INVESTIGATION OF
CONSTANT TEMPERATURE TRANSFORMATION
OF AL-CU - MG-ZN SOLID SOLUTIONS

by
Ronald F. Dickerson

A Thesis Submitted to the Graduate Committee
For the Degree of

MASTER OF SCIENCE

in

Metallurgical Engineering

Approved:

Head of Major Department

Dean of Engineering

Director of Graduate Studies

Virginia Polytechnic Institute
Blacksburg, Virginia
1948

TABLE OF CONTENTS

TABLE OF CONTENTS
(cont.)

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to Prof. H. V. White of the Department of Metallurgy, Virginia Polytechnic Institute, for the valuable suggestions and encouragement given by him throughout the work of this investigation.

The author also wishes to express his appreciation to Dr. P. V. Faragher, Educational Representative of the Aluminum Company of America, and to the Aluminum Company of America for the material used in the experiments and for the references furnished. Further appreciation is expressed to Mr. F. J. Maher of the Applied Mechanics Department, Virginia Polytechnic Institute, for certain testing equipment which was used for the mechanical testing.

Ronald F. Dickerson

INTRODUCTION

The fully tempered condition of aluminum alloys is obtained by a process which involves two steps. The first step, which is termed solution heat treatment, consists of heating the alloy to a temperature at which various constituents form saturated solid solutions with aluminum. When these solutions have been formed the metal is cooled rapidly to room temperature. This rapid cool results in the formation of super saturated solid solutions.

If, after this **treatment**, the alloy is allowed to rest at room temperature, or in many cases at slightly elevated temperatures, it attempts to reach equilibrium by the precipitation of certain phases in the form of submicroscopic particles. These precipitated phases account for the tensile strength and hardness which is possessed by the fully heat treated alloy. This age hardening or precipitation heat treatment is the second of the two steps mentioned in the opening sentence of this introduction.

The aluminum alloy 75-S obtains its maximum mechanical properties when it is aged at a temperature of 121° C. The purpose of this investigation is to determine the effect on mechanical properties which results when alloy 75-S is cooled rapidly from the solution temperature to the aging temperature rather than to room temperature.

LITERATURE REVIEW

The review of literature has been divided into three sections for the purpose of clarity. As an understanding of the fundamental theories of age hardening or precipitation hardening is necessary in the study of the heat treatment of an aluminum alloy the first section contains a brief review of literature on this subject. The second section is composed of information concerning the various phases present in an alloy of the 75S type (an aluminum rich alloy of Cu, Mg, Zn) and the third section contains information dealing with present commercial methods of heat treatment for an aluminum alloy of the 75 S type.

SECTION I : GENERAL SURVEY OF AGE HARDENING IN ALUMINUM ALLOYS.

The theory that age hardening is caused by the precipitation of particles from a super saturated solid solution was put forth by P. D. Mercia, R. G. Waltenberg and H. Scott. In recent publications by W. L. Fink and Dana Smith[1,2] this theory has been substantiated. In these investigations Fink and Smith studied precipitation during aging of (a) an Al-Cu alloy containing 5.17% Cu and (b) an Al-Mg alloy containing 10.3% Mg.

These investigations resulted in the following conclusions:

(1) The lattice parameter is not changed by precipitation of minute particles during age hardening as it is by precipitation under equilibrium conditions.

(2) Anomalous density changes can be explained by particles size or the precipitation of certain phases.

(3) Precipitation at grain boundaries can be observed before aging has progressed far enough to change yield strength and elongation to any great degree.

(4) There seems to be no justification for modification of the theory of precipitation hardening of Mercia, Waltenberg and Scott.

It must be remembered that the alloys used in this work were binary alloys. However, the conslusions of the investigators may be applied in general to the ternary and quaternary systems of aluminum.

If, in the case of an aluminum alloy which has been quenched in water from the solution temperature, hardness is plotted against time of aging the resultant curve, in many cases, will exhibit a double peak, the second peak being higher than the first. Investigation of these "Double Aging Peaks" resulted in two explanations which are not similar. Fink and Smith[3] in another publication of their series on the age hardening of aluminum alloys concluded from their experimental results that the first peak of the aging curve could be explained by more precipitation in the regions that have experienced plastic deformation during quenching and that softening which follows the first hardening may be due to overaging of the same regions. The further hardening shown by the second peak is accompanied by more general precipitation.

Marie L. V. Gayler[5] in her discussion of the "Theory of Age Hardening" accounts for the initial peak of the curve by considering a first phase of aging due to diffusion of solute atoms to planes about which precipitation proper will ultimately take place. In other words, a process of nucleus formation around which precipitation proper takes place occurs at first. In reference to aging temperature Mme. Gayler concludes that if such temperature is near the lower limit the first phase (diffusion) takes place slowly, so slowly in fact that the second phase (precipitation proper) will enter only after a long period of time, and conversely if the aging temperature is at the upper limit the second phase enters so rapidly that the first phase will be undetected.

From a review of these conflicting theories, however, it can be deduced that an alloy which is quenched from the solution temperature to the exact temperature at which it is to be aged will, in all probability, not exhibit a double peak in the hardness versus time curve.

SECTION II: PHASES PRESENT IN AN ALLOY OF THE 75-S TYPE.

In a recent investigation of the constitution of Al-Cu-Mg-Zn alloys at 460°C. made by D. J. Strawbridge, W. Hume-Rothery and A. T. Little[•] several important facts concerning an alloy of the 75-S type were published.

It was found that the solubility of copper in aluminum is increased by the presence of zinc in the alloy. Not only does the presence of zinc increase the solubility of copper but the degree of solubility varies directly with the amount of zinc present. From this it could be assumed that in alloy 75-S a large percentage of the copper would go into solution.

The authors also gave a description of the phases which may be present in a quaternary alloy of this type. The description of these phases follows:

(1) <u>$CuAl_2$ or θ Phase</u> contains only a small percentage of magnesium but is able to take from 1-2% zinc in solid solution.

(2) <u>' S ' Phase of Al-Cu-Mg</u> may be formed over a wide

range of quaternary alloys and dissolves little or no zinc.

(3) **The 'T' Phase**, a solid solution of Al-Cu-Mg-Zn, may be present.

(4) **The 'M' Phase**, a solid solution of Al-Cu-Mg*Zn, may exist in an aluminum rich alloy if the zinc content is sufficiently great.

(5) **The 'Z' Phase**, may be present as a Al-Cu-Mg-Zn Solid solution.

(In the section of this thesis devoted to Microscopic Examination a series of photomicrographs of 75-S will be found showing the presence of several of the phases mentioned above.)

SECTION III: COMMERCIAL HEAT TREATMENT OF ALLOY 75-S

Two methods of heat treating alloy 75-S are used in commercial practice. Of these methods, which are listed below, the first method (the use of a single stage precipitation heat treatment) is used to the greatest extent.

METHOD 1

In this method the alloy is given the solution heat treatment at a temperature between 860° F and 930° F. The time at which the alloy is held at this temperature depends on the type of medium used for the treatment and the size and type of material being heated. However, the principle factor which controls the time of heat is the time required for the solution forming constituents to go into solution. The alloy is quenched in cold water from this heat.

In the precipitation heat treatment the alloy is heated to from 245°F to 255°F (118°- 124°C) and held at this temperature for 22 to 26 hours. The cooling rate from this heat is not critical, however, it must be more rapid than a furnace cool.

METHOD 2

This method of heat treating the alloy is the same as Method 1 until the precipitation heat treatment step is reached. In this step the material is heated to 205°F to 215°F (96°- 102°C) and held at this temperature for 4 to 6 hours. At the end of this period the metal is cooled to room temperature (rate of cool not critical) and reheated to 310°F - 320°F (154°- 160°C). The alloy is held at this temperature for 8 to 10 hours. The rate of cool after this treatment is not critical.

THE INVESTIGATION

OBJECT:

In the heat treatment of aluminum alloys the effect of a quench from the solution temperature which is maintained at a temperature equal to the aging temperature of the alloy has not been investigated. The object, then, of this investigation is to determine the effect of such a constant temperature transformation on the mechanical properties of the aluminum alloy 75-S.

MATERIALS:

The metal used for this investigation was an aluminum base wrought alloy furnished by the Aluminum Company of America with the following composition limits:

COMPOSITION LIMITS - 75-S SHEET

COMPONENTS (Per cent)										IMPURITIES
Zn Min	Zn Max	Mg Min	Mg Max	Cu Min	Cu Max	Cr Min	Cr Max	Mn Min	Mn Max	Max.percent
5.1	6.1	2.1	2.9	1.2	2.0	.15	.40	.10	.30	Fe -.7% Si -.5% Ti -.2%

The alloy was received from Alcoa in the form of standard tensile test specimens for sheet. All specimens were prick punched for 2 inch gage length.

APPARATUS:

HEAT TREATING EQUIPMENT:

The annealing and solution heat treatment operations necessary in this investigation were accomplished with a Hoskins electric furnace, type FD. The temperature of this furnace was controlled by means of a chrome-alumel thermocouple connected to a Leeds and Northrup "Micro-Max" temperature control. A wire rack was constructed to support the specimens above the furnace floor and to assure that they were kept flat during the operations.

An electric laboratory oven with a temperature range of 35°C to 180°C was used for precipitation heat treating. The temperature of the oven was controlled by an automatic control which was calibrated to hold the temperature of the oven at the exact point desired. A constant check was maintained on this temperature by use of a high grade mercury thermometer which could be read at the top of the oven.

In all operations requiring a water quench a porcelain pan was used. The capacity of this container was large enough to insure a rapid quench and its diameter was such that the test specimens could be quenched longitudinally.

In the operations requiring a controlled temperature quench an aluminum pan was used. This container was long enough to insure an even quench of the specimen and its capacity was such that a sufficient volume of the quenching medium could be used to insure an even and rapid transfer of heat from the specimen. An electric heavy duty laboratory hot plate was used to bring all mediums used in the control quench to the proper temperature.

TESTING EQUIPMENT:

Tensile tests were made on a Dillon hand operated tensile tester. The dynamometer used for reading stress values was of 10,000 pound capacity and was calibrated in divisions of 100 pounds. Strain values were obtained by using a Riehle extensometer designed for a two inch gage length and calibrated in divisions of .001 inch. Yield strengths were obtained by drawing stress-strain diagrams for each specimen.

In all cases elongation in two inches was found by measuring the distance between gage pricks after rupture with a pair of sharp pointed measuring dividers. The distance between divider points was then measured by using an accurate Lufkin steel rule divided into .01 inch divisions.

