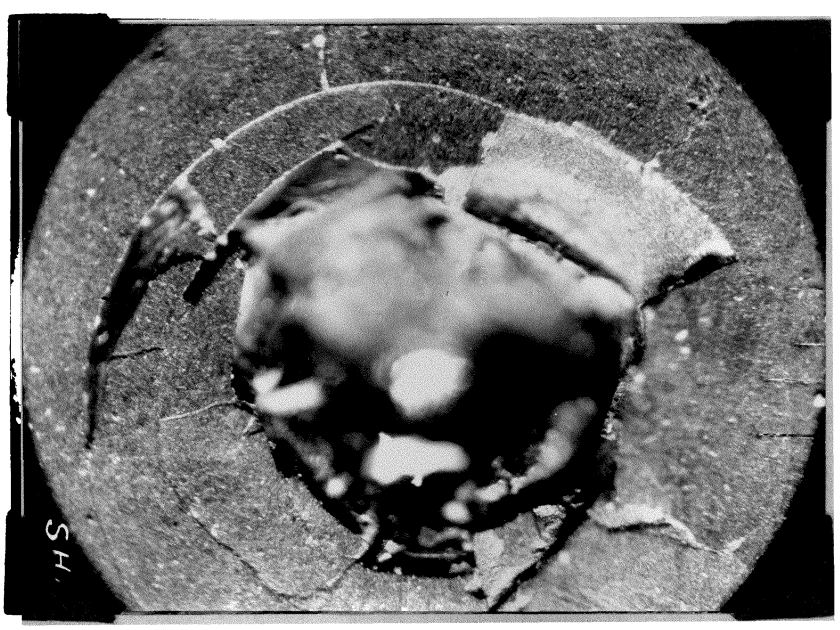
Sample 9.—Penetrator hole made before heating 1500 hours at 100 degrees Centigrade.



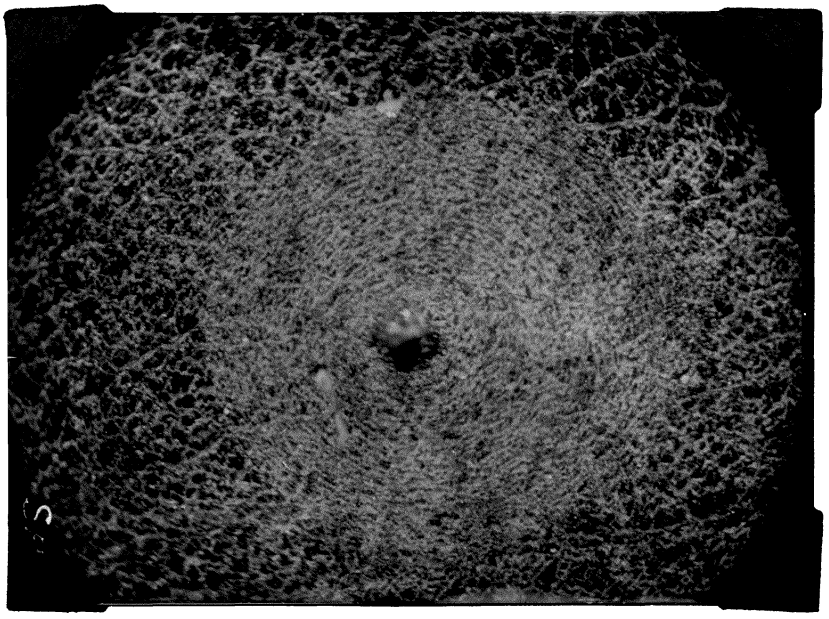
Sample 9.—Penetrator hole made after heating 1500 hours at 100 degrees Centigrade.



