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A STUDY OF GRAIN GROWTH IN ALLOYS

TO THE

MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

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Course X.

Submitted by:

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Director

Cambridge, Massachusetts.

A STUDY OF GRAIN GROWTH IN ALLOYS

ACKNOWLEDGEMENT

I wish to thank Doctor Robert S. Williams for suggesting the topic of this thesis to me and for his valuable assistance in carrying out the experimental work.

I am indebted, also, to Mr. J. Weston Pratt for many timely suggestions in connection with the experimental technique.

Appreciation is also expressed to the American Brass Company and to the Aluminum Company of America, who supplied some of the material used in this theses.

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INTRODUCTORY

Many metallic articles, in use in industry and in the household too, are made by subjecting a piece of the metal in sheet form to a drawing operation to take the general shape of the article, then annealed for some definite period of time.

The drawing operation causes a certain amount of cold work to be done on the metal. The metal is liable to have been strained, hence the annealing process to eliminate the strains.

It has been found in some cases that after such cold work and annealing that the finished product showed a rough surface in places, was weak at the place and liable to fracture. Certain investigators found that the roughness and weakness was due to the presence of large grains in the structure, brought out by the cold work and annealing operations and that the excessive grain growth could be prohibited by control of the annealing temperatures. Some investigators have formulated the opinion that this excessive grain growth is dependent upon critical strain in the metal or alloy.

Purpose

This thesis, then, is a study of grain growth in some alloys, studying particularly the relation between cold work and annealing temperature and grain or crystal growth.

The work of this thesis is not attacked with the thought that some definite relation exists and that the writer will find it, nor does he hope to bear out the opinions of experienced investigators that grain growth is dependent upon critical strain.

However, if some relation, or any relation between grain growth and strain will be found, such that it will encourage one to further investigation or even be of some help to later experimenters, the writer will feel well rewarded for his efforts.

Previous Work

The effect of cold work and annealing has been studied by many investigators and many of them agree that critical strain is necessary to promote grain growth.

Carpenter and Elam

Carpenter and Elam[1] have made an intensive study of aluminum. In their paper "Crystal Growth and Recrystallization in Metals", read before the British Institute of Metals of September 15, 1920,

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(1) Carpenter and Elam, J. Inst. Metals. No. 2, 1920.

they show that if aluminum is annealed at 1022° Fahrenheit for sixty-five hours, a critical point appears when the aluminum has undergone a four per cent elongation. Therefore, they suggest that grain growth is dependent upon critical strain. Furthermore, they point out that absorption of the crystals takes place if strained below the critical point and that no change will be shown by unstrained crystals.

A. P. Knight[1], working to determine the cause of very large crystals forming on the bottom of aluminum coffee pots, agrees with the opinions of Carpenter and Elam. He concludes that the metal must have been critically strained at that particular point, because if annealing alone had brought about the formation of very large crystals, the center surface of the coffee pot would have showed the large crystals. Knight suggests also that excessive grain growth follows from critical strain especially when the metal has been heated a long time near its melting point. Knight, however, found that in his particular problem excessive grain growth was avoided if the pots were annealed at a temperature 100° less than that at which the large

A. P. Knight

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(1) Knight, Chem. and Met., Vol. 24, P. 29.

grains were produced.

Chappell's[1] tapered bar shows clearly the point at which grain growth begins. At that section of the bar having the least strain, the grains are small, then they increase in size very markedly and as the degree of strain increased, the size of the grain decreased. A study of Chappell's bar would indicate also that critical strain caused the excessive grain growth. Chappell

Professor A. Sauveur[2] is another prominent advocate of the theory that critical strain is necessary to grain growth. He also believes that in the cases of steels there is a critical carbon content. Sauveur

H. M. Howe[3] believes that the development of abnormally large grains may be called germination and that the temperature range where the large grains are formed is the germinative temperature range. Howe

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(1) Chappell J, Iron Steel Inst., No. 1, pp 460-496-1914.

(2) The Metallography and Heat Treatment of Iron & Steel.

(3) Grain Growth, Trans. Am. Inst. Mining Eng. Vol. 56.

Jeffries and Archer

Jeffries and Archer[1] believe that any tendency for the occurrence of grain growth is determined by grain size, and depends upon what they call "grain size contrast," and that large grains tend to grow at the expense of the smaller ones.

Jeffries and Archer take issue with Carpenter and Elam[2] as to which grain grows, the grain of least strain, or the grain of greatest strain. To quote from Jeffries and Archer:- "In an aggregate of grains which are strained to various extents, the grains which are least strained are in a position to grow by feeding upon their more severely strained, i.e., fragmented--neighbors. It has been a common mistake to consider that, since strain leads to grain growth, the grains which are most strained are the ones which grow. This fallacy seems to be based upon a false conception of the energetics of the case. It is held that energy is required to impart the power to grow, and that this energy must be stored in some way in the grain. The strained grain is therefore, regarded as the one endowed with the power of growth. Actually, the conditions are the exact reverse. The unit which does the growing is the grain of greatest thermodynamic stability, and hence least energy content. The

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(1) Jeffries and Archer, the Science of Metals.

(2) Chem. and Met., Vol. 24, P. 224.

logic of this is apparent on considering the conditions on the solidification of a metal from the molten state. The solid, unstrained grains feed upon the molten phase, which has the higher energy content."

They also maintain that germinative centers are found at the point of greatest strain, and that the grain size will be larger the farther apart are these centers. Severe strain tends to produce uniform strain which in turn, tends to bring the points of equal strain close together. Abnormal grain growth follows from mild deformation.

Jeffries and Archer dwell at great length on the theories and causes of grain growth. They end their discussion with the following tabulation: "There is a critical amount of mechanical obstruction which favors the establishment of these necessary differences in growth velocity and hence, germination.

Summary

Certain investigators have worked with many kinds of pure metals and alloys, studying grain growth and its causes and effect. Although they may disagree as to the mechanism of grain growth from a consideration of a balance of energy forces, they all come to the same conclusion; namely, that there is a critical point where abnormal grain growth occurs.

EXPERIMENTAL WORK

The drawing of the specimens, or the cold work was done by means of an Olsen Cupping Machine, employing the Ericksen principle.

Olsen Cupping Machine

The Olsen Cupping Machine consists of a heavy base having a screw arrangement that forces a steel ball of one inch diameter up through a space in the jaws or gripping part of the machine. The jaws are operated also by a screw device. The specimen, or rather the flat piece of metal to be cupped is inserted between the jaws, taking care that the ball is sufficiently clear of the piece. The jaws are clamped down tight, but loosened very slightly in order that the piece may be drawn and not cut. An "Ames" dial, recording the depth of cup in inches, operates by a spindle which is in touch with the metal just above the point of contact with the ball underneath. The spindle is set in position, with the dial registering zero, with the steel ball just in contact with the specimen piece. By means of the screw, operated by a large wheel, the ball is slowly forced up into the piece being cupped. The "Ames" dial must be under constant inspection and the reading must be taken just previous to actual fracturing of the piece. If the

reading is taken at fracture, it will be high, due to a jump of the spindle as the metal cracks. It is good practice to make a trial test in order that the reading may be taken just before fracture.

A pressure gauge, showing the pressure applied in pounds per square inch was also attached to the cupping instrument. The reading was taken, also just previous to fracture, and had to be taken very quickly as the needle went back to zero when the pressure was released. The "Ames" dial retained the reading until the spindle was again set, with the dial showing the zero position. The photograph and diagram on the following page describe the Olsen Cupping Machine.

Cupping Specimens

The cupping of the pieces was the elementary part of this thesis, and all pieces of the brasses, steels and aluminum alloys were cupped at this time. Trial tests were made to find out the best time to take the readings from the "Ames" dial and the pressure gauge. Tests were then made in the case of each alloy to obtain the point of maximum depth of cup, and the pressure. There was no very great variation, but five tests were made, and the average of these readings were taken as representing the maximum depth of cup.

Figure "A", OLSEN CUPPING MACHINE

OLSEN CUPPING MACHINE

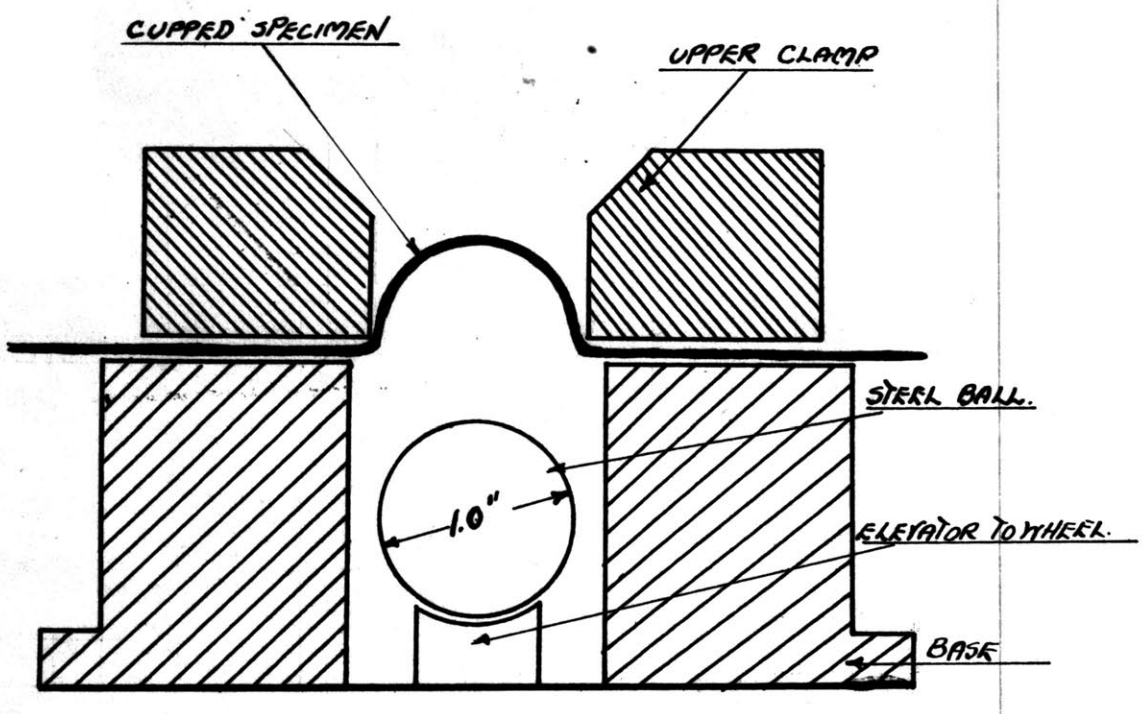


Figure "B". Sketch shows the cupped specimen, the ball in lowered position, the ball socket, ball pit, elevator and clamp and base.

Since it was decided to work with four series of specimens, showing respectively, full cup, one-half cup, three-quarters cup and one-quarter cup, the maximum depth of cup just previous to fracture was designated as full cup, and calculations were then made to determine what depths would show three-quarters cup, one-half cup, and one-quarter cup. All pieces were then cupped, with readings from the "Ames" dial controlling the operation. The readings of cup in inches and the working pressure in pounds per square inch were recorded.

At the beginning of the thesis, a study of three types of steels were also considered; namely, those of low carbon content or soft; medium carbon content or medium, and high carbon content or hard. Time was insufficient for the proper heat treatment and further study with respect to the steel specimen, hence they will receive no other mention in this thesis. Some heat treatment of these steels was carried out, especially with the soft type, but a study of the crystal structure or grain growth was not attempted.

Having in mind the idea of obtaining checks in data, the pieces were cut in double lengths so as to include two cups of same depth, close together,

from the same section of the original sheet, in order that they would be subjected to the same temperature in the annealing furnace.

The work of this thesis was confined then, chiefly to brasses and aluminum alloys. Muntz metal, usually referred to as 60-40 brass, and Alpha brass, referred to as 70-30, were the brasses used. Aluminum alloys, similar in composition to the alloy referred to as Duralumin, containing aluminum, copper, manganese, iron, magnesium and silican, were also studied.

HEAT TREATMENT

It might be well to consider briefly the heating treating apparatus.

Furnaces

The furnaces were of the resistance type, wound with Chromel wire, good up to approximately 1800°-2000° Fahrenheit for short periods of time, but having a good life if the temperature is kept below 1600° Fahrenheit. Both potentiometer and automatic control furnace were used in this work.

The thermo couples were of base metal, Iron-Constantan, good up to approximately 2000° Fahrenheit.

Muntz

Four strips of Muntz Metal, each having two cups of the same depth were put in the center of the annealing furnace just under the thermo couple junction. The furnace was brought to the temperature desired and held constant for ten minutes. The pieces were then introduced as quickly as possible, furnace brought to temperature if necessary, and the heat held constant to ten degrees for thirty minutes. Potentiometer control was employed in this case. The specimens were allowed to cool in the furnace, and in every case over night. Temperatures were: 620-800-975-1160-1360-1550° Fahrenheit.

Alpha Brass

Four strips of Alpha Brass of two cups each were heated at various temperatures, keeping temperature constant to ten degrees by means of potentiometer control, for thirty minutes. As in the case of the Muntz Metal, the pieces were put quickly into the furnace after the furnace was brought up to temperature and held constant for a trial period. Cooling of the heated specimens was furthered by drawing them from the furnace and allowing them to remain in contact with the stone table top until cool. Temperatures were: 865-1010-1265-1400-1565° Fahrenheit.

Aluminum Alloys

Specimens of Aluminum Alloys (17 ST and 51 ST) were heat treated in furnace with automatic control, keeping constant to ten degrees for one hour after bringing the furnace to heat. All specimens were furnace cooled. Temperatures were:

(17 ST) 750-850-900-980° Fahrenheit.

(51 ST) 660-750-850-900-980° Fahrenheit.

