HEAT TREATING CHARACTERISTICS OF FIVE BINARY BERYLLIUM-COPPER ALLOYS

Thesis for the Degree of M. S.

MICHIGAN STATE COLLEGE

Vaughn Dale Hildebrandt

1946

THESIS

This is to certify that the

thesis entitled

Heat Treating Characteristics of Five Binary Beryllium-Copper Alloys

presented by

Vaughn Dale Hildebrandt

has been accepted towards fulfillment of the requirements for

M. S. degree in Metallurgical Engineering

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Major professor

Date 7/27/46

M-795

HEAT TREATING CHARACTERISTICS OF FIVE BINARY BERYLLIUM-COPPER ALLOYS

by

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A THESIS

Submitted to the School of Graduate Studies of Michigan State College of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Department of Chemical and Metallurgical Engineering

1946

7/26/46
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ACKNOWLEDGEMENT

The author is deeply indebted to Professor C. C. DeWitt and Mr. D. D. McGrady for their guidance, advice and assistance. Appreciation is also expressed to the members of the mechanical engineering staff for their valuable advice.

INTRODUCTION

The problem of properly heat treating beryllium-copper alloys has been a nemesis to the engineer since the early days of the war. The exceptional properties developed by beryllium-copper alloys have been recognized by many industries, but attainment of the desired physical properties is not accomplished by haphazard, "hit or miss" heat treating procedures.

The heat treatment of a particular alloy of copper and beryllium is dependent upon many factors. The most important of these factors are: (1) the use to which the material will be put, i.e., does it require maximum hardness, maximum conductivity, maximum elongation or minimum drift; (2) the metallurgical history of the alloy, i.e., amount of "working" of cast alloy before and after solution heat treatment; and, (3) the complete chemical analysis of the alloy. At the present time, the manufacturers of the alloys are supplying the heat treating procedures with the alloy. However, it would appear that these heat treating procedures have become standardized and are unvariant.

In order that an intelligent analysis of the heat treating processes be made, it was necessary to eliminate as many of the variables as was possible. This elimination procedure resulted in : (1) the selection of

five binary alloys of beryllium and copper, (2) using "unworked" cast test bars solution heat treated at definite temperatures, and (3) aging to obtain maximum hardness.

The data thus obtained enables one to draw many general conclusions regarding the intricacies of proper heat treatment.

HISTORY

The credit for the discovery of the remarkable light metal, beryllium, must be given to the French investigator Vauquelin.[22] In attempting to find similarities between the precious stones, beryl and emerald, Vauquelin found, in 1797, that an oxide of an unknown constituent was common to both stones. The new element was given the name glucinum because the salts produced from the element were very sweet tasting. The name glucinum is still largely retained in French scientific literature, but the element is more commonly known as beryllium.

The problem of the isolation of elemental beryllium was not solved until 1828,[5] when Wohler succeeded in obtaining metallic beryllium from beryllium chloride by heating it with flat, pressed balls of calcium. From 1828 until 1889 there was little research devoted to beryllium and its compounds and alloys except for minor discoveries of the unusual behavior of beryllium salts. The first important advancement in the research history of beryllium was the production of high purity beryllium by electrolysis of the fused double flouride of beryllium and sodium by LeBeau in 1889.[5] In addition to the researches on the production of beryllium, LeBeau studied several of the beryllium alloys. Among the alloys

studied was a series of beryllium-copper alloys ranging up to 10% beryllium. The physical properties of the alloys were recorded as regards color, malleability, tarnish resistance, sonority and solubility in acids.(7) Research development again declined until about 1915. In 1916 Osterheld published his systematic investigation of the beryllium-copper alloys and their structures. The equilibrium diagram proposed by Osterheld is shown in the top figure of Figure I.(24)

In 1919 Stock and Goldschmidt began their investigation of electrolytic production processes for obtaining metallic beryllium. By 1921 Stock and Goldschmidt had succeeded in producing molten beryllium by electrolysis and the detailed description of their laboratory experiments was published in 1925. Future work was then undertaken by Siemens and Halske A.-G. The age-hardening or precipitation hardening properties of beryllium-copper alloys was discovered by Masing, about 1926, as a by-product of the study of the age-hardening of aluminum-copper alloys. Masing then became interested in redetermining the Osterheld equilibrium diagram because the shape of the solid solubility lines did not conform to the accepted diagram for age-hardenable alloys. Masing confirmed his supposition about the inaccuracy of the Osterheld diagram and the new equilibrium diagram showed considerable alteration of the solid solubility lines. Masing's diagram is shown as the middle figure of

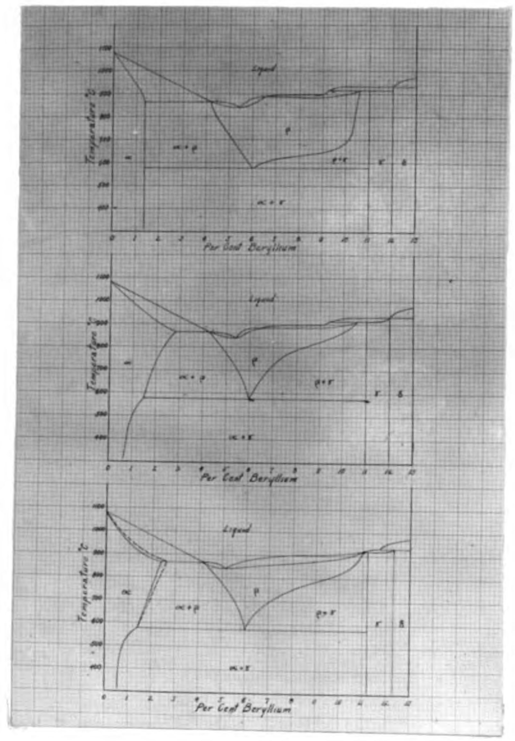


Figure I. Chronological development of the accepted equilibrium diagram for beryllium-copper alloys.

Top diagram: Proposed by Osterheld in 1916.

Center diagram: Proposed by Masing in 1929.

Bottom diagram: Accepted diagram. A combination of the works of Masing (1929), Borchers (1932), and Tanimura and Wasserman (1933).

Figure I.

The American counter-part of Siemens-Halske A.-G. was the Beryllium Corporation of America which was organized and began production in 1927.[2] The early work on beryllium was concerned primarily with the properties of beryllium-copper alloys as a possible substitute for zinc and tin. The initial high cost of extracting pure beryllium caused the investigations to be dropped. However, the discovery of the exceptional spring properties of beryllium-copper alloys caused a revival of research interest. In 1932[15] J.K. Smith reported his research results on a beryllium-copper alloy containing 2.5% beryllium. Smith's investigations established the accepted mill procedure and confirmed the properties obtainable upon age-hardening.

The accepted equilibrium diagram is a combination of the works of Masing (published in 1932), Borchers (published in 1932) and, Tanimura and Wasserman (published in 1933). This diagram is shown as the bottom figure of Figure I.[23] A survey of more recent literature discloses no marked changes in the accepted equilibrium diagram or in the established procedures.

TABULATED DATA

Table 1. Solution heat treating data for a cast 2.82% Be-96.81% Cu alloy solution heat treated at 1510°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "G") Maximum	Minimum	Average
.25	51	47	50
.50	50	44	47
1.00	48	45	47
2.00	49	41	46
3.00	45	41	44
4.00	43	39	43
8.00	46	43	44
12.00	48	44	46
24.00	46	39	43
48.00	47	41	44

Table 2. Solution heat treating data for a cast 2.82% Be-96.81% Cu alloy solution heat treated at 1470°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "G") Maximum	Minimum	Average
.25	51	48	50
.50	51	46	49
1.00	49	41	46
2.00	50	44	46
3.00	49	43	46
4.00	45	42	43
8.00	49	40	44
12.00	44	41	43
24.00	47	40	43
48.00	43	36	40

Table 3. Solution heat treating data for a cast 2.82% Be-96.81% Cu alloy solution heat treated at 1440°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "G") Maximum	Minimum	Average
.25	51	48	50
.50	50	48	49
1.00	50	43	47
2.00	46	43	45
3.00	48	45	45
4.00	49	43	45
8.00	45	41	44
12.00	45	38	42
24.00	48	39	43
48.00	40	37	39

Table 4. Solution heat treating data for a cast 2.61% Be-97.16% Cu alloy solution heat treated at 1510°F.

Time at Temp. (Hours)	Hardness Reading (Rockwell "G") Maximum	Minimum	Average
.25	57	53	55
.50	54	49	52
1.00	54	52	53
2.00	53	50	52
3.00	52	51	52
4.00	53	50	51
8.00	51	49	50
12.00	52	49	50
24.00	52	46	49
48.00	52	47	50

Table 5. Solution heat treating data for a cast 2.61% Be-97.16% Cu alloy solution heat treated at 1470°F.

Time at Temp. (Hours)	Hardness Reading (Rockwell "G") Maximum	Minimum	Average
.25	56	49	55
.50	54	52	53
1.00	55	50	52
2.00	53	49	51
3.00	51	48	50
4.00	51	49	50
8.00	53	48	52
12.00	53	49	51
24.00	50	47	49
48.00	49	42	46

Table 6. Solution heat treating data for a cast 2.61% Be-97.16% Cu alloy solution heat treated at 1440°F.

Time at Temp. (Hours)	Hardness Reading (Rockwell "G") Maximum	Minimum	Average
.25	57	54	55
.50	54	51	52
1.00	53	50	52
2.00	54	51	52
3.00	53	50	51
4.00	53	49	51
8.00	53	50	51
12.00	52	48	50
24.00			50
48.00	50	44	47

Table 7. Solution heat treating data for a cast 2.26% Be-97.58% Cu alloy solution heat treated at 1510°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "B") Maximum	Minimum	Average
.25	50	41	46
.50	48	46	47
1.00	46	43	44
2.00	49	43	45
3.00	44	40	43
4.00	46	40	43
8.00	46	39	43
12.00	48	44	46
24.00	43	30	40

Table 8. Solution heat treating data for a cast 2.26% Be-97.58% Cu alloy solution heat treated at 1470°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "B") Maximum	Minimum	Average
.25			46
.50	52	41	46
1.00	40	38	40
2.00	46	40	42
3.00	42	33	39
4.00	42	37	39
8.00	42	38	39
12.00	42	23	36
24.00	40	38	39
48.00	41	36	39

Table 9. Solution heat treating data for a cast 2.26% Be-97.58% Cu alloy solution heat treated at 1440°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "B") Maximum	Minimum	Average
.25	47	42	44
.50	44	41	42
1.00	46	32	39
2.00	42	30	39
3.00	43	32	39
4.00	41	35	38
8.00	40	30	36
12.00	46	33	40
24.00	43	37	40
48.00	46	38	43

Table 10. Solution heat treating data for a cast 2.01% Be-97.79% Cu alloy solution heat treated at 1510°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "B") Maximum	Minimum	Average
.25	36	29	33
.50	34	31	33
1.00	32	27	31
2.00	36	30	33
3.00	33	16	26
4.00	31	27	29
8.00	34	27	30
12.00	34	31	32
24.00	33	25	29
48.00			33

Table 11. Solution heat treating data for a cast 2.01% Be-97.79% Cu alloy solution heat treated at 1470°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "B") Maximum	Minimum	Average
.25	37	30	33
.50	35	28	31
1.00	32	29	31
2.00	32	28	31
3.00	32	26	30
4.00	32	21	28
8.00	33	25	30
12.00	36	30	32
24.00	33	23	28
48.00	36	27	32

Table 12. Solution heat treating data for a cast 2.01% Be-97.79% Cu alloy solution heat treated at 1440°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "B") Maximum	Minimum	Average
.25	39	34	37
.50	38	29	32
1.00	38	28	33
2.00	33	32	33
3.00	37	27	32
4.00	34	30	31
8.00	36	28	31
12.00	34	29	31
24.00	38	31	35
48.00	37	29	33

Table 13. Solution heat treating data for a cast 1.78% Be-97.98% Cu alloy solution heat treated at 1510°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "B") Maximum	Minimum	Average
.25	27	16	21
.50	23	12	17
1.00	18	7	12
2.00	17	5	10
3.00	7	1	4
4.00	14	7	10
8.00	17	5	12
12.00	15	5	10
24.00	12	1	7
48.00	24	4	15

Table 14. Solution heat treating data for a cast 1.78% Be-97.98% Cu alloy solution heat treated at 1470°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "B") Maximum	Minimum	Average
.25	30	20	26
.50	21	1	12
1.00	12	5	8
2.00	12	7	10
3.00	12	2	8
4.00	12	1	8
8.00	13	4	9
12.00	11	6	8
24.00	18	1	11
48.00	15	12	14

Table 15. Solution heat treating data for a cast 1.78% Be-97.98% Cu alloy solution heat treated at 1440°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "B") Maximum	Minimum	Average
.25	31	25	27
.50	23	18	22
1.00	23	14	20
2.00	23	20	21
3.00	16	10	12
4.00	18	10	12
8.00	19	12	16
12.00	22	14	17
24.00	21	18	20
48.00	16	10	13

Table 16. Aging data for a cast 2.82% Be-96.81% Cu alloy solution heat treated at 1510°F. for 15 minutes and aged at 680°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "C") Maximum	Minimum	Average
.00			-13
.50	40	33	36
1.00	44	40	42
2.00	40	36	39
4.00	40	30	34
8.00	37	29	33
12.00	30	27	30
16.00	26	22	24
24.00	25	22	24

Table 17. Aging data for a cast 2.82% Be-96.81% Cu alloy solution heat treated at 1510°F. for 15 minutes and aged at 630°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "C") Maximum	Minimum	Average
.00			-13
.50	12	9	11
1.00	38	36	37
2.00	42	39	41
4.00	46	40	43
8.00	25	20	24
12.00	27	23	24
16.00	29	22	26
24.00	28	18	22

Table 18. Aging data for a cast 2.82% Be-96.81% Cu alloy solution heat treated at 1510°F. for 15 minutes and aged at 580°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "C") Maximum	Minimum	Average
.00			-13
.50	33	32	33
1.00	41	36	39
2.00	45	42	43
4.00	46	43	45
8.00	41	35	39
12.00	40	37	38
16.00	39	35	37
24.00	36	30	33

Table 19. Aging data for a cast 2.82% Be- 96.81% Cu alloy solution heat treated at 1470°F. for 15 minutes and aged at 680°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "C") Maximum	Minimum	Average
.00			-10
.50	43	40	42
1.00	43	40	42
2.00	43	37	40
4.00	39	28	34
8.00	35	26	32
12.00	31	25	28
16.00	31	22	25
24.00	23	19	21

Table 20. Aging data for a cast 2.82% Be- 96.81% Cu alloy solution heat treated at 1470°F. for 15 minutes and aged at 630°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "C") Maximum	Minimum	Average
.00			-10
.50	20	16	18
1.00	37	34	35
2.00	44	41	43
4.00	46	29	40
8.00	25	20	22
12.00	23	21	22
16.00	27	21	24
24.00	24	18	21

Table 21. Aging data for a cast 2.82% Be- 96.81% Cu alloy solution heat treated at 1470°F. for 15 minutes and aged at 580°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "C") Maximum	Minimum	Average
.00			-10
.50	35	30	34
1.00	43	36	40
2.00	43	38	41
4.00	45	38	43
8.00	43	35	38
12.00	42	37	39
16.00	41	34	37
24.00	35	31	33

Table 22. Aging data for a cast 2.82% Be- 96.81% Cu alloy solution heat treated at 1440°F. for 15 minutes and aged at 680°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "C") Maximum	Minimum	Average
.00			- 8
.50	41	39	40
1.00	44	38	41
2.00	42	38	40
4.00	36	31	33
8.00	35	26	30
12.00	33	25	28
16.00	29	25	27
24.00	27	19	22

Table 23. Aging data for a cast 2.82% Be- 96.81% Cu alloy solution heat treated at 1440°F. for 15 minutes and aged at 630°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "C") Maximum	Minimum	Average
.00			- 8
.50	35	29	32
1.00	42	39	40
2.00	45	43	45
4.00	45	42	43
8.00	25	22	23
12.00	29	22	26
16.00	26	20	23
24.00	26	24	23

Table 24. Aging data for a cast 2.82% Be- 96.81% Cu alloy solution heat treated at 1440°F. for 15 minutes and aged at 580°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "C") Maximum	Minimum	Average
.00			- 8
.50	34	32	34
1.00	43	38	40
2.00	44	41	43
4.00	46	43	45
8.00	43	37	42
12.00	43	34	39
16.00	39	33	36
24.00	40	32	35

Table 25. Aging data for a cast 2.61% Be- 97.16% Cu alloy solution heat treated at 1510°F. for 15 minutes and aged at 680°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "C") Maximum	Minimum	Average
.00			-33
.50	22	13	19
1.00	39	34	37
2.00	39	33	37
4.00	35	30	32
8.00	36	31	33
12.00	31	22	27
16.00	28	23	26
24.00	27	21	24

Table 26. Aging data for a cast 2.61% Be- 97.16% Cu alloy solution heat treated at 1510°F. for 15 minutes and aged at 630°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "C") Maximum	Minimum	Average
.00			-33
.50	- 1	- .5	- .5
1.00	35	33	34
2.00	43	30	38
4.00	42	36	40
8.00	27	25	26
12.00	29	25	28
16.00	28	21	26
24.00	27	24	26

Table 27. Aging data for a cast 2.61% Be- 97.16% Cu alloy solution heat treated at 1510°F. for 15 minutes and aged at 580°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "C") Maximum	Minimum	Average
.00			-33
.50	19	11	15
1.00	38	35	37
2.00	41	37	40
4.00	43	40	41
8.00	41	34	38
12.00	37	31	35
16.00	36	26	32
24.00	33	30	31

Table 28. Aging data for a cast 2.61% Be- 97.16% Cu alloy solution heat treated at 1470°F. for 15 minutes and aged at 680°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "C") Maximum	Minimum	Average
.00			-13
.50	38	35	37
1.00	43	40	41
2.00	40	34	39
4.00	38	31	35
8.00	39	29	35
12.00	29	26	27
16.00	28	25	27
24.00	27	22	25

Table 29. Aging data for a cast 2.61% Be- 97.16% Cu alloy solution heat treated at 1470°F. for 15 minutes and aged at 630°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "C") Maximum	Minimum	Average
.00			-13
.50	29	26	28
1.00	37	33	35
2.00	44	38	42
4.00	46	35	40
8.00	26	22	24
12.00	27	21	23
16.00	25	20	21
24.00	24	20	22

Table 30. Aging data for a cast 2.61% Be- 97.16% Cu alloy solution heat treated at 1470°F. for 15 minutes and aged at 580°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "C") Maximum	Minimum	Average
.00			-13
.50	30	27	29
1.00	39	35	37
2.00	42	38	41
4.00	44	39	41
8.00	42	35	39
12.00	41	35	38
16.00	39	32	36
24.00	38	30	34

Table 31. Aging data for a cast 2.61% Be- 97.16% Cu alloy solution heat treated at 1440°F. for 15 minutes and aged at 680°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "C") Maximum	Minimum	Average
.00			-16
.50	40	38	39
1.00	43	41	42
2.00	43	36	39
4.00	38	33	35
8.00	35	31	33
12.00	28	22	26
16.00	28	20	24
24.00	24	20	22

Table 32. Aging data for a cast 2.61% Be- 97.16% Cu alloy solution heat treated at 1440°F. for 15 minutes and aged at 630°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "C") Maximum	Minimum	Average
.00			-16
.50	17	9	13
1.00	39	36	38
2.00	43	42	43
4.00	44	39	42
8.00	26	23	25
12.00	27	21	24
16.00	28	20	25
24.00	26	19	24

Table 33. Aging data for a cast 2.61% Be- 97.16% Cu alloy solution heat treated at 1440°F. for 15 minutes and aged at 580°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "C") Maximum	Minimum	Average
.00			-16
.50	35	32	34
1.00	42	36	39
2.00	44	39	42
4.00	46	42	44
8.00	43	37	40
12.00	41	34	38
16.00	39	33	35
24.00	34	28	30

Table 34. Aging data for a cast 2.26% Be- 97.58% Cu alloy solution heat treated at 1510°F. for 15 minutes and aged at 680°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "C") Maximum	Minimum	Average
.00			-38
.50	14	- 2	7
1.00	45	40	42
2.00	38	32	36
4.00	36	26	32
8.00	29	21	26
12.00	31	24	27
16.00	27	20	26
24.00	23	19	21

Table 35. Aging data for a cast 2.26% Be- 97.58% Cu alloy solution heat treated at 1510°F. for 15 minutes and aged at 630°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "C") Maximum	Minimum	Average
.00			-38
.50	15	8	11
1.00	37	29	33
2.00	40	37	39
4.00	43	36	39
8.00	26	20	24
12.00	30	21	25
16.00	29	20	26
24.00	28	24	26

Table 36. Aging data for a cast 2.26% Be- 97.58% Cu alloy solution heat treated at 1510°F. for 15 minutes and aged at 580°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "C") Maximum	Minimum	Average
.00			-38
.50	- 6	3	1
1.00	33	30	31
2.00	41	38	40
4.00	43	41	41
8.00	41	34	37
12.00	40	34	36
16.00	40	34	37
24.00	37	31	33

Table 37. Aging data for a cast 2.26% Be- 97.58% Cu alloy solution heat treated at 1470°F. for 15 minutes and aged at 680°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "C") Maximum	Minimum	Average
.00			-22
.50	41	36	39
1.00	44	40	43
2.00	40	37	39
4.00	37	30	34
8.00	36	31	34
12.00	30	24	28
16.00	31	23	27
24.00	26	16	22

Table 38. Aging data for a cast 2.26% Be- 97.58% Cu alloy solution heat treated at 1470°F. for 15 minutes and aged at 630°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "C") Maximum	Minimum	Average
.00			-22
.50	41	32	38
1.00	43	40	41
2.00	44	39	42
4.00	45	38	42
8.00	24	20	22
12.00	27	20	22
16.00	24	21	23
24.00	23	20	21

Table 39. Aging data for a cast 2.26% Be- 97.58% Cu alloy solution heat treated at 1470°F. for 15 minutes and aged at 580°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "C") Maximum	Minimum	Average
.00			-22
.50	32	29	32
1.00	39	35	37
2.00	44	37	41
4.00	47	41	44
8.00	40	36	38
12.00	37	34	36
16.00	39	31	34
24.00	39	27	30

Table 40. Aging data for a cast 2.26% Be- 97.58% Cu alloy solution heat treated at 1440°F. for 15 minutes and aged at 680°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "C") Maximum	Minimum	Average
.00			-19
.50	40	36	38
1.00	38	30	35
2.00	42	38	39
4.00	36	31	33
8.00	36	24	32
12.00	31	23	27
16.00	28	23	25
24.00	23	16	20

Table 41. Aging data for a cast 2.26% Be- 97.58% Cu alloy solution heat treated at 1440°F. for 15 minutes and aged at 630°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "C") Maximum	Minimum	Average
.00			-19
.50	21	13	18
1.00	37	32	34
2.00	43	37	40
4.00	45	37	41
8.00	25	20	23
12.00	24	20	23
16.00	27	20	24
24.00	23	19	22

Table 42. Aging data for a cast 2.26% Be- 97.58% Cu alloy solution heat treated at 1440°F. for 15 minutes and aged at 580°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "C") Maximum	Minimum	Average
.00			-19
.50	32	27	30
1.00	39	35	37
2.00	42	37	41
4.00	43	41	42
8.00	39	36	38
12.00	36	28	34
16.00	33	30	32
24.00	32	28	30

Table 43. Aging data for a cast 2.01% Be- 97.79% Cu alloy solution heat treated at 1510°F. for 15 minutes and aged at 680°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "G") Maximum	Minimum	Average
.00			-15
.50	20	17	18
1.00	70	54	62
2.00	95	85	89
4.00	93	91	93
8.00	91	80	88
12.00	90	82	85
16.00	88	80	84
24.00	85	79	83

Table 44. Aging data for a cast 2.01% Be- 97.79% Cu alloy solution heat treated at 1510°F. for 15 minutes and aged at 630°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "G") Maximum	Minimum	Average
.00			-15
.50	8	- 2	2
1.00	58	46	51
2.00	88	75	80
4.00	96	92	94
8.00	91	82	88
12.00	90	83	87
16.00	91	83	87
24.00	90	85	88

Table 45. Aging data for a cast 2.01% Be- 97.79% Cu alloy solution heat treated at 1510°F. for 15 minutes and aged at 580°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "G") Maximum	Minimum	Average
.00			-15
.50	23	11	19
1.00	70	62	65
2.00	90	72	83
4.00	98	92	96
8.00	98	93	96
12.00	99	94	96
16.00	99	93	96
24.00	97	90	95

Table 46. Aging data for a cast 2.01% Be- 97.79% Cu alloy solution heat treated at 1470°F. for 15 minutes and aged at 680°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "G") Maximum	Minimum	Average
.00			-16
.50	20	13	17
1.00	88	60	77
2.00	96	83	88
4.00	91	83	88
8.00	96	85	91
12.00	90	78	86
16.00	87	86	87
24.00	83	74	80

Table 47. Aging data for a cast 2.01% Be- 97.79% Cu alloy solution heat treated at 1470°F. for 15 minutes and aged at 630°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "G") Maximum	Minimum	Average
.00			-16
.50	20	7	12
1.00	54	46	51
2.00	95	90	93
4.00	97	92	95
8.00	94	91	93
12.00	92	89	89
16.00	94	88	91
24.00	93	86	90

Table 48. Aging data for a cast 2.01% Be- 97.79% Cu alloy solution heat treated at 1470°F. for 15 minutes and aged at 580°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "G") Maximum	Minimum	Average
.00			-16
.50	2	11	8
1.00	58	50	55
2.00	85	55	68
4.00	97	88	92
8.00	98	88	94
12.00	98	91	95
16.00	98	95	96
24.00	97	90	94

Table 49. Aging data for a cast 2.01% Be- 97.79% Cu alloy solution heat treated at 1440°F. for 15 minutes and aged at 680°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "G") Maximum	Minimum	Average
.00			-17
.50	23	12	18
1.00	78	62	58
2.00	93	76	84
4.00	95	85	92
8.00	96	91	94
12.00	91	89	90
16.00	89	84	87
24.00	88	83	86

Table 50. Aging data for a cast 2.01% Be- 97.79% Cu alloy solution heat treated at 1440°F. for 15 minutes and aged at 630°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "G") Maximum	Minimum	Average
.00			-17
.50	15	1	7
1.00	82	66	74
2.00	95	92	94
4.00	98	97	98
8.00	92	87	89
12.00	90	85	88
16.00	92	86	89
24.00	89	80	85

Table 51. Aging data for a cast 2.01% Be- 97.79% Cu alloy solution heat treated at 1440°F. for 15 minutes and aged at 580°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "G") Maximum	Minimum	Average
.00			-17
.50	16	2	7
1.00	62	55	57
2.00	90	86	87
4.00	100	95	98
8.00	99	96	98
12.00	99	94	97
16.00	100	97	98
24.00	99	92	96

Table 55. Aging data for a cast 1.78% Be- 97.98% Cu alloy solution heat treated at 1470°F. for 15 minutes and aged at 680°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "B") Maximum	Minimum	Average
.00			23
.50	26	13	19
1.00	61	33	42
2.00	75	49	63
4.00	85	68	78
8.00	97	68	88
12.00	94	87	91
16.00	97	87	93
24.00	94	85	91

Table 56. Aging data for a cast 1.78% Be- 97.98% Cu alloy solution heat treated at 1470°F. for 15 minutes and aged at 630°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "B") Maximum	Minimum	Average
.00			23
.50	28	19	24
1.00	42	31	39
2.00	27	21	26
4.00	51	33	44
8.00	91	83	87
12.00	90	82	86
16.00	92	80	87
24.00	92	83	88

Table 57. Aging data for a cast 1.78% Be- 97.98% Cu alloy solution heat treated at 1470°F. for 15 minutes and aged at 580°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "B") Maximum	Minimum	Average
.00			23
.50	42	10	23
1.00	55	40	45
2.00	73	46	60
4.00	59	47	55
8.00	90	73	85
12.00	90	79	87
16.00	93	84	88
24.00	96	92	94

Table 58. Aging data for a cast 1.78% Be- 97.98% Cu alloy solution heat treated at 1440°F. for 15 minutes and aged at 680°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "B") Maximum	Minimum	Average
.00			24
.50	34	19	25
1.00	57	37	48
2.00	71	58	66
4.00	86	76	81
8.00	94	73	86
12.00	97	86	92
16.00	89	79	85
24.00	90	81	86

Table 59. Aging data for a cast 1.78% Be- 97.98% Cu alloy solution heat treated at 1440°F. for 15 minutes and aged at 630°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "B") Maximum	Minimum	Average
.00			24
.50	34	30	33
1.00	47	30	37
2.00	60	39	49
4.00	74	61	68
8.00	98	91	95
12.00	98	93	95
16.00	98	92	94
24.00	95	86	91

Table 60. Aging data for a cast 1.78% Be- 97.98% Cu alloy solution heat treated at 1440°F. for 15 minutes and aged at 580°F.

Time at Temp. (Hours)	Hardness Readings (Rockwell "B") Maximum	Minimum	Average
.00			24
.50	32	23	28
1.00	49	31	43
2.00	52	33	40
4.00	79	45	61
8.00	77	66	73
12.00	90	76	82
16.00	91	79	86
24.00	96	88	91

Table 61. Hardness conversion data, Rockwell "B"- Rockwell "G".

Rockwell "B"	12	31	46	54	68	78	80
Rockwell "G"	-35	-20	0	20	38	50	55

Table 62. Hardness conversion data, Rockwell "G"- Rockwell "C".

Rockwell "G"	69	80	96
Rockwell "C"	1	14	33

Table 63. Physical properties of five binary beryllium-copper alloys in the "as cast" condition.

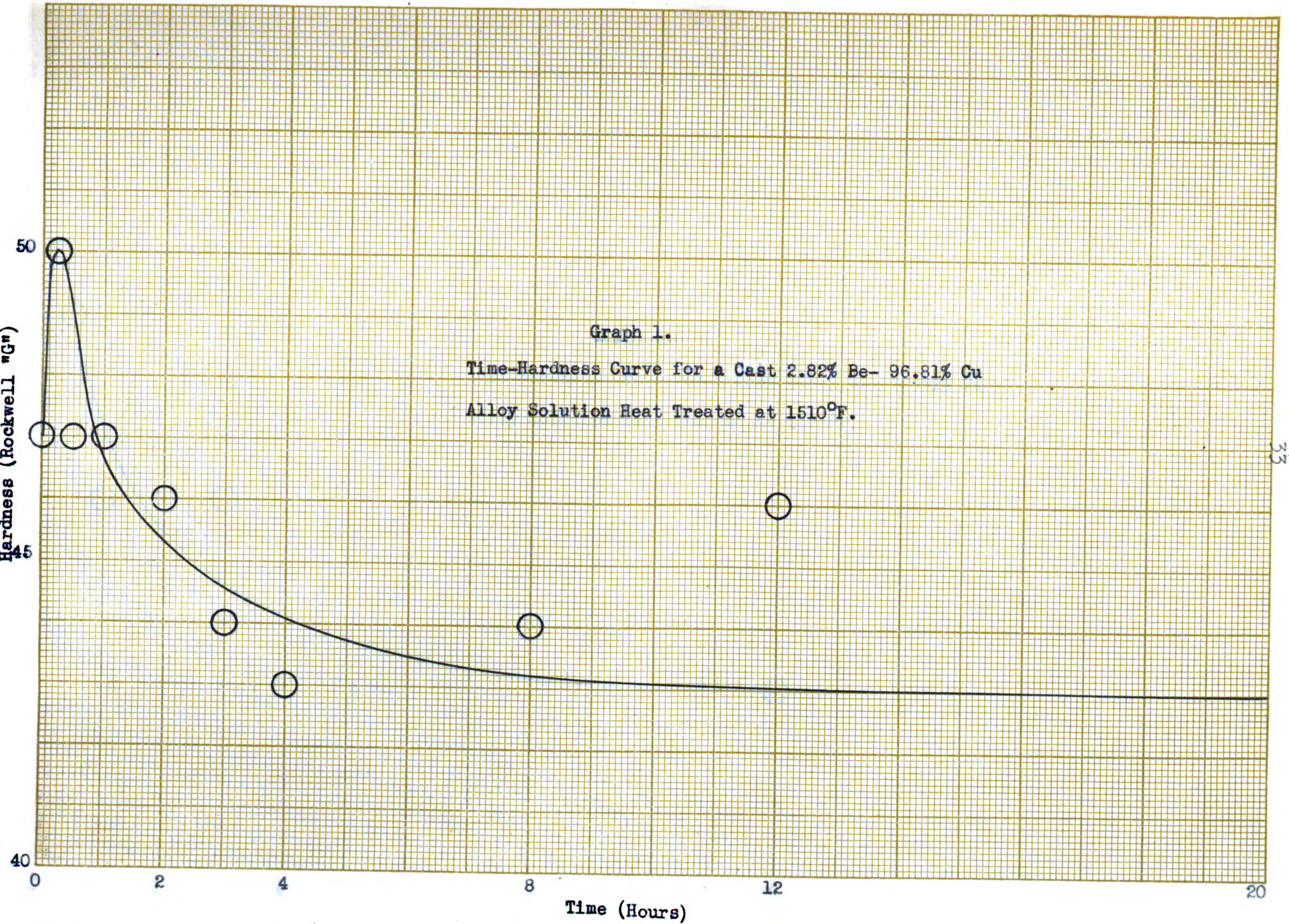
Heat Number		1	2	3	4	5
% Beryllium		2.82	2.61	2.26	2.01	1.78
Tensile Strength (psi)		80,000	78,200	55,400	39,750	30.150
% Elongation in 2 Inches.		24.55	21.5	15.4	17.5	6.8
Rockwell Hardness	Maximum	50 G	44 G	71 B	61 B	46 B
	Minimum	44 G	36 G	62 B	38 B	25 B
	Average	47 G	40 G	68 B	54 B	34 B
Condition of Fracture.		Good	Good	Good	Good	Good

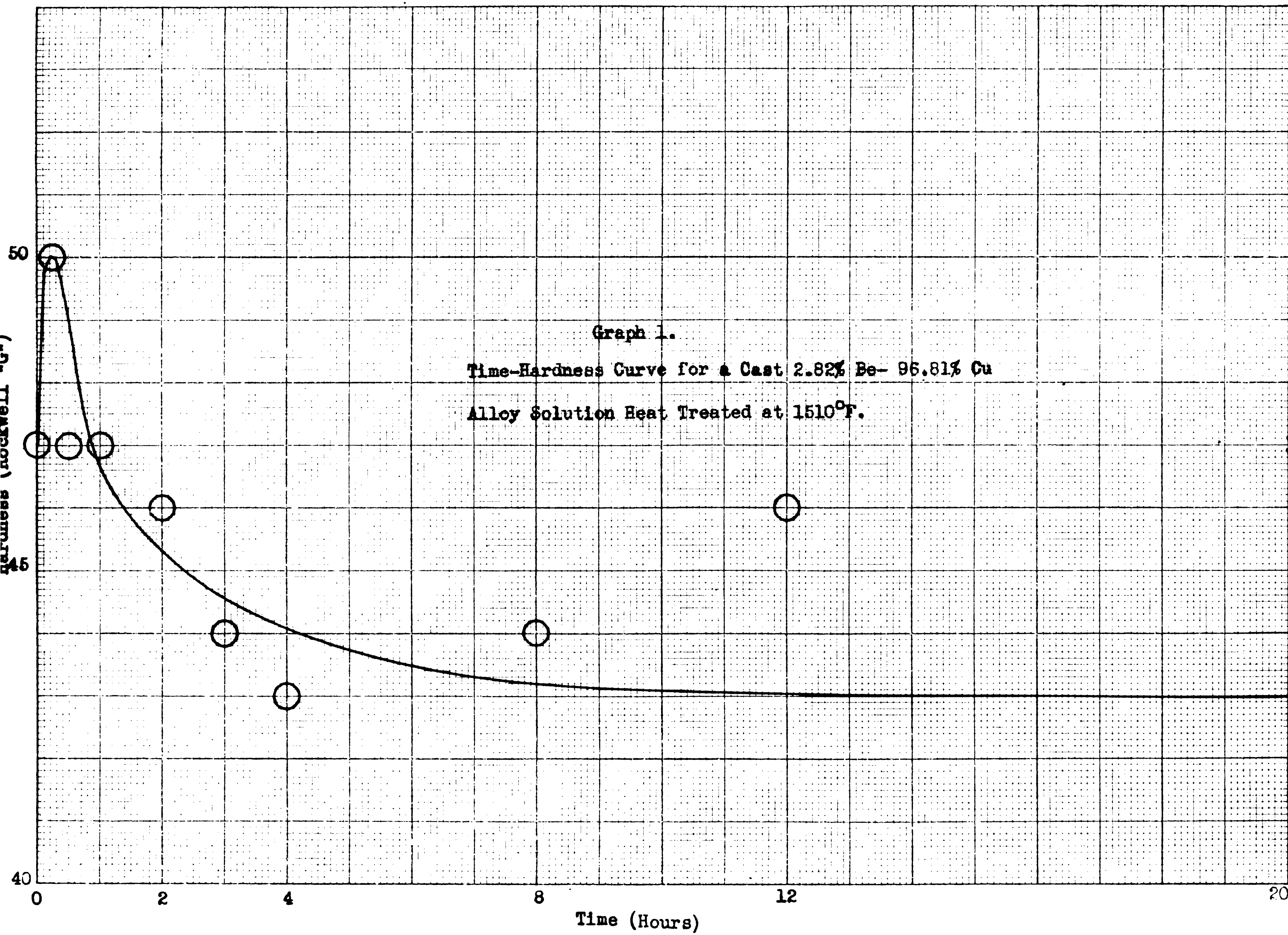
Table 64. Physical properties of five cast beryllium-copper alloys after solution heat treatment at the indicated temperatures for 15 minutes.