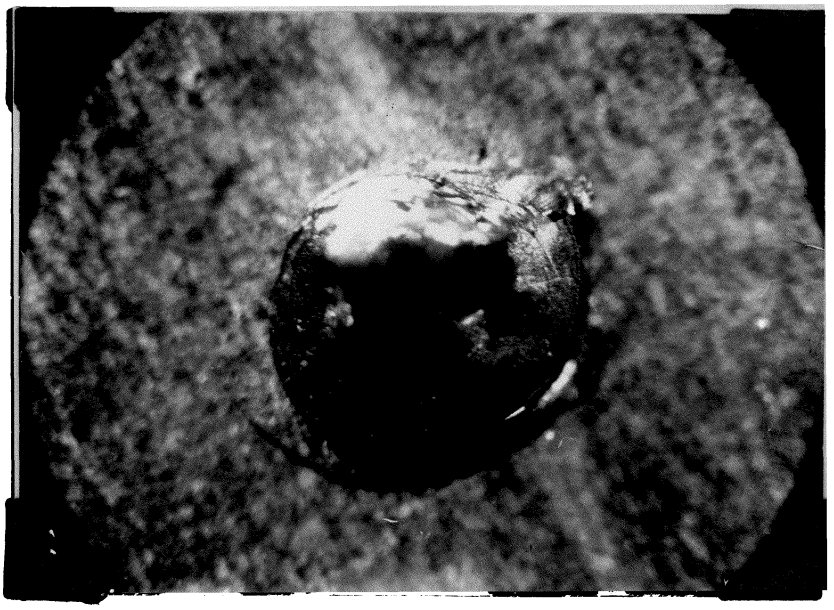
Sample 10.—Penetrator hole made before heating 1500 hours at 100 degrees Centigrade.



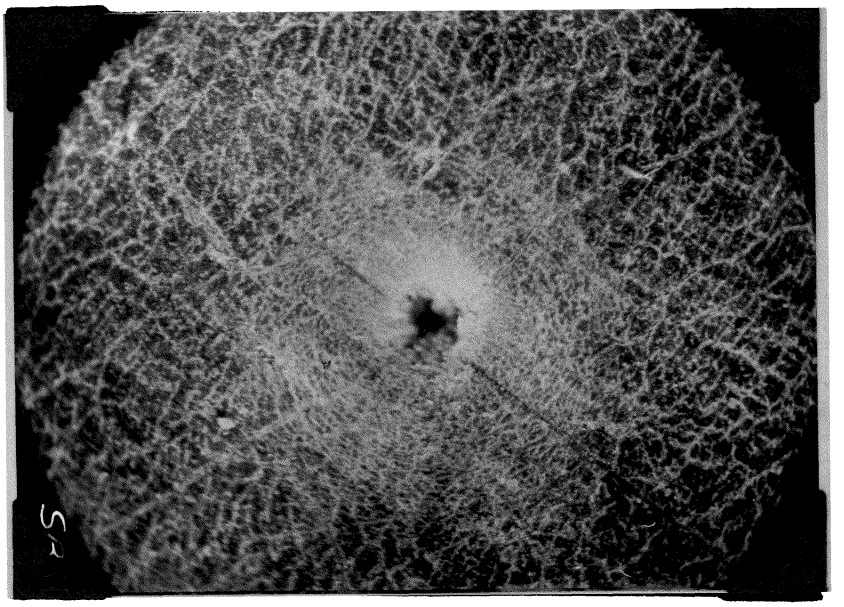
Sample 10.—Penetrator hole made after heating 1500 hours at 100 degrees Centigrade.



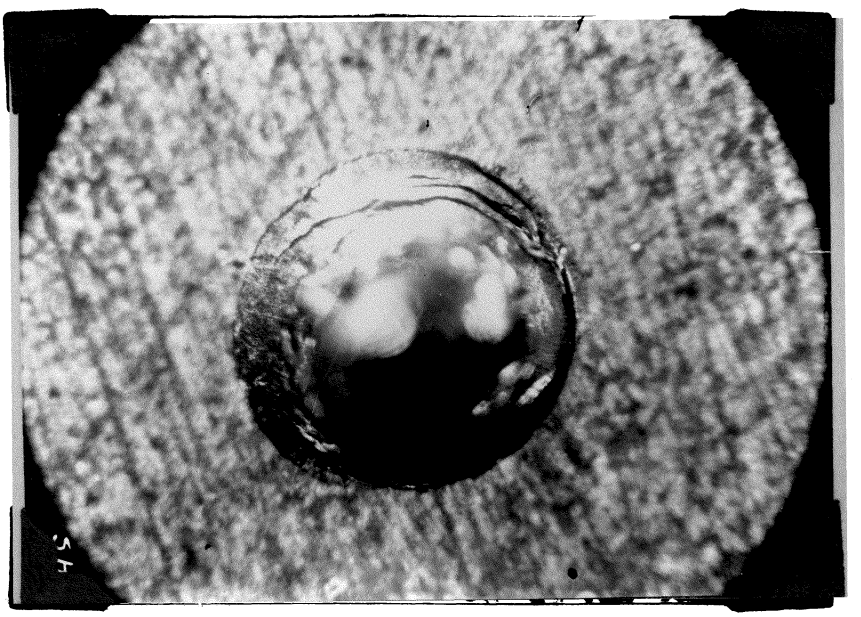
Sample No. 11.—Penetrator hole made before heating 1500 hours at 100 degrees Centigrade.



