AGE HARDENING OF HEAT TREATED ALUMINUM ALLOY.

AN INVESTIGATION OF THE FLUCTUATION OF HARDNESS WITH TIME OF AGEING OF HEAT TREATED ALUMINUM ALLOY SHEET.

THESIS

by

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I. ACKNOWLEDGMENTS:

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In particular they wish to thank Dr. T. von Karman, Director of the laboratory, Dr. E. E. Sechler, under whose direction this research was carried out, Mr. W. L. Howland for his valuable assistance during the investigation, and the Northrop Aircraft Corporation for its hearty co-operation.

II. SUMMARY:

The authors have found what they believe to be a tendency for a certain Aluminum Alloy, namely 24-SO, to fluctuate in strength, and hardness, during the process of age hardening, after heat treatment.

This variation in hardness of the material, while the ageing process is going on, is accompanied by a change in ultimate strength, and in the stress- strain relationship of the material; and in general the condition of the alloy is indicated by the hardness number.

The limited scope of this research does not indicate that this phenomenon of fluctuation of hardening is constant in occurrence; as the number of tests made were insufficient to determine the regularity, or irregularity, of this characteristic of the material.

All of the metal tested became stable within the commonly accepted range of ultimate strength for this alloy.

From these few experiments it appears that although the hardness varies with time the alloy, if allowed to age sufficiently, will develop its rated strength.

III. INTRODUCTION:

Various reports have been made to the effect that sheet aluminum alloy, after being heat treated, quenched, and allowed to begin normal age hardening, did not respond to ageing as might be expected, nor did it follow the theoretical hardening curve with reasonable agreement. It was found that sheet material, although apparently properly heat treated, had not hardened, or acquired its full strength, when inspected by hardness testing methods.

From observations it was found that the same piece, which was observed to be soft, when allowed to age for a longer period and tested again for hardness, had in some cases come up to the required standard, and in others had exceeded the inspection limits.

To the best of the authors knowledge no systematic investigation of this phenomenon has been undertaken, and as a preliminary quest in this field of research a periodic measurement of hardness, and tensile strength, was carried out to determine the actual manner in which the selected material would harden with time, and to correlate its indicated hardness with the strength of the piece at the time of measurement.

IV. EXPERIMENTAL INVESTIGATION:

As the number of variables involved in this problem would necessitate an extensive research program, if all were brought into agreement, it was attempted to control but a few, and to use only two sheets of the same material of different thickness. Specimens from both sheets were constructed, heat treated, and tested under as near identical conditions as were possible in an attempt to obtain data for a first comparison.

Tensile test specimens such as shown in figure "A" were cut with the grain of the material, before the metal was heat treated, from standard 24-SO Aluminum Alloy sheet of 0.020 inches and 0.040 inches in thickness.

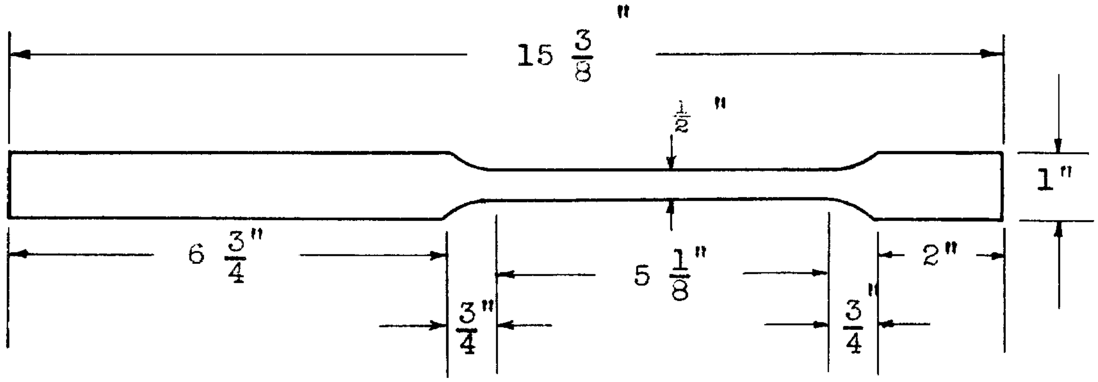


Figure "A"

One end of the test blank was made longer to afford sufficient material to obtain hardness readings before breaking the piece in the testing machine.

The 0.020 material was heat treated in a circulating air furnace at 920 degrees Fahrenheit for twenty two (22) minutes at heat, spray quenched, and immediately packed in dry ice to retard ageing during the two hour interval necessary to take them to the laboratory for testing. The 0.040 specimens were subjected to the same handling, except, the heat treatment was for thirty (30) minutes at heat.

Zero time of age hardening was taken as the time that the specimens reached room temperature after being removed from the dry ice. The investigation began at this point, and hardness readings, both Shore Scleroscope and Rockwell, stress-strain data, and ultimate strength based on original area, were taken at hourly intervals for twenty nine (29) hours; three (3) hour intervals for eighteen (18) hours, and for the remainder of the experiment at six (6) hour periods.

Upon completion of this series a second test was conducted, under the same circumstances, in an attempt to duplicate the first forty (40) hours of the initial hardening curves. For this second run the 0.020 material was taken from a different shipment of sheet.

In connection with this second experiment a plain test blank, of both materials, was heat treated with the tensile specimens, and during the run hardness numbers were taken on these pieces for a comparison with those of the second series.

The equipment used in carrying out this problem were standard laboratory and production control instruments; and consisted of a Riehle Testing Machine of 3000 pounds capacity, a Shore,Diamond Point, Self Recording Scleroscope, and a Rockwell Hardness Testing Machine.

The Diamond Point Scleroscope was used as this was the only instrument of this type available.

The ultimate strengths as shown are expressed in pounds per square inch, based on original area; all Scleroscope numbers are the dial readings of the instrument; the Rockwell numbers result from using a one-sixteenth (1/16) inch steel ball with a sixty (60) kilogram load, and are expressed as "F" scale numbers, i.e. (F96). This Rockwell combination was selected because of the thin material used in the investigation.

The Scleroscope hardness numbers plotted on all curves are an average of ten (10) or more readings on each specimen, while the Rockwell numbers are an average of six (6) or more measurements on each test blank.

V. DISCUSSION OF RESULTS:

Because the initial time interval selected for each individual test was small, (one hour), only one specimen of each material could be tested, hence the results presented on the accompanying curves are single specimen tests, and not the average for a group as would be desired. On all the curves, except the stress-strain which are faired and corrected to zero, the experimental points, as obtained, are connected to show any variation.

Figures 1 and 2 are plots of ultimate strength, Scleroscope, and Rockwell hardness numbers of both materials for test 1. One specimen, as shown, was tested after 840 hours to observe any changes in this group after an extensive elapse of time. After approximately forty (40) hours the material has stabilized above 60,000 pounds per square inch.

Figures 3 and 4 are reproductions of the first forty-seven hours of the first test on a larger scale.

Figure 5 is a comparison between the ultimate strengths and hardness numbers of the two materials for the first forty-seven hours of the first test.

Figures 6 and 7 are superpositions of the stress-strain curves of various specimens, selected from points on the curves of figures 1 and 2 at which major changes show in the above curves. It can be seen that these stress-strain curves vary as do the ultimate strength or hardness curves. From data taken in the second experiment it was found that the stress-strain curves also varied in the same manner, hence the curves were not duplicated.

Figures 8 and 9 are curves similar to figures 3 and 4, for the two materials of test 2.

Figure 10 is a comparison of the two materials of test 2 such as that shown in figure 5.

Figures 11 and 12 are combinations of tests 1 and 2, and are a comparison of the ultimate strengths and hardness numbers of like thickness of material of experiments 1 and 2.

Figures 13 and 14 are comparison curves of the hardness numbers of the single hardness test blank and the individual specimens of experiment 2.

Figures 15 and 16 are plots of the hardness numbers against ultimate strength.

As previously mentioned the hardness numbers as plotted are an average of ten (10) or more Scleroscope readings and six (6) or more Rockwell. Throughout the entire experiment the limits of scatter of the hardness readings were about six (6) points for the Scleroscope and four (4) numbers for the Rockwell, however as a whole the consistency of the hardness numbers, especially Rockwell, was surprisingly good.

The following are representative tests taken at random for the two materials:

EXPERIMENT #1.

Test #17, 8th. Hour, Specimen #7, Material 0.020, Area 0.01050 in.^{2}

TEST LOAD	STRESS-LBS./IN.^{2}	STRAIN INCHES	SCLEROSCOPE READING	ROCKWELL NUMBER
50	4765	.0007	15.0	F 82.0
100	9520	.0011	15.0	F 82.0
150	14280	.0018	14.0	F 82.0
200	19050	.0025	15.0	F 83.0
250	23800	.0043	13.0	F 82.0
300	28560	.0097	17.0	F 81.0
325	30950	.0140	16.0	
350	33320	.0193	15.0	Average-
375	35700	.0255	14.0	F 82.0
400	38100	.0334	16.0	
425	40450	.0431		
450	42800	.0528	Average-	
475	45250	.0651	15.0	
500	47600	.0818		
513	48850	.0900		
550	52350	----		

Specimen broke in the middle.

