PROGRESS REPORT

TO

MATERIALS LABORATORY, AIR MATERIEL COMMAND

DEPARTMENT OF THE AIR FORCE

ON

FOUR LOW ALLOY STEELS FOR ROTOR DISKS OF GAS TURBINES IN JET ENGINES

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IN JET ENGINES

SUMMARY

The investigation is to establish curves of stress against time out to 1000 hours for rupture, start of third-stage creep, 1, 0.5, 0.2 and 0.1 percent total deformation for four low alloy steels in the form of J-33 jet engine disks. The steels are 4340, Timken 17-22A(S), H-40 and Crucible 422. Four disks of each alloy are to be supplied. One of each is to be normalized, one oil quenched, one given an interrupted quench (except for C-422 alloy which does not have proper transformation characteristics for this treatment), and one left in the as-forged condition. All heat treated disks are to be tempered to 280-320 Brinell hardness.

The relative properties of the heat treated disks are to be established at 1100° F. The disk having the most practical properties based on the survey at 1100° F will be used to establish the "design" curves at two other temperatures.

A second part of the investigation includes determination of the creep and rupture characteristics of the products of isothermal transformation of the four steels. This work will be done on bar stock and carried out to correlate with the results of the work on the disks.

To date, the disks have not yet been received for the program. Bar stock of 4340 and 17-22A(S) steels have been supplied gratis for the isothermal transformation work and notice has been received which indicates that the H-40 and C-422 bar stock should be available about May 1.

This report outlines the details of the proposed program. Actual results are confined to partial isothermal transformation data and tempering data for

4340 and 17-22A(S) steels.

INTRODUCTION

This report covers the progress made through March 31, 1951 on an investigation of the high temperature properties of four ferritic alloys in the form of rotor disks for gas turbines in jet engines. The work is being carried out for the Materials Laboratory, Air Materiel Command, Department of the Air Force under Air Force Contract Number AF33(038)-13496 (Expenditure Order Number 605-227 SR-7).

Design data in the form of curves of stress versus time for total deformation are to be obtained at three temperatures from forged and heat treated disks of the type used for the gas turbine in the J-33 jet engine. Disks made from 4340, Timken 17-22A(S), H-40 and Crucible 422 steels are to be tested.

Disks are to be supplied in the following conditions:

(a) Normalized and tempered.

(b) Oil quenched and temperature.

(c) As transformed at an intermediate temperature.

Preliminary testing is to be carried out to establish which heat treatment gives the best high-temperature properties, and should be used to obtain complete design data. As a further clarification of the effect of the condition of heat treatment, a concurrent program is to be carried out to relate the products of isothermal transformation to properties at high temperatures for the four steels in the program.

The progress made to date has been largely confined to procurement of bar stock for the isothermal transformation work and to the early phases of the transformation studies. The disks have not yet been received for the accumulation of design data.

This report, therefore, is largely a detailed statement of the work planned

under the contract and the reasons for the particular procedures being adopted.

PROCEDURE

Four disks each of 4340, Timken 17-22A(S), H-40 and Crucible 422 steels are to be supplied by the Air Materiel Command. One disk of each steel will have been oil quenched and tempered and another normalized and tempered. A third disk of 4340, Timken 17-22A(S) and H-40 will have been given an interrupted quench to produce an intermediate temperature transformation product. One disk of these three steels and two disks of the Crucible 422 steel will be supplied in the as-forged condition. The heat treated disks are to be furnished to the University by the Canton Drop Forge and Manufacturing Company under direct contract with the Air Materiel Command.

The heat-treated disks are to be surveyed by a limited number of tests to establish the effect of the three types of heat treatment on the high temperature properties of the disks. The heat-treated condition which is found to have the best properties is to be extensively tested so as to provide curves of stress versus time for rupture, stress versus time for start of third stage creep, and stress versus time for total deformations of 0.1, 0.2, 0.5 and 1 percent at each of three temperatures. Initial sorting is to be carried out at 1100° F. The final temperatures for complete testing are to be established from these preliminary tests, known high temperature characteristics of the alloys and probably service temperature requirements for disks of this type. The final property curves are to be established out to 1000 hours. Specimens are to be examined after testing for structural stability. Each disk will be surveyed for normal tensile and hardness properties.