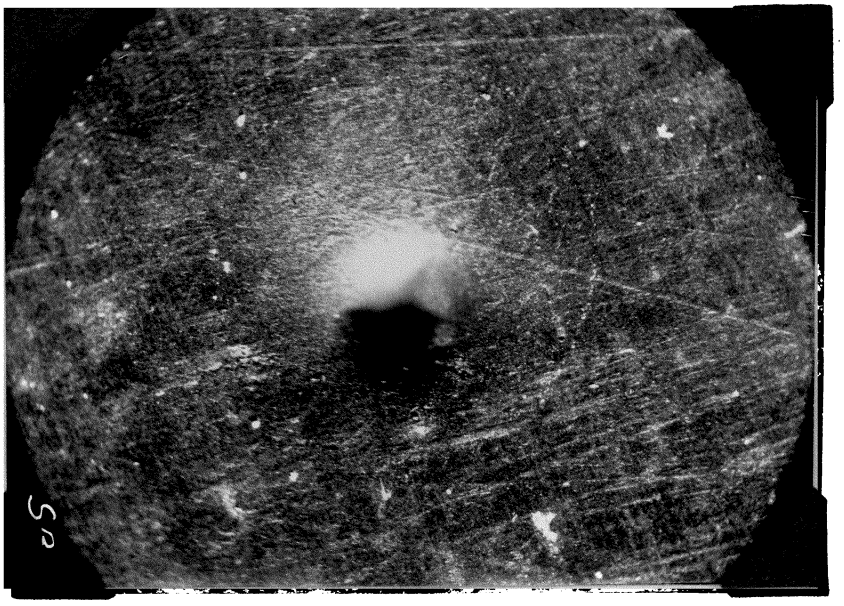
Sample No. 11.—Penetrator hole made after heating 1500 hours at 100 degrees Centigrade.



Sample No. 12.—Penetrator hole made before heating 1500 hours at 100 degrees Centigrade.

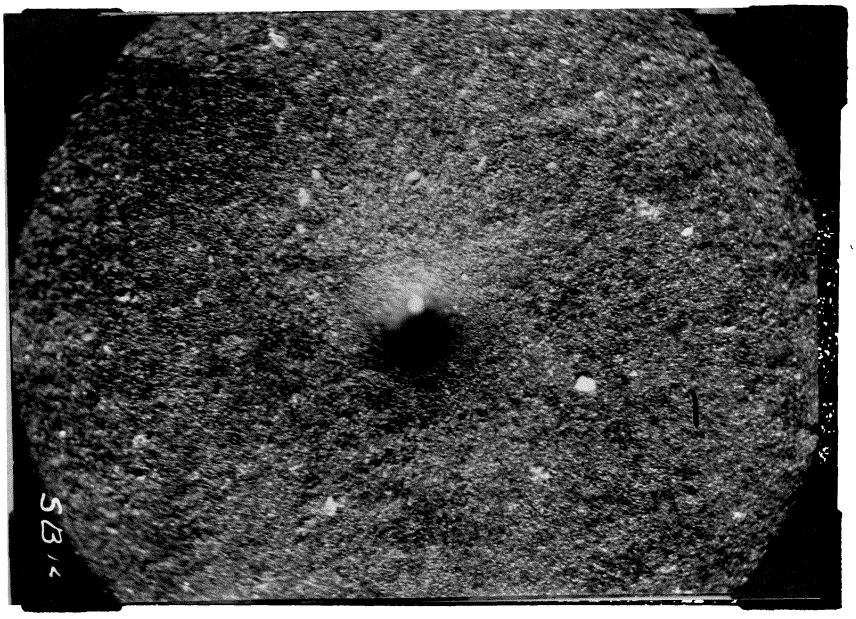


Sample No. 12.—Penetrator hole made after heating 1500 hours at 100 degrees Centigrade.