Numbering

Before the heat treatment, all specimens were numbered, using a very simple system of numbering. In order to differentiate between the Muntz Metal specimen and the Alpha Brass specimens at any later period, the respective pieces were stamped "M" and

"A", the letter followed by numbers representing the temperature of heat treatment. For instance, the piece of Muntz heated to 975° Fahrenheit was designated and numbered as "M-975". Since the heats were all of the same duration of time, there was no need to number the time. However, in order that there might be no mistakes made in identifying some of the specimens they were later marked to show which depth of cup they represented, such as one-quarter cup, one-half cup, three-quarters cup and full cup. Hence, complete identification of each specimen was possible.

After the heat treatment, the cups were sawed in half. The cutting was done with an ordinary hack saw, allowing the saw to make its own progress and never trying to force it. The cuts were made in the middle of each cup, through the point representing the maximum depth in each cup. Later the specimen pieces were trimmed so that they might be handled easily in the polishing operations.

At first each specimen piece was polished separately, carried through all the operations, finally to the etching and microscopical examina-

tion. Such a method was tedious, disadvantageous in that it tended to destroy the polish, and inaccurate as the edges tended to round during the polishing operation.

Mounting Specimens

At the suggestion of Mr. J. W. Pratt, the specimens were cast in molds which would hold all four pieces of the same temperature of heat treatment. Having the specimens so arranged helped very materially in the polishing, etching and examination, and especially when taking the photomicrographs. It might be of interest to mention briefly how the pieces were cast. "Lipowitz", the casting metal, is a low melting alloy of the following composition:-

Bismuth	50%
Lead	27%
Tin	13%
Cadmium	10%

The metal was kept in the melted condition in a crucible on an electric hot plate. Rings sawed from cast iron pipe of diameter 1.5 to 2.0 inches and of a depth of one-half an inch served as the molds. These rings were filed smooth on one side, heated for a brief time on the hot

plate so as to keep the metal warm while working, and then placed on a clean glass plate. The molten Lipowitz was poured into the ring molds and while molten, the four specimens of the heat, held in a pair of tongs were pushed down into the molten metal and held there until the Lipowitz hardened. After cooling, the excess Lipowitz was filed off just enough to expose the cross sections of each piece of brass in the cast.

Each mold, having four specimens, was carried through the polishing operations. The brasses, both Muntz and Alpha, were cast as above, using the Lipowitz alloy.

Sulphur was used in the case of the Aluminum alloys. Here the procedure was different, necessarily, as the sulphur hardened so rapidly. At first it was considered that casting might be facilitated by keeping the ring on a warm block of steel. Poor results were obtained because the sulphur would run out around the bottom and would not stay in the mold. Hence, the four pieces were held tight in the ring and molten sulphur poured around them from a hard glass test tube. As soon as the melt hardened, the ring block was turned over and more molten sulphur poured in the crevices between each piece of Aluminum alloy.

After smoothing with a file, a good firm mold was obtained. All the Aluminum alloy pieces examined were cast in this manner.

Polishing

A file was used only to smooth off the Lipowitz metal and the sulphur, so that the cross sections of the specimen pieces showed at the surface. Rough polishing, to take off the file marks, was done on the emery endless belt. Each piece was carried through #1G, 0, 00, emery paper, turning the pieces so that the scratches showed at right angles to the scratches from the previous polishing operation. After the emery paper, the pieces were carried through the following polishing wheels. #1, using a canvas wheel and carborundum suspension. The suspension was put up by adding a teaspoonful of powdered carborundum to a liter of water. #2, a broadcloth wheel, using the carborundum suspension. After the carborundum polish, the specimens were carefully washed and then polished on a broadcloth wheel using a coarse suspension of alundum in water. Wheel #4 was of broadcloth, this time using a fine suspension of alundum in water. Final treatment varied. Clean broadcloth and water was tried, but gave a poor polish. However, a good polish was obtained from "Kitten's Ear", using a fine suspension of alundum

in soapy water. The last polishing operation left a soap film on the surface of the metal, hence, it had to be washed off by gently rubbing the metal with cotton batting soaked in alcohol.

For the Aluminum alloys the polishing technique differed a little from that for the brass, since the Aluminum alloys scratched very easily. After filing to smooth off the sulphur, the pieces were put on a fairly worn emery endless belt. Omitting the 1G, the pieces were carried down through #0, 00, 000 emery paper, polishing with oil in each case; then through the broadcloth wheel using carborundum, washed carefully and through the broadcloth wheels, using coarse and fine suspensions of alundum, respectively, and finally given the finished polish on the "Kitten's Ear" using soapy, fine alundum suspension. Before etching, the pieces were all washed in alcohol to remove the soap film. In all cases, best results were obtained only by etching followed by more polishing, going back sometimes as far as the broadcloth wheel and the coarse alundum suspension.

Etching

The brass pieces were etched with 3% H_2O_2 and Concentrated Ammonium Hydroxide. The use of a set ratio of the etching reagents was not attempted. The ratio was varied in each case in order to

obtain the optimum etch.

Several etching reagents were tried on the Aluminum alloys. Dilute Hydrofluoric Acid gave poor results as did 0.10 per cent Sodium Hydroxide in alcohol. Villella's reagent (HCL-HNO_3-Glycerine) gave fair results, as did Frick's reagent, (HF-H_2O-HCL).

A combination of Villella's and Frick's reagents gave the best results in bringing out the grain boundaries. Villella's reagent was good for bringing out the grain boundaries and worked very quickly, but the surface appeared to be covered by a film which made the boundaries hazy under the microscope. It was found that an initial treatment with Villella's reagent, followed by a rapid treatment with Frick's reagent gave a clear surface, with the boundaries nicely outlined.

MICROSCOPIC EXAMINATION AND GRAIN COUNTING.

Two types of photomicrographic apparatus were used in the examination. One, the Bausch and Lomb, and the other, the Leitz. Having the specimen pieces to be examined mounted in the pieces of pipe facilitated their examination. It was almost impossible to arrange a single specimen on the camera table so that it would stand firm. As the

specimens were so thin, fairly high magnifications were necessarily employed.

The grain counting method used was that proposed by Zay Jeffries and recommended by the American Association for Testing Materials. The image of the specimen is projected on a ground glass plate. A circle, 5000 square millimeters in area, and 79.8 millimeters in diameter is inscribed on the ground glass plate. The grains of the particular area studied are checked with a glass marking pencil on the smooth surface of the plate, so that after each count, the marks may be eliminated by rubbing lightly with a damp cloth. The writer checked each whole grain by the regulation check mark (√) and each grain intersecting the circumference of the circle was checked with an (X). The number of grains completely included within the circle plus five-tenths of the number of grains intersecting the circumference, gave a fairly approximate number of grains present. To obtain the number of grains per square millimeter, the number of grains counted is miltiplied by a factor, the factor depending upon the magnification used. A table showing standard magnification may be found in Williams' Metallography. The diameter

STANDARD MAGNIFICATIONS

AS RECOMMENDED BY THE AMERICAN SOCIETY

FOR TESTING MATERIALS.

Diameter of circle in millimeters.	Magnification used.	Multiplying factor to obtain grains per square millimeter.
79.8	10	0.020
79.8	25	0.125
79.8	50	0.500
79.8	75	1.125
79.8	100	2.000
79.8	150	4.500
79.8	250	12.500
79.8	500	50.000
79.8	125	3.121*

* Calculated by the writer.

of the average grain in millimeters is calculated by considering the diameter equal to the reciprocal of the square root of the number of grains per square millimeter.

If a permanent record of the grain count is desired, then white tracing paper may be fastened to the glass plate with small gummed labels and the grains checked on a circle inscribed on the paper.

The above multiplying factors are found by Jeffries' formula that:

$$f = \frac{m^2}{5000}$$

where (f) = factor, and (m) = the magnification. For 125 magnifications, the factor was calculated to be 3.12 and is included in the above table.

It is perhaps worth mentioning at this time that all grain counts were made at the point on the specimen corresponding to the point of maximum depth of the cup, or in close proximity to that point. A count taken at the exact point would probably have no very great meaning since at some other point close to it a different count might be obtained. For this reason, all counts as recorded represent the average of five counts made at five different places near the point mentioned above.

PHYSICAL DATA

Muntz Metal

	1/4 Cup	1/2 Cup	3/4 Cup	Full Cup
Depth (ins.)	.120	.235	.360	.450
Pressure	450	1550	3400	4900

Alpha Brass

Depth (ins.)	.095	.180	.270	.345
Pressure	500	1500	2800	3850

Aluminum Alloy (17 ST)

Depth (ins.)	.096	.140	.190	.245
Pressure	400	800	1350	2200

Aluminum Alloy (51 ST)

Depth (ins.)	.060	.100	.140	.180
Pressure	200	500	850	1300

THICKNESS

Muntz Metal-- .039 inches.

Alpha Brass-- .036 inches.

Aluminum Alloy (17 ST) -- .033 inches.

Aluminum Alloy (51 ST) -- .033 inches.

CHEMICAL ANALYSIS

Alpha Brass

	A	B
Copper	66.35%	66.25%
Tin	none	none
Iron	none	none
Lead	none	none
Zinc (by diff.)	33.65%	33.75%

Muntz Metal

	A	B
Copper	61.87%	61.90%
Lead	0.83%	0.77%
Iron	trace	trace
Tin	none	none
Zinc (by diff.)	37.30%	37.33%

CHEMICAL ANALYSIS

ALUMINUM ALLOY 17 ST

Silicon	0.66
Iron	0.40
Copper	3.77
Magnesium	0.26
Manganese	0.48
Aluminum (by diff.)	94.43

ETCHING REAGENTS

Brasses

3% Hydrogen Peroxide

Concentrated Ammonium Hydroxide.

Aluminum Alloys

Frick's	HF Conc.	10 c.c.
	HCL Conc.	15 c.c.
	H_2O	10 c.c.

Dip specimen in reagent, wash in hot water, dip in concentrated HNO_3, wash.

Villella's	HF Conc.	2 parts
	HNO_3 Conc.	1 part
	Glycerine	3 parts

GRAIN COUNT --- MUNTZ METAL

Annealing Temperature	Cup Depth	Magnification	Grain Count
1550° F.	.450	150	40
	.360	150	53
	.235		
	.120	150	48
1360° F.	.450	125	99
	.360	125	103
	.235	125	61
	.120	125	57
1160° F.	.450	125	99
	.360	125	125
	.235	125	88
	.120	125	98
975° F.	.450	125	98
	.360	125	103
	.235	125	72
	.120	125	30
800° F.	.450	200	131
	.360	200	108
	.235	125	148
	.120	125	119

Muntz Metal

Annealing Temperature	Cup Depth	Magnification	Grain Count
620° F.	.450	125	81
	.360	125	71
	.235	125	76
	.120	125	71

GRAIN COUNT --- ALPHA BRASS

150 Magnification

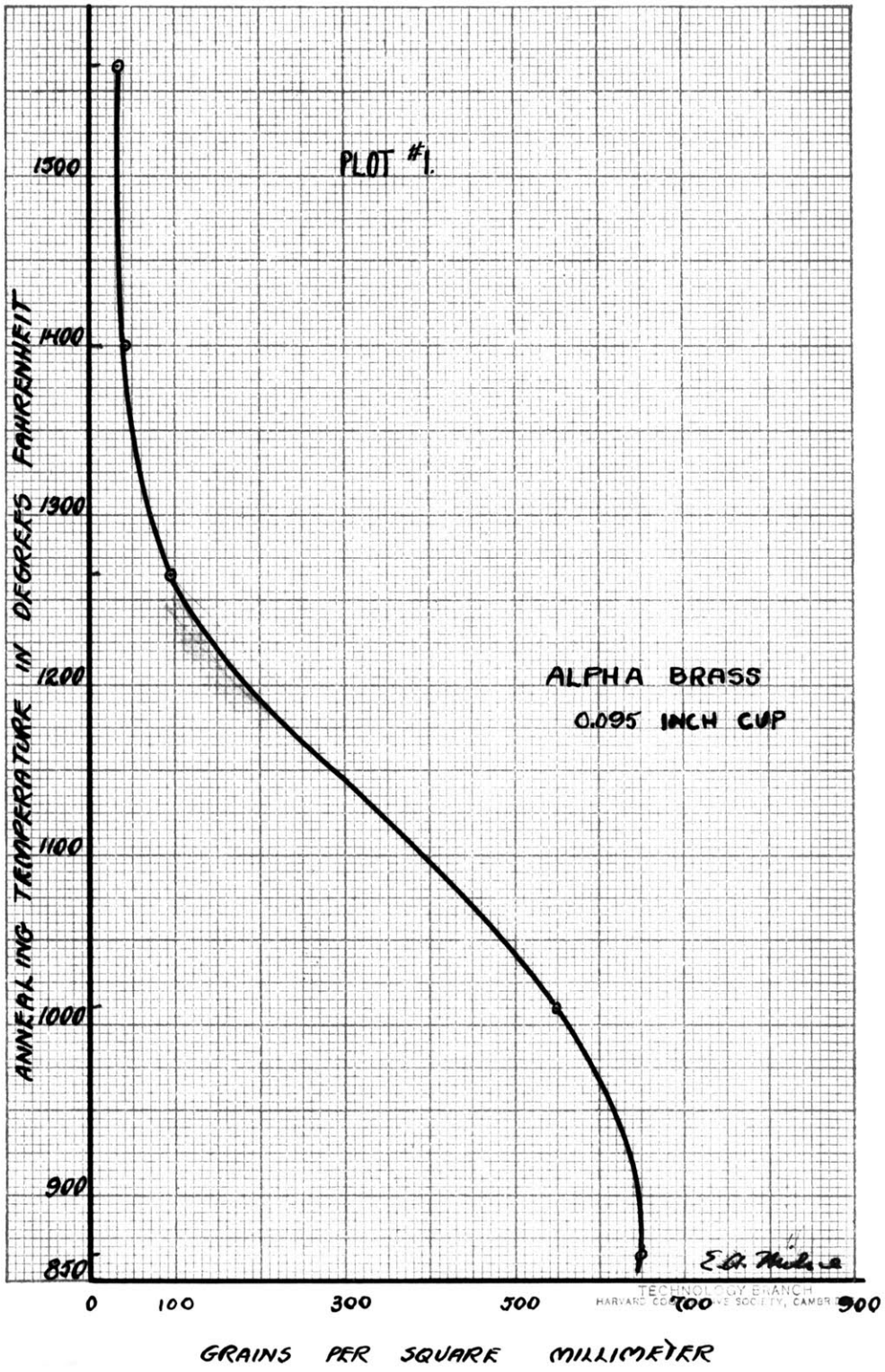
Annealing Temperature	Cup Depth	Grain Count
1565° F.	.095	7
	.180	10
	.270	7
	.345	7
1400° F.	.095	9
	.180	11
	.270	9
	.345	10
1265° F.	.095	21
	.180	17
	.270	19
	.345	18
1010° F.	.095	122
	.180	143
	.270	165
	.345	121
865° F.	.095	144
	.180	175
	.270	258
	.345	177