The as-forged disks are to be retained for possible future study as indicated by the results of this investigation.

Part of the objective of this investigation is to clarify the relationship between heat treatment and types of microstructure to properties of such alloys at elevated temperatures. For this purpose, specimens prepared from bar stock of the four alloys are to be transformed isothermally to definite, known microstructures. The relationship between these microstructures and their properties at elevated temperatures will be established in a manner to explain the properties of the variously heat-treated disks.

TEST MATERIALS

The nominal chemical compositions of the four steels to be used for manufacturing the disks are:

Type Steel	C (%)	Mn (%)	Ni (%)	Cr (%)	Mo (%)	W (%)	V (%)	Heat Numbers
4340*	0.40	0.7	1.75	0.80	0.25	-	-	Republic E-68709
17-22A(S)	0.30	0.55	-	1.25	0.50	-	0.25	Timken - ?
H-40	0.20	-	-	2.8	0.50	0.50	0.75	Crucible K-2509
C-422	0.20	0.75	0.75	13.8	1.0	1.0	0.30	Crucible - ?

*Specification AMS 6415 or MIL-S-5000

Actual analyses are not yet available.

The Timken Roller Bearing Company has furnished, without charge, hot-rolled bar stock of 4340 and 17-22A(S) steels for the isothermal transformation work. The analyses of these were:

Type Steel	C (%)	Mn (%)	Si (%)	P (%)	S (%)	Cr (%)	Ni (%)	Mo (%)	V (%)	Cu (%)	Heat Number
4340	0.40	0.70	0.30	0.02	0.019	0.78	1.75	0.26	-	0.12	19053
17-22A(S)	0.30	0.63	0.60	0.016	0.018	1.25	0.25	0.52	0.25	0.10	24797

The Crucible Steel Company has agreed to furnish bar stock from the same heats used for the disk billets of H-40 and 422 alloys.

The specified heat treatments for the disks are:

4340 Steel

1. Cool after forging until almost black, then charge into furnace at 1200° F and hold for 30 hours, then air cool.

2. Heat three disks in furnace at 1750° F for 4 hours total time.

   (a) Air cool one disk and then temper at 1200° F for 2 hours at temperature (total time in furnace 6 hours). Brinell hardness specified 280-320.

   (b) Oil quench one disk and then temper at 1200° F for 8 hours. Brinell hardness specified 280-320.

   (c) Submerge one disk into water only until black, then withdraw until glow returns; repeat this procedure until glow does not return after withdrawal from water; transfer to furnace at 700° F for 8 hours, air cool. Temper at 1200° F for 2 hours at temperature (6 hours total furnace time) and air cool. Brinell hardness specified 280-320.

3. Leave the fourth disk as finished in Step 1.

17-22A(S) Steel

1. Cool after forging until almost black, then charge into furnace at 1200° F, hold for 8 hours and air cool.

2. Heat treat disks following same procedure used for 4340 steel disks.

H-40 Steel

1. Cool after forging until almost black, then charge into furnace at 1200° F, hold for 8 hours and air cool.

2. Same treatments as for 4340 and 17-22A(S) steels except that the temperature of heating for hardening is 1950° F instead of 1750° F.

C-422 Steel

1. Cool after forging until almost black, charge into furnace at 1200° F, hold for 8 hours and air cool.

2. Heat two disks at 1900° F for 4 hours total time.

   (a) Air cool one disk and then temper at 1200° F for 2 hours at temperature (total time in furnace 6 hours). Brinell hardness specified 280-320.

   (b) Oil quench one disk and then temper at 1200° F for 8 hours. Brinell hardness specified 280-320.

3. Leave the other two disks as finished in step 1.

NOTE: The interrupted quench is to be omitted in the 422 steel because Crucible Steel Company data indicates that the time for transformation is too long for transformation to occur during the interrupted quench.

PROPOSED TESTING CONDITIONS

It is anticipated that the testing of the disks and the structural studies, for the most part, will be carried on concurrently. For this reason, the testing schedule for the disks will be somewhat arbitrary. It is epected, however, that sufficient structural studies will be completed in time to help clarify the results of the tests on the disks.