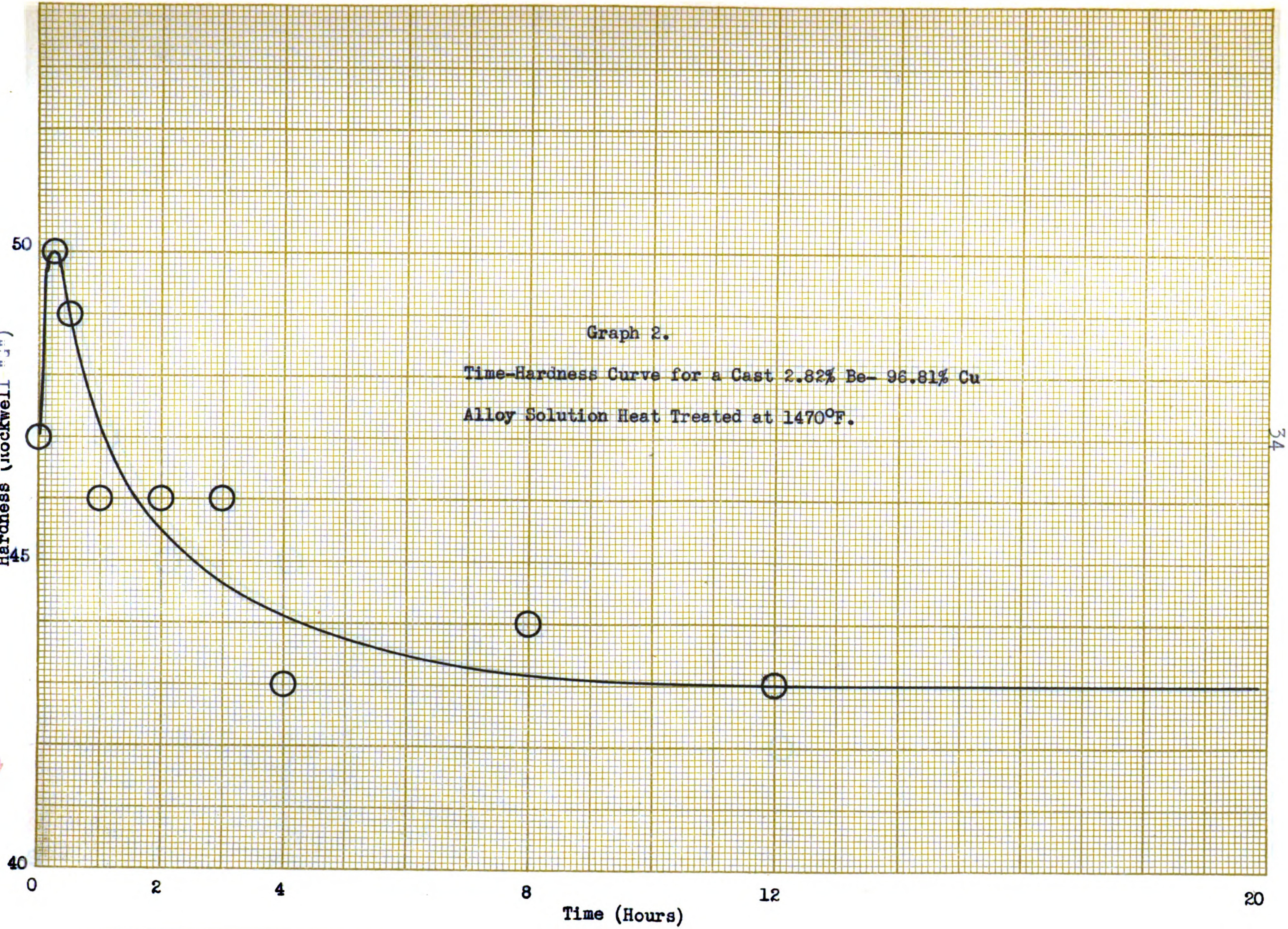
Heat Number	1	2	3	4	5
% Beryllium	2.82	2.61	2.26	2.01	1.78
Tensile Strength (psi.)					
S.H.T. at 1510°F.	98,600	58,100	54,100	45,900	20,300
S.H.T. at 1470°F.	73,600	74,000	78,000	40,100	------
S.H.T. at 1440°F.	90,900	71,700	78,500	35,800	32,400
% Elongation in 2 in.*					
S.H.T. at 1510°F.	26.8	14.1	14.1	25.2	5.7
S.H.T. at 1470°F.	10.9	24.2	18.8	20.3	---
S.H.T. at 1440°F.	10.8	8.8	24.2	14.7	10.6
Rockwell Hardness					
S.H.T. at 1510°F.					
Maximum	51 G	32 G	59 B	40 B	24 B
Minimum	45 G	22 G	51 B	31 B	17 B
Average	48 G	29 G	57 B	35 B	20 B
S.H.T. at 1470°F.					
Maximum	51 G	34 G	76 B	40 B	27 B
Minimum	42 G	31 G	71 B	31 B	19 B
Average	48 G	33 G	74 B	36 B	23 B
S.H.T. at 1440°F.					
Maximum	51 G	47 G	65 B	41 B	26 B
Minimum	42 G	41 G	57 B	33 B	16 B
Average	48 G	44 G	62 B	37 B	24 B
Condition of Fracture					
S.H.T. at 1510°F.	Good	Good	Good	Good	Gas Pockets
S.H.T. at 1470°F.	Porous	Good	Good	Porous	Gas Pockets
S.H.T. at 1440°F.	Good	Good	Good	Good	Gas Pockets

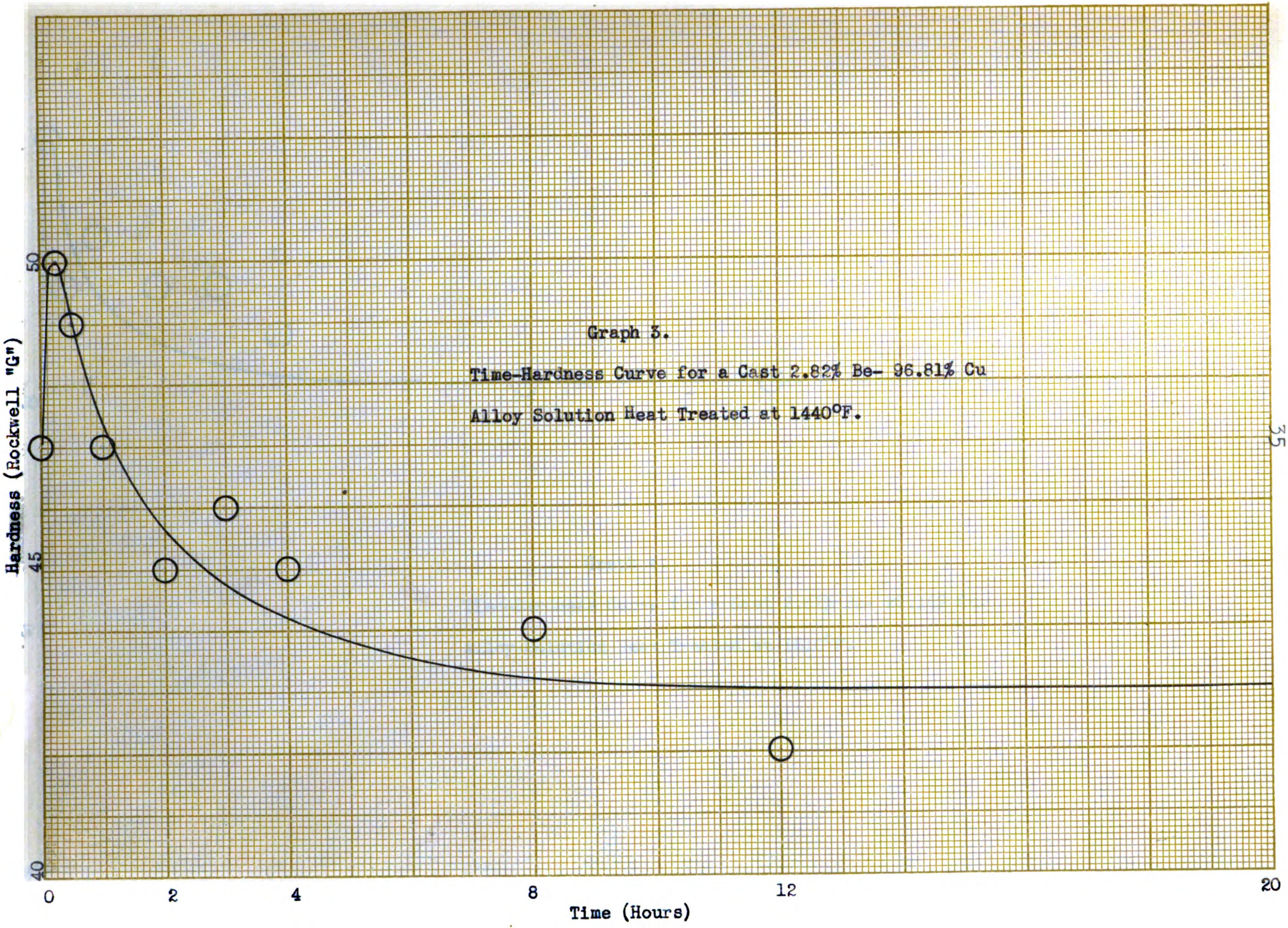
Table 65. Physical properties of five cast beryllium-copper alloys after solution heat treatment and age hardening at the indicated times and temperatures.

Heat Number	1	2	3	4	5
% Beryllium	2.82	2.61	2.26	2.01	1.78
Tensile Strength (psi.)					
S.H.T.at 1510°F.,15 min.:A.H.at 680°F.	155,500	134,500	108,800	92,600	98,700
S.H.T.at 1470°F.,15 min.:A.H.at 630°F.	120,000	128,800	102,000	109,500	113,700
S.H.T.at 1440°F.,15 min.:A.H.at 580°F.	149,800	131,100	127,800	91,900	102,800
% Elongation in 2 inches.					
S.H.T.at 1510°F.:A.H.at 680°F.	0.65	0.62	0.65	---	1.05
S.H.T.at 1470°F.:A.H.at 630°F.	.85	0.85	0.70	1.45	2.50
S.H.T.at 1440°F.:A.H.at 580°F.	0.70	0.70	0.70	0.70	0.85
Rockwell Hardness					
S.H.T.at 1510°F.:A.H.at 680°F.					
Maximum	41	35	41	31	31
Minimum	37	39	37	26	23
Average	39	37	40	29	25
S.H.T.at 1470°F.:A.H.at 630°F.					
Maximum	43	45	45	34	34
Minimum	41	41	41	29	28
Average	42	42	42	31	31
S.H.T.at 1440°F.:A.H.at 580°F.					
Maximum	47	43	42	29	37
Minimum	38	40	41	25	28
Average	42	41	42	27	33
Condition Of Fracture					
S.H.T.at 1510°F.:A.H.at 680°F.	Good	Good	Porous	Porous	Porous
S.H.T.at 1470°F.:A.H.at 630°F.	Good	Good	Porous	Good	Good
S.H.T.at 1440°F.:A.H.at 580°F.	Good	Good	Good	Porous	Good


Graph 1.
Time-Hardness Curve for a Cast 2.82% Be- 96.81% Cu
Alloy Solution Heat Treated at 1510°F.
Hardness (Rockwell "G")
50
45
40
0
2
4
8
12
20
Time (Hours)


Graph 1.
Time-Hardness Curve for a Cast 2.82% Be- 96.81% Cu
Alloy Solution Heat Treated at 1510°F.
Hardness (Rockwell "C")
50
45
40
0
2
4
8
12
20
Time (Hours)

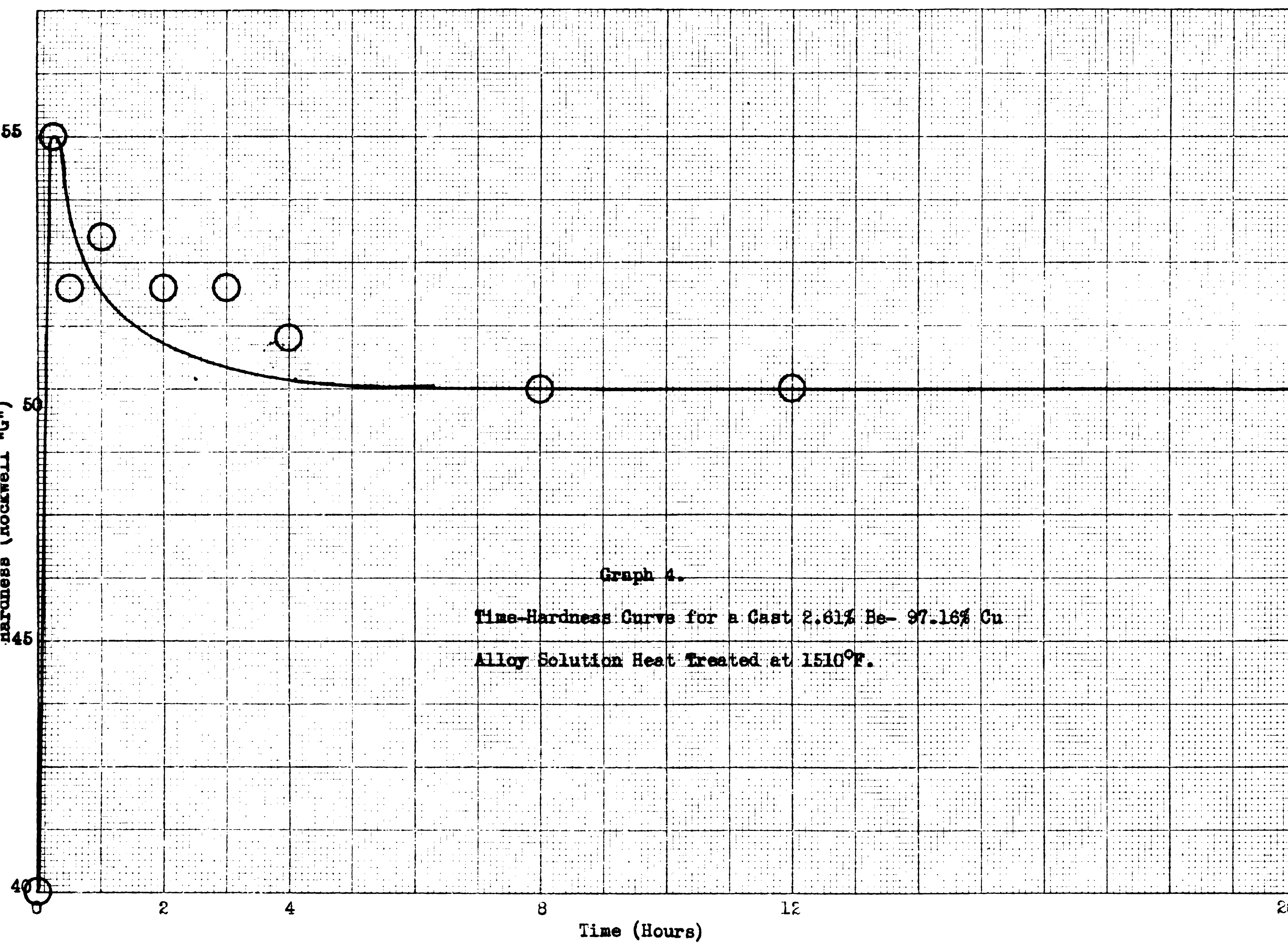

Graph 2.
Time-Hardness Curve for a Cast 2.82% Be- 96.81% Cu
Alloy Solution Heat Treated at 1470°F.
Hardness (Rockwell "F")
50
45
40
0
2
4
8
12
20
Time (Hours)



Graph 3.

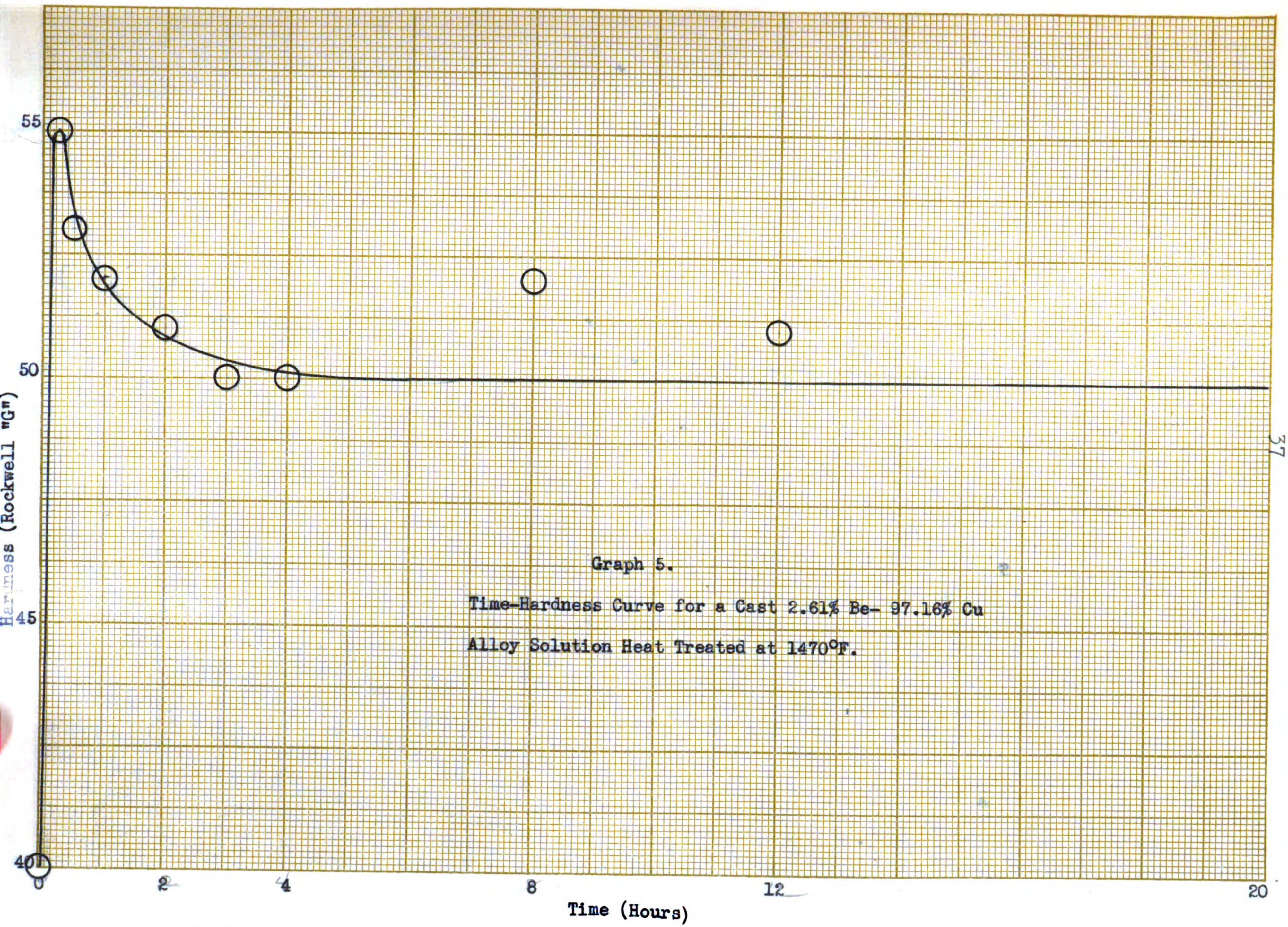
Time-Hardness Curve for a Cast 2.82% Be- 96.81% Cu

Alloy Solution Heat Treated at 1440°F.



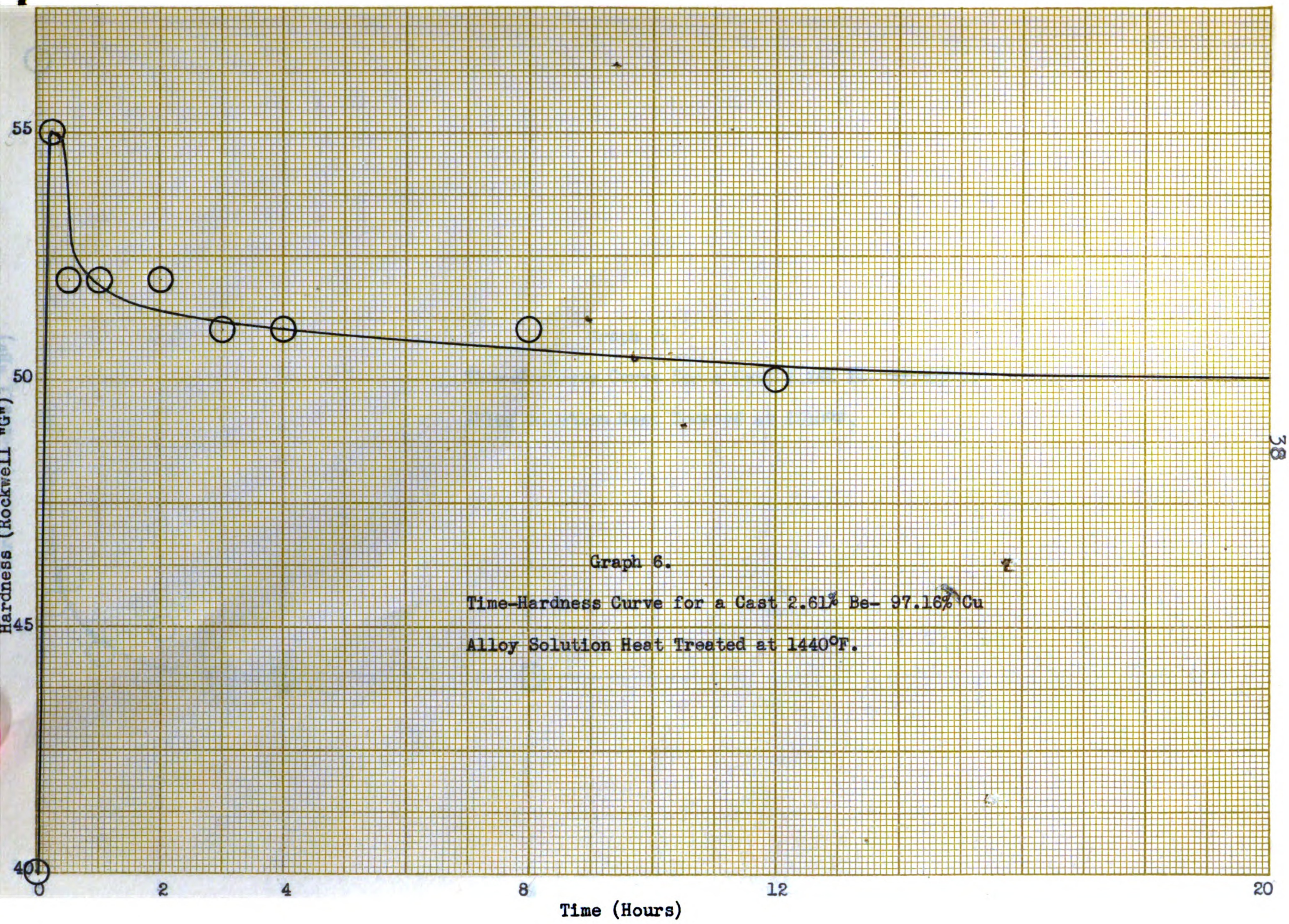
Graph 4.

Time-Hardness Curve for a Cast 2.61% Be- 97.16% Cu Alloy Solution Heat Treated at 1510°F.



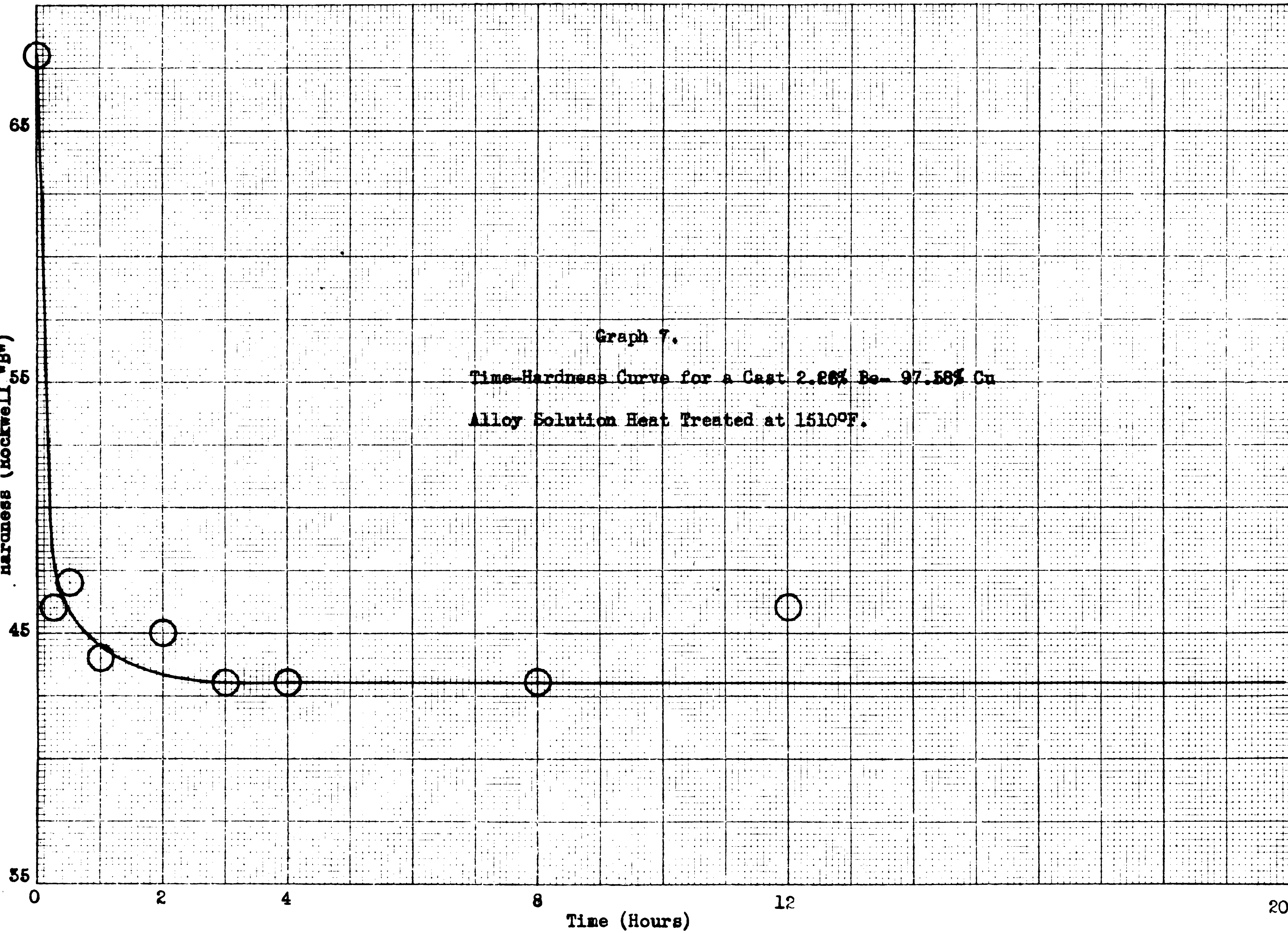
Graph 5.

Time-Hardness Curve for a Cast 2.61% Be- 97.16% Cu Alloy Solution Heat Treated at 1470°F.



Graph 6.

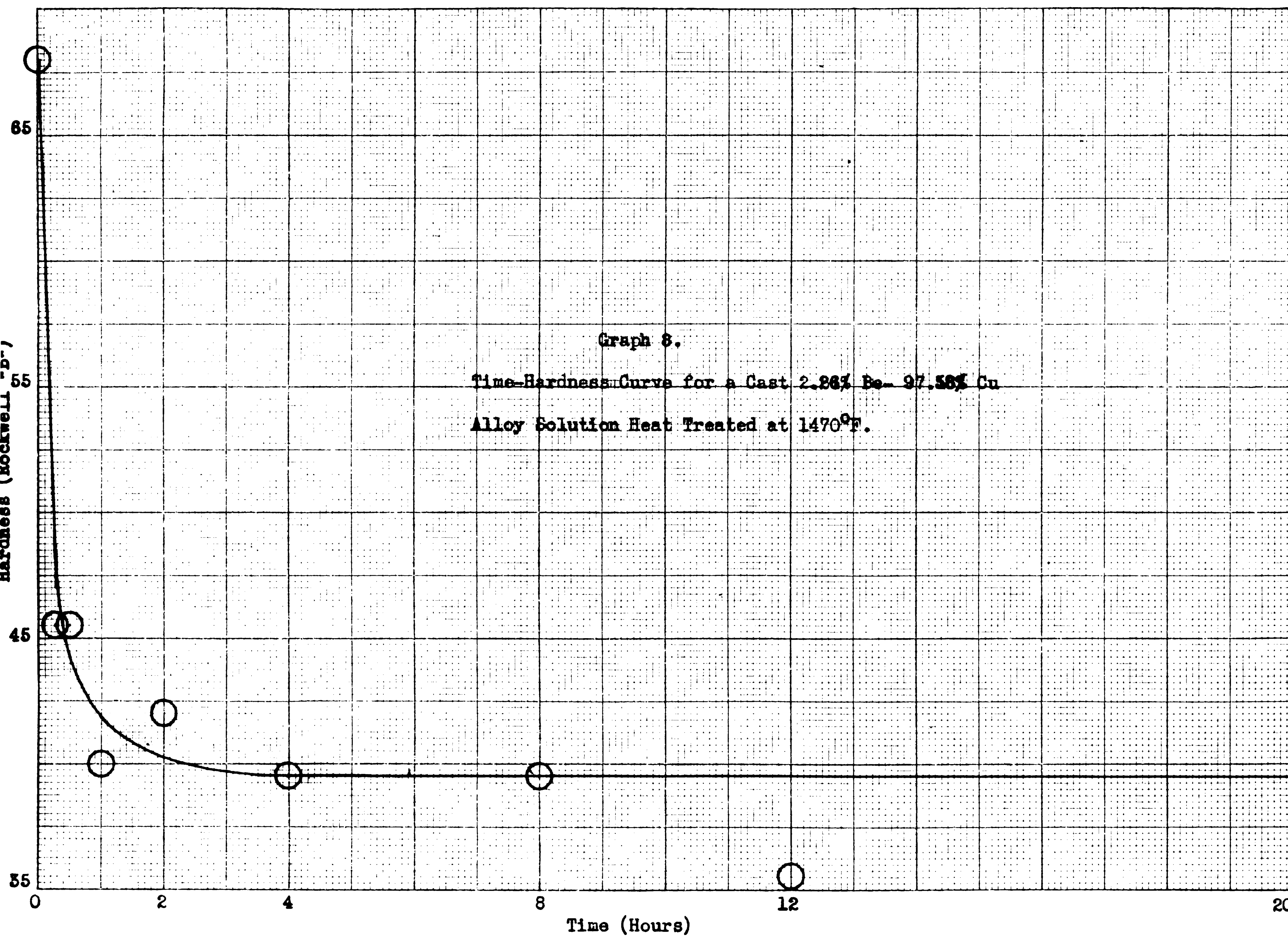
Time-Hardness Curve for a Cast 2.61% Be- 97.16% Cu Alloy Solution Heat Treated at 1440°F.



Graph 7.

Time-Hardness Curve for a Cast 2.26% Be- 97.58% Cu

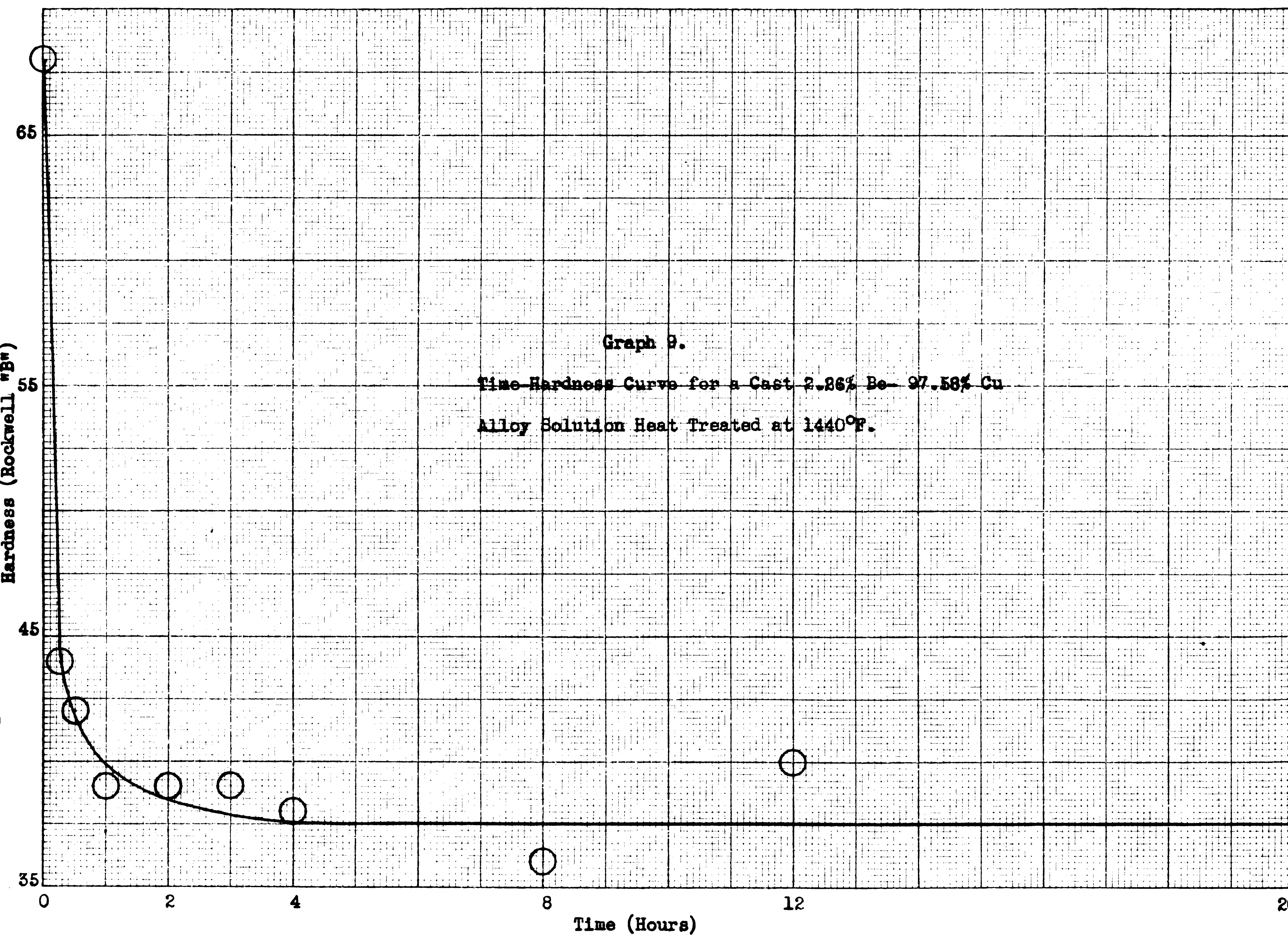
Alloy Solution Heat Treated at 1510°F.



Graph 8.

Time-Hardness Curve for a Cast 2.26% Be- 97.58% Cu

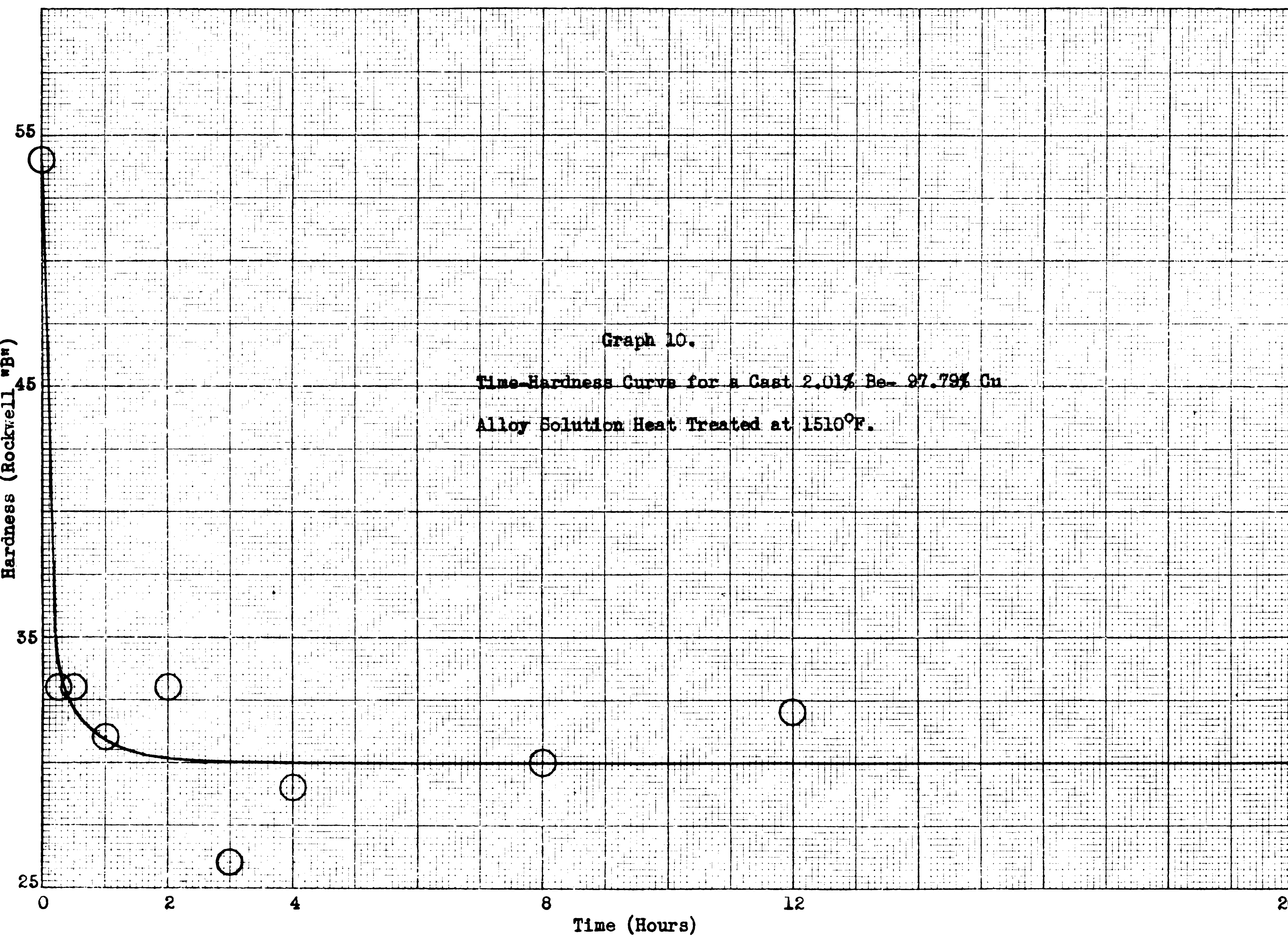
Alloy Solution Heat Treated at 1470°F.

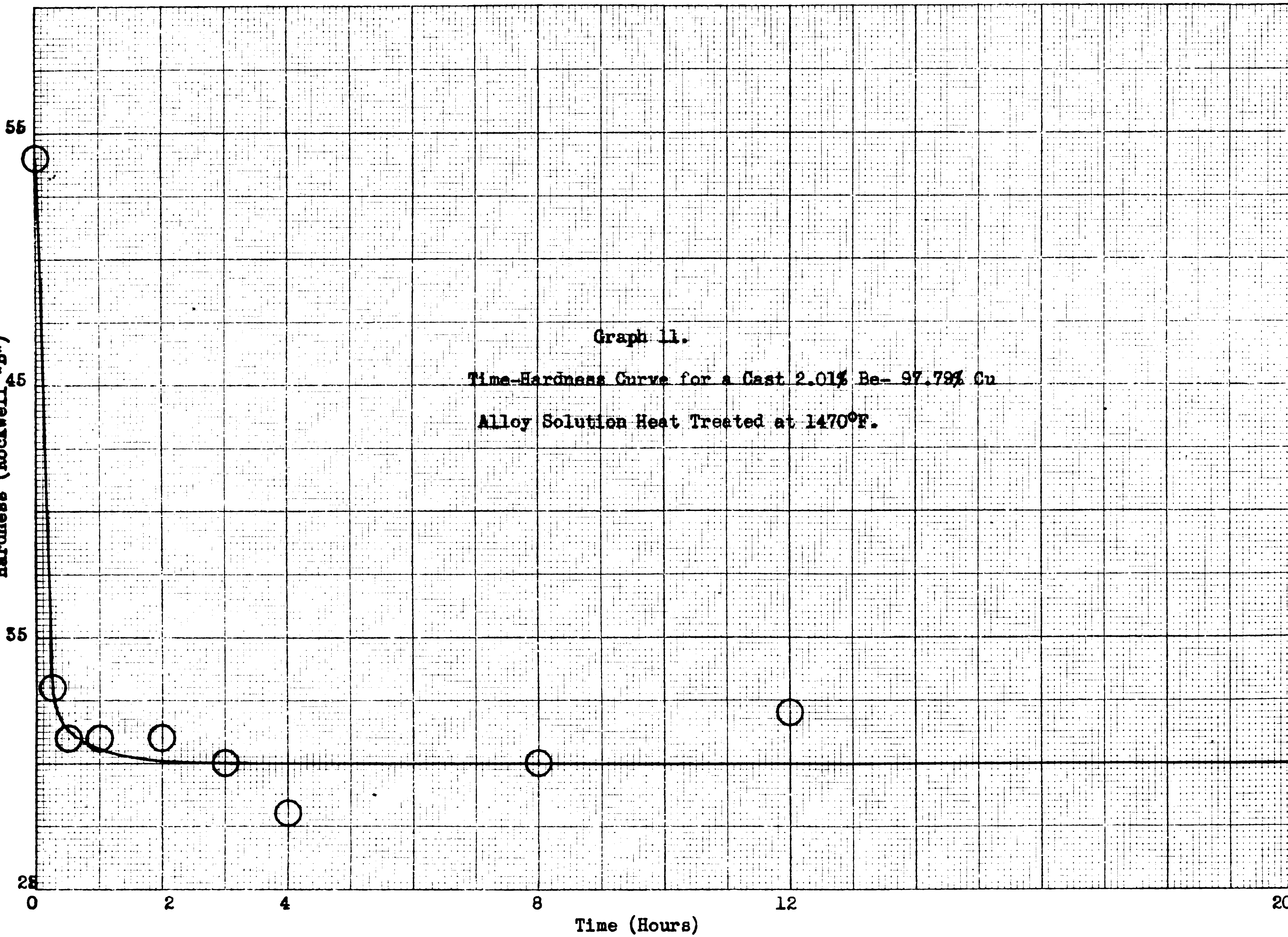


Graph 9.

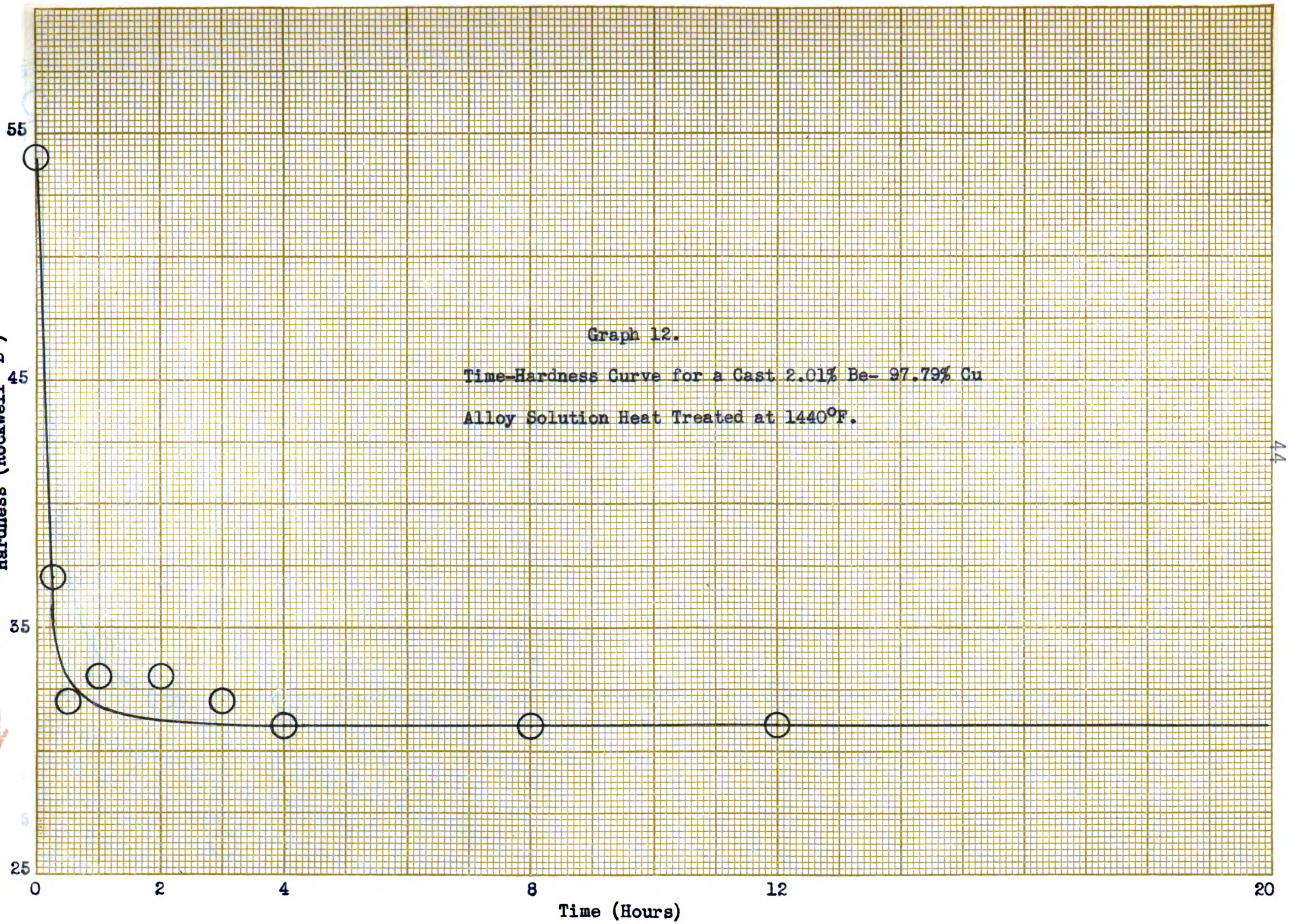
Time-Hardness Curve for a Cast 2.26% Be- 97.58% Cu

Alloy Solution Heat Treated at 1440°F.