The Brinell Hardness Tester used was equipped with a fixed load of 45 kg. attached directly to the penetrator. The specimen to be tested was placed on a flat anvil and both anvil and specimen were raised by means of a hydraulic jack until the penetrator transmitted the full load to the specimen. The diameter of the penetrator used for the tests was 3mm. This was computed by the following formula:

$$P\ kg = 500\ \frac{D^2}{10^2} = 5\ D^2$$

Where:
P equals load
D equals diameter of penetrator

All Rockwell hardness tests were performed on a standard Rockwell Hardness Tester. Three different types of Rockwell tests were used in this investigation.

Scale Symbol	Penetrator	Load in kg.
R_A	Diamond Point	60
R_B	1/16" Steel Ball	100
R_F	1/16" Steel Ball	60

METALLOGRAPHIC EQUIPMENT:

As it was necessary to polish and examine metallographic specimens after heat treating operations which were carried out at temperatures prohibitively high for pressed bakelite mountings it was necessary to devise a specimen holder which could be used. This holder was made by cutting three pieces of 3/32" sheet Lucite to a size convenient to hold while polishing. From the center of one of these pieces of Lucite a section the size of the metallographic specimens was cut. The sections of Lucite were then glued together with Ambroid liquid cement. After drying the holder was finished on a grinding wheel to the correct size. During polishing a specimen was held in place by rubber cement. After polishing was completed the specimen could be easily removed for heat treating.

A Bausch and Lomb ILS Metalloscope with a type G Camera attached was used for the examination and photographing of metallographic specimens. The source of illumination was a 4.5 ampere carbon arc. All photomicrographs were made with Eastman commercial ortho 4" x 5" sheet film which was developed in Eastman developer 61 A.

TESTING TECHNIQUE:

For the purpose of clarity the technique used in testing all specimens for their mechanical properties will be recorded in this section. No further mention will then be made of these techniques.

In performing hardness tests at least three impressions were made on each specimen before the material was subjected to tensile tests. The impressions were so located to insure no interference with the accuracy of the tensile tests. (Because of the thin cross section of the specimens the Rockwell " A " and Rockwell " B " values recorded may not compare favorably with tests made on thicker specimens of the alloy. However, the values will offer an accurate comparison of hardness values for the purpose of this investigation.)

Before making the tensile test each specimen was carefully measured to the nearest .001 inch. The extensometer was then attached and the specimen pulled in tension. Extensometer readings were taken at 200 pound intervals of dynamometer scale and for values above 2000 pounds readings were taken at 100 pound intervals. Yield strength was obtained by plotting a stress - strain diagram. After rupture elongation was measured by the use of an accurate set of dividers and an accurate steel scale.

EXPERIMENTAL PROCEDURE:

A series of specimens as received from the Aluminum Company of America were tested. These specimens had been fully heat treated and were received with temper designation 75 S T6. The results of these tests for typical specimens are shown in Table 1 on page 21.

As conditions in the laboratory differ greatly from conditions in the metallurgical plant a series of specimens were given a heat treating cycle in the laboratory which was a duplication of commercial practice. These specimens were first fully annealed to remove all results of former heat treatment. They were then heated to 870°F (466°C) and held at this temperature for five hours. This period of soak allowed more than ample time for solution conditions to be reached by the metal.

At the end of the "soaking" period the specimens were quenched to room temperature. (At this point in the investigation two temperatures of water quench were used. One group of specimens was quenched in water at 4°C and the other in water at 30°C. However, as comparison of the results will show the resultant properties are the same.) After quenching, all specimens were aged in air at 250°F (121°C) for 24 hours. The results for typical specimens which were treated by this "duplication method" are shown in Table 2 on page 22.

With the basis for comparison now firmly established it was possible to proceed with the investigation. The necessity of finding a quenching medium which could be used satisfactorily at a temperature of 250°F (121°C) was apparent. In the beginning common solutions which would boil at exactly 121°C. plus or minus 2°C were investigated. As a result of this work it was found that by proper dilution, a saturated solution of $CaCl_2$ could be used. The boiling point of a solution of four parts saturated solution of $CaCl_2$ and one part water was determined experimentally to be 121°C.

With the above mentioned quenching medium established another series of specimens were fully annealed and given the solution heat treatment for five hours at 466°C. At the end of this period the specimens were quenched to 121°C by using the $CaCl_2$ solution as a quenching medium. The pan containing the bath and specimens was then transferred to the oven which was at a temperature of 121°C. These specimens were allowed to age in this bath for a period of 24 hours.

At the end of this period the specimens were cooled to room temperature and examined. As had been expected corrosion was severe. The specimens were tested and in every case rupture occurred in corroded areas. Typical results of these tests are tabulated in Table 3 on page 23.

With the damaging results of corrosion obscuring the results of the controlled quench a new approach was necessary if the same quenching medium were to be used. It was thought that corrosion might be eliminated if, after the specimens were quenched, they could be transferred from the quenching medium and aged in air. As the heat lost from a specimen when it is quickly transferred from the quenching bath at 121°C to the oven at 121°C is negligible an operation of this type could be accomplished.

Therefore another series of specimens were fully annealed, solution heat treated at 466°C for five hours and quenched in the $CaCl_2$ solution at 121°C. After soaking in the quenching medium for at least five minutes the specimens were transferred quickly from the bath to the oven. During the transfer the temperature of the oven dropped only a fraction of a degree centigrade.

After aging for twenty four hours at 121°C these specimens were removed from the oven and cooled to room temperature. Surface corrosion was apparent and in the tensile tests breaks occurred in the more severely corroded areas. The results of the tests on typical specimens of this series are tabulated in Table 4 page 24.

From the results of the previous experiments it was apparent that a non corrosive quenching medium was needed. Glycerine, which has the non corrosive properties desired, was chosen as the quenching medium. It was now necessary to devise a means of controlling the temperature of the quench as " boiling point " control could no longer be used.

When the fact that the critical range of temperature for the precipitation heat treatment of 75-S amounts to 6°C (118°C - 124°C) is considered the problem of temperature control of the bath was simplified. In tests which were run in order to attempt to obtain a close control of temperature within this range it was found that the volume of glycerine used for the quenching operation would hold its heat, when removed from the source of heat, for a period in excess of five minutes. It was also found that if the glycerine were removed from the source of heat its temperature would increase from 4° to 6°C before reaching the peak.

A thermometer rack was so constructed that a laboratory mercury thermometer could be placed in the glycerine bath and temperature checks could be made. As the bath was heated to the critical temperature a constant temperature check was made and as the thermometer reading approached 118°C (the lower limit of the precipitation temperature range) the quenching bath was removed from the hot plate and placed on an insulating surface near the furnace door. After the specimens were quenched a constant temperature check was made and the specimens were allowed to soak until the temperature reading approached 120°C.

With glycerine as a quenching medium another series of specimens were fully annealed. These specimens were held at 466°C for five hours and then quenched in the glycerine bath. After soaking for a period of five minutes the specimens were transferred quickly from a bath to the oven an allowed to age. After aging eighteen hours a group of specimens were cooled and tested, after a period of twenty four hours still another group of specimens were cooled and tested and at the end of a period of thirty hours still another group of specimens were cooled and tested. The results of tests made on typical specimens from each of these groups are tabulated in Table 5 on page 25.

The comparison of the effects of a water quench and a glycerine quench at 121°C on the microstructure of the alloy are shown in the section of this thesis entitled "Microscopic Examination".

As a final step in the investigation a series of specimens were given the solution heat treatment at 466°C for five hours and then quenched to 121°C inthe glycerine bath. The bath which contained the specimens was then transferred to the oven, which was at a temperature of 121°C, and aged for a period of twenty four hours. The specimens were then cooled and tested. Typical results of these mechanical tests are tabulated in Table 6 on page 26.

RESULTS:

The results of the mechanical tests made in the experiments described in the preceding paragraphs will be found in Tables 1 to 6 which are reproduced on pages 21 to 26. The results of the constant temperature transformation on the microstructure of the alloy are discussed in the section of this thesis devoted to "Microscopic Examination". Special attention is called to Figures 1 and 2 of this section.

DISCUSSION OF RESULTS:

As can be seen from a comparison of the values in both Tables 1 and 2 the results are relatively constant in both cases. A good value for the various mechanical properties can be chosen from the table if the obvious low values and the obvious high values are discarded and the lowest value is chosen from those remaining.

In the experiments using the $CaCl_2$ quench the effects of corrosion are easily apparent. Naturally those specimens which were aged in a bath of $CaCl_2$ for twenty four hours show this to a greater extent than do those specimens which were merely quenched in the solution and then aged in air.

When glycerine was used as a quenching medium no corrosion was observed. The tabulated results also definitely show by variations in tensile and yield strength that if the alloy is aged for only 18 hours it is underaged and if it is aged for 30 hours it is overaged. However, even at the correct aging period the results (tensile and yield strengths) are of lower values than those achieved when a series was run in the laboratory in duplication of the commercial process. However, when the specimens were allowed to age for the correct period in the bath of glycerine at 121°C the results are surprizingly constant and compare very favorably with those of the alloy which had been treated by the commercial method. The results of the various mechanical tests made on this series of specimens ran much more constant than the results from any other series. (This can be seen by comparing the typical results in the tables.)

TABLE 1

RESULTS OF TESTS ON ALLOY AS RECEIVED.

Specimen	Tensile Strength psi	Yield Strength psi	Elongation % in 2"	Brinell 45 kg 3 mm	Rockwell		
					R_A	R_B	R_F
I	81,000	69,500	10.5	134.5	54	90	
II	84,000	70,000	10.5	134.5	54	90	
*III	81,000	70,000	10.2	134.5	54	90	
I 0	84,000	71,500	10	156.7	54		9
II 0	84,000	71,500	10	134.5	54		9
III 0	82,500	70,500	10.5	134.5	54		9
IV 0	84,000	71,500	10.5	134.5	54		9
V 0	84,000	71,500	10.5	134.5	54		9

* An example curve was plotted from this set of data and it may be found in the section of this thesis devoted to curves.