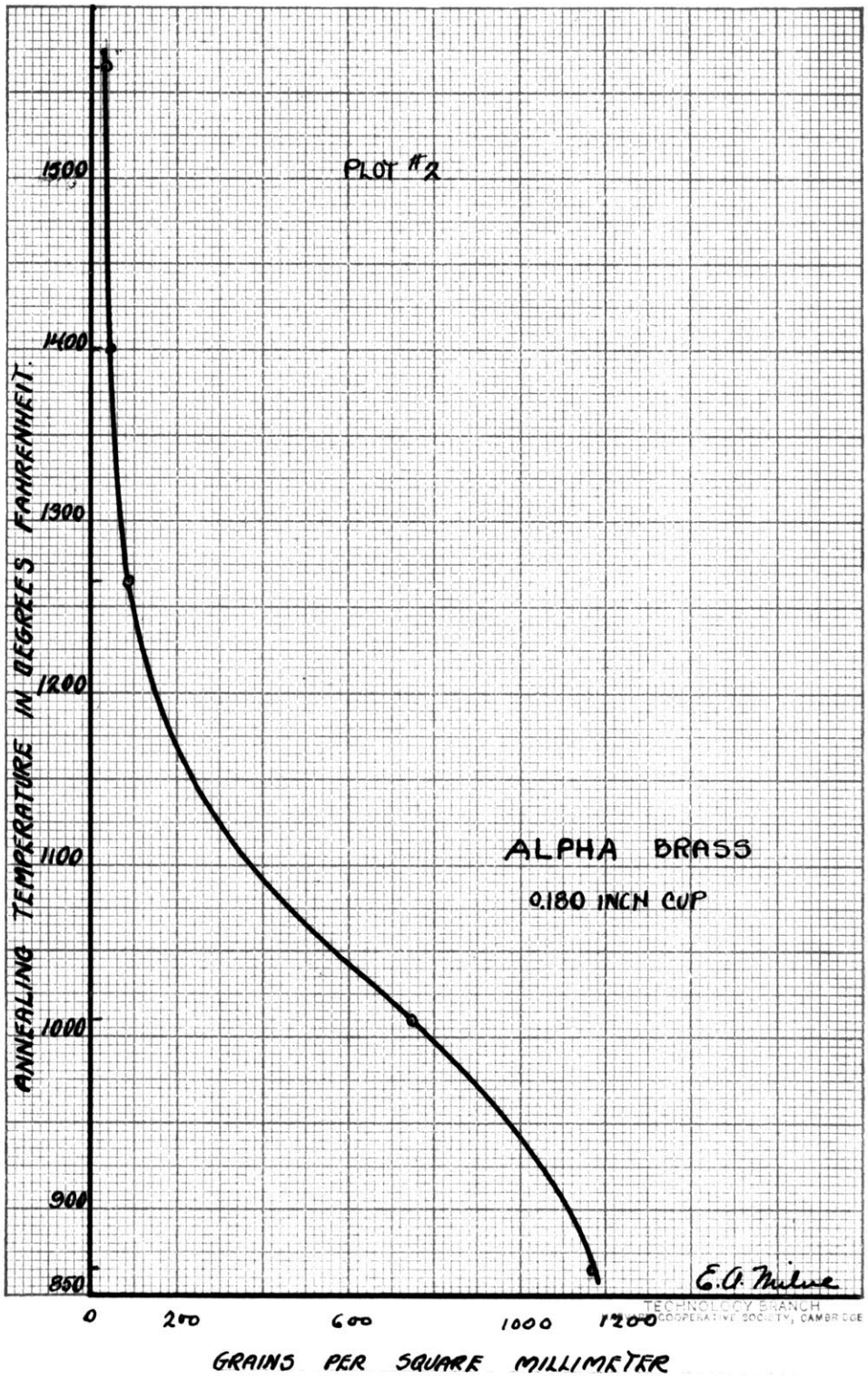
GRAIN COUNT --- ALUMINUM ALLOY 17 ST

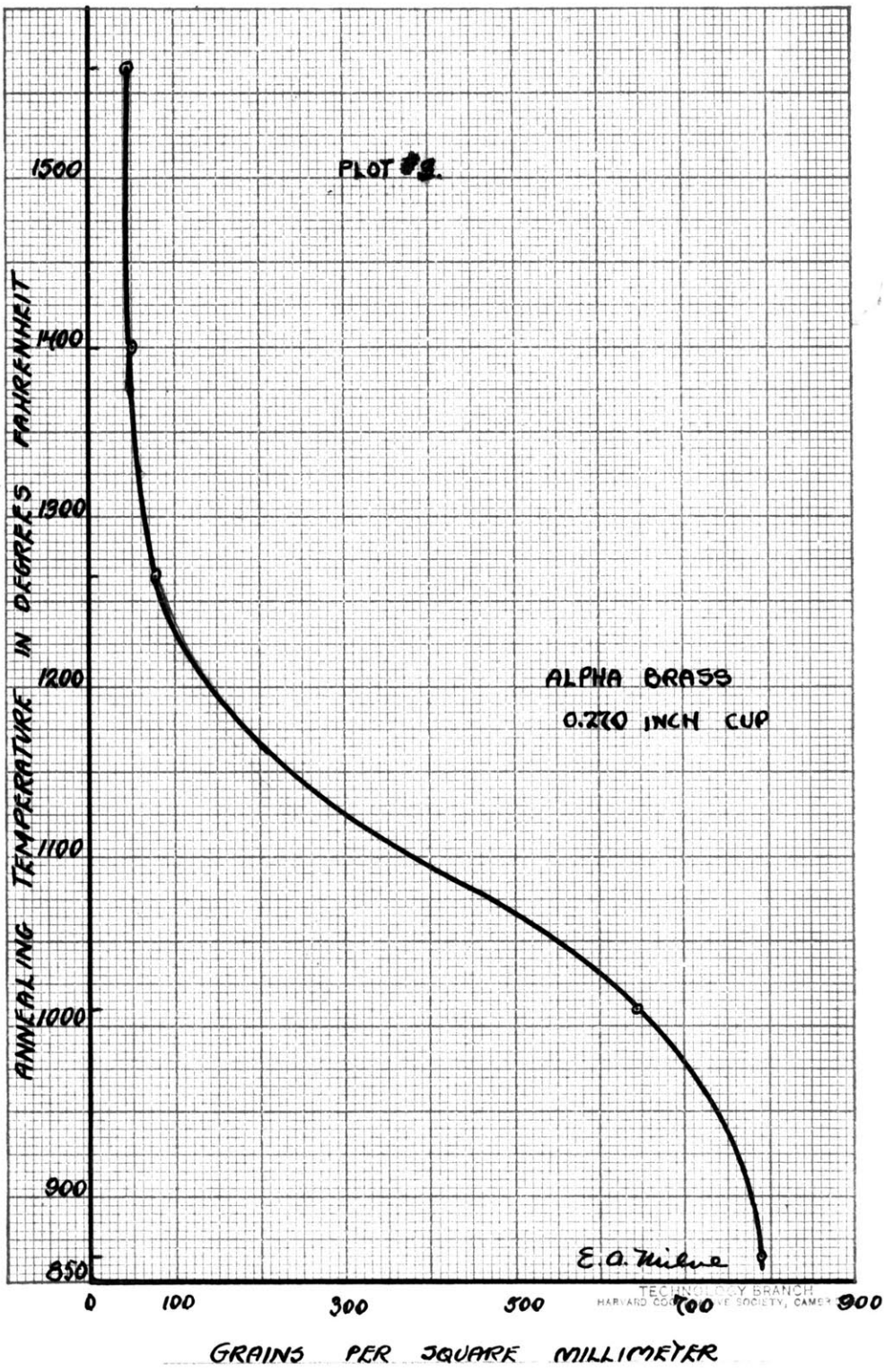
200 Magnification

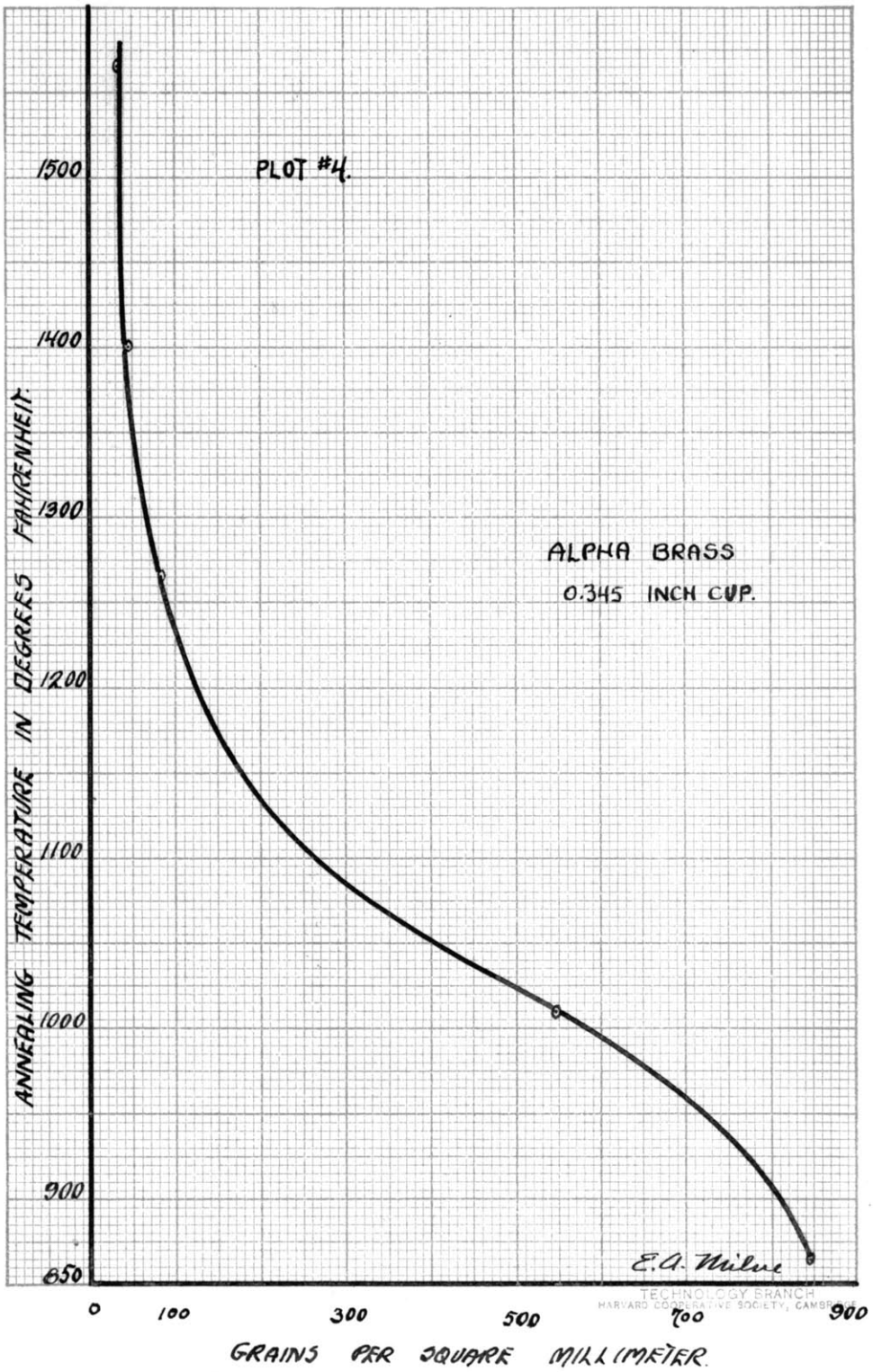
Annealing Temperature	Cup Depth	Grain Count
850° F.	.245	210
	.190	281
	.140	239
	.096	216
900° F.	.245	107
	.190	
	.140	174
	.096	163
925° F.	.245	81,24,25,112,118
	.190	20,156,21,154,29
	.140	190,23,25,34,153
	.096	121,208,84,95,100