EXPERIMENT# 2

Test #46, 20th. Hour, Specimen #21, Material 0.040, Area 0.02004 in.^{2}

TEST LOAD	STRESS LBS./IN.^{2}	STRAIN INCHES	SCLEROSCOPE READING	ROCKWELL NUMBER
50	2495	.00045	25.0	F 94.5
100	4980	.0007	23.0	F 94.0
150	7480	.0009	22.0	F 94.5
200	9980	.0011	21.5	F 94.0
250	12460	.0013	25.5	F 94.0
300	14950	.0016	23.5	F 94.5
350	17450	.00185	23.5	F 95.0
400	19950	.00205	24.0	
450	22450	.0023	25.0	Average-
500	24950	.0025	25.5	F 94.5
550	27420	.0028	25.0	
600	29920	.0032		
650	32400	.0038	Average-	
700	34900	.0051	24.0	
750	37400	.0074		
800	39900	.0114		
850	42400	.0168		
900	44800	.0225		
950	47375	.0297		
1000	49800	.0388		
1050	52400	.0500		
1100	54800	.0612		
1150	57300	.0750		
1173	58500	.0900		
1268	63150	---		

Specimen broke in the middle.

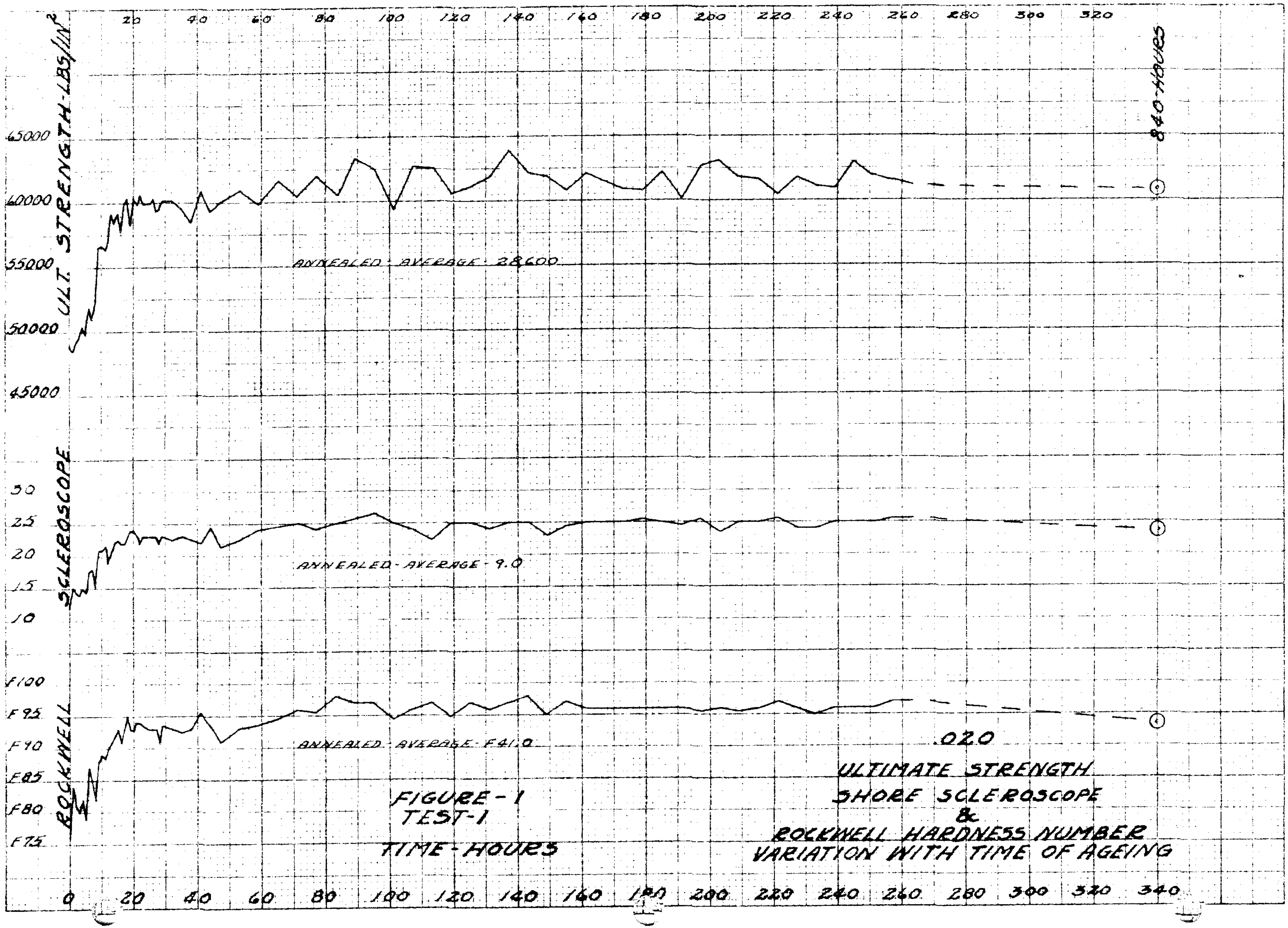
It is believed that the relation between the ultimate strength and Rockwell numbers are more reliable as the test methods were more nearly identical in each case, while it is felt that the Scleroscope readings afford more of a variation due to the manner in which it was necessary to take these hardness numbers, however the Scleroscope numbers do form a good basis for comparison.

In general where there is a fluctuation in ultimate strength there is also a corresponding change in the hardness number, however the agreement between the two materials of different thickness, and also between the two different tests is not as close as might be expected.

The results of this research indicate that there is a tendency for the material to fluctuate in hardening; however as is shown in figure 9 this tendency may not be constant. In both cases the material did arrive at a reasonable maximum strength and apparently became stable.

The results of this preliminary research are by no means conclusive as all the variables of the problem; such as variation in material, differences in methods of heat treating, changes in heat treating temperatures, different methods of quench, variation in retardation of age hardening and many others, were not investigated.

Insufficient tests were made even in the small field of this research problem, however from this investigation the authors believe there is sufficient evidence of vacillation of the alloy in age hardening to warrant further search to verify and explain this phenomenon.


ULT. STRENGTH-LBS/IN²
65000
60000
55000
50000
45000
ANNEALED-AVERAGE-28600
SCLEROSCOPE
30
25
20
15
10
ANNEALED-AVERAGE-9.0
ROCKWELL
F100
F95
F90
F85
F80
F75
ANNEALED-AVERAGE-F41.0
840-HOURS
.020
ULTIMATE STRENGTH
SHORE SCLEROSCOPE
&
ROCKWELL HARDNESS NUMBER
VARIATION WITH TIME OF AGEING
FIGURE-1
TEST-1
TIME-HOURS
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340

