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Report on

Substitute Solders of 85-15
Lead-Tin Type

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ABSTRACT

Very little research has been done on substitute solders of the 85-15 lead-tin class alloy. In accordance with the tin conservation program an investigation has been made on alloys of this type.

The effects of eleven elements on the solder properties of a 15 per cent tin, balance lead, alloy were investigated to find an alternate solder for the tin solders now specified under Navy Specification 46S46 (INT) (containing 18 to 20 per cent tin). The following composition ranges were found to have the most desirable solder properties

	<u>Indium</u>	<u>Silver</u>	<u>Per Cent Elements</u>		<u>Tin</u>	<u>Lead</u>
			<u>Copper</u>	<u>Antimony</u>		
1.	0.3 to 0.5	1.7 to 2	0.15 to 0.25		15	Balance
2.	0.5 to 1.0	1.6 to 2			15	Balance
3.		1.7 to 2		0.8 to 1.2	15	Balance
4.		1.7 to 2	0.10 to 0.35		15	Balance
5.			0.15 to 0.25		15	Balance

The solders were found to be satisfactory substitutes for the Navy Specification solder and adequate substitutes in some applications for the 40-60 tin-lead solder and are suggested for commercial tests.

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INTRODUCTION

AUTHORIZATION

1. The project was authorized by the Bureau of Ships Project Order 318/43 contained in letter JJ46-5(350) dated 8 September 1942.

STATEMENT OF PROBLEM

2. The object of this project was to investigate the physical properties of solders of the 85-15 lead-tin type with the view of developing one or more low-tin solders as alternates for the tin solders now specified under Navy Specification 46S46 (INT).

3. It is not difficult to increase the strength of lead base solders by minor alloy additions and since an increase of strength is relatively of less importance than the improvement of other properties of wiping and general purpose solders, the problem was that of finding 15 per cent tin-balance lead base alloys approximating as closely as possible the solidification and "wetting" characteristics of the standard 40-60 tin-lead solder. In this case the ultimate aim was to improve the properties of the 46S46 (INT) Navy Specification solder (containing 18-20 per cent tin) or to equal those properties with alloys containing not more than 15 per cent tin.

SCOPE OF INVESTIGATION

4. In the course of this investigation, eleven elements were used in various combinations with the basic 85-15 lead-tin alloy. These elements were antimony, silver, copper, indium, thallium, lithium, calcium, barium, potassium, sodium and arsenic. Zinc was not used since work by other investigators (3, 14) has shown this element to be injurious to the "workability" of solders because of the high dross formation even when present in amounts as low as 0.01 per cent. Its characteristic drossing also has a deleterious effect on the other physical properties.

5. A total of 116 low tin and 14 "no tin" solders were investigated. The alloys were investigated with the idea of developing a solder which will give satisfactory working properties, as compared with Navy Specification solder 46S46 (INT) for 20 per cent tin solders, specifically in regard to "wetting" of copper, brass and iron, thermal arrests, solidification range, capillarity and shear strength of a soldered joint. The relative importance of these various properties plays an important role in the search for substitute solders since it is almost impossible to retain all of the desired qualities and still make drastic changes in the alloy. Because of the expected uses of a general purpose solder, it

is necessary that its properties be such, especially in regard to wettability, that the alloy be applicable to the more commonly used metals. For a reliable measurement of this property, the wetting test in any of several modifications has generally been accepted in experimental testing.

6. A knowledge of the strength of a soldered joint is useful in design problems. Although there is little agreement as to the best method of testing for strength of a soldered joint, it is uniformly agreed that some sort of measurement is necessary.

7. A high liquidus temperature limits the use of a solder in fragile equipment and the total range between liquidus and solidus governs its application to wiping. A careful consideration of these two properties can allocate a solder to general or special classifications.

8. Even though capillarity plays a very important part in the actual application of a solder, the many different methods of testing which have been proposed make a criterion for capillarity difficult to establish in a specification.

KNOWN FACTS BEARING ON THE PROBLEM

I. General Theoretical Consideration

9. Before determining the effects of alloy additions on the basic 85-15 lead-tin alloy, it is desirable, first of all, to consider more thoroughly those properties listed in the preceding paragraphs which determine the usefulness of a solder.

(a) Liquidus Temperature

10. The maximum liquidus temperature that a solder can have is limited by the particular application involved and the temperature that can be obtained by the source of heat. If a soldering iron is used, the iron must be able not only to melt the solder but also to heat the components being soldered to the desired temperature. High temperature may cause excessive oxidation of the solder and may also injure the components of a soldered joint by buckling, warping, etc. This is very important when working with fine radio equipment. In soldering operations where a torch or furnace is used to heat the component parts of a soldered joint, high temperature may bring about an undesirable change in the physical properties of the components either by a change in metallurgical structure or by excessive alloy penetration of the solder into the components.

(b) Solidification Range

11. The solidification range is of utmost importance in governing the "workability" of a solder. If the range is too great the segregation of intermetallic compounds causes

sluggishness before complete solidification. Excessive thickness of the intermetallic compound layers results in a decrease of joint strength. Also it may be difficult to hold the components rigid during the solidification of the solder. On the other hand, if the temperature range is too short, the solder will solidify before sufficient spreading and penetration has taken place. The solidification range of a general purpose solder must be a compromise between the two extremes.

(c) Wettability

12. The "wetting" quality of a solder, or its ability to spread on the base metal, is a property which, along with the liquidus temperature, largely determines the ease of the soldering operation. The mechanism of wetting is essentially one of surface tension which in turn is dependent upon the difference between the cohesive forces within the solder itself and the adhesive forces between the solder and the base metal. In order to have good wetting the adhesive forces must greatly exceed the cohesive forces. Coffman and Parr (2), in their work on surface tension of metals with reference to soldering conditions, have established a quantitative expression evaluating the mechanism of spreading. They state further that "the larger the difference in atomic volumes and surface tension between two metals the more of a decrease will be obtained in surface tension upon alloying the two". This partially accounts for the excellent spreading properties of the high tin-lead solders.

(d) Capillarity

13. The forces involved in capillarity are quite similar to those in wetting of a flat surface except that in the former, adhesion is acting against gravity. In addition, the distance between the components being soldered plays an important role as capillary action varies inversely with the distance. Experimental work by other investigators has shown that the soundest soldered joints are obtained with clearances of from 0.003" to 0.005" which indicates the importance of the wetting and capillary qualities of the solder, since these two factors enable the solder to penetrate into such small openings.

(e) Joint Shear Strength

14. Judging from the literature, the tensile strength of a solder itself seems to bear little relation (or at least a very indefinite relation) to the strength of a soldered joint. The important factors are the thickness of the soldered layer and the nature of the bond between the solder and the components. Dirt, oxides, flux and excess intermetallic compounds all tend to break the continuity of the solder film; this results in a decrease in shear strength of a joint. The exact metallurgical nature of the bond formed immediately after contact between the solder and base metal has not been clearly defined. With tin, a diffusion process occurs which results in

the formation of a layer of a new phase. Rhines (3) proves this to be the case with a lead-tin solder on copper although no mention is made of the time involved in forming the new phase. It has been shown, however, that the initial composition of the solder and base metal, the temperature and time of application, the lapse of time before testing as well as the thickness of the solder layer, have a marked effect on the ultimate strength of a soldered joint. Since these factors also govern the formation of new phases (solid solutions or compounds) by the process of diffusion, one is lead to suspect that in the more common soldering operations a fairly rapid formation of new phases takes place in the bonding layer. Swanger and Maupin (4), working with 50-50 and 95-5 lead-tin alloys in making lap joints with copper plate, found that thin diffusion layers formed at once. The layer formed with the high-tin solder was somewhat thicker than the other. At room temperature, further diffusion was found to be very slow; however, with increase in time, at constant load and temperature the amount of Cu_3Sn in the bonding layer increased. Structural changes were complete after 2000 hours with the greatest changes taking place within 800-1200 hours. The increase in Cu_3Sn is accompanied by an increase in the hardness and brittleness of the bonding layer and an increase in the overall strength of the bond.

15. Some interesting observations have been made on the relation between the physical properties of solders and the joint tear strength (5). However, much remains to be desired in this type of test before any definite conclusions can be made. This is readily understandable since the metallurgical changes that occur within a layer of solder .003-.005" thick, which affect the original mechanical or physical properties of the solder, have not been definitely established. It was not the purpose of this work to undertake an investigation of the exact correlation, if any, between joint strengths and the physical properties of solders, such as tensile strength, percentage elongation, impact toughness and hardness. Although the significance of such tests may be more clearly indicated in the future, it is believed that the determination of the shear strength of a soldered joint will be adequate for the present case.

(f) Appearance

16. The appearance of a solder such as bright and shiny as compared to a dull or dark gray may not mean a serious change of physical properties, but poor appearance may have a rather important effect on the mechanic who is accustomed to working with higher tin alloys in that too much emphasis might be placed on the correlation between brightness and solderability. A comparison of the appearance "as cast" and after a period of storing will give an indication of the ability of the solder to stand exposure without deteriorating. This offers a fairly good criterion on which to predict the amount of oxidation to

be expected during storage. Our tests have shown that a number of elements, e.g. lithium, sodium, barium, cause solders to deteriorate on standing and hence they must be used sparingly, if at all.

(g) Tinning Qualities

17. The tinning quality of a solder is related to "spreading". However, in this case it is regarded as the ability of a solder to wet a soldering iron readily and be retained on the iron in a reasonably large drop, which facilitates the ease of the soldering operation. It also implies the ease with which the solder wets the components. Rhines and Anderson (3) express it as "a technician's impressions of the working qualities of each alloy".

II. Industrial Experience

18. Little information is contained in the literature pertaining to research, development, or industrial use of solders containing 15 per cent tin. In recent years solders containing 20 per cent tin with no bismuth or cadmium have been developed by a few progressive companies and personnel have been properly instructed in their use. In addition, since the tin shortage, a number of solders containing less than 10 per cent tin and some with no tin at all are being used in special applications; however, a solder of this type has yet to be developed that is satisfactory as a general purpose or wiping solder. The war-time restriction of bismuth and cadmium, elements which have beneficial results on fluidity and strength, makes it increasingly difficult to develop a general purpose solder containing a maximum of 15 per cent tin.

19. One large company claims to have saved 850,000 pounds of tin since the beginning of the present emergency by utilizing substitute solders. A general purpose alloy containing 20 per cent Sn, 1.25 Ag, 1.5 Sb and balance Pb, has been successfully used with non corrosive fluxes on bare, pre-tinned or cadmium plated surfaces (6). Calwell and Land (7) state further that 15 per cent tin has been used with the same amounts of silver and antimony. Investigations at this Laboratory also have proven alloys of this type to be satisfactory.

MATERIALS USED IN TESTS

20. The lead, tin, and antimony used were of commercial purity containing in the order of 0.1 - 0.15 per cent total impurities. All other elements were of high chemical purity.

EXPERIMENTAL PROCEDURES

Melting

21. All alloys were made with 400 gram charges melted in 250 cc graphite crucibles, pure charcoal being used for a protective covering. Melting was done in an automatically controlled electric furnace. For ease of melting, master alloys with lead were used for silver and copper additions.

Casting

22. All melts were cast in a mold made from half inch angle iron. Care was taken to cast the charges so that each sample had the same cross sectional area of approximately 0.07 square inches. This was to insure a reasonably good comparison in the hand bend tests which are reported on the data sheets. A solder bar was taken to be very ductile when it could withstand a 180° bend without cracking, ductile if able to take a 180° bend with slight cracking, slightly ductile if the specimen fractured between 90° and 180°, brittle if the fracture occurred between 45° and 90°, and very brittle if the specimen fractured with an angle of less than 45°.

Appearance

23. The appearance of the top and bottom sides of the alloy bars was noted shortly after casting and is given on the data sheets in self-explanatory terms. Observations were repeated after four months and are also recorded.

Sampling

24. To insure representative samples for chemical analyses each cast bar of solder was broken into segments $2\frac{1}{2}$ and $3\frac{1}{2}$ inches long and filings (totaling approximately 50 grams) were taken from the ends of each piece.

Melting Characteristics

25. Thermal arrests were determined for all alloys. In each case a representative sample of approximately 70 grams, contained in 1 $\frac{3}{4}$ " nickel crucible, was melted in a controlled electric furnace. The charges were covered with charcoal to prevent excess oxidation. To insure reasonably slow cooling, the crucibles were placed in asbestos fibre packed in a 1000 cc beaker. A 30 gage iron-constantan thermocouple was inserted about $\frac{3}{4}$ " into the melt and millivolt readings were taken every 15 seconds. Cooling rates through the critical ranges varied from approximately 14 to 18°C per minute. Due to the comparatively rapid cooling rates used in determining the thermal arrests the temperatures obtained are reproducible only within $\pm 2^\circ\text{C}$. However, the liquidus temperatures reported are satisfactory as far as the scope of this report is concerned as a few degrees variance in the

temperature and solidification range from the actual is not important from a practical standpoint.

Wetting Tests

26. The "spread of a drop" test was used as a measure of wettability of a solder on base metal. Spreading tests were made on copper with all alloys. The results of some of these tests are expressed graphically on Plates 14 to 17. Wetting tests were also run on brass and iron with a selected group of solders from each of the composition series prepared, the purpose being to determine the comparative wettability of the various solders on the three base metals.

27. Spread tests were made on plates 4" x 4" x 1/8". The plates were heated over a 4" x 12" furnace element with the energy input controlled by a 110/220 volt auto-transformer. For temperature control of the plates, iron-constantan thermocouples (30 gage wire) were peened to the surface (top side) of the plates about 1 1/4 inches in from a corner (Plate 1). This method assures accurate measurement of the temperature at the surface of the plate.

(A) Procedures

28. To standardize procedure, all wetting tests were made at 60°C above the liquidus of the alloy. The eutectic flux containing by weight 71 parts water, 19 parts ZnCl₂ and 10 parts NH₄Cl was used with copper and brass; however, in order to clean iron properly a weak acid was found necessary in addition to the eutectic flux. The exact procedure used with copper plates was as follows:

- (a) While fluxing at frequent intervals (approximately 2 minutes) the plate was brought to a temperature about 70°C above the liquidus and the power input reduced.
- (b) The plate then was fluxed continuously until the temperature as indicated by the potentiometer, dropped to slightly more than 60° above the liquidus. Flux was applied by means of glass wool swab on a porcelain tube.
- (c) At the desired temperature two solder pellets of .025 cc volume were dropped on the plate and a stopwatch started simultaneously.
- (d) The thermocouple wires were cut close to the plate.
- (e) After 15 seconds the plate was carefully removed with pliers from heating element and quenched on the bottom with a fine stream of water.
- (f) The plate was washed and the area of spread measured with a planimeter.

29. Using the foregoing procedure on brass, some dezincification of the surface of the plate occurred. To obtain a more accurate evaluation of the spread of the solders on brass, the procedure was modified as follows:

- (a) The eutectic flux was applied to the surface of the plate while merely warm. On continued heating, the water vaporized off, leaving a sheet of crystalline flux which acted as a protection.
- (b) Upon approaching the desired temperature the flux will begin to fuse. When slightly above the proper temperature, the heat was cut off, the plate was swabbed well with clean flux and the pellets dropped on the plate.

30. The test used on black iron was as follows:

- (a) The warming plate was cleaned with dilute HCl until the oxide coating was removed and then flux was applied. A crystalline sheet formed which aided as a partial protection against further oxidation. Separate swabs for the acid and flux were used.
- (b) When at temperature, the plate was cleaned at the desired spot with dilute HCl, the flux was applied and one pellet was dropped on the plate. Because the thermal conductivity of iron was lower than that of copper, some time was taken before the pellet broke into a molten state. The 15 seconds are measured from this "breaking point" instead of the dropping point as was the case with copper and brass. With iron the spreading of the main body of solder was preceded by a very thin film of solder similar to a pretinning procedure. The difference in area of the film and actual solder varies from 0.00 to 0.15 square inches. This effect was seen also with copper and brass but to a lesser extent. Tests have shown that almost invariably the maximum spread of low tin solder on copper and brass was obtained within 15 seconds at 60°C above the liquidus. Greater spreading, however, will result on iron with increase in time. High tin solders tended to give maximum spreading at approximately 40°C above the liquidus temperature.

(B) Solder Pellets

31. The pellets used in the spreading tests were of constant volume (0.025 cc). A very simple piece of equipment was devised to make them. This set-up is shown unassembled in Plate 2 and assembled in Plate 3. To make the pellets the assembled piece was clamped in a vise and heated with a slightly oxidizing flame. This formed a fine oxide film on the steel to make the surface non-wettable. Then 15 to 20 grams of molten solder was poured from a nickel crucible, containing a representative sample of about 50 grams, directly

over the holes. The solder was heated briefly with a slightly reducing flame and at the same time worked into the holes with a spatula. The 12 holes ($1/8$ " x $1/8$ " each) were filled in as short a time as possible. The cross piece was pulled through about $1/4$ inch while the solder was still in a soft or mushy stage as the pellets were badly distorted if the solder was allowed to completely solidify before loosening the cross piece - the three pieces having been clamped so as to give a snug but not a tight fit. After the metal had cooled sufficiently to handle, the screws were taken out and the excess solder was scraped from the plates with a sharpened spatula. Care was taken to make the pellets flush with the surface of the steel. The solder was tapped from the holes with a piece of drill rod.

32. The greatest advantage of the foregoing procedure for spreading tests lies in its simplicity, ease of operation and the reproducibility of results. The latter is proved by the fact that in a number of wetting tests, using two pellets per plate on three plates for each alloy, results showed the same area or only small variances in the order of $\pm .01$ to $.02$ square inch.