Graph 10.
Time-Hardness Curve for a Cast 2.01% Be- 97.79% Cu
Alloy Solution Heat Treated at 1510°F.
Hardness (Rockwell "B")
55
45
35
25
0
2
4
8
12
20
Time (Hours)

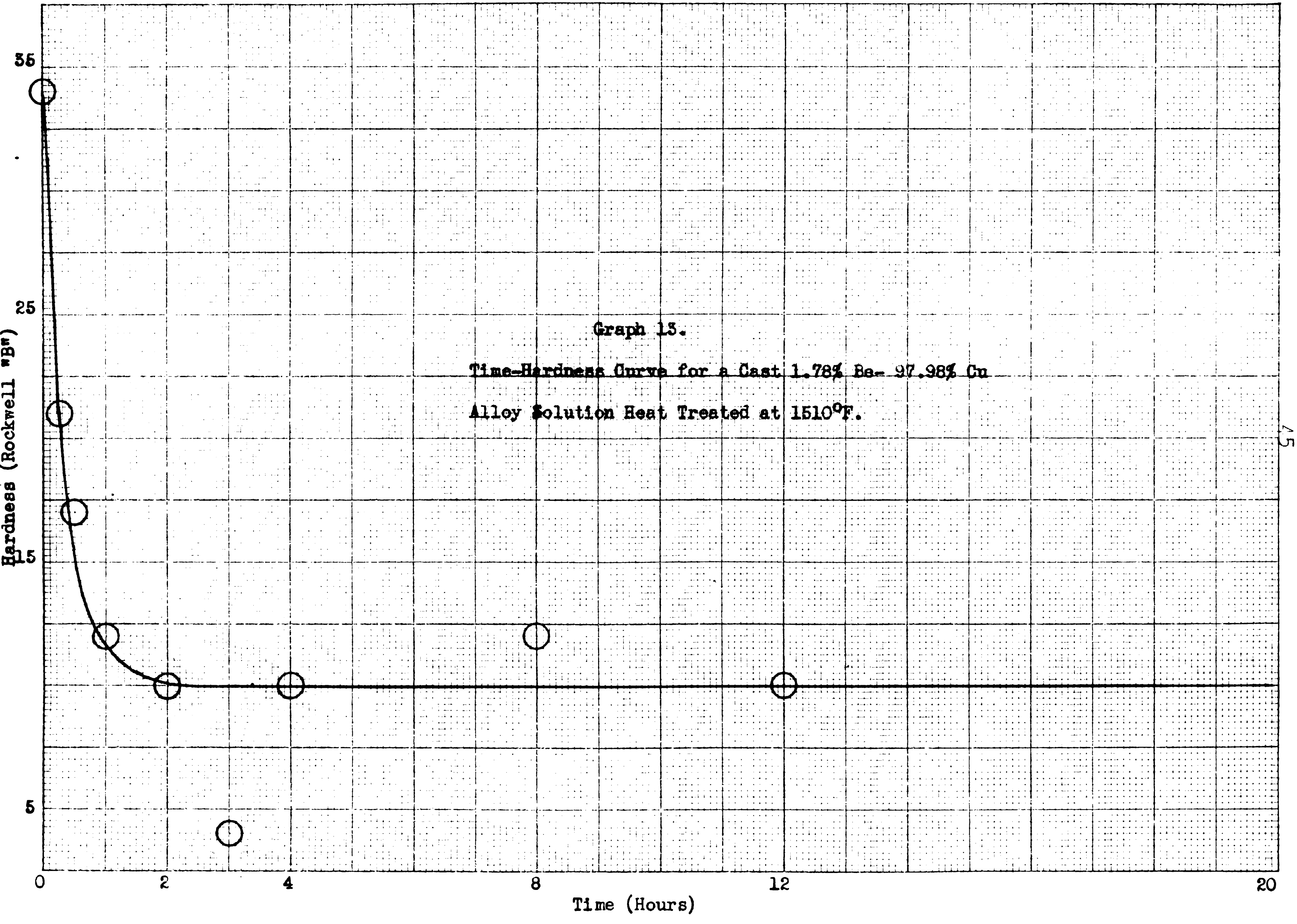


Graph 11.
Time-Hardness Curve for a Cast 2.01% Be- 97.79% Cu
Alloy Solution Heat Treated at 1470°F.
55
45
35
25
0
2
4
8
12
20
Time (Hours)



Graph 12.

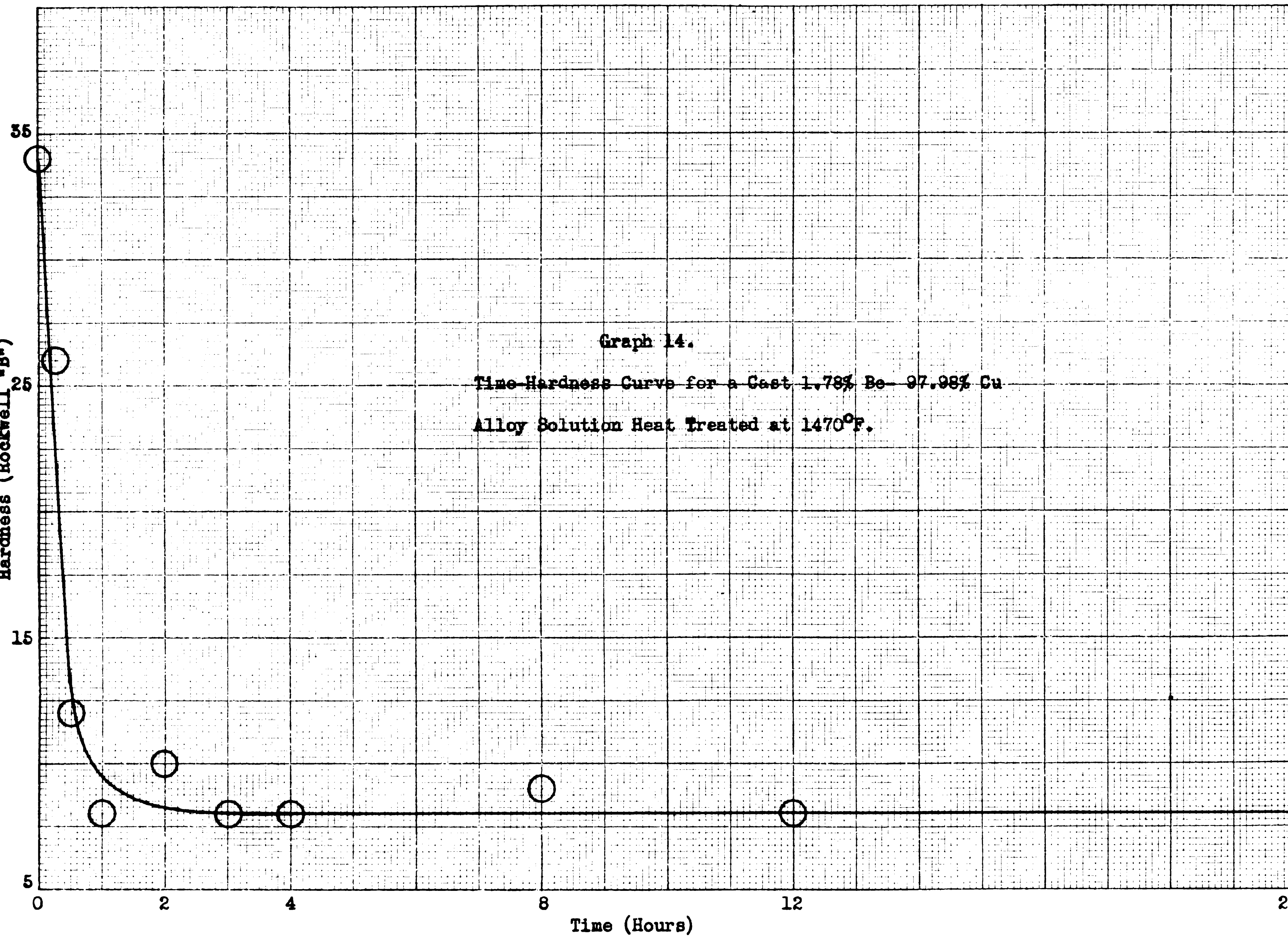
Time-Hardness Curve for a Cast 2.01% Be- 97.79% Cu Alloy Solution Heat Treated at 1440°F.

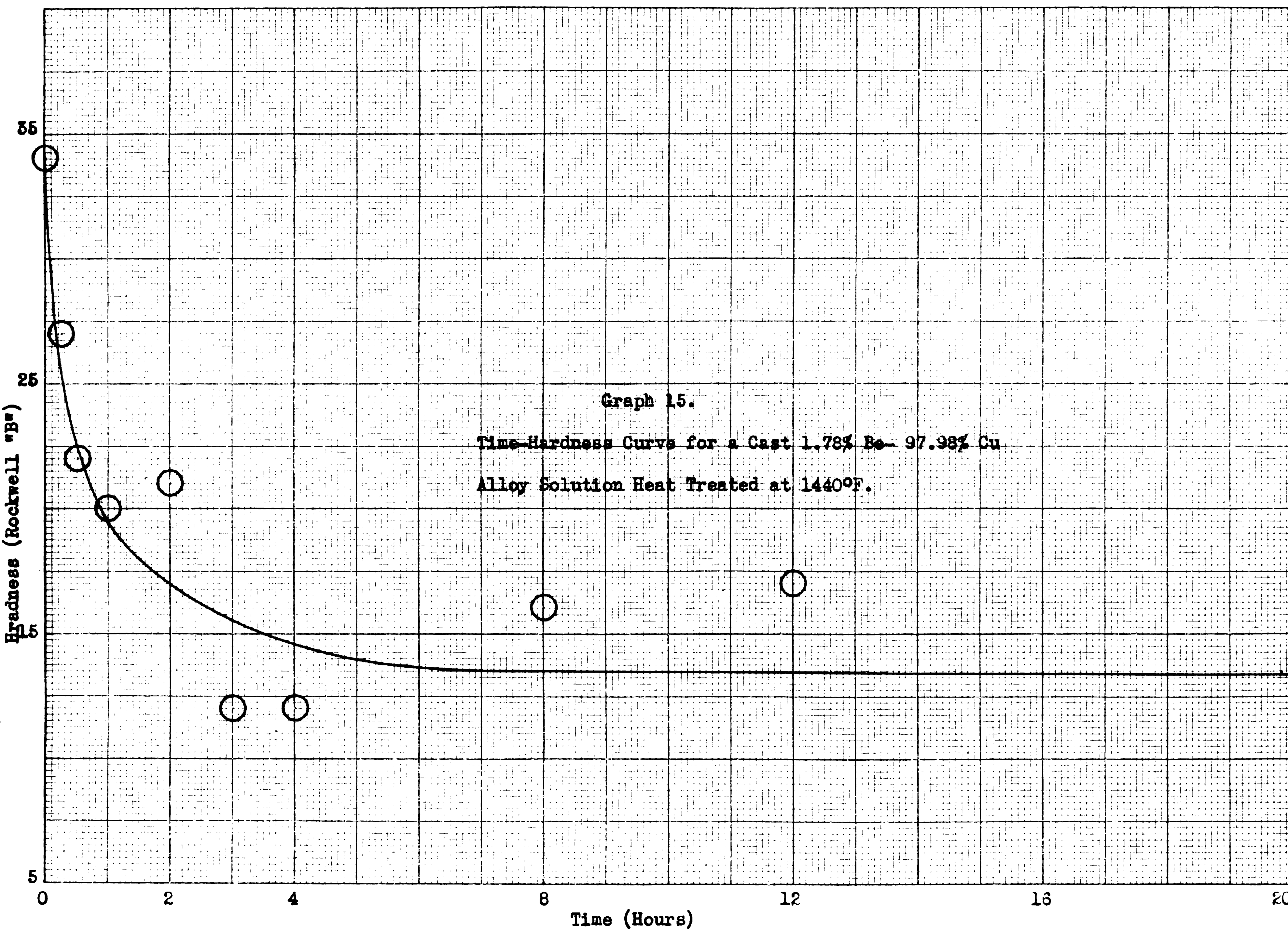


Graph 13.

Time-Hardness Curve for a Cast 1.78% Be- 97.98% Cu

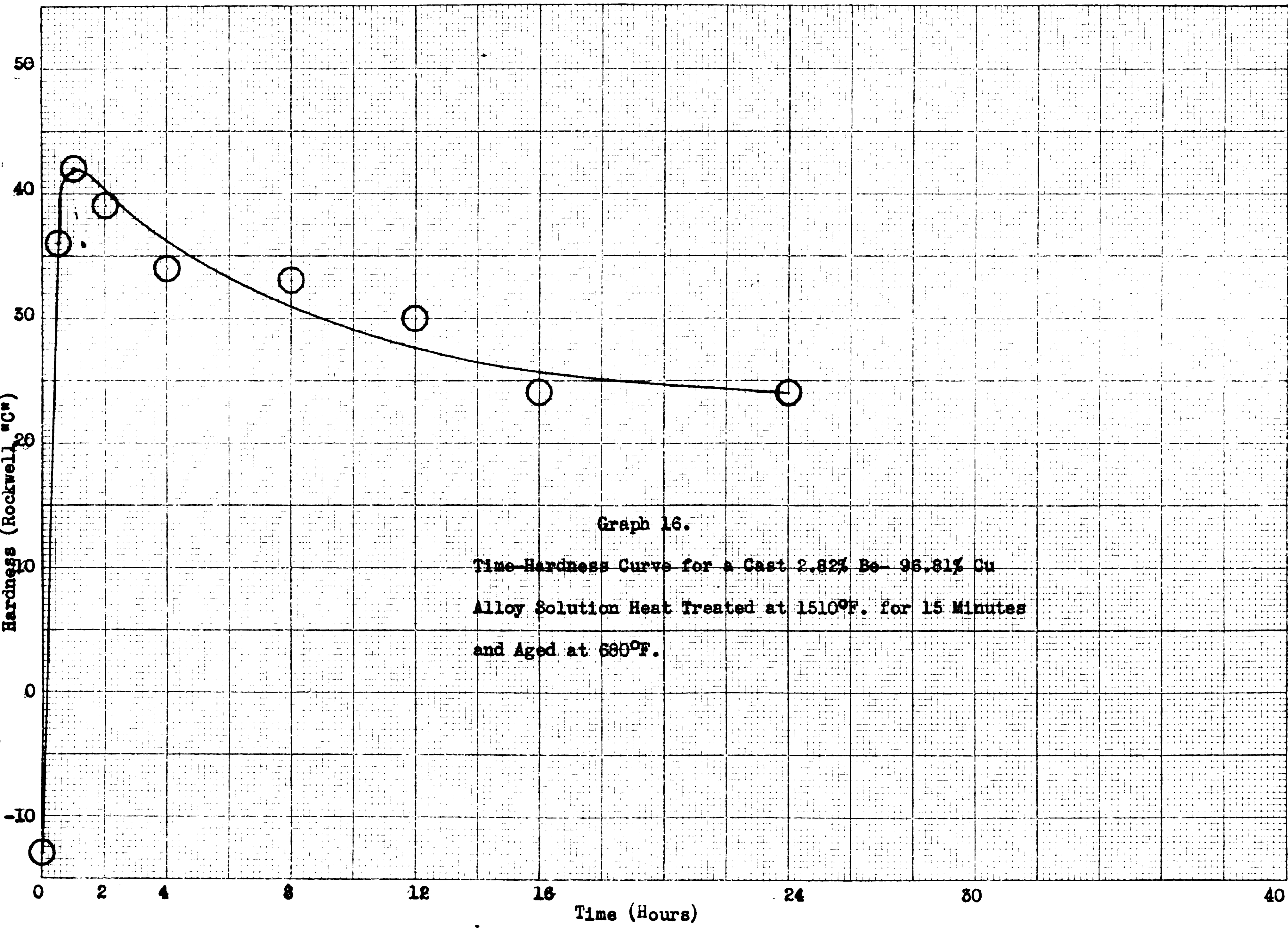
Alloy Solution Heat Treated at 1510°F.


Graph 14.
Time-Hardness Curve for a Cast 1.78% Be- 97.98% Cu
Alloy Solution Heat Treated at 1470°F.
Hardness (Rockwell "B")
35
25
15
5
0
2
4
8
12
24
Time (Hours)



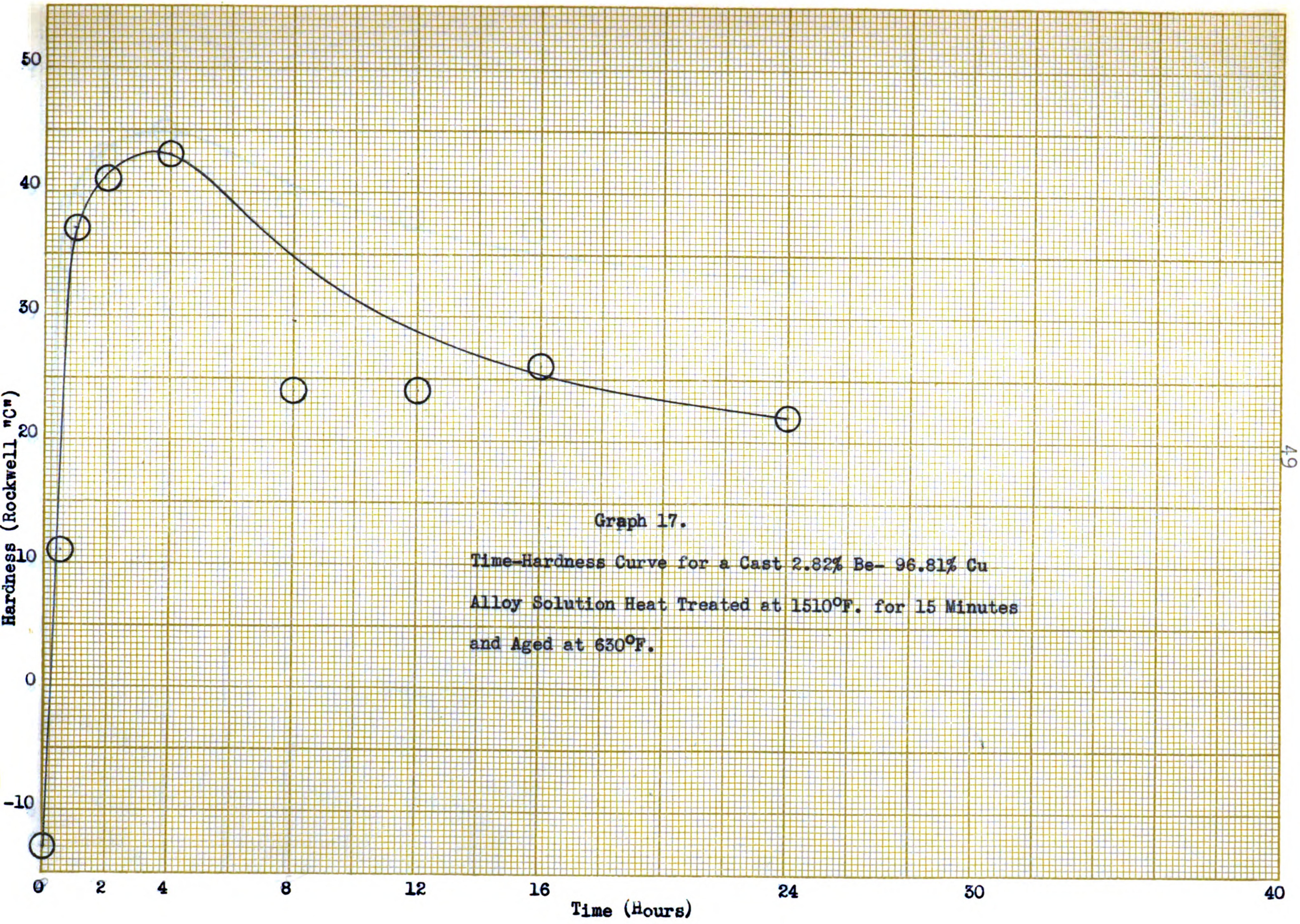
Graph 15.

Time-Hardness Curve for a Cast 1.78% Be- 97.98% Cu Alloy Solution Heat Treated at 1440°F.



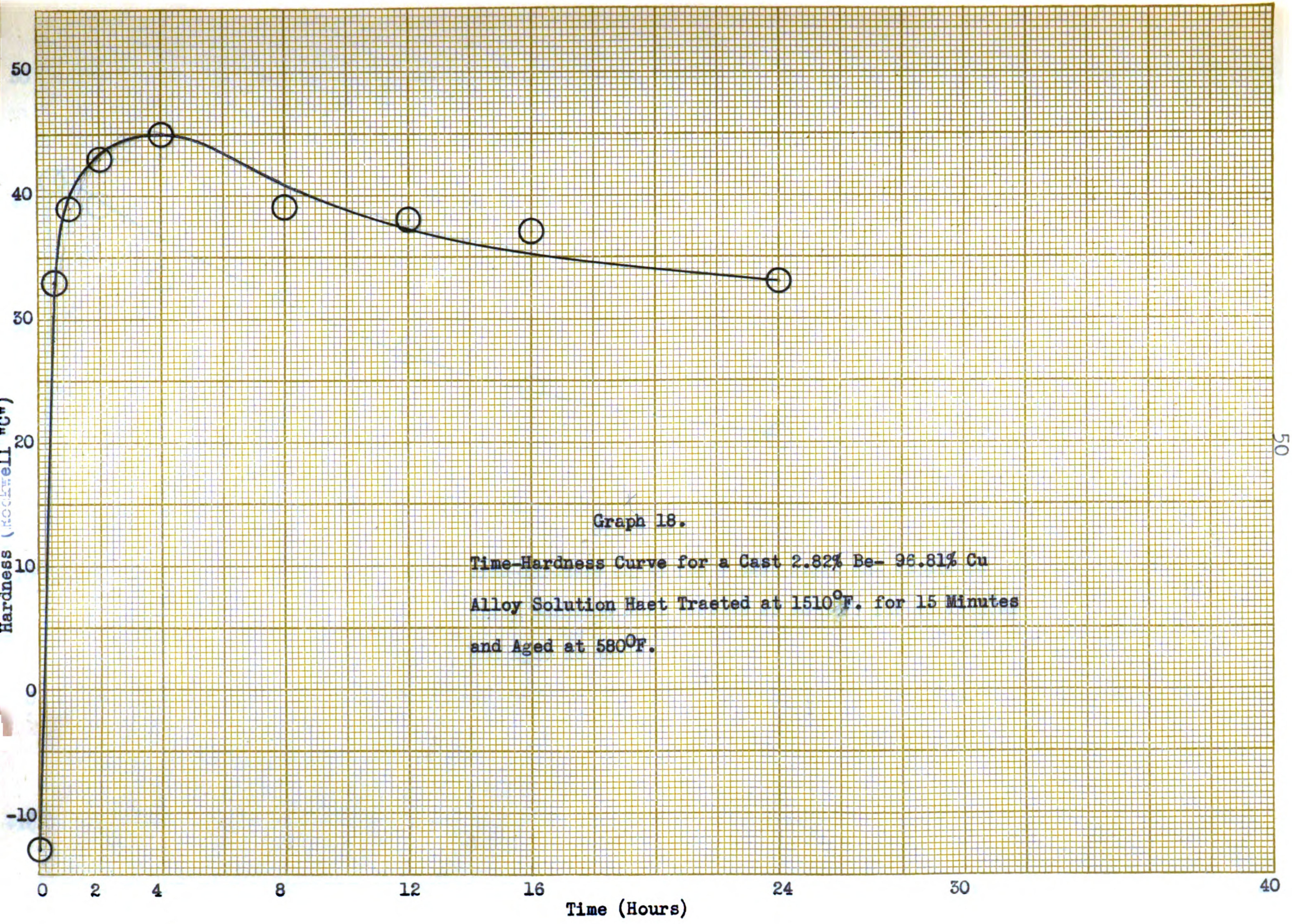
Graph 16.

Time-Hardness Curve for a Cast 2.82% Be- 96.81% Cu Alloy Solution Heat Treated at 1510°F. for 15 Minutes and Aged at 680°F.



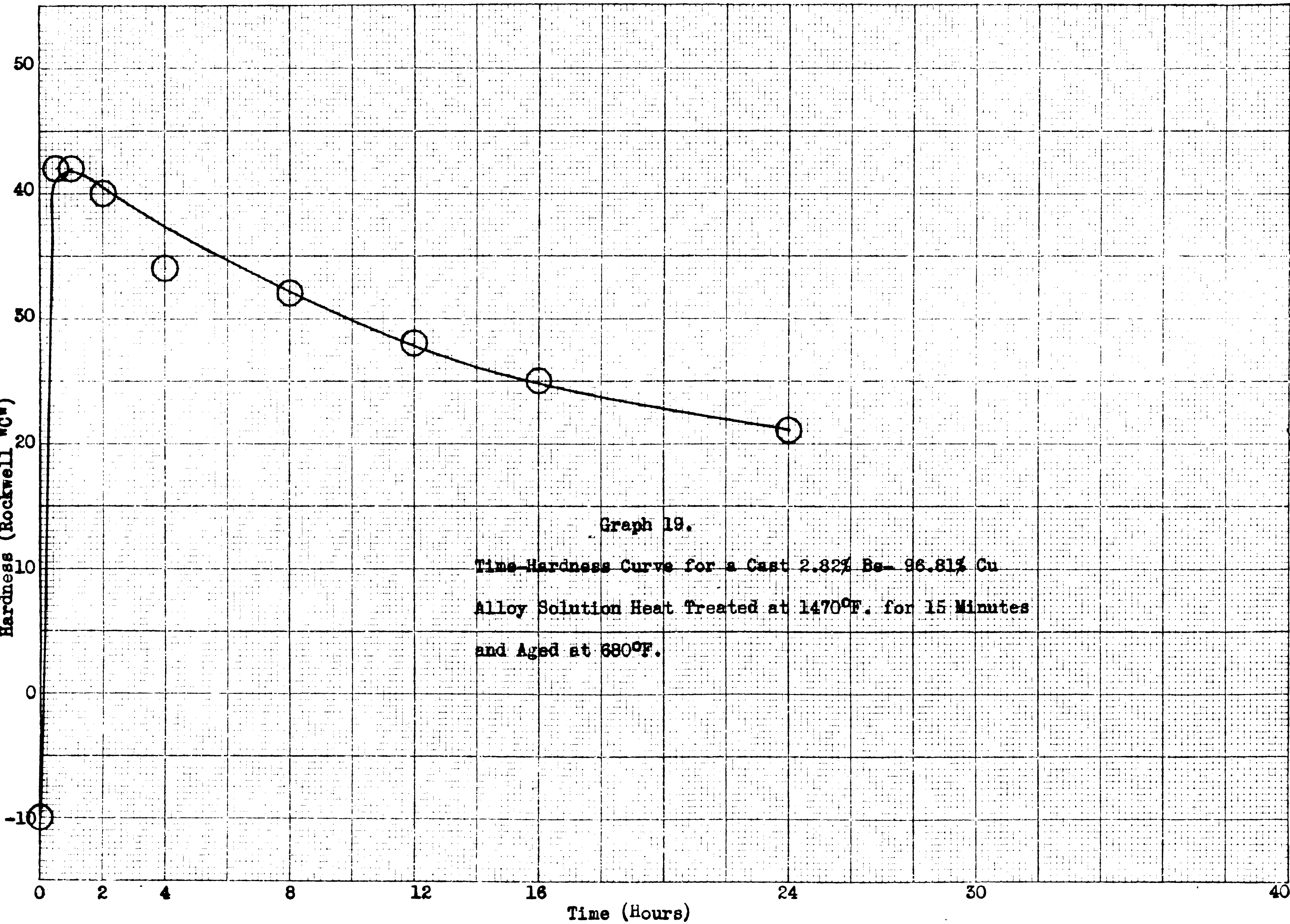
Graph 17.

Time-Hardness Curve for a Cast 2.82% Be- 96.81% Cu Alloy Solution Heat Treated at 1510°F. for 15 Minutes and Aged at 630°F.



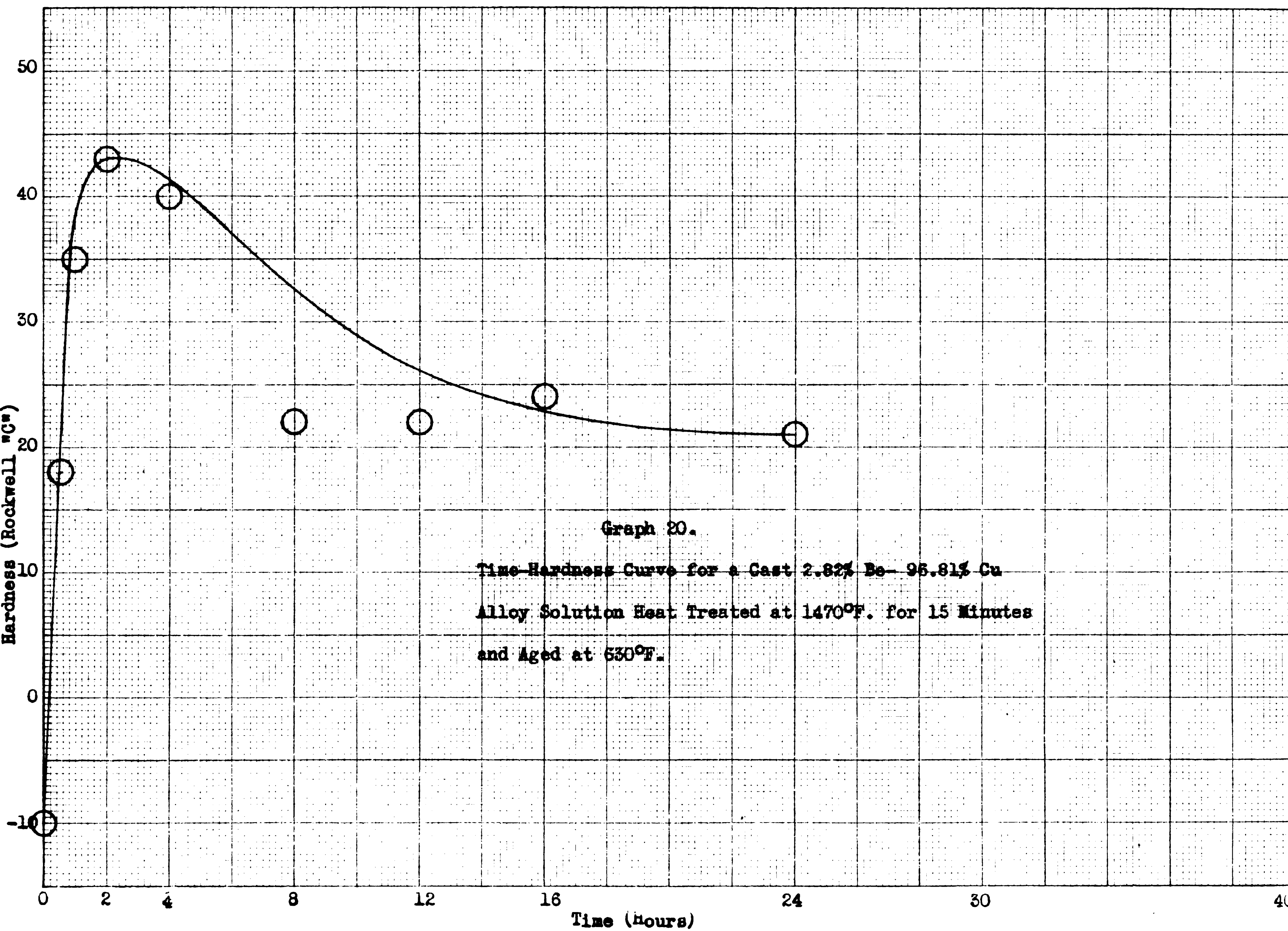
Graph 18.

Time-Hardness Curve for a Cast 2.82% Be- 96.81% Cu Alloy Solution Haet Traeted at 1510°F. for 15 Minutes and Aged at 580°F.



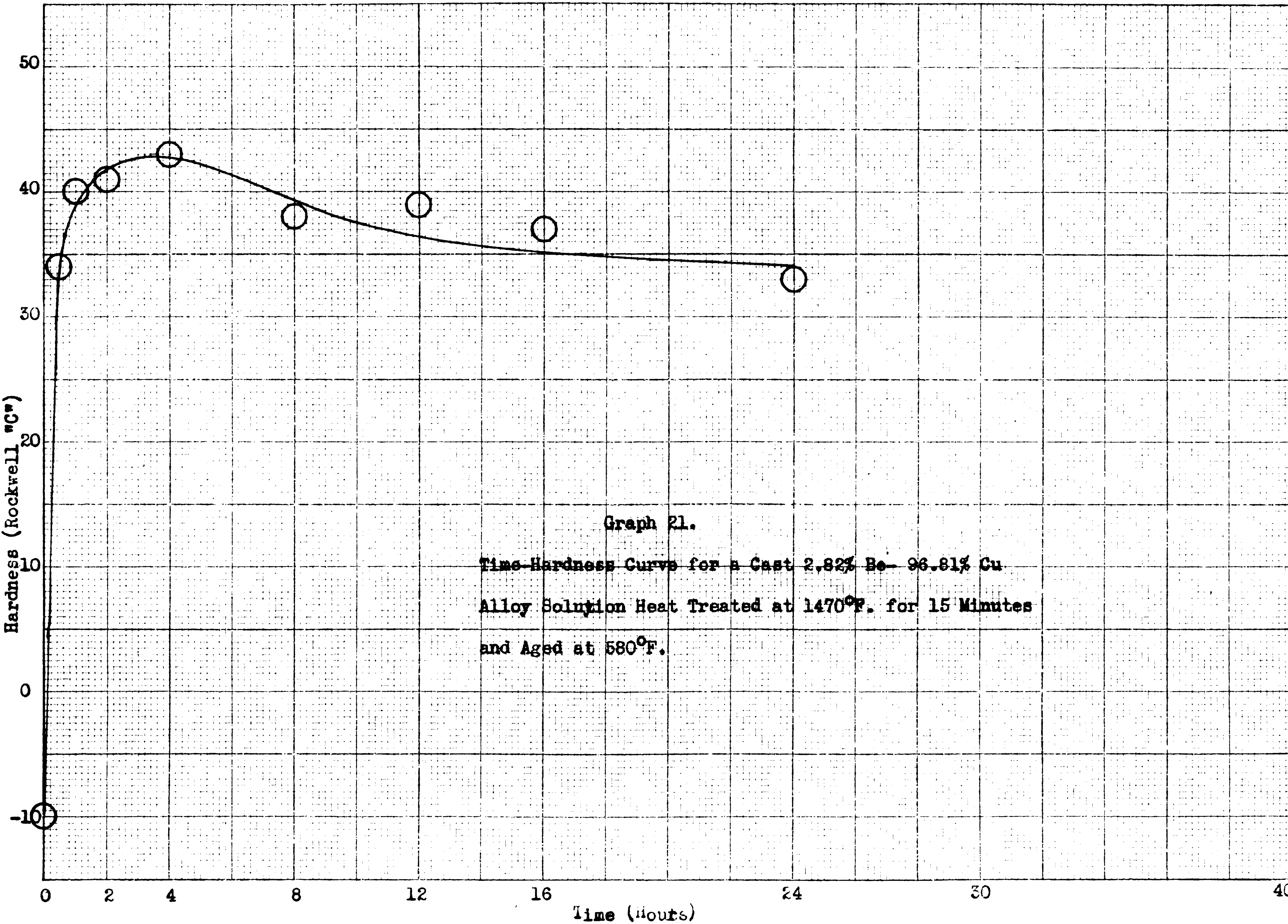
Graph 19.

Time-Hardness Curve for a Cast 2.82% Be- 96.81% Cu Alloy Solution Heat Treated at 1470°F. for 15 Minutes and Aged at 680°F.



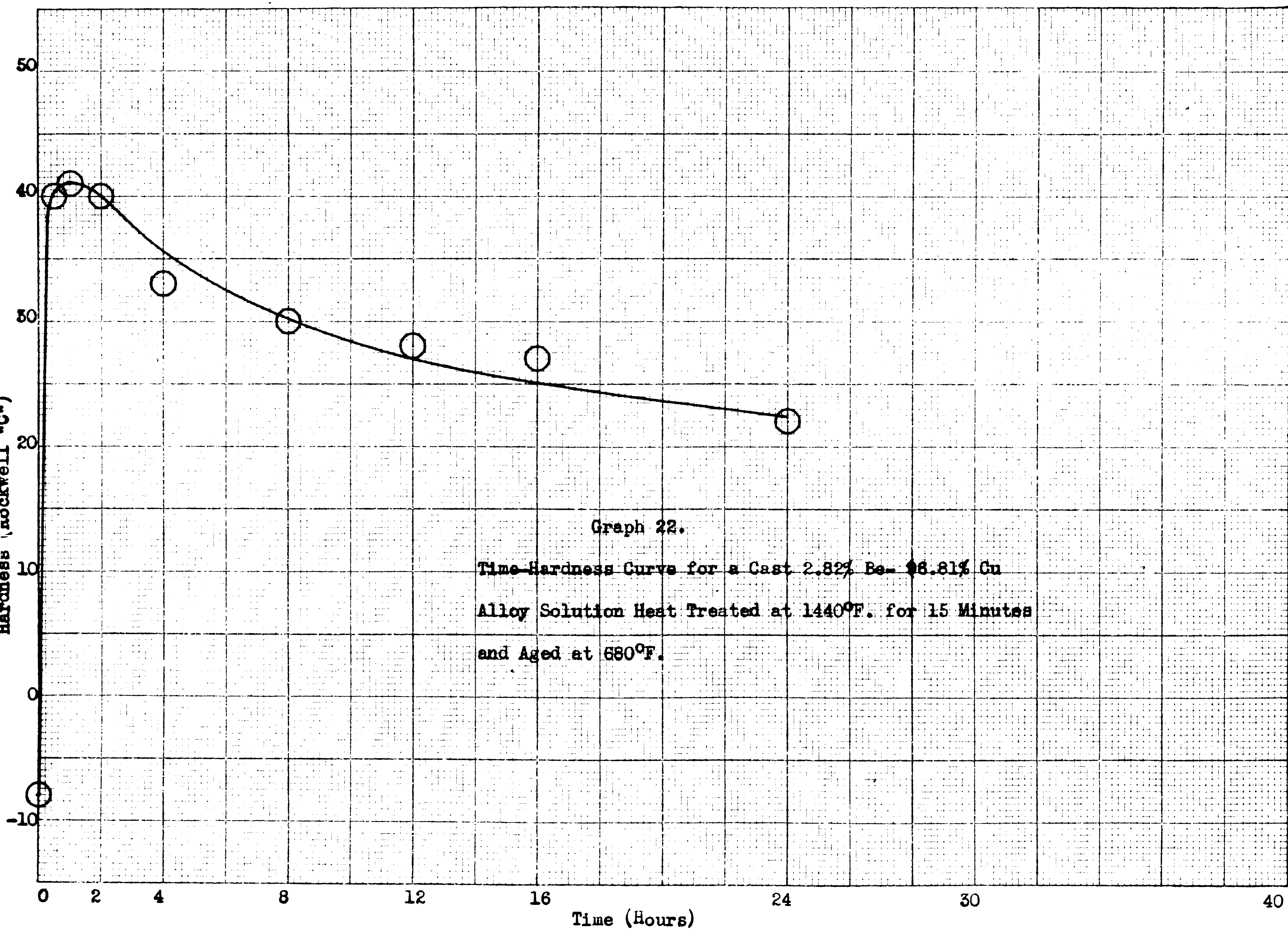
Graph 20.

Time-Hardness Curve for a Cast 2.82% Be- 96.81% Cu Alloy Solution Heat Treated at 1470°F. for 15 Minutes and Aged at 630°F.



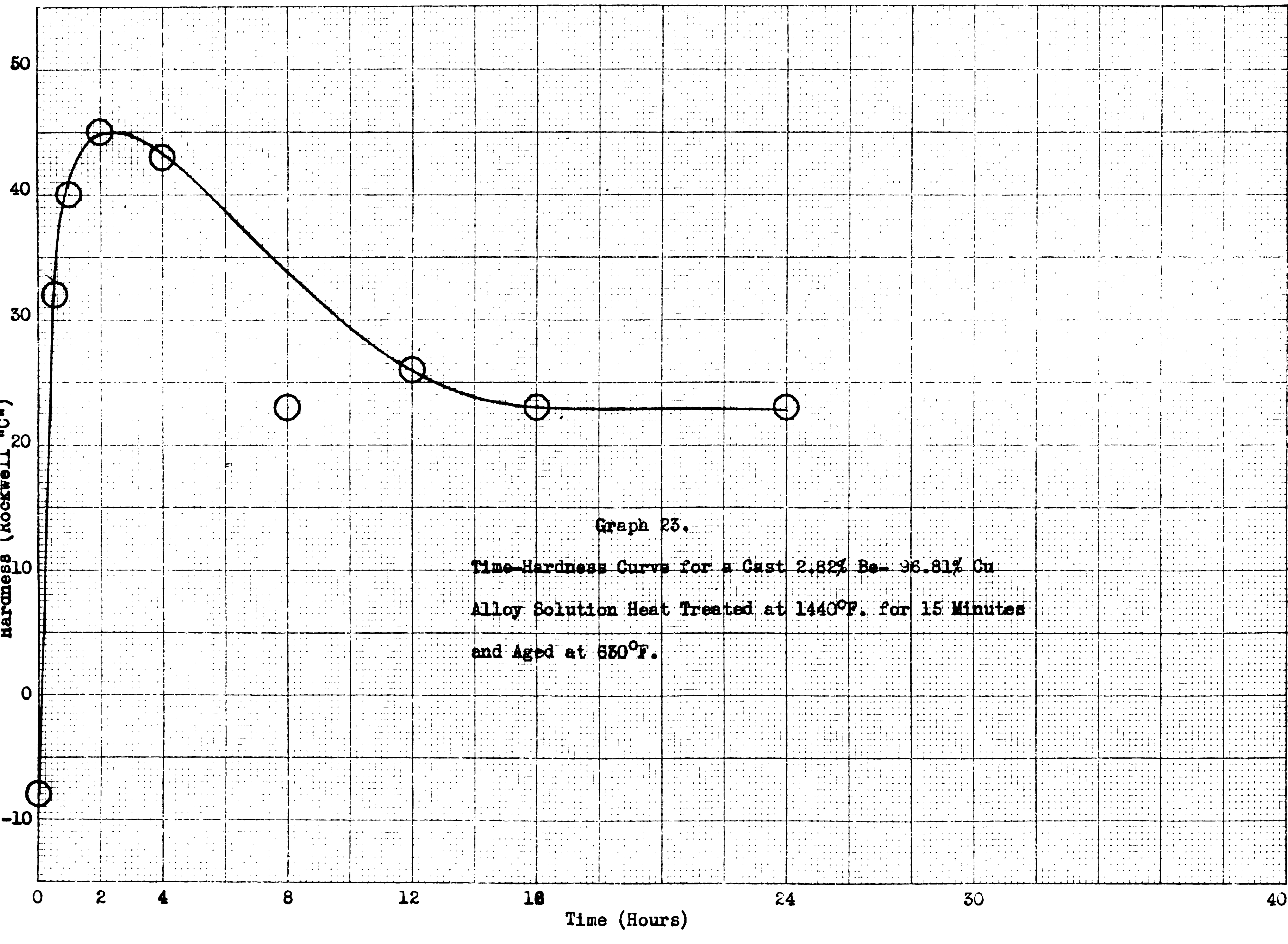
Graph 21.