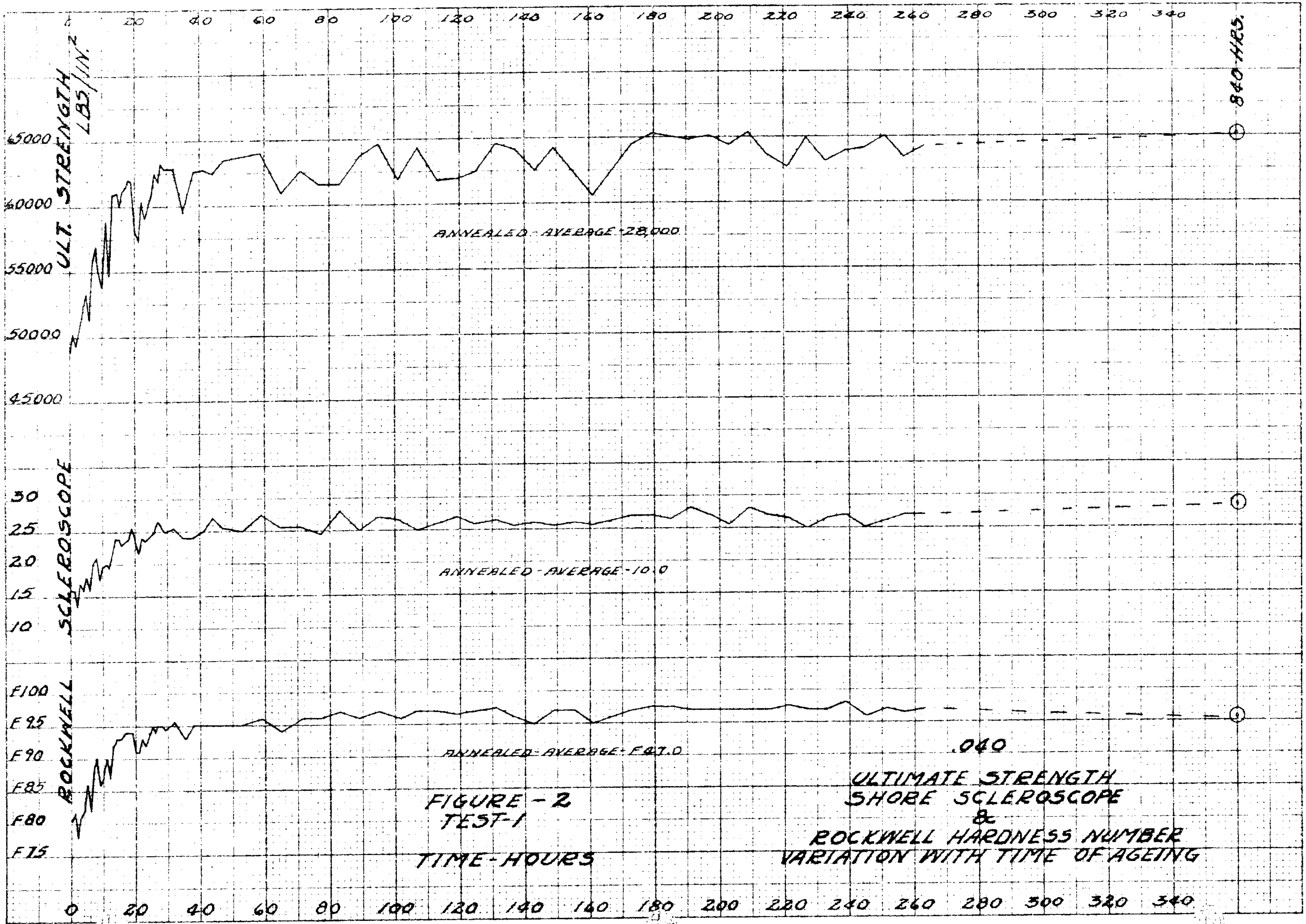
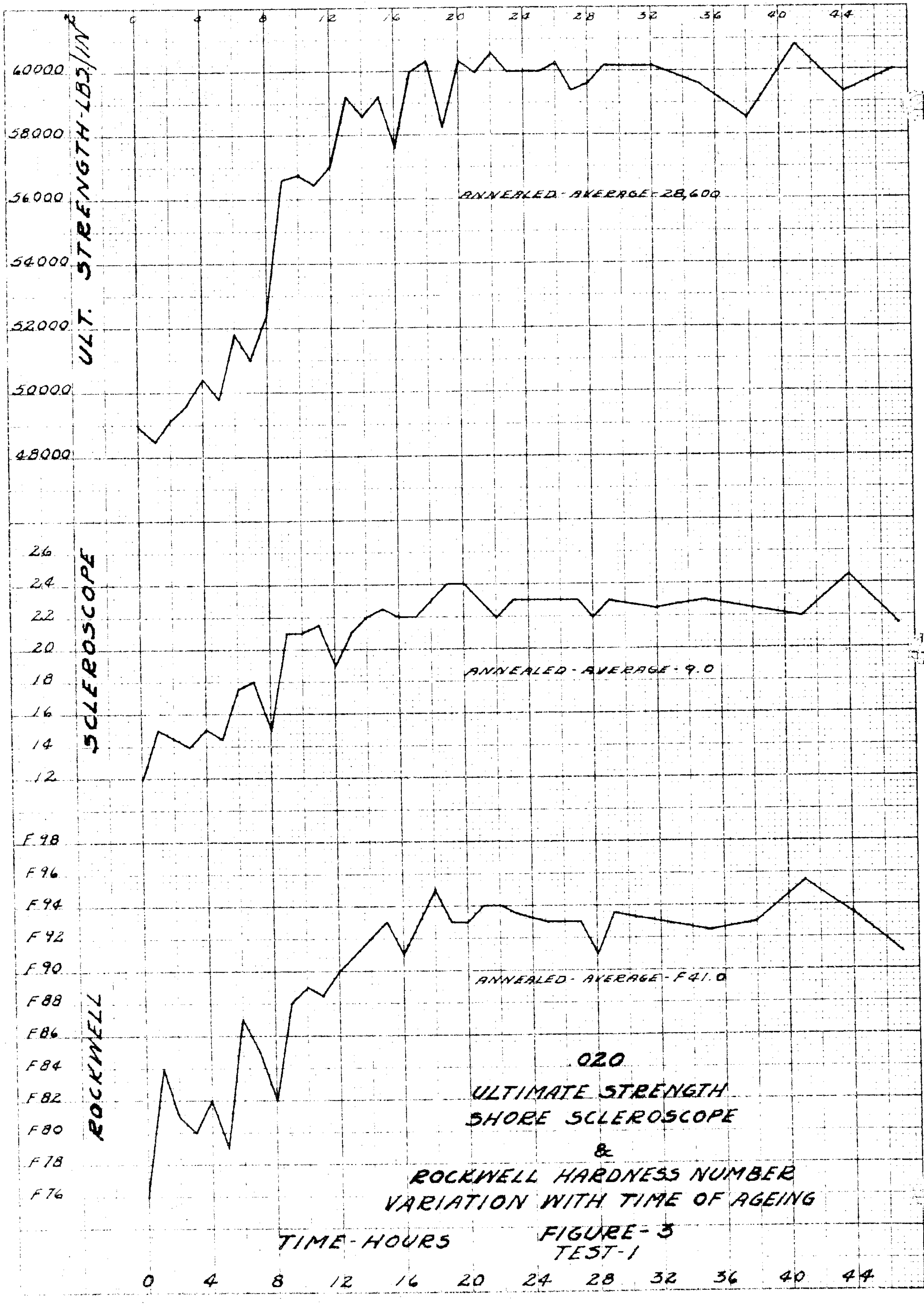