Capillarity Tests

33. The relative capillarity of the solders was determined by measuring the rise of an alloy column in a hole, 0.04 inches in diameter, drilled in copper. The standard specimens were $3/4$ inch in diameter and $3/4$ inch high. However, if an alloy gave an exceptionally good rise in a standard specimen and the column approached the top, a second test was made using a specimen 1 inch high. A hole $1/8$ inch in diameter was drilled partly through to hold an iron-constantan thermocouple. A detailed sketch of the specimen is given on Plate 5 and a photograph on Plate 6.

(A) Procedure

34. The equipment used in the capillarity tests is shown on Plate 7 and the procedure used is described below:

- (a) The capillarity specimen was clamped in a brass ring and a thermocouple (30 gage - Iron-Constantan), enclosed in refractory tubing, was inserted in the thermocouple hole. The purpose of the brass ring was to decrease the cooling rate of the capillary specimen while applying the solder. The bottom of the specimen extended about $1/16$ inch below the outer ring in order to prevent the two from being soldered together.
- (b) The assembly was placed in a resistance furnace with automatic control to prevent overheating. The exact temperature desired (60°C above liquidus) was measured by the potentiometer.

- (c) When the specimen neared the desired temperature, the assembly was removed and fluxed on the bottom with the eutectic $ZnCl_2-NH_4Cl$ mixture. Flux was applied until it came out the top of the small capillary hole.
- (d) The assembly was replaced in the furnace and heated to a temperature about 70° above the liquidus. It was removed again and placed over a $7/8$ inch hole cut in a sheet of brass which rested on a tripod stand.
- (e) The specimen was fluxed as before until the temperature was $60^\circ C$ above the liquidus, or just slightly above, and a solder stick applied to the bottom of the specimen for 15 seconds.
- (f) The specimen was cooled rapidly by carefully placing the assembly on a thick copper bar and removing the brass ring. A stream of air also may be directed on the specimen. Plate 4 shows the assembly ready for final fluxing and soldering. In order to minimize the loss of heat to the solder, each alloy was pounded into sticks $1/16$ to $3/32$ inches in diameter.

For accurate determination of capillary rise the specimens were x-rayed and measurements were made on the negative using dividers and a steel rule calibrated to $1/100$ of an inch. The lead base alloys show up sharply on the negative when placed on a viewing screen. The use of radiographs facilitated the measurements and showed any discontinuity present in the capillary column.

35. Considerable difficulty was encountered in obtaining consistent results in the capillarity tests. At first specimens having two capillary holes each were used. However, as is shown in Figure 1B, Plate 6, the two values obtained from each specimen varied radically in almost every case. It was found that more consistent results were obtained with a given solder by using several test specimens with only one capillary hole rather than specimens with two holes each. This is borne out by the remaining figures on Plate 6 which are typical of specimens from which the final data was taken. At first, breaks in the capillary columns, as shown in the right hand specimen of Figure 45, occurred frequently. These can be eliminated by careful fluxing and handling of the specimens. Nevertheless, much remains to be desired in this and other types of capillary tests. The "human element" still plays an important role in eliminating the undesirable effects that invariably occur. The values reported are the average of 2 to 4 determinations. Reproducibility in this case is within $\pm .05$ ".

(B) X-Ray Procedure

36. The open ends were covered with scotch tape and the capillary specimens then buried half way in fine copper shot contained in a small box. Care was taken to set the subject directly in the center of the x-ray beam. The radiographic technique used was 220 kilovolts, 2400 milliampereseconds, 36 inches source to film distance with Eastman Industrial type K-Film.

Shear Test

37. To determine the strength of a soldered joint, the brass "ring and plug" type of specimen was used. Specimens were machined from commercial brass as shown on Plate 5 and on Figure 1, Plate 9. A jig made of transite board, as shown in Figure 2, Plate 9, was used to hold the specimen while heating and applying the solder. The wire inserted in the hole (Figure 3, Plate 9) at the bottom of the plug together with the snug fit of the latter, enabled the ring to be rotated and raised up and down, thus assuring the best tinning possible. An iron-constantan thermocouple was peened in the small hole shown at the top of the plug. The whole set-up was heated to temperature (60°C above liquidus) in a resistance furnace of the type shown on Plate 7. Both pieces were thoroughly fluxed with $\text{ZnCl}_2\text{-NH}_4\text{Cl}$ eutectic mix. Solder was applied until it ran out the bottom of the joint and the assembly was removed from the furnace. Oxide scum, if any, was fluxed intermittently off the top of the specimen while applying the solder. The ring was moved only when the set-up was in the furnace and fully up to temperature. All excess solder was machined off in a lathe and the height of each specimen measured with a micrometer. Care was taken to make the top of the plug and the bottom of the specimen parallel so that the direction of the compressive force was along the axis, insuring a positive shearing action. The rate of loading was kept approximately constant, with the speed of the moving cross-head changing from about .04 to .02 inch per minute through the breaking range. The rupture load was recorded and the shear strength expressed in psi.

38. The highest shear strength was recorded in each case, and this value was duplicated within 8 per cent in all cases while the majority checked within 5 per cent or less. From 2 to 5 specimens were made with each alloy. The soundness of the joint was judged from the best shear strength obtained and the appearance of the bond after testing.

Tinning Tests

39. Tinning qualities were ascertained mainly by the readiness with which the solder adhered to a clean iron. A solder was said to have good tinning qualities if it wet the iron readily. It is important in this respect that the solder be retained in a reasonably large globule without excessive

scum formation. In addition, as a further test for workability, copper wire was soldered to copper terminal lugs and to copper plate. Resin flux was used in this case. The soldering iron was filed and cleaned with eutectic zinc-ammonium chloride flux prior to testing each solder.

40. The various tests just described are believed by the authors to be adequate for determining the basic properties of general purpose and wiping solders with which this work is concerned. There are other types of quantitative tests used to study the same properties covered in this report and other properties as well. Kies and Roesner (12), Swanger and Maupin (4) have studied other properties of solders which are of equal importance under certain conditions of temperature and stress.

RESULTS

41. The results of the tests are listed in Table V, Parts I and II, and shown graphically on Plates 10 to 20. Only those alloys which gave promising results with the wetting tests were tested further for capillary rise, joint shear strength and tinning properties. Data on these alloys are also included in Table V.

42. It was not the intent of this work to investigate thoroughly the effects of any one element or group of elements on the 15 per cent Sn, balance lead basic alloy. Consequently, additional data obtained from further investigation may result in modification of some of the curves on Plates 12 to 20. These plates, however, offer a ready interpretation of the data as presented.

DISCUSSION OF RESULTS

43. In this investigation the effect of antimony on the solidification range and "wetting" was found to be of much greater magnitude than that of any other element. Eight per cent antimony added to a 15 per cent tin, balance lead alloy will almost exactly reproduce the solidification range of 40-60 tin-lead solder (liquidus 238°C, solidus 183°C). No other element or group of elements was found to be very effective in reducing the liquidus temperature of the 15 per cent tin, balance lead alloy. For this reason it was believed desirable to approach the problem by studying the effects of alloy additions on the 15 per cent Sn, balance lead and the 15 per cent Sn, plus Sb, balance lead systems. Using the per cent antimony as the basis for subdivision, the alloys fall into six groups for comparison. The groups are as follows:

- 15% Sn, balance Pb
- 15% Sn, 2% Sb or less, balance Pb
- 15% Sn, 2.25% Sb, balance Pb
- 15% Sn, 5.15% Sb, balance Pb
- 15% Sn, 6% Sb, balance Pb
- 15% Sn, 8% Sb, balance Pb

A few additional alloys containing other percentages of antimony were also investigated.

44. In order to determine approximately the amounts of other alloy additions to be added, the available constitution diagrams of the various combinations were studied with special emphasis on solidification ranges and eutectic compositions.

45. As a preliminary step a lead-tin-antimony thermal arrest diagram, sectioned at 15 per cent tin, was determined and is shown on Plate 10. The effect of 2 per cent silver on the 15 per cent tin, antimony, balance lead system is indicated by means of the dotted lines. In this diagram the lower thermal arrests do not represent a true solidus. This is due to the fact that the melts were not cooled under equilibrium conditions (not stirred) and consequently segregation of lead-tin and tin-antimony compounds occurred. The segregation of Pb-Sn compound accounts for the extremely low thermal arrests. Actually the true solidus would fall slightly below the intermediate arrests in a manner similar to that shown on the equilibrium diagram of the 12 per cent tin, plus antimony, balance lead system (Plate 10A) determined by Weaver (23) in her study on type metal alloys.

46. Experiments were run to ascertain whether or not the lower thermal arrests of 180-185°C (Plate 10) are significant with regards to the softening temperature of a solder in a soldered joint. Lap joints (5/8") were made with the copper strips each 10" x 5/8" x 1/16". Each specimen was extended vertically through the center of a tube resistance furnace and tensioned with a 25 pound load. For accurate temperature control, a thermocouple was peened to the copper strip adjacent to the lap joint. The specimens were heated to the rupture point of the bond and the millivolt readings taken simultaneously.

47. The lower arrests were found to be insignificant as far as the softening point of a solder of this type is concerned. The temperatures of joint rupture of four solders tested are as follows:

<u>Composition</u>	<u>Temperature</u>
15% Sn - 85% Sb	253°C
" - " 1.7% Sb	230
" " 3.25% Sb	235
" " 2.56 Sb, 2 Ag	207

It is evident that the rupture points lie slightly above the intermediate arrests (Plate 10). The change of composition resulting from the formation of the new phase CuSn in the bonding layer between the copper strips would account partially for the breaks not occurring at lower temperatures.

48. The solidification ranges reported in this investigation are not the true values as would be obtained under equilibrium conditions; however, these values may be more representative of the complete solidification ranges obtained in soldering operations.

49. Silver lowers the liquidus temperature of the basic alloy and is useful in this respect. However, when silver is present in amounts over 2 per cent, an excess of the compound Ag_3Sn forms at an undesirably high temperature thereby greatly increasing the solidification range. This is indicated more clearly on Plate 11A. The effect of antimony and 2 per cent silver plus antimony on the solidification range of the base alloy is shown on Plate 11. The Ag_3Sn compound is undesirable in general purpose or wiping solders. At temperatures used in ordinary soldering operations the compound causes the solder to become sluggish. Minarcik and Gruber (8) give a good account of the effect of silver on 10 per cent tin solder. Excess Ag_3Sn compound in this case was formed at 1.7 per cent silver.

50. In general, most of the alloying additions listed on Plate 12 tend slightly to increase ΔT (solidification range). Copper, when used singly or in combination with 2 per cent silver, raises ΔT as its content is increased to approximately 0.1 per cent; ΔT is slightly decreased, however, with further increase in copper (curves A and B). Lithium, potassium and sodium have a similar affect (Curves G, H, J). Copper, in the presence of two addition elements, causes ΔT to increase steadily (Curves D, E, F). The behavior of potassium and calcium in the presence of antimony (Curves K, L) is rather indefinite.

51. All but three curves on Plate 10 fall above the solidification range of 91°C as obtained with the Naval Specification solder (No. 3, Table V). Of the solders tested completely, only numbers 34 to 39, 108 to 110, 112 and 113 fall within the specified range (Table V), but these in turn, with the exception of No. 113, have a corresponding decrease in wetting. The longer solidification ranges (ΔT of $102\text{-}104^\circ\text{C}$) obtained with some solders, that otherwise compare favorably with that Naval Specification solder, will not prove too detrimental to the workability provided that personnel are properly instructed in their use.

52. The data plotted on Plate 13 fall well within the desired solidification range; however, it is shown on Plates 15 and 16 that similar compositions have extremely poor wettability. From Plate 14 it is seen that the maximum spread obtained with silver alone is at approximately $2\frac{1}{2}$ per cent silver. It is evident further that antimony has a very harmful effect on the wetting qualities when present either alone or with silver. On the other hand, up to 0.20 per cent, copper has a beneficial affect on wettability with or without silver (Plate 15). It

is more desirable, however, to use copper with silver as the solidification range is better (Plate 12). Copper decreases further the wetting quality of a solder in the presence of antimony with or without silver (Plate 15) and at the same time, with 2.5 per cent antimony or less, raises ΔT (curve E, Plate 12). Strangely enough, with 5 per cent antimony and 2 per cent silver, small additions of copper (up to 0.15 per cent) tend to lower the solidification range (curve C, Plate 13).

53. Of the other elements used, indium proved most beneficial. Indium itself showed no appreciable effect on the wetting quality of the base alloy; however, in combination with silver excellent spreading was obtained (Plate 17), even surpassing that of the Naval Specification solder and the commercial 40-60 tin-lead solder. Indium, in the presence of silver, has no appreciable effect on the solidification range (curve C, Plate 12). The addition of copper, however, to the silver-indium alloy has the undesirable effect of raising the solidification range when indium is present in amounts over 1 per cent (curve D, Plate 12).

54. In amounts up to 0.14 per cent, lithium slightly increases the solidification range and the wettability as well. Further addition will lower ΔT but has no additional effect on spreading. However, lithium is undesirable as an addition element because even in amounts less than 0.1 per cent it oxidizes so rapidly that it is practically impossible to make a satisfactory joint.

55. In the presence of antimony, sodium increases ΔT considerably whereas with antimony and silver the addition of sodium decreases ΔT (Curves D, E, Plate 11). Sodium increases the wettability whether used singly, with antimony, or with antimony and silver. However, due to its rapid oxidation and its deleterious affect on physical properties, sodium should not exceed 0.25 per cent. Sodium also considerably increases the fluidity of a 15 per cent tin, balance lead solder. Potassium shows no beneficial effect.

56. Thallium as a single addition element has a negligible affect on the solidification range; however, in amounts over $\frac{1}{2}$ per cent it decreases considerably the wettability of the basic 15 per cent tin alloy. Likewise, thallium does not improve the "spreading" of alloys containing antimony.

57. In amounts up to 0.1 per cent, calcium and barium increase the spreading quality but further addition causes a rapid decrease. Neither element has an appreciable effect on the solidification range. Additions of 0.5 per cent arsenic or less to the base alloy will lower ΔT , but at the same time decrease the wettability. Arsenic does not improve the effect of antimony and silver.

58. Plates 18 and 19 indicate the effect of alloying additions on the shear strength of soldered joints made as previously described (Paragraph 37). It is seen that soundest joints were obtained with the silver plus antimony, copper and sodium additions. However, satisfactory strength, as judged from the Naval Specification solder, also was obtained with solders containing thallium, silver plus indium and silver plus copper. Calcium and lithium, in quantities as low as .05 per cent are extremely detrimental to the ability of a solder to produce a sound joint. Good joints could undoubtedly be obtained with a number of other alloys listed in Table V; however, due to their undesirable spreading properties, they are disqualified as far as a general purpose or wiping solder is concerned.

59. Values obtained in tests for capillary rise varied from 0.32 to 0.575 inches for the substitute solders as compared with 0.54 inches of the low Naval Specification solder and 0.61 inches of 40-60 tin-lead alloy. The results obtained from the capillary tests are not too informative as far as determining the effect on capillary rise of minor variations of a single element within a given group of alloys. However, it is seen that the best capillary action was obtained with the 85-15 base alloy containing sodium, silver plus copper and antimony plus silver (solder No. 14, 20, 21 and 39). Several other solders follow closely; e.g. numbers 5, 6, 13, 16, 31, 35 and 37.

60. From tests on brass and iron, it was found that only a few solders gave better wettability on brass than on copper, whereas, in each case, the results on iron greatly surpassed those on either copper or brass (except with those solders containing no tin). In general, the solders containing over 2 per cent antimony have a similarly low wetting on copper and brass. The alloys which showed better wetting on brass than on copper were the basic 85-15 lead-tin alloy and slight modifications thereof, excluding antimony (Nos. 1, 13, 14, 23).

61. Tests were made to determine the effect of the soldering temperature (degrees above the liquidus) on wettability. The results are plotted on Plate 20. It is seen that most of the alloys reach their maximum spread at approximately 60 degrees C above the liquidus. It is evident further that a higher operating temperature will not improve the wetting of alloys containing high antimony. Commercial 40-60 tin-lead solder gave a maximum spread at 40°C above the liquidus. Kies and Roesner (12) using a different procedure, found the maximum spread of a 50-50 solder to occur at approximately 100°C above the liquidus. This is one of many differences found in literature on solder which indicates the necessity of a series of standardized tests for evaluating the properties of solders.

62. Fourteen solders containing no tin were made to investigate their feasibility for high temperature work on electrical equipment etc. At present the 2½ per cent Ag, 0.25 per cent Cu, first used by Westinghouse, or slightly

modified alloys are most popular. Antimony, antimony and arsenic, and antimony and silver additions were tried (alloys 119-124). These alloys have very desirable solidification ranges for high temperature work but their wettability is poor. The silver-indium and silver-indium-copper additions (#46 and 47) show promising results. Although their liquidus temperatures are considerably higher than that of the silver-copper combination, their wetting qualities are equally good and solidification ranges better.

SUMMARY OF THE EFFECT OF ALLOYING ADDITIONS ON THE PROPERTIES OF THE 85-15 LEAD-TIN BASE ALLOY AS DETERMINED IN THIS INVESTIGATION

63. Antimony - decreases liquidus and solidification ranges; has a deleterious effect on wettability on copper -- the above holds true in the presence of silver but to a lesser extent, increases joint shear strength when present in amounts over 2 per cent, but in the presence of silver increases shear strength up to 2 per cent; decreases capillary rise, but increases it in presence of silver; does not impair ductility in amounts less than 4 per cent; improves appearance of the base alloy.

64. Silver - lowers the major liquidus in amounts up to approximately 4 per cent Ag, but sharply increases the complete liquidus temperature when present in amounts over 2 per cent due to formation of Ag_3Sn ; increases the wettability considerably up to 2 per cent improves the general effect of low antimony on the base alloy; raises further the solidification range but improves slightly the wettability of the base alloy containing high antimony (+4 per cent); improves appearance and ductility; improves capillary action with or without antimony; lowers joint shear strength, but raises it when present with $1\frac{1}{2}$ to $2\frac{1}{2}$ per cent antimony.