Disks

1. A vertical section, 3/4-inch thick, is to be taken across the diameter of each heat-treated disk.

2. The Brinell hardness distribution and the macrostructure of each disk will be determined from this slice.

3. The tensile properties at the center of the disk are to be established at room temperature by specimens taken from this slab of material.

4. The high temperature properties of the material at the rim of each heat treated disk are to be surveyed at 1100° F to provide enough data for a stress-rupture curve and an indication of the stress to cause 1-percent total deformation in 1000 hours.

5. The data obtained in step 4, above, should establish the effect of the three types of heat treatment on properties at elevated temperatures. The heat treated condition found to have the best properties is to be tested at three temperatures to obtain design data including curves of stress versus time for start of third stage creep, and of stress versus time for total deformation of 0.1, 0.2, 0.5 and 1.0 percent.

Isothermal Transformation Studies

Over most of the useful temperature range of low-alloy steels, normalizing yields higher creep and rupture strengths than either annealing or liquid quenching. This behavior is characteristic for both low and, for those steels which will air harden, high hardness levels. Generally, low elongation in the rupture test is also characteristic of the normalized condition.

The reasons for the superior creep and rupture properties of the normalized condition are not known. One of the possible reasons is the microstructure, which is governed by the temperatures of transformation. The assumption being that transformation at intermediate cooling rates produces a structure which either has inherently high creep resistance or greater structural stability.

In this investigation, the structures associated with isothermal transformation are to be established for the four steels and their characteristic creep and rupture strengths measured. The results will be used to correlate and interpret the properties of the disks. The detailed experimental program in progress is as follows:

1. Use the same austenitizing temperatures to be used to heat treat the

disks: 1750° F for 4340 and 17-22A(S) steel; 1900° F for C-422 steel; and 1950° F for H-40.

2. The proposed structures to be tested include the following:

(a) Normalized structure

(b) Oil quenched structure

(c) Upper Pearlite

(d) Lower Pearlite

(e) Upper Bainite

(f) Lower Bainite

It is known that all of these structures can be obtained with 4340 and 17-22A(S), but as yet, it is not known whether or not all of these structures can be developed in the H-40 and C-422 steels.

3. In order to determine the temperatures to be used for isothermal transformation to obtain specific microstructures, it will be necessary to outline the time-temperature-transformation curves for 17-22A(S), H-40 and C-422. The time-temperature-transformation curve for 4340 is outlined in the literature(1).

4. The as-transformed structures with a hardness greater than 300 Brinell are to be tempered to a hardness of 300 Brinell and then tested. This is to correlate with the specified hardness for the heat treated disks.

Those transformed structures which have a hardness less than 300 Brinell (pearlitic structures), are to be tempered to a common hardness level and then tested. Testing at other hardness levels may be required.

Wherever possible, test specimens are to be tempered at the same temperature used for the disks, using time as a variable to arrive at the desired hardness level.

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(1) Atlas of Isothermal Transformation Diagrams, United States Steel Corporation, 1943, p. 64.

5. The first criterion to be used for evaluation of the high temperature properties of the four steels, and their different microstructures, is the stress to cause 1-percent total deformation in 1000 hours at 1100° F. The stress to cause 1-percent total deformation for the normalized structure, tempered to a hardness of 300 Brinell, is to be used as an initial stress for testing the other structures.

RESULTS

The results obtained to date are presented separately for each steel tested.

4340 Steel

The time-temperature-transformation diagram for 4340 as outlined in the literature was checked by transforming slugs of this steel at 650°, 850° and 1200° F, and the diagram was found to be sufficiently accurate for use in this investigation.

The hardness values obtained on normalizing and oil quenching from 1750° F were as follows:

Treatment	Brinell Hardness
As normalized	390
As oil quenched	585

The tempering behavior of these structures is shown in Figures 1 and 2. From these curves, it can be seen that in one hour, the 4340 tempers rapidly even at 1100° F.

No creep tests have been started to date.

17-22A(S) Steel

The time-temperature-transformation curve has been tentatively outlined and is shown in Figure 3.