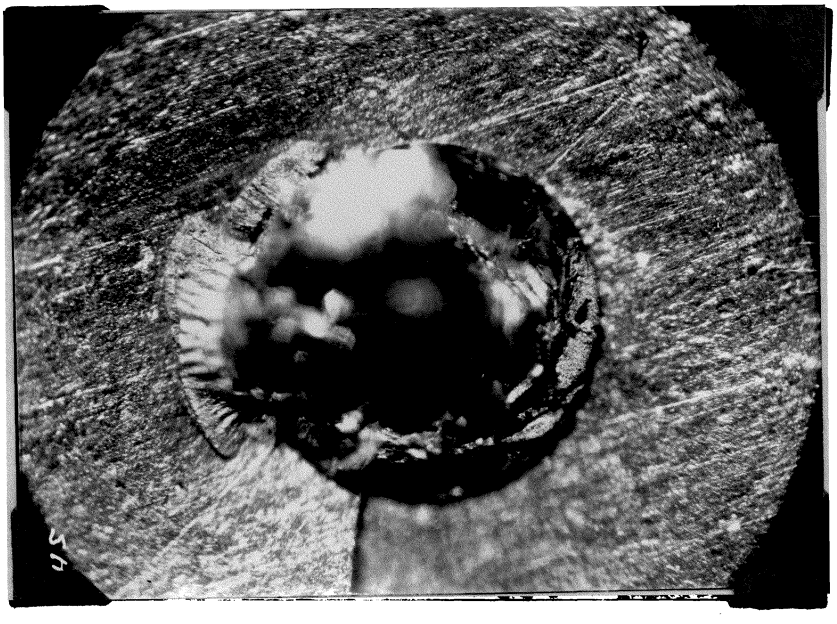


Sample No. 13.—Penetrator hole made before heating 1500 hours at 100 degrees Centigrade.

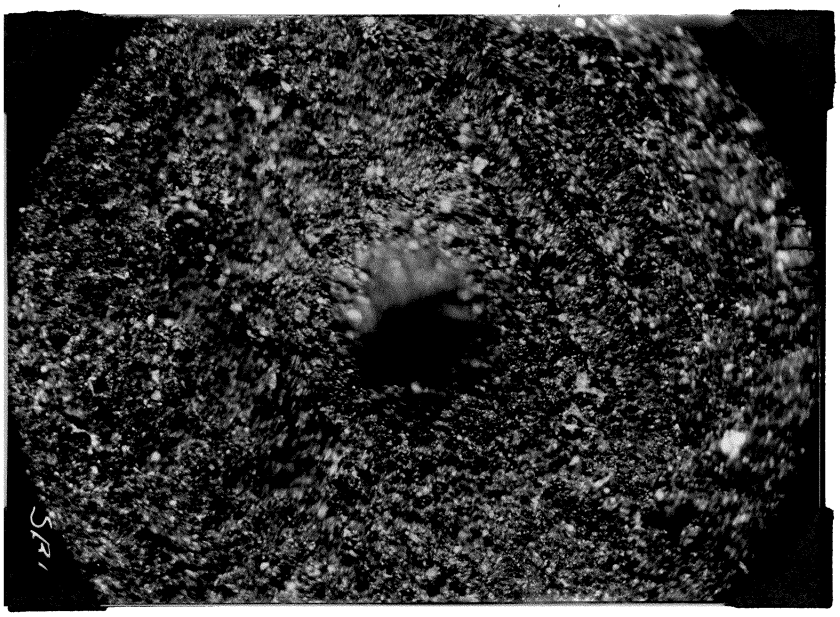
Sample No. 13.—Penetrator hole made after heating 1500 hours at 100 degrees Centigrade.



Sample No. 14.—Penetrator hole made before heating 1500 hours at 100 degrees Centigrade.