FIGURE - 2
TEST-1

ULTIMATE STRENGTH
SHORE SCLEROSCOPE
&
ROCKWELL HARDNESS NUMBER
VARIATION WITH TIME OF AGEING



.020
ULTIMATE STRENGTH
SHORE SCLEROSCOPE
&
ROCKWELL HARDNESS NUMBER
VARIATION WITH TIME OF AGEING

FIGURE-3
TEST-1

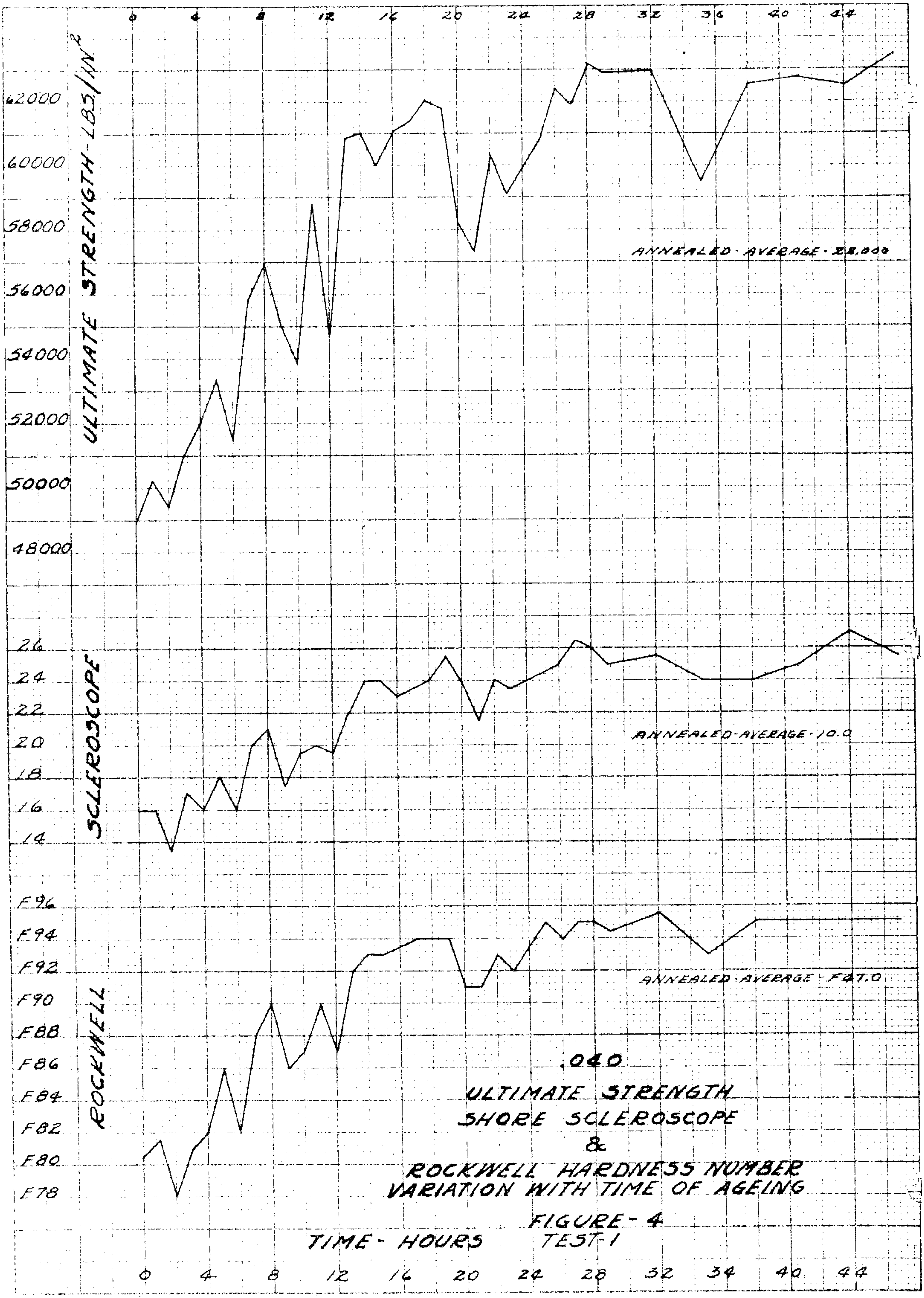
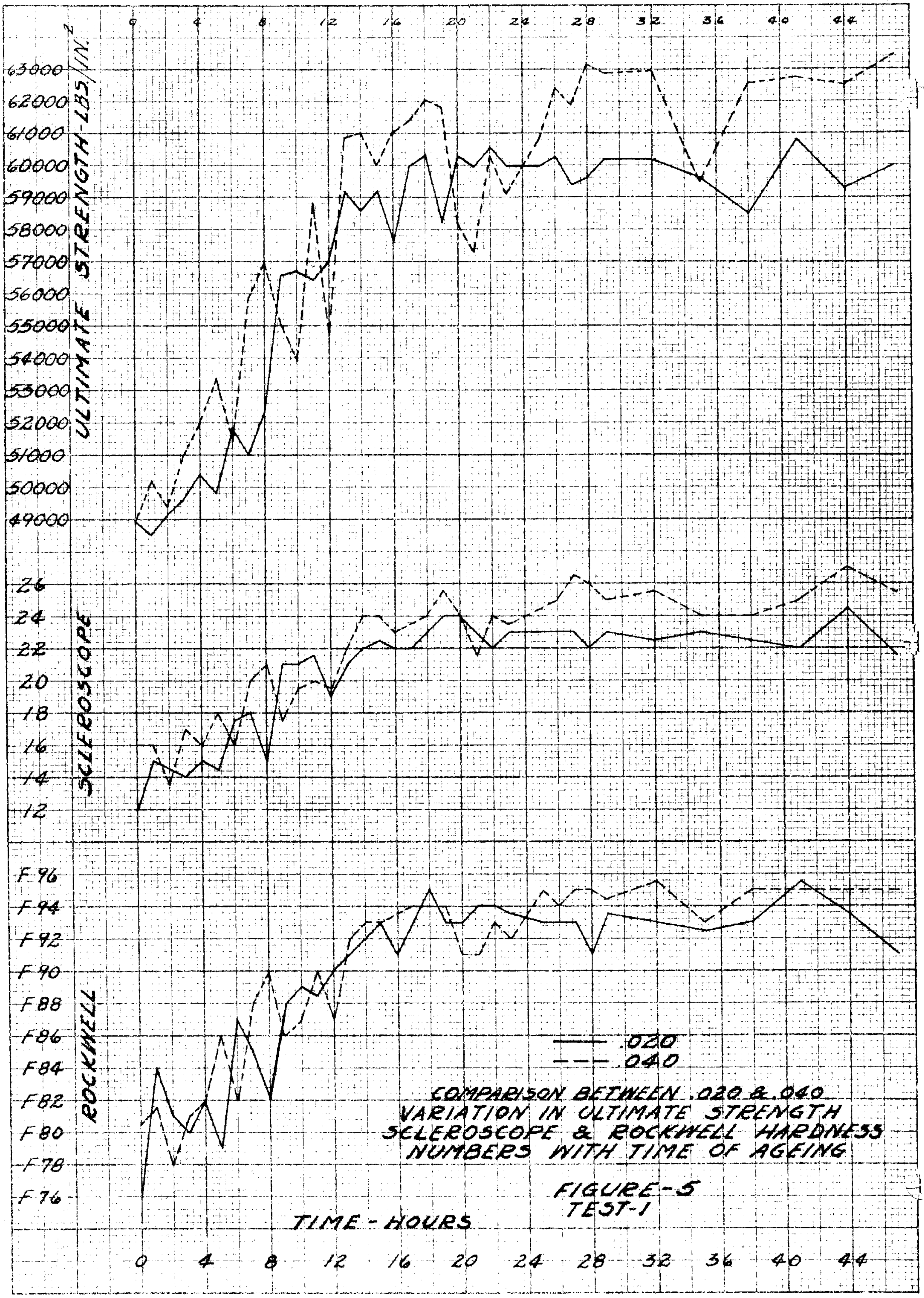
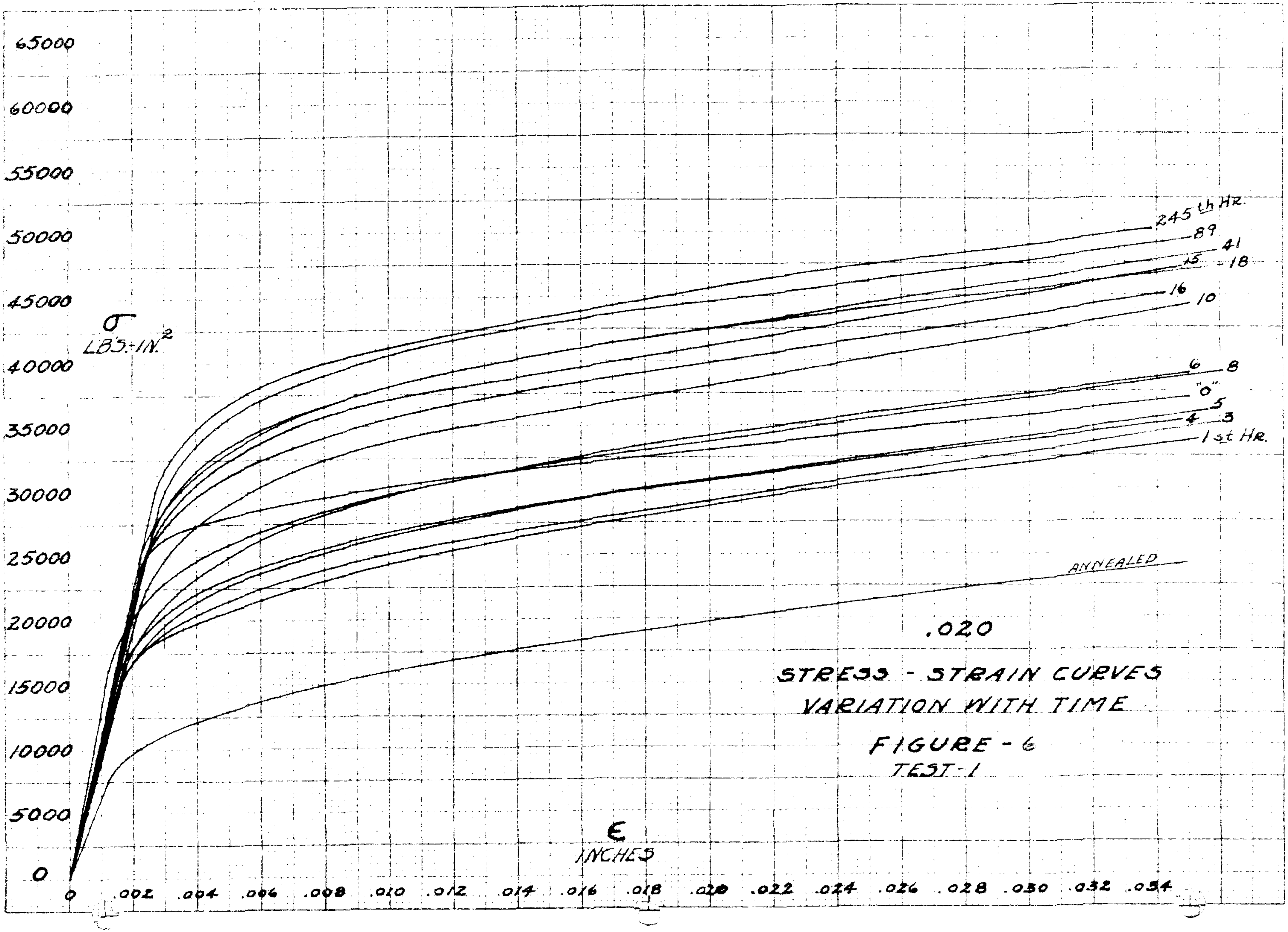


FIGURE - 4
TEST - 1



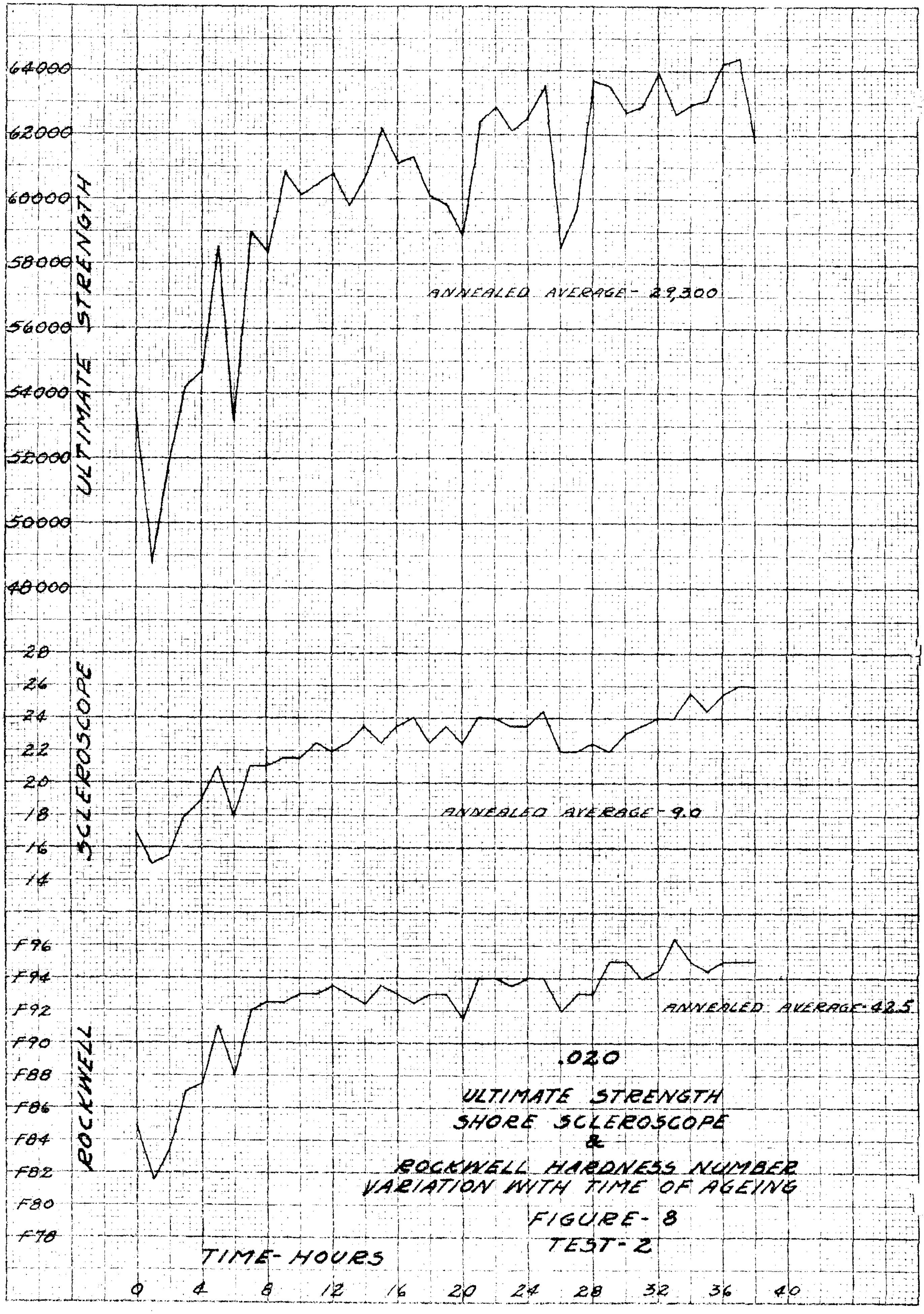
COMPARISON BETWEEN .020 & .040
VARIATION IN ULTIMATE STRENGTH
SCLEROSCOPE & ROCKWELL HARDNESS
NUMBERS WITH TIME OF AGEING