The hardness value obtained on normalizing from 1750° F is 361 Brinell. The tempering behavior of this structure at 1200° F is shown in Figure 4.

No creep tests have been started to date.

H-40 and C-422 Steels

To date, bar stock of either H-40 or C-422 has not been received.

FUTURE WORK

The disks should be received during the next three months. The testing program will be started concurrently on all four materials as soon as they are received.

The program on bar stock will be continued to define the relationship between microstructure and creep-rupture properties as outlined in the report. It is expected that the H-40 and C-422 bar stock will be received during this next period.

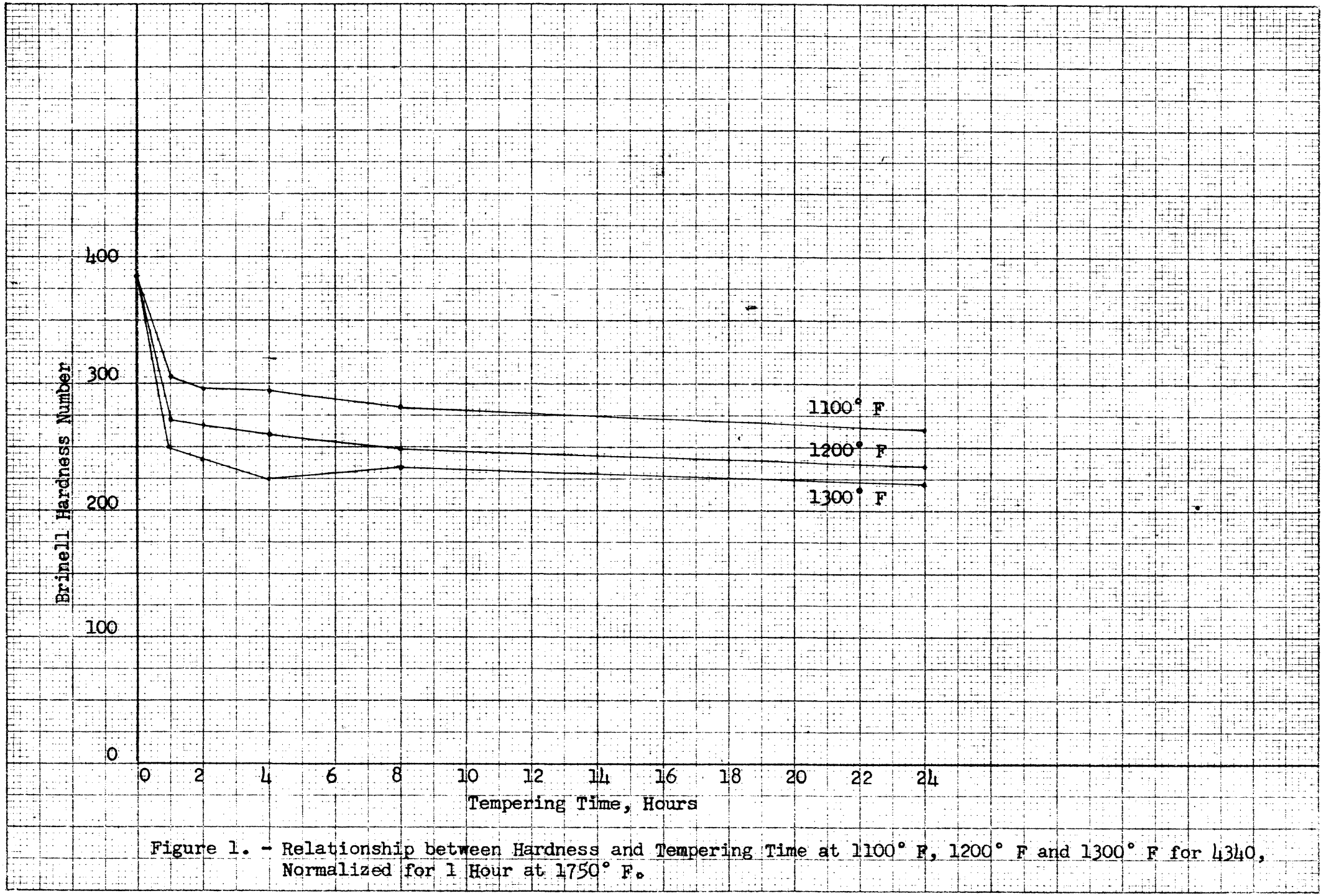

Figure 1. - Relationship between Hardness and Tempering Time at 1100° F, 1200° F and 1300° F for 4340, Normalized for 1 Hour at 1750° F.