65. Indium - in amounts up to 1 per cent has no appreciable effect on wettability, but this element lowers both liquidus and solidus considerably; greatly increases wettability in the presence of silver; impairs capillary action and joint shear strength except in presence of silver; with additions over 1 per cent markedly increases solidification range (mainly by lowering solidus temperature) in presence of silver and copper, and decreases wettability under similar circumstances; improves the appearance and ductility; is beneficial in lead-silver solders; in amounts up to 1 per cent increases considerably the joint shear strength of the silver-copper combination.

66. Copper - slightly increases the solidification range in quantities up to 0.2 per cent; improves the wettability considerably; has no great effect on joint shear strength; impairs wettability in presence of antimony; does not improve

the properties of the antimony-silver system; is desirable in amounts up to 0.25 per cent with the silver-indium alloys provided that indium is less than 1 per cent; is desirable in small percentages with silver as it improves the capillary and wetting qualities of the silver addition.

67. Thallium - has little effect on solidification range; decreases wettability in quantities over $1\frac{1}{2}$ per cent; has no effect on capillary rise; decreases joint shear strength slightly; in general does not improve the properties of the high antimony and antimony-silver solders; causes a slight tarnish with time; does not impair ductility; increases joint shear strength but otherwise does not enhance the effect of silver. Care should be taken in its use because of its toxic properties.

68. Sodium - up to 0.5 per cent has a negligible effect on the solidification range and at the same time increases the wettability; cannot be used in quantities above 0.25 per cent due to its deleterious effect on ductility and appearance; tends to increase the fluidity; increases slightly the wettability of the antimony and antimony-silver additions; gives a surprisingly high joint shear strength; will cause slight brittleness in presence of antimony and copper but is not disqualifying in this respect. Sodium, however, is quite impractical in some applications along with the other alkali metals because of its reactivity. This is easily perceivable on any exposed molten puddle of alloys containing these metals.

69. Lithium - raises slightly the solidification range in amounts up to 0.1 per cent and imparts a small increase in wettability as well; is injurious to ductility and appearance in amounts over 0.1 per cent; greatly decreases joint shear strength due to presence of oxide grit; offers no improvement to the high antimony addition; impairs the general workability of the alloy due mainly to its high dross formation; can be disqualified as a possible addition element.

70. Potassium - has no appreciable effect on the solidification range with or without antimony - likewise on wettability; greatly decreases the joint shear strength; is detrimental to capillary qualities; is disqualified as an addition element; should not be allowed to exceed 0.02 to 0.03 per cent.

71. Calcium - has no appreciable effect on the solidification range with or without antimony; increases wettability in amounts not over 0.1 per cent; impairs capillarity; causes oxide grit which is extremely detrimental to joint shear strength; is not beneficial as an addition element; should not exceed 0.02 to 0.03 per cent.

72. Barium - has a negligible effect on the solidification range in amounts up to 1 per cent; increases wettability in quantities up to approximately 0.2 per cent; is slightly detrimental to capillary rise; will not greatly decrease joint shear strength in quantities less than 0.15 per cent; causes high dross and oxide grit in amounts over approximately 0.2 per cent; may be considered a beneficial addition to the base alloy in amounts up to 0.15 per cent.

73. Arsenic - lowers considerably the solidification range of the base alloy in amounts up to 0.3 to 0.4 per cent after which there is a sharp increase; decreases wettability in any amount; offers no beneficial effects in the presence of high antimony; over approximately 2 per cent promotes large grain size which in turn decreases ductility; should not exceed 0.1 to 0.15 per cent in a 15 per cent tin solder. Arsenic is poisonous and therefore should be used with descretion.

SUMMARY AND CONCLUSIONS

74. An acceptable solder must have physical properties that equal or better those of the Bureau of Ships Specification Solder 46S46 (INT) (Table I) which are as follows:

Solidification range ($\Delta T^{\circ}C$)	91 $^{\circ}C$
Wetting on Copper	0.19 sq. in.
Shear Strength of Soldered Joint	3400 p.s.i.
Capillary Rise	0.54 inch
Tinning Properties	Good
Ductility	Good

Results are based on experimental procedures described in this report. As was pointed out in paragraph 51, ΔT may be 10 to 12 $^{\circ}$ higher without impairing the workability. Due to the nature of the test, small variances are allowable in capillary rise.

75. Of the alloys investigated, nine passed specification property requirements. These alloys are listed in Table II. A second group of alloys which closely approach the specification is listed in Table III. Alloys 5, 6, 7, 11, and 15 can be used where slightly higher temperatures can be obtained as in torch soldering. The remainder of the alloys in the above group may be considered general low grade solders and can be used in jointing, coating, moderately high temperature uses and dip soldering where wettability is not too important.

76. It is to be noted that only one solder containing antimony (#113) passed Naval Specifications (except in capillary rise). This alloy only has a solidification range comparable to the Naval Specification solder and at the same time has better wettability. Alloys number 108, 109 and 112 containing 2 Ag and 2 Sb, 1.25 Ag and 1.50 Sb and 1 Ag and 1 Sb,

respectively, closely approach but do not meet the specified wetting requirement. However, as was pointed out in the previous paragraph, these solders can be used in limited applications, especially those in which the components are easily accessible. Of the indium bearing solders, numbers 105 and 106 look most promising. The silver-low indium-low copper combination imparts very satisfactory properties to the base alloy. A test was run to show approximately the comparative wettability of the solders mentioned in this paragraph. Results are shown on Plate 4.

77. To produce a 15 per cent tin solder, containing neither cadmium nor bismuth and having solidification and wetting properties comparable to that of a high tin solder, is only a remote possibility. The main reasons for this are:

1. Of the addition elements available, antimony is the only one which has an appreciable effect on the solidification range. No other element or group of elements was found to be very effective in reducing the liquidus temperature. However, in order to maintain satisfactory wettability, such as that required by a general purpose solder, less than 1.2 per cent antimony must be used and this amount will not give a solidification range comparable to that of a higher tin solder.
2. The addition of silver, alone or with other elements, is limited to 2 per cent because of the formation of excess Ag_3Sn compound.
3. The addition of indium is limited by its high cost - 1 per cent being the maximum amount economically feasible.
4. Of the remaining addition elements investigated; namely, copper, thallium, sodium, calcium, lithium, potassium, barium, and arsenic, none was able to improve to a satisfactory extent the wettability of a 15 per cent tin solder containing antimony.

78. Fifteen per cent tin solders having a solidification range comparable to or slightly above that of the Naval Specification solder 46S46 (INT) - all other properties being satisfactory - have been developed in the course of this investigation. The composition ranges of this group of solders, as ascertained from the experimental data, are given in Table IV.

79. Inasmuch as most solders are made from secondary metals, the results of this investigation should prove helpful in determining the maximum allowable impurities. Many of the residual impurities present in secondary metals have been covered in this investigation and their actual affects, individually, and to a lesser extent collectively, on the

physical properties of the 15-85 tin-lead base alloy have been determined. It is felt that the restrictions on allowable impurities in substitute solders may be relaxed considerably.

80. It is recommended that solders having compositions within the ranges specified in Table IV, especially numbers 1 to 3, be given a commercial trial.

BIBLIOGRAPHY

1. B. W. Gonser and C. A. Reichelderfer, "Investigation of Tin-Lead Alloy Coatings for Copper Wire Conductors", Battelle Memorial Institute for War Metallurgy Committee, Restricted, Serial No. W-58, Page 10, 6 October 1943.
2. A. W. Coffman and S. W. Parr, "Surface Tension of Metals with Reference to Soldering Conditions", Industrial and Engineering Chemistry, Vol. 19, No. 12, Pages 1308-1311.
3. F. N. Rhines and W. A. Anderson, "Substitute Solders", Metals and Alloys, Vol. 14, No. 5, Nov. 1941, pp. 704-711.
4. W. H. Swanger and A. R. Maupin, "Structural Changes in the Bonding Layer of Soft-Soldered Joints in Copper Pipe Lines", Journal of Research, National Bureau of Standards, Vol. 28, No. 4, April 1942, pp. 479-487.
5. G. E. Behr, G. O. Hiers, E. H. Minarcik, C. H. Hack, "Properties of Solders", Preliminary Report, Research Project No. 1219, National Lead Company, 6 April 1943.
6. "Saved - 850,000 lbs. of Tin", Welding Journal, Vol. 23, No. 1, January 1944, Page 59-s.
7. D. L. Colwell and W. C. Lang, "Conservation of Tin in Soft Solders", A.S.T.M., 1943, Preprint No. 35.
8. E. J. Minarcik, E. Gruber, "Melting Characteristics of Silver-Lead Solders (2.5 silver or less) with from 0 to 10 Per Cent Tin. Research Pb. No. 5-46, Nat'l Lead Company, 7 May 1943.
9. R. Chadwick, "The Influence of Surface Alloying on the Strength of Soft Soldered Joints", Journal, Inst. Metals, Vol. 62, pp. 277-305 (1938).
10. "Two Lead-Silver Solders - Their Properties and Possible Uses", Lab. Pub. No. 59, Nat'l Lead Co., 16 February 1942.
11. S. Turkus and A. A. Smith, Jr., "Some Properties of Low-Tin Solders Containing Silver and Bismuth", Metals and Alloys 15 No. 3, pp. 412-413, March 1942.
12. J. A. Kies and W. F. Roesner, "The Testing and Properties of Low-Tin Solders Listed in Recent Federal Specifications", A.S.T.M., 1943, Preprint No. 36.
13. J. S. Nightingale "Tin Solders".
14. E. R. Thoms "Metallurgy of White Metal Scrap and Residues" P. 80.

15. B. Blumenthal, "The Constitution of the Lead-Antimony and Lead-Antimony-Silver Systems". T.P. 1634, Metals Technology, September 1943.
16. E. E. Schumacher, G. M. Bouton, G. S. Phipps, "The Metallurgy of Fillet Wiped Soldered Joints", T. P. 1566, Metals Technology, February 1943. Vol. 10, No. 2.
17. J. Ireland, "Tin Conservation in Britain", Metals and Alloys, 17, No. 3, 544-6, March 1943.
18. G. F. Beard, "Solders That Save Tin", Can. Metals and Met. Inds., Vol. 6, March 1943, Page 20-23.
19. "Tips on Using War-Time Solders", Railroad Mech, Eng. 117 - 431, September 1943.
20. E. H. Tovee, "Using Substitute Solders", Gas Age 92:20, September 1943.
21. G. R. Cowgill and K. Solomon, "Possible Toxicity of Lead Alloys, J. Ind. Hygiene, 25: 81-90, March 1943.
22. M. Hansen, Aufbau der Zweistofflegierungen, 1936.
23. F. D. Weaver, "Type Metal Alloys", Journal, Institute of Metals, Vol. 56, No. 1, pp. 209-240, 1935.
24. R. S. Dean and R. V. Wilson, "Action of Fluxes in Soft Soldering", Industrial and Engineering Chemistry, Vol. 19, No. 12, pp. 1312-1314.
25. B. W. Gonser and C. M. Heath, "Physical Properties of Soft Solders and the Strength of Soldered Joints", Metals Tech. 3; Tech.Publ. No. 727, Aug., 1936.

TABLE I CHEMICAL COMPOSITION OF NAVY SPECIFICATION SOLDER
46S46 (INT)

Percent Tin	Percent Bismuth ¹ (max.)	Percent Silver	Percent Bismuth plus Silver (min.)	Percent Antimony (Max.)	Percent Copper (Max.)	Other ² (Max.)	Percent Lead
18.0- 20.0	0.80	0.10-1.25	0.85	0.50	0.13	0.03	Balance

¹ When silver is present in excess of 1 per cent, the Bi content shall be 0.50 per cent or over.

² Total not to exceed 0.10 per cent

TABLE II SOLDERS WHICH PASS NAVY SPECIFICATION 46S46

Alloy No. (New)	Per Cent Composition					Remarks
	Sn	Cu	Ag	In	Sb	
8	14.2	.20				T slightly high
20	14.2	.1	2.00			----
21	14.0	.37	2.03			----
30	14.3		2.02	.75		Capillary rise .08" low
31	14.3		2.06	1.30		Capillary rise .05" low
104	14.70		2.06	0.25		Capillary rise .03" low
105	14.82		2.02	0.54		Capillary rise .08" low
106	14.50	0.18	2.05	0.34		Capillary rise .05" low
113	15.10		2.04		0.96	Capillary rise .08" low

TABLE III SOLDERS WHICH FALL SLIGHTLY BELOW NAVY SPECIFICATIONS

Alloy No.	Per Cent Composition					Tl	Remarks
	Sn	Cu	Ag	Sb	Na		
5	14.1		3.03				Capp. .03" low-high arrest due to Ag_3Sn compound
6	13.2		5.08				Same as above
35	14.6		2.07	2.56			Wetting .03 sq.in. low; capp. .04" low
32							
7	14.1	0.11					Wetting .015 sq.in. low; capp. .08" low; liquidus temperature slightly high
11	14.2					0.52	Wetting .04 sq.in. low; capp. .07" low; liquidus temperature slightly high
36	15.3	0.07	2.03	2.24			Wetting .06 sq.in. low; capp. .07" low
37	14.9	0.14	2.04	2.13			Wetting .08 sq.in. low; capp. .05" low
15	14.6				0.24		Wetting .05 sq.in. low; capp. .06" low-liquidus temperature slightly high
38	15	.06	2	2.14	0.10		Wetting .06 sq.in. low; capp. .06" low
39	15		1.93	3.60			Wetting .07 sq.in. low; capp. .01" low
108	14.95		2.06	1.89			Wetting .04 sq.in. low; capp. .09" low
109	15.15		1.26	1.51			Wetting .03 sq.in. low; capp. .06" low
111	14.48		2.04			0.72	Wetting .04 sq.in. low; capp. .08" low
112	15.24		1.02	0.94			Wetting .03 sq.in. low; capp. .05" low

TABLE IV RECOMMENDED COMPOSITION RANGES

	Tin	Per Cent Composition			Copper	Lead
		Silver	Indium	Antimony		
1.	14.5-15.5	1.7-2.0	0.3-0.5		0.15-0.25	Balance
2.	14.5-15.5	1.6-2.0	0.5-1.0			Balance
3.	14.5-15.5	1.7-2.0		0.8-1.2		Balance
4.	14.5-15.5	1.7-2.0			0.1 -0.35	Balance
5.	14.5-15.5				0.15-0.25	Balance

TABLE V COMPARISON OF THE PROPERTIES OF SUBSTITUTE SOLDERS
Part I

New Alloy No.	Alloy No.	Per Cent Composition*	Thermal Arrests °C	ΔT°C	Solidification Range
1	1B	15 Sn, 85 Pb (Basic Alloy)	284-180		104
2	76	19.1 Sn, 0.46 Sb, 0.87 Ag, 0.64 Bi, 0.06 Cu	270-178		92
3	114c	18.1 Sn, 0.52 Sb, 0.47 Ag, 0.60 Bi, 0.06 Cu	264.4-173.4		91
4	7	14.4 Sn, 0.96 Ag	282-178		104
5	8	14.1 Sn, 3.03 Ag	(317)-278-177	(140)-101	
6	9	13.2 Sn, 5.08 Ag	(359)-280-176	(183)-104	
7	11	14.1 Sn, 0.11 Cu	288-181	107	
8	12	14.2 Sn, 0.20 Cu	288-182	106	
9	21	40.0 Sn, 0.60 Pb	238-183	55	
10	24	15.1 Sn, 0.06 Tl	284-181	103	
11	25	14.2 Sn, 0.52 Tl	287-182	105	
12	23B	14.5 Sn, 0.68 Tl	285-179	106	
13	29	14.2 Sn, 1.82 Tl	286-181	105	
14	45	14.3 Sn, 0.50 Na	282-213-178	104	
15	61	14.6 Sn, 0.24 Na	282-177	105	
16	52B	15.4 Sn, 0.03 Ca	286-180	106	
17	53B	15.4 Sn, 0.07 Ca	283-181	102	
18	54B	15.8 Sn, 0.10 Ca	283-180	103	
19	57B	14.6 Sn, 0.10 Ca	284-180	104	
20	67	14.2 Sn, 2 Ag, 0.1 Cu	279-176	103	
21	68	14.0 Sn, 2.03 Ag, 0.37 Cu	276-177	99	
22	89	15.2 Sn, 1 In	279-173	106	
23	92	15.3 Sn, 0.03 Li	282-176	106	
24	93	15.4 Sn, 0.08 Li	286-179	107	
25	94	15.4 Sn, 0.17 Li	282-178	104	
26	101	15.3 Sn, 0.06 K	285-180	105	
27	102	15.0 Sn, 0.10 K	288-184	104	
28	27B	15 Sn, 0.08 Ba	284-179	105	
29	28B	15.1 Sn, 0.75 Ba	285-182	103	
30	111	14.3 Sn, 2.02 Ag, 0.75 In	271-169	102	

Table V-Part I (Continued)