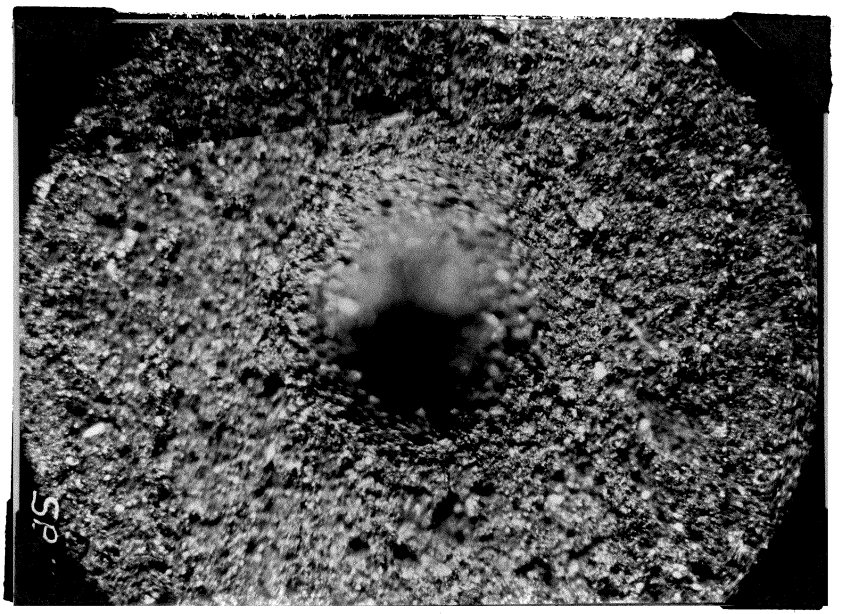


Sample No. 14.—Penetrator hole made after heating 1500 hours at 100 degrees Centigrade.

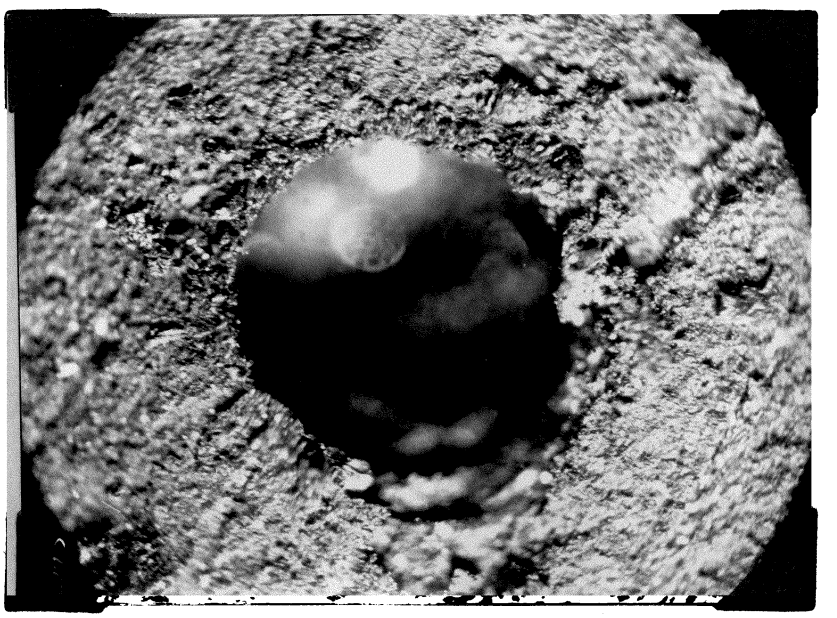


Sample No. 15.—Penetrator hole made before heating 1500 hours at 100 degrees Centigrade.

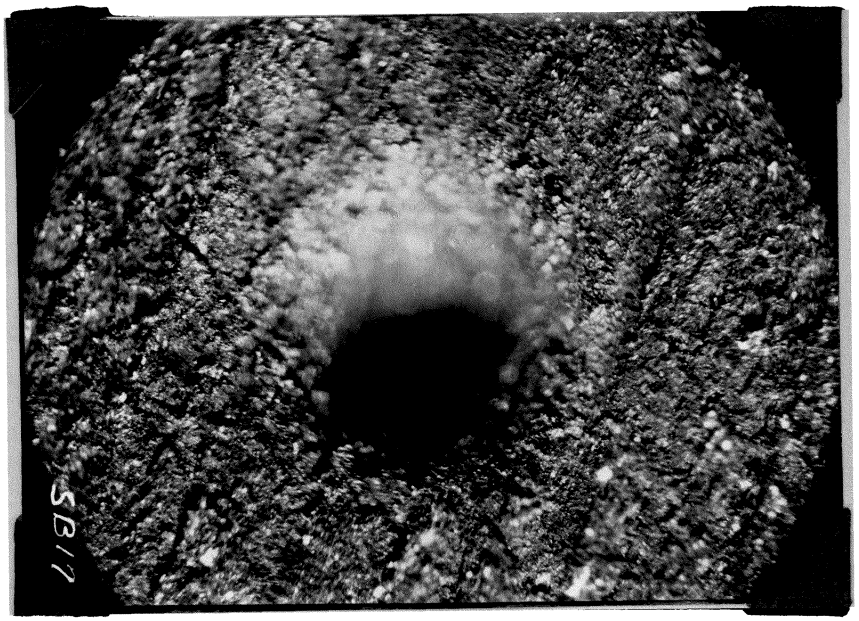
Sample No. 15.—Penetrator hole made after heating 1500 hours at 100 degrees Centigrade.