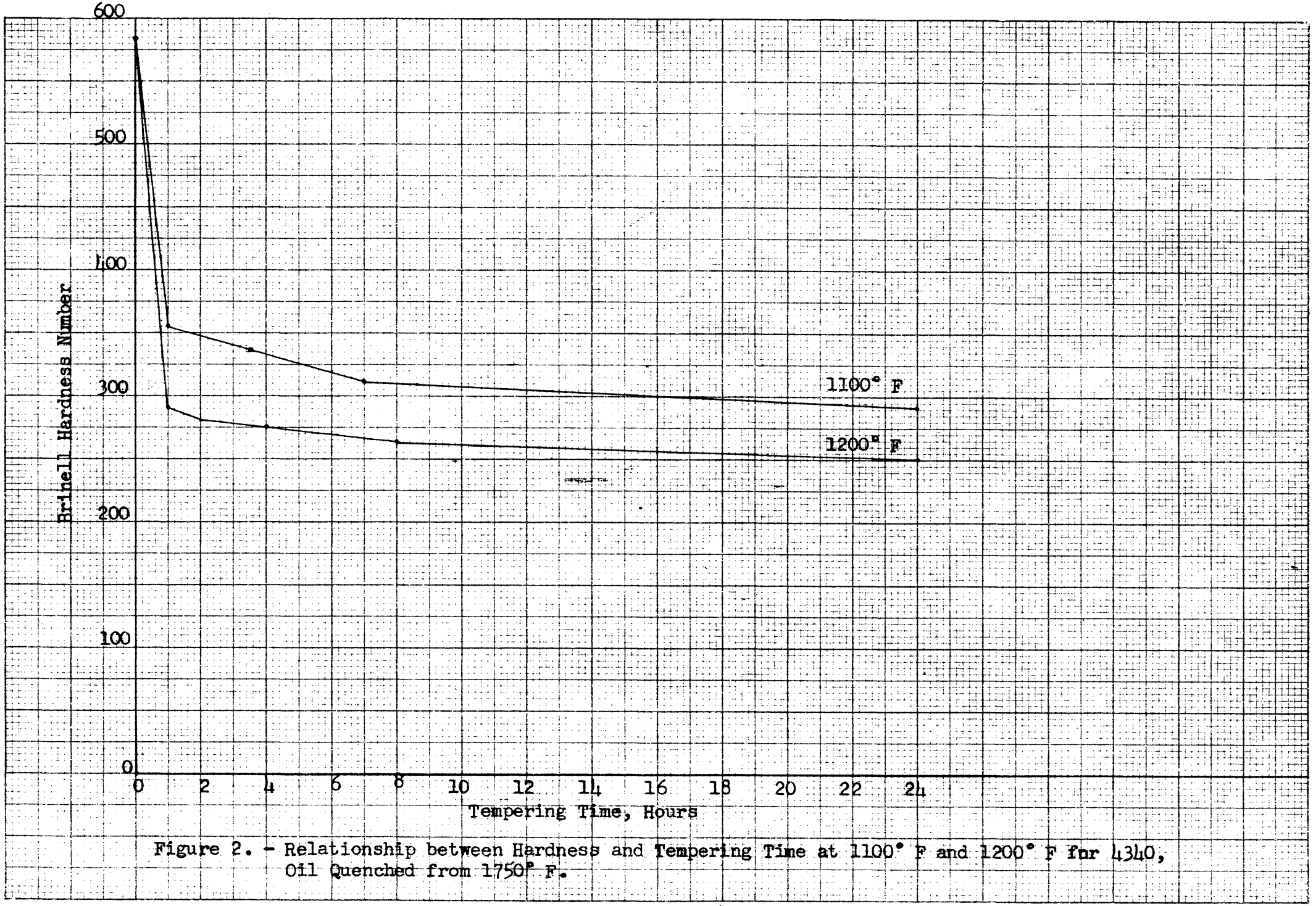

Figure 2. - Relationship between Hardness and Tempering Time at 1100° F and 1200° F for 4340, Oil Quenched from 1750° F.