TABLE 2

ALLOY HEAT TREATED IN THE LABORATORY IN DUPLICATION OF COMMERCIAL PROCESS

Specimen	Tensile Strength psi	Yield Strength psi	Elongation % in 2"	Brinell 45 kg 3 mm	Rockwell R_A	R_B	R_F
A. Quenched from Solution Heat in water at 4 C							
I	84,000	72,500	13.5	134.5	55	91	
*II	84,000	72,500	12.5	134.5	54	91	
III	84,000	73,000	11.5	134.5	54	91	
B. Quenched from Solution Heat in water at 30 C.							
I	84,000	72,000	13	134.5	55	91	
II	84,000	72,500	13	134.5	55	91	
III(IP)	84,000	72,500	11.5	134.5	55	91	9
II P	84,000	72,500	12.5	134.5	56	91	9
III P	84,000	73,000	11	134.5	55	91	9
IV P	85,000	73,500	11	134.5	54	91	9
*V P	84,000	73,500	12.5	134.5	55	92	9

*An example curve was plotted from each set of data so marked. These curves are found in the section of this thesis devoted to curves.

TABLE 3

ALLOY QUENCHED IN $CaCl_2$ AT 121°C: AGED IN BATH 24 HOURS

Specimen	Tensile Strength psi	Yield Strength psi	Elongation % in 2"	Brinell 45 kg 3 mm	Rockwell	
					R_A	R_B
I	75,000	66,500	4	134.5	53	86
II	79,500	68,500	6	134.5	54	91
*III	82,500	70,500	11	134.5	54	91

*An example curve was plotted from this set of data and is found in the section devoted to curves in this thesis.

NOTE: The erratic data shown by these typical specimens was due to the severe corrosive action of the quenching medium. When the depth of corrosion was considered the results are surprizingly high.

TABLE 4

ALLOY QUENCHED IN $CaCl_2$ AT 121°C.
TRANSFERRED TO AIR AT 121°C: AGED 24 HOURS

Specimen	Tensile Strength psi	Yield Strength psi	Elongation % in 2"	Brinell 45 kg 3 mm	Rockwell R_A	R_E
I A	61,000	68,500	12	134.5	53	90
II A	81,000	70,000	11	134.5	54	90
*III A	82,500	70,500	12	134.5	54	91
IV A	83,000	70,500	11	134.5	54	90

*An example curve was plotted from this set of data and is found in the section devoted to curves in this thesis.

NOTE: In these tests rupture occurred in corroded areas.

TABLE 5

ALLOY QUENCHED IN GLYCERINE AT 121°C.
TRANSFERRED TO AIR AT 121°C.:AGED 24 HOURS

Specimen	Tensile Strength psi	Yield Strength psi	Elongation % in 2"	Brinell 45 kg 3 mm	Rockwell	
					R_A	R_B
A. Aged 18 hours						
I C	81,000	70,000	12.5	134.5	54	91
*II C	81,000	70,000	12.5	134.5	54	91
III C	82,000	70,000	12	134.5	54	91
B. Aged 24 hours						
*II B	82,500	71,000	12	156.7	55	92
*III B	85,000	73,000	13	134.5	55	92
IV B	82,000	71,000	12	134.5	55	92
C. Aged 30 hours						
V B	79,000	69,500	11	134.5	54	91
V BA	79,000	68,000	11	134.5	54	91

*An example curve was plotted from each set of data so marked and these curves may be found in the section of this thesis devoted to curves.

TABLE 6

ALLOY QUENCHED IN GLYCERINE AT 121°C
AGED 24 HOURS IN BATH.

Specimen	Tensile Strength psi	Yield Strength psi	Elongation % in 2"	Brinell 45 kg 3 mm	Rockwell R_A	R_B	R_F
I F	84,000	73,500	13	134.5	56	92	9
*II F	84,000	73,500	13	134.5	56	92	9
III F	84,000	73,000	13	134.5	56	92	9
IV F	84,000	73,000	12.5	134.5	56	92	9
V F	84,000	73,500	13	134.5	56	92	9

*An example curve was pltted from this set of data and will be found in the section of this thesis devoted to curves.

CONCLUSIONS:

The results obtained from the experiments performed in this investigation of the constant temperature transformation occurring when alloy 75-S is quenched from the solution heat directly to the aging temperature indicate the following conclusions:

1. The results of mechanical tests performed on the alloy which had been quenched and aged in a non-corrosive bath are equal to the best results obtained and exhibited by the alloy which had been treated in the conventional manner. Therefore, it may be said that in the treatment of alloy 75-S it is unnecessary to quench from the solution heat to room temperature and reheat to the aging temperature in order to develop maximum physical properties.
2. Although it is realized that too few specimens were tested to establish the fact the results indicate that the properties resulting from this type of constant temperature transformation exhibit a consistency of values which does not normally occur.
3. The correct period of aging at 121°C for alloy 75-S is not altered by the change in quenching

technique.

4. The changes occurring in the microstructure during the solution heat treatment are not altered by the use of the constant temperature quench.
5. The transfer of the alloy from a liquid medium at the aging temperature to air at the same temperature for completion of the aging cycle does not develop maximum tensile and yield strengths.

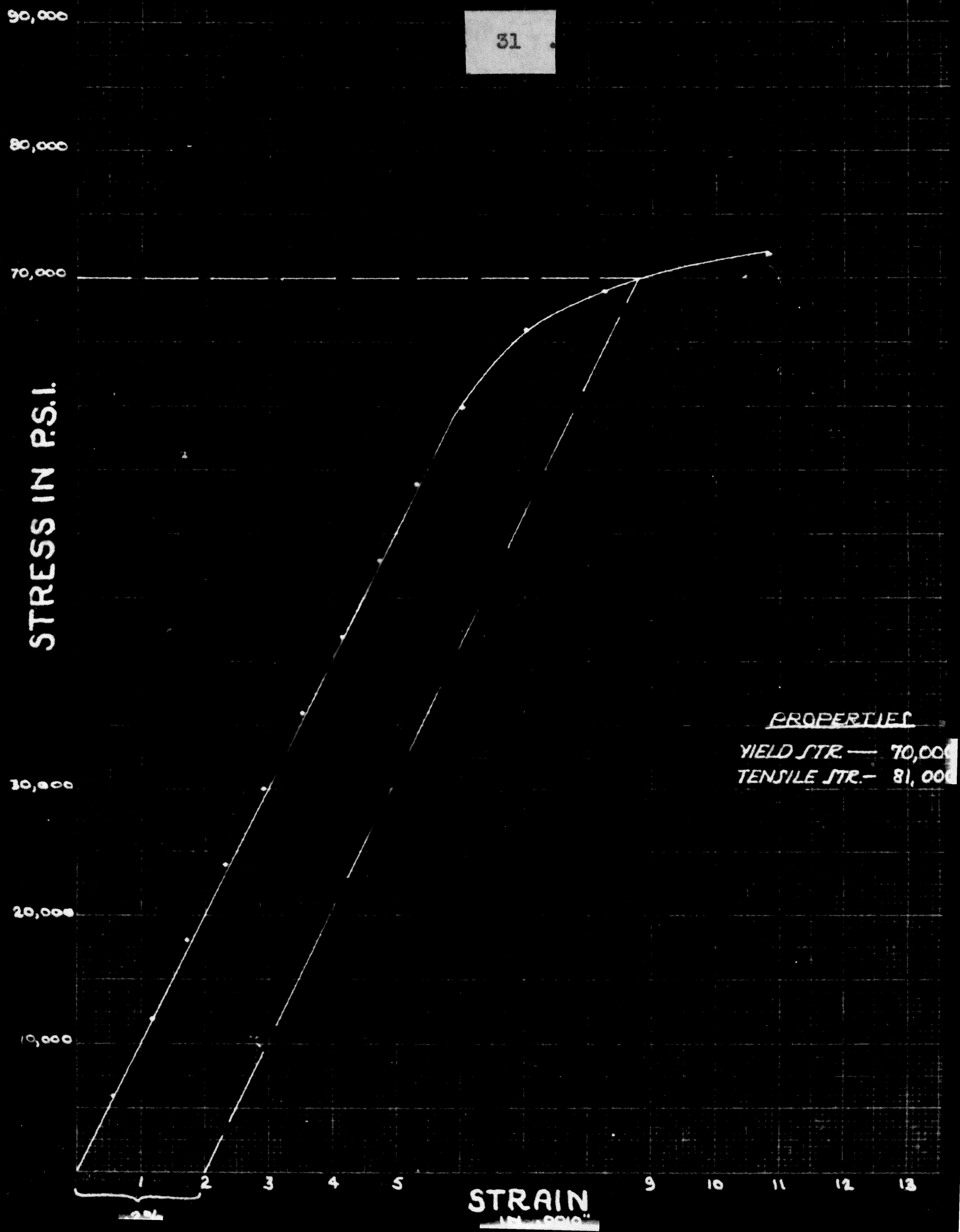
SUMMARY:

This investigation has established the fact that the alloy 75-S can obtain maximum physical properties without being cooled to a temperature below the aging temperature at any point in the heat treating cycle. However, such a method of heat treatment in no way alters the time required for the precipitation heat treatment at 121°C. This refers to specimens of the type used in this investigation.