FIGURE-5
TEST-1



STRESS - STRAIN CURVES
VARIATION WITH TIME

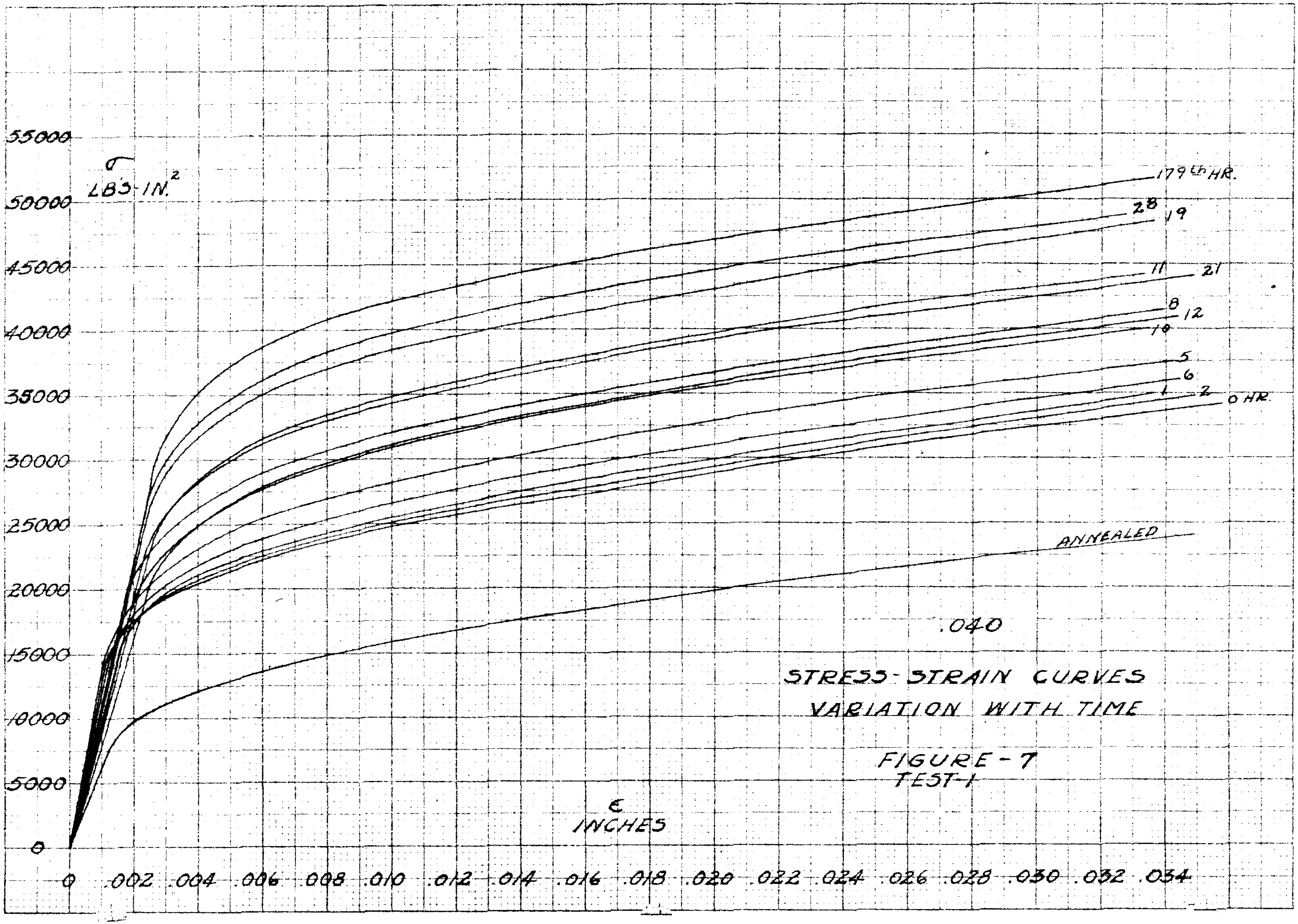
FIGURE - 6
TEST - 1



.020

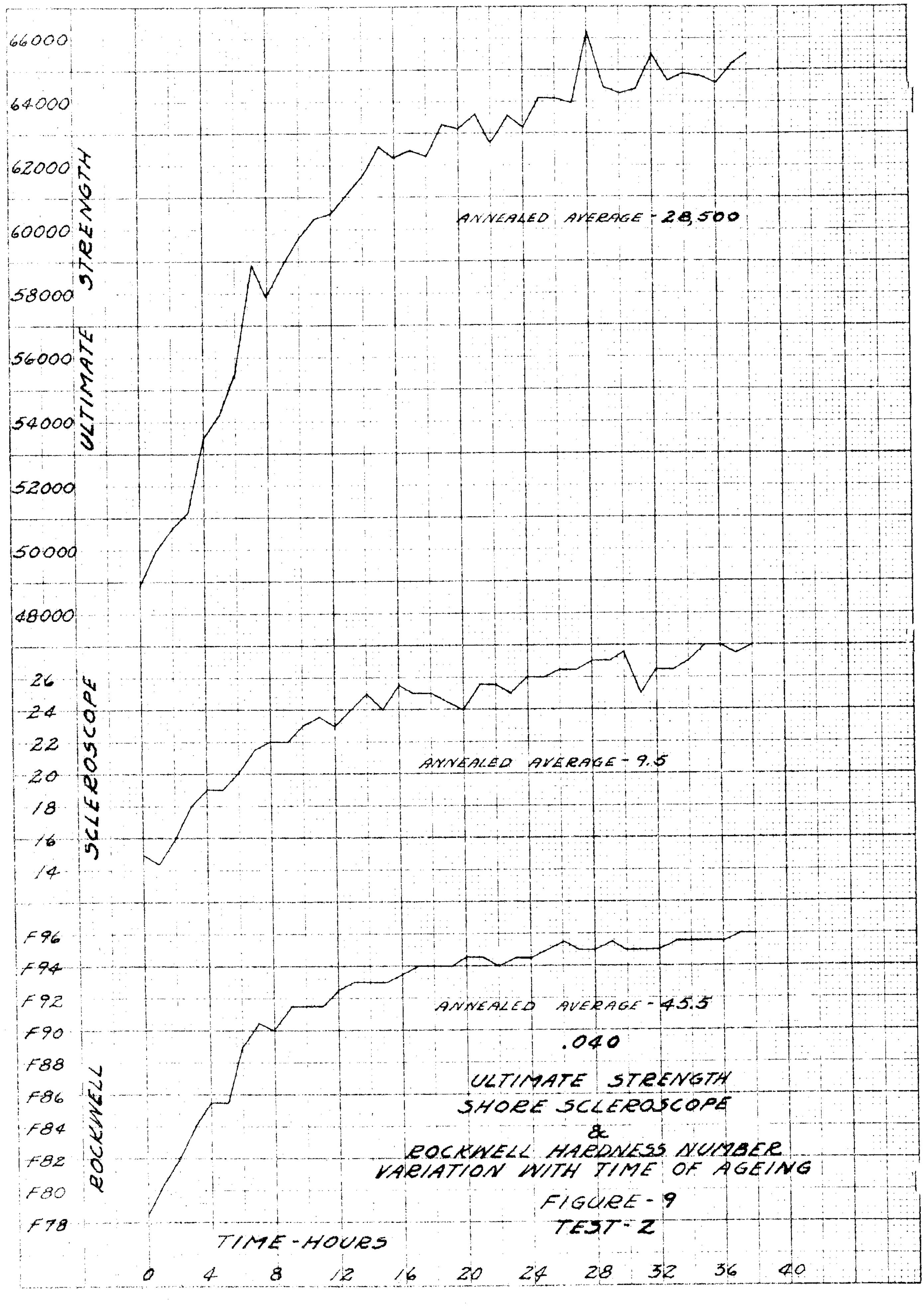
ULTIMATE STRENGTH
SHORE SCLEROSCOPE
&
ROCKWELL HARDNESS NUMBER
VARIATION WITH TIME OF AGEING