Time-Hardness Curve for a Cast 2.82% Be- 96.81% Cu Alloy Solution Heat Treated at 1470°F. for 15 Minutes and Aged at 580°F.



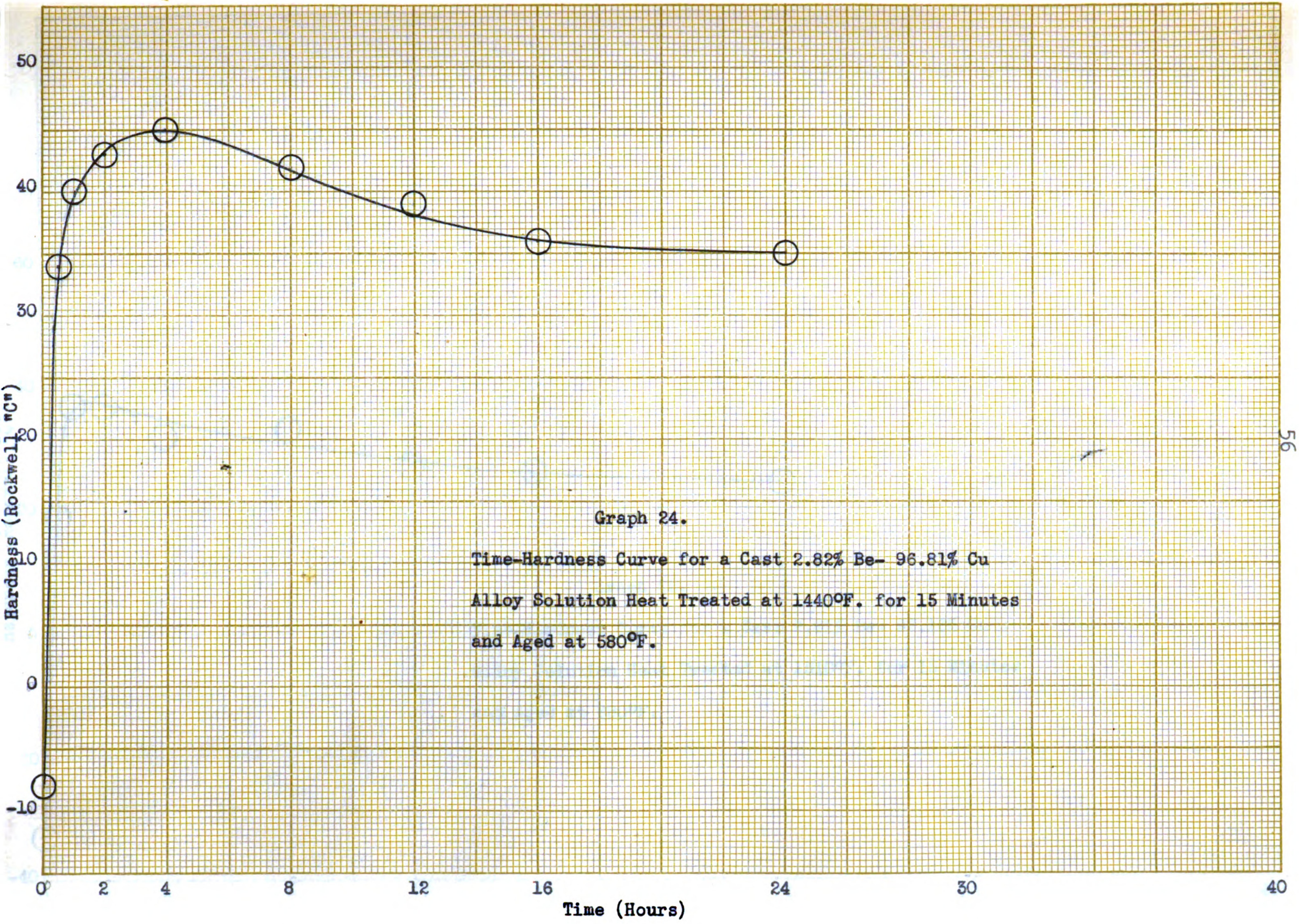
Graph 22.

Time-Hardness Curve for a Cast 2.82% Be- 96.81% Cu Alloy Solution Heat Treated at 1440°F. for 15 Minutes and Aged at 680°F.



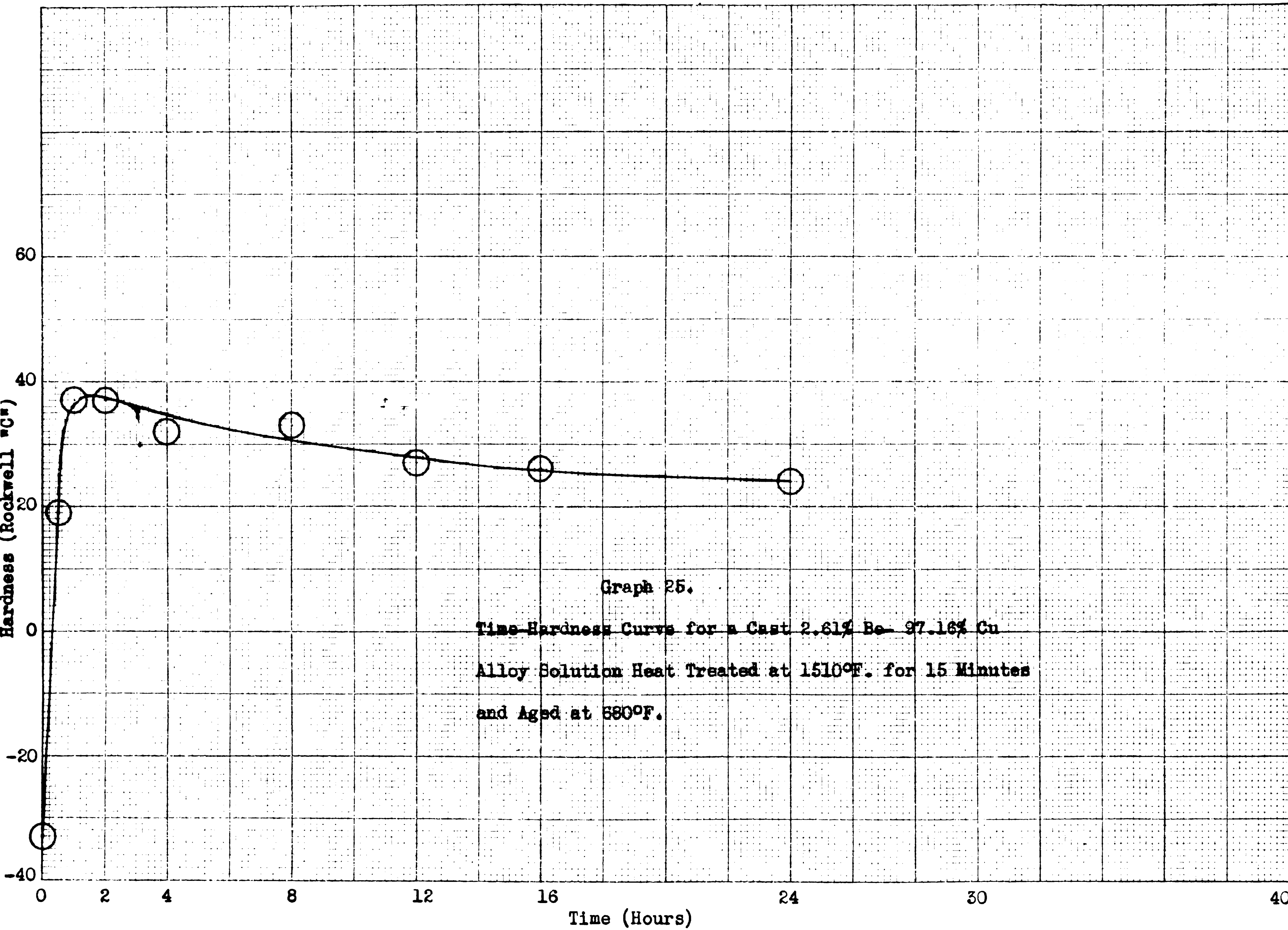
Graph 23.

Time-Hardness Curve for a Cast 2.82% Be- 96.81% Cu Alloy Solution Heat Treated at 1440°F. for 15 Minutes and Aged at 630°F.



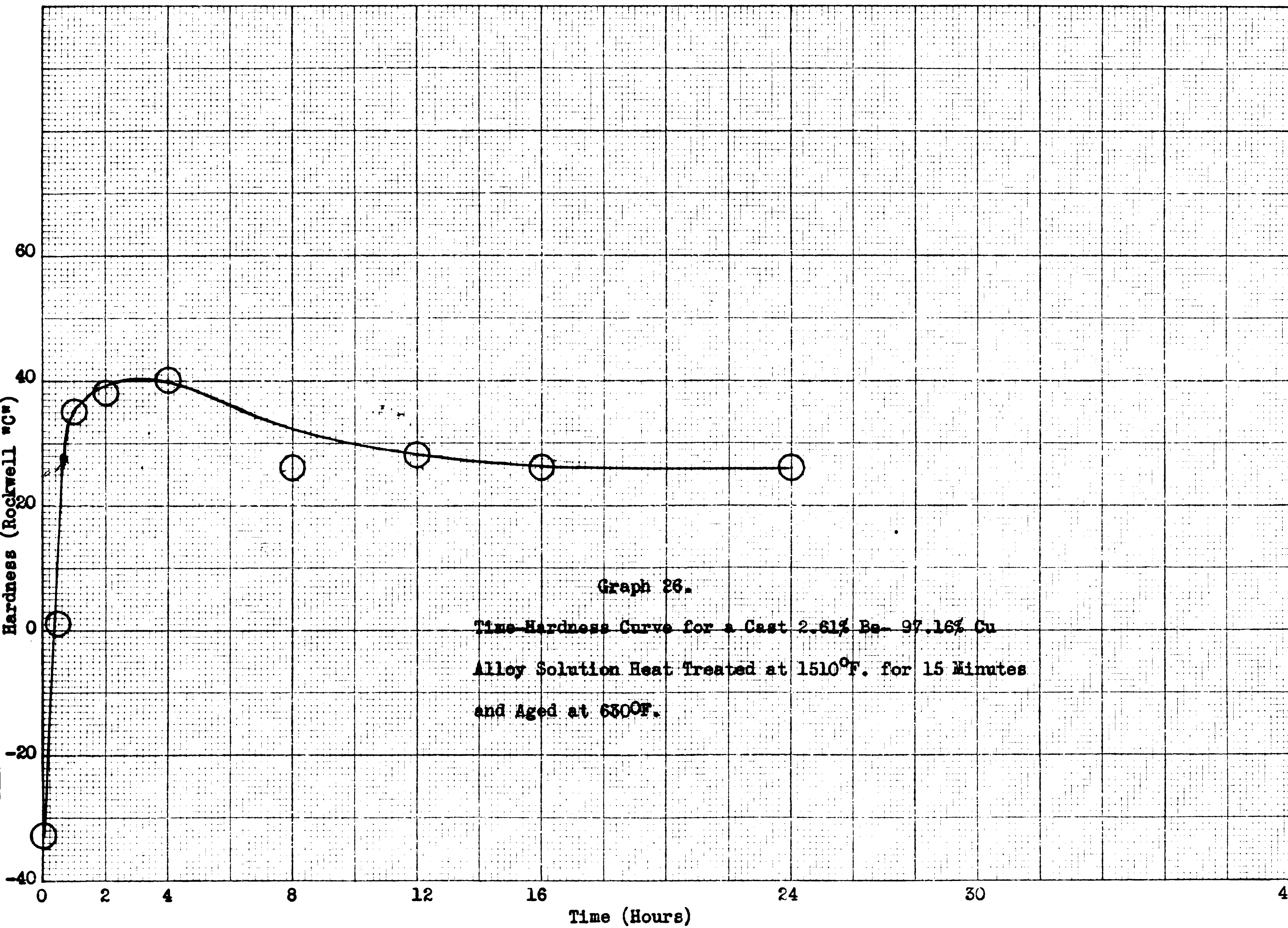
Graph 24.

Time-Hardness Curve for a Cast 2.82% Be- 96.81% Cu Alloy Solution Heat Treated at 1440°F. for 15 Minutes and Aged at 580°F.



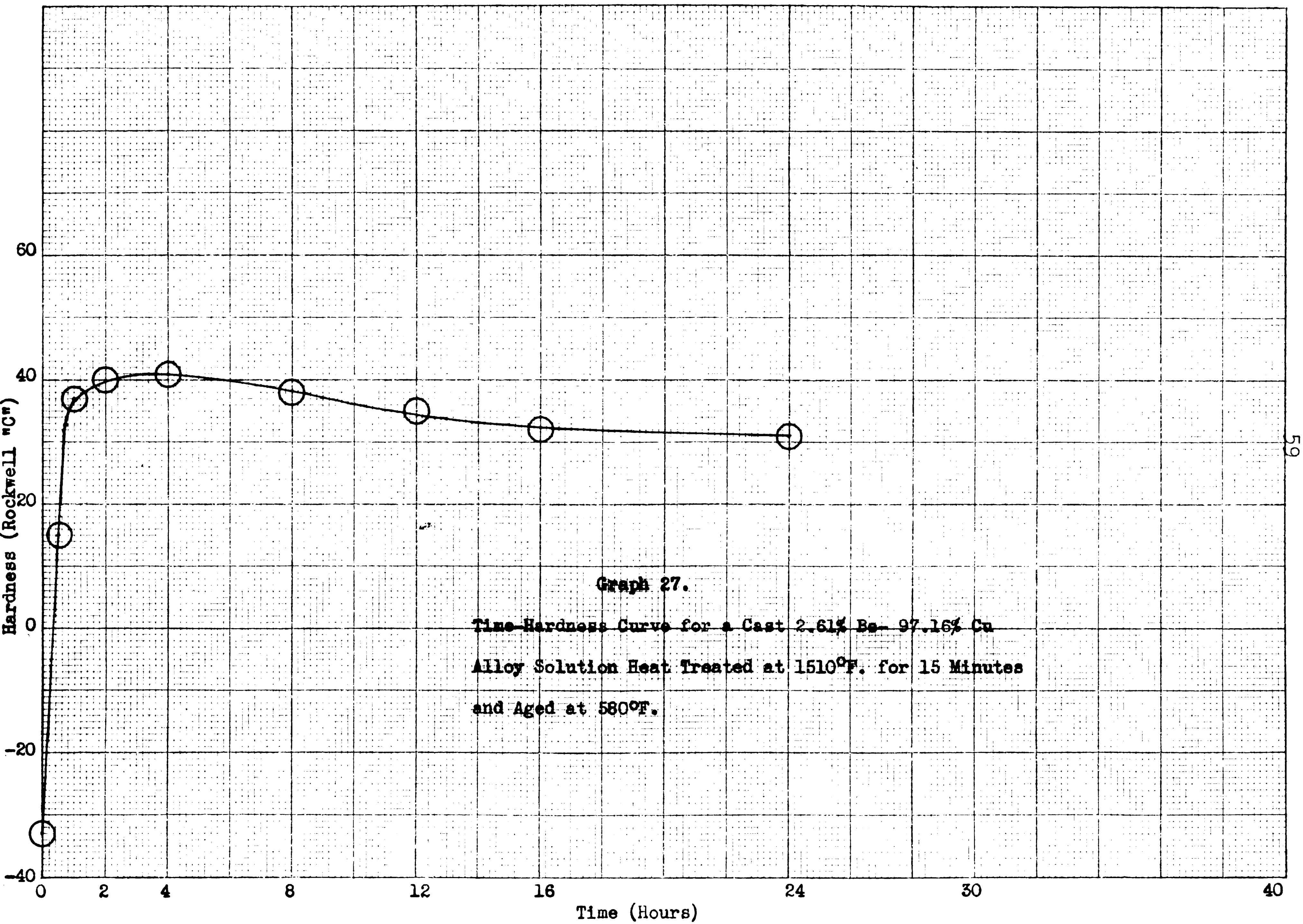
Graph 25.

Time-Hardness Curve for a Cast 2.61% Be- 97.16% Cu Alloy Solution Heat Treated at 1510°F. for 15 Minutes and Aged at 680°F.



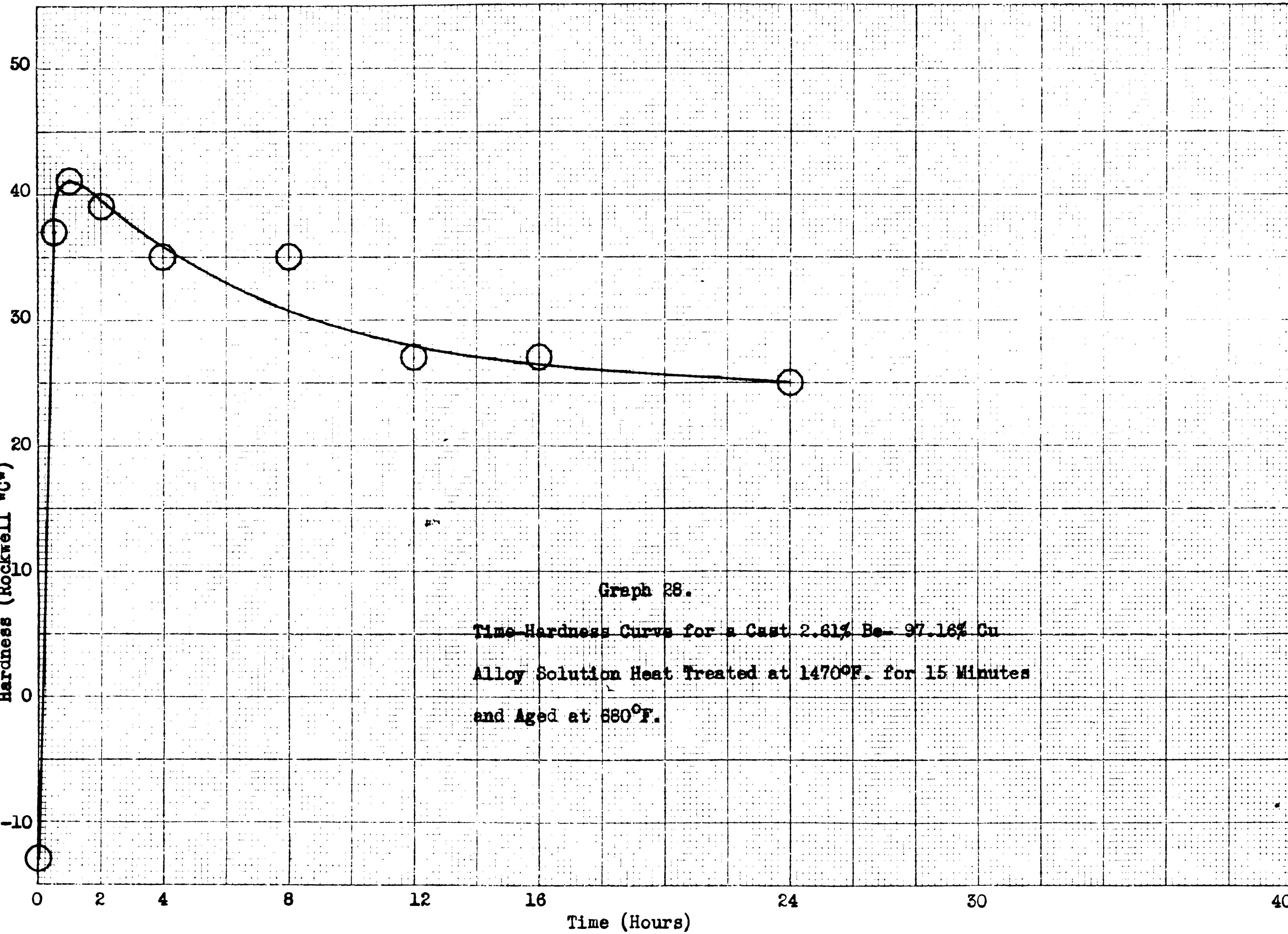
Graph 26.

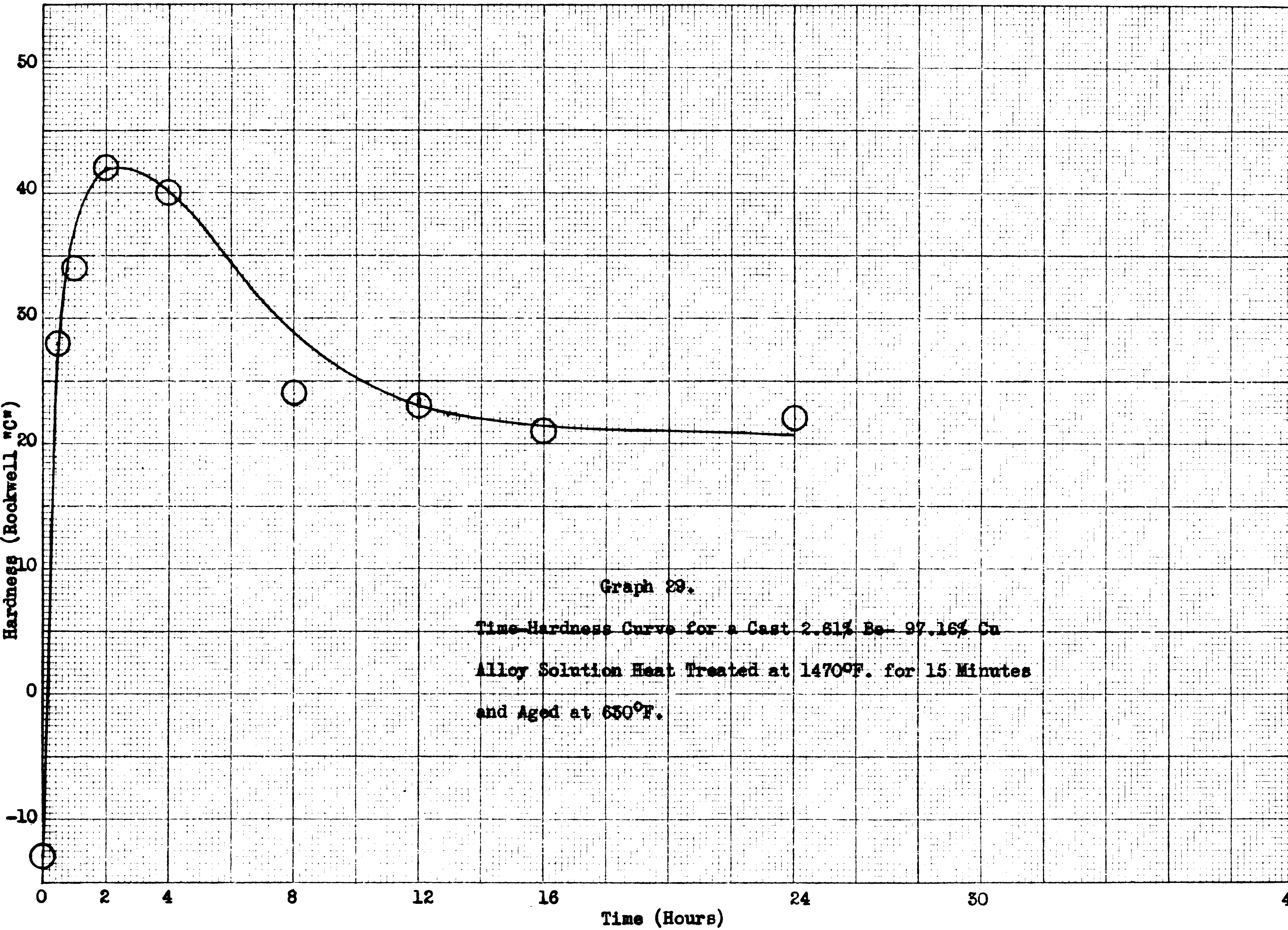
~~Time-Hardness Curve~~ for a Cast 2.61% Be- 97.16% Cu Alloy Solution Heat Treated at 1510°F. for 15 Minutes and Aged at 630°F.



Graph 27.

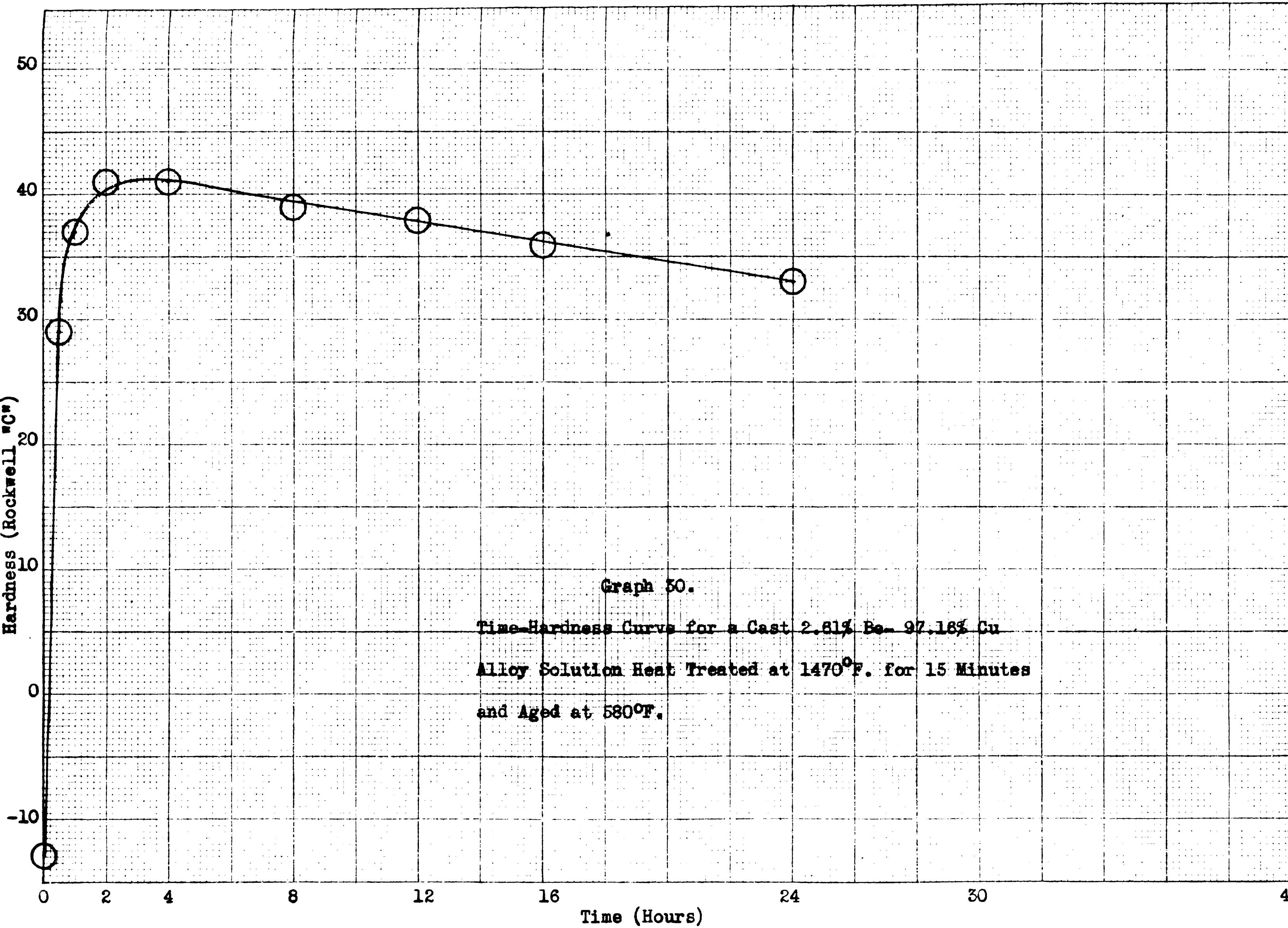
Time-Hardness Curve for a Cast 2.61% Be- 97.16% Cu Alloy Solution Heat Treated at 1510°F. for 15 Minutes and Aged at 580°F.


Hardness (Rockwell "C")
50
40
30
20
10
0
-10
0
2
4
8
12
16
24
30
40
Time (Hours)
Graph 28.
Time-Hardness Curve for a Cast 2.61% Be- 97.16% Cu
Alloy Solution Heat Treated at 1470°F. for 15 Minutes
and Aged at 680°F.



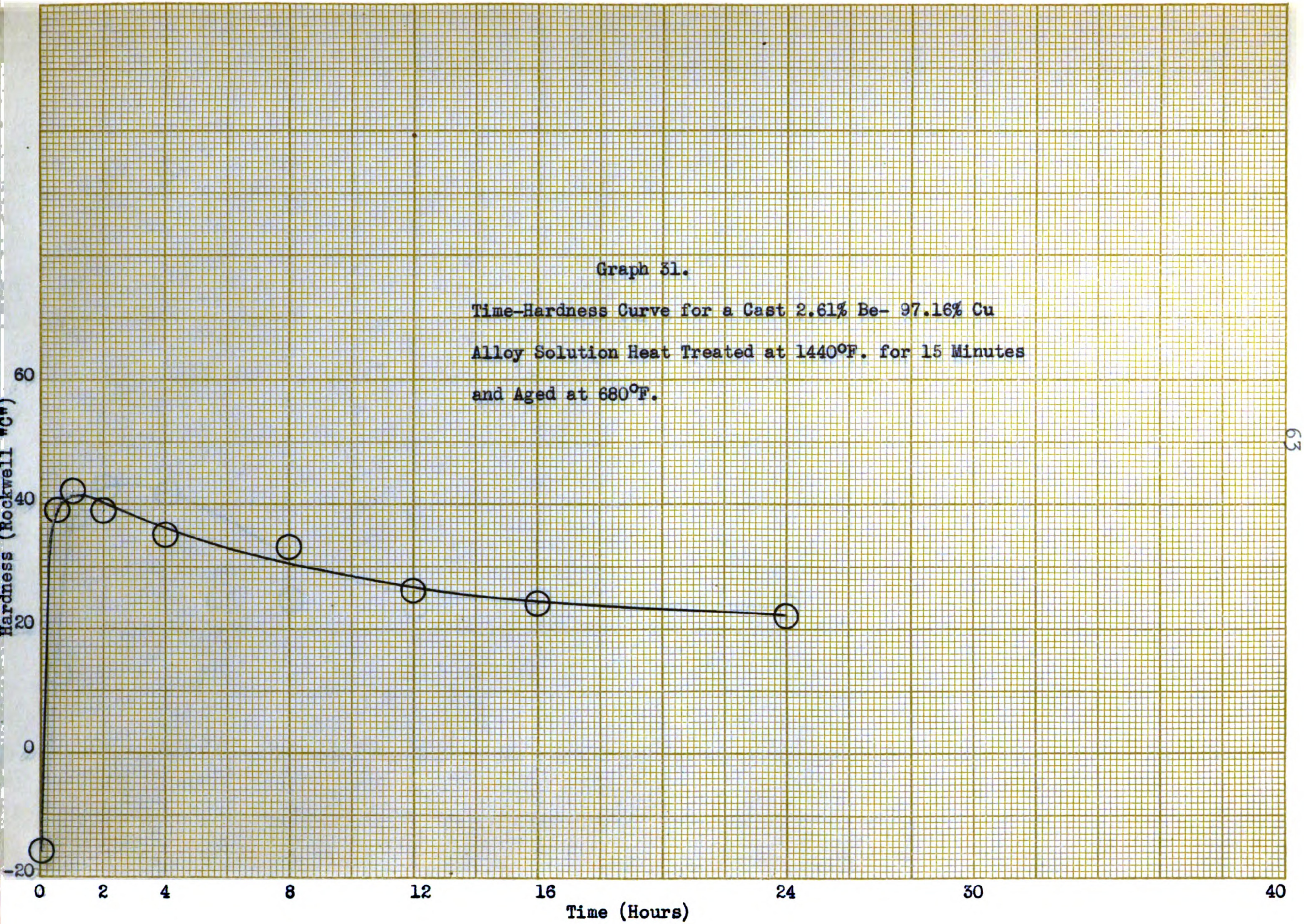
Graph 29.

Time-Hardness Curve for a Cast 2.61% Be- 97.16% Cu Alloy Solution Heat Treated at 1470°F. for 15 Minutes and Aged at 650°F.



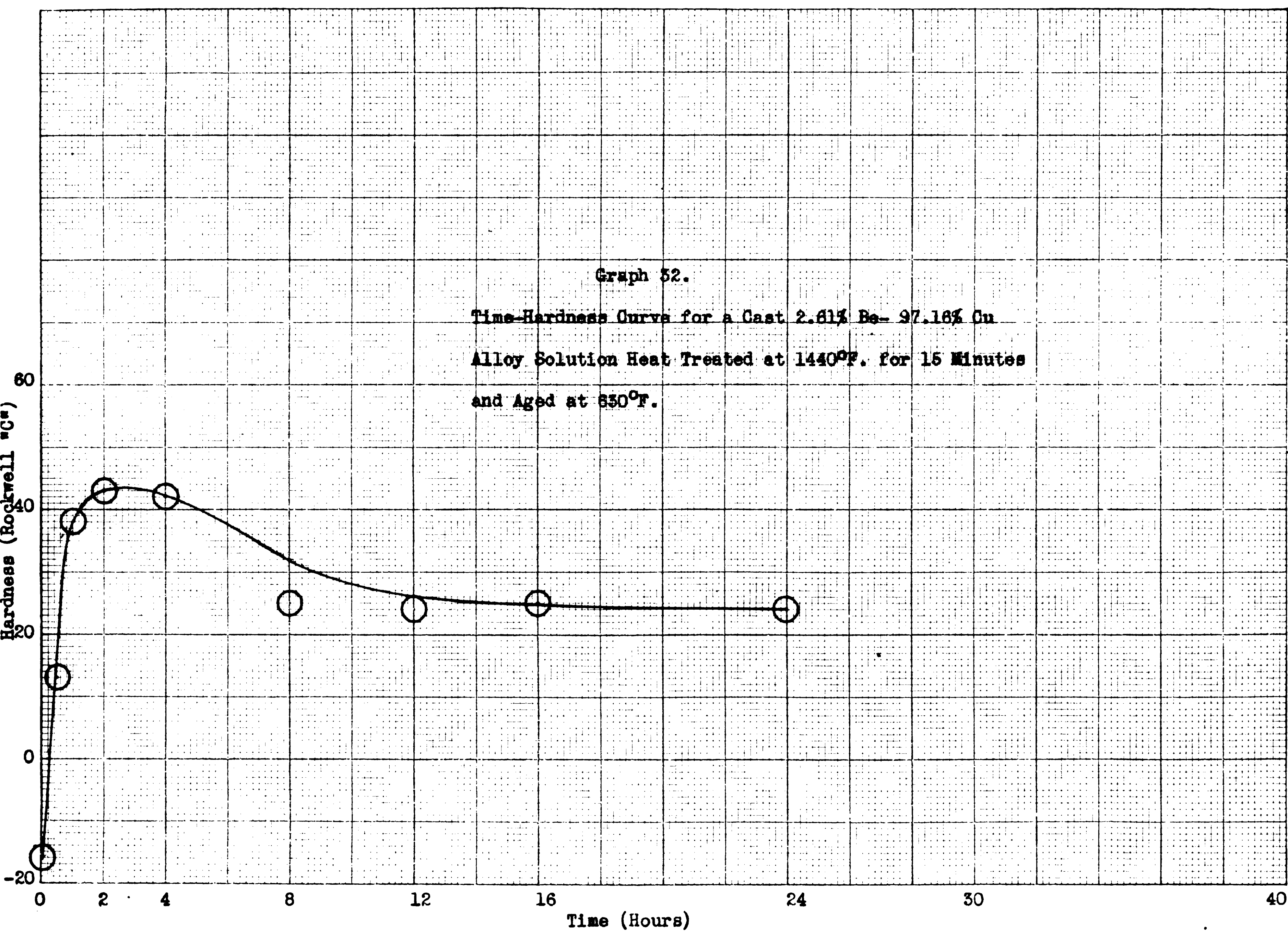
Graph 50.

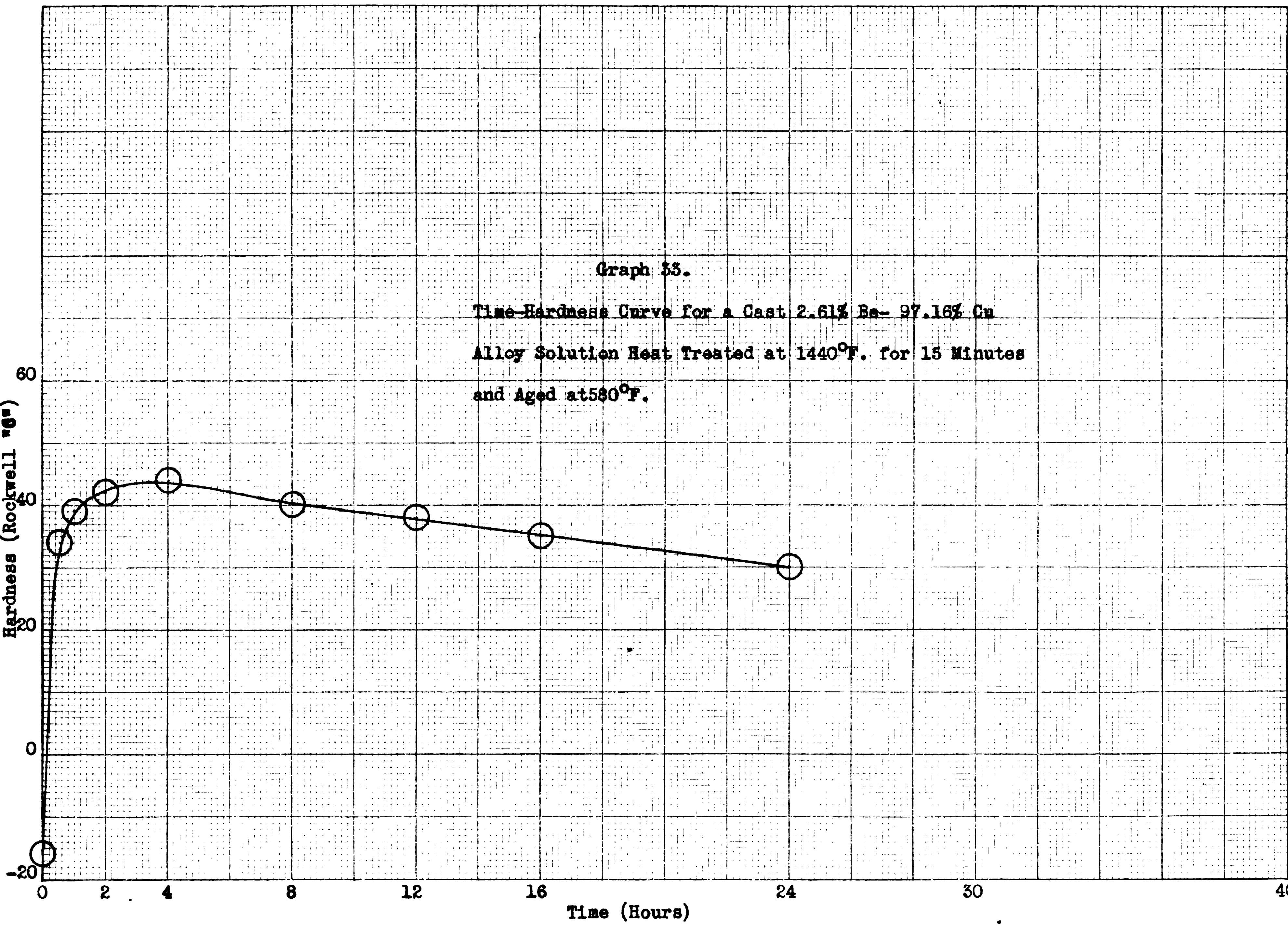
Time-Hardness Curve for a Cast 2.61% Be- 97.16% Cu Alloy Solution Heat Treated at 1470°F. for 15 Minutes and Aged at 580°F.



Graph 31.

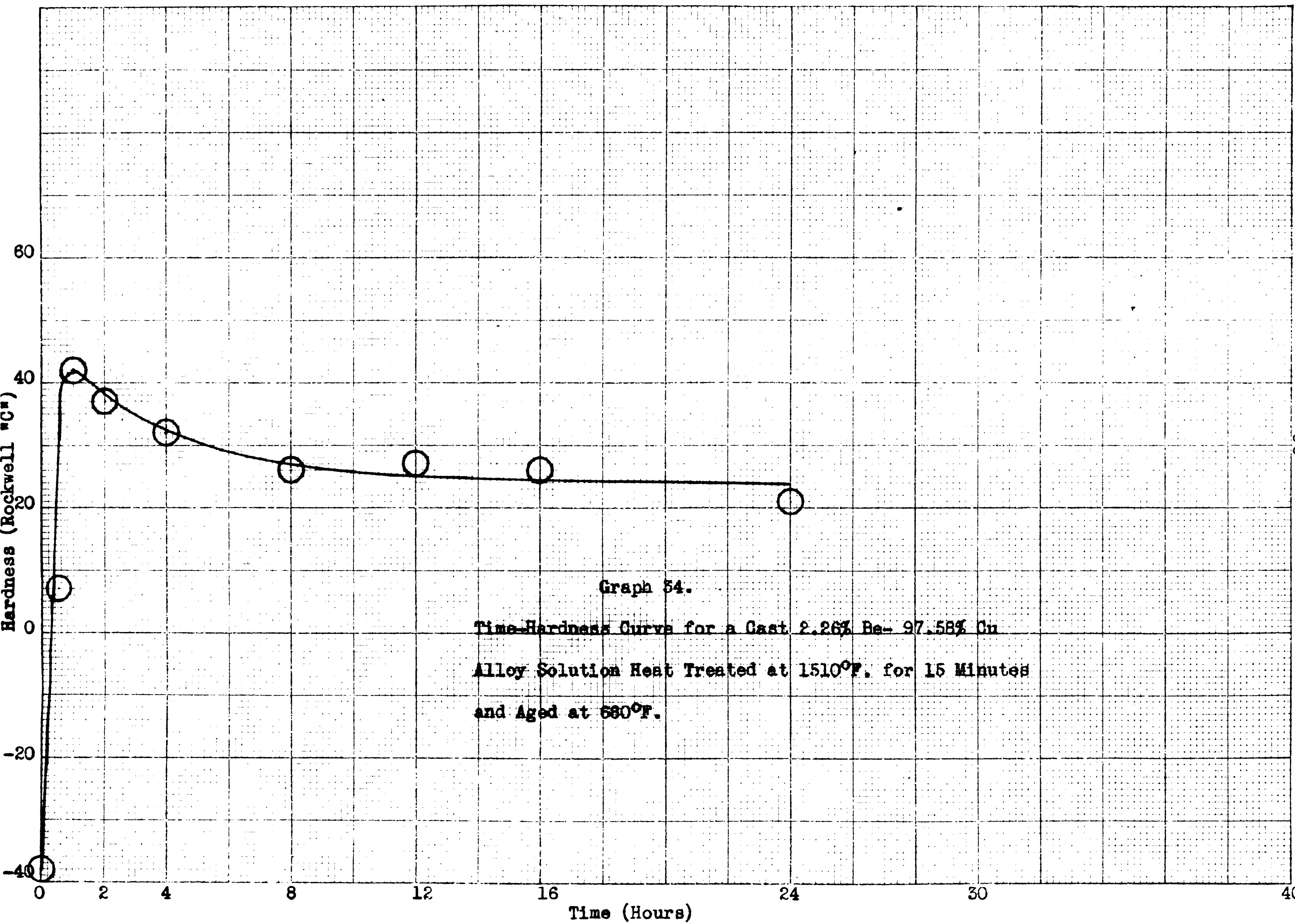
Time-Hardness Curve for a Cast 2.61% Be- 97.16% Cu Alloy Solution Heat Treated at 1440°F. for 15 Minutes and Aged at 680°F.