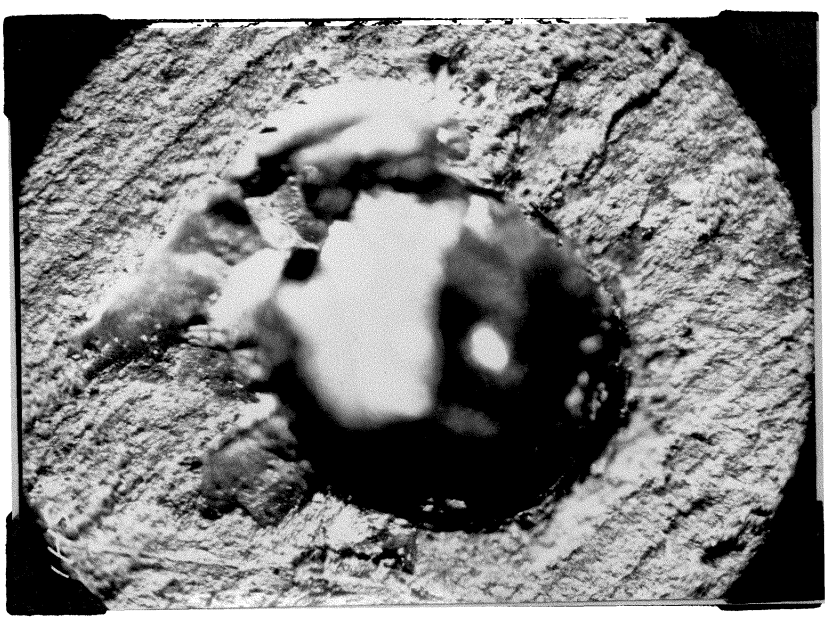
Sample No. 16.—Penetrator hole made before heating 1500 hours at 100 degrees Centigrade.



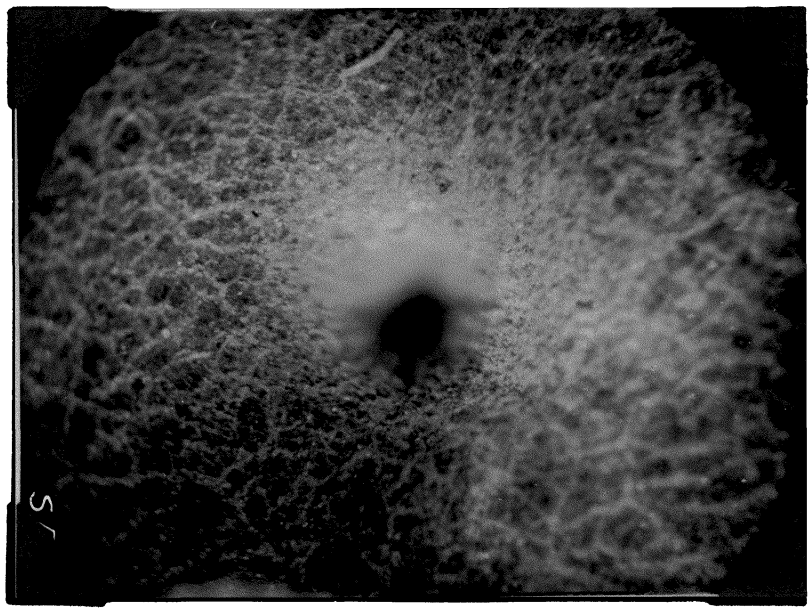
Sample No. 16.—Penetrator hole made after heating 1500 hours at 100 degrees Centigrade.



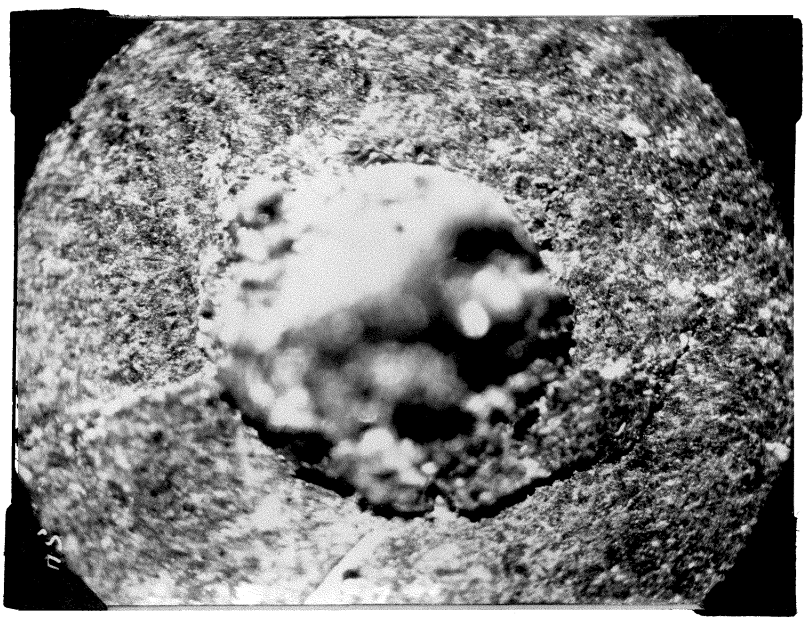
Sample No. 17.—Penetrator hole made before heating 1500 hours at 100 degrees Centigrade.