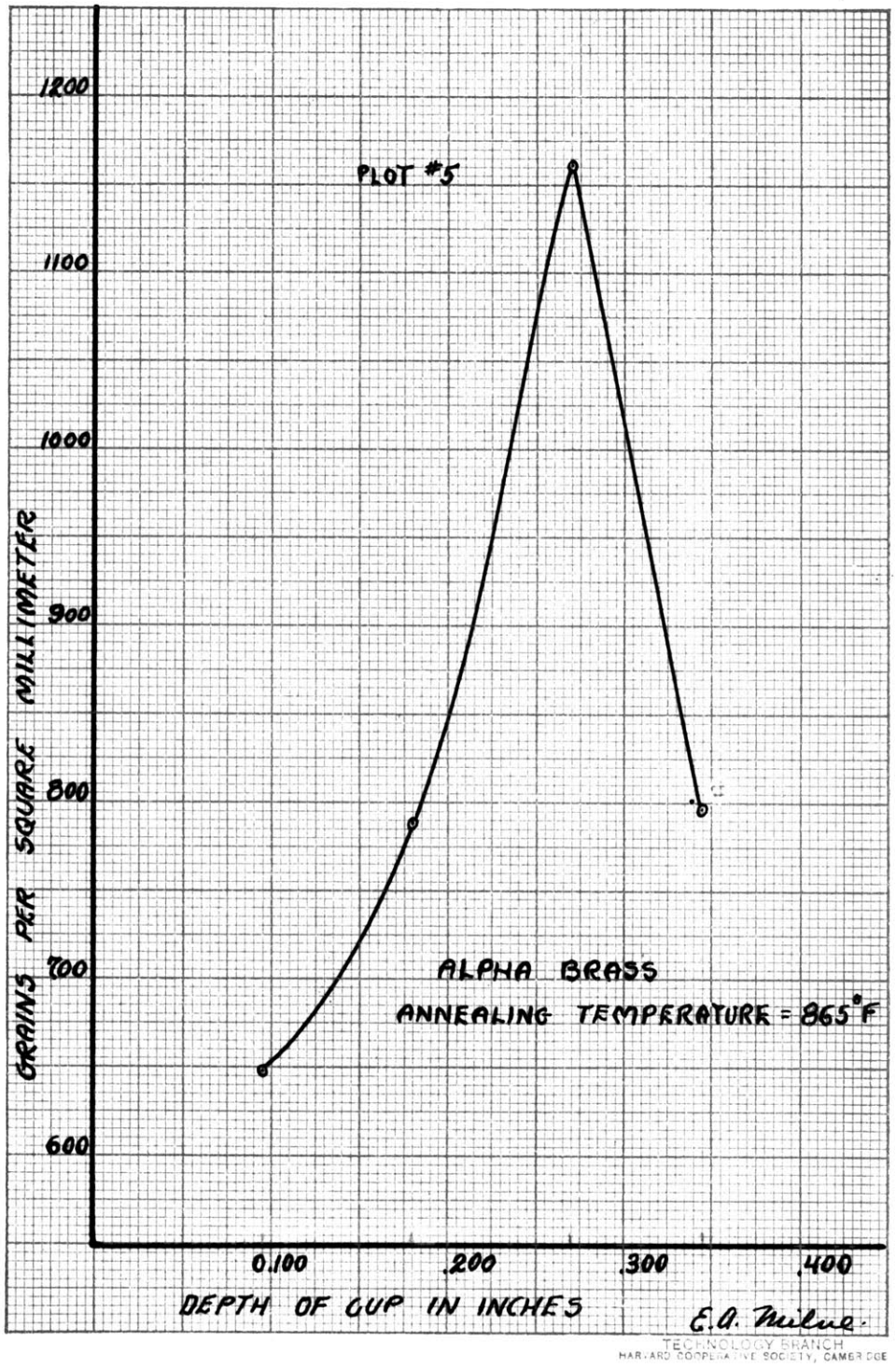
The data collected is plotted on the following pages. The plots are self-explanatory, but it might be mentioned here that they attempt to show the relation between the annealing temperatures and the number of grains per square millimeter, also the relation between strain (expressed in inches) and the number of grains per square millimeter.

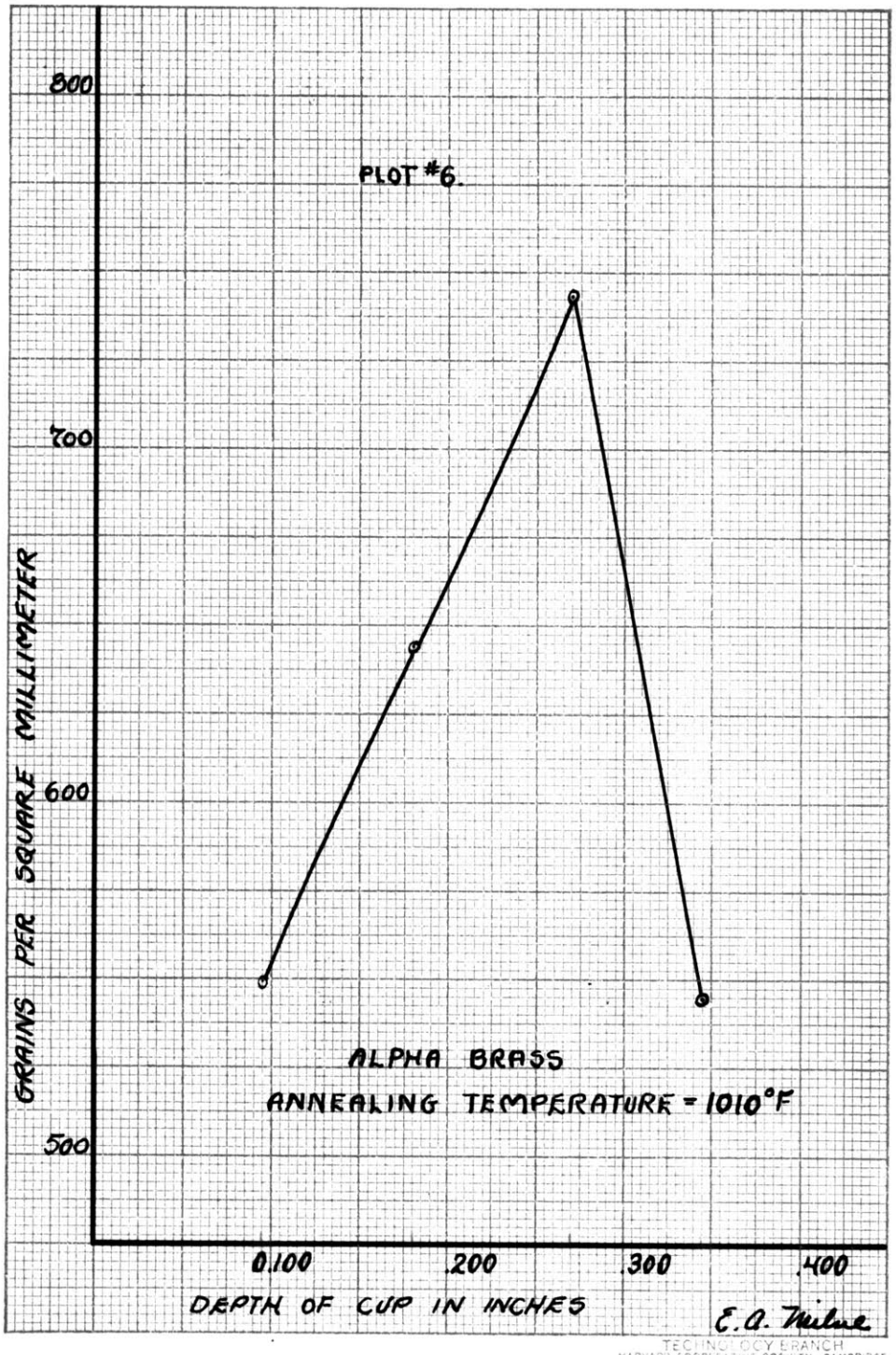

PLOT #1.
ALPHA BRASS
0.095 INCH CUP
ANNEALING TEMPERATURE IN DEGREES FAHRENHEIT
1300
1100
1300
1200
1100
1000
900
850
0
100
300
500
700
900
GRAINS PER SQUARE MILLIMETER

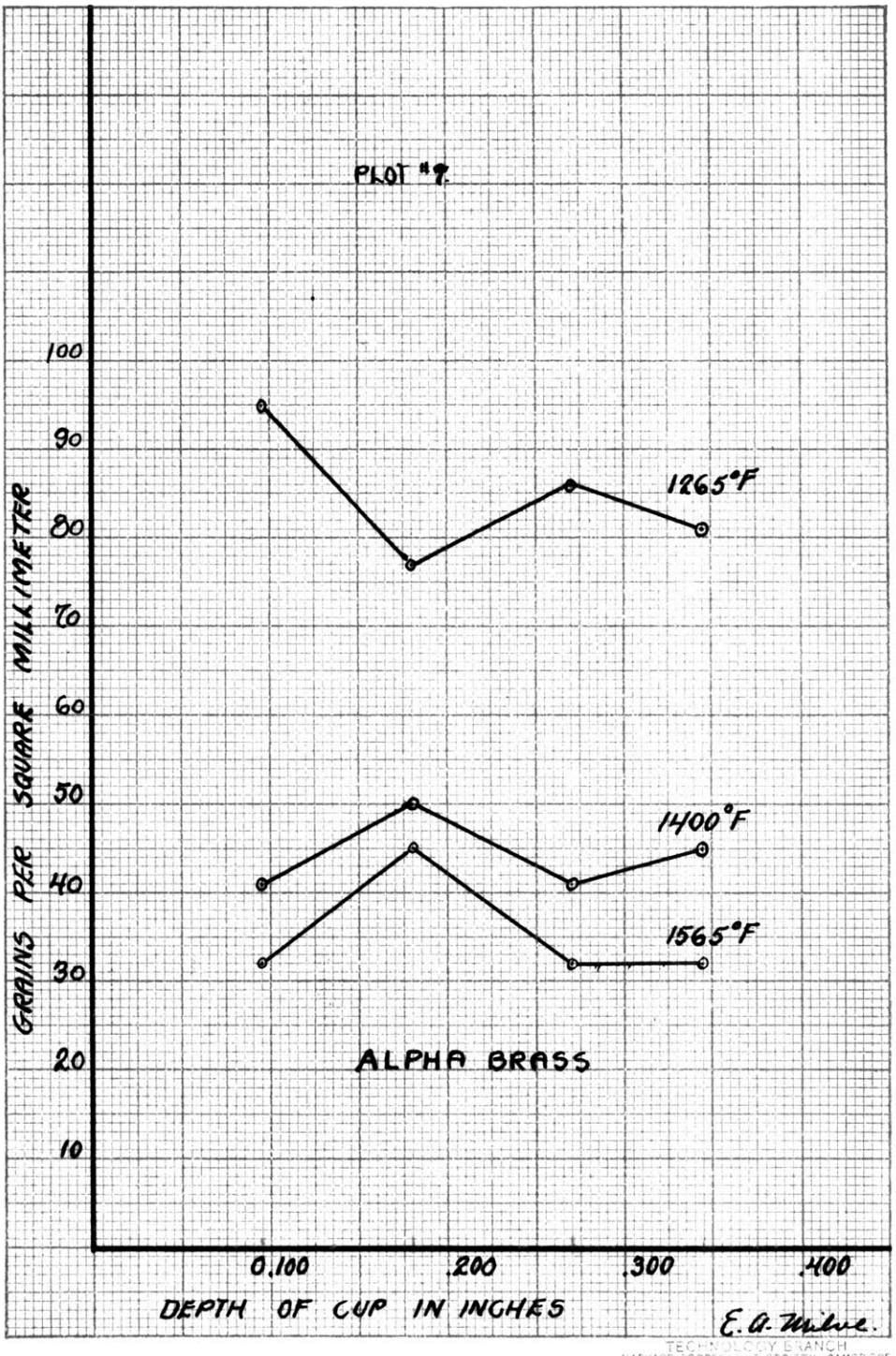

PLOT #2
ALPHA BRASS
0.180 INCH CUP
E.O. Milne
TECHNOLOGY BRANCH
COOPERATIVE SOCIETY, CAMBRIDGE
ANNEALING TEMPERATURE IN DEGREES FAHRENHEIT.
1500
1400
1300
1200
1100
1000
900
850
0
200
600
1000
1200
GRAINS PER SQUARE MILLIMETER

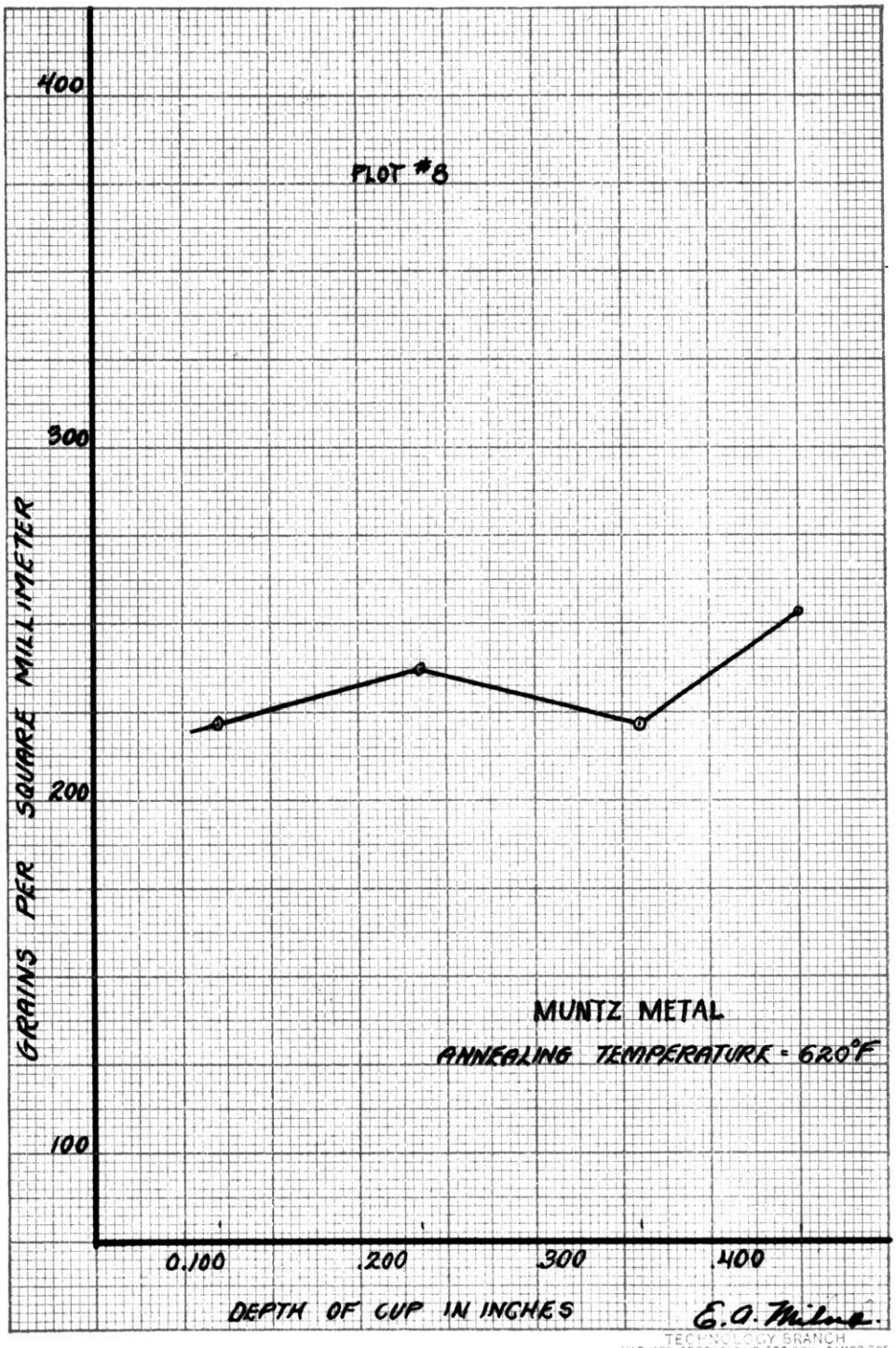

PLOT #8.
ALPHA BRASS
0.270 INCH CUP
E. A. Nilne
ANNEALING TEMPERATURE IN DEGREES FAHRENHEIT
1500
1400
1300
1200
1100
1000
900
850
0
100
300
500
700
900
GRAINS PER SQUARE MILLIMETER