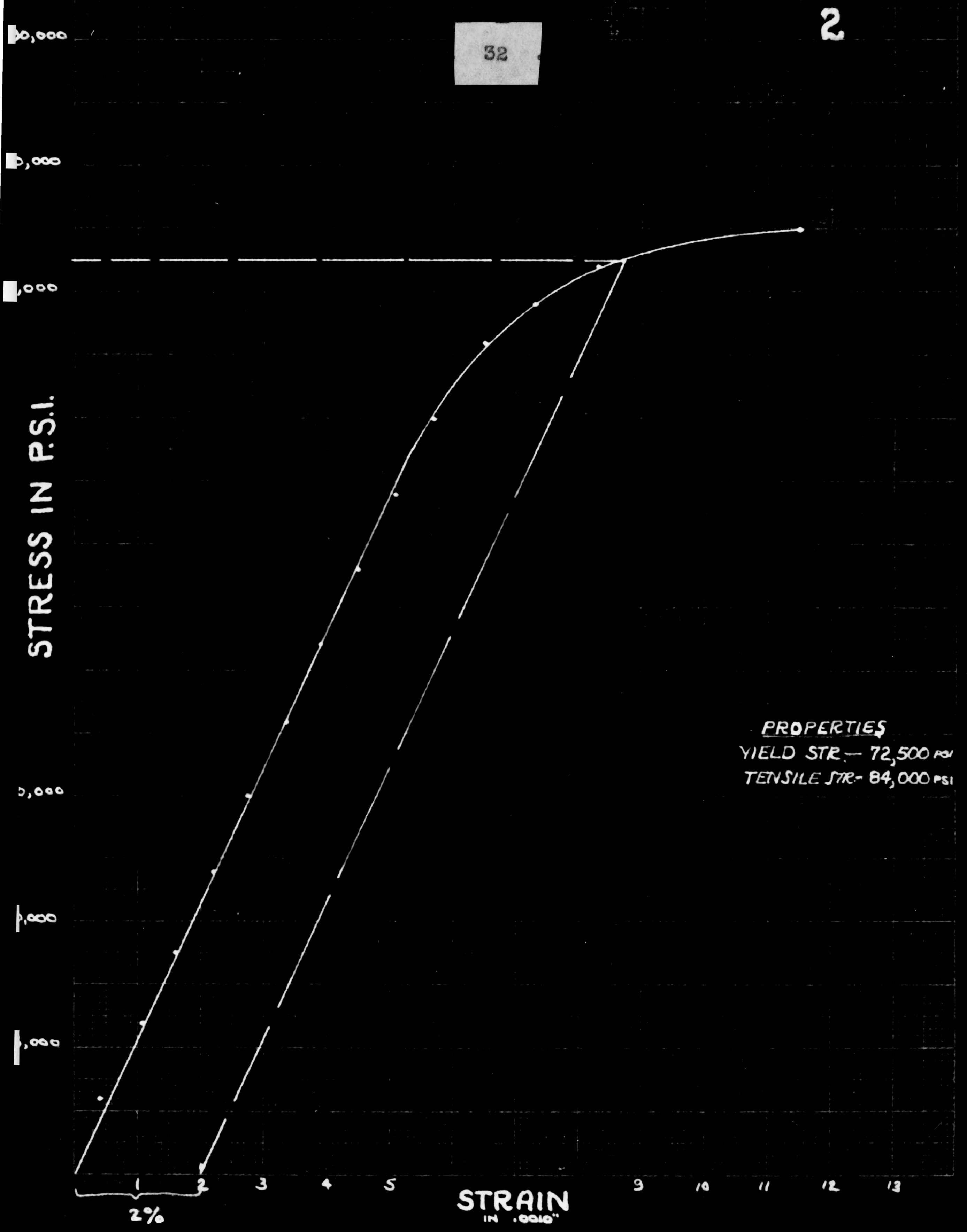
The medium which is used for the constant temperature quench must be non-corrosive. Glycerine was used in this work because a supply of the material was in stock.

INDEX OF CURVES

INDEX OF CURVES
(cont.)

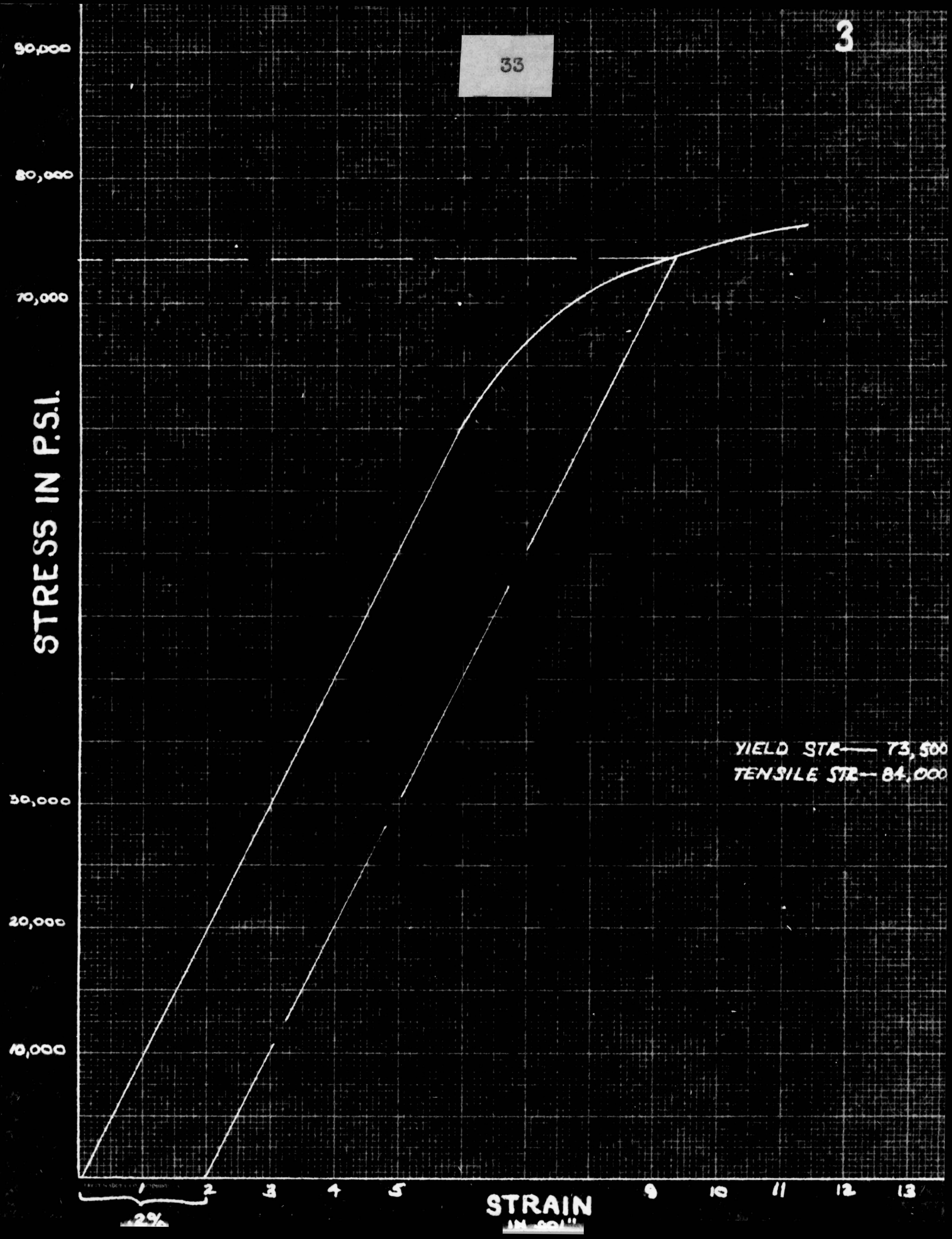

90,000
80,000
70,000
30,000
20,000
10,000
STRESS IN P.S.I.
1
2
3
4
5
9
10
11
12
13
STRAIN
PROPERTIES
YIELD STR. — 70,00
TENSILE STR.– 81,00

2



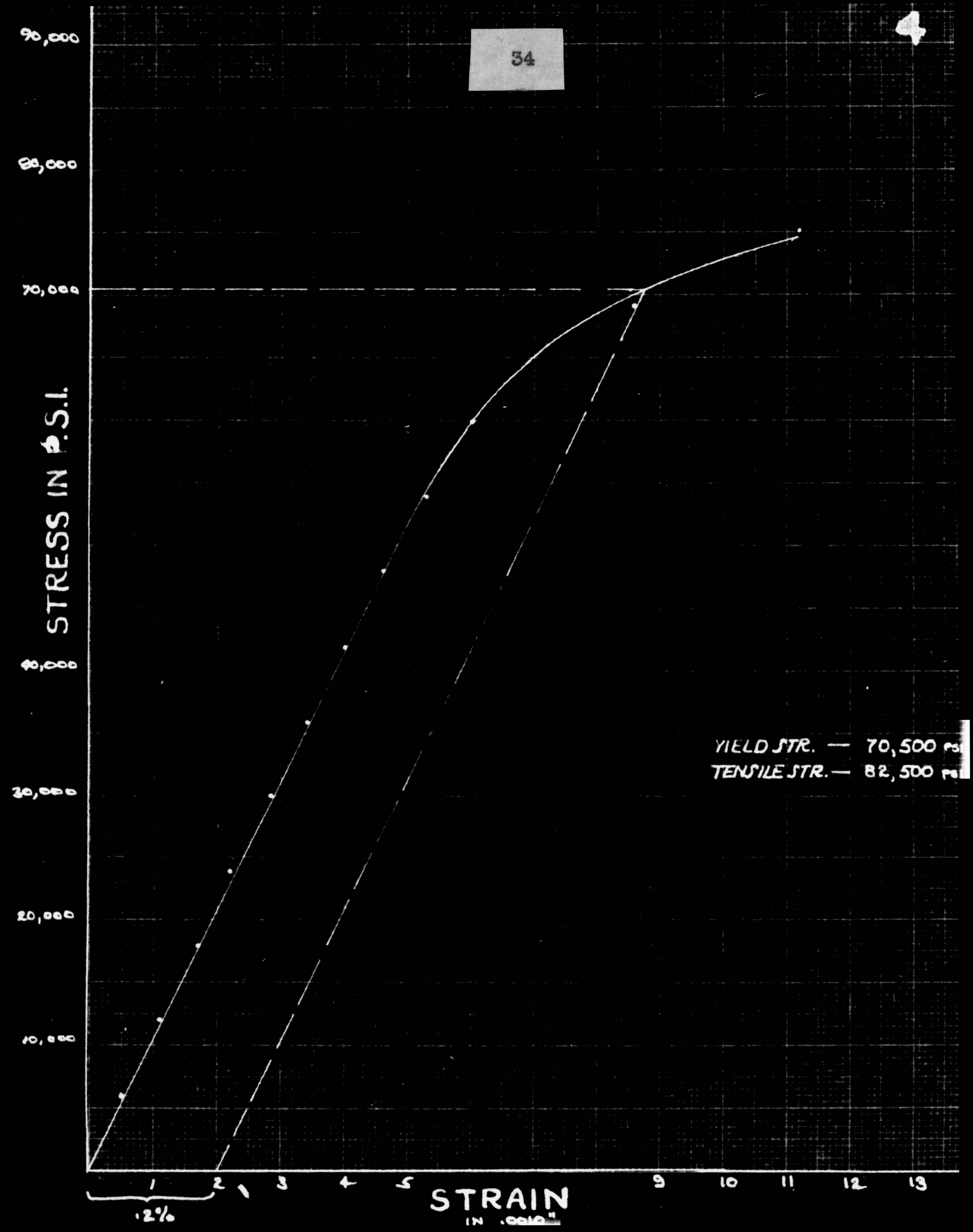
PROPERTIES
YIELD STR. — 72,500 PSI
TENSILE STR. - 84,000 PSI