Graph 32.
Time-Hardness Curve for a Cast 2.61% Be- 97.16% Cu
Alloy Solution Heat Treated at 1440°F. for 15 Minutes
and Aged at 630°F.
60
40
20
0
-20
Hardness (Rockwell "C")
0
2
4
8
12
16
24
30
40
Time (Hours)



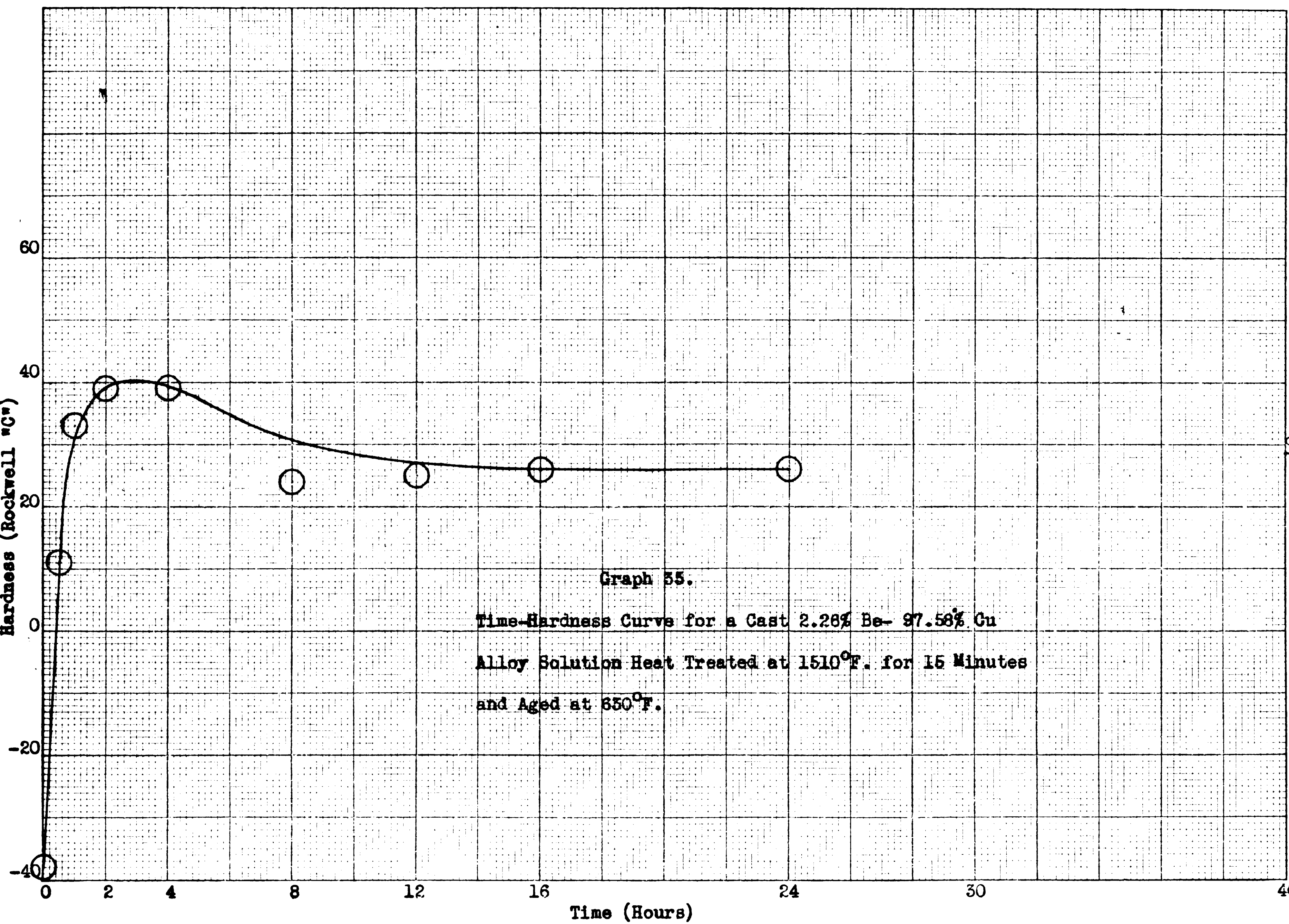
Graph 33.

Time-Hardness Curve for a Cast 2.61% Be- 97.16% Cu Alloy Solution Heat Treated at 1440°F. for 15 Minutes and Aged at580°F.



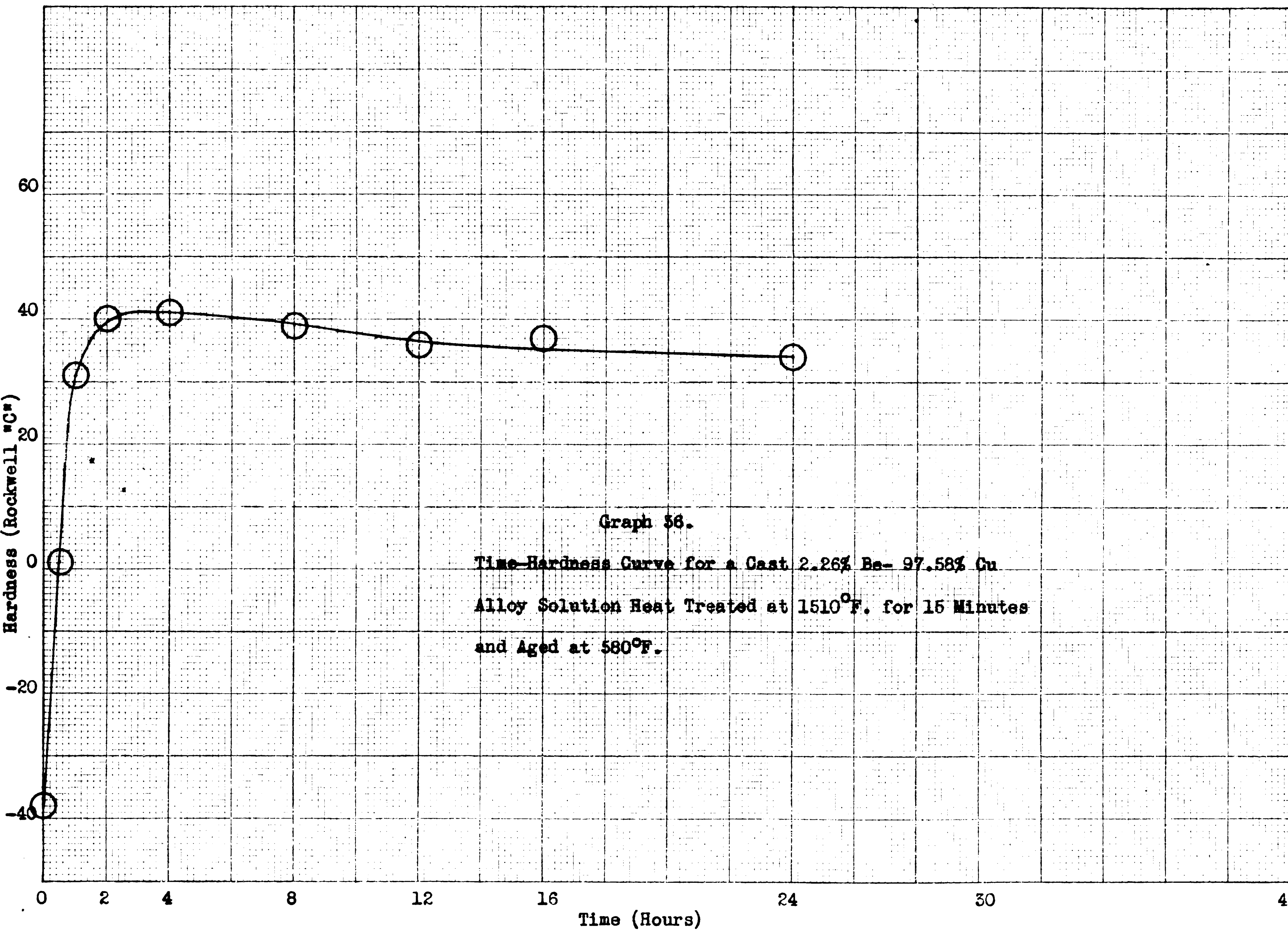
Graph 54.

Time-Hardness Curve for a Cast 2.26% Be- 97.58% Cu Alloy Solution Heat Treated at 1510°F. for 15 Minutes and Aged at 680°F.



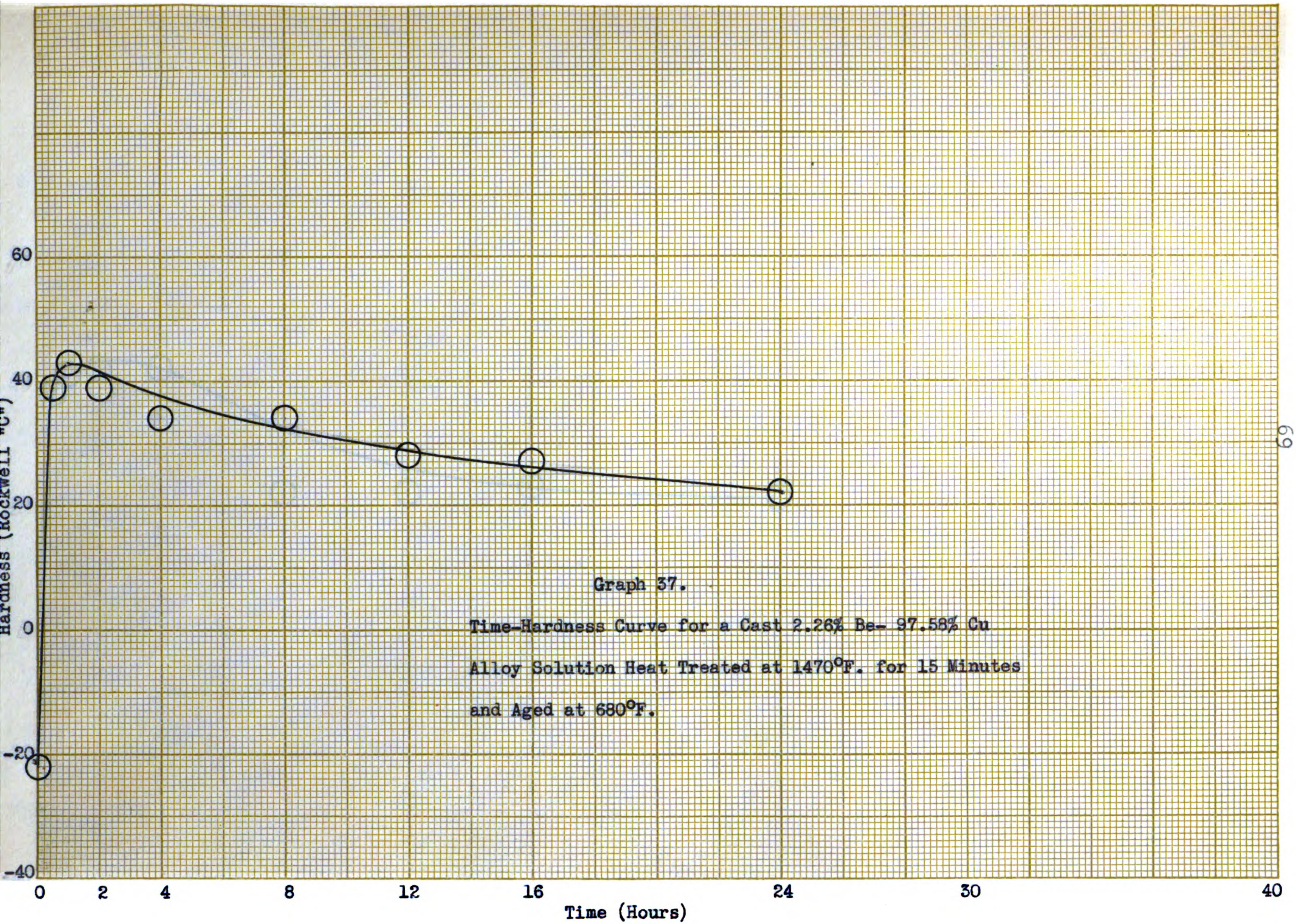
Graph 35.

Time-Hardness Curve for a Cast 2.26% Be- 97.58% Cu Alloy Solution Heat Treated at 1510°F. for 15 Minutes and Aged at 650°F.



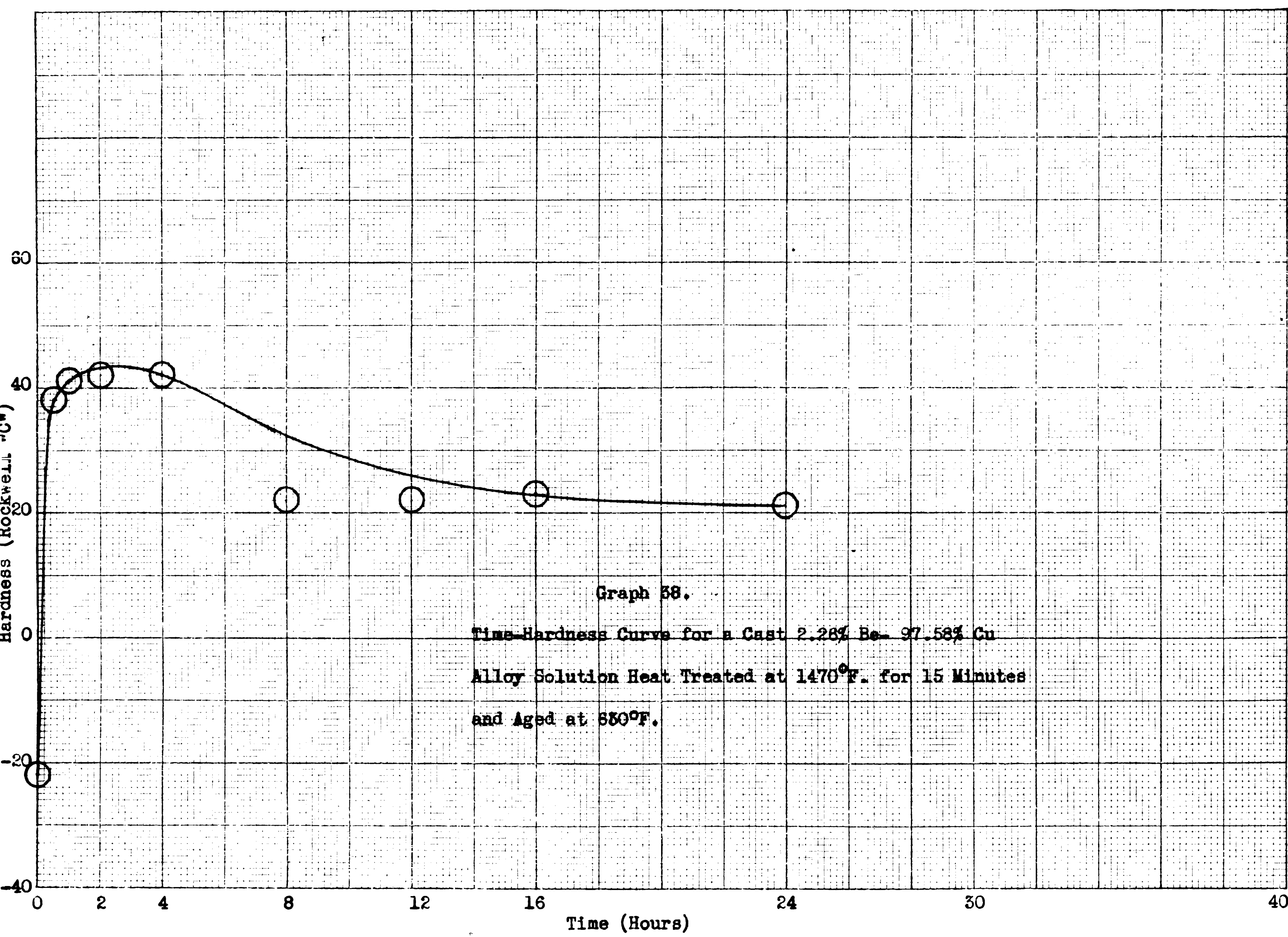
Graph 56.

Time-Hardness Curve for a Cast 2.26% Be- 97.58% Cu Alloy Solution Heat Treated at 1510°F. for 15 Minutes and Aged at 580°F.



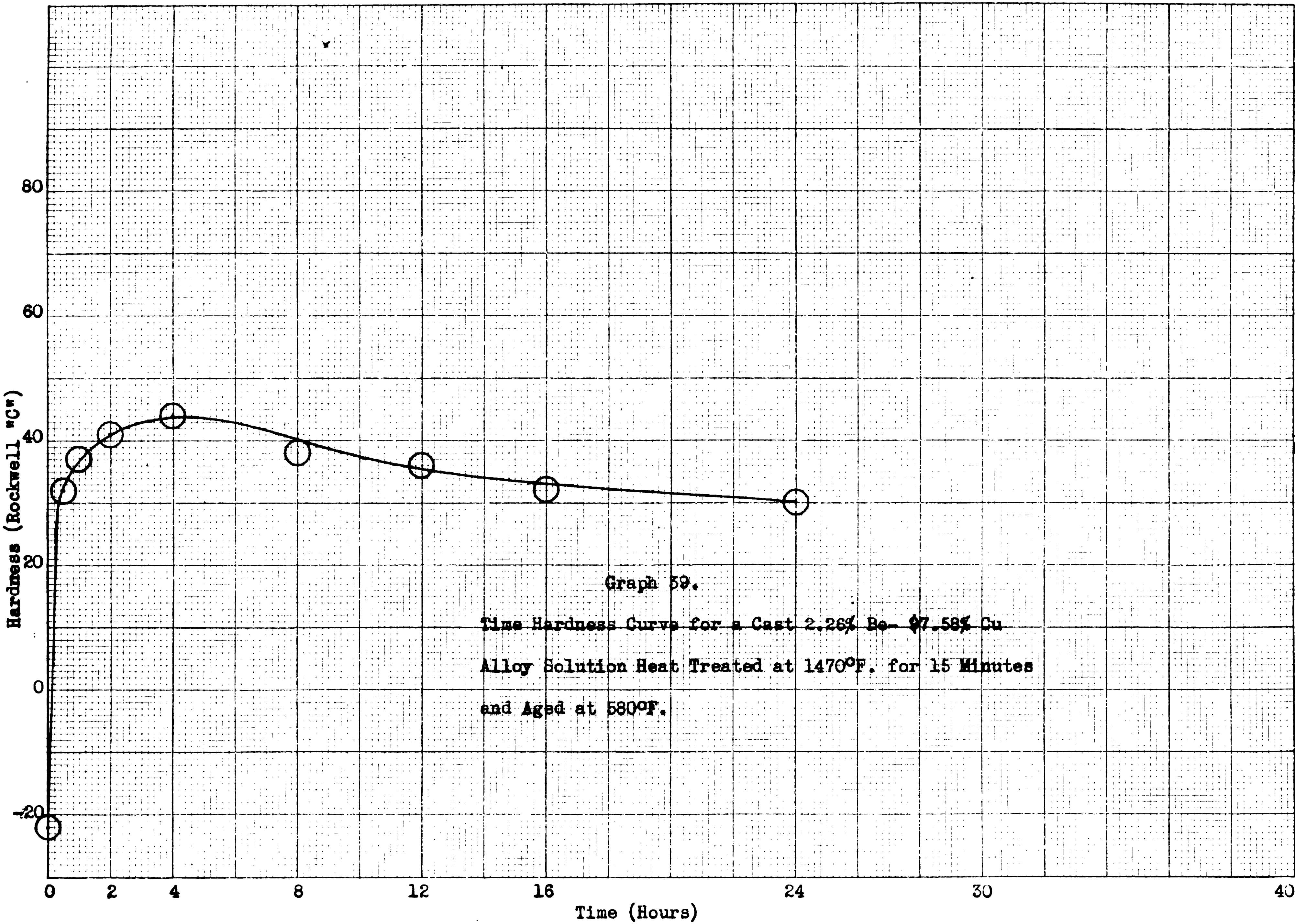
Graph 37.

Time-Hardness Curve for a Cast 2.26% Be- 97.58% Cu Alloy Solution Heat Treated at 1470°F. for 15 Minutes and Aged at 680°F.



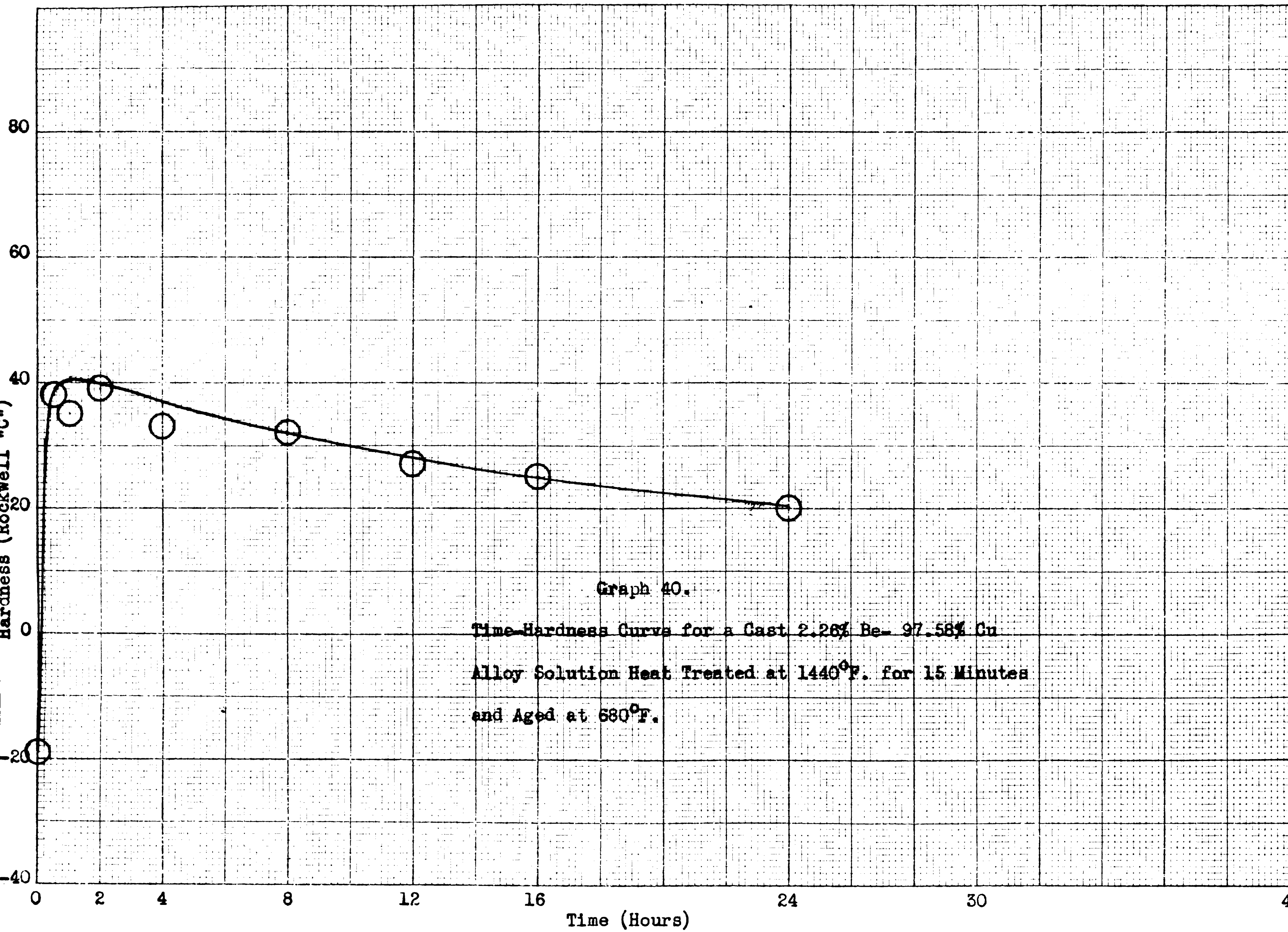
Graph 38.

Time-Hardness Curve for a Cast 2.28% Be- 97.58% Cu Alloy Solution Heat Treated at 1470°F. for 15 Minutes and Aged at 650°F.



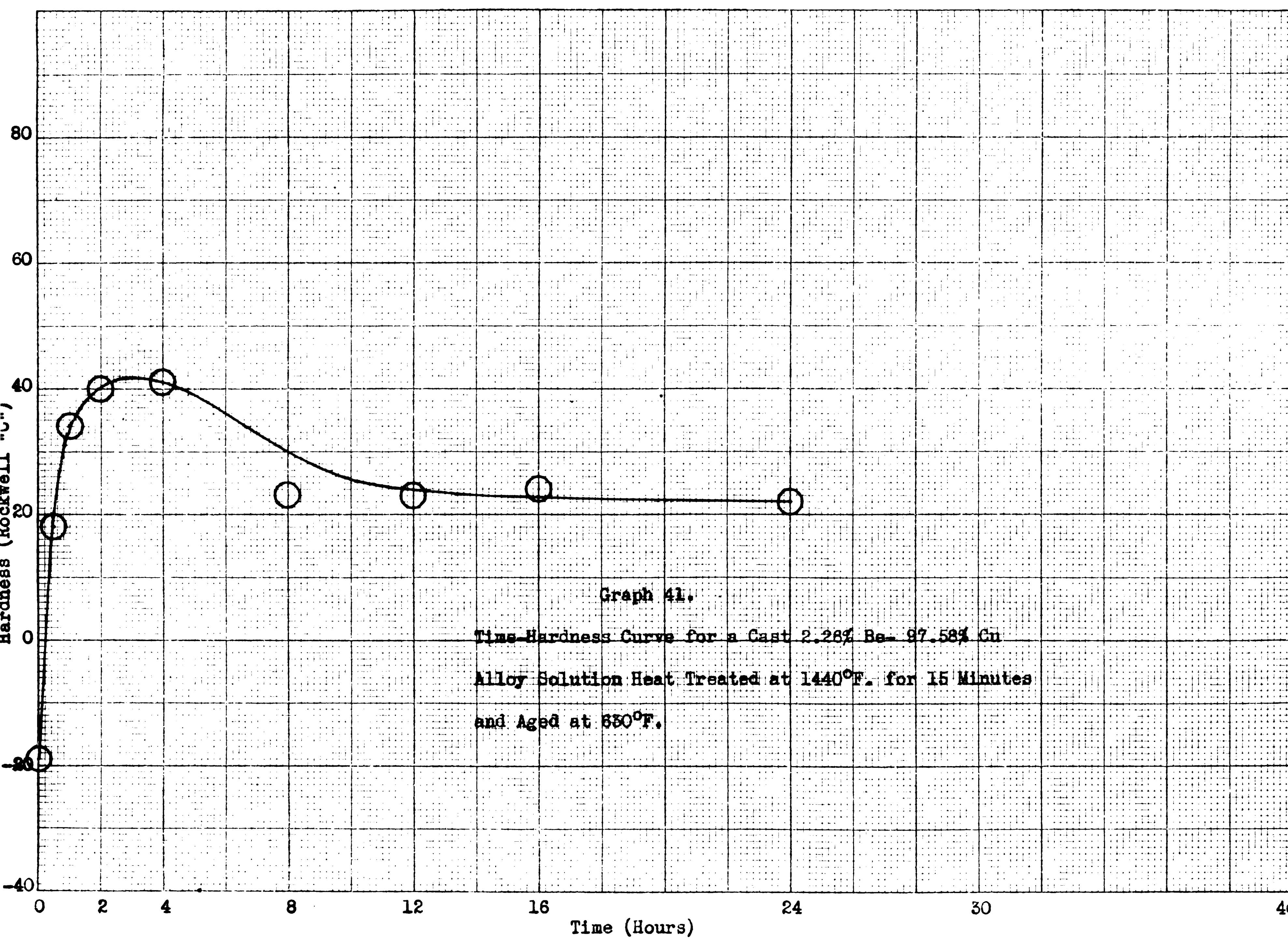
Graph 59.

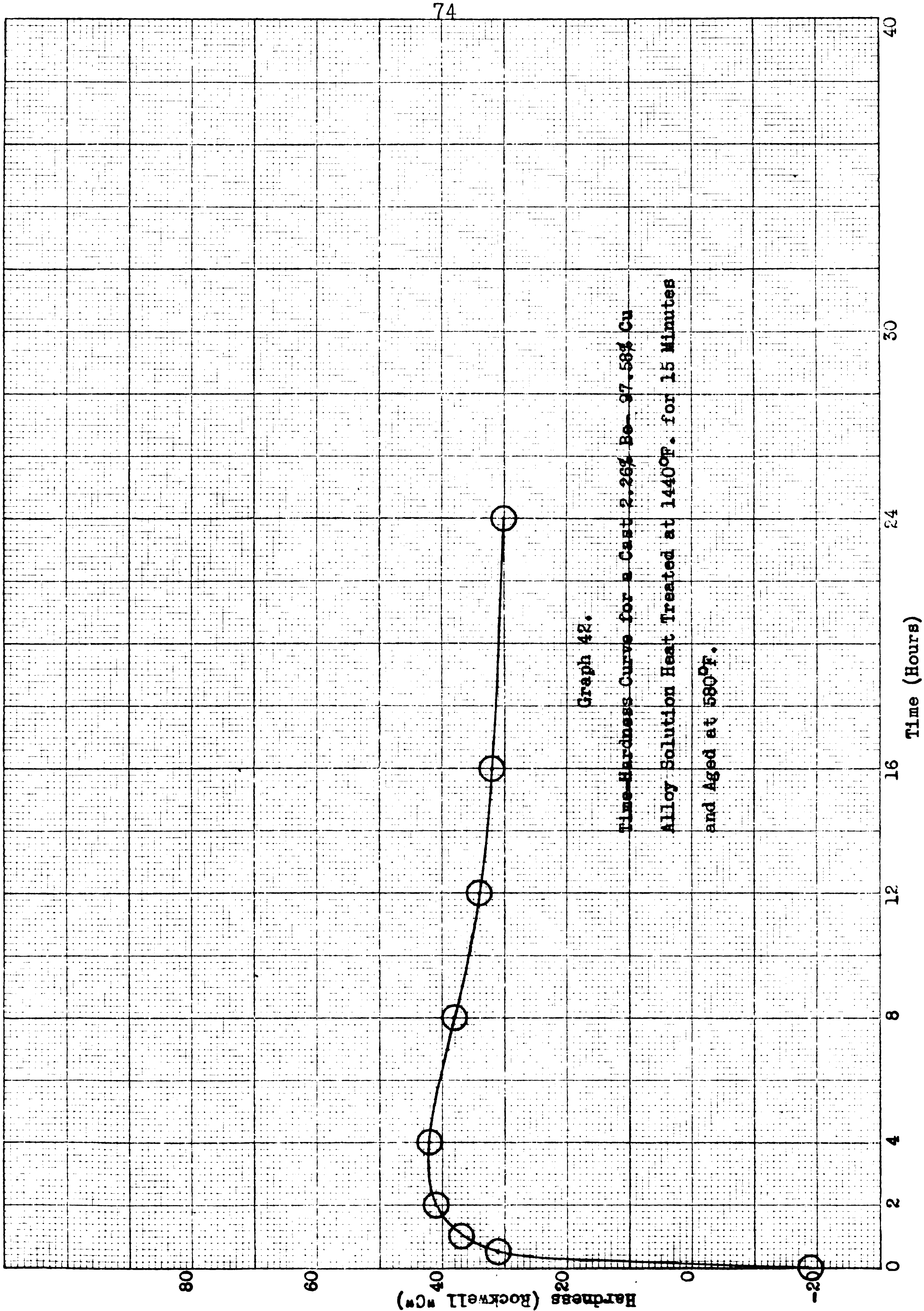
Time Hardness Curve for a Cast 2.26% Be- 97.58% Cu Alloy Solution Heat Treated at 1470°F. for 15 Minutes and Aged at 580°F.



Graph 40.

Time-Hardness Curve for a Cast 2.26% Be- 97.58% Cu Alloy Solution Heat Treated at 1440°F. for 15 Minutes and Aged at 680°F.


Graph 41.
Time-Hardness Curve for a Cast 2.28% Be- 97.58% Cu
Alloy Solution Heat Treated at 1440°F. for 15 Minutes
and Aged at 630°F.
Hardness (Rockwell "C")
80
60
40
20
0
-20
-40
0
2
4
8
12
16
24
30
40
Time (Hours)

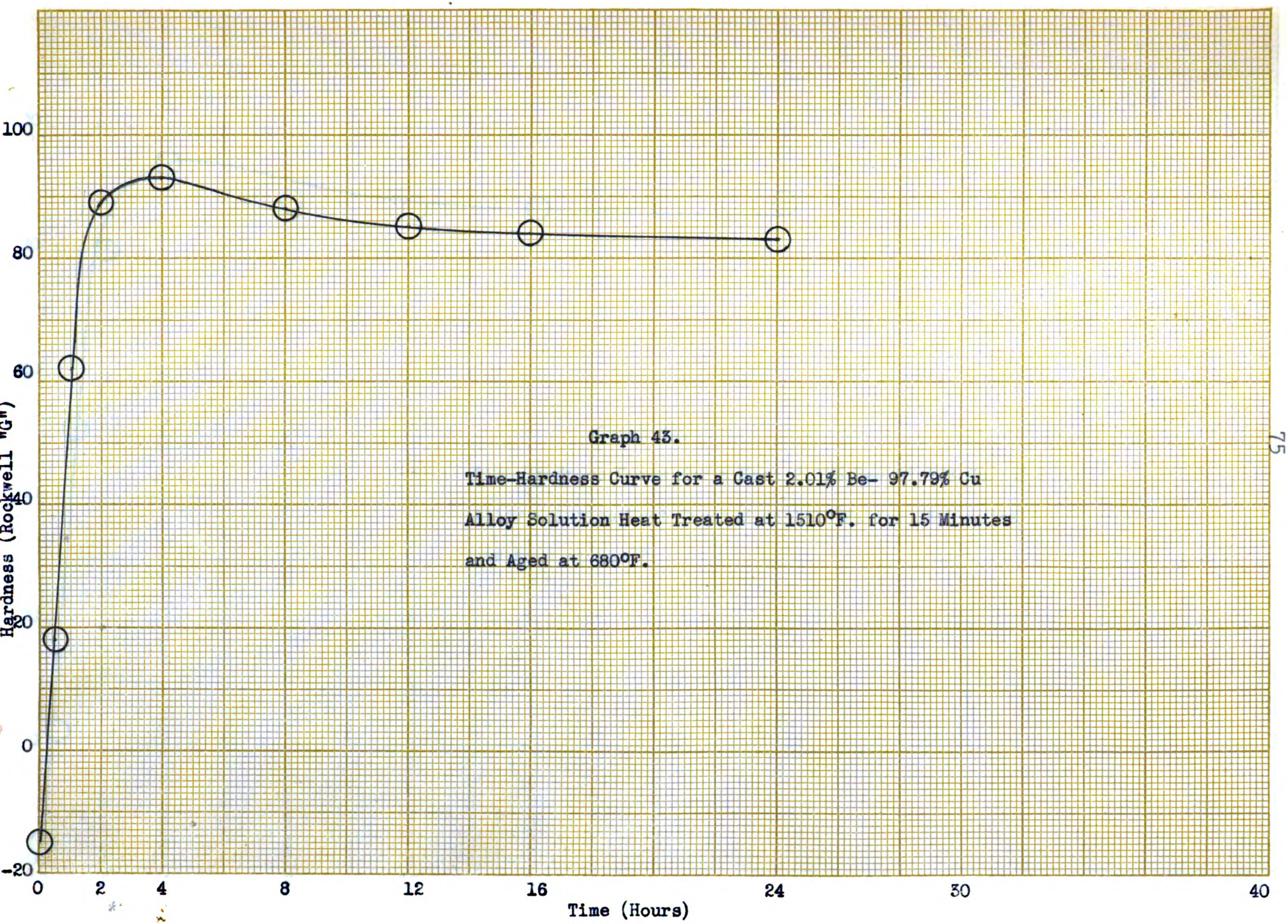


Graph 42.

Time-Hardness Curve for a Cast 2.26% Be- 97.58% Cu

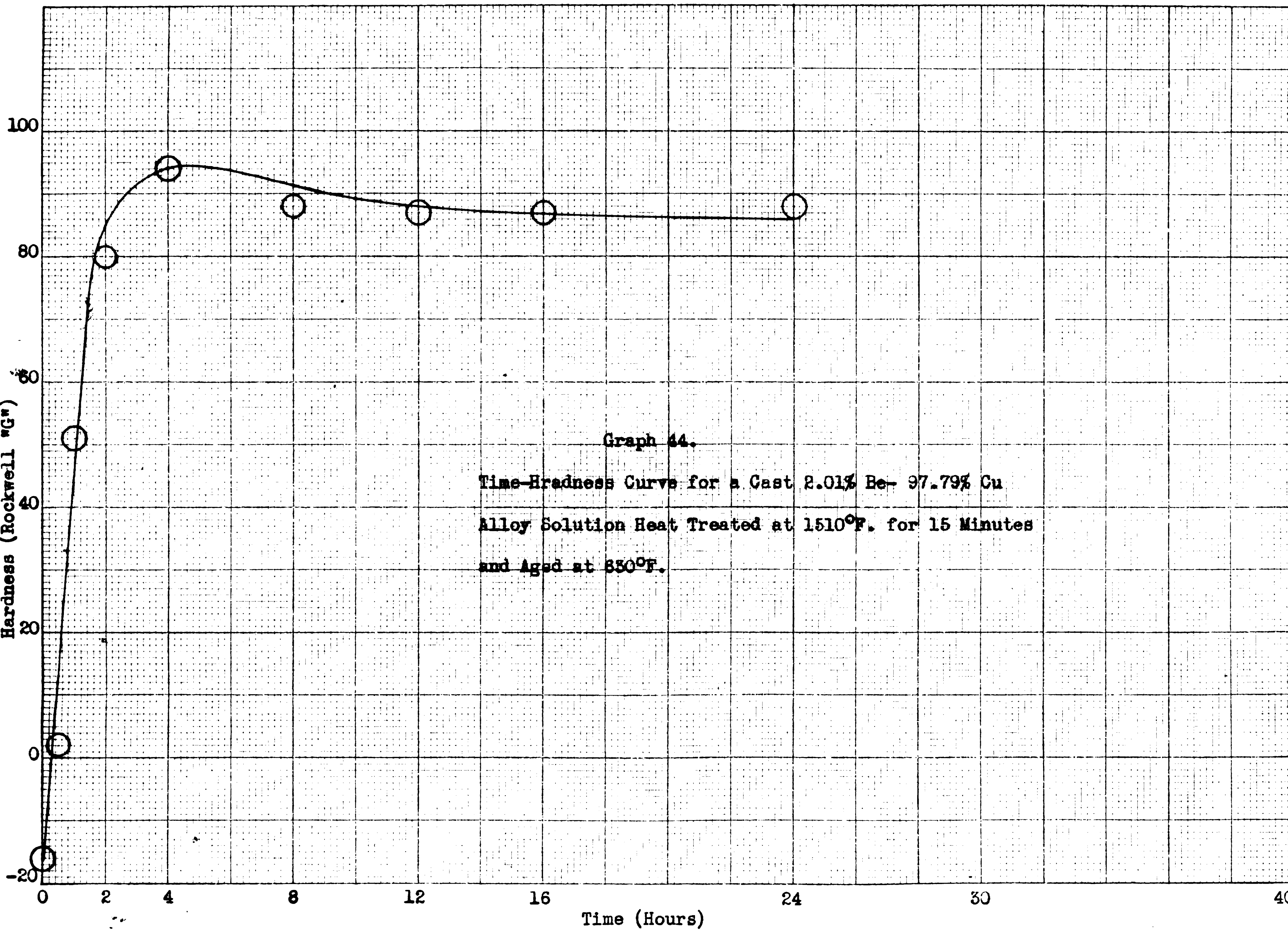
Alloy Solution Heat Treated at 1440°F. for 15 Minutes

and Aged at 580°F.