Sample No. 17.—Penetrator hole made after heating 1500 hours at 100 degrees Centigrade.

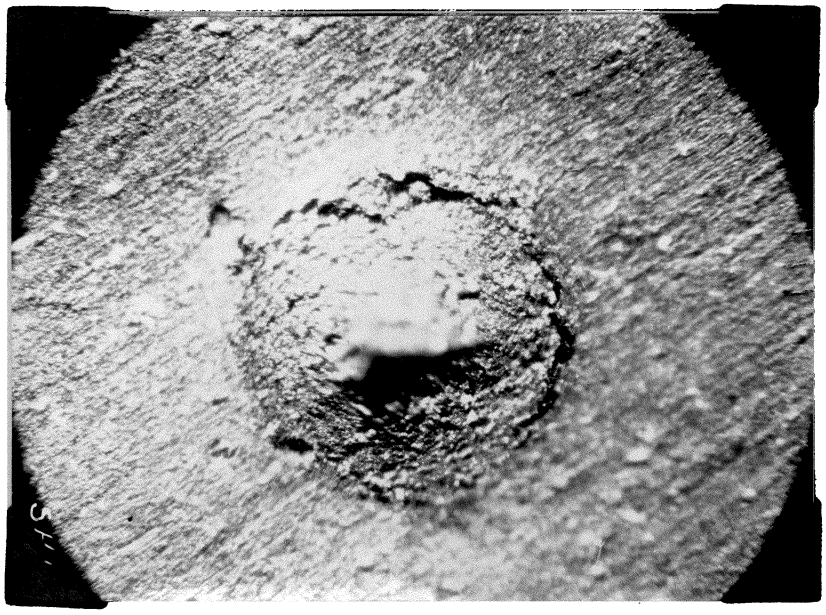


Sample No. 18.—Penetrator hole made before heating 1500 hours at 100 degrees Centigrade.

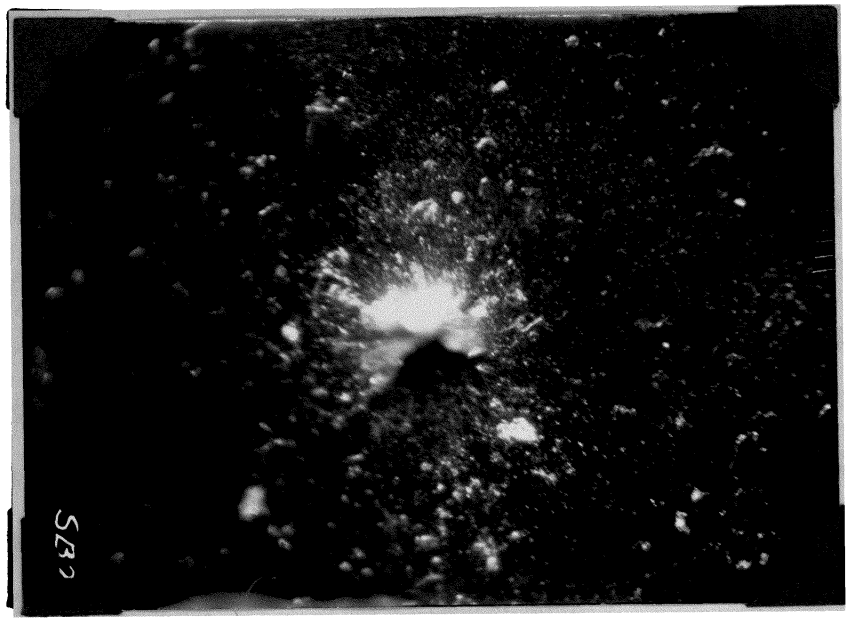


Sample No. 18.—Penetrator hole made after heating 1500 hours at 100 degrees Centigrade.