3



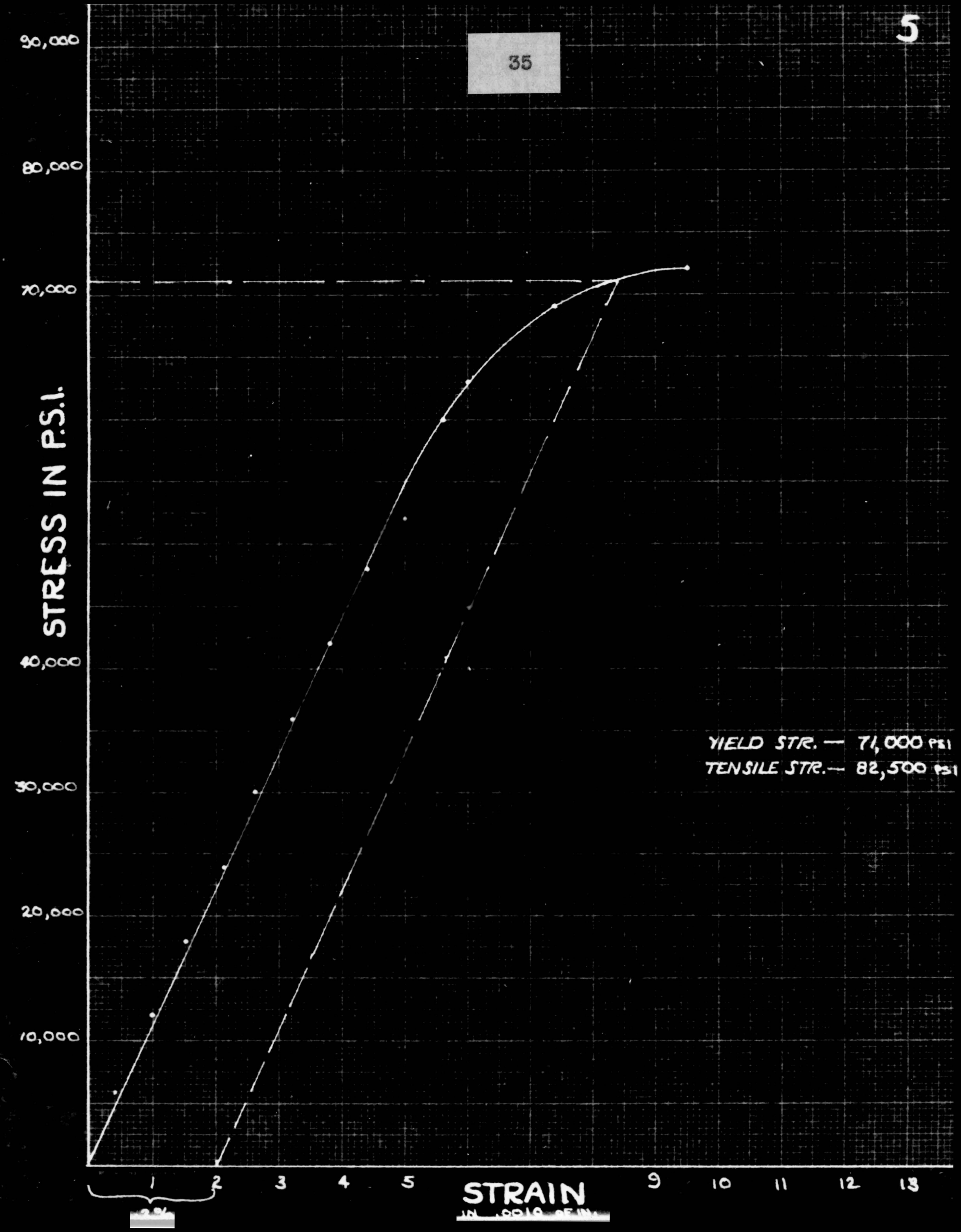
YIELD STR—— 73,500
TENSILE STR-- 84,000

4



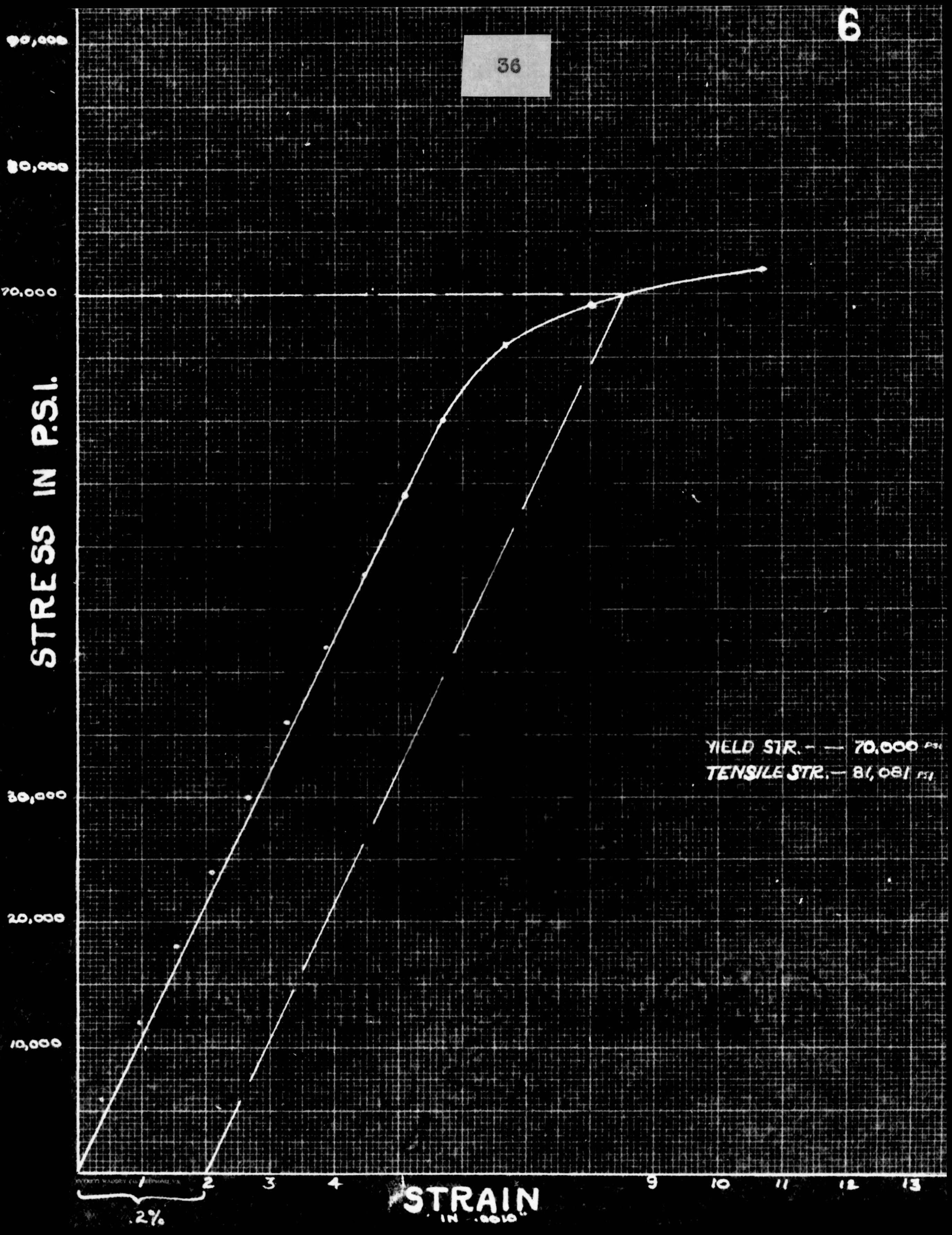
YIELD STR. — 70,500 psi
TENSILE STR. — 82,500 psi

5



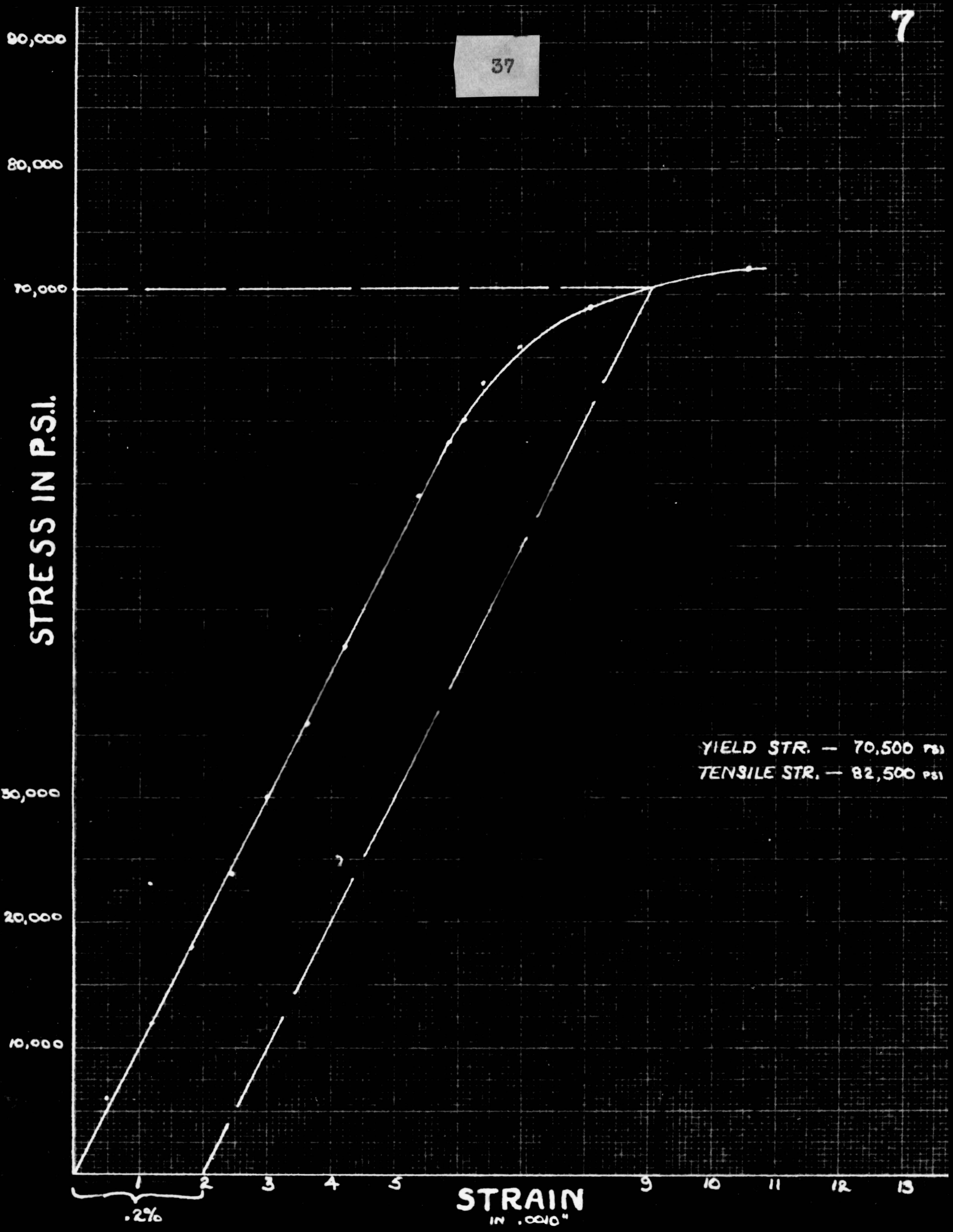
YIELD STR. — 71,000 PSI
TENSILE STR. — 82,500 PSI