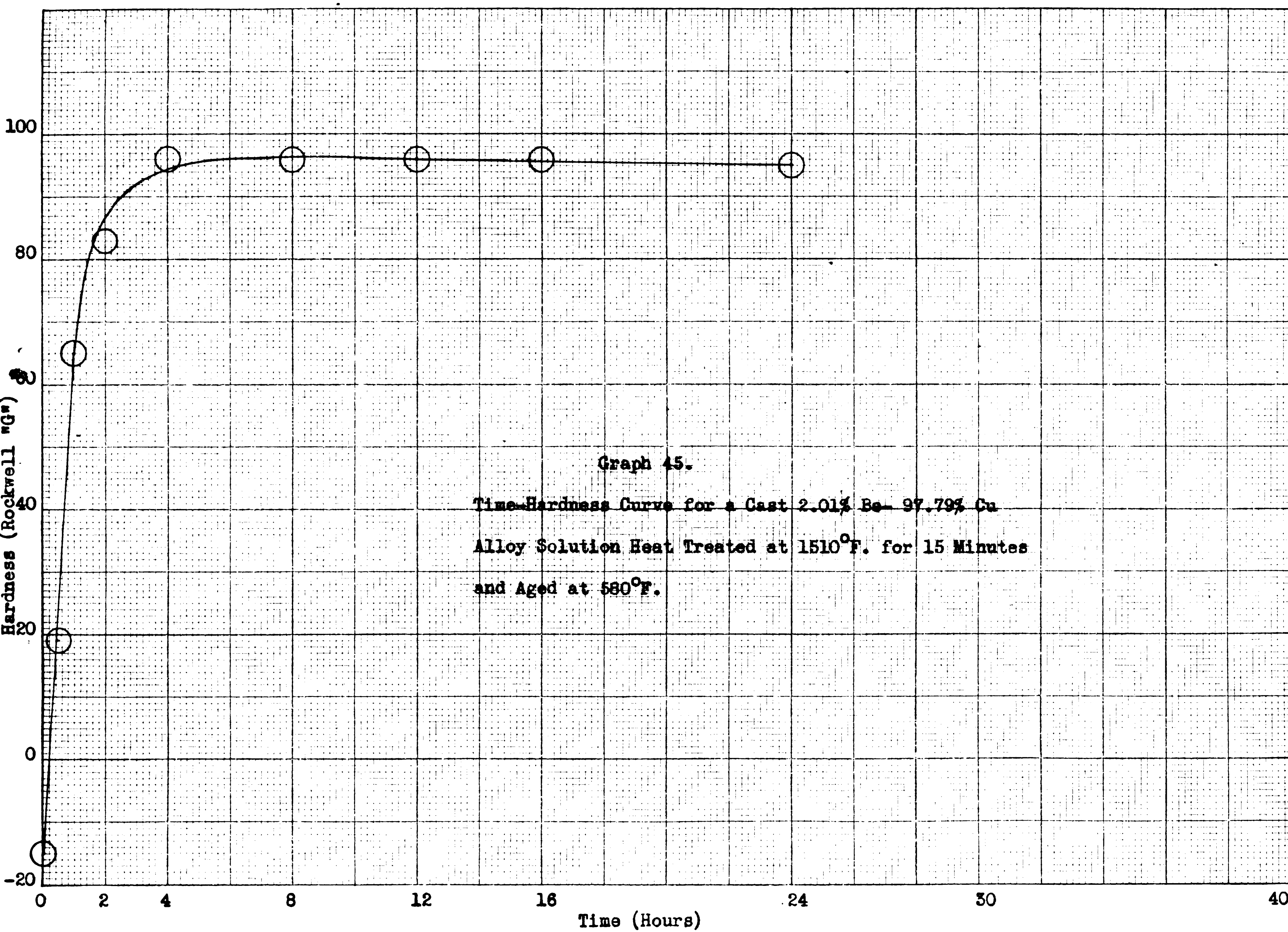
Graph 43.

Time-Hardness Curve for a Cast 2.01% Be- 97.79% Cu Alloy Solution Heat Treated at 1510°F. for 15 Minutes and Aged at 680°F.



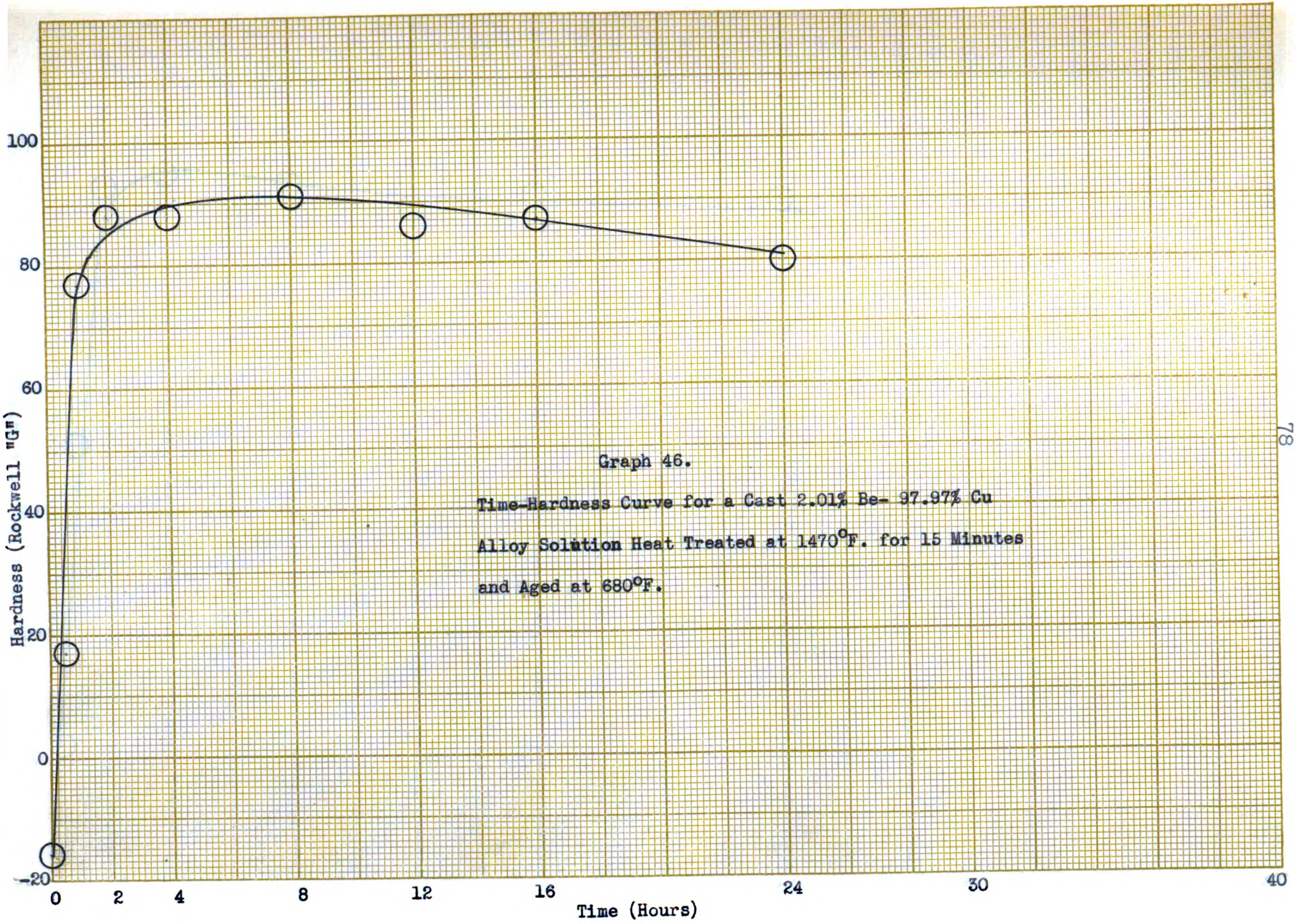
Graph 44.

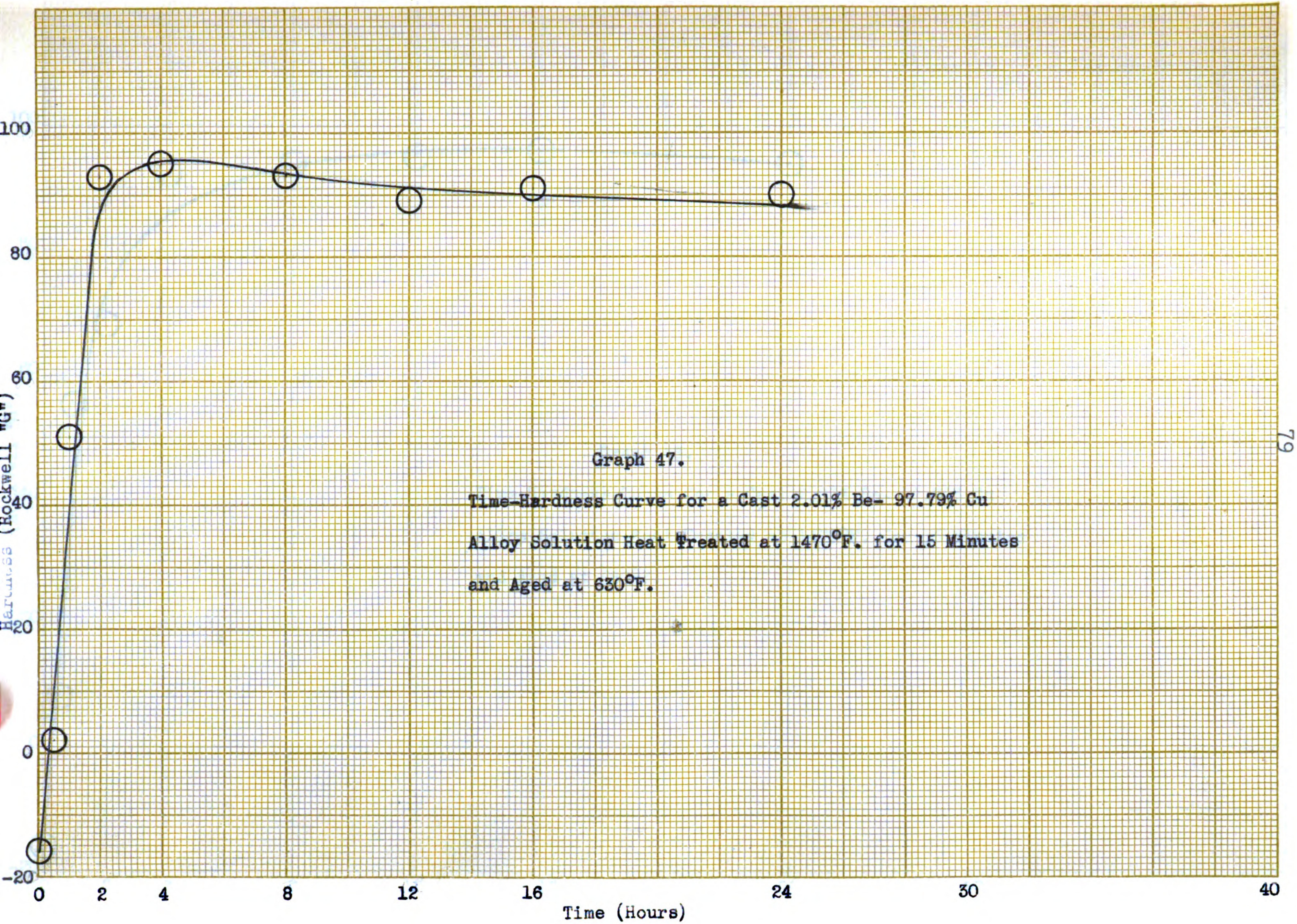
Time-Hradness Curve for a Cast 2.01% Be- 97.79% Cu Alloy Solution Heat Treated at 1510°F. for 15 Minutes and Aged at 650°F.



Graph 45.

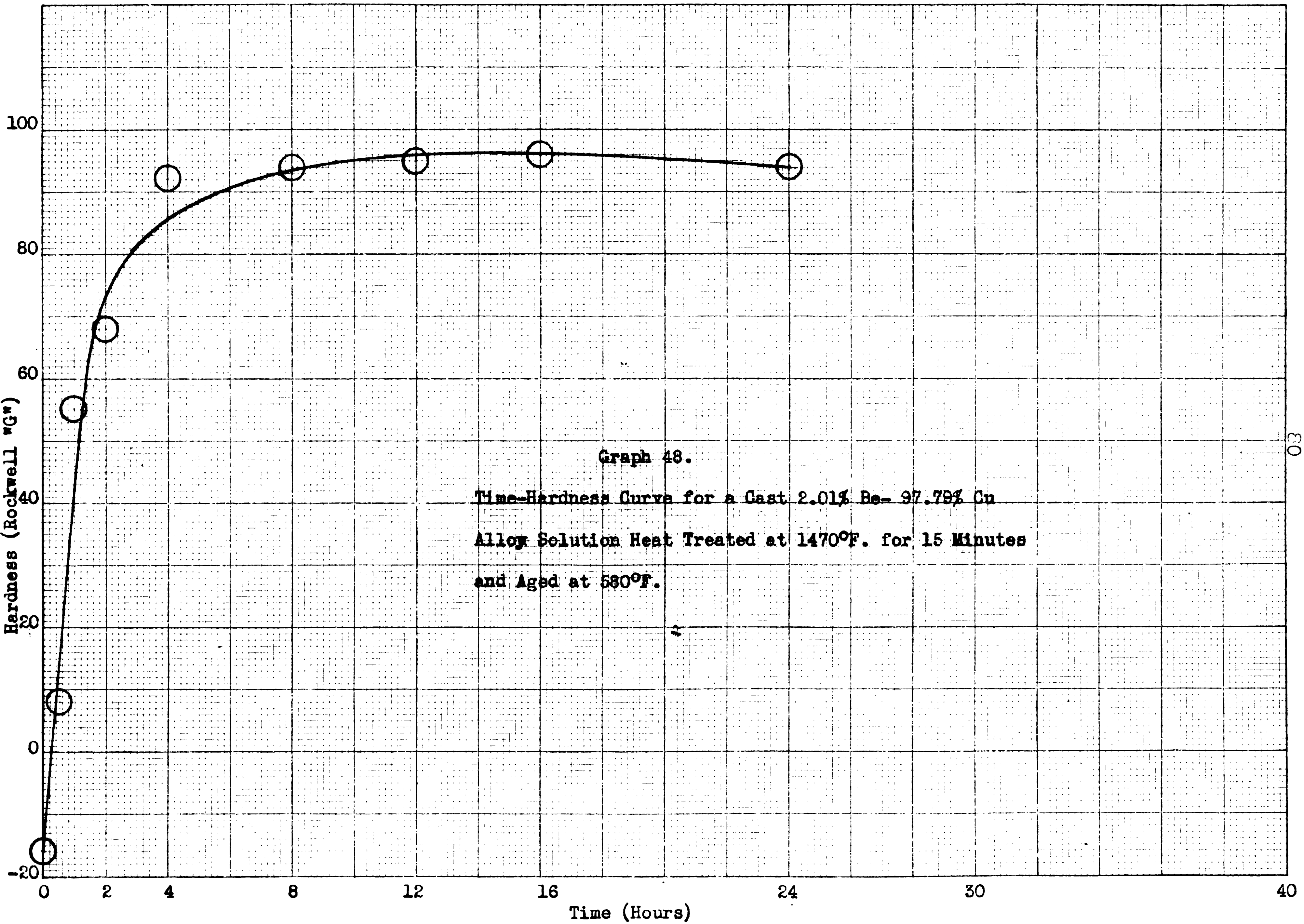
Time-Hardness Curve for a Cast 2.01% Be- 97.79% Cu Alloy Solution Heat Treated at 1510°F. for 15 Minutes and Aged at 580°F.


Graph 46.
Time-Hardness Curve for a Cast 2.01% Be- 97.97% Cu
Alloy Solution Heat Treated at 1470°F. for 15 Minutes
and Aged at 680°F.
Hardness (Rockwell "G")
100
80
60
40
20
0
-20
0
2
4
8
12
16
24
30
40
Time (Hours)

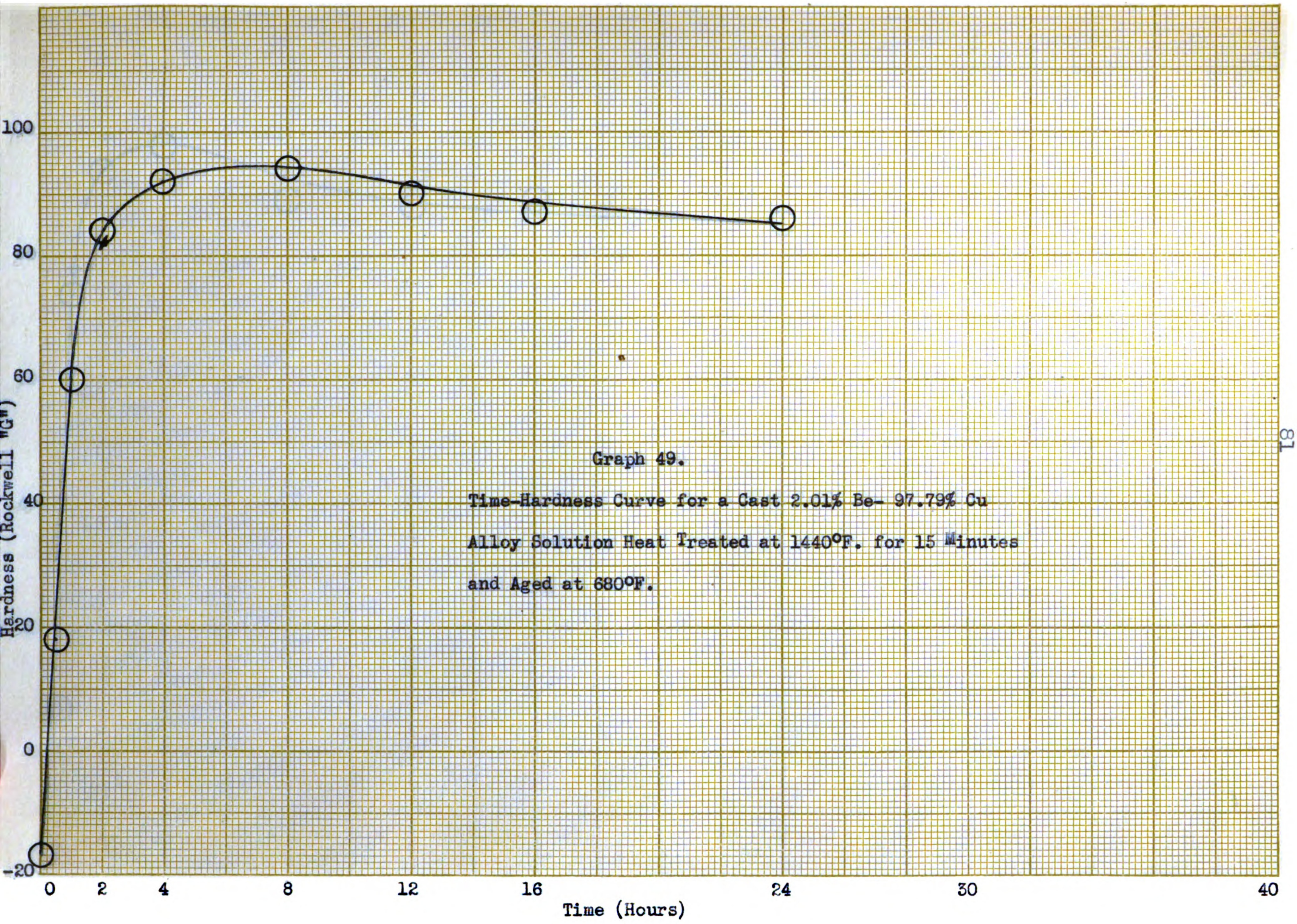


Graph 47.

Time-Hardness Curve for a Cast 2.01% Be- 97.79% Cu Alloy Solution Heat Treated at 1470°F. for 15 Minutes and Aged at 630°F.

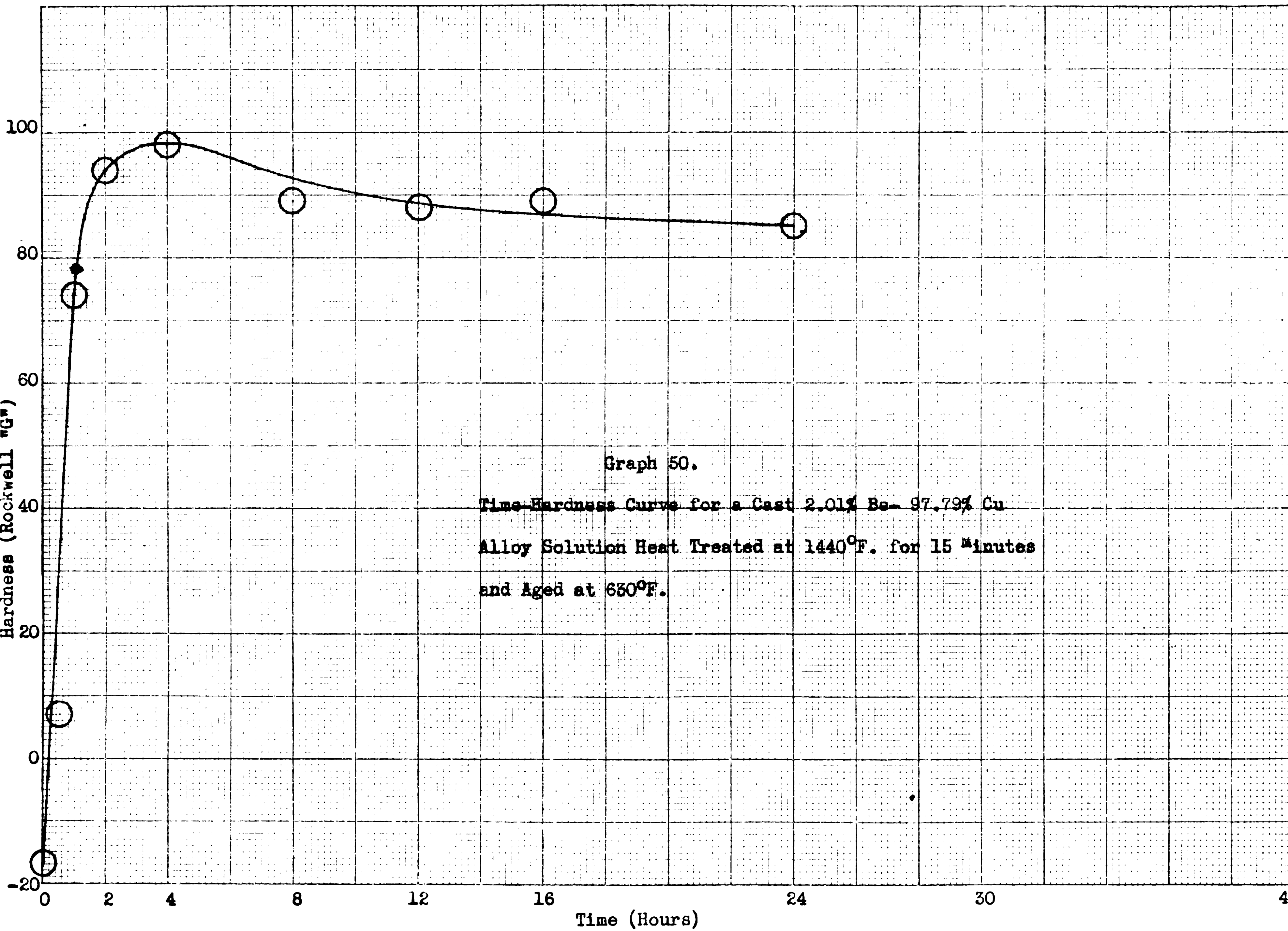


Graph 48.
Time-Hardness Curve for a Cast 2.01% Be- 97.79% Cu
Alloy Solution Heat Treated at 1470°F. for 15 Minutes
and Aged at 580°F.
Hardness (Rockwell "G")
100
80
60
40
20
0
-20
0
2
4
8
12
16
24
30
40
Time (Hours)
03



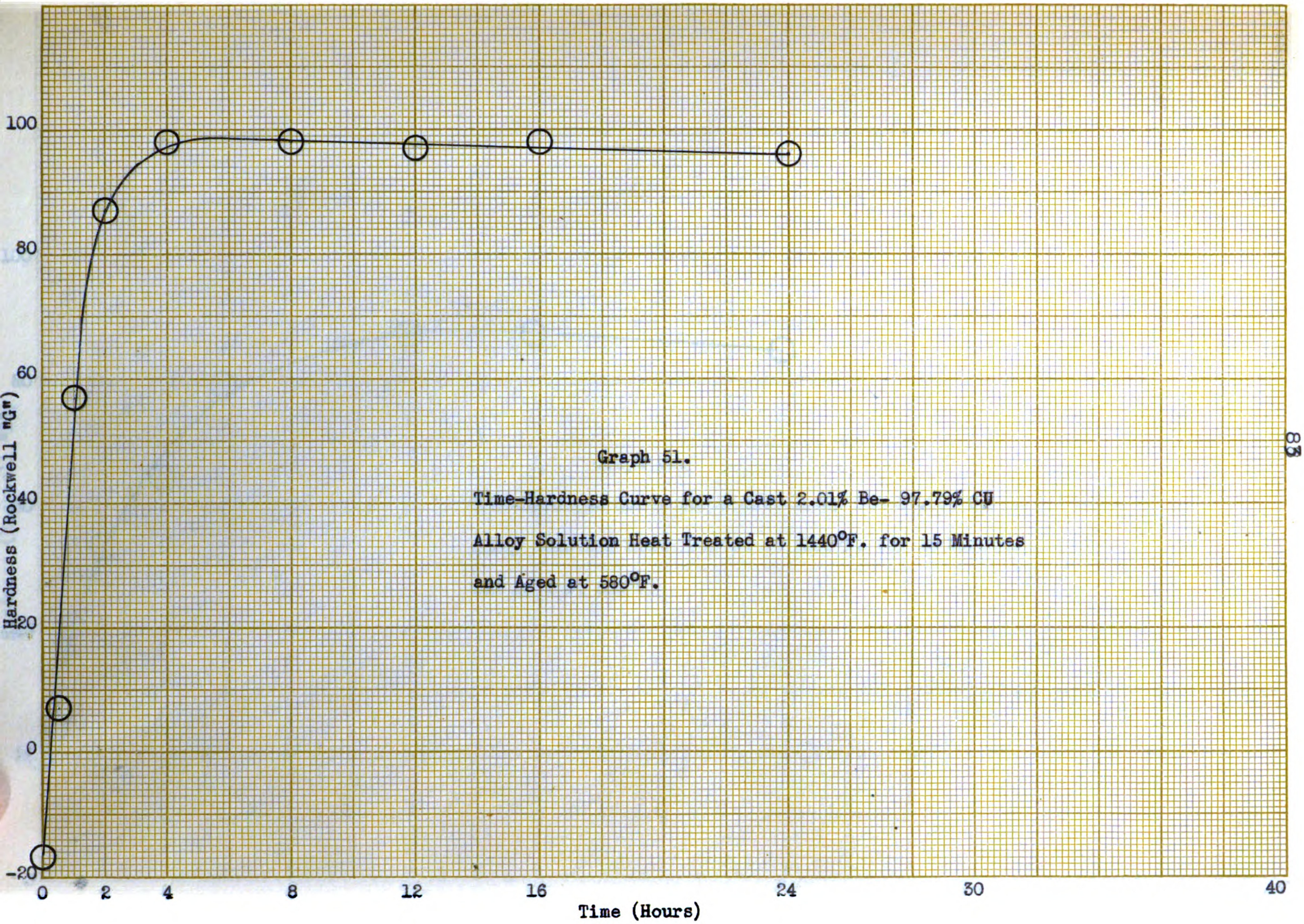
Graph 49.

Time-Hardness Curve for a Cast 2.01% Be- 97.79% Cu Alloy Solution Heat Treated at 1440°F. for 15 Minutes and Aged at 680°F.



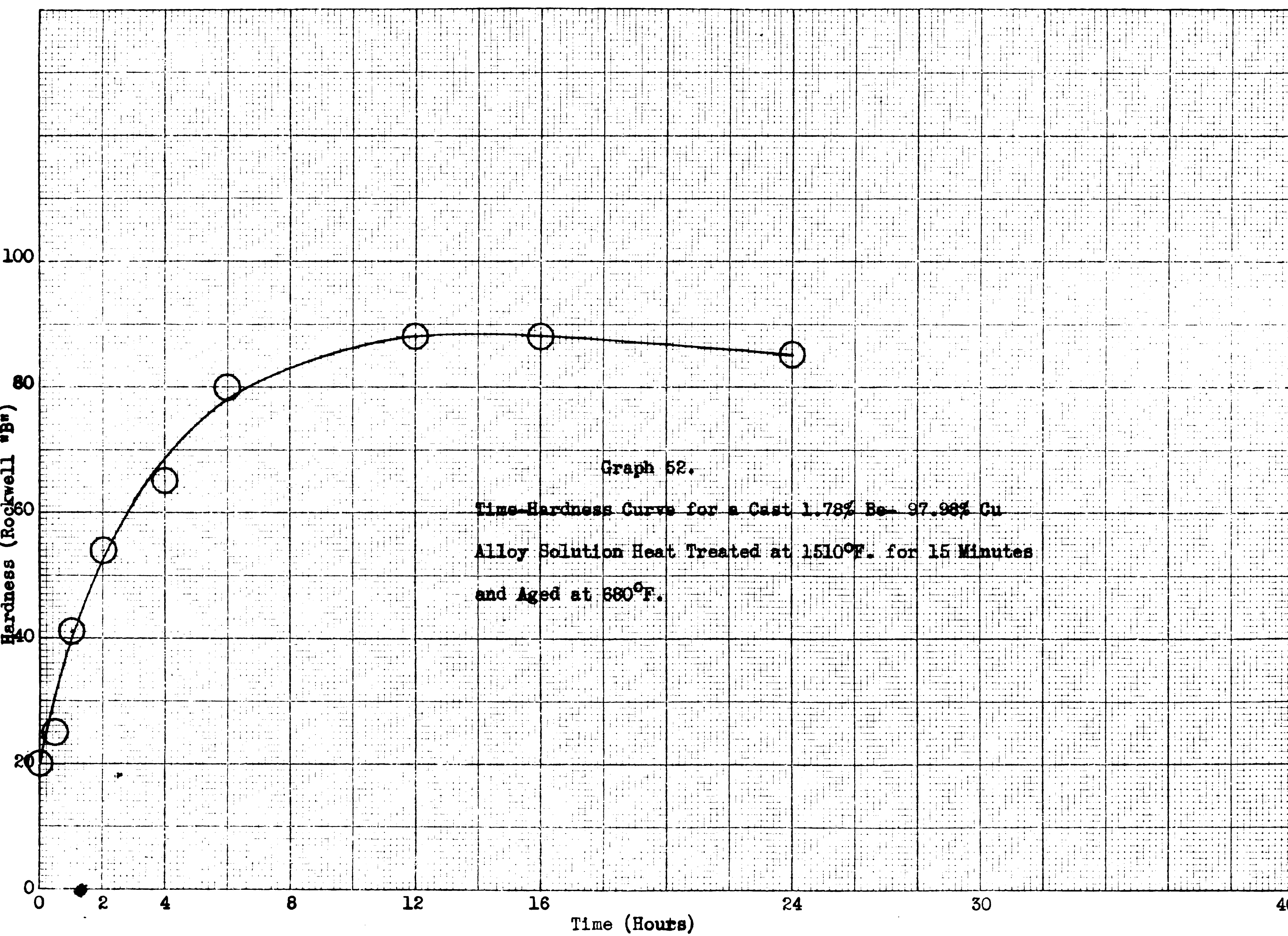
Graph 50.

Time-Hardness Curve for a Cast 2.01% Be- 97.79% Cu Alloy Solution Heat Treated at 1440°F. for 15 Minutes and Aged at 630°F.



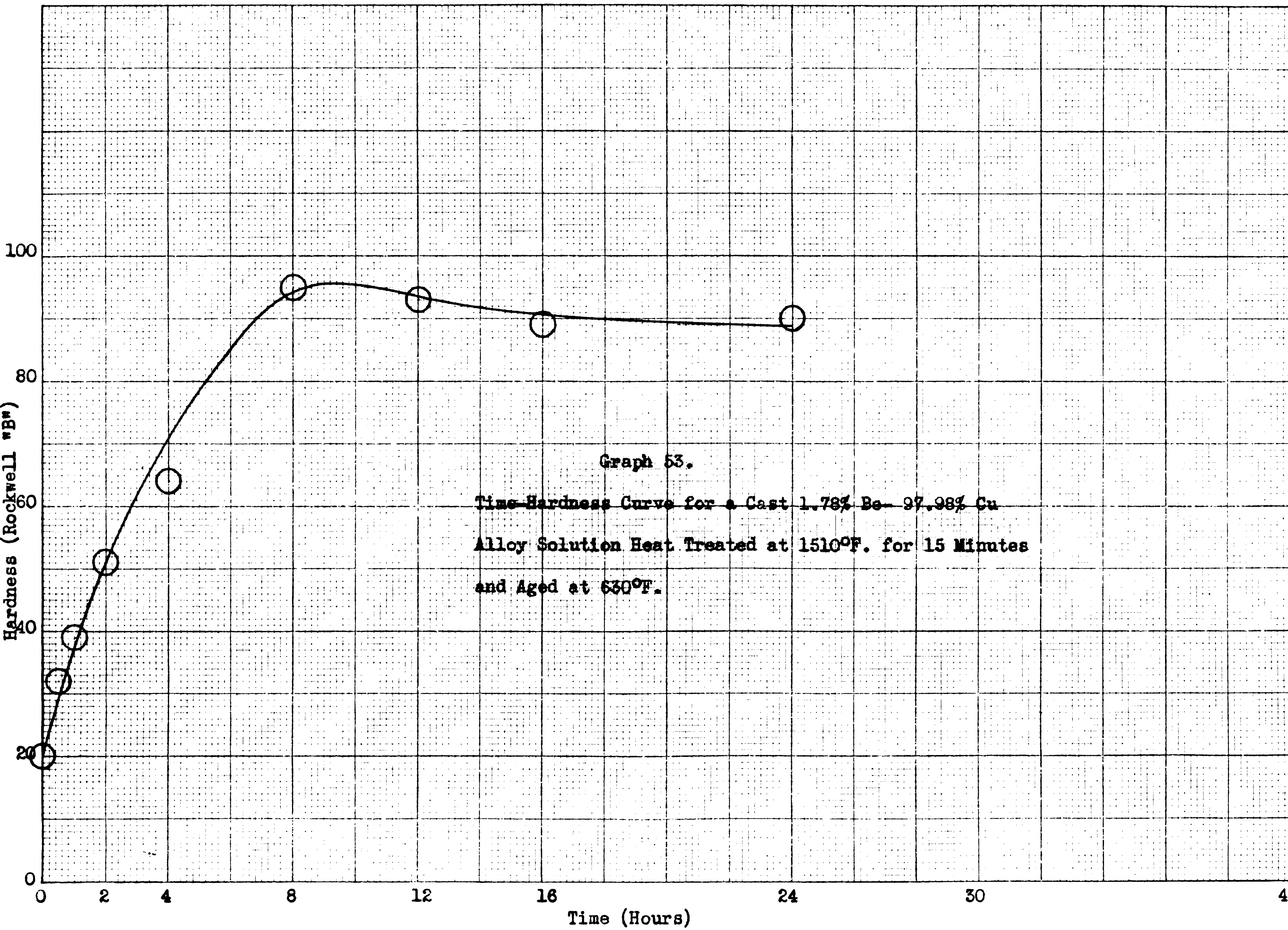
Graph 51.

Time-Hardness Curve for a Cast 2.01% Be- 97.79% CU Alloy Solution Heat Treated at 1440°F. for 15 Minutes and Aged at 580°F.



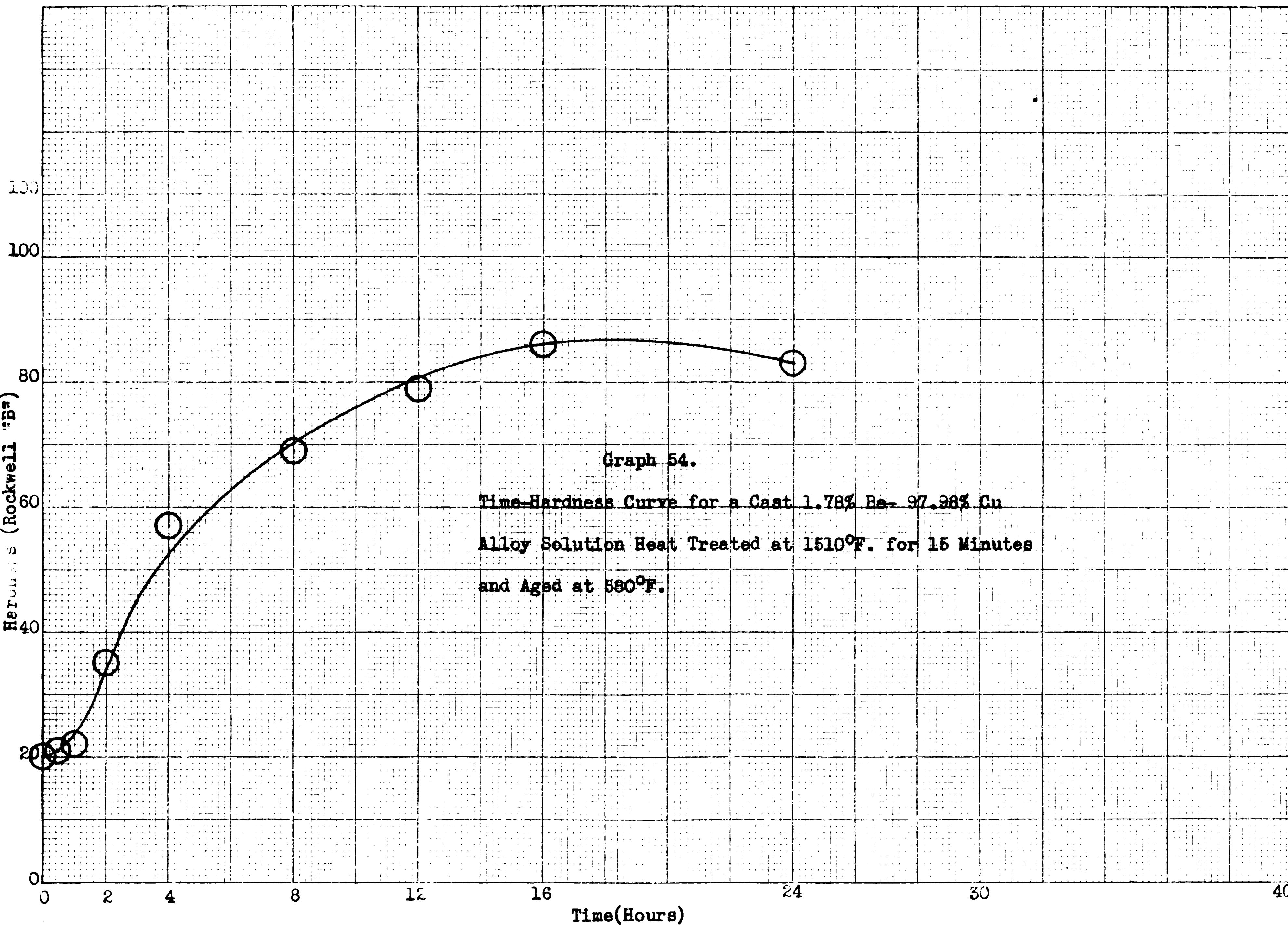
Graph 52.

Time-Hardness Curve for a Cast 1.78% Be- 97.98% Cu Alloy Solution Heat Treated at 1510°F. for 15 Minutes and Aged at 680°F.



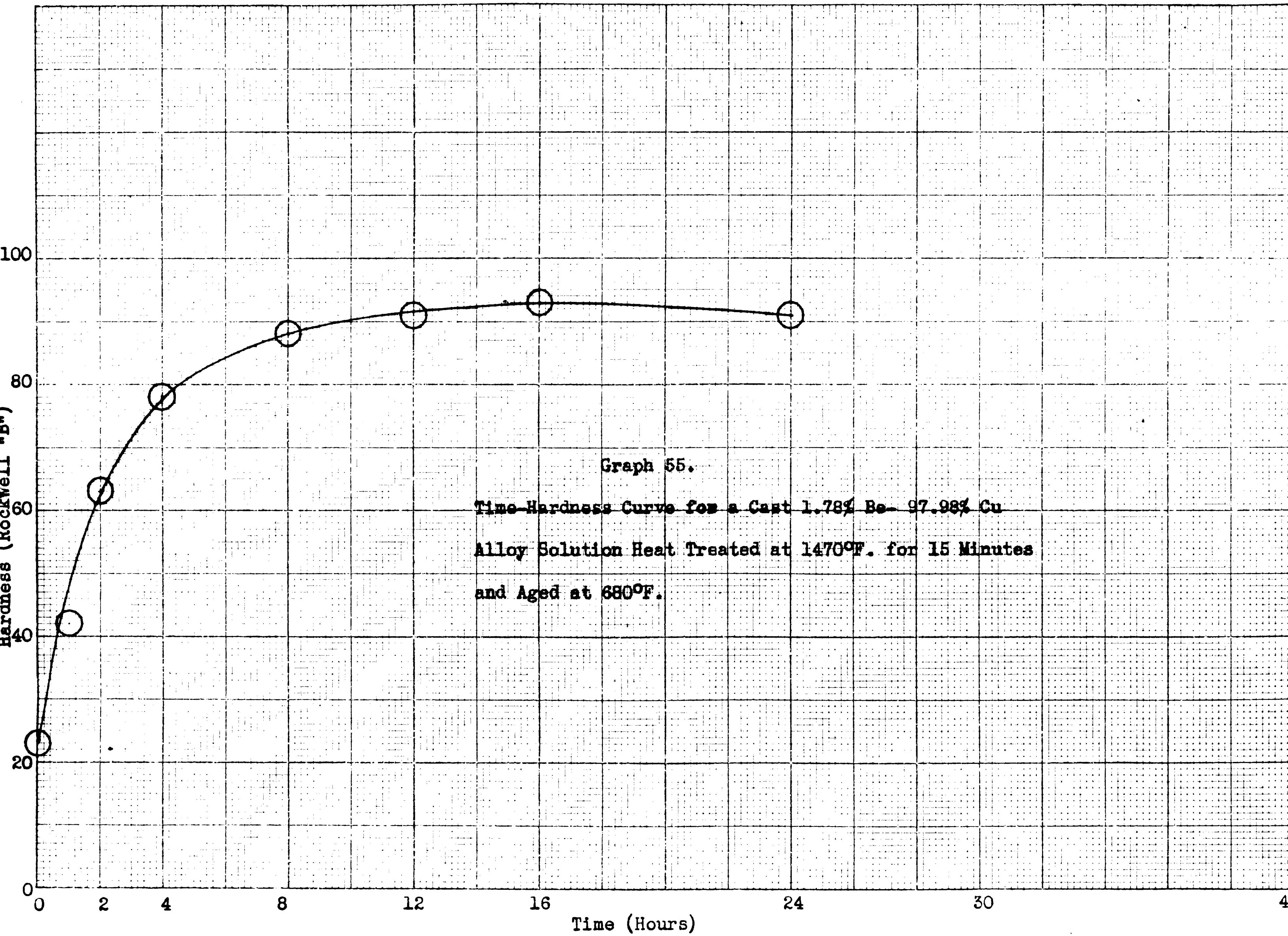
Graph 53.