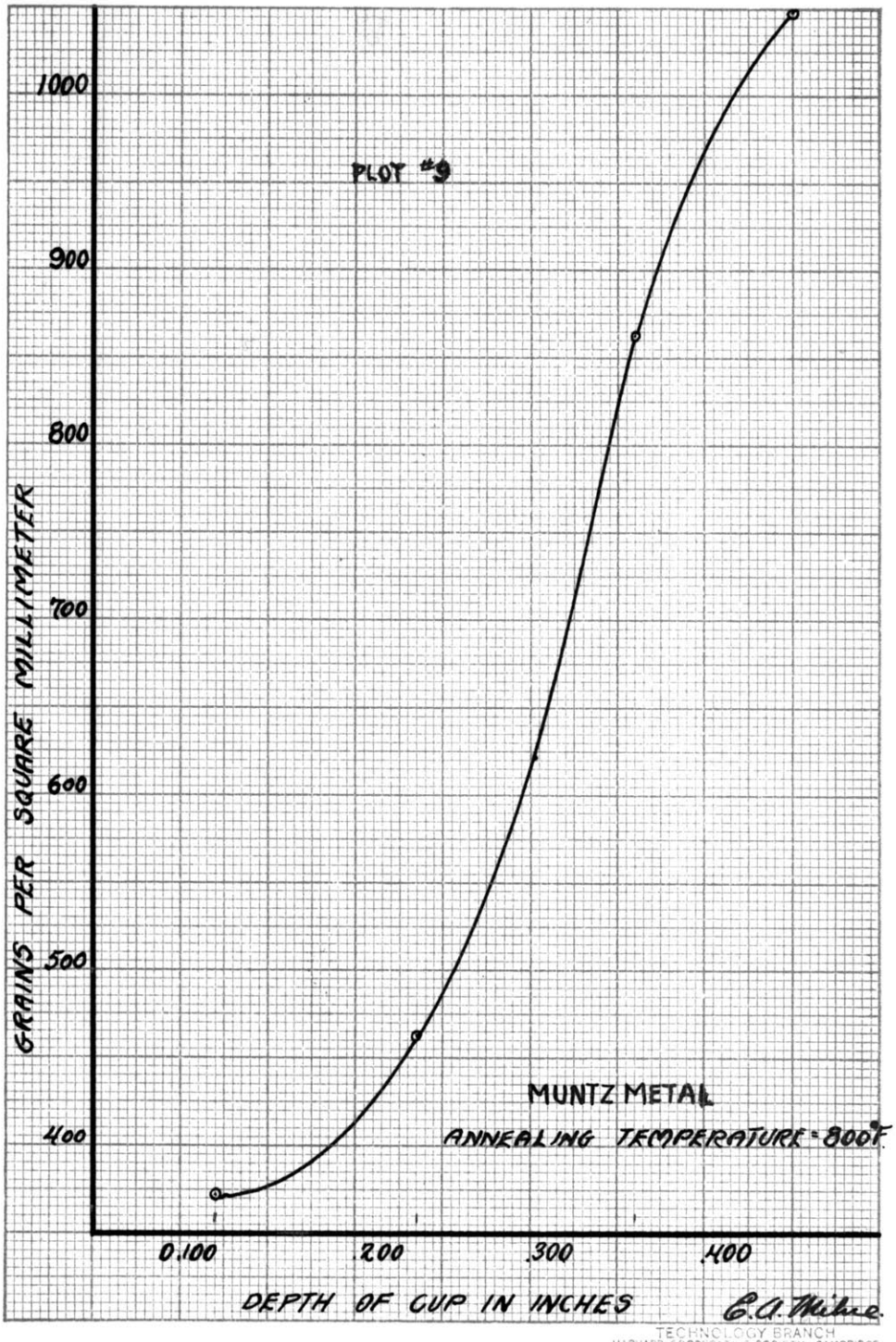

PLOT #4.
ALPHA BRASS
0.345 INCH CUP.
ANNEALING TEMPERATURE IN DEGREES FAHRENHEIT.
1500
1400
1300
1200
1100
1000
900
850
0
100
300
500
700
900
GRAINS PER SQUARE MILLIMETER.
E. A. Milne
TECHNOLOGY BRANCH
HARVARD COOPERATIVE SOCIETY, CAMBRIDGE

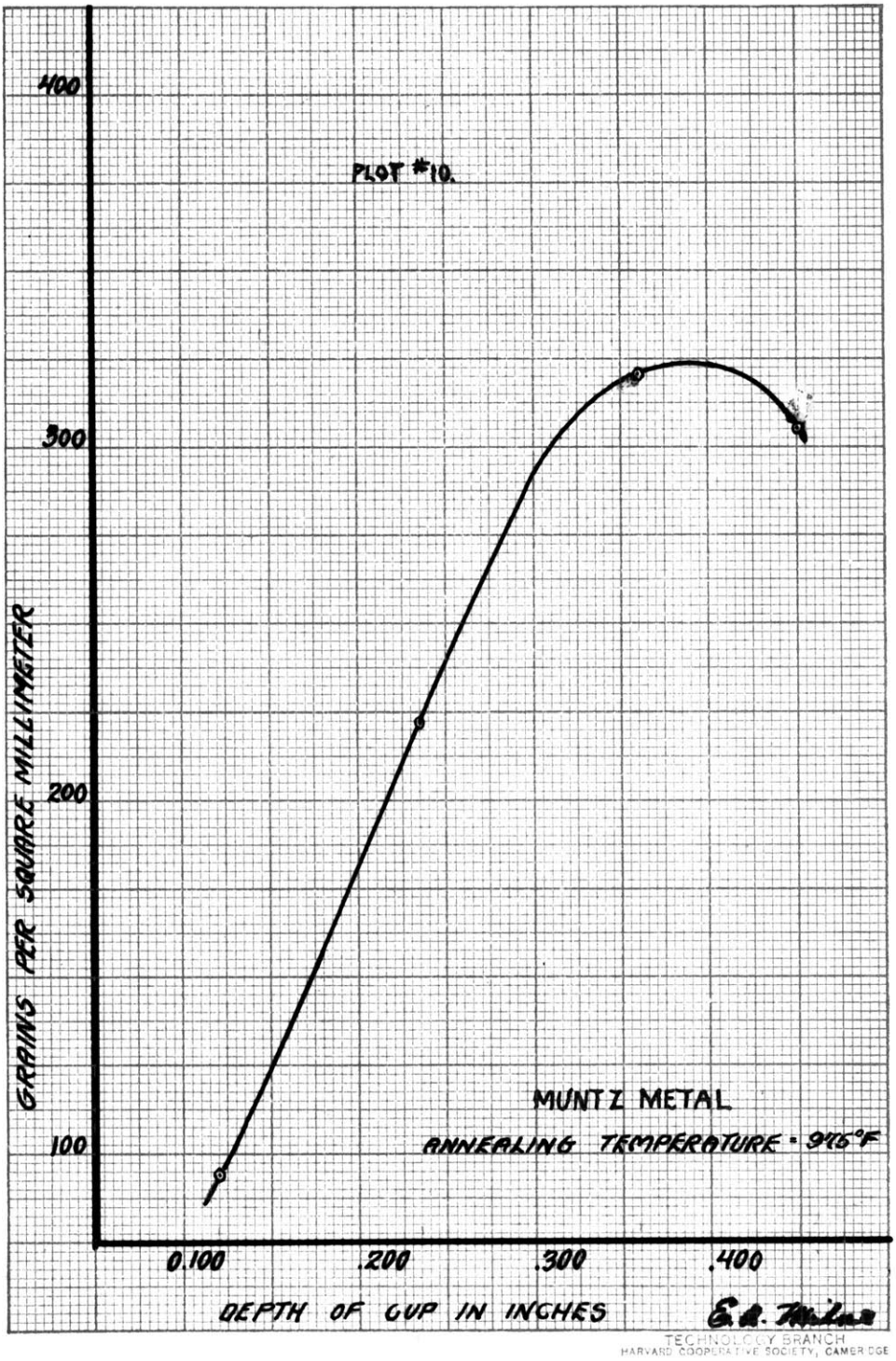

PLOT #5
1200
1100
1000
900
800
700
600
GRAINS PER SQUARE MILLIMETER
ALPHA BRASS
ANNEALING TEMPERATURE = 865°F
0.100
.200
.300
.400
DEPTH OF CUP IN INCHES
E.A. Nelson
TECHNOLOGY BRANCH
HARVARD COOPERATIVE SOCIETY, CAMBRIDGE

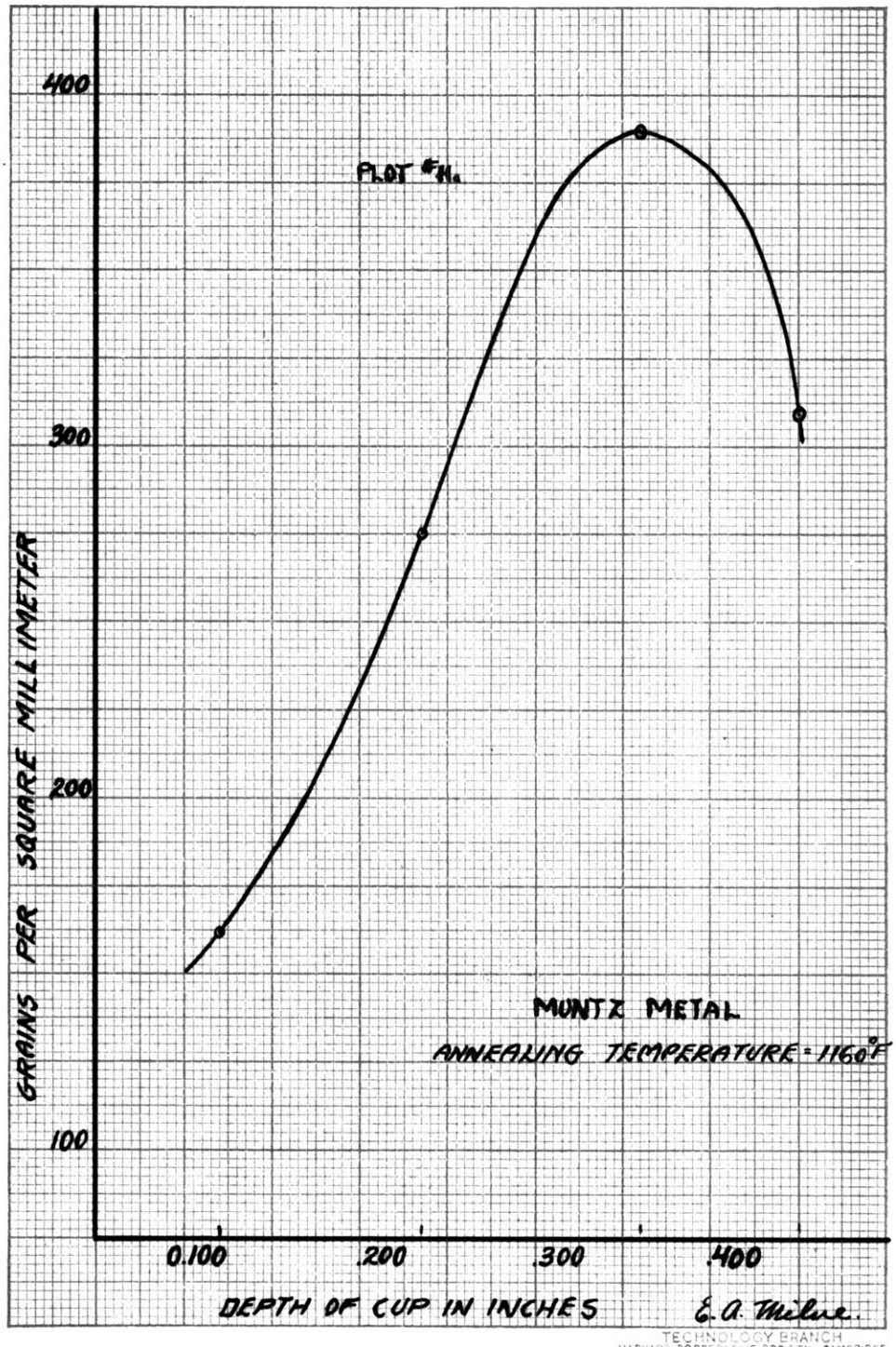

800
700
600
500
PLOT #6.
GRAINS PER SQUARE MILLIMETER
ALPHA BRASS
ANNEALING TEMPERATURE = 1010°F
0.100
.200
.300
.400
DEPTH OF CUP IN INCHES
E. A. Nelson
TECHNOLOGY BRANCH
HARVARD COOPERATIVE SOCIETY, CAMBRIDGE