Alloy No.	Per Cent Composition*	Thermal Arrests °C	Solidification Range ΔT °C
31	14.3 Sn, 2.06 Ag, 1.30 In	270-167	103
32	13.1 Sn, 2.01 Ag, 0.90 In, 0.22 Cu	289-185	104
33	13.9 Sn, 2.00 Ag, 1.95 In, 0.21 Cu	271-159	112
34	14.3 Sn, 1.70 Sb	276-212-184	92
35	14.6 Sn, 2.56 Sb, 2.07 Ag	265-209-179	86
36	15.3 Sn, 2.24 Sb, 2.03 Ag, 0.07 Cu	266-212-180	86
37	14.9 Sn, 2.13 Sb, 2.04 Ag, 0.14 Cu	270-211-180	90
38	15 Sn, 2.14 Sb, 2 Ag, 0.06 Cu, 0.10 Na	268-180	88
39	15 Sn, 3.60 Sb, 1.93 Ag	258-225-180	78
<u>Solders Containing No Tin</u>			
40	1.04 Ag	313-302	11
41	2.03 Ag	302-299	3
42	2.99 Ag	303 ---	---
43	2.04 Ag, 0.12 Cu	301 ---	---
44	2.04 Ag, 0.21 Cu	301 ---	---
45	2.04 Ag, 0.31 Cu	(312)-302-301	(11)-1
46	2.01 Ag, 0.98 In	327-310	17
47	1.95 Ag, 1.04 In, 0.20 Cu	332-310	22
48	14.3 Sn, 5.26 Tl	290-182	107
49	13.8 Sn, 1.60 Na	279-211-170	109
50	14.8 Sn, 0.32 As	281-243-184	97
51	14.6 Sn, 1.10 As	287-284-178	100
52	15.1 Sn, 0.005 Ca	286-182	104
53	15 Sn, 3 Ba (nominal)	(340)-298-180	(160) 118
54	14.4 Sn, 2.24 Sb, 0.03 Ca	278-220-185	93
55	14.7 Sn, 2.20 Sb, 0.10 Ca	275-205-185	90
56	14.9 Sn, 2.27 Sb, 1.97 Ag, Tr. Ba.	261.5-207-177.5	84
57	15.1 Sn, 2.20 Sb, 1.02 Ag, 0.07 Cu	270-209-180	90

* Balance Pb

Table V-Part I (Continued)

New Alloy No.	Per Cent Composition*										Thermal Arrests °C	ΔT°C	Solidification Range
58	15.1 Sn,	2.31 Sb,	1.08 Ab,	0.15 Cu							269-206-178	91	
59	15.4 Sn,	2.29 Sb,	1.09 In								269-199-174	95	
60	14.8 Sn,	2.22 Sb,	0.13 Cu,	0.06 K							279-220-186	93	
61	15.0 Sn,	2.22 Sb,	0.11 K								275-217-184	91	
62	14.8 Sn,	2.41 Sb,	0.13 K								273-207-184	89	
63	15.2 Sn,	2.23 Sb,	0.02 K								270-208-182	88	
64	15.1 Sn,	2.37 Sb,	0.20 Ca								274.5-179.2	95	
65	15.2 Sn,	1.95 Sb,	0.25 Ca								270-206-181.3	89	
66	15.0 Sn,	2.22 Sb,	0.12 Cu								268-212.3-181	87	
67	14.7 Sn,	2.34 Sb,	2.01 Ag,	0.41 Ba,	0.13 Cu						(379)-267.7-179	(200)88.7	
68	15.4 Sn,	4.16 Sb,	2.04 Ag,	0.05 Cu							261-229-183	78	
69	4.58 Sn,	10.2 Sb,	0.07 Cu								257-240	17	
70	9.6 Sn,	10.4 Sb,	0.09 Cu								242	----	
71	15.0 Sn,	3.26 Sb									268-229-185	83	
72	15.0 Sn,	5.64 Sb,	0.06 Cu								262-216-186	76	
73	15.0 Sn,	5.21 Sb,	1.89 Ag								256-229-179	77	
74	14.8 Sn,	5.20 Sb,	1.96 Ag,	0.14 Na							254-233-181	73	
75	14.8 Sn,	5.13 Sb,	2.0 Ag,	0.29 Na							(274)-255-230-181	(93)74	
76	14.9 Sn,	5.00 Sb,	2.08 Ag,	0.09 Cu							252-181	71	
77	15.2 Sn,	5.22 Sb,	2.01 Ag,	0.32 Cu							252-228-179	73	
78	15.1 Sn,	2.06 Ag,	5.17 Sb								254-228-179	75	
79	14.9 Sn,	5.08 Sb,	2.03 Ag,	0.38 Na,	0.15 Cu						252-229-182	70	
80	15.0 Sn,	5.17 Sb,	2.03 Ag,	0.27 Tl							257-229-179	78	
81	15.0 Sn,	5.05 Sb,	2.0 Ag,	0.80 Tl							252-228-179	73	
82	15.3 Sn,	5.17 Sb,	1.02 In								260-227-176	84	
83	15.3 Sn,	5.13 Sb,	0.05 Li								258-234-179	79	
84	15.5 Sn,	5.17 Sb,	0.08 Li								259-234-181	78	
85	15.2 Sn,	5.18 Sb,	0.16 Li								261-230-183	78	
86	13.6 Sn,	5.15 Sb,	0.19 Ba								262-236-183	79	
37B	14.1 Sn,	5.12 Sb,	1.28 Ba								260-232-182	78	
34B	14.5 Sn,	5.78 Sb									252-236-184	68	

* Balance Pb

Table V-Part I (Continued)

New Alloy No.	Alloy No.	Per Cent Composition*	Thermal Arrests °C	ΔT°C Solidification Range
89	20	15.0 Sn, 7.5 Ag, 6 Sb, Tr As**	369-248-233-197	72
90	38B	15.5 Sn, 5.55 Sb, 0.07 Ba	259-182	77
91	35	12.1 Sn, 6.00 Sb, 2.02 Ag, 0.14 As	240-185	55
92	50	14.5 Sn, 6.15 Sb, 0.51 As	259-229-182	77
93	57	13.8 Sn, 6.04 Sb, 2.26 As	265-252	13
94	48	15.0 Sn, 6.09 Sb, 1.03 Ag	250-231-213-181	69
95	59	15.0 Sn, 6.07 Sb, 1.98 Ag	251-232-179	72
96	60	15.0 Sn, 6.13 Sb, 3.07 Ag	250-231-177	73
97	62	14.8 Sn, 6.14 Sb, 0.31 Na	263-236-181	82
98	63	14.8 Sn, 6.10 Sb, 0.66 Na	255-208-178	77
99	39B	12.4 Sn, 5.58 Sb, 0.06 Ba, 0.10 Cu	261-252	9
100	5	14.9 Sn, 7.98 Sb	250-183	57
101	31	14.7 Sn, 7.85 Sb, 0.76 Tl	239-184	55.5
102	32	14.7 Sn, 7.89 Sb, 3.95 Tl	240-182	58
103	36	14.6 Sn, 8.33 Sb, 1.99 Ag, 0.12 As	240 ---	--
104	1X	14.74 Sn, 2.06 Ag, 0.25 In	274.7-172	102.7
105	2X	14.82 Sn, 2.02 Ag, 0.54 In	267.5-168	99.5
106	3X	14.50 Sn, 2.05 Ag, 0.34 In, 0.18 Cu	270.0-168	102.0
107	4X	15.24 Sn, 1.50 Sb, 0.58 In	270.5-176	94.5
108	5X	14.95 Sn, 2.06 Ag, 1.89 Sb	265.0-178	87.0
109	6X	15.15 Sn, 1.26 Ag, 1.51 Sb	268.5-179.2	89.3
110	7X	15.2 Sn, 1.03 Ag, 1.02 Sb, 0.66 Tl	267.5-188-180	87.5
111	8X	14.48 Sn, 2.04 Ag, 0.72 Tl	275.4-175	100.4
112	9X	15.24 Sn, 1.02 Ag, 0.94 Sb	269.7-179	90.7
113	10X	15.10 Sn, 2.04 Ag, 0.96 Sb	268-177	91.0
114	81	15.0 Sn, 3.06 Sb, 2.08 Ag, 0.08 Cu	264-218-180	84
115	82	15.0 Sn, 2.97 Sb, 2.05 Ag, 0.16 Cu	259-213-176	83
116	83	14.8 Sn, 3.01 Sb, 1.01 Ag, 0.08 Cu	267-210-179	88
117	84	15.3 Sn, 3 Sb, 1.06 Ag, 0.15 Cu	262-217-180	82
118	86	15.3 Sn, 3.28 Sb, 2.02 Ag, 0.05 Cu, 0.07 Na	264-222-178	86

* Balance Pb

** Nominal Composition

Table V-Part I (Continued)

New No.	Alloy No.	Per Cent Composition*	Solders Containing No Tin	Thermal Arrests °C	ΔT°C Solidification Range
118	2.10 Sb			307-220	87
119	3.90 Sb (.86 Sn residual)			299-238	61
120	2.19 Sb, 0.29 As			308-241	67
121	2.16 Sb, 0.70 As			302-256	46
122	2.07 Sb, 2.02 Ag			291 ---	--
123	4.03 Sb, 2.03 Ag, 0.27 Sn			283-233	50

* Balance Pb

TABLE V COMPARISON OF THE PROPERTIES OF SUBSTITUTE BULLETS
PART II

New No.	Wetting in 2"		Cap. Rise In.	Shear Strength psi	Tinning Property	Appearance after Casting	Appearance after 4 Mos.*	Bend Test
	Cu	Brass Fe						
1	.14	.185	.49	4280	Fair	Shiny silver	Dull silver	V. Ductile
2	.24	.155	.57	3870	Good	Dull silver	Dull silver	V. Ductile
3	.19	.13	.54	3400	Good	Dull silver - Dull scum on top	Dull silver	V. Ductile
4	.15	.11	.32	4040	Good	Slightly dull	Unchanged	Ductile
5	.20	.135	.51	3900	Good	Shrinkage porosity on top frosty bright on bottom	Dull silver	Ductile
6	.20	---	.505	----	Good (lumpy)	Appeared etched on top-bright on bottom	Unchanged	V. Ductile
7	.175	.06	.46	3550	V. Good	Slightly dull sil.	Unchanged	V. Ductile
8	.195	.08	.47	4130	V. Good	Slightly dull sil.	Unchanged	V. Ductile
9	.23	.185	.61	4900	V. Good	Shiny silver	Unchanged	V. Ductile
10	.14	.13	.49	3420	V. Good	Slightly dull sil.	Unchanged	V. Ductile
11	.15	.135	.47	3400	V. Good	Slightly dull sil.	Slightly dull gray	V. Ductile
12	.13	---	.39	2610	V. Good	Silvery	Unchanged	V. Ductile
13	.135	.15	.51	3680	V. Good	Slightly dull sil.	Light gray	V. Ductile
14	.18	.23	.56	2360	Good	Dull gray scum	Unchanged	V. Brittle
15	.14	.105	.48	3970	Good	Dull silver	Grayish	V. Ductile
16	.155	.105	.51	2780	Good	Silvery	Silvery gray	V. Ductile
17	.17	---	.35	2510	Good	Silvery	Light gray	Ductile
18	.155	.115	.39	2290	V. Good	Silvery	Dull gray	V. Ductile
19	.15	.14	.45	2720	Good	Dull silver	Grayish	S. Brittle
20	.21	.155	.575	3760	V. Good	Slightly dull sil.	Unchanged	Ductile
21	.20	.13	.53	3800	Good	Dull silver	Dull silver	S. Brittle
22	.13	.08	.37	2620	Good	Silvery	Slightly discolored	V. Ductile
23	.135	.155	.40	2710	Good	Dull silver	Dull silver	Ductile
24	.15	.125	.39	2760	Good Tinning (oxide grit)	Dull silver	Light gray	S. Brittle
25	.15	---	.40	2240	Fair-scummy	Light gray	Darker gray	S. Brittle

* "Unchanged" refers to appearance after casting

Table V Part II (Continued)

New No.	Wetting in 2"		Cap. Rise In.	Shear Strength psi	Tinning Property	Appearance after Casting	Appearance after 4 Mos*	Bend Test
	Cu	Brass Fe						
47	.105	.075	.06	2170	Fair-lumpy	Bright silver	Silver-gray	V. Ductile
48	.10	.12	.37			Slightly dull sil.	Unchanged	V. Ductile
49	.05	---	---			Dull scum-grayish	Chalky gray	Brittle
50	.10	.135	.33			Red-brown scum dull silver	Dull gray	Ductile
51	.07	---	---			Dull gray scum dull silver	Unchanged	S. Brittle
52	.15	---	---			Dull silver on top silvery on bottom	Unchanged	V. Ductile
53	.13	---	---			Dull gray	Blue-white chalky crust	Brittle
54	.10	.10	.30			Bright silver	Dull gray	Ductile
55	.11	---	---			Dull silver	Bluish-silver gray	V. Ductile
56	.105	.10	.31			Dull silver-scummy	Unchanged	V. Ductile
57	.10	---	---			Dull silver	Dull light gray "	Ductile
58	.10	.11	.32			Dull silver	S. dull sil.	Ductile
59	.08	---	---			Silvery	Dark gray	S. Brittle
60	.10	.08	.29			Pale yellow scum silvery		S. Brittle
61	.10	---	---			Dull scum-dull sil.	Grayish	S. Brittle
62	.105	---	---			"	Light gray	S. Brittle
63	.105	---	---			Silvery	Dull light gray	Ductile
64	.09	.08	.32			Scum-dull silver	Light gray	V. Ductile
65	.105	---	---			Dull silver	Dull bluish gray	Ductile
66	.09	.075	.41			Dull silver	L. silvery gray	V. Ductile
67	.12	---	---			Dull silver	Dull silver grayish	S. Brittle
68	.09	---	---			Dull silver	Unchanged	S. Brittle
69	.055	.055	.08			Shiny silver	Unchanged	Ductile

* "Unchanged" refers to appearance after casting.

Table V Part 1J (Continued)

New No.	Wetting in 2"		Cap. Rise In.	Shear Strength psi	Tinning Property	Appearance after Casting	Appearance after 4 Mos.*	Bend Test
	Cu	Brass						
70	.075	.05	.15		Shiny silver	Unchanged	Unchanged	Ductile
71	.09	---	---		Slightly dull sil.	Unchanged	Unchanged	V.Ductile
72	.09	---	---		Slightly dull sil.	Unchanged	Unchanged	Brittle
73	.10	---	---		Slightly dull sil.	Dull silvery	Dull silvery	S.Brittle
74	.12	.09	.23		Dull silver	gray	gray	Brittle
75	.11	---	---		Grayish	Dark gray	Dark gray	V.Brittle
76	.09	.085	.27		Silvery	Dull white	Dull white	Brittle
77	.08	---	---		Silvery	S.dull sil.	S.dull sil.	Brittle
78	.085	.08	.23		Dull silver	Unchanged	Unchanged	Brittle
79	.08	.07	.23		Very dull silver	Dull dark	Dull dark	V.Brittle
80	.08	.085	.21		Dull silver	gray-chalky crust	gray-chalky crust	S.Brittle
81	.08	---	---		Dull silver	gray	gray	S.Brittle
82	.08	---	---		Silvery	Bluish-black tinge	Bluish-black tinge	S.Brittle
83	.08	.07	.31		Dull silver	Dull silver	Dull silver	Brittle
84	.075	---	---		Dull silver	Dull light	Dull light	S.Brittle
85	.06	---	---		Dull silver	gray	gray	Brittle
86	.09	---	---		Light gray	Dull frosty	Dull frosty	Brittle
87	.09	.075	.21		Silvery	Dark gray	Dark gray	V.Brittle
88	.08	---	---		Dull silver	Dull gray sil.	Dull gray sil.	S.Brittle
89	.10	---	---		S. dull silver	Dull dark	Dull dark	Brittle
90	.08	---	---		Silvery	gray	gray	V.Brittle
91	.085	.075	.28		Silvery	Light gray	Light gray	S.Brittle
92	.07	---	---		Dull silver	Light gray	Light gray	S.Brittle
93	.05	---	---		Silvery	Blue-gray	Blue-gray	V.Ductile
						Unchanged	Unchanged	S.Brittle
						Unchanged	Unchanged	Brittle
						S.dull sil.	S.dull sil.	V.Brittle

* "Unchanged" refers to appearance after casting.

Table V Part II (Continued)

New No.	Wetting in 2"		Cap. Rise In.	Shear Strength psi	Tinning Property	Appearance after Casting	Appearance after 4 Mos.*	Bend Test
	Cu	Brass						
94	.08	---	---			S. dull silver	S. dull sil.	Brittle
95	.09	.07	.17			Some scum-dull sil.	Unchanged	Brittle
96	.09	---	---			"	Unchanged	Brittle
97	.08	---	---			Dull gray	Chalky gray	V. Brittle
98	.09	.085	.19			Dark gray	Chalky gray	V. Brittle
99	.08	---	---			Black oxide-silvery	Dull gray	Ductile
100	.07	---	---			Porous surface	Unchanged	Brittle
						shiny silver		
101	.06	---	---			Bright silver	Unchanged	S. Brittle
102	.07	---	---			Bright silver	Unchanged	Brittle
103	.08	---	---			S. dull silver	Unchanged	V. Brittle
104	.20	---	---	.51	Good	Bluish scum-dis-		Ductile
						appeared on re-		
						melting		
105	.23	---	---	.46	Good	"		Ductile
106	.30	---	---	.49	Good	"		Ductile
107	.11	---	---	.37	Good	"		Ductile
108	.15	---	---	.45	Good	Dull silver		Ductile
						(some scum)		
109	.15	---	---	.48	Good	"		Ductile
110	.145	---	---	---	Fair	Dull silver		Ductile
111	.15	---	---	.46	Good	Dull silver		Ductile
						(some scum)		
112	.16	---	---	.49	Good	"		Ductile
113	.22	---	---	.47	Good	"		Ductile
114	.09	---	---	---		Dull silver	Dull gray	Brittle
115	.095	---	---	---		Dull silver	Light gray	Brittle
116	.09	---	---	---		Dull silver	Dull white	S. Brittle
117	.095	.085	.22	---		Dull silver	Dull gray	S. Brittle
118	.11	---	---	---		Dull silver	Dusty light gray	V. Brittle

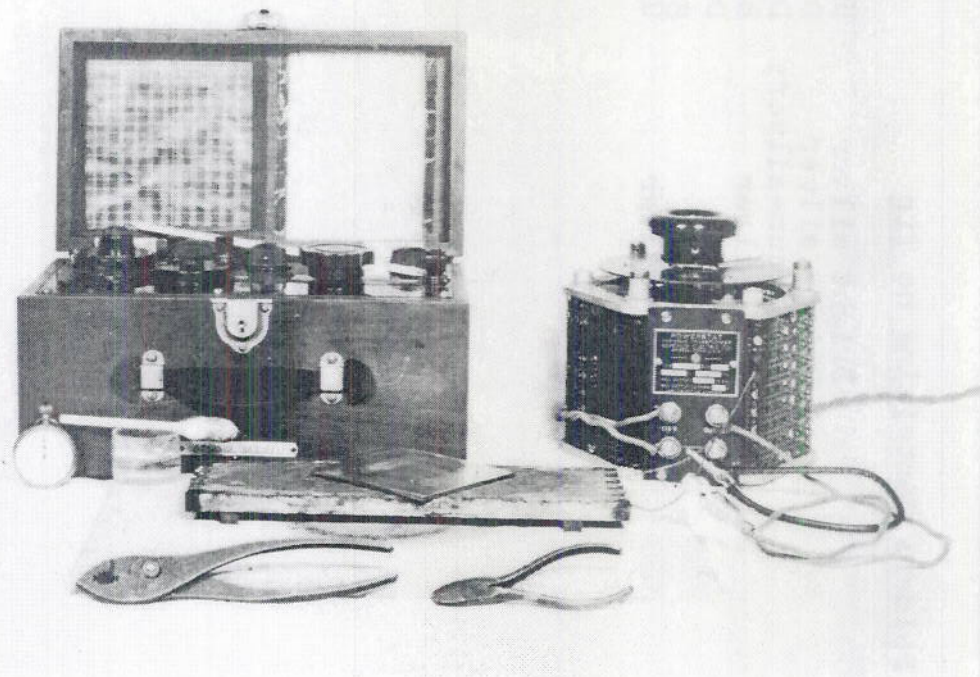
* "Unchanged" refers to appearance after casting.