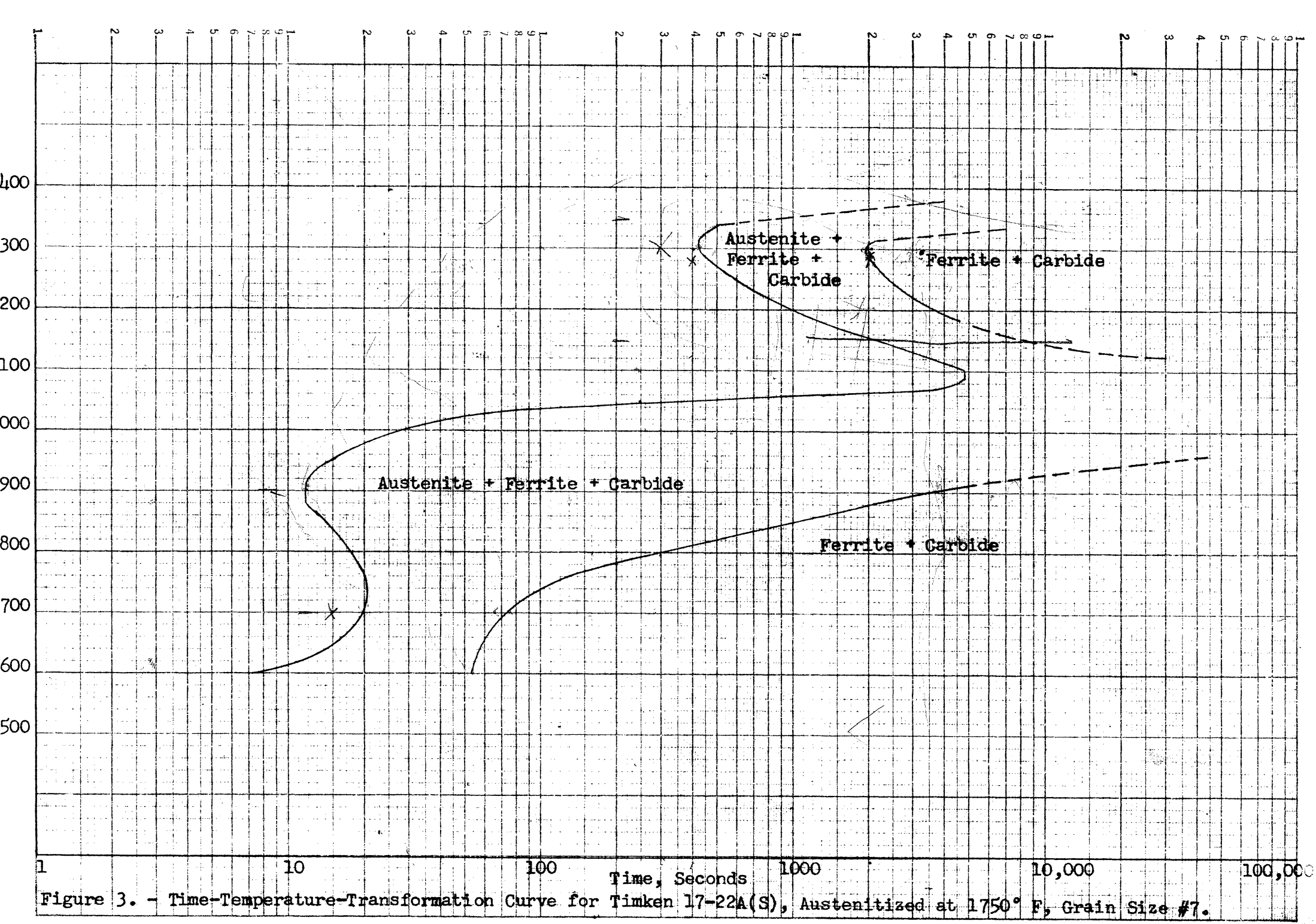

Figure 3. - Time-Temperature-Transformation Curve for Timken 17-22A(S), Austenitized at 1750° F, Grain Size #7.