6



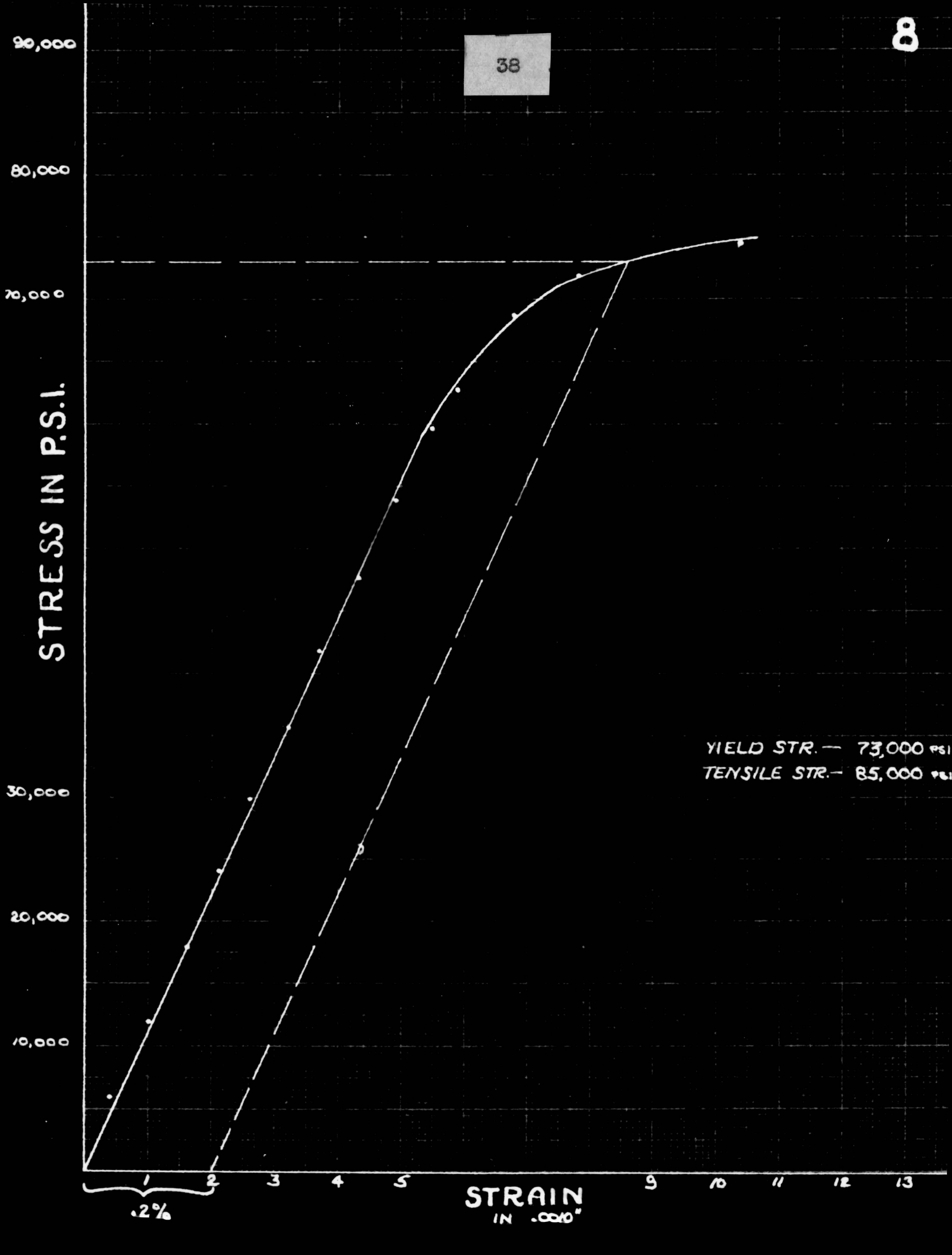
YIELD STR. — 70,000 PSI
TENSILE STR. — 81,081 PSI

7



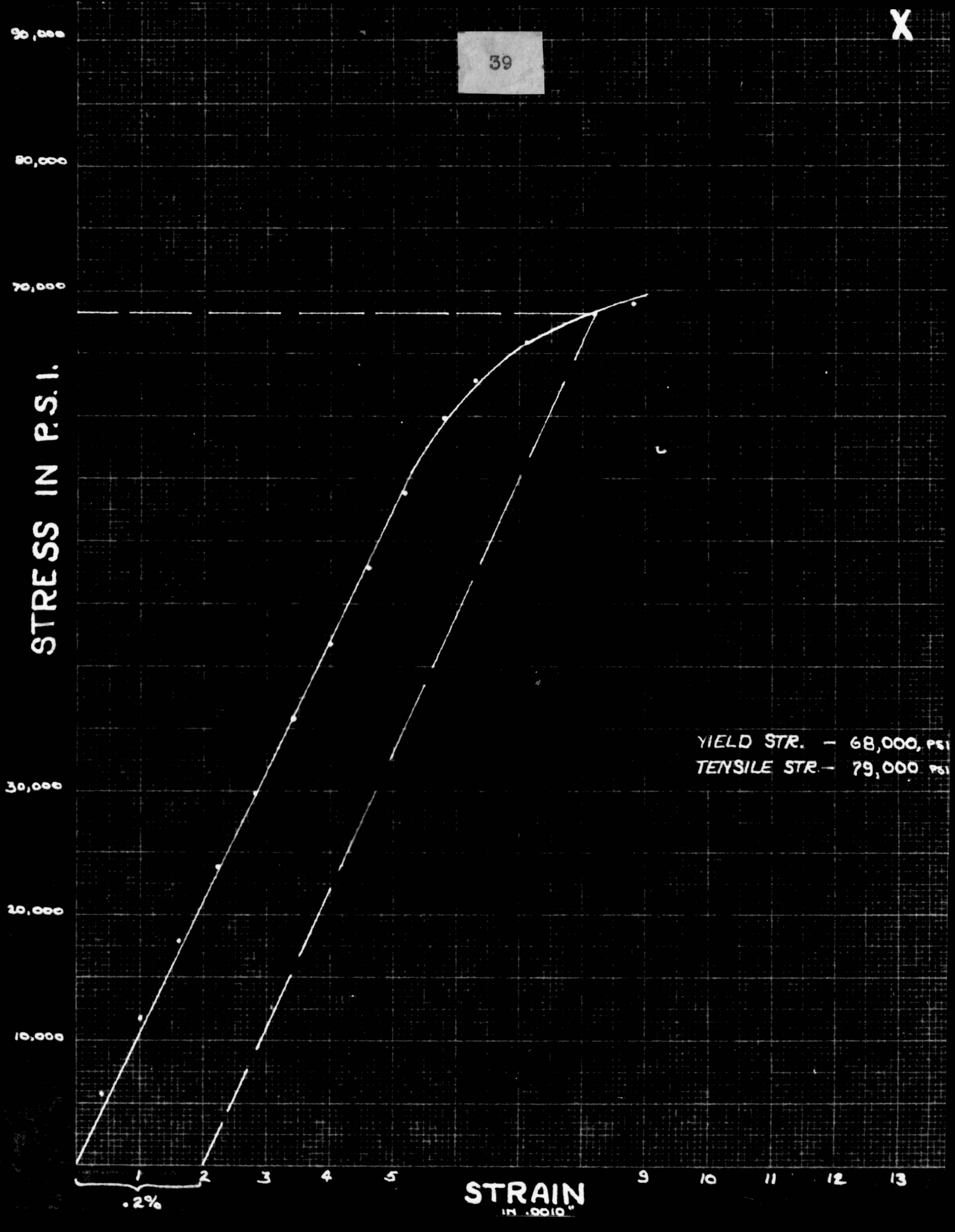
YIELD STR. — 70,500 PSI
TENSILE STR. — 82,500 PSI