FIGURE - 8
TEST - 2



STRESS-STRAIN CURVES
VARIATION WITH TIME

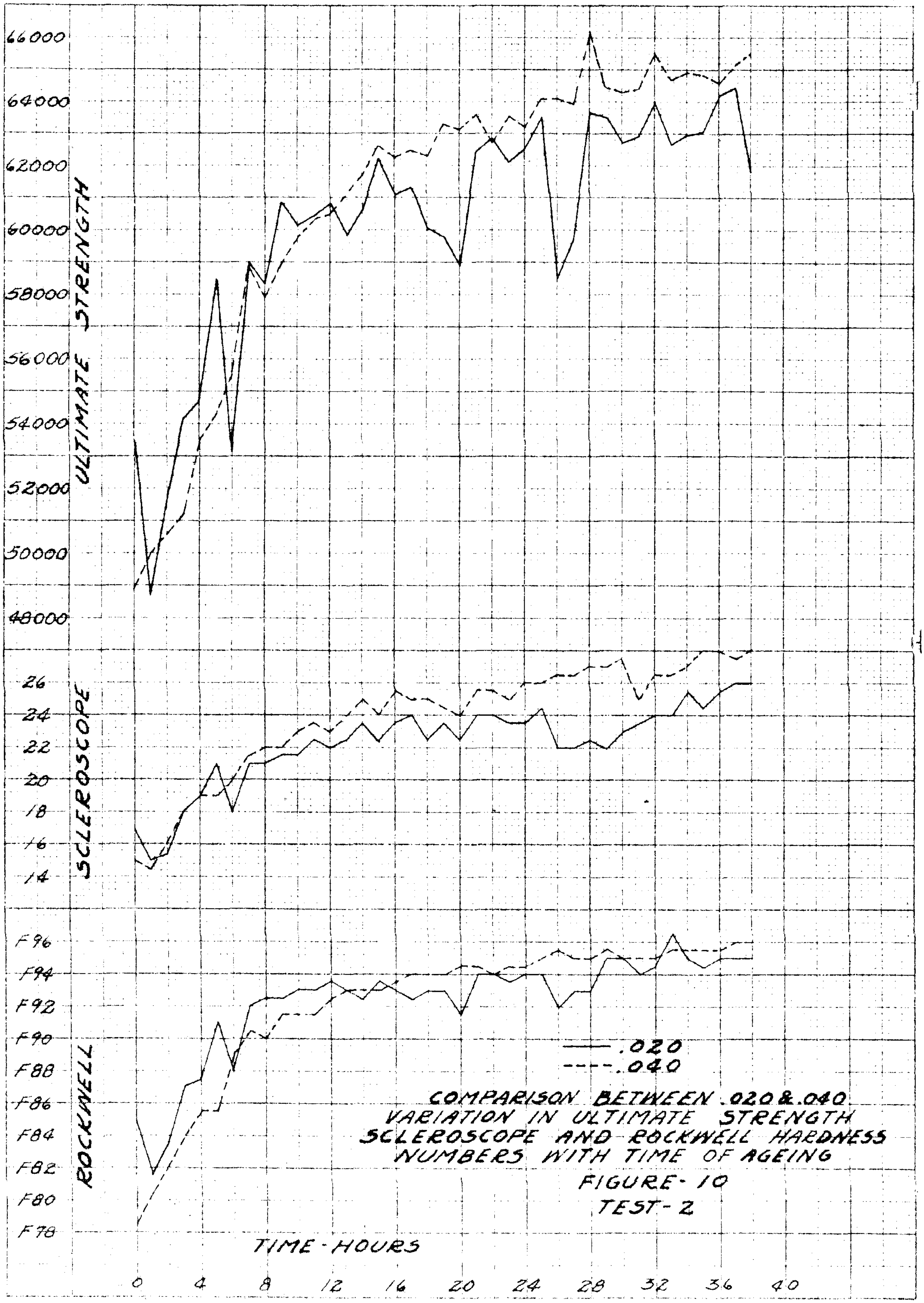
FIGURE-7
TEST-1



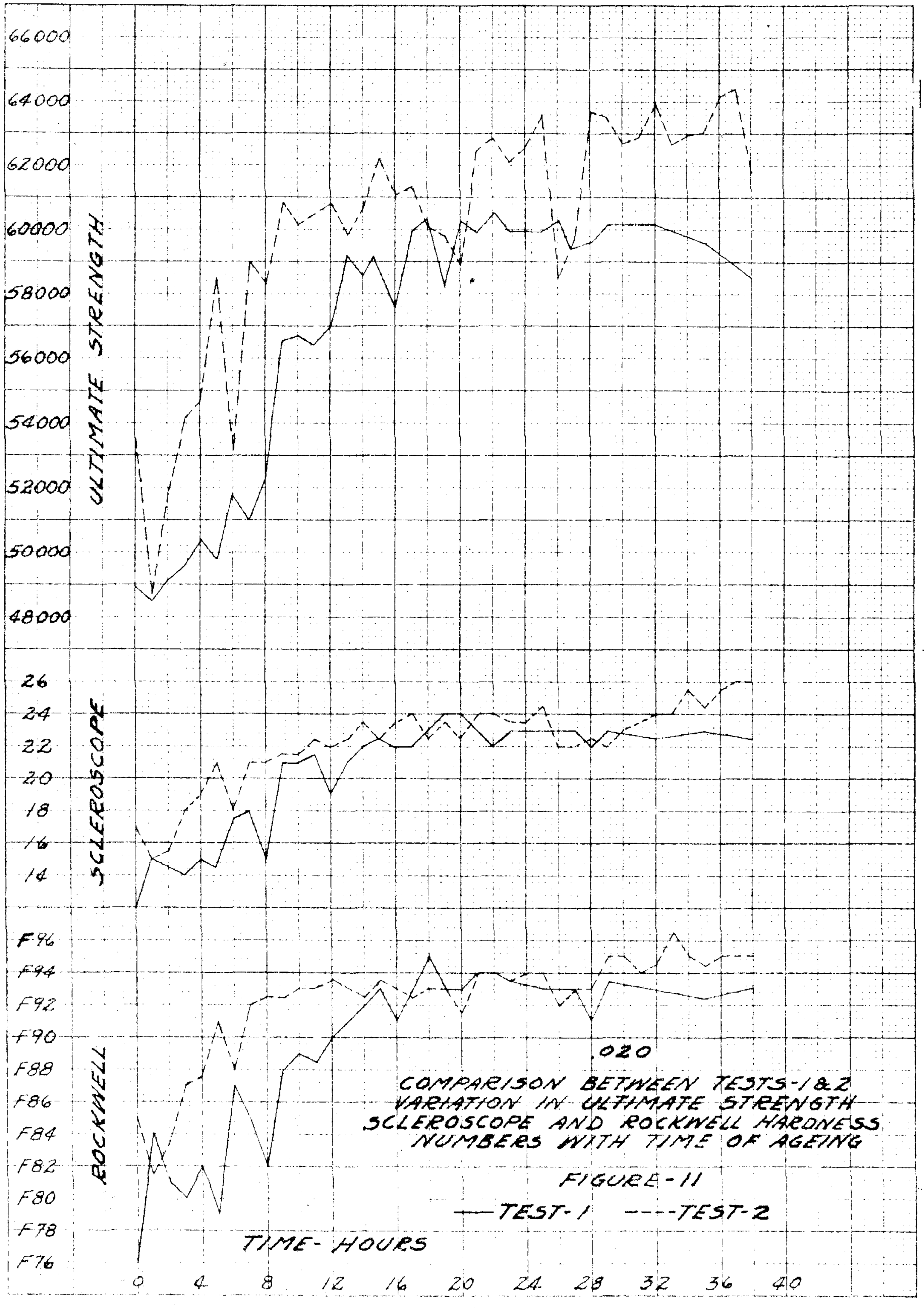
ULTIMATE STRENGTH
SHORE SCLEROSCOPE
&
ROCKWELL HARDNESS NUMBER
VARIATION WITH TIME OF AGEING