Time-Hardness Curve for a Cast 1.78% Be- 97.98% Cu Alloy Solution Heat Treated at 1510°F. for 15 Minutes and Aged at 630°F.



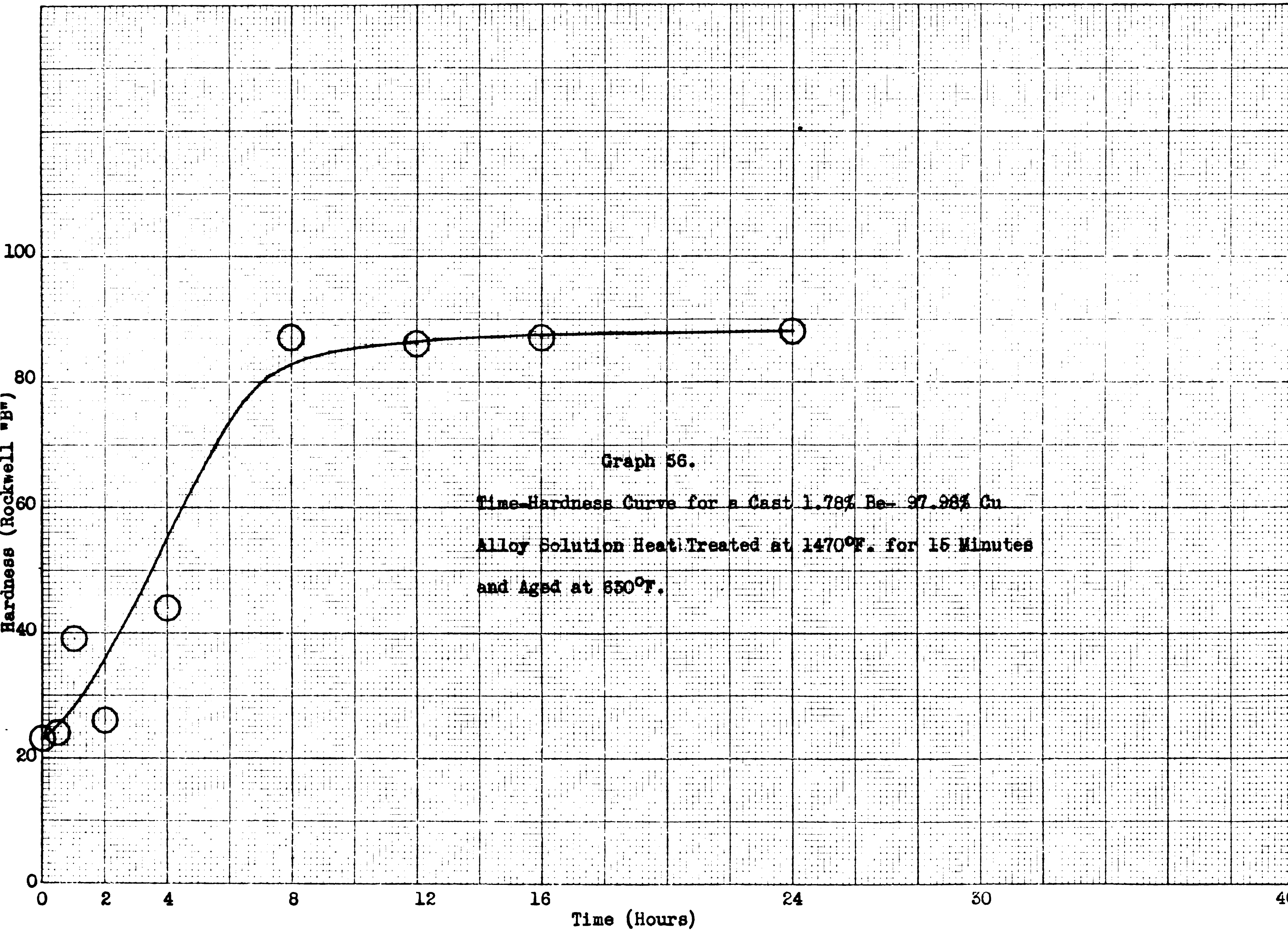
Graph 54.

Time-Hardness Curve for a Cast 1.78% Be- 97.98% Cu Alloy Solution Heat Treated at 1510°F. for 15 Minutes and Aged at 580°F.

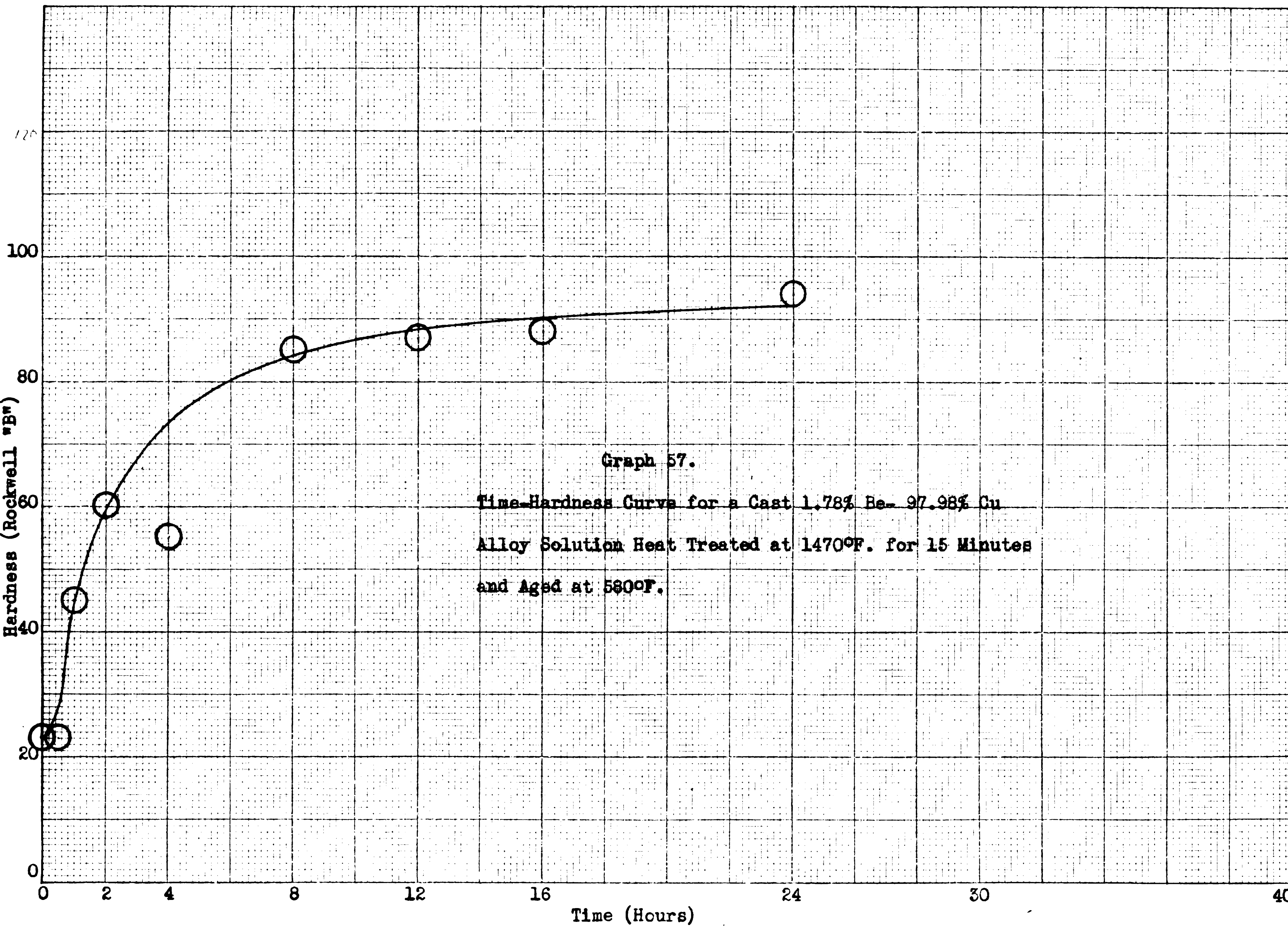


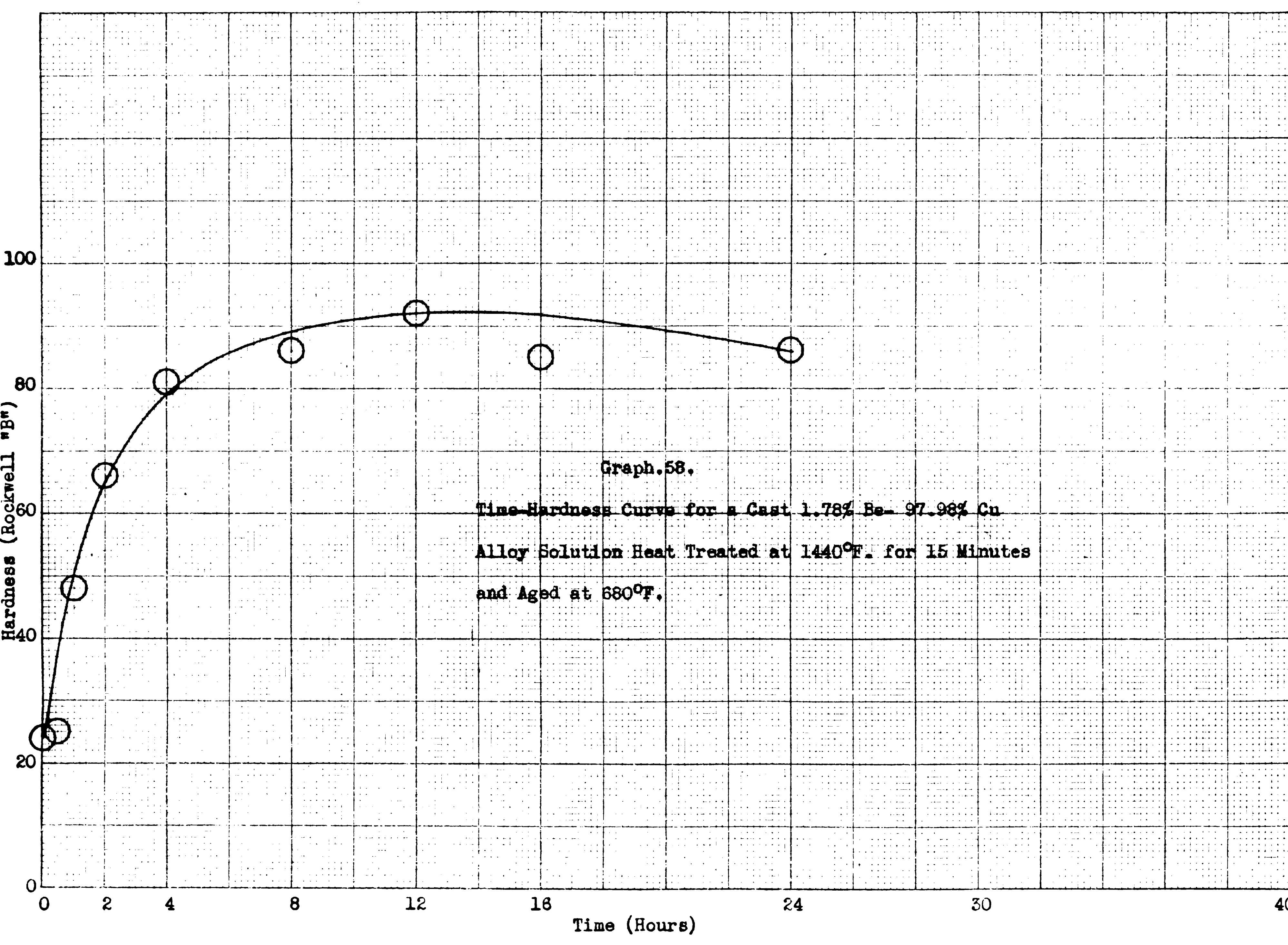
Graph 55.

Time-Hardness Curve for a Cast 1.78% Be- 97.98% Cu Alloy Solution Heat Treated at 1470°F. for 15 Minutes and Aged at 680°F.



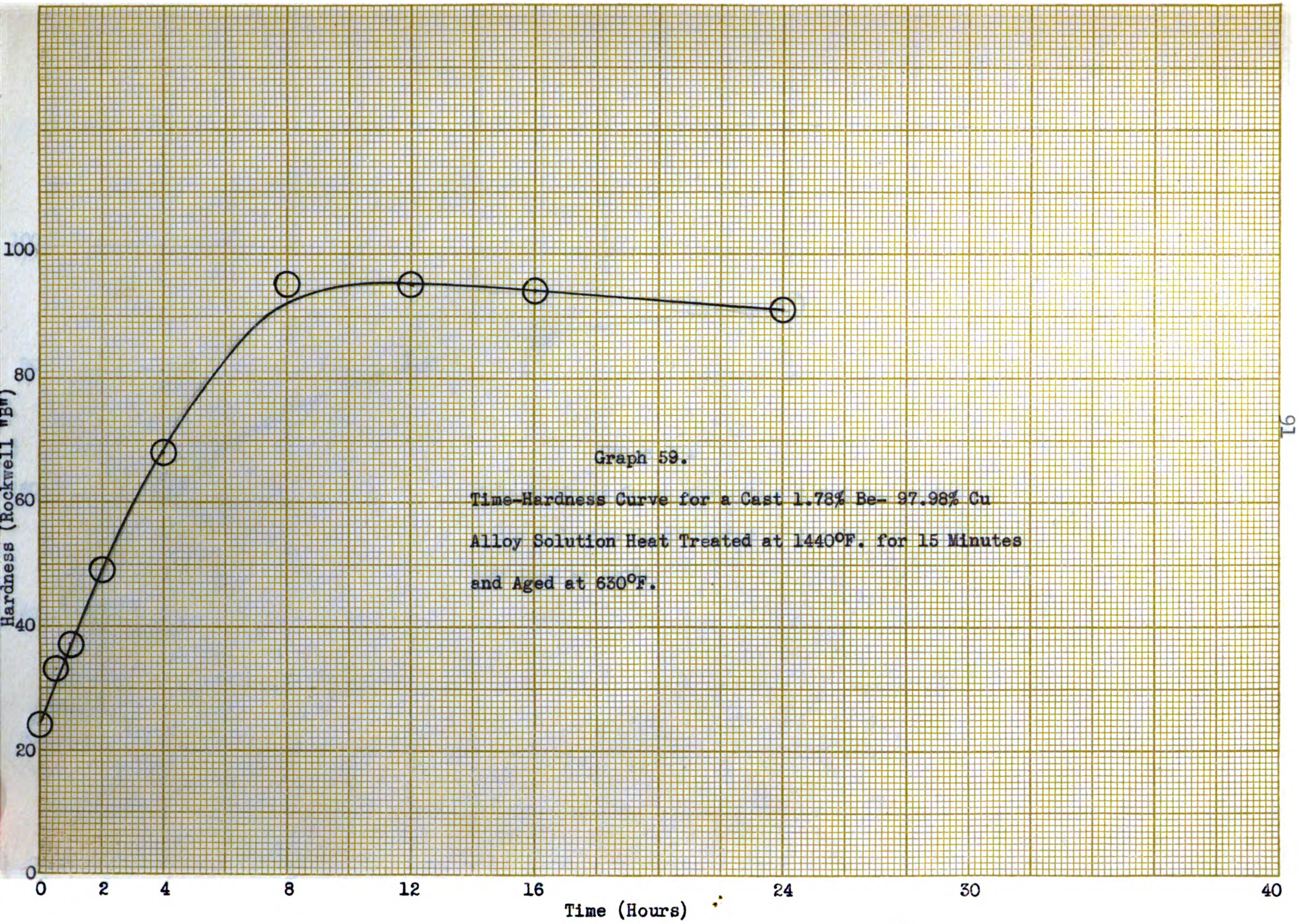
Graph 56.
Time-Hardness Curve for a Cast 1.78% Be- 97.98% Cu
Alloy Solution Heat Treated at 1470°F. for 15 Minutes
and Aged at 650°F.
Hardness (Rockwell "B")
100
80
60
40
20
0
0
2
4
8
12
16
24
30
40
Time (Hours)


Graph 57.
Time-Hardness Curve for a Cast 1.78% Be- 97.98% Cu
Alloy Solution Heat Treated at 1470°F. for 15 Minutes
and Aged at 580°F.
Hardness (Rockwell "B")
100
80
60
40
20
0
0
2
4
8
12
16
24
30
40
Time (Hours)



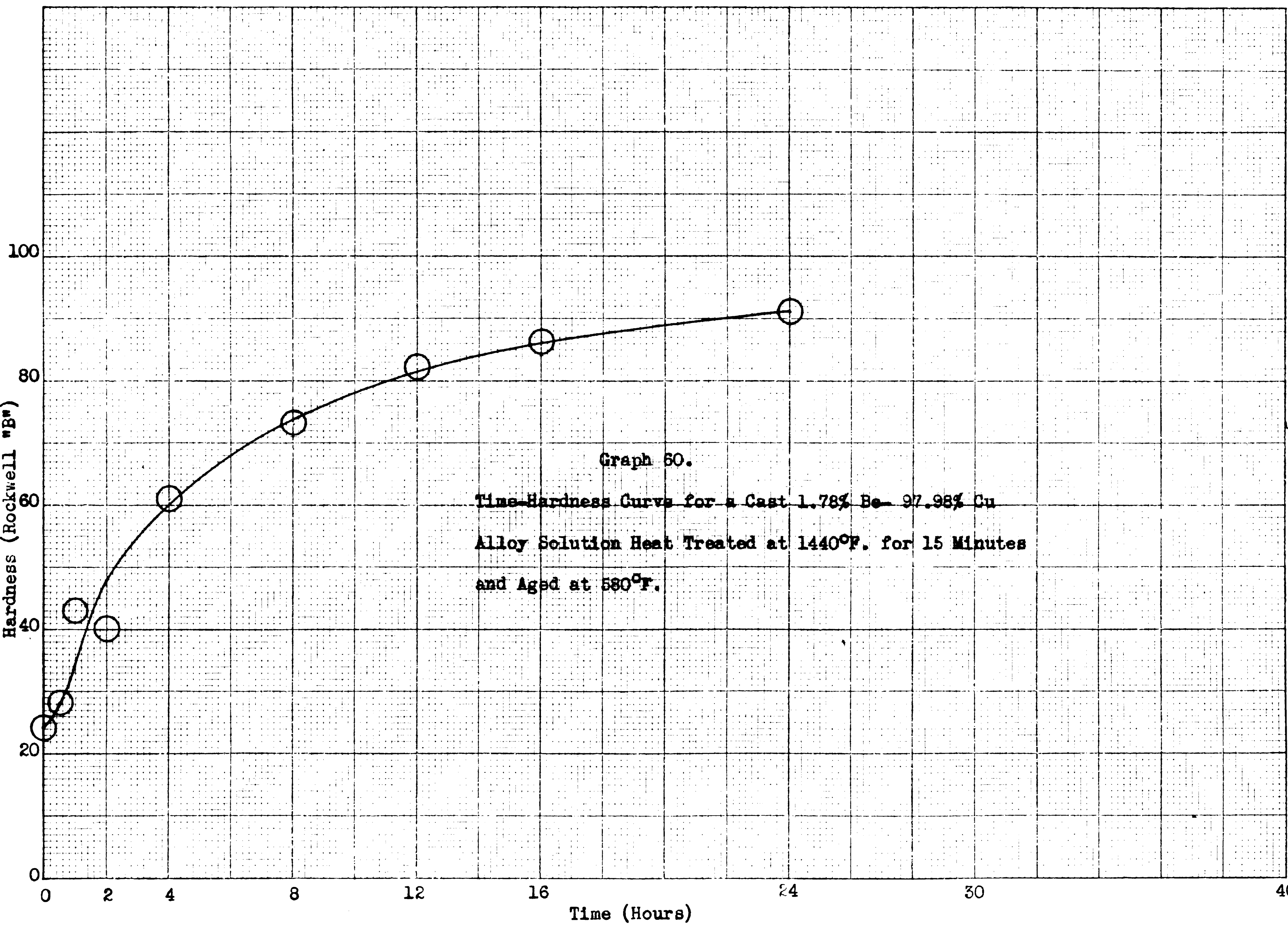
Graph.58.

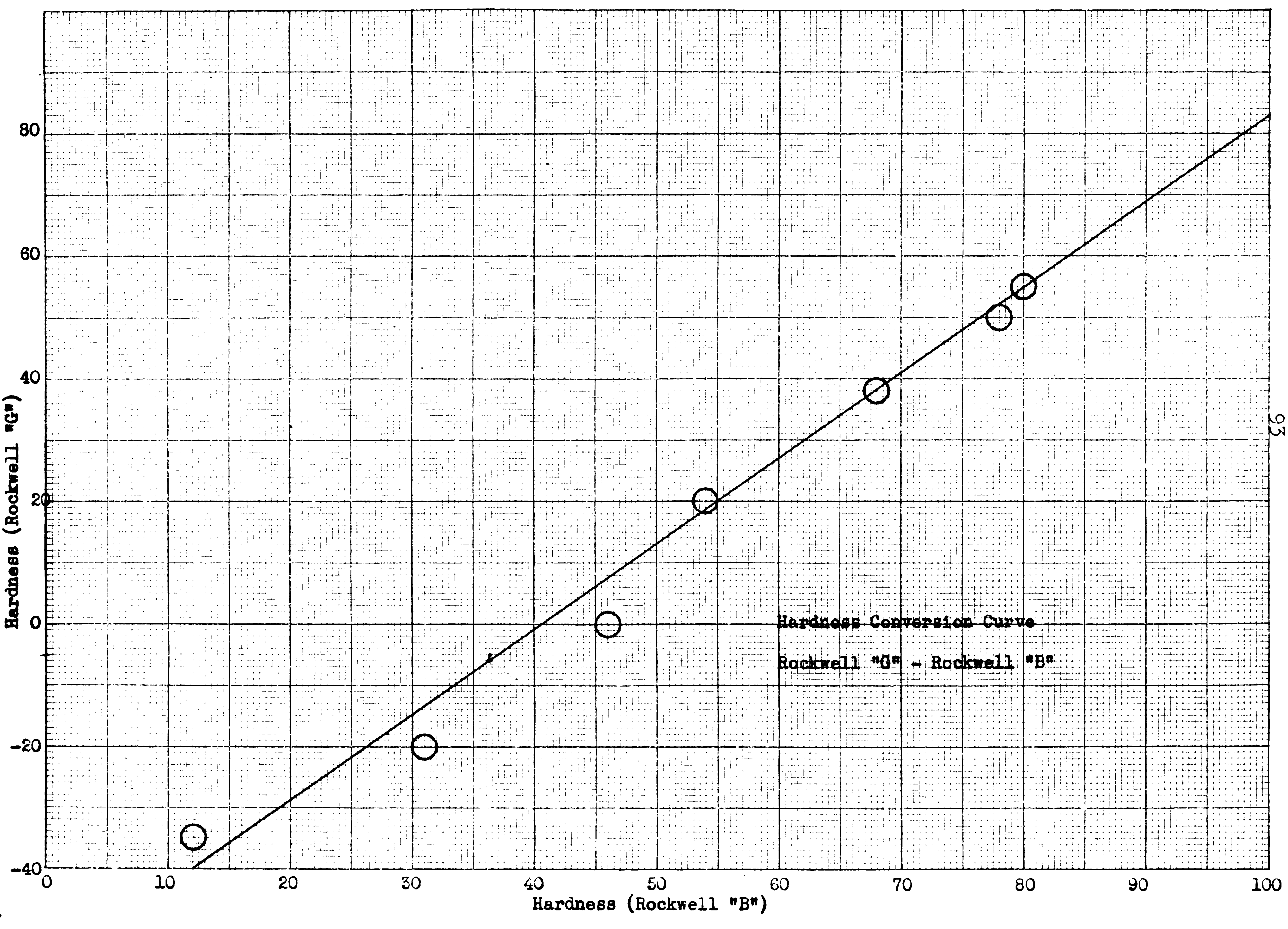
Time-Hardness Curve for a Cast 1.78% Be- 97.98% Cu Alloy Solution Heat Treated at 1440°F. for 15 Minutes and Aged at 680°F.



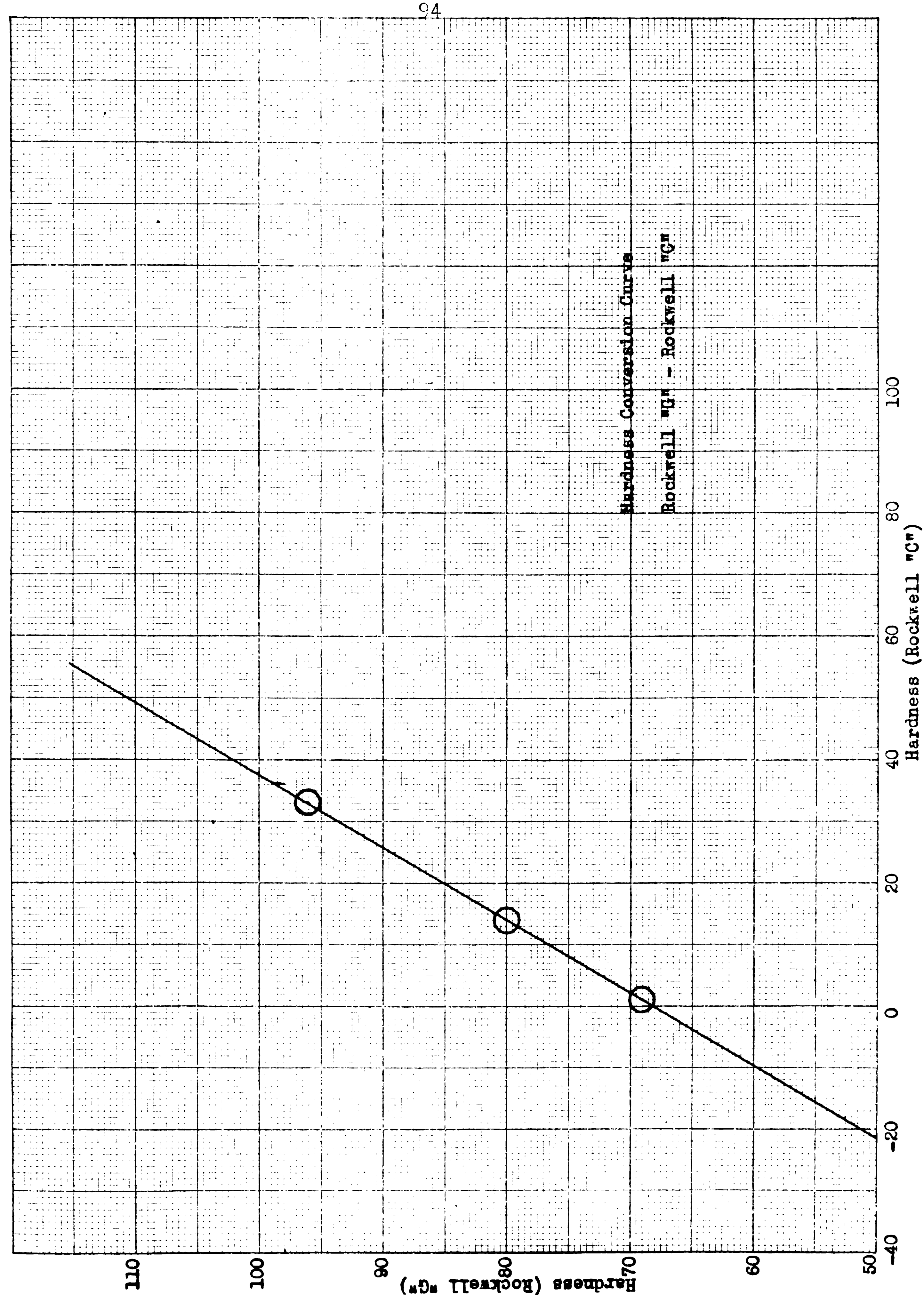
Graph 59.

Time-Hardness Curve for a Cast 1.78% Be- 97.98% Cu Alloy Solution Heat Treated at 1440°F. for 15 Minutes and Aged at 630°F.


100
80
60
40
20
0
Hardness (Rockwell "B")
0
2
4
8
12
16
24
30
40
Time (Hours)
Graph 60.
Time-Hardness Curve for a Cast 1.78% Be- 97.98% Cu
Alloy Solution Heat Treated at 1440°F. for 15 Minutes
and Aged at 580°F.



Hardness Conversion Curve
Rockwell "G" - Rockwell "B"
Hardness (Rockwell "G")
80
60
40
20
0
-20
-40
Hardness (Rockwell "B")
0
10
20
30
40
50
60
70
80
90
100


Hardness Conversion Curve
Rockwell "G" - Rockwell "C"
Hardness (Rockwell "C")
-40
-20
0
20
40
60
80
100
Hardness (Rockwell "G")
50
60
70
80
90
100
110

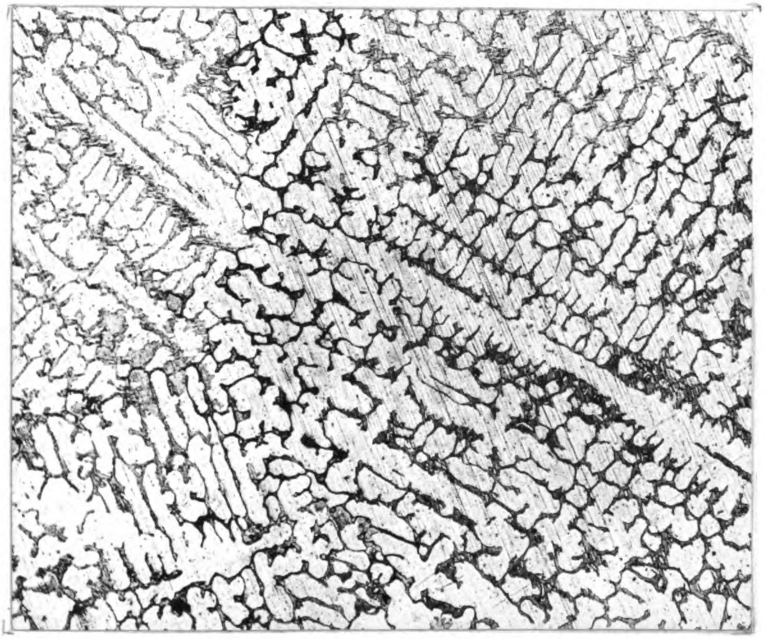


Figure 1. Microstructure of a 2.82% Be-96.82% Cu alloy in the "as cast" condition. Magnification: 100X Etchant: $FeCl_3$

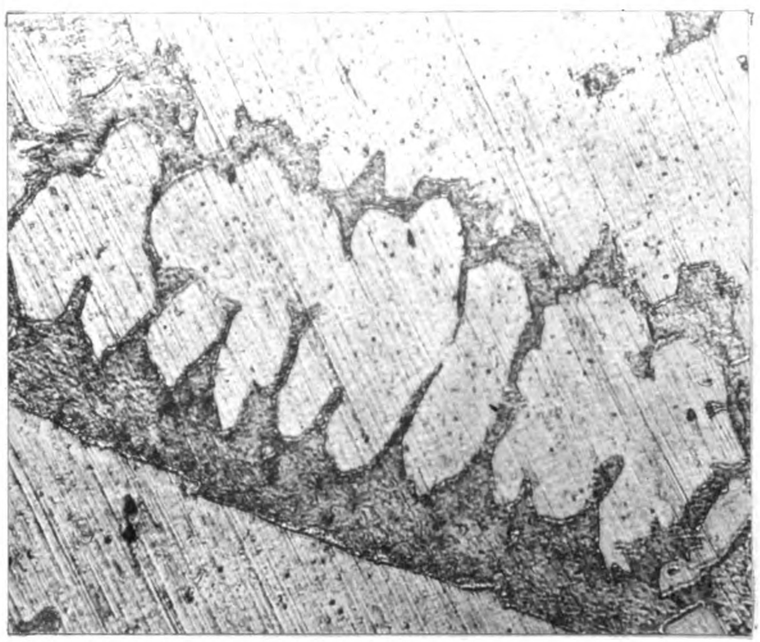


Figure 2. Microstructure of a 2.82% Be-96.82% Cu alloy in the "as cast" condition. Magnification: 500X Etchant: $FeCl_3$

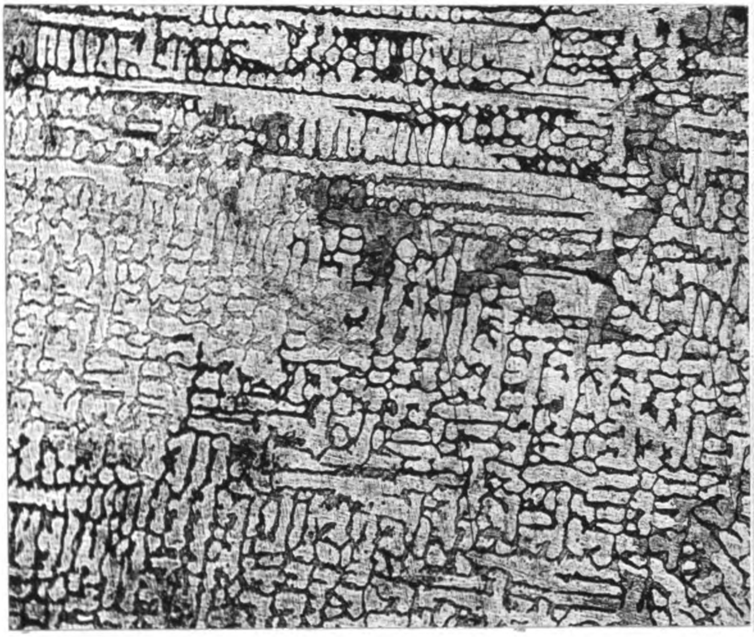


Figure 3. Microstructure of a 2.61% Be-97.16% Cu alloy in the "as cast" condition.
Magnification: 100X Etchant: $FeCl_3$

Figure 4. Microstructure of a 2.26% Be-97.58% Cu alloy in the "as cast" condition.
Magnification: 100X Etchant: $FeCl_3$

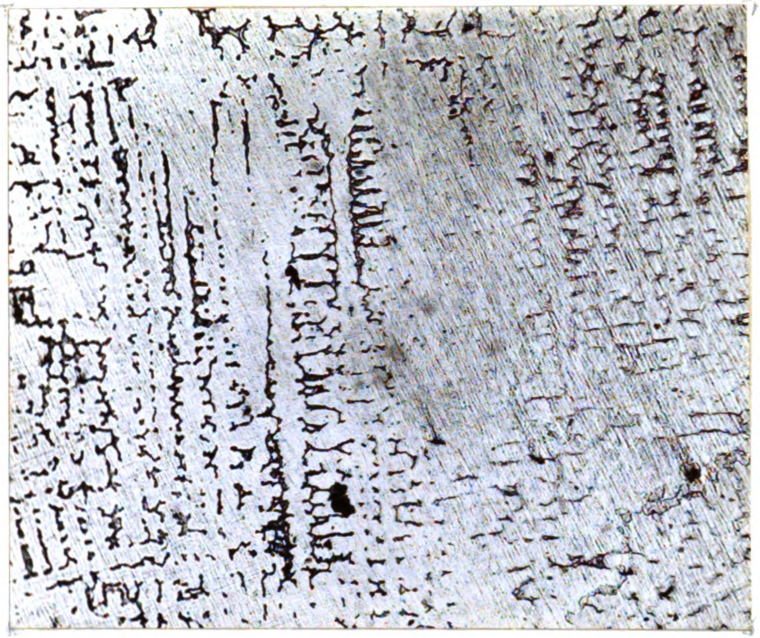


Figure 5. Microstructure of a 2.01% Be-97.79% Cu alloy in the "as cast" condition.
Magnification: 100X Etchant: $FeCl_3$

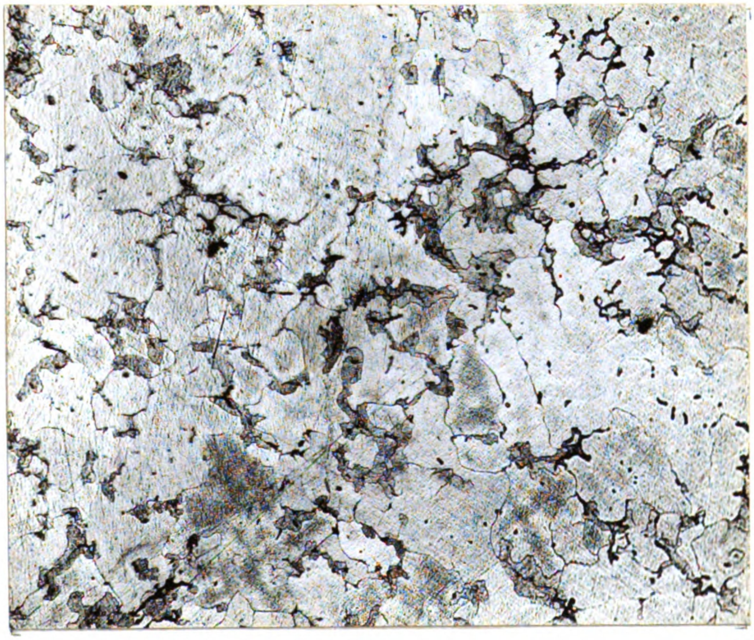


Figure 6. Microstructure of a 1.78% Be-97.98% Cu alloy in the "as cast" condition.
Magnification: 100X Etchant: $FeCl_3$

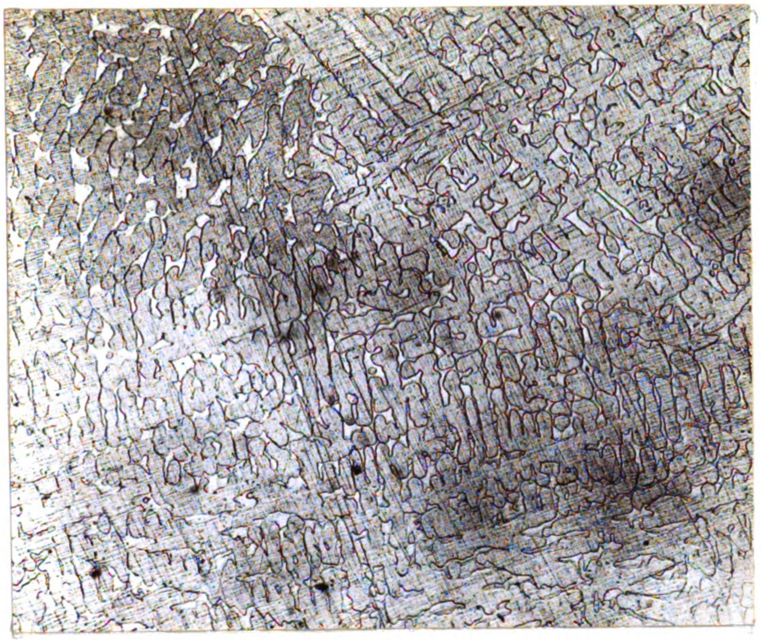


Figure 7. Microstructure of a cast 2.82% Be-96.82% Cu alloy after solution heat treatment at 1470°F. for 15 minutes.
Magnification: 100X Etchant: $FeCl_3$

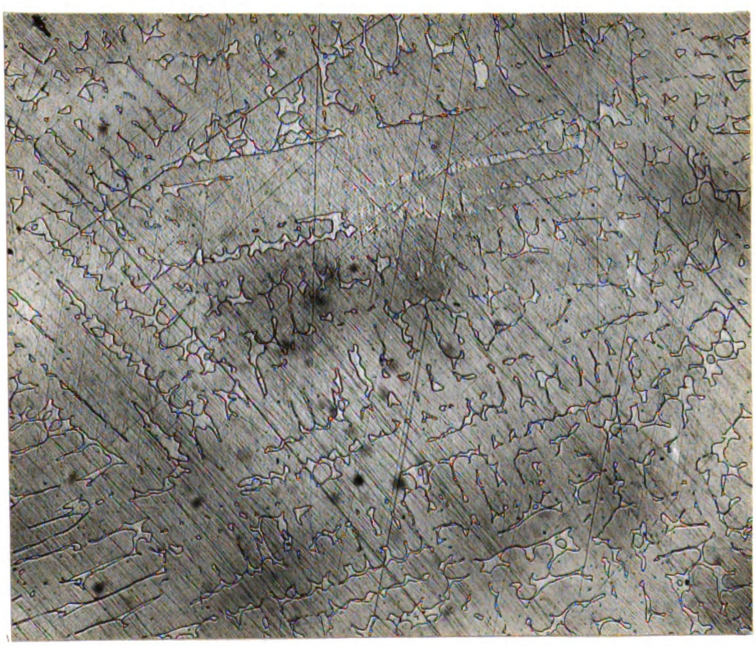


Figure 8. Microstructure of a cast 2.61% Be-97.82% Cu alloy after solution heat treatment at 1470°F. for 15 minutes.
Magnification: 100X Etchant: $FeCl_3$

Figure 9. Microstructure of a cast 2.26% Be-97.58% Cu alloy after solution heat treatment at 1470°F. for 15 minutes.
Magnification: 100X Etchant: $FeCl_3$

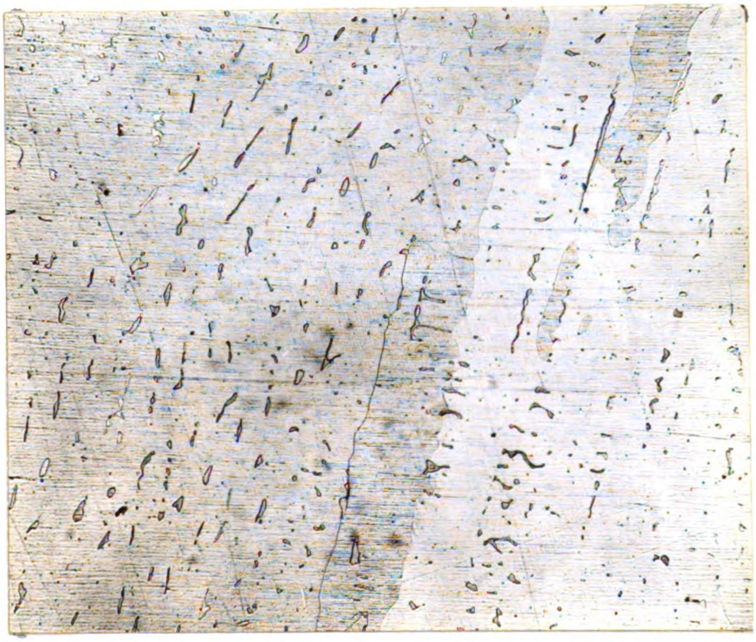


Figure 10. Microstructure of a cast 2.01% Be-97.79% Cu alloy after solution heat treatment at 1470°F. for 15 minutes.
Magnification: 100X Etchant: $FeCl_3$