Table V Part II (Continued)

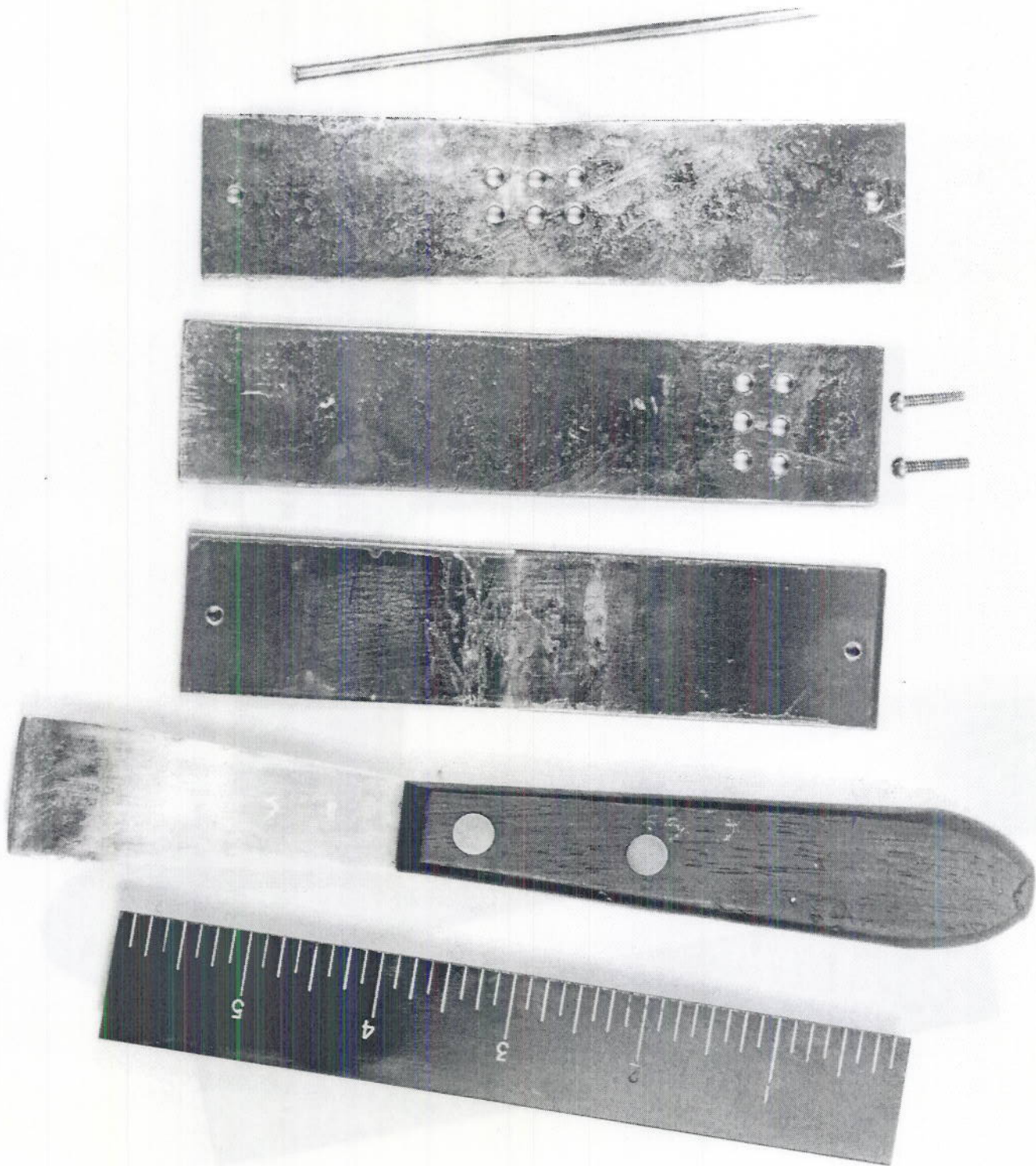
New No.	Wetting in 2"		Cap. Rise In. psi	Shear Strength psi	Tinning Property	Appearance after Casting	Appearance after 4 Mos.*	Bend Test
	Cu	Brass						
119	.045	---	---	---	Bright silver	Unchanged	Unchanged	V.Ductile
120	.055	---	---	---	Bright silver	Dull silver	Dull silver	V.Ductile
121	.055	---	---	---	Some scum-silvery	Dull silver	Dull silver	V.Ductile
122	.06	.05	.06	---	Dull silver	Bluish sil.	Bluish sil.	V.Ductile
123	.075	.07	.04	---	Silvery	Dull bluish-gray	Dull bluish-gray	V.Ductile
124	.06	---	---	---	Dull silver	Unchanged	Unchanged	V.Ductile

Solders Containing no Tin

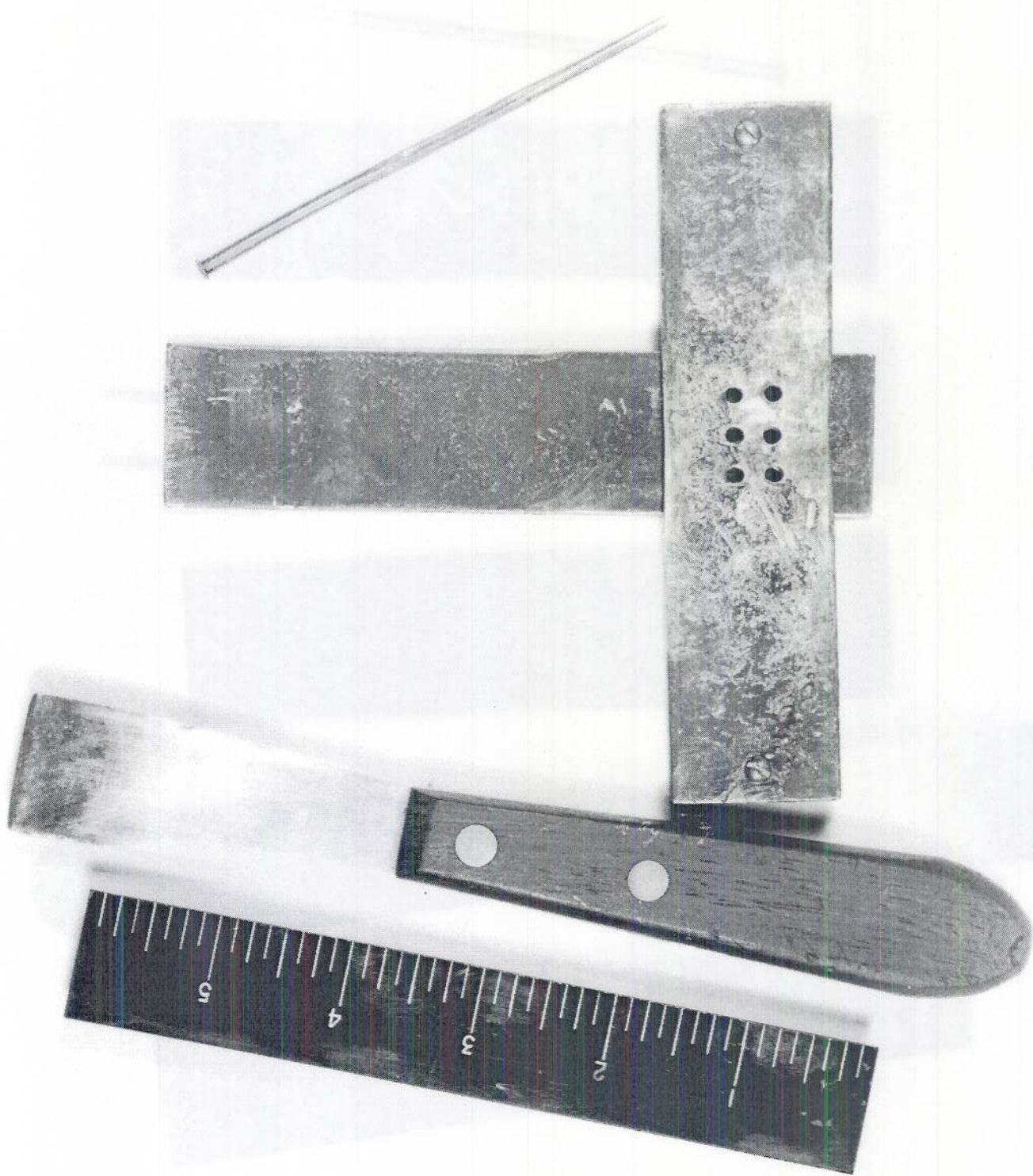
* "Unchanged" refers to appearance after casting.



EQUIPMENT USED IN TESTING
FOR WETTABILITY

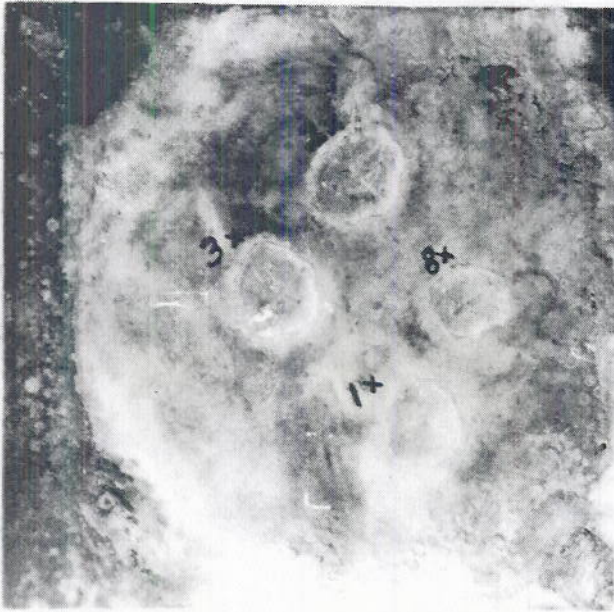


DEVICE FOR MAKING SOLDER
PELLETS (UNASSEMBLED)



DEVICE FOR MAKING SOLDER
PELLETS (ASSEMBLED)

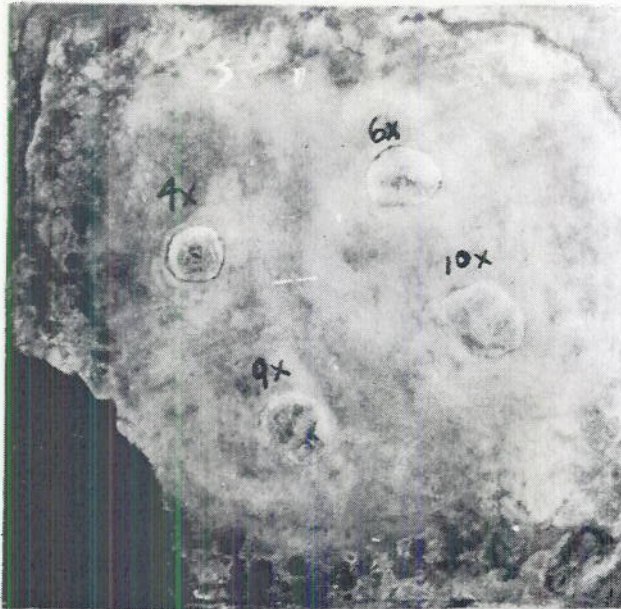
TEST SHOWING COMPARATIVE WETTABILITY
OF EIGHT SOLDERS



COMPOSITIONS

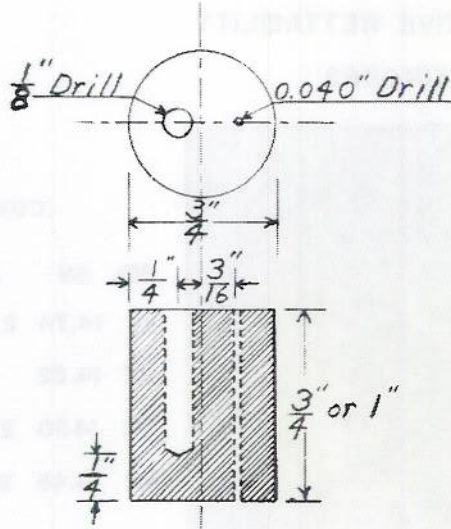
NO.	SN	AG	TL	IN	CU
1X	14.74	2.06		0.25	
2X	14.82			0.54	
3X	14.50	2.05		0.34	0.18
8X	14.48	2.04	0.72		

TESTS RUN AT 60°C ABOVE THE AVERAGE
LIQUIDUS TEMPERATURE OF THE SOLDERS ON
EACH PLATE. ACTUAL SIZE.

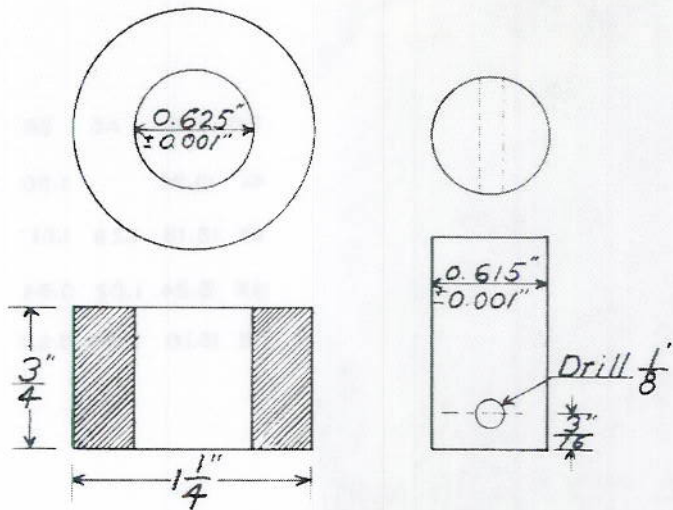


NO.	SN	AG	SB	IN
4X	15.24		1.50	0.58
6X	15.15	1.26	1.51	
9X	15.24	1.02	0.94	
10X	15.10	2.04	0.96	

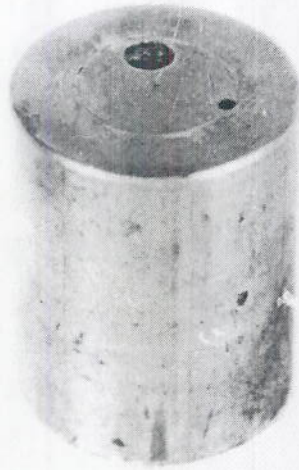
PLATES SLIGHTLY POLISHED.