FIGURE - 9

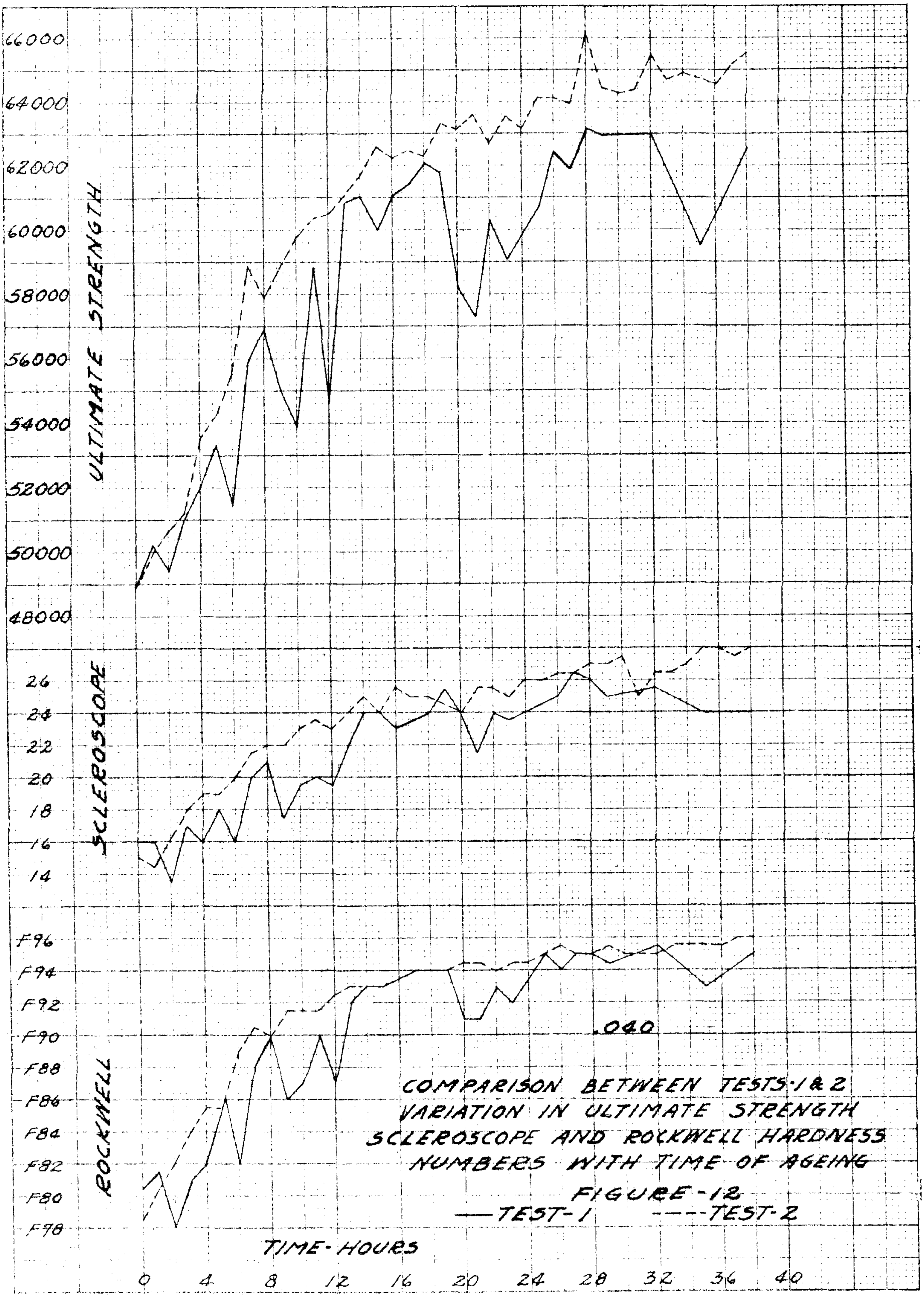
TEST - Z



COMPARISON BETWEEN .020 & .040
VARIATION IN ULTIMATE STRENGTH
SCLEROSCOPE AND ROCKWELL HARDNESS
NUMBERS WITH TIME OF AGEING
FIGURE - 10
TEST - 2

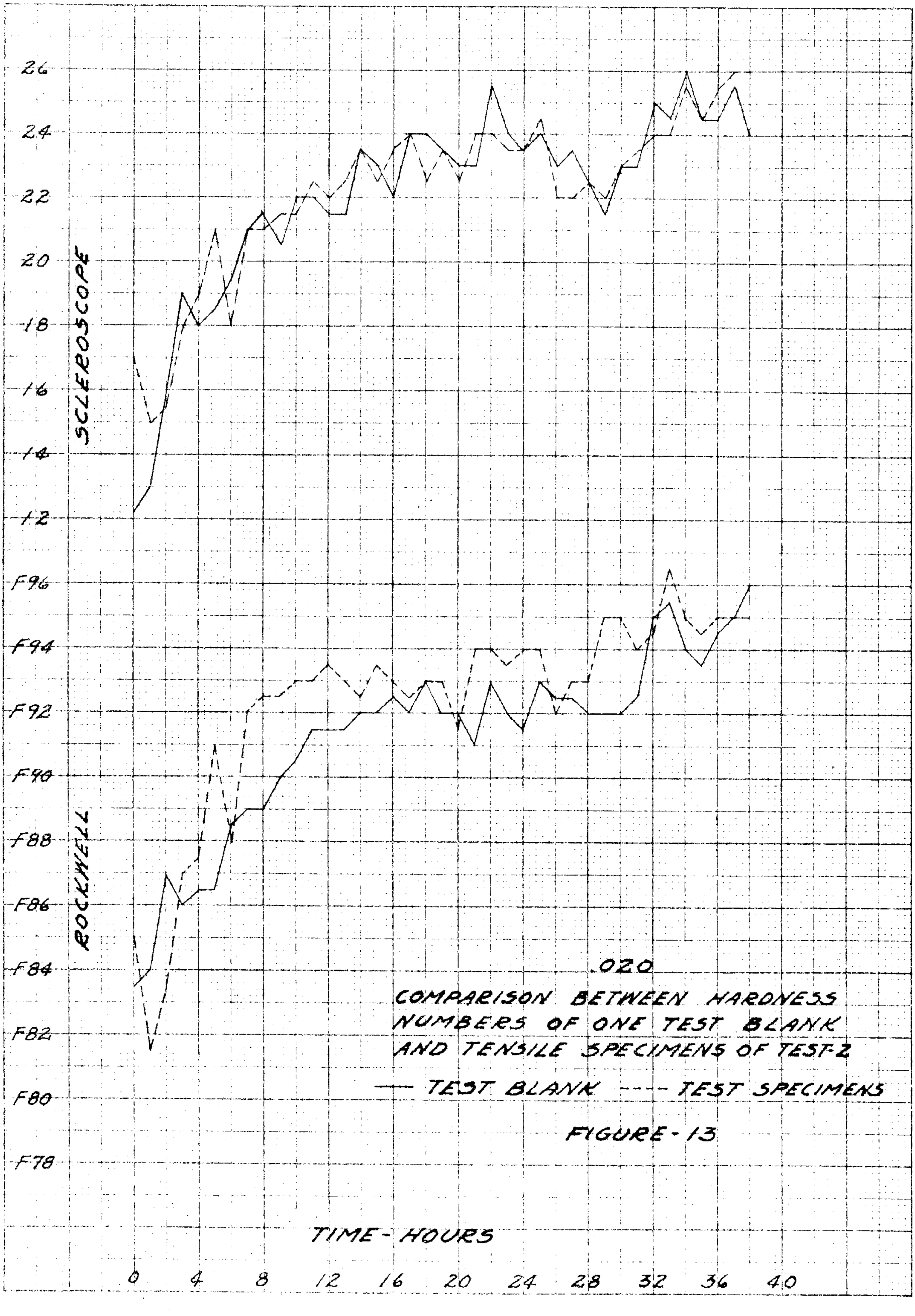


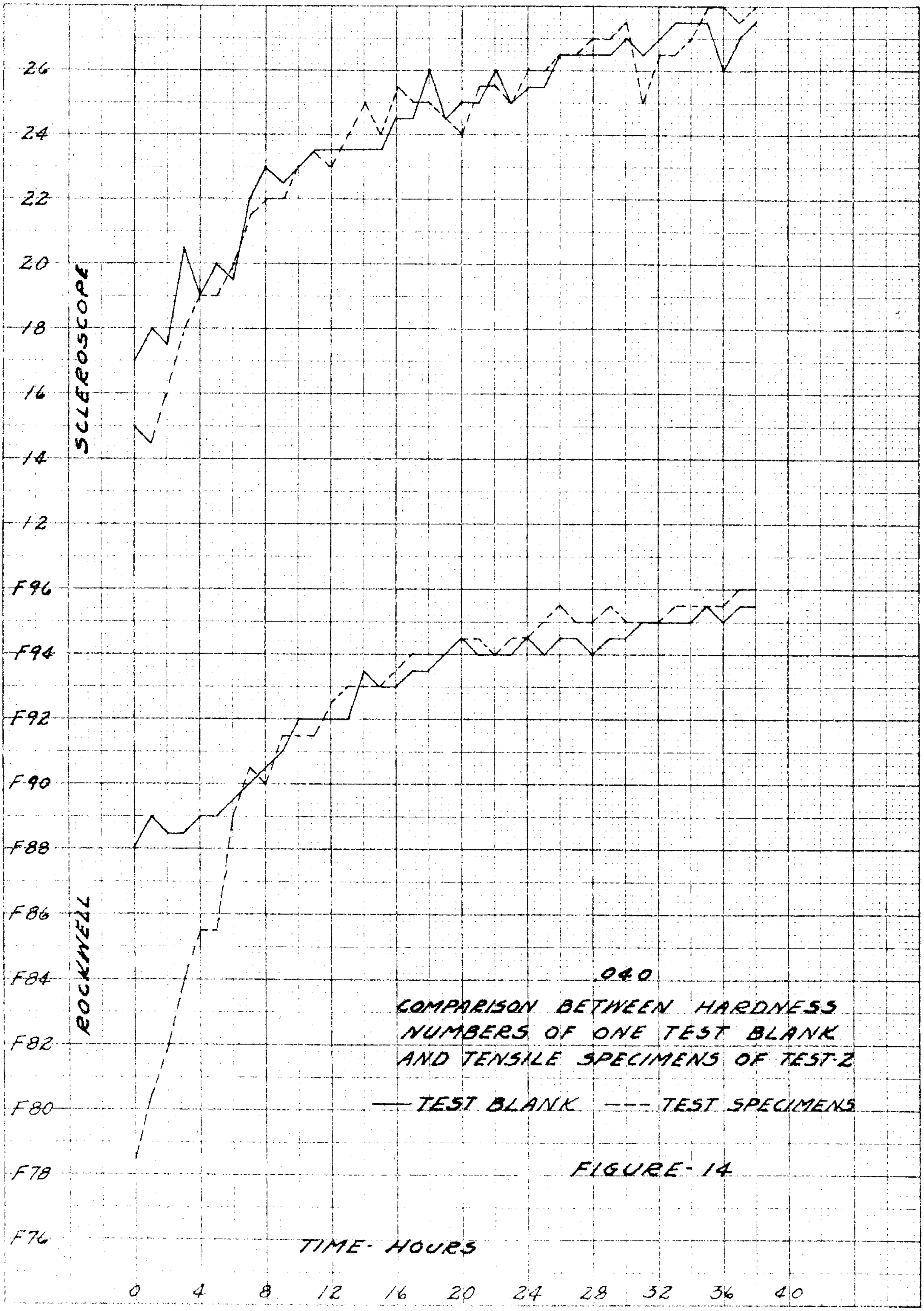
66000
64000
62000
60000
58000
56000
54000
52000
50000
48000
ULTIMATE STRENGTH
26
24
22
20
18
16
14
SCLEROSCOPE
F96
F94
F92
F90
F88
F86
F84
F82
F80
F78
F76
ROCKWELL
0
4
8
12
16
20
24
28
32
36
40
TIME- HOURS
.020
COMPARISON BETWEEN TESTS-1&2
VARIATION IN ULTIMATE STRENGTH
SCLEROSCOPE AND ROCKWELL HARDNESS
NUMBERS WITH TIME OF AGEING
FIGURE-11
TEST-1
TEST-2