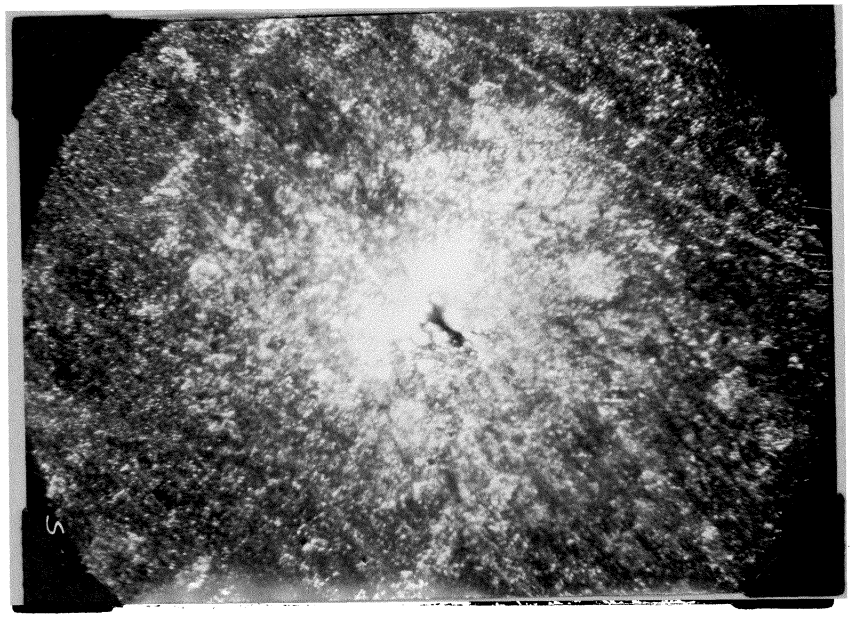
Sample No. 19.—Penetrator hole made before heating 1500 hours at 100 degrees Centigrade.



Sample No. 19.—Penetrator hole made after heating 1500 hours at 100 degrees Centigrade.



Sample No. 20.—Penetrator hole made before heating 1500 hours at 100 degrees Centigrade.



Sample No. 20.—Penetrator hole made after heating 1500 hours at 100 degrees Centigrade.

B. SHRINKAGE OF SAMPLE DUE TO HEATING 1500 HOURS AT 100 DEGREES CENTIGRADE

The thicknesses of the twenty samples were measured with a micrometer before and after heating 1500 hours at 100 degrees Centigrade. The average shrinkage for the twenty samples was 2.25 percent. Sample No. 15 showed no shrinkage while Sample No. 4 showed the maximum shrinkage of 10.8 percent. The excessive shrinkage of Sample No. 4 may have been due to the fact that it was water soluable and contained a high percentage of water.

Shrinkage of Samples After Heating 1500 Hours at a Constant Temperature of 100 Degrees Centigrade.

Sample No.	Thickness of Sample before Heating (Cm.)	Thickness of Sample 145 Hrs. after start (Cm.)	Thickness of Sample after Heating (Cm.)
1	.225	.221	.218
2	.650	.640	.629
3	.760	.755	.648
4	.650	.630	.580
5	.725	.720	.705
6	.650	.645	.640
7	.690	.685	.671
8	.680	.675	.661
9	.670	.665	.654
10	.675	.672	.669
11	.600	.585	.576
12	.600	.600	.596
13	.535	.530	.527
14	.202	.200	.200
15	.320	.322	.320
16	.325	.325	.322
17	.317	.315	.313
18	.674	.670	.672
19	.460	.460	.458
20	.335	.335	.325

Shrinkage of Samples After heating 1500 Hours at a Constant Temperature of 100 Degrees Centigrade.

Sample No.	Difference in thickness of samples before heating and after heating 1500 hours (Cm.)	Percentage of shrinkage (%)
1	.007	3.1
2	.021	3.2
3	.012	1.6
4	.070	10.8
5	.020	2.8
6	.010	1.5
7	.019	2.8
8	.019	2.8
9	.016	2.4
10	.006	0.9
11	.024	4.0
12	.004	0.7
13	.008	1.5
14	.002	1.0
15	.000	0.0
16	.003	0.9
17	.004	1.3
18	.002	0.3
19	.002	0.4
20	.010	3.0

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