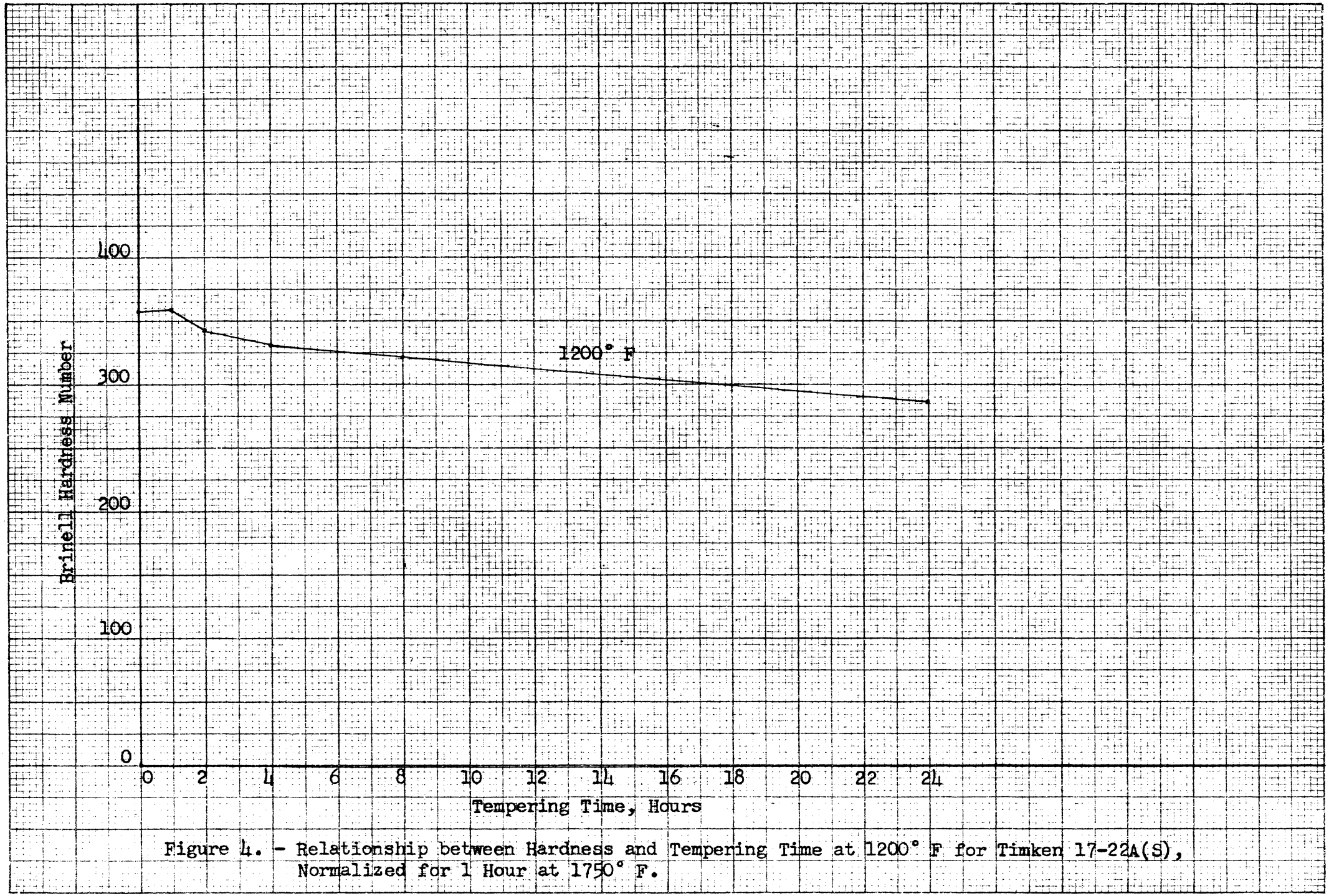

Figure 4. - Relationship between Hardness and Tempering Time at 1200° F for Timken 17-22A(S), Normalized for 1 Hour at 1750° F.