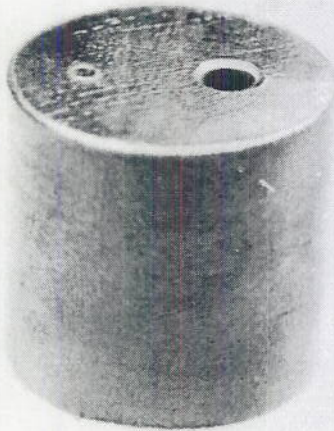
Capillarity Specimen
Copper



Shear Test Specimen
Commercial Brass

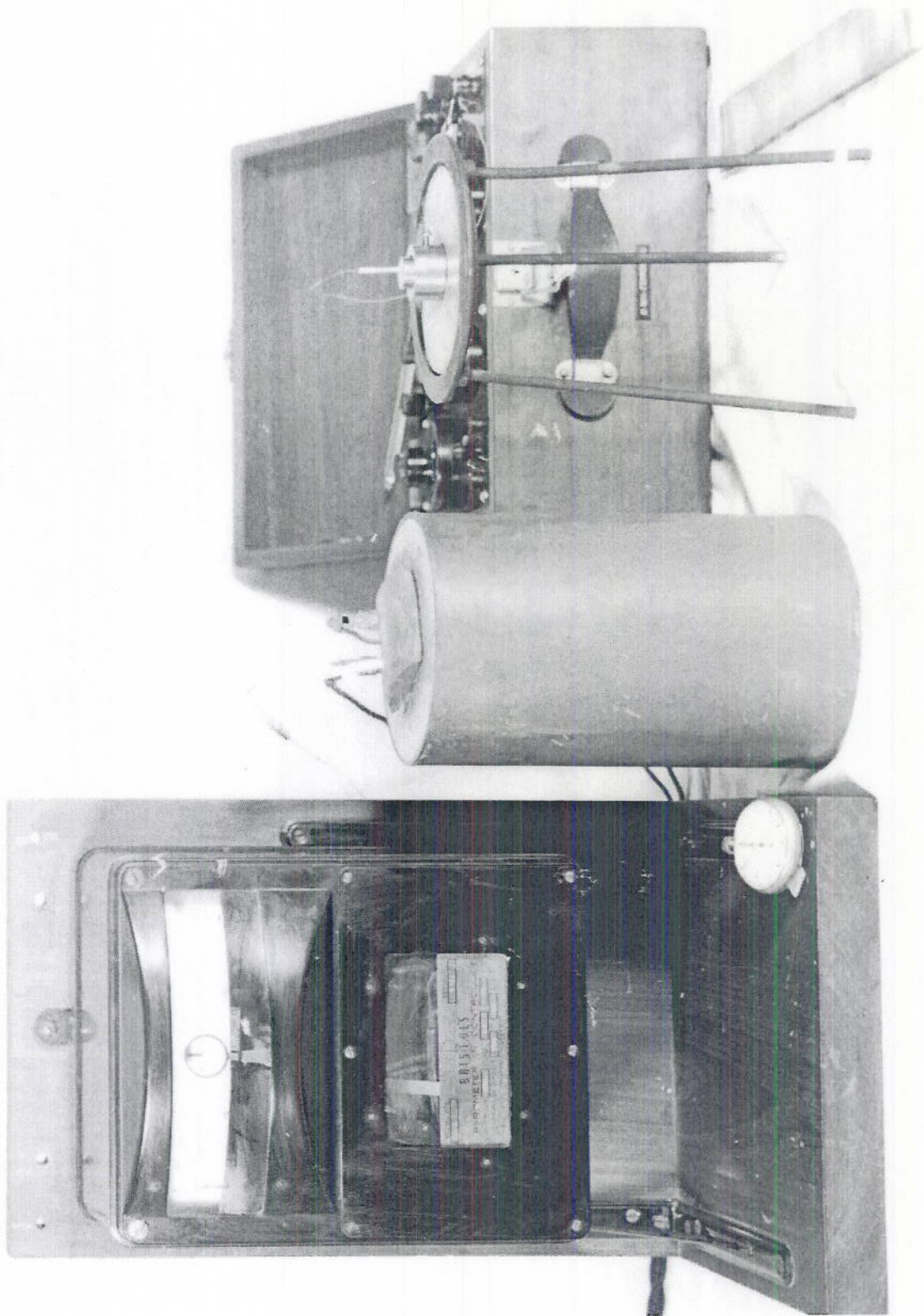


**EXTRA HIGH CAPILLARY
SPECIMEN-2X**



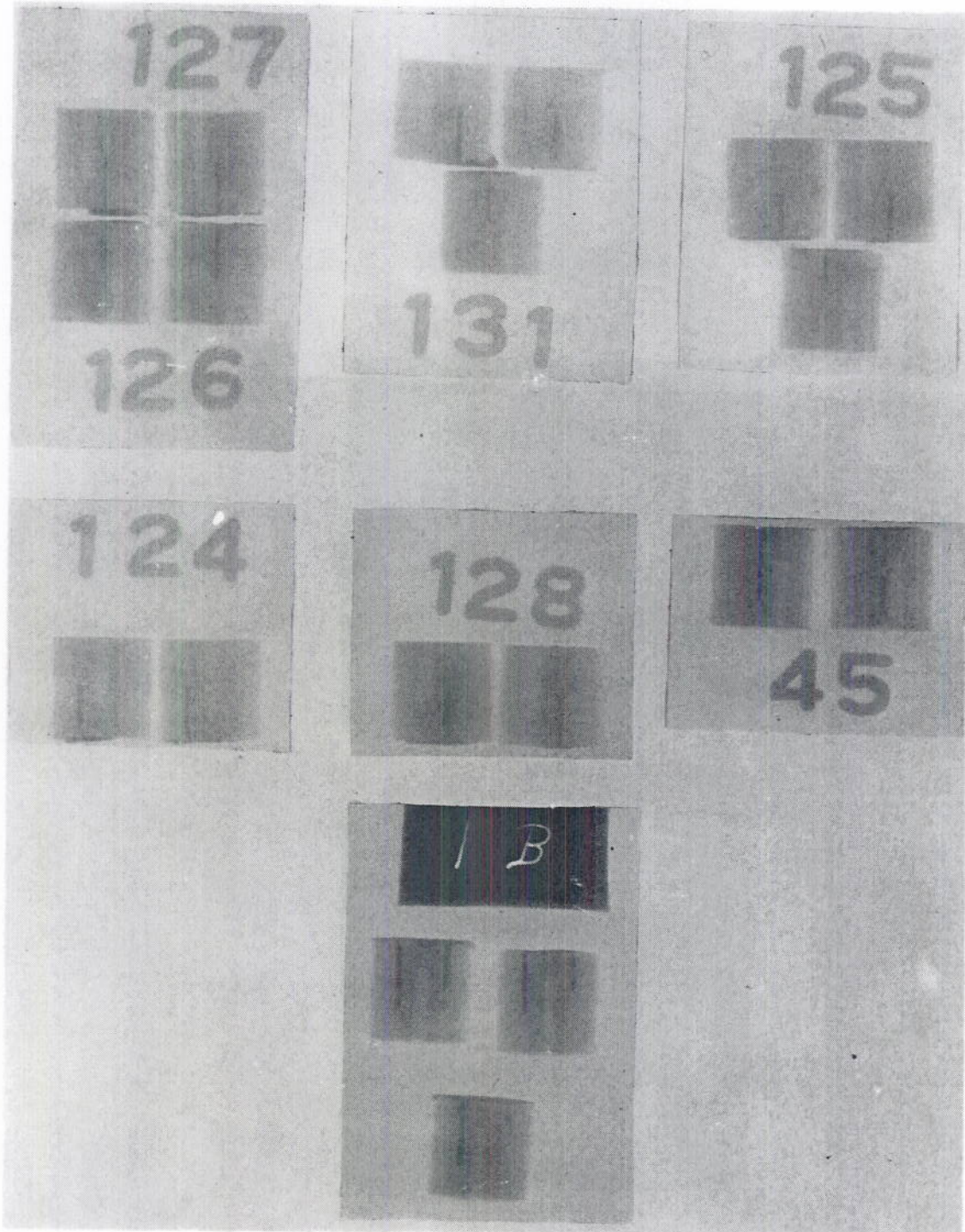
STANDARD SPECIMEN-2X

EQUIPMENT USED IN
CAPILLARY TESTS



EQUIPMENT USED IN
CAPILLARITY TESTS

RADIOGRAPHS OF CAPILLARITY TESTS



ASSEMBLY USED IN PREPARING SPECIMENS
FOR JOINT SHEAR TESTS

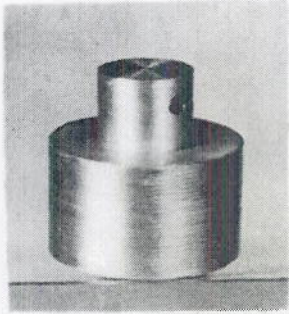


FIG. 1

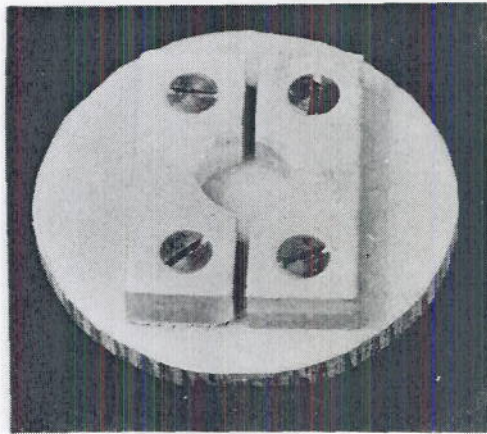


FIG. 2

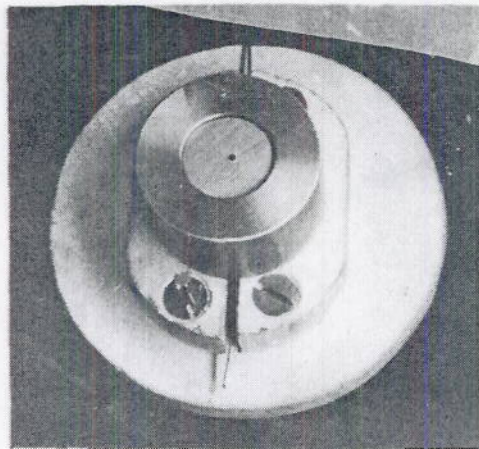
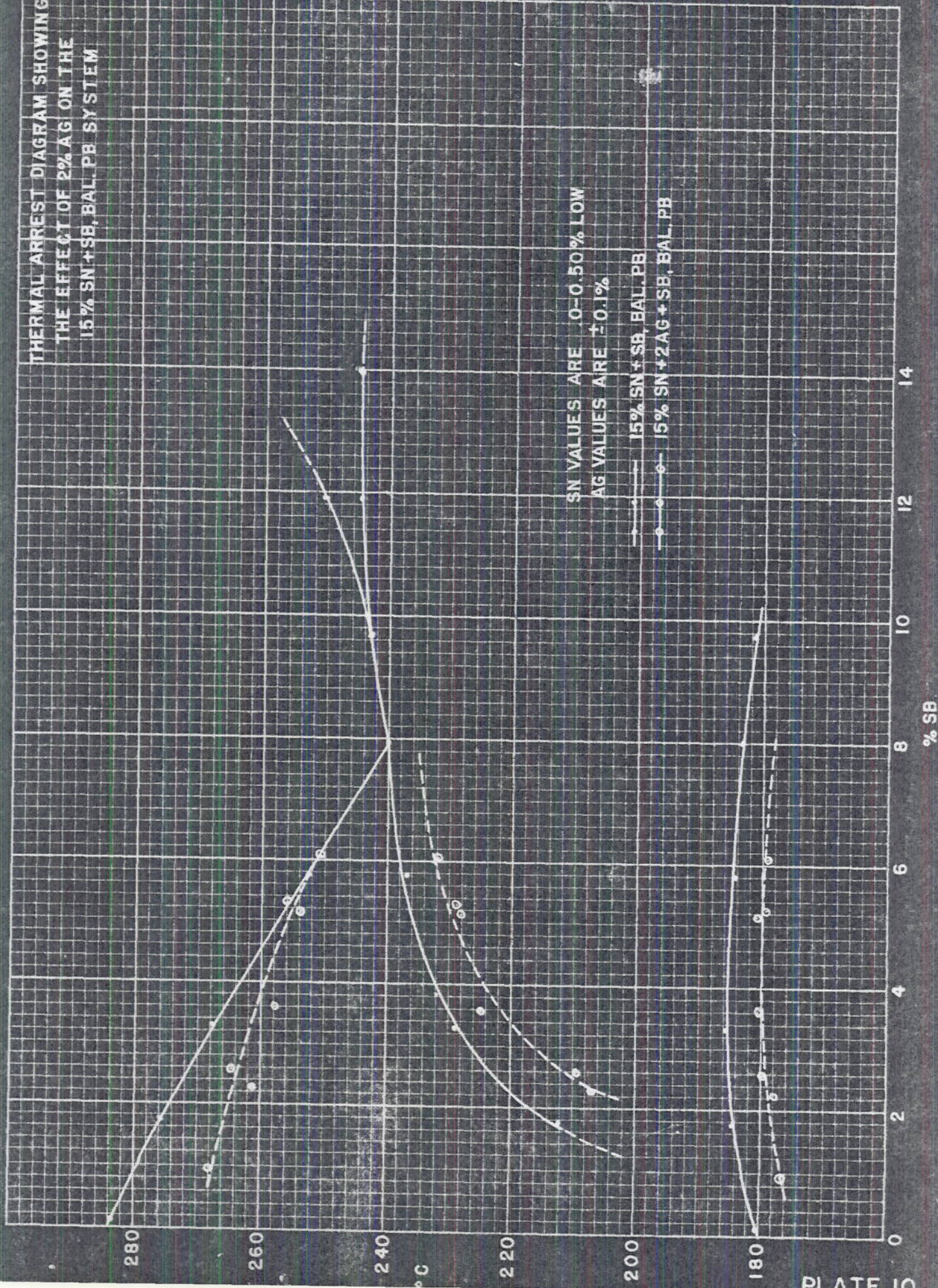


FIG. 3

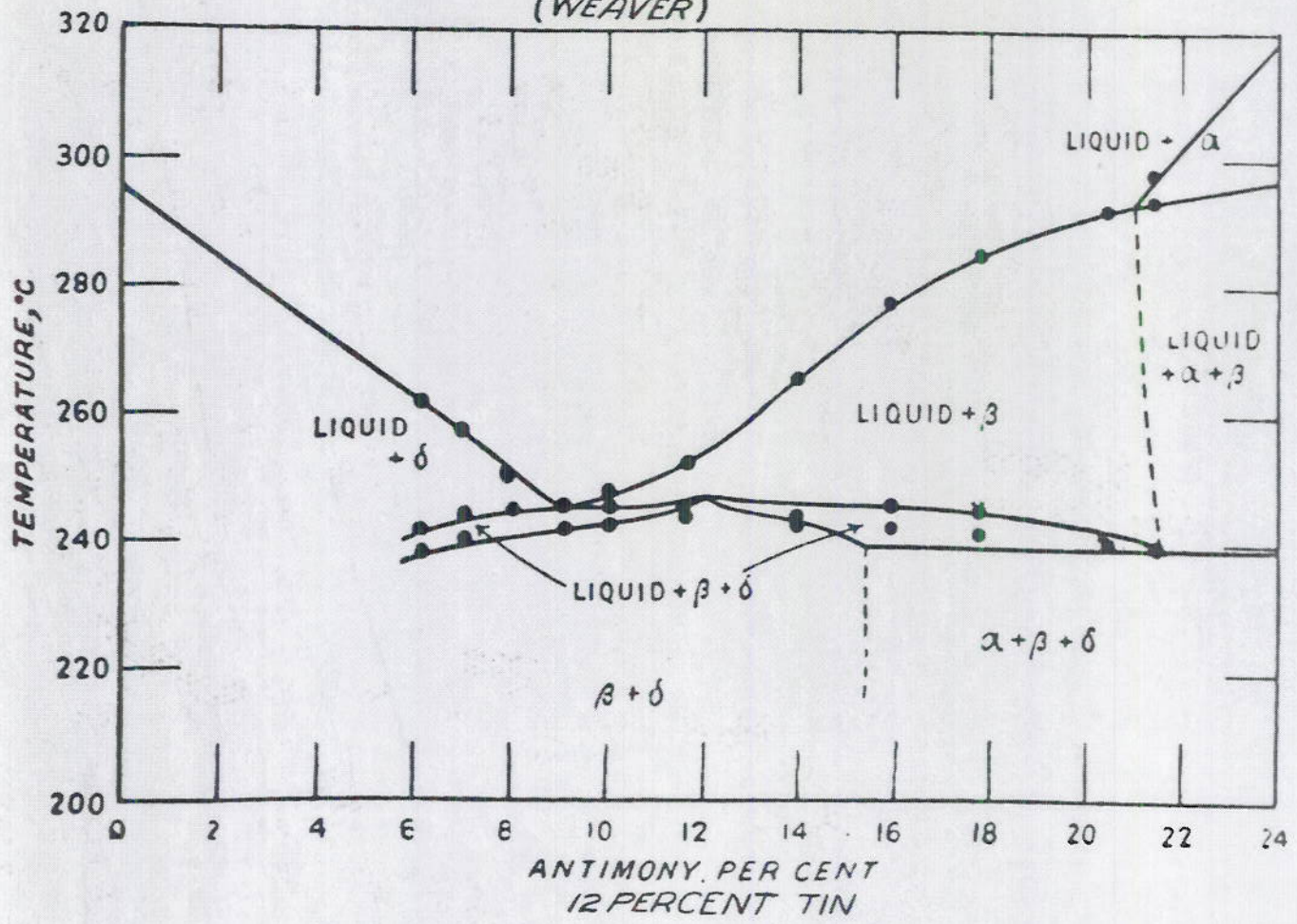
**THERMAL ARREST DIAGRAM SHOWING
 THE EFFECT OF 2% AG ON THE
 15% SN+SB, BAL. PB SYSTEM**