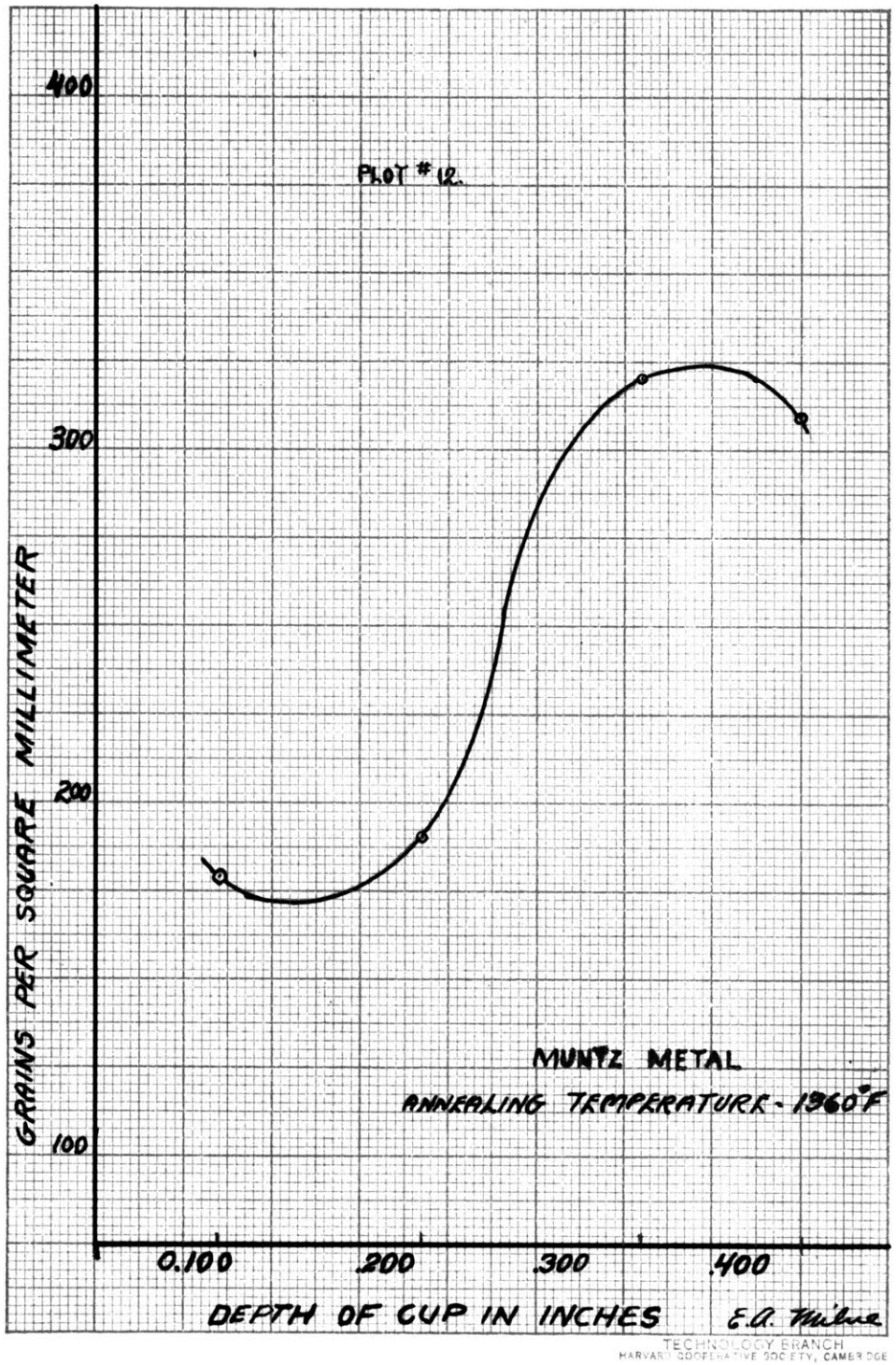

PLOT "F"
GRAINS PER SQUARE MILLIMETER
100
90
80
70
60
50
40
30
20
10
1265°F
1400°F
1565°F
ALPHA BRASS
0.100
.200
.300
.400
DEPTH OF CUP IN INCHES
E. A. Nelve.
TECHNOLOGY BRANCH
HARVARD COOPERATIVE SOCIETY, CAMBRIDGE

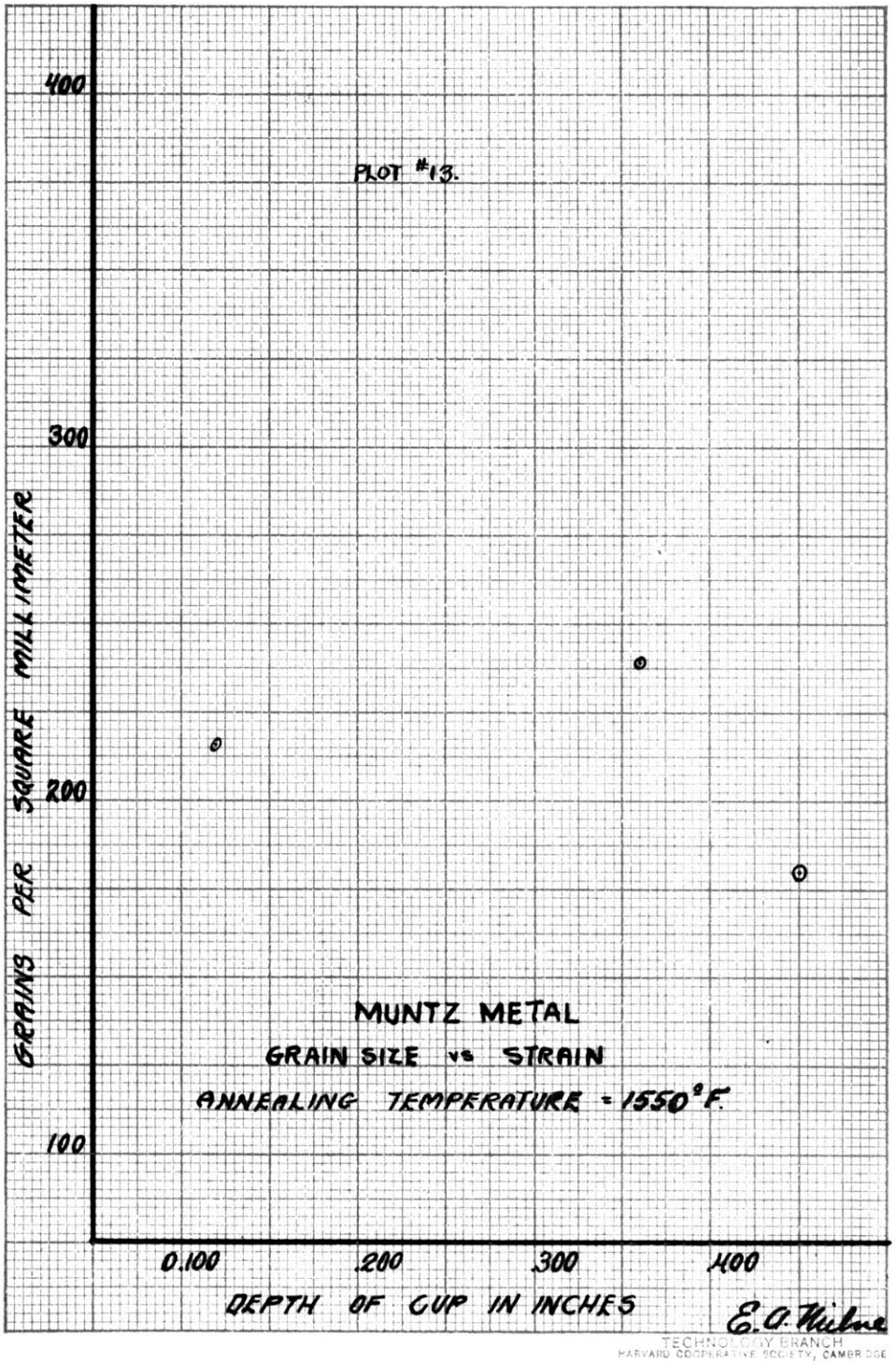

400
300
200
100
PLOT #8
GRAINS PER SQUARE MILLIMETER
MUNTZ METAL
ANNEALING TEMPERATURE - 620°F
0.100
.200
.300
.400
DEPTH OF CUP IN INCHES
E.O. Milner.
TECHNOLOGY BRANCH
HARVARD COOPERATIVE SOCIETY, CAMBRIDGE

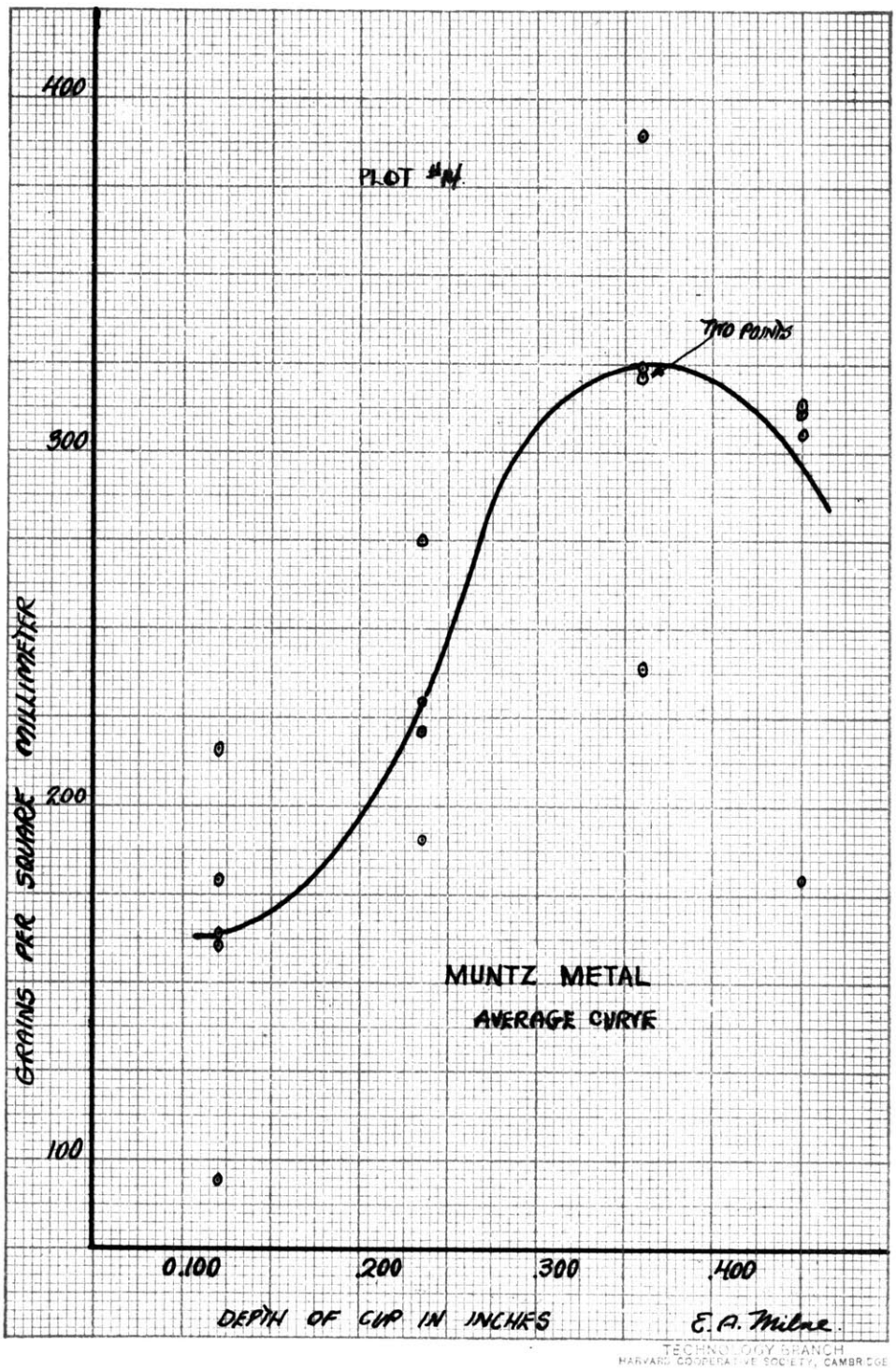

PLOT #9
1000
900
800
700
600
500
400
GRAINS PER SQUARE MILLIMETER
MUNTZ METAL
ANNEALING TEMPERATURE = 800°F.
0.100
.200
.300
.400
DEPTH OF CUP IN INCHES
C.A. Meline
TECHNOLOGY BRANCH
HARVARD COOPERATIVE SOCIETY, CAMBRIDGE


400
300
200
100
PLOT #10.
GRAINS PER SQUARE MILLIMETER
MUNTZ METAL
ANNEALING TEMPERATURE - 946°F
0.100
.200
.300
.400
DEPTH OF CUP IN INCHES
E. A. Miller
TECHNOLOGY BRANCH
HARVARD COOPERATIVE SOCIETY, CAMBRIDGE