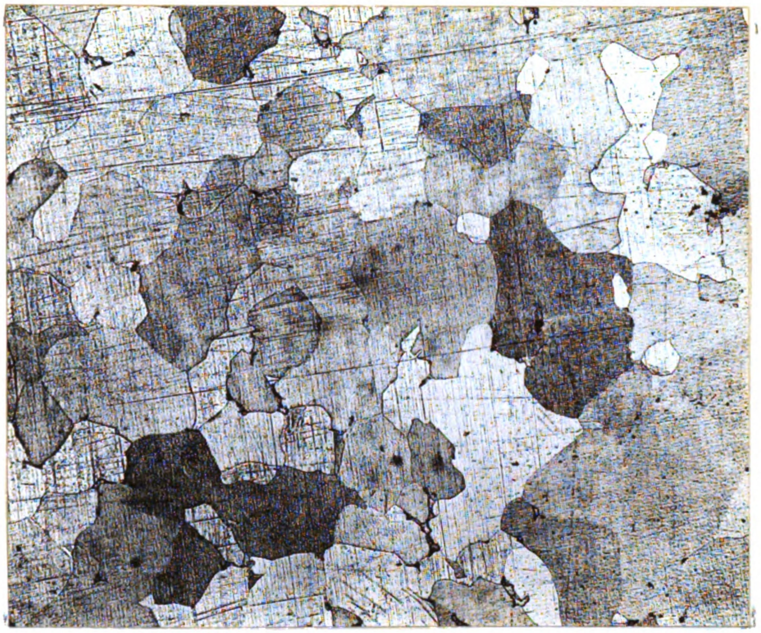


Figure 11. Microstructure of a cast 1.78% Be-97.98% Cu alloy after solution heat treatment at 1470°F. for 15 minutes.
Magnification: 100X Etchant: $FeCl_3$

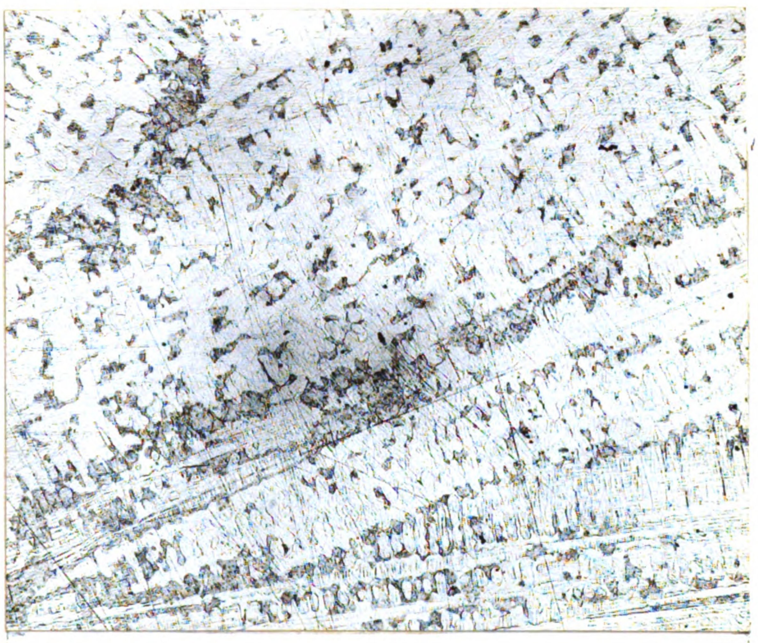


Figure 12. Microstructure of a cast 2.82% Be-96.82% Cu alloy after solution heat treatment at 1510°F. for 15 minutes and aging at 680°F. for 1 hours.
Magnification: 100X Etchant: $FeCl_3$

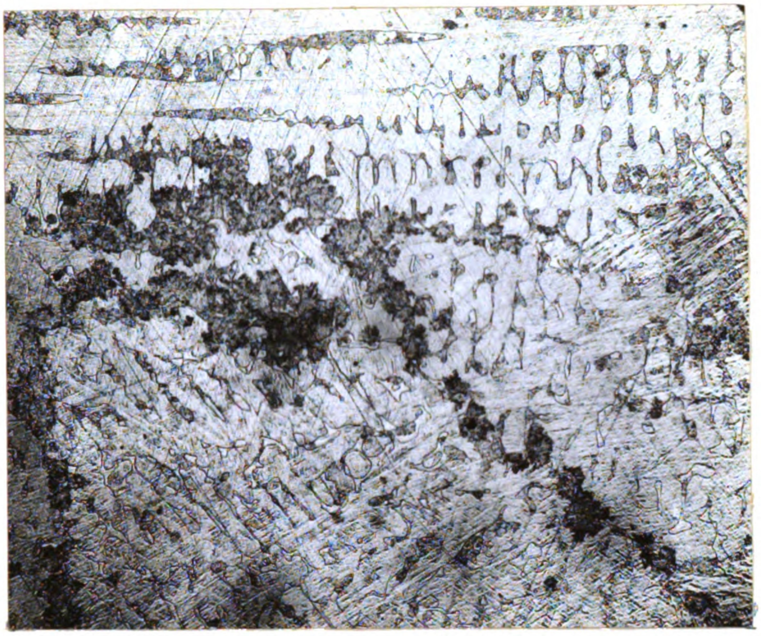


Figure 13. Microstructure of a cast 2.61% Be-97.16% Cu alloy after solution heat treatment at 1510°F. for 15 minutes and aging at 680°F. for 1 hours.
Magnification: 100X Etchant: $FeCl_3$

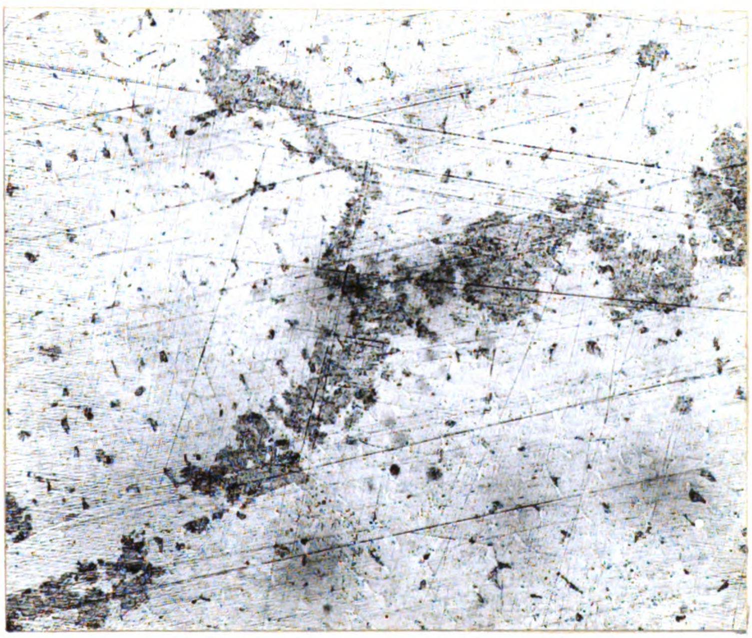


Figure 14. Microstructure of a cast 2.26% Be-97.58% Cu alloy after solution heat treatment at 1510° F. for 15 minutes and aging at 680°F. for 1 hours.
Magnification: 100X Etchant: $FeCl_3$

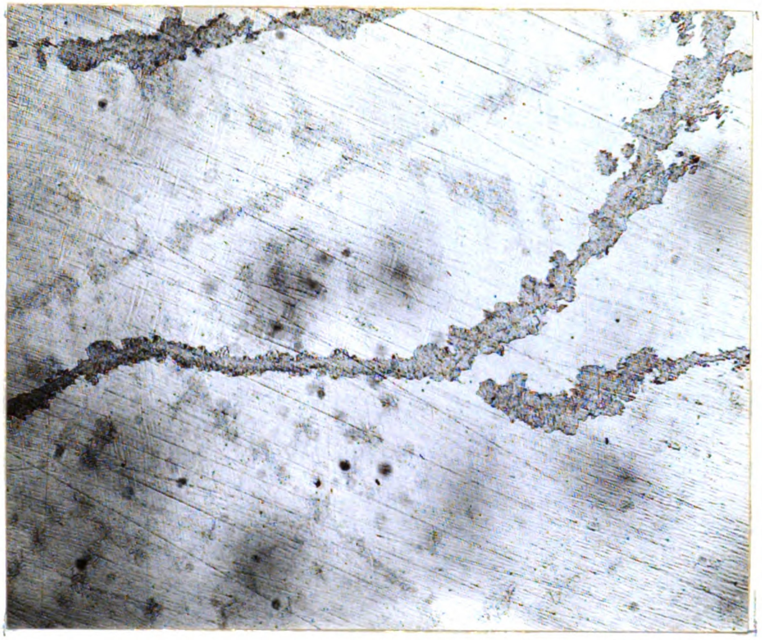


Figure 15. Microstructure of a cast 2.01% Be-97.79% Cu alloy after solution heat treatment at 1510°F. for 15 minutes and aging at 680°F. for 4 hours.
Magnification: 100X Etchant: $FeCl_3$

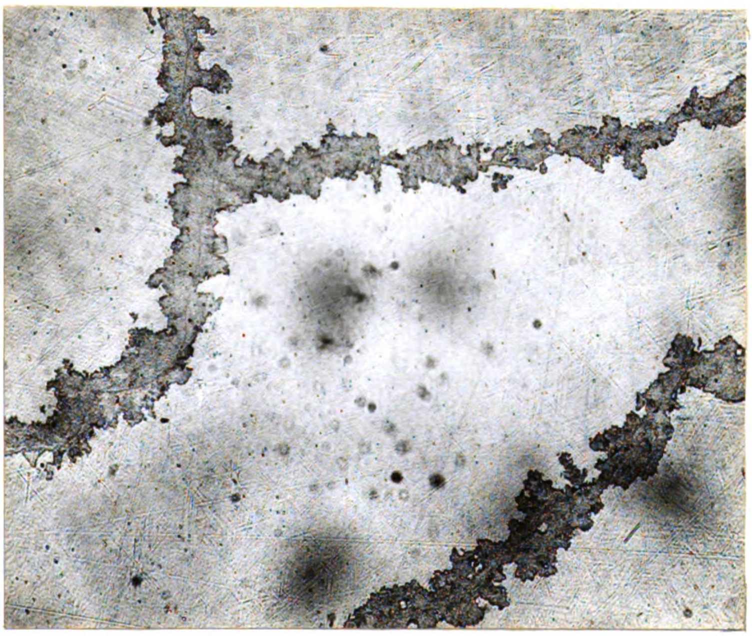


Figure 16. Microstructure of a cast 1.78% Be-97.98% Cu alloy after solution heat treatment at 1510°F. for 15 minutes and aging at 680°F. for 16 hours.
Magnification: 100X Etchant: $FeCl_3$

DISCUSSION

As indicated in the introduction to this investigation, the remarkable physical properties of beryllium-copper alloys are dependent upon the close control of heat treating processes. The object of this investigation is concerned with the correlation of beryllium content, heat treating temperatures, time at temperature and hardness; noting characteristic microstructures, tensile strength and elongation at various stages of processing.

Since commercial heat treating processes seem to have become standardized over a narrow temperature range, it was deemed advisable to investigate the heat treating characteristics of five binary alloys of beryllium and copper over the temperature range recommended in commercial practice.

Inspection of the equilibrium diagram (Figure I.) shows that the solution heat treating temperature, over the range of 1.7% Be to 2.9% Be, ranges from 1200°F. to 1545°F. Commercial practices recommend that the solution heat treating temperatures be in the range of 1400°F.[5,18,19] to 1500°F.[3,6] However, the common commercial beryllium-copper alloys contain 2.0% Be to 2.5% Be. The most probable explanation for the 30° difference in the upper limit of the theoretical and recommended temperatures is fear of "burning out" the alloy. "Burning out" is defined as the segregation of the beta phase at the grain boundries due to solution heat treating at too high a temperature. The beta phase has a melting point of 1545°F. and commercial processes do not have the close temperature control necessary to remain within the narrow temperature range, 1520°F. to 1545°F. It is also logical to assume that solution heat treating at the higher temperatures would require less time at temperature than at a lower temperature. At temperatures slightly above the minimum solution temperature, there is considerably less driving force than at a higher temperature and the atomic mobility is very low. As the temperature increases, atomic mobility increases and the rate of diffusion is high, hence, the equilibrium condition is reached more rapidly. There is still another factor to be considered and that is the effect of cold and hot working. Both hot and cold working of the alloys would tend to increase the rate of diffusion because of the high stress condition existing in the structure; possibly lowering the solution heat treating an appreciable amount.

In view of the factors enumerated in the previous discussion, the cast alloys were subjected to solution heat treatment at temperatures of 1440°F., 1470°F. and 1510°F. for periods up to 48 hours. In order that the super-saturated condition be retained, a necessary condition for age hardening, the alloys were quenched in cold water. Commercial processes nearly all call for a water quench because the temperature gradients are much higher than those obtained by oil quenching.

After the problem of solution heat treating has been solved, there remains the problem of aging the alloy. Inspection of the equilibrium diagram discloses that the possible hardening temperature range is from room temperature to 1065°F. Commercial hardening practices call for hardening over a narrow temperature range from 525°F. to 700°F.[3,5,6,7,11,15,17,18,19,21] This narrow temperature range for hardening is characteristic of many of the age hardenable alloys, e.g., magnesium-aluminum alloys (Dowmetal) and aluminum-copper alloys (Dural). In accordance with the accepted theory of hardening, there is an optimum particle size which causes the maximum amount of keying action on the potential slip planes with a resulting maximum increase in hardness and tensile strength. In order to secure the desired precipitation, the temperature must be such that there is sufficient atomic mobility to produce the optimum particle size. As the temperature increases, the atomic mobility increases and the rate of diffusion is high, causing a coalescence of precipitated particles to a size greater than the optimum. The desired physical properties decrease as the particle size increases. The selection of the commercial aging temperatures is not easily justified on the basis of the previous discussion because it is believed that time at temperature is as important as the temperature. Commercial processes are generally constituted so that time at temperatures are as short as possible without sacrificing uniformity of product.

The problem confronting the commercial heat treaters of beryllium-copper alloys is one of selecting a solution heat treating temperature and an aging temperature that can be utilized on a production basis and still maintain uniformity of products. This problem resolves itself into two separate problems, (1.) accuracy of temperature control, and (2.) accuracy in controlling time at temperature.

The aging characteristics of the alloys used were studied at temperatures of 580°F., 630°F. and 680°F. after solution heat treatment at 1440°F., 1470°F. and 1510°F.

The relationship of commercial and laboratory practices has been discussed in sufficient detail to warrant a discussion of laboratory results.

The selected alloys were cast without a great deal of difficulty in accordance with the technique described in Part 2 of the Appendix. The analysis of the first heat did not conform to the calculated composition, however, the master alloy was not analyzed until after the heats were cast because of the analysis supplied with the alloy. The beryllium content of the master alloy, as determined in the laboratory, was .30 percent higher than indicated by the data supplied with the alloy. Caculating the heats showed that the analysis obtained (see analysis data, Part 1, Appendix) were correct and the amount of beryllium loss was negligible.

After completing the casting, the test bars were cut from the pouring basin, properly labeled, machined to size (see Figure 17a) and punch marked for elongation measurements. One bar was selected from each heat for

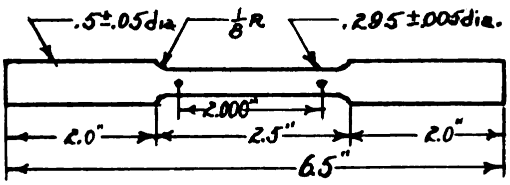


Figure 17a. Dimensions of Test Bars.

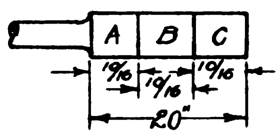


Figure 17b. Sampling The Test Bars.

determining the physical properties in the "as cast" condition. The specimens were mounted in a Dillon Tensile Tester in the manner shown in Figures 18a and 18b. Tension was applied until the specimen broke and the breaking load, the elongation and the appearance of the fracture were noted and recorded. The hardness of the bottom end of the test bar was determined and the same end cut into 3 equal portions as shown in Figure 17b. The physical properties of the alloys in the "as cast" condition are shown in Table 63.

It is interesting to note that hardness, tensile strength and elongation are proportional to the amount of beryllium that is present in the alloy. The values obtained are in accordance with those obtained by other investigators, although the test specimen was not of adequate size. It is recommended that future work be carried on using test specimens not less than one inch in diameter.

The microstructure of each of the broken specimens was examined after a macroscopic examination disclosed the presence of a dendritic structure upon fracture. Typical microstructures are shown in Figures 1, 3, 4, 5 and 6, representing, respectively, each of the heats cast. It should be noted that there is a definite dendritic pattern in evidence in the first four heats cast, while the last heat cast exhibits a modified dendritic structure. The equilibrium diagram shows that there should be two phases, alpha and gamma solid solution, present in the microstructure if a condition of true equilibrium exists. However, equilibrium does not exist because of the high cooling rate obtained upon casting. Under the existing condition of non-equilibrium, the microstructure should be constituted of alpha and beta solid solutions with traces of gamma solid solution. All three of the components, alpha, beta and gamma solid solutions, can be recognized in the microstructures of each of the heats cast. The alpha solid solution is the light etching constituent which constitutes the bulk of the structure. The alpha solid solution is the first solid solution formed and solidifies in a dendritic pattern. The beta solid solution is the last of the melt to solidify and it is found in the dendritic interstices and outlining the grains of alpha solid solution. The beta solid solution is the dark etching constituent in the microstructure. The gamma solid solution is a transformation product of the beta solid solution. It is found in the middle of the beta solid solution areas that have remained at temperature long enough for some transformation to occur. The gamma solid solution appears as light etching areas.

A representative sample (Section A., Figure 17b.) was taken from each heat and solution heat treated at 1510°F. Hardness readings were taken after solution heat treating for .25, .50, 1.0, 2.0, 3.0, 4.0, 8.0, 12.0, 24.0 and 48.0 hours.

The second portion of each broken test bar was heat treated at 1470°F. according to the scheme described above. The same procedure was repeated using the third portion of the test bar at a temperature of 1440°F.

The cumulative data obtained is expressed in tabular form, Tables 1 through 15, and in graphical form, Graphs 1 through 15.

There are several characteristics of the graphical data that merit considerable comment. It should be noted that the six hardness readings were taken to determine the average hardness. The maximum and minimum hardness readings were recorded to show the degree of uniformity or non-uniformity obtained by the heat treating processes. Average values may be misleading unless there are indications as to the amount of variation encountered.

A significant feature of the time hardness solution heat treating curves is the slight increase in hardness exhibited by the alloys of 2.82% Be- 96.81% Cu and 2.62% Be- 97.16% Cu upon initial solution heat treatment. This is in contrast to characteristics of the other three alloys which exhibit a rapid drop in hardness in the early stages of solution heat treatment. The most probable explanation for the increase in hardness is that of accelerated age hardening. The composition of the alloys is beyond the alpha solid solubility limit and, There is an appreciable quantity of the gamma phase to be found in the microstructure. Upon rapid cooling of the cast alloy, there would be an appreciable degree of supersaturated solid solution. On short time at high temperatures, the gamma solid solution would precipitate causing a slight increase in hardness and corresponding physical properties.

The heat treating characteristics, exemplified by time-hardness relationships, may be best summarized by examining a consolidation of the series of curves for the various alloys at a specific temperature. A generalized set of curves is shown in Figure 19a. As the beryllium content increases, the hardness of the solution heat treated alloy increases. However, beyond a critical time limit there is little change in the inherent hardness of each alloy.

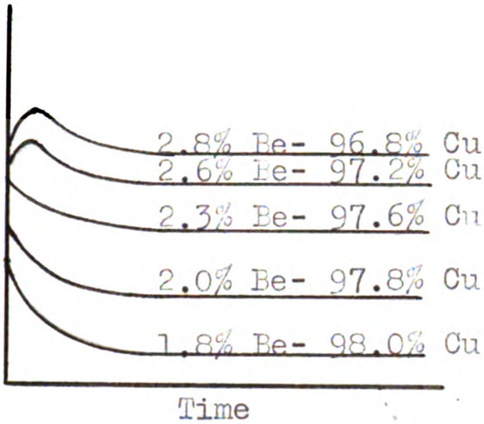


Figure 19a. Time-hardness curves for a series of cast Be-Cu alloys S.H.T. at 1510°F.

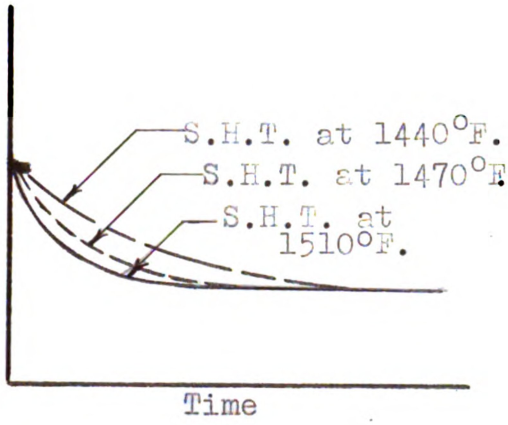


Figure 19b. Time-hardness curves for a cast 2.01% Be- 97.79% Cu alloy S.H.T. at 1440°F., 1470°F. and 1510°F.

The critical time limit will be a function of the solution heat treating temperature as evidenced by an inspection of a generalized, consolidated, time-hardness curve for a particular alloy at various solution heat treating temperatures. This curve is shown in Figure 19b. It should be noted that the critical time limit increases as the solution heat treating temperature decreases. Beyond the critical time limit there is very little change in the hardness value no matter what the solution heat treating temperature may be. In other words, short time-high temperature solution heat treatment may be duplicated by prolonged solution heat treatment at lower temperatures.

Since the greatest changes seem to appear in all the alloys after 15 minutes of solution heat treatment at each of the selected temperatures, it was considered that a 15 minute solution heat treatment would add to the interest

Figure 18a. Dillon Tensile Tester with specimen mounted.

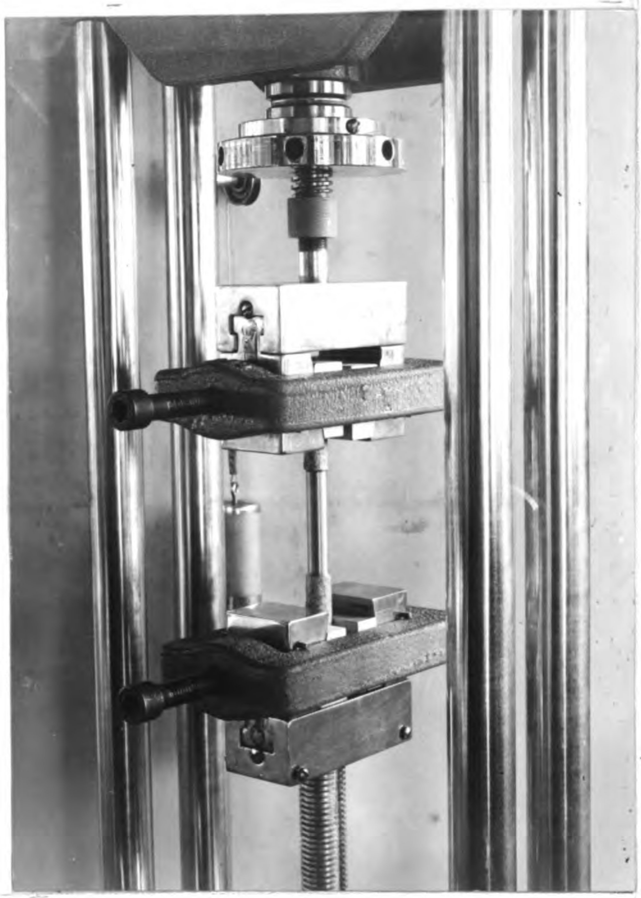


Figure 18b. Detailed view of the mounted specimen.

of the investigation. It is realized that optimum aging properties cannot be expected with insufficient heat treatment.

Three test bars from each of the heats cast were solution heat treated at 1440°F., 1470°F. and 1510°F. for a period of 15 minutes and quenched in cold water. One bar from each heat solution heat treated at the appropriate temperatures (15 bars in all) were selected to determine the physical properties of the alloys at this stage of processing. The specimens were broken in the Dillon Tensile Tester and the following facts noted and recorded: breaking load, elongation and fracture appearance. The hardness of the bottom end of the test bar was determined and the same end cut into 3 equal portions. The physical properties of the alloys in the solution heat treated condition are summarized in Table 64.

The most striking feature of the alloys in the solution heat treated state is the erratic character of the physical properties. Although the average hardness for each alloy solution heat treated at the selected temperatures is uniform, the variation in the hardness of each specimen is considerable. This would seem to indicate that the microstructure of the alloys would show soft and hard constituents. Tensile strength and elongation are very erratic, which may be due, in part, to the size of the test specimen. Light porsity in a small diameter test bar will accentuate a decrease in tensile strength because the effective area will be greatly decreased. When bars of larger diameter are used, the decrease in the effective area is not so great. Elongation is also dependent upon the soundness of the test bars.

Characteristic microstructures are exhibited in Figures 7 through 11. Examination of the photomicrographs shows that the microstructure of each of the alloys is a transformation product of the cast structures. The beta phase has disappeared leaving the microstructure composed of two solid solutions. The darker etching constituent is the supersaturated alpha solid solution, which is very soft and ductile. The light etching constituent, standing in relief, is the gamma solid solution. The gamma phase is very hard and brittle. Decreasing beryllium content gives a decreasing amount of gamma phase in the microstructure. This is justifiable on the basis of the following explanation. When high beryllium alloys are cast, there w will be considerable beta phase present in massive form. As the beryllium content decreases the amount of the beta phase will become smaller and smaller. In alloys of low beryllium content, the beta phase would have disappeared almost completely leaving only alpha solid solution. Solution heat treating would decompose the beta phase leaving the gamma phase in the form of massive particles. Larger particles of gamma phase are more difficult to dissolve because the alpha solid solution in the immediate vicinity of the gamma particles become supersaturated very quickly and the rate of diffusion is materially decreased.

One section from each test bar was taken, as previously described, and aged at 580°F. Hardness readings were taken on each specimen after aging for periods of .50, 1.0, 2.0, 4.0, 8.0, 12.0 and 24.0 hours. The second portion of each test bar was aged at 630°F. according to the scheme described above. The same procedure was repeated using the third portion of the test bar at a temperature of 680°F.

The cumulative data is expressed in tabular form, Tables 16 through 60, and in graphical form, Graphs 16 through 60.

The graphical data has several characteristics that are worthy of considerable comment. It should be noted that six hardness readings were taken to determine the average hardness. Maximum and minimum hardness readings were recorded to show the degree of uniformity obtained upon aging.

It was found that maximum hardness obtainable upon age hardening is a function of the beryllium content, up to a certain concentration, 2.26% Be. Alloys richer in beryllium showed little or no increase in hardness. This is explainable upon investigation of the equilibrium diagram. The solubility of beryllium in the alpha solid solution increases to a maximum at 2.4% Be at approximately 1580°F. At the solution heat treating temperature, the maximum amount of beryllium expected in the alpha solid solution is approximately 2.3 percent. This concentration of beryllium will produce the maximum amount of precipitation of gamma solid solution along the potential slip planes with maximum hardness resulting. However, a large excess of the gamma phase will cause a higher reading by virtue of the inherent hardness of the gamma solid solution. This extremely hard condition was observed in the master alloy (containing 4.28% Be).

Solution heat treating at different temperatures appears to have no noticable effect on the time-hardness curve. However, the temperature at which aging proceeds has a very pronounced effect on the shape of the time-hardness curves. Examination of the shapes of the curves discloses that the rate of aging increases with increasing aging temperatures. After full hardening, the rate of overaging also increases as the aging temperature is increased. It should be noted that full hardening is dependent upon time at temperature and not on aging temperature. This is true of all the alloys studied.

There is still another characteristic of the series of curves that is of prime importance and should be commented upon. Although maximum hardness is not a strict function of beryllium content, rate of aging and beryllium content are very closely related. Alloys of beryllium, richer in beryllium than 2.4 percent, produce a highly supersaturated solution upon proper solution heat treatment. Upon aging, the gamma phase precipitates very readily and optimum particle size is obtained very quickly and, hence, produce full hardness over short time intervals. Alloys containing less than 2.4 percent beryllium are not highly supersaturated, even though properly solution heat treated. Aging low beryllium (2.4% Be or less) causes precipitation of the gamma phase once again. However, since the solid solution is not highly supersaturated, much diffusion may be necessary before the particles may coalesce to the optimum size. This rate of diffusion is greater at higher temperatures giving rise to the possibility of using considerably higher temperatures when aging the low beryllium alloys. As discussed above, maximum hardness is a function of time at temperaturesand not temperature.

Lack of sufficient time forced the investigation to a close and it was decided to determine the physical properties of the aged alloys after aging as indicated on the following page.

Each specimen was broken in an Olsen Tensile Tester and the following facts noted and recorded: breaking load, elongation and fracture appearance. Hardness readings were taken on the bottom end of the bar. The physical properties of the alloys in the aged condition are summarized in Table 65.

Table I. Aging procedure.

% Be	S.H.T. Temp.	Time at Temp.	Aging Temp.	Time at Temp.
2.82	1510°F.	15 min.	680°F.	1 hour
2.62	1510°F.	15 min.	680°F.	1 hour
2.26	1510°F.	15 min.	680°F.	1 hour
2.01	1510°F.	15 min.	680°F.	4 hours
1.78	1510°F.	15 min.	680°F.	16 hours
2.82	1470°F.	15 min.	630°F.	2 hours
2.62	1470°F.	15 min.	630°F.	2 hours
2.26	1470°F.	15 min.	630°F.	2 hours
2.01	1470°F.	15 min.	630°F.	4 hours
1.78	1470°F.	15 min.	630°F.	16 hours
2.82	1440°F.	15 min.	580°F.	4 hours
2.62	1440°F.	15 min.	580°F.	4 hours
2.26	1440°F.	15 min.	580°F.	4 hours
2.01	1440°F.	15 min.	580°F.	8 hours
1.78	1440°F.	15 min.	580°F.	24 hours.

The most significant feature of the physical properties is, of course, the great increase in hardness. It should be noted that the tensile strength and elongation have behaved in the manner that was expected, i.e., tensile strength increased and elongation decreased greatly. The properties of the aged alloys are in accordance with results of other investigations.

The microstructure of a typical aged specimen from each heat was investigated and photographed. Photomicrographs of typical structures are shown in Figures 12 through 16. The photomicrographs give evidence that hardening has taken place because of the dark-etching gamma phase precipitated at the grain boundaries. The lighter etching constituent is that part of the gamma phase remaining after solution heat treatment. The matrix is the hardened alpha solid solution phase.

CONCLUSION

It is realized that the results of this investigation are not complete enough to warrant their incorporation into commercial practices, however, several general conclusions can be drawn as regards the effect of heat treatment upon cast alloys.

The results indicate that the physical properties of the cast alloys are proportional to the ammount of beryllium in the alloy. Hardness, tensile strength and elongation increase as the beryllium content increases from 1.78 percent to 2.82 percent. The physical properties obtained are in good agreement with those obtained by other investigators.

It was found that the solution heat treating temperature does not materially affect the physical properties of the alloys in the aged condition, if the solution heat treatment has been proper, i.e., time at temperature has been long enough to insure homogenity. As the solution heat treating temperatures are increased, shorter times at temperature may be employed with the same resultant properties. Proper solution heat treatment results in a decrease in hardness and tensile strength and an increase in elongation as compared to the corresponding properties of the cast alloy. When high beryllium alloys are used, accelerated aging may take place in the early stages of solution heat treatment. Because of insufficient heat treatment, the physical properties obtained were only in fair agreement with those obtained by other investigators.

The greatest effect of heat treatment was obtained upon aging. The shape of the aging curve is dependent upon the beryllium content of the alloy and the temperature. As the beryllium content increases, the alloys harden more rapidly until the beryllium content reaches 2.3 percent. Alloys richer than 2.3% Be all age harden in approximately the same time interval. Increasing the aging temperature decreases the aging time, however, the maximum hardness is dependent on the beryllium content. Above 2.3% Be, the hardness increases by virtue of the inherent hardness of the gamma phase. The tensile strength of aged alloys is increased greatly as compared to the cast and solution heat treated alloys. The elongation is extremely low as was expected. The physical properties obtained are in fair agreement with those obtained by other investigators.

Even though the investigation is incomplete, it is believed that commercial practices could utilize higher solution heat treating temperatures, 1510°F. to 1535°F., if accurate temperature control were maintained. It is also believed that higher aging temperatures, 700°F. to 750°F., could be used with low beryllium alloys. For increasing beryllium content the aging temperature should be lower proportionately.

APPENDIX

Part 1. Analysis Procedure.[25]

Determination of Copper.

In a 400 ml. beaker, dissolve 5 g. of well mixed turnings in 50 ml. of mixed acid solution. Dilute to 250 ml. and determine copper by electrolytic method (Fischer Electro-Analyzer) using platinum gauze cathodes. Pass .3 amperes through the solution for a period of 24 hours. From the weight of copper deposited, calculate the percentage of copper

Determination of Silicon, Iron and Aluminum, and Beryllium.

Evaporate solution from copper determination to 100 ml. concentrated sulfuric acid and evaporate to fumes of sulfur trioxide. Take up with 100 ml. of water containing 10 ml. hydrochloric acid, bring to a boil and filter through ashless paper. Wash thoroughly with hot water and save filtrate for determination of iron, aluminum and beryllium. Ignite residue in a weighed platinum crucible and weigh, moisten the residue with a few drops of sulfuric acid, add 10 ml. hydroflouric acid and evaporate to dryness. Ignite at a dull red heat for 5 minutes, cool and weigh. The loss in weight is silicon dioxide. If any residue remains it must be redissolved in hydrochloric acid and added to the original filtrate.

Evaporate original filtrate plus "silica washings" to 100 ml., add 3 drops of methyl red indicator, neutralize with ammonium hydroxide and, then, add hydrochloric acid dropwise until the solution is acid and clear. Heat to 60°C. and add an excess of 8-hydroxyquinoline. Add 2.0-N. ammonium acetate solution until all the aluminum and iron are precipitated, then add 25 ml. excess. Filter and wash with cold water. Ignite precipitate in a weighed platinum crucible for 1 hour at 1000°C. Difference in weight is the combined weight of Al_2O_3 and Fe_2O_3 from which the combined percentage of iron and aluminum may be calculated. The iron may be determined by making a potassium bisulfate fusion, dissolving the fusion in sulfuric acid, passing the solution through a Jones' reductor and then titrating the iron with a standard potassium permanganate solution. The iron is also calculated in terms of Fe_2O_3 so that the Al_2O_3 and, hence, the percentage of aluminum may be calculated.

Heat the filtrate from the iron-aluminum determination plus the "cold water washings" to 60°C. and add ammonium hydroxide until alkaline to phenopthalein. Cool to room temperature and filter precipitate on ashless paper. Wash precipitate with 1% ammonium chloride solution. Evaporate filtrate and washings to one-forth their original volume and precipitate any remaining beryllium. Filter and add the second precipitate to the first precipitate. Ignite in a weighed platinum crucible at 1000°C. after the paper has been burned off. Cool, weigh rapidly and record increase in weight as BeO. Calculate percentage beryllium. Duplicate samples are run throughout the entire analysis.

Preparation of Reagents

Mixed Acid Solution.

To 625 ml. of distilled water add 250 ml. of concentrated sulfuric acid and 175 ml. of nitric acid.

8-Hydroxyquinoline Solution.

Triturate 2.5 g. of solid reagent with 5 ml. of glacial acetic acid. When completely dissolved pour into 100 ml. of distilled water and heat to 60°C.

Ammonium Chloride Washing Solution.

Dissolve 10 g. ammonium chloride in distilled water, make just alkaline with ammonium hydroxide and dilute to 100 ml.

Ammonium Acetate 2.0-N. Solution.

Dissolve 15.4 g. ammonium acetate in distilled water and dilute to 100 ml.

Tabulated Analysis Data

Heat Number	1	2	3	4	5
% Beryllium	2.82	2.61	2.26	2.01	1.78
% Copper	96.81	97.16	97.58	97.79	97.98
% Silicon	.104	.101	.105	.085	.063
% Iron and Aluminum	.150	.133	.135	.125	.168
Total	99.984	100.004	99.980	100.000	99.991

Part 2. Casting Procedure

Mold Preparation

All heats were cast in core-sand molds made up in the following manner. To 100 parts of lake sand add 5 parts of cereal binder and mix well, add 5 parts of water and mix well, and finally, add 2.5 parts of oil binder and mix well. The resulting core-sand mixture is rammed tightly in a mold-box (shown in Figure 21.) and the mold-box removed. The green molds are then baked for 24 hours at approximately 500°F. When cool, the cured molds are given a light wash with mold-coating in order to secure a cleaner casting. The coated molds are dried at 300°F. for 16 hours.

Melting and Casting Technique[3]

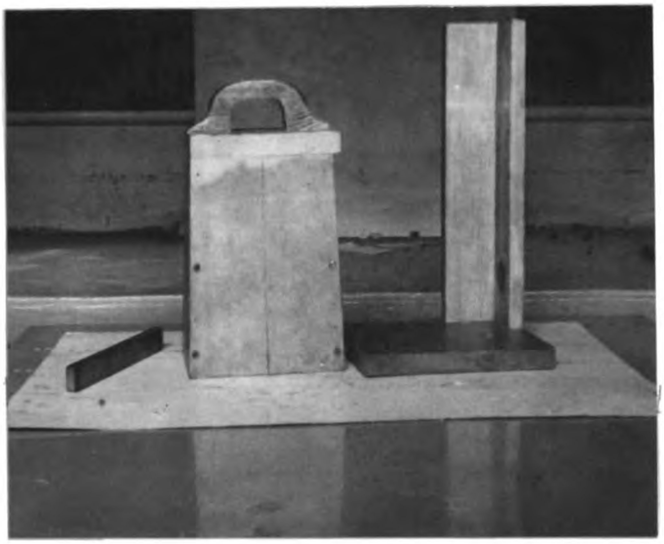
Calculate the correct proportions of master alloy and electrolytic copper necessary to make up a heat of the required size. Melt the copper in a crucible (shown in Figure 23.) using a layer of coarse graphite as a protective covering. When the molten copper reaches a temperature of 2000°F., the pigs of master alloy are dropped in, one by one. Raise the temperature of the melt to 2100°F. and remove the crucible from the furnace. Stir the melt with the thermocouple to insure homogenity and remove the protective layer of graphite with a "slag skimmer". Allow the melt to cool to 2000-1950°F. and pour the melt into the molds with a minimum amount of delay.

The loss of beryllium, by oxidation, in the melting practice used, was negligible.

Calculation of Heats Melted

Heat Number	1	2	3	4	5
% Beryllium (Calculated)	2.50	2.25	2.00	1.75	1.50
Weight of Master Alloy Used	5966g.	5270g.	5230g.	4949g.	4148g.
Beryllium in Master Alloy*	238g.	211g.	209g.	197g.	165g.
Estimated Loss of Beryllium#	17g.	15g.	15g.	14g.	12g.
Weight of Copper Used	2924g.	3330g.	4970g.	5508g.	6052g.
% Beryllium (Actual)	2.82	2.61	2.26	2.01	1.78

* Calculated on the basis of 4% beryllium in the master alloy.
# Calculated on the basis of a theoretical loss of 7% of the contained beryllium.



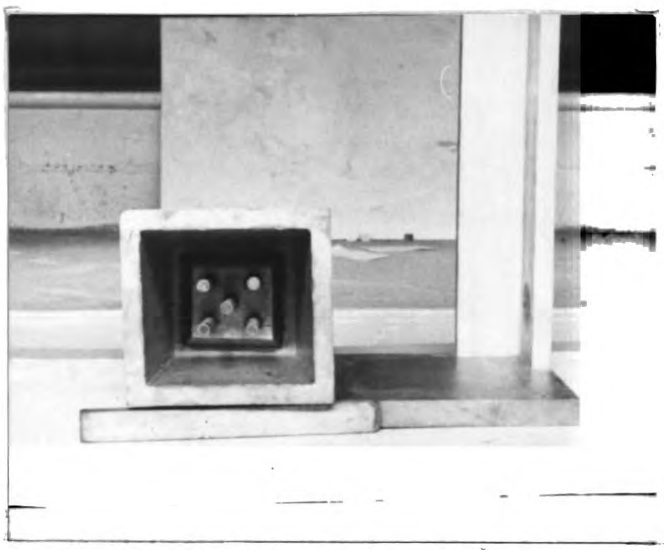


Figure 21. Two views of the mold box.

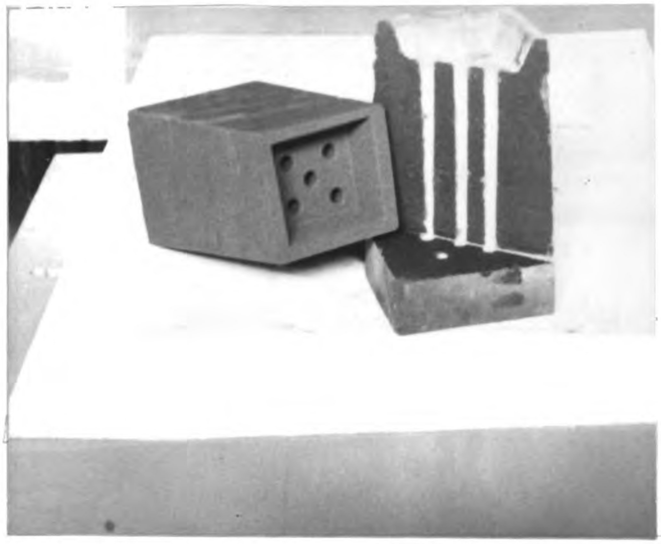


Figure 22. View of coated and
uncoated molds.

Figure 23. Materials and equipment.

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