8

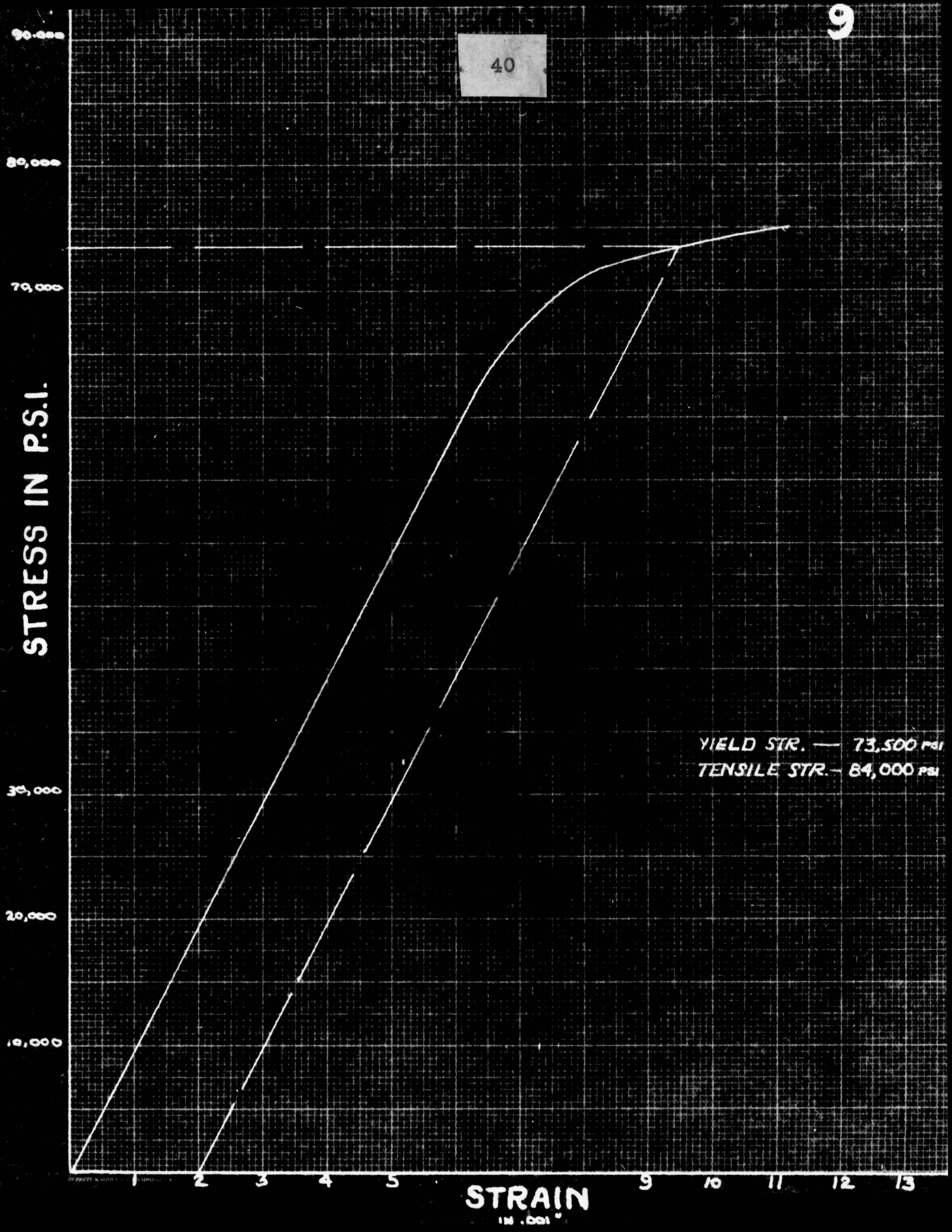


YIELD STR. — 73,000 PSI
TENSILE STR.— 85,000 PSI

X



YIELD STR. – 68,000, PSI
TENSILE STR.– 79,000 PSI



YIELD STR. — 73,500 psi
TENSILE STR.— 84,000 psi

MICROSCOPIC EXAMINATION

PREPARATION FOR MICROSCOPIC EXAMINATION:

Specimens for examination were cut from the fully heat treated tensile bars. All cuts were made under a stream of water with an abrasive cutting wheel. The edges of each piece were beveled on a grinding wheel, care being taken not to overheat the metal. The specimens were then mounted for polishing in the holder previously described in this thesis.

The following procedure was used in preparing a specimen for examination:

1. The specimen was rubbed successively on No. 0, 00, and 000 emery paper that had been coated with a solution of paraffin and kerosene. Each cut was made at right angles to the previous cut.
2. Rough polishing was accomplished on a rotating disc covered with flannel using a water suspension of 600 alundum flour. The polishing disc rotated at between 250 and 300 rpm.
3. The final polish was given the specimen on a disc covered with a " Velvette " polishing cloth which was boiled frequently to soften it. The disc was rotated at between 150 and 200 rpm and magnesium oxide (heavy) was used as a polishing medium.

The cloth was kept moist with distilled water and small quantities of magnesium oxide powder were worked into it with the fingers. As the polishing neared completion the pad was washed nearly free of magnesium oxide and the specimen was completed using a copious supply of distilled water.

MAGNIFICATION:

All photomicrographs in this section were made at 500 diameters. This magnification was achieved by use of an 8 mm. achromatic objective and a 7.5 hyperplane eyepiece.

DISCUSSION OF PHOTOMICROGRAPHS:

The photomicrographs which have been reproduced on the pages of this section have been printed in logical series. Explanation and discussion of the individual pictures in each series is recorded on the following pages.

SERIES -- 1

FIGURE 1: This specimen was polished and then annealed for five hours at 466°C. Unetched (500 x)

FIGURE 2: The same specimen after repolishing was solution heat treated at 466°C for five hours and quenched in water at 20°C. Unetched (500 x)

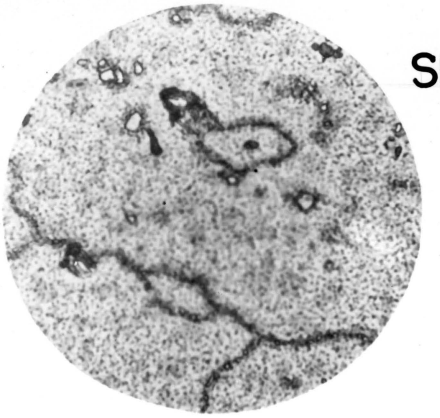
A Comparison of Figure 1 and Figure 2 will show to a limited degree a change in structure after solution heat treatment.

FIGURE 3: The same specimen as in the preceding photomicrographs has been aged at 121°C for 8 hours. It was then repolished and etched for one minute with 25% HNO_3 and then for one minute with Keller's Reagent. (500x) Precipitation of $CuAl_2$ (θ) can be noticed to slight degree along grain boundaries.

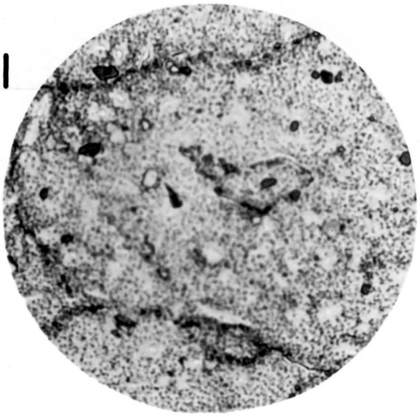
FIGURE 4: The same specimen is shown after having aged 17 hours at 121°C. The specimen was polished and etched in the same manner as for Figure 3. (500 x) $CuAl_2$ (θ) precipitation along the grain boundaries has increased.

FIGURE 5: The same specimen is shown after having aged 25 hours at 121°C. The specimen was polished and etched in the same manner as for Figure 3. (500 x) After comparing Figures 3 and 4 it is apparent that the $CuAl_2$

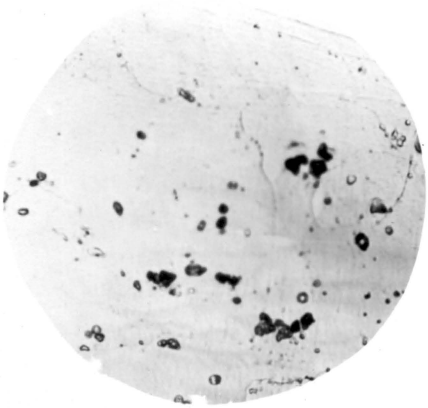
SERIES — I



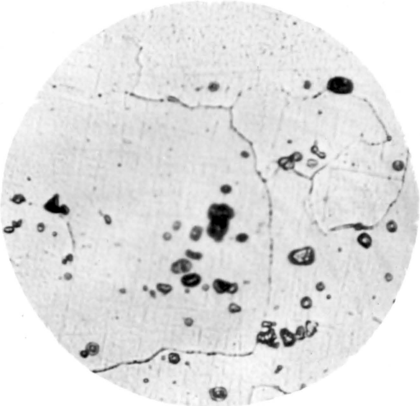
1



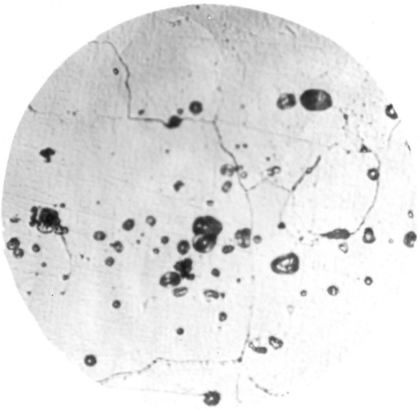
2



3



4



5

precipitation in the grain boundaries has ceased after the specimen had been aged for a maximum of seventeen hours. This, of course, does not indicate that general precipitation ceased after seventeen hours of aging.

SERIES -- 2

FIGURE 1: This specimen was polished in the fully hardened state and then annealed for five hours at 466°C. Unetched (500 x)

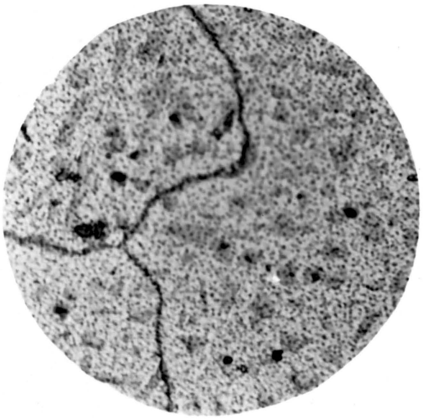
FIGURE 2: The same specimen without repolishing was heated to 466°C and held at that temperature for five hours and then quenched in water at 25°C. Unetched (500 x)

FIGURE 3: This specimen was polished in the fully hardened state and then annealed for five hours at 466°C. Unetched (500 x)

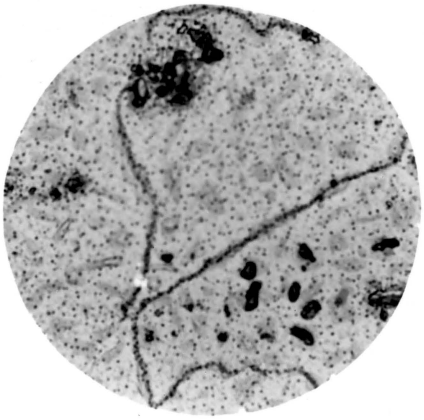
FIGURE 4: The same specimen as in Figure 3 after having been heated to and held at 466°C for five hours and then quenched in a bath of glycerine at 121°C. Specimen was held in the bath at this temperature for five minutes and then quenched in water at 5°C. Unetched (500 x)

Comparison of the photomicrographs of this series will show that the as quenched specimens are similiar. It might then be said that the differences in quenching media temperatures does not change the microstructure appreciably.