SN VALUES ARE 0-0.50% LOW
 AG VALUES ARE $\pm 0.1\%$

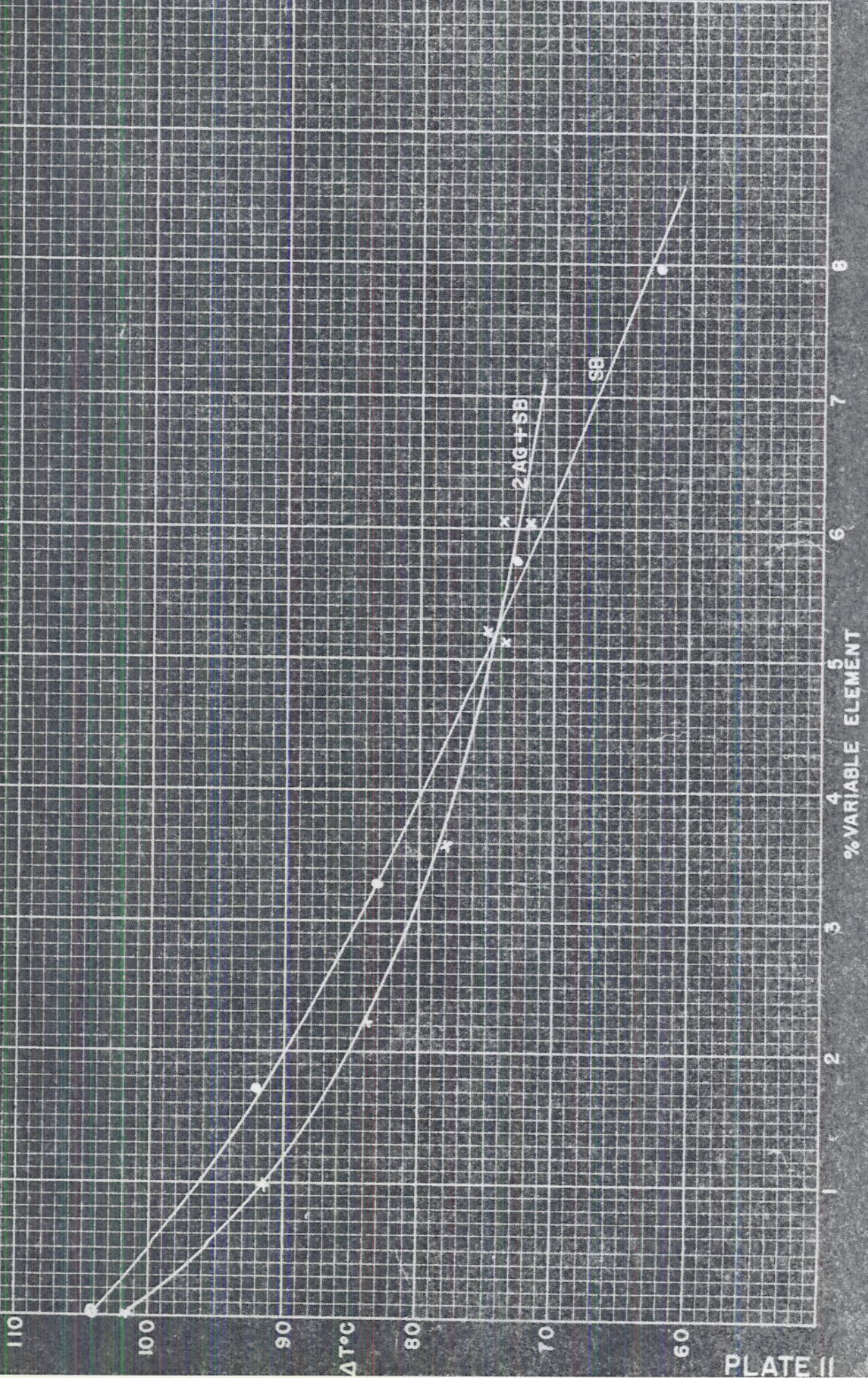
——— 15% SN+SB, BAL. PB
 —•— 15% SN+2AG+SB, BAL. PB



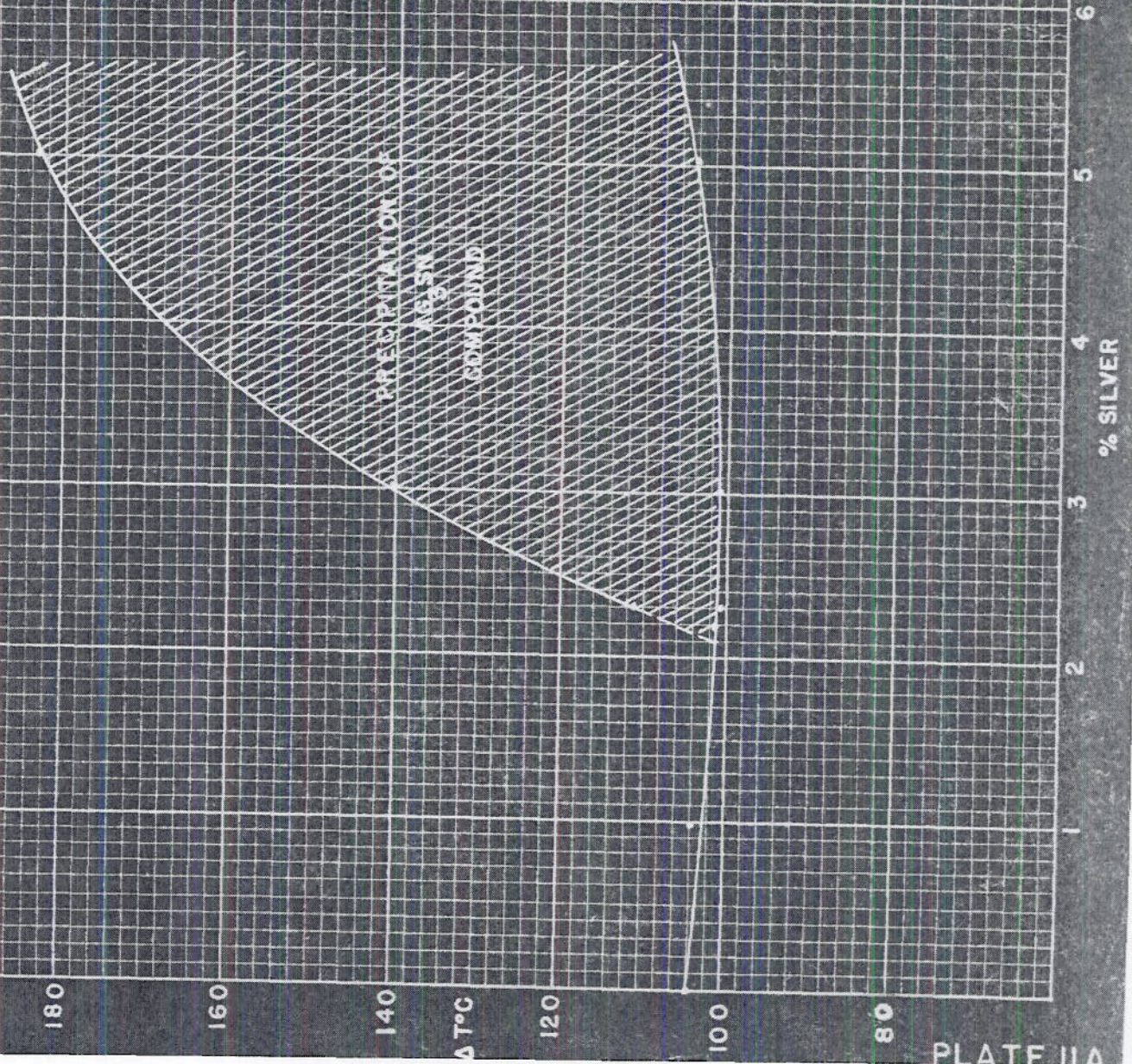
TERNARY CONSTITUTIONAL DIAGRAM
(WEAVER)