COMPARISON BETWEEN TESTS-1&2
VARIATION IN ULTIMATE STRENGTH
SCLEROSCOPE AND ROCKWELL HARDNESS
NUMBERS WITH TIME OF AGEING

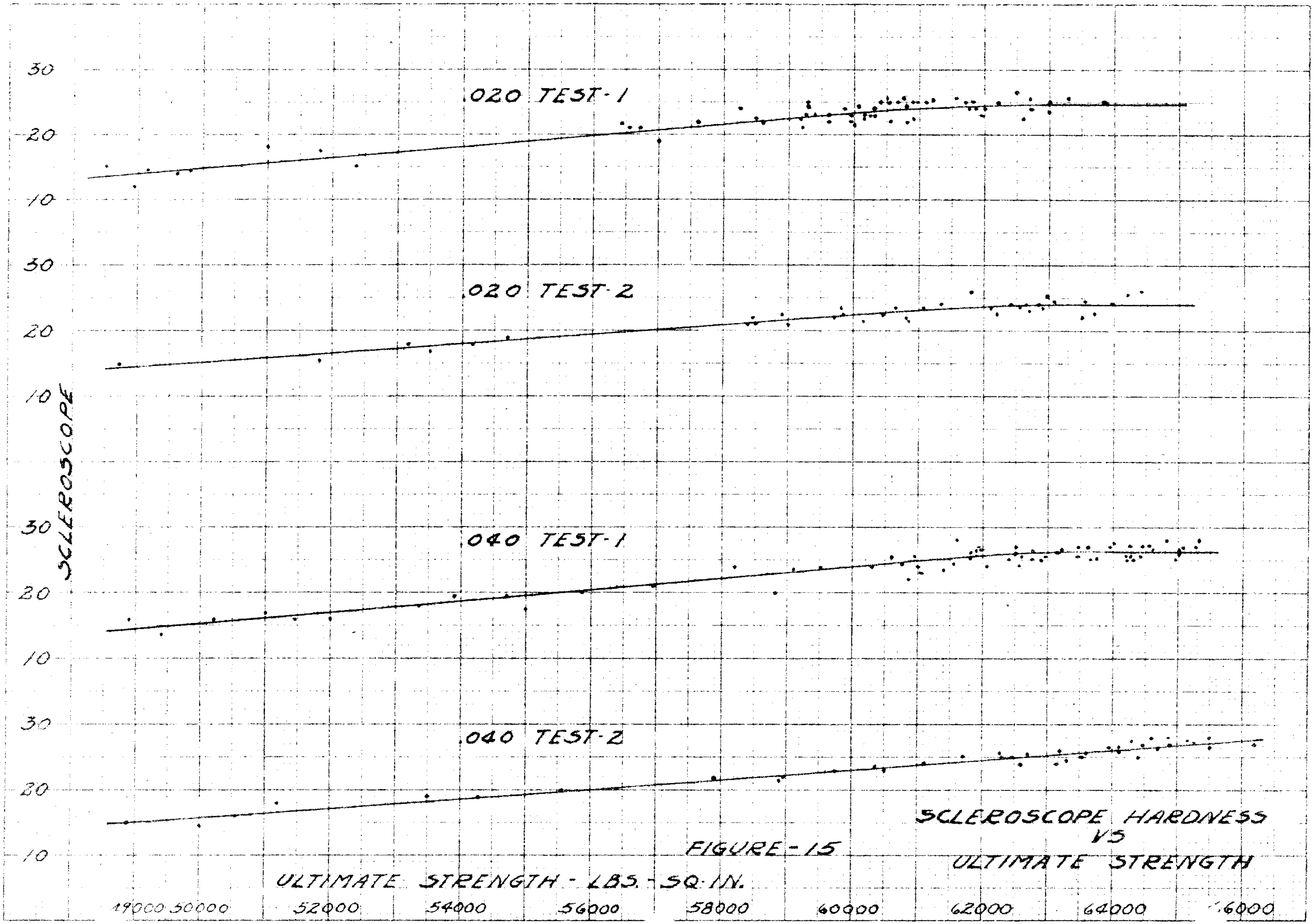
FIGURE-12


26
24
22
20
18
16
14
12
SCLEROSCOPE
F96
F94
F92
F90
F88
F86
F84
F82
F80
F78
ROCKWELL
.020
COMPARISON BETWEEN HARDNESS NUMBERS OF ONE TEST BLANK AND TENSILE SPECIMENS OF TEST-2
— TEST BLANK ---- TEST SPECIMENS
TIME- HOURS
0 4 8 12 16 20 24 28 32 36 40
FIGURE-13



COMPARISON BETWEEN HARDNESS NUMBERS OF ONE TEST BLANK AND TENSILE SPECIMENS OF TEST-Z

FIGURE- 14



SCLEROSCOPE
.020 TEST-1
.020 TEST-2
.040 TEST-1
.040 TEST-2
30
20
10
ULTIMATE STRENGTH - LBS.-SQ.IN.
49000 50000
52000
54000
56000
58000
60000
62000
64000
SCLEROSCOPE HARDNESS VS ULTIMATE STRENGTH

FIGURE-15

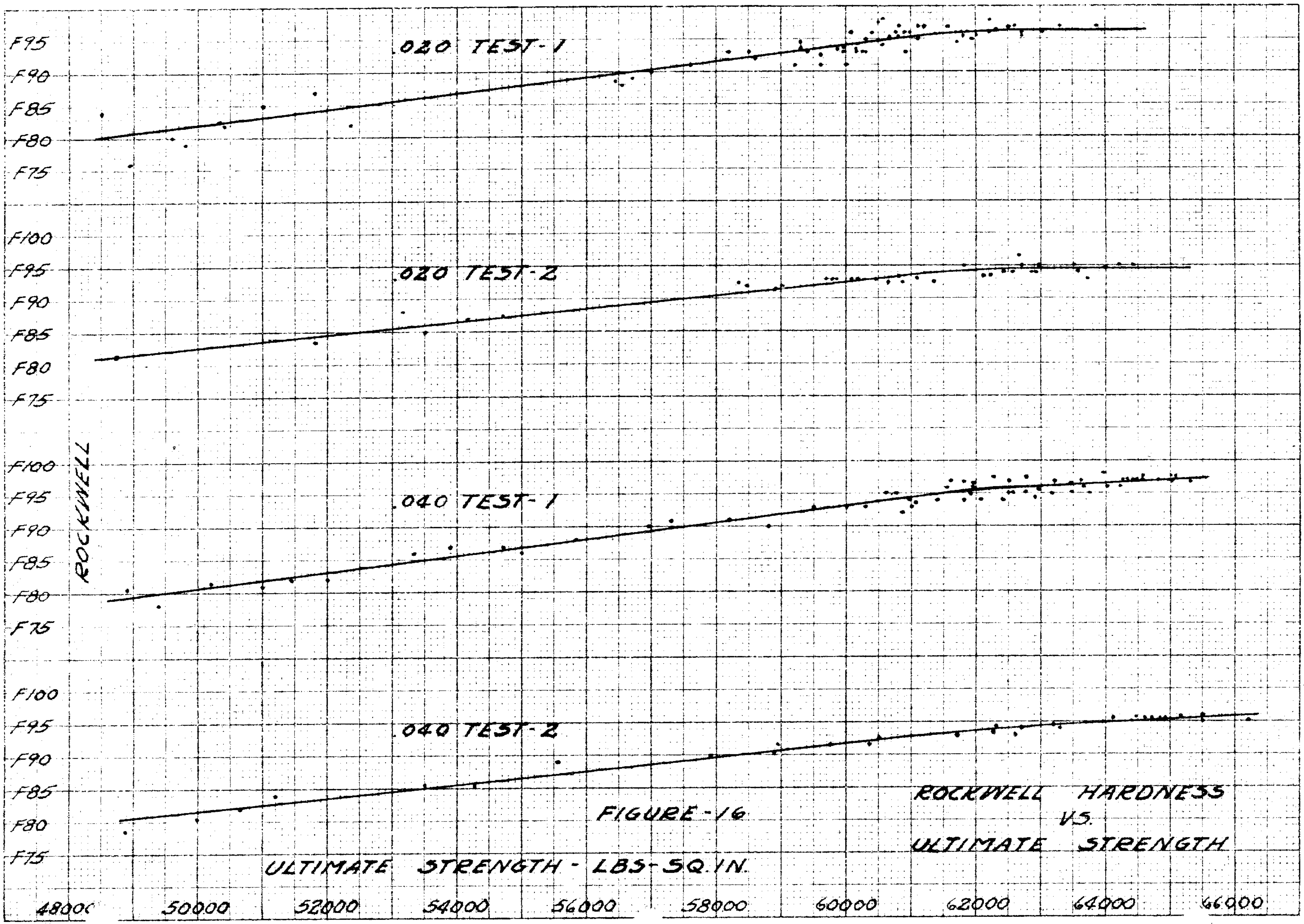

ROCKWELL
.020 TEST-1
.020 TEST-2
.040 TEST-1
.040 TEST-2
F75
F80
F85
F90
F95
F100
ULTIMATE STRENGTH - LBS-SQ.IN.
48000
50000
52000
54000
56000
58000
60000
62000
64000
66000
ROCKWELL HARDNESS VS. ULTIMATE STRENGTH

FIGURE-16