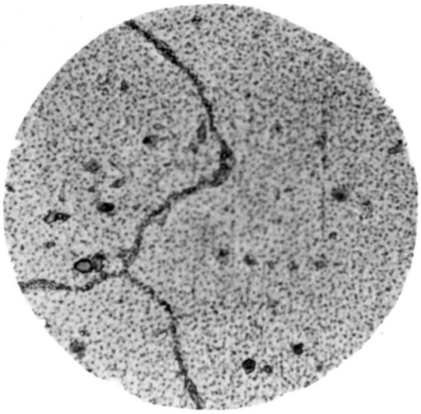
SERIES —— 2



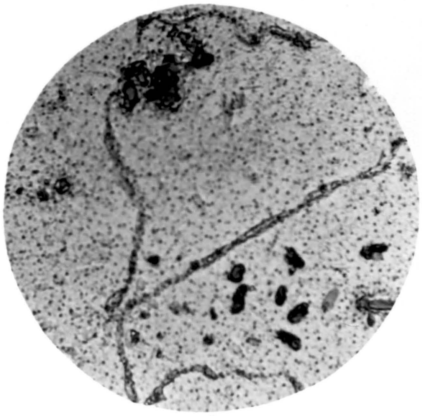
1



3



2



4

SERIES -- 3

FIGURE 1: Fully heat treated metal which is unetched. (500x). (The dark grey area was the result of improper development)

FIGURE 2: The same specimen after etching for 30 sec. with 10% NaOH. (500 x)

FIGURE 3: The same specimen after repolishing and etching with Keller's Reagent for 20 sec. (500 x)

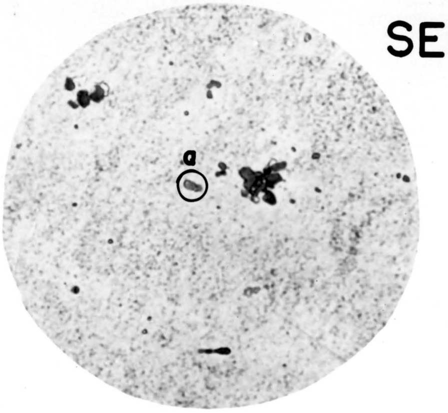
FIGURE 4: The same specimen after repolishing and reetching with Ψ molybdate for one minute and 30 sec. (500 x)

FIGURE 5: The specimen after repolishing and etching with .5% HF for 40 sec. (500 x)

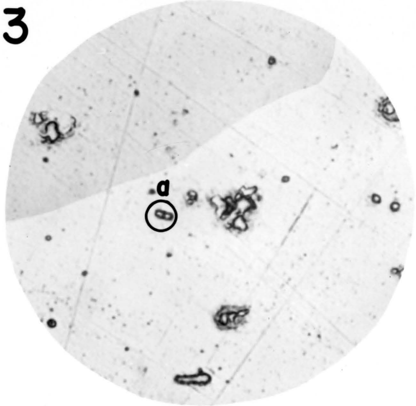
FIGURE 6: The specimen was repolished and etched with Conc. HNO_3 for 8 sec. (500 x)

The method by which the various constituents are identified can best by explained by using the table which is reproduced on page 50.

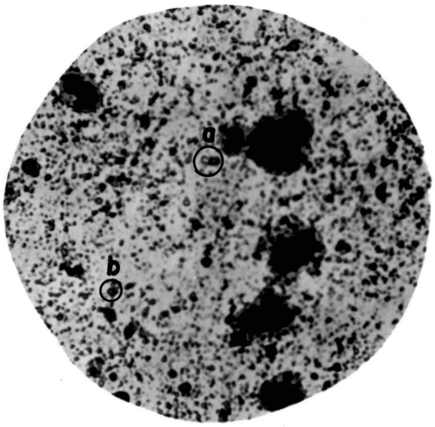
SERIES — 3



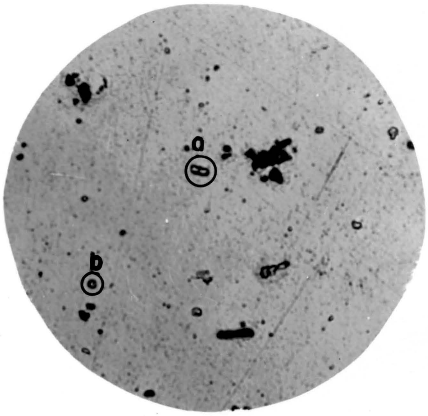
2



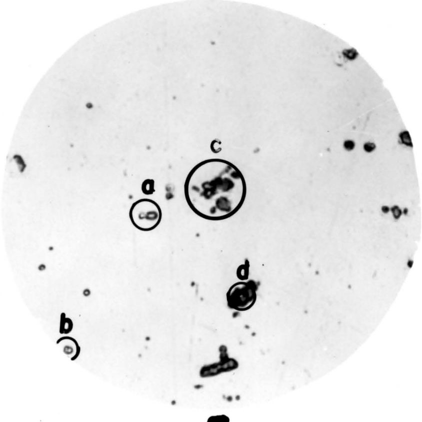
1



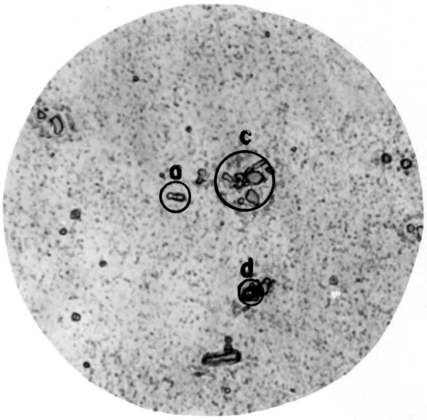
4



3



6



5

IDENTIFICATION CHART FOR SERIES -- 3

Symbol	Constituent	Fig.1	Fig.2	Fig.3	Fig.4	Fig.5	Fig.6
$\overset{a}{\bigcirc}$	$CuAl_2$ or θ	Grey	Outline Brown	Thin Outline	Unetch		
$\overset{b}{\bigcirc}$	S			Smooth Black	Black		Unetched
$\overset{c}{\bigcirc}$	M					Thin Outline Grey	Dissolved or Pitted
$\overset{d}{\bigcirc}$	T					Black	Black Outline Brown

SERIES -- 4

FIGURE 1: Fully heat treated metal which was polished and unetched. (500 x)

FIGURE 2: The same specimen was repolished and etched for 15 sec. with .5% HF. (500 x)

FIGURE 3: The same specimen was repolished and etched for 30 sec. with 20% H_2SO_4. (500 x)

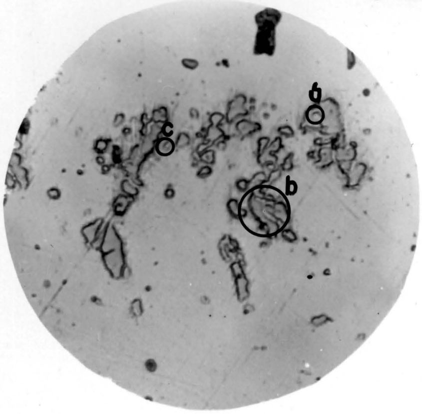
FIGURE 4: The same specimen was repolished and etched with 1% NaOH (500 x). A different field was used in this photomicrograph than was used in other members of the series.

Identification of several constituents is as follows:

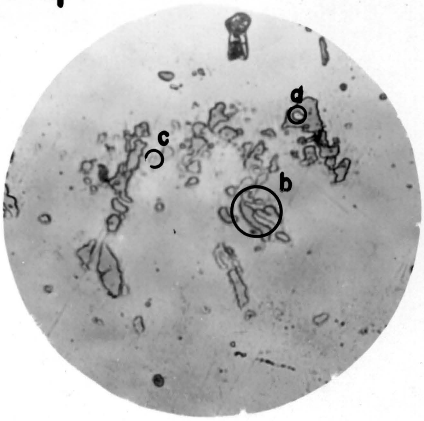
1. The small particle designated by $\overset{a}{\bigcirc}$ is $CuAl_2$ or θ phase.
2. The particle designated by $\overset{b}{\bigcirc}$ is $MgZn_2$ or $MgZn_5$, (Strawbridge identifies this phase as Phase 'M', an Al-Cu-Mg-Zn solid solution)
3. The particle designated by $\overset{c}{\bigcirc}$ can be identified as Al-Mg phase.
4. The particle designated by $\overset{d}{\bigcirc}$ can be identified as Al-Cu-Mg.

NOTE: The method etching for identification of constituents may be reviewed by referring to references 6,13,14,15.

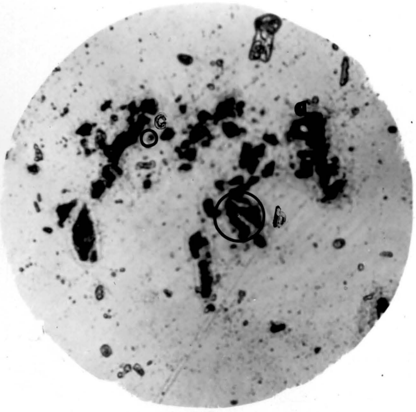
SERIES — 4



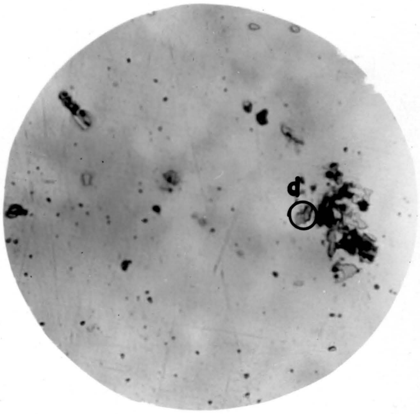
1



2



3



4

BIBLIOGRAPHY

1. W. Fink and D. Smith : Trans AIME (1936) 122, 184

2. W. Fink and D. Smith : Trans AIME (1937) 124, 162

3. W. Fink and D. Smith : Trans AIME (1938) 128, 223

4. W. Fink and D. Smith : Trans AIME (1940) 137, 95

5. M.L.V. Gayler : Jnl Inst Metals (1937) 1,249

6. D. J. Strawbridge, A. Hume-Rothery and A.T. Little
: Jnl Inst Metals (1947)74,206

7. M. Cohen : Trans AIME (1939) 133, 35

8. R.F.Mehl, C. S. Barrett and F. N. Rhines
: Trans AIME (1932) 99, 203

9. A.Phillips and R.Brick:Trans AIME (1934) pg 94

10. L. W. Kempf, H. L. Hopkins and E. V. Ivanso
: Trans AIME (1934) 158

11. Aluminum Co. of America: Alcoa Aluminum and Its Alloys.

12. METALS HANDBOOK(1948): Aluminum and Aluminum Alloys

13. L. F. Mondolfo : Metallography of Aluminum Alloys

14. Metal Progress Data Sheets (1946) : Nos. 120-128

15. F. Keller and Wilcox : Metals Progress (April 1933)

16. F. Keller : Mining and Metallurgy
(December 1935) pg 513

17. R. L. Templin : Proc ASTM (1926) 26,II, 378

18. ASTM Standards (1946) Section E18-42