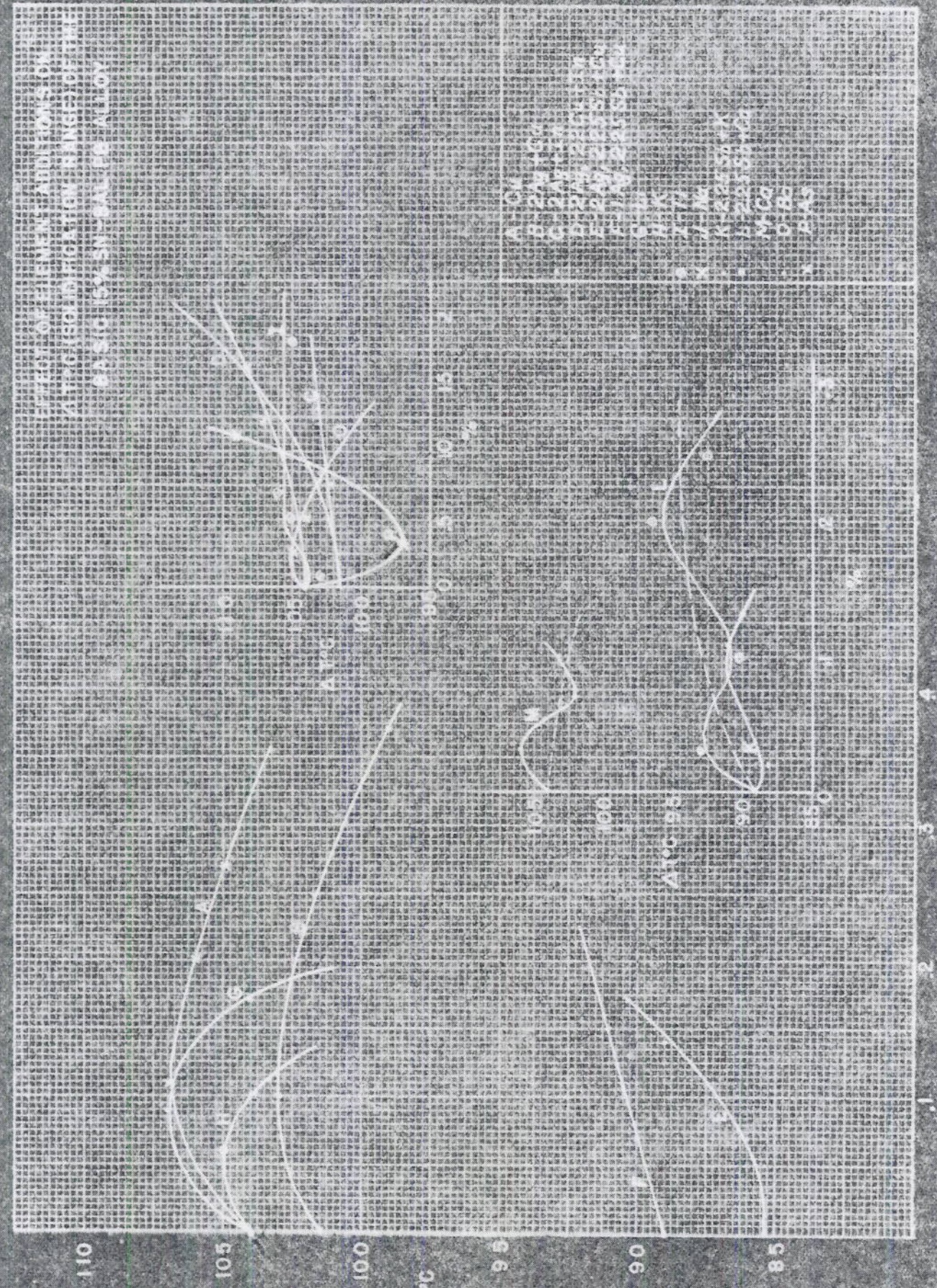


EFFECT OF ELEMENT ADDITIONS ON
 $\Delta T^{\circ}C$ (SOLIDIFICATION RANGE) OF
 THE BASIC 15% SN-BAL. PB ALLOY



EFFECT OF ELEMENT ADDITIONS ON
 $\Delta T^{\circ}C$ (SOLIDIFICATION RANGE) OF
THE BASIC 15% SN-BAL PB ALLOY





% VARIABLE ELEMENT

10

20

30

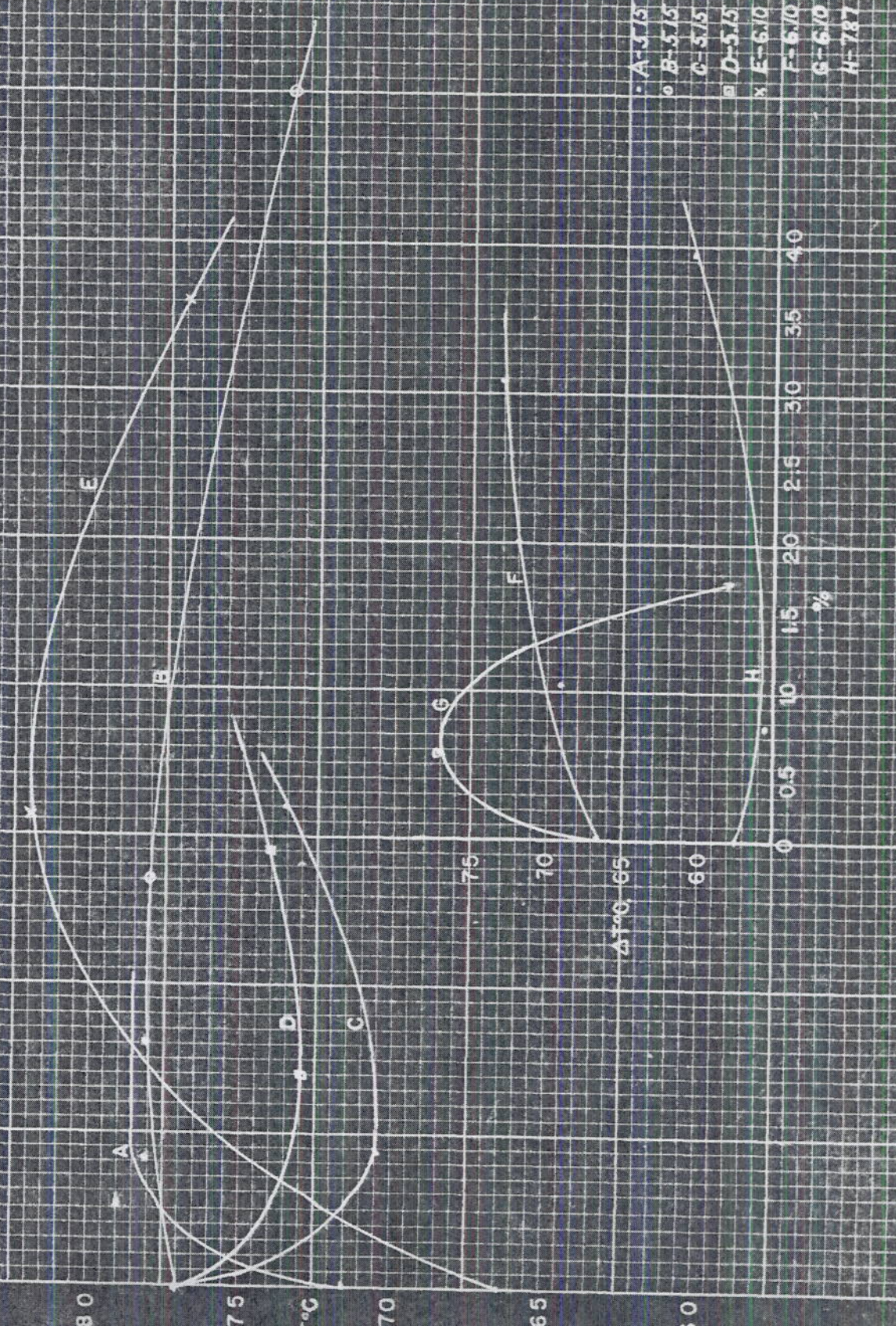
40

50

60

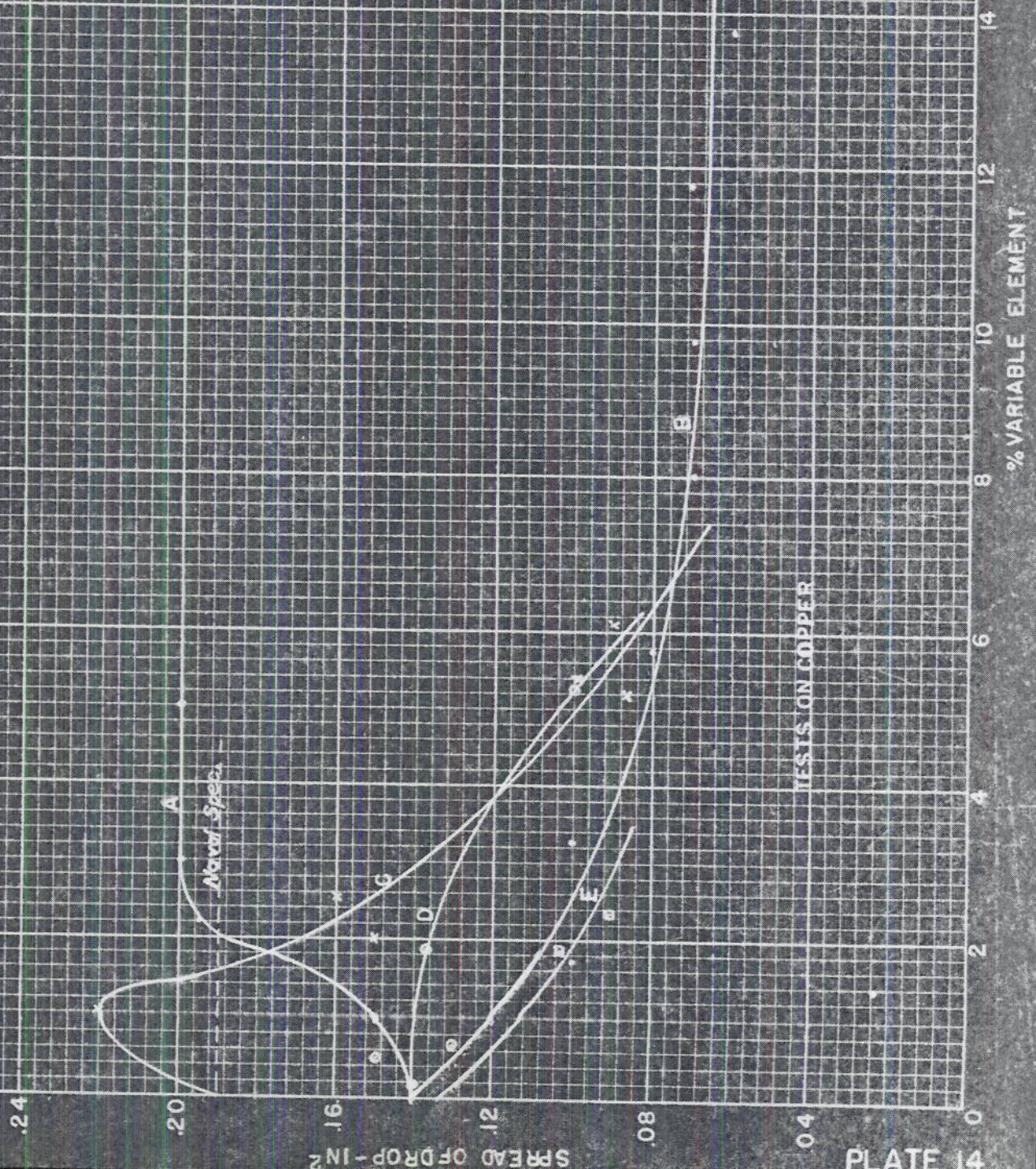
PLATE 12

EFFECT OF ELEMENT ADDITIONS ON
 $\Delta T^{\circ}C$. (SOLIDIFICATION RANGE) OF THE
 BASIC 15% Sn-BAL. Pb ALLOY



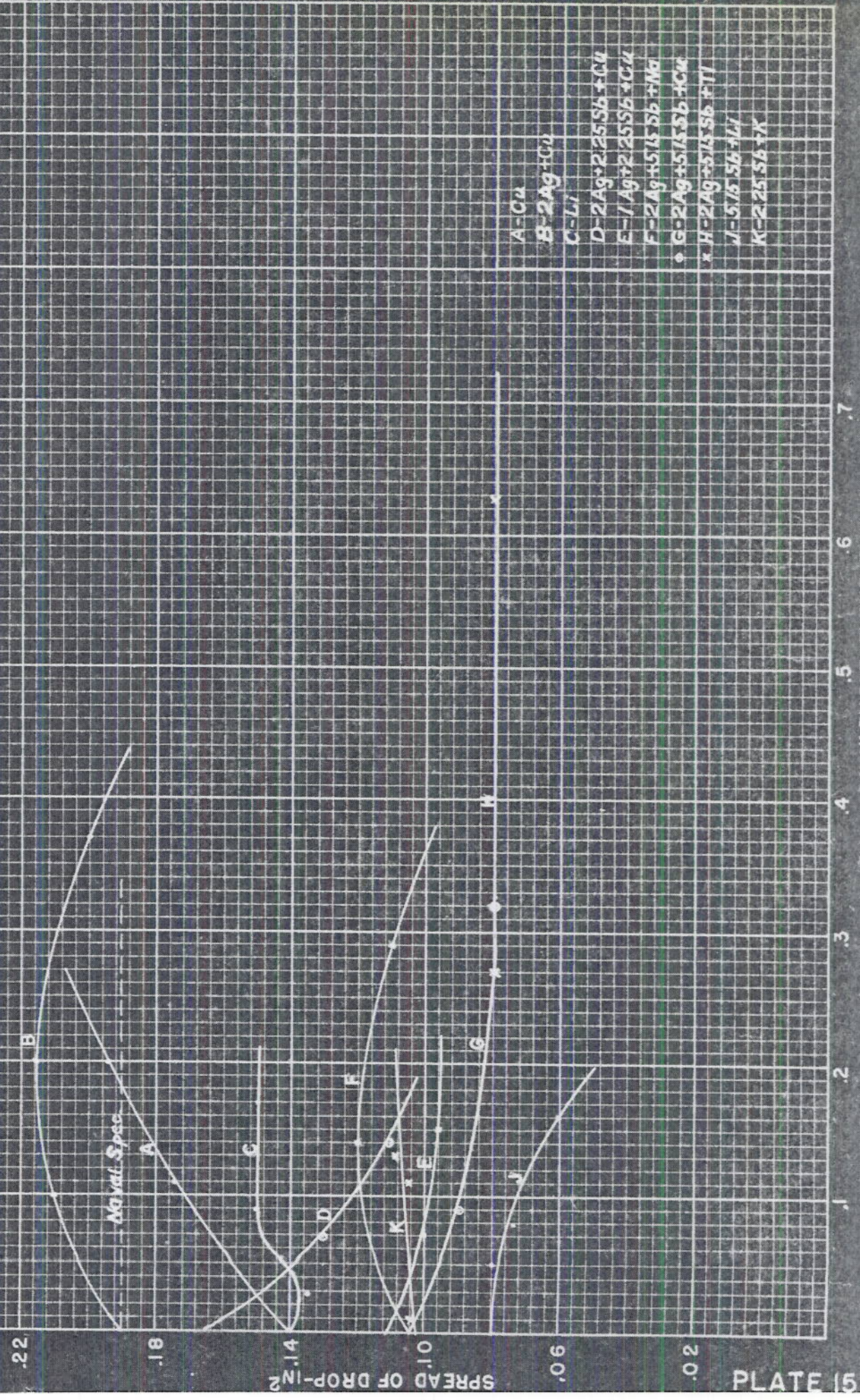
- A-3.75 Sb + Li
- B-5.75 Sb + 2Ag + 7I
- ◻ C-5.75 Sb + 2Ag + Cu
- ◼ D-5.75 Sb + 2Ag + Na
- × E-6.10 Sb + Mo
- ◊ F-6.10 Sb + Ag
- ◊ G-6.10 Sb + As
- ◊ H-7.87 Sb + 7I

EFFECT OF ELEMENT ADDITIONS ON
THE WETTABILITY OF THE BASIC
5% SN-BAL. PB ALLOY



WETTING ON COPPER

EFFECT OF ELEMENT ADDITIONS ON
THE WETTABILITY OF THE BASIC
15% SN-BAL. PB ALLOY



- A-Cu
- B-2Ag+Cu
- C-Li
- D-2Ag+2.25Sb+Cu
- E-1Ag+2.25Sb+Cu
- F-2Ag+5.15Sb+Ni
- G-2Ag+5.15Sb+Cu
- H-2Ag+5.15Sb+Ti
- I-5.15Sb+Li
- K-2.25Sb+K

EFFECT OF ELEMENT ADDITIONS ON
THE WETTABILITY OF THE BASIC
15% SN-BAL. PB ALLOY

.22

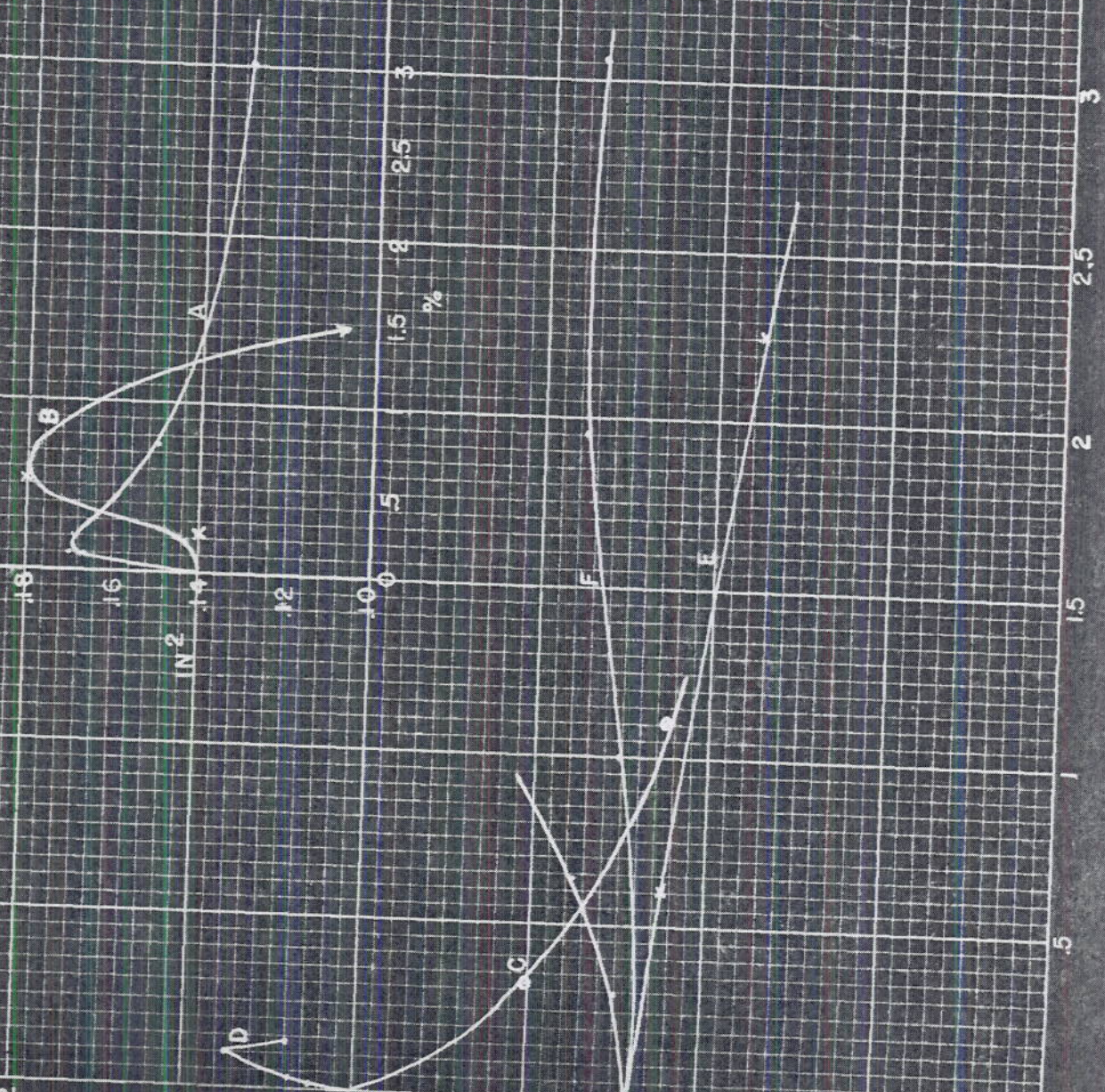
.18

SPREAD OF DROP IN IN^2

.06

.02

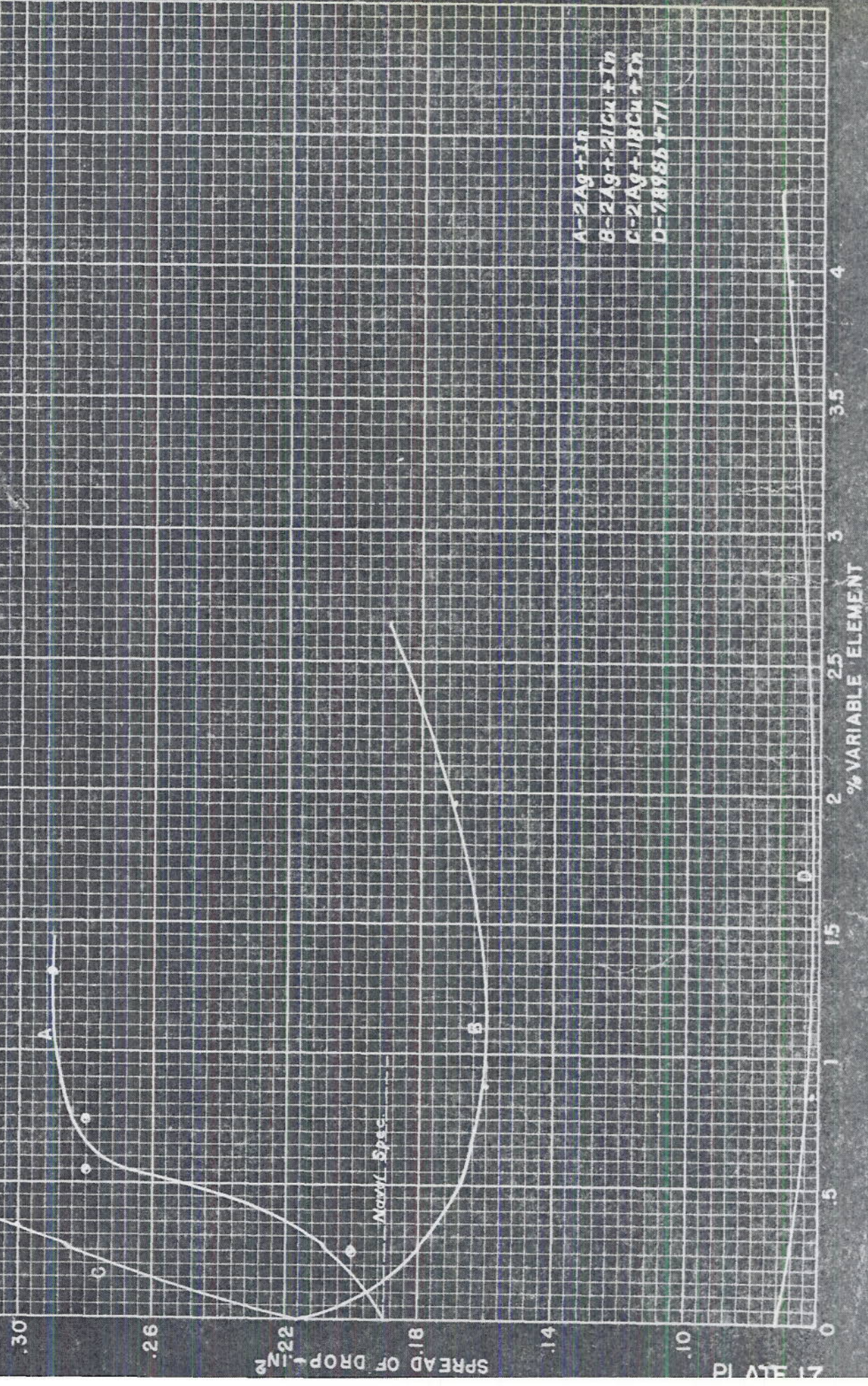
PLATE 9



- A-Ba
- B-Na
- C-As
- D-Cd
- F-6.10.5b+As
- F-6.10.5b+Ag
- G-6.10.5b+Ag

% VARIABLE ELEMENT

EFFECT OF ELEMENT ADDITIONS ON
THE WETTABILITY OF THE BASIC
15% Sn-BAL. PB ALLOY



A-2Ag+In
B-2Ag+21Cu+In
C-2Ag+18Cu+In
D-789Sb+77

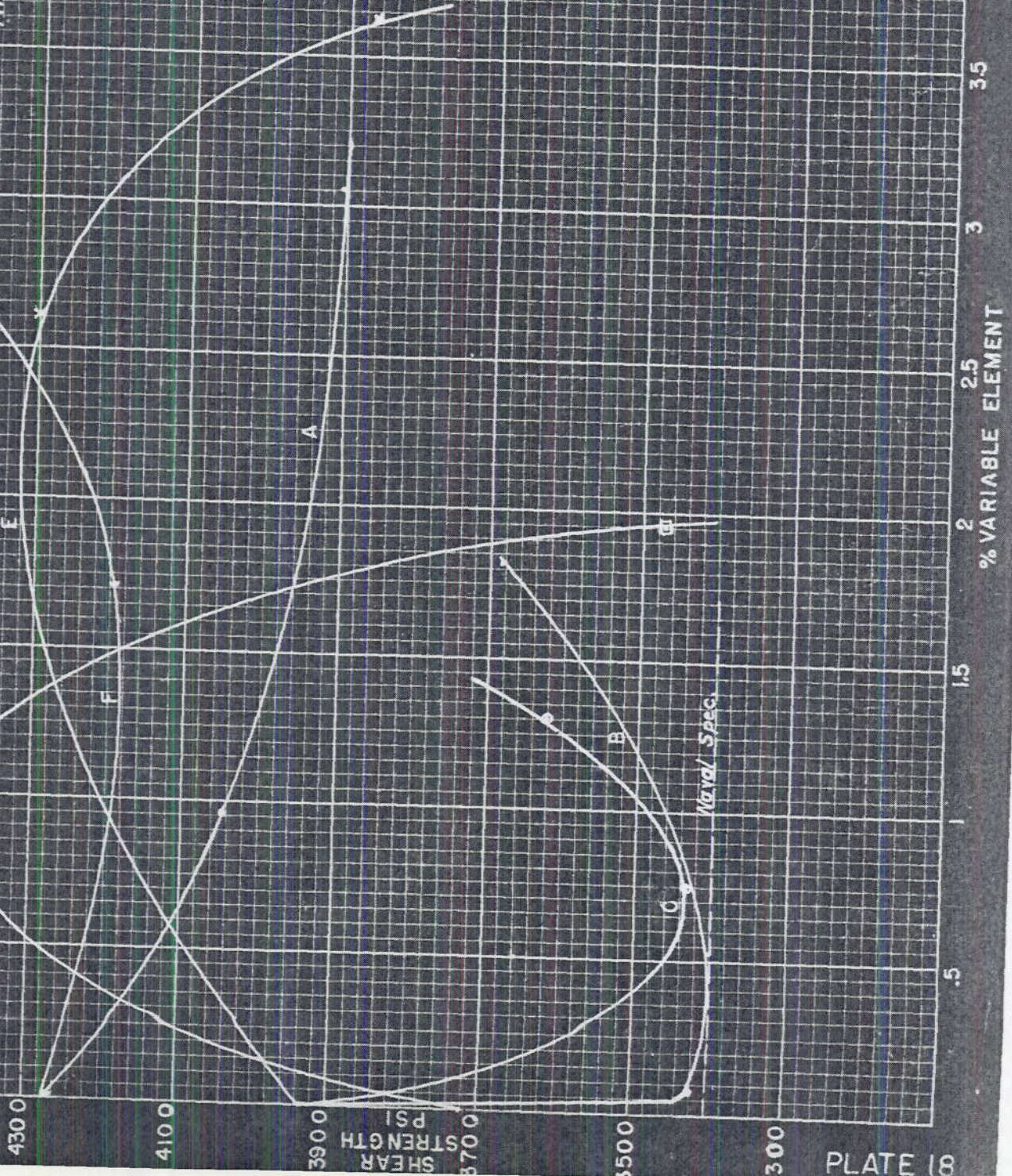
Narrow Spc.

SPREAD OF DROP IN°