400
300
200
100
PLOT # 12.
GRAINS PER SQUARE MILLIMETER
MUNTZ METAL
ANNEALING TEMPERATURE - 1960°F
0.100
.200
.300
.400
DEPTH OF CUP IN INCHES
E.A. Milne
TECHNOLOGY BRANCH
HARVARD COOPERATIVE SOCIETY, CAMBRIDGE


PLOT #13.
400
300
200
100
GRAINS PER SQUARE MILLIMETER
MUNTZ METAL
GRAIN SIZE vs STRAIN
ANNEALING TEMPERATURE = 1550° F.
0.100
200
300
400
DEPTH OF CUP IN INCHES
E.O. Hulme
TECHNOLOGY BRANCH
HARVARD COOPERATIVE SOCIETY, CAMBRIDGE


400
300
200
100
PLOT #M.
TWO POINTS
GRAINS PER SQUARE MILLIMETER
MUNTZ METAL
AVERAGE CURVE
0.100
.200
.300
.400
DEPTH OF CUP IN INCHES
E. A. Milne.
TECHNOLOGY BRANCH
HARVARD COOPERATIVE SOCIETY, CAMBRIDGE

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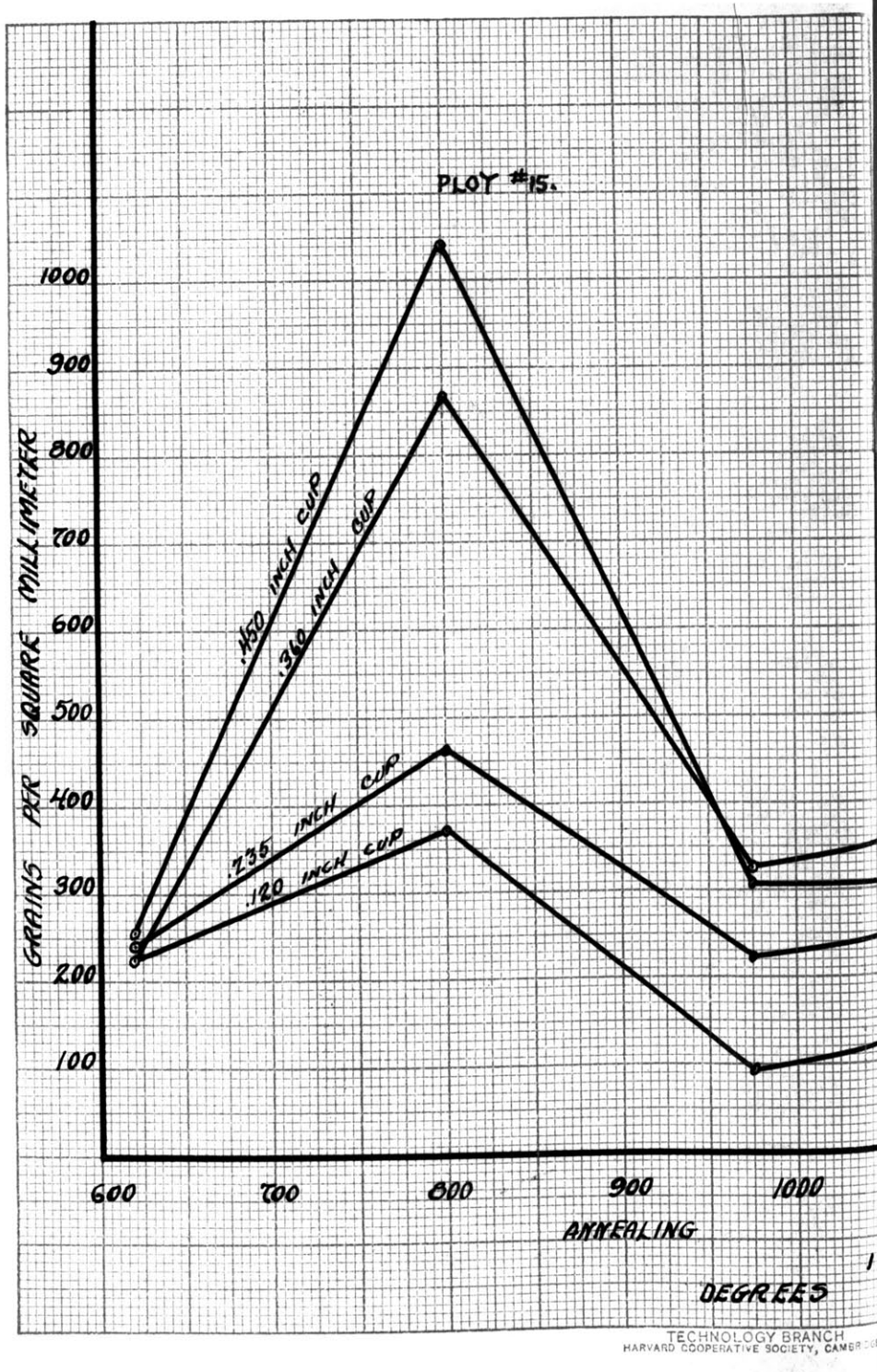
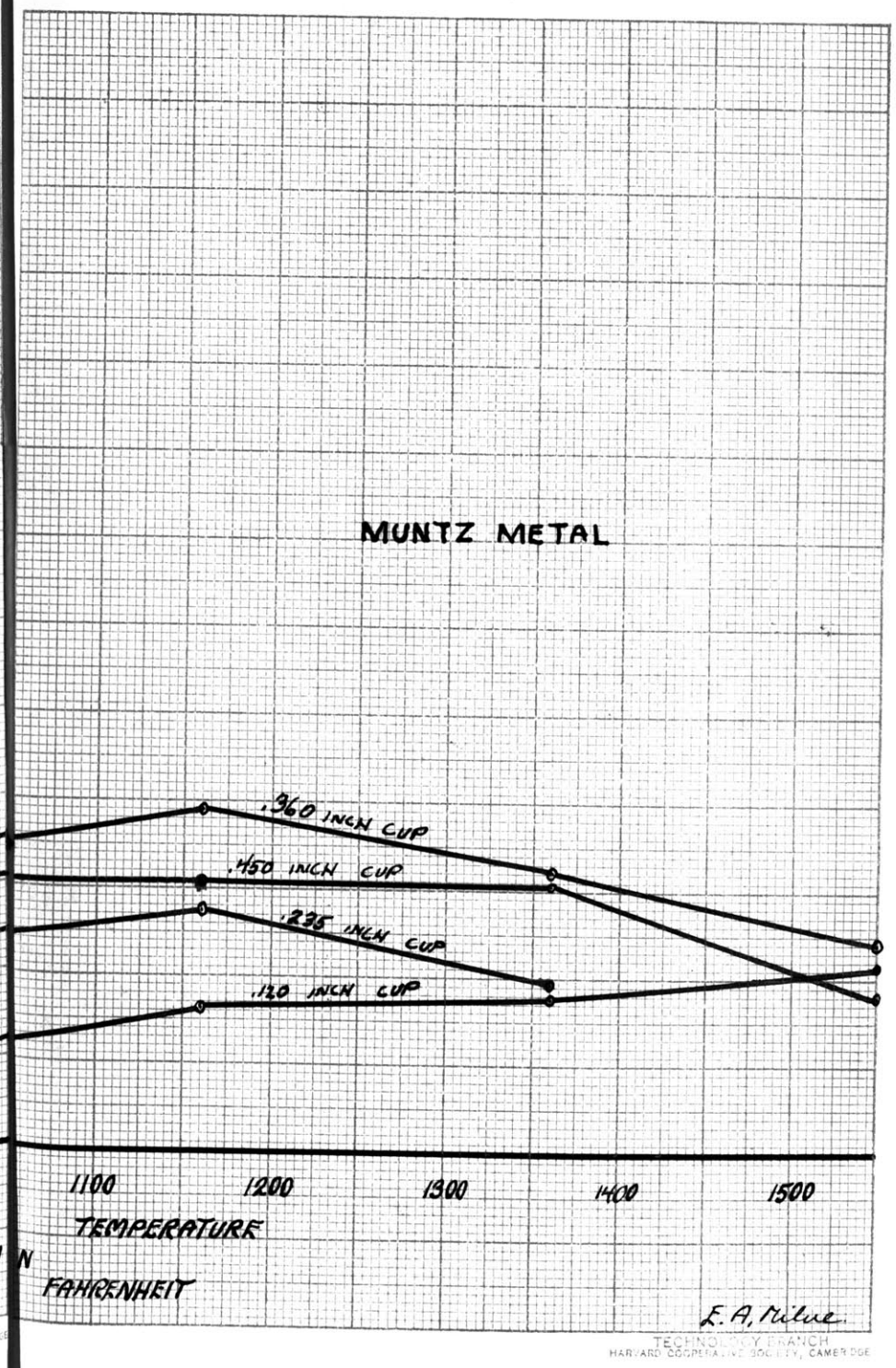
PLOT #15.



MUNTZ METAL



E. A. Mulve

DISCUSSION OF RESULTS

Considering first the results obtained on the Alpha Brass, there is no indication of critical strain. True, inspection of the grain count data shows a very marked increase in the size of the grains at a temperature of 1250° Fahrenheit. The grains per square millimeter and the strain are plotted on separate pages for temperatures 865° and 1010°. The relations for the temperatures 1250°, 1400° and 1565° are all plotted on the same sheet. With respect to the latter, there is no evidence of a critical point, in fact there is some evidence of a straight line and parallel to the horizontal axis. If so it would seem that at these temperatures, there is no critical strain. For the temperatures 865° and 1010° there is a maximum point to be sure, but no doubt recrystallization is going on in this range, and that only recrystallization and initial grain growth is apparent.

There seems to be some relation between the annealing temperatures and the grain size. All four curves have the same general shape, almost "S" curves, and appear to show two points of

inflexion. The curves appear to parallel the vertical axis after a certain point which may indicate that there is no remarkable grain growth at high temperatures. The center portion of the curves seems to be a straight line, indicating a possible direct relation between annealing temperature and grain size in this range.

The data on the Muntz metals is more pronounced than that of the Alpha Brass. The relation between the strain and the grain size is plotted for each temperature. Some of these show markedly, the possibility of critical strain. One plot shows only the points, since another valuable point had been destroyed because of overheating of that particular specimen. Since the relation for the higher temperatures indicate critical strain, a curve considered from the average of all the points at the higher temperatures was drawn. This curve indicates the maximum point somewhere near the point of fracture for the material.

Other plots show the relation between annealing temperature and grain size for the Muntz metal. It is interesting to note the straight line almost parallel to the horizontal axis for the .450 inch cup. This curve shows particularly that there is very

little difference in the size of the grain over a large temperature range. The others indicate somewhat of the same thing, but not so clearly.

Plots showing relation of data for the Aluminum alloy 17 ST have not been made. The grain count varied so greatly that good data were impossible. The variations are clearly shown on the data sheet.

There is some indication of critical strain in plot #(15). For the metal having greater strain, there seems to be a tendency toward a smaller grain at some point, although the point is not clearly shown.

The photomicrographs indicate the grain structure and growth in the alloys tested. There are one or two photomicrographs that probably bear special mention. Figure (14) shows a number of small grains and some very large grains. Such structure is worthy of note since there seems to be a layer of small grains bounded on two sides by grains very much larger in size. Some irregularity is evident, either a local strain gradient or temperature gradient, or both. If one considers figures (15) and (16), showing the structure of

the brass heated at the same temperature as that in figure (14), there is a noticeable difference. Initial grain growth is apparent and there are indications too that larger grains are growing at the expense of smaller ones. The structure shown in figure (14) may have been brought about by that particular specimen being on the bottom of the furnace and being heated to a higher temperature.

That large grains grow at the expense of the small ones seems to be indicated too, in the structure of the Aluminum alloys, figures (26) and (27).

Figure (22) shows a part of one grain.

CONCLUSIONS

The writer does not believe that the results of this thesis show any positive, publishable phenomena. The results on the Alpha Brass tend to show that there is no critical strain. On the other hand, results on the Muntz metal do indicate the possible presence of a critical point of cold work, that there is critical strain, and that critical strain occurs very close to the ppint of fracture when the metal is subjected to a drawing operation.

The results on the Muntz metal show the

breaking down of the grains by increased amount of work and that the greater the amount of work, the smaller the grains -- below 1000° Fahrenheit. Moreover, that very little grain growth occurs in badly strained Muntz metal, between the temperatures 1000° Fahrenheit and 1400° Fahrenheit. The critical point may be so affected by temperature.

It is concluded that some relation exists between grain size and annealing temperature for Alpha Brass, irrespective of the amount of cold work. In a certain temperature range the relation seems to be an indirect proportion. Also, above the temperatures 1400° Fahrenheit, there is very little grain growth.

It is also concluded from a study of the pictures that large grains grow at the expense of smaller grains.

Finally, too much care in control of local strain or temperature gradients is impossible.

SUGGESTIONS

As one approaches the end of a given piece of work, the realization comes that some other thing may have been done in an experimental way to improve the quality of the results obtained. So it is with me.

I suggest, then, or rather I hope and urge someone to carry on with this particular investigation. Doubtless many may be working on it, but that does not mean that others may not work on it too. Hence, I summarize a few suggestions as follows:

(1.) Confine the work to brass - Alpha and Muntz.

(2.) Work with sheet about 0.05 inches in thickness; in so doing it allows the work to be done at smaller magnifications.

(3.) Confine the work to severely strained metal, that is, taking a series of cups very close to the point of fracture. Work from about 65% of the size of cup at fracture.

(4.) Exercise care in cupping - do not let cupping machine jump.

(5.) Exercise care in heat treatment, too much care is not enough.

(6.) In cutting the sections, use a jeweler's saw. File lightly whenever necessary.

(7.) Take grain count at as low a magnification as possible (see #2 above.)

PHOTOMICROGRAPHS

APPENDIX "A"

Figure #1
Original Muntz Metal
as received.
125 X

Figure #2.
Muntz Metal - Full worked
.450 in. cup
125 X

APPENDIX "B"

Figure #3.
Muntz Metal - M-620-3/4.
.360 in. cup.
Heated 620° F.- 30 mins.
125 X.

Figure #4.
Muntz Metal - M-800-1/4.
.120 in. cup.
Heated 800° F.- 30 mins.
125 X.

APPENDIX "C"

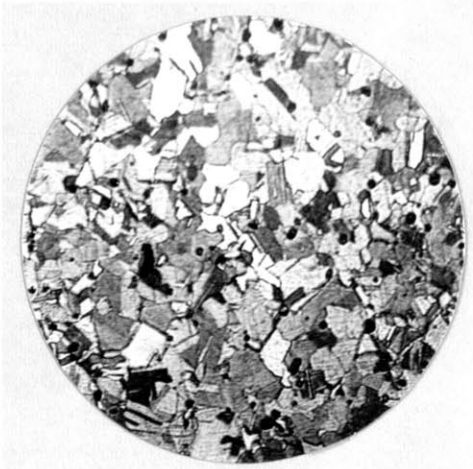


Figure #5.
Muntz Metal - M-800-3/4.
.360 in. cup.
Heated 800° F.- 30 mins.
125 X.

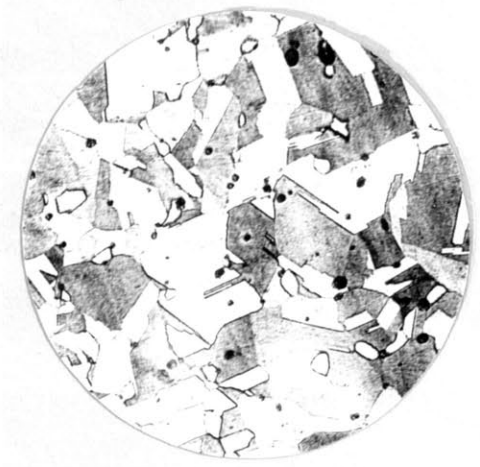


Figure #6.
Muntz Metal - M-1160-1/4
.120 in. cup.
Heated 1160° F.- 30 mins.
125 X.

APPENDIX "D"

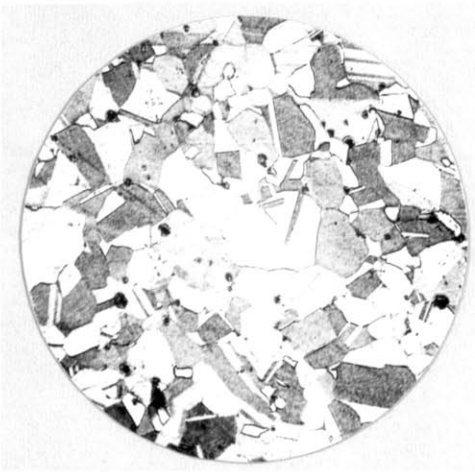


Figure #7.
Muntz Metal - M-1160-3/4.
.360 in. cup.
Heated 1160° F.- 30 mins.
125 X.

Figure #8.
Muntz Metal - M-1550-1/4.
.120 in. cup.
Heated 1550° F.- 30 mins.
125 X.

APPENDIX "E"

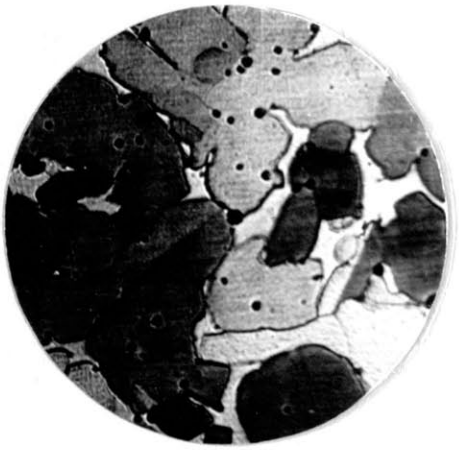


Figure #9.
Muntz Metal - M-1550-1/2.
.235 in. cup.
Heated 1550° F.- 30 mins.
125 X.

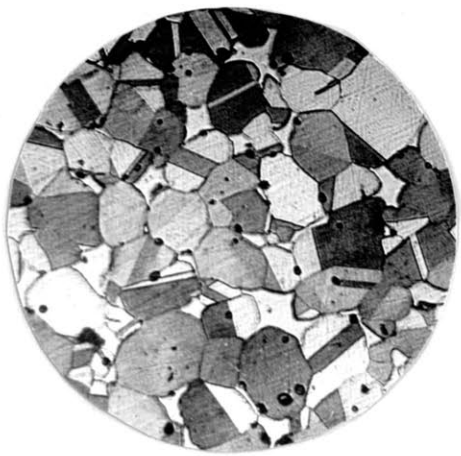


Figure #10.
Muntz Metal - M-1550-3/4.
.360 in. cup.
Heated 1550° F.- 30 mins.
125 X.

APPENDIX "F"

Figure #11.
Muntz Metal - M-1550-F.
.450 in. cup.
Heated 1550° F.- 30 mins.
125 X.

Figure #12.
Original Alpha Brass,
as received.
125 X.

APPENDIX "G"

Figure #13.
Alpha Brass - Full Worked.
.345 in. cup.
125 X.

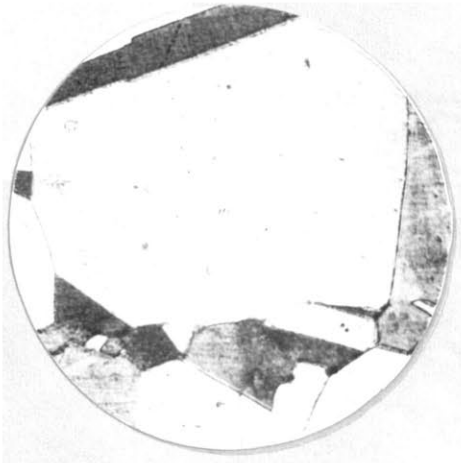


Figure #14.
Alpha Brass - A-1010-1/4.
.095 in. cup.
Heated 1010° F.- 30 mins.
125 X.

APPENDIX "H"

Figure #15.
Alpha Brass - A-1010-1/2.
.180 in. cup.
Heated 1010° F.- 30 mins.
125 X.

Figure #16.
Alpha Brass - A-1010-3/4.
.270 in. cup.
Heated 1010° F.- 30 mins.
125 X.

APPENDIX "I"

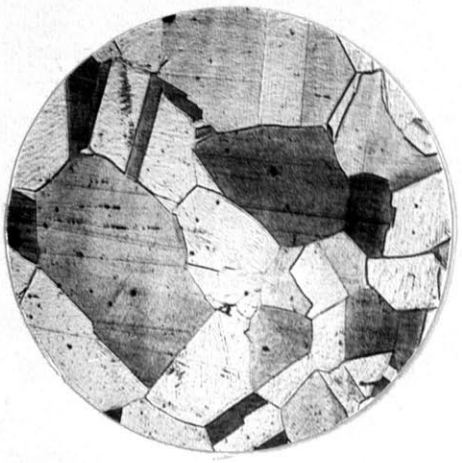


Figure #17.
Alpha Brass - A-1265-1/4.
.095 in. cup.
Heated 1265° F.- 30 mins.
125 X.

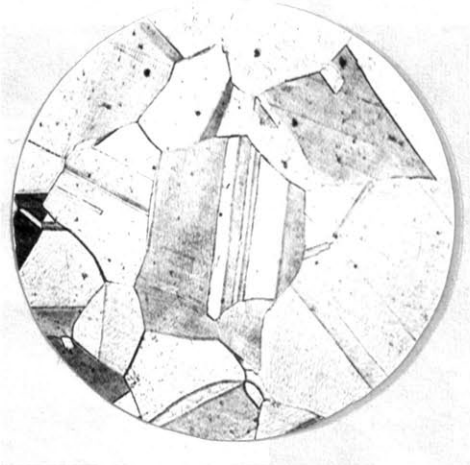


Figure #18.
Alpha Brass - A-1265-1/2.
.180 in. cup.
Heated 1265° F.- 30 mins.
125 X.

APPENDIX "J"

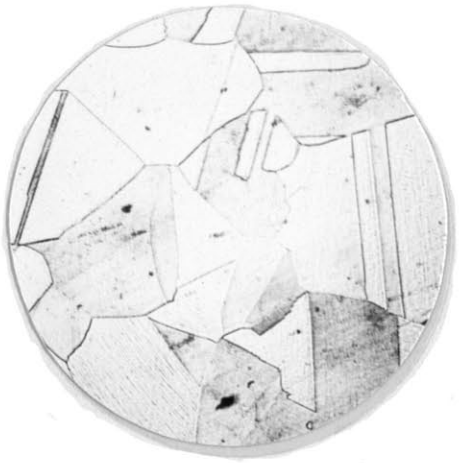


Figure #19.
Alpha Brass - A-1400-1/2.
.180 in. cup.
Heated 1400° F.- 30 mins.
125 X.

Figure #20.
Alpha Brass - A-1565-1/2.
.180 in. cup.
Heated 1565° F.- 30 mins.
125 X.

APPENDIX "K"

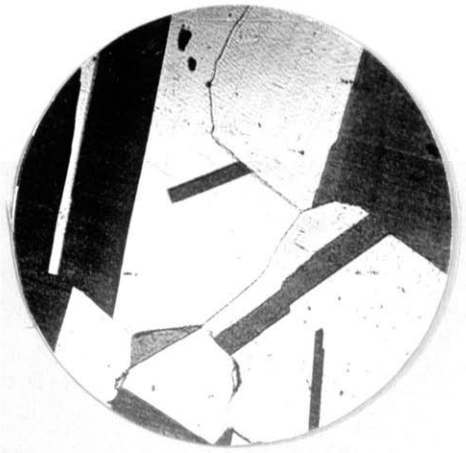


Figure #21.
Alpha Brass - A-1565-3/4.
.270 in. cup.
Heated 1565° F.- 30 mins.
125 X.

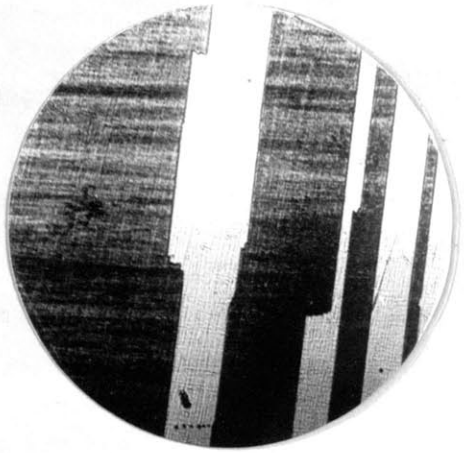


Figure #22.
Alpha Brass - A-1565-F.
.345 in. cup.
Heated 1565° F.- 30 mins.
125 X.

APPENDIX "L"

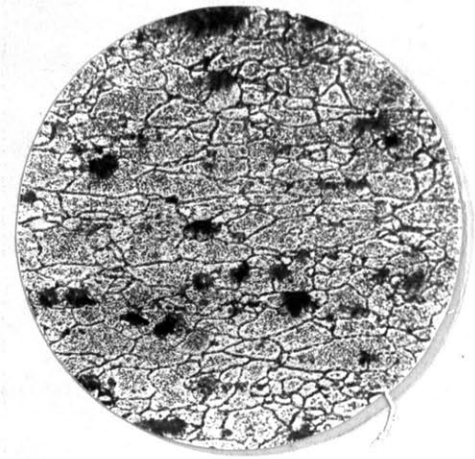


Figure #23.
"Al." Alloy - 17 ST-850-1/2.
.140 in. cup.
Heated 850° F.- 60 mins.
200 X.

Figure #24.
"Al." Alloy - 17 ST-850-3/4.
.190 in. cup.
Heated 850° F.- 60 mins.
200 X.

APPENDIX "M"

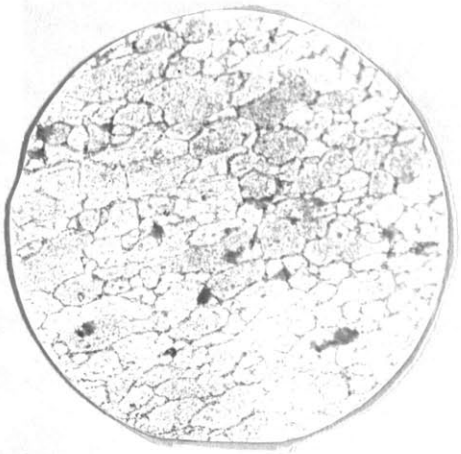


Figure #25.
"Al." Alloy - 17 ST-925-1/4.
.096 in. cup.
Heated 925° F.- 60 mins.
200 X.

Figure #26.
"Al." Alloy - 17 ST-925-3/4.
.190 in. cup.
Heated 925° F.- 60 mins.
200 X.

APPENDIX "N"

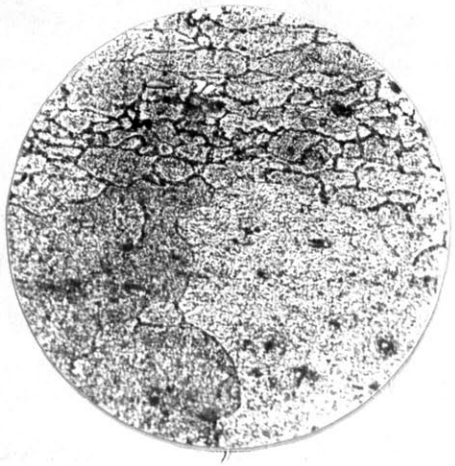


Figure #27.
"Al." Alloy - 17 ST-925-F.
.245 in. cup.
Heated 925° F.- 60 mins.
200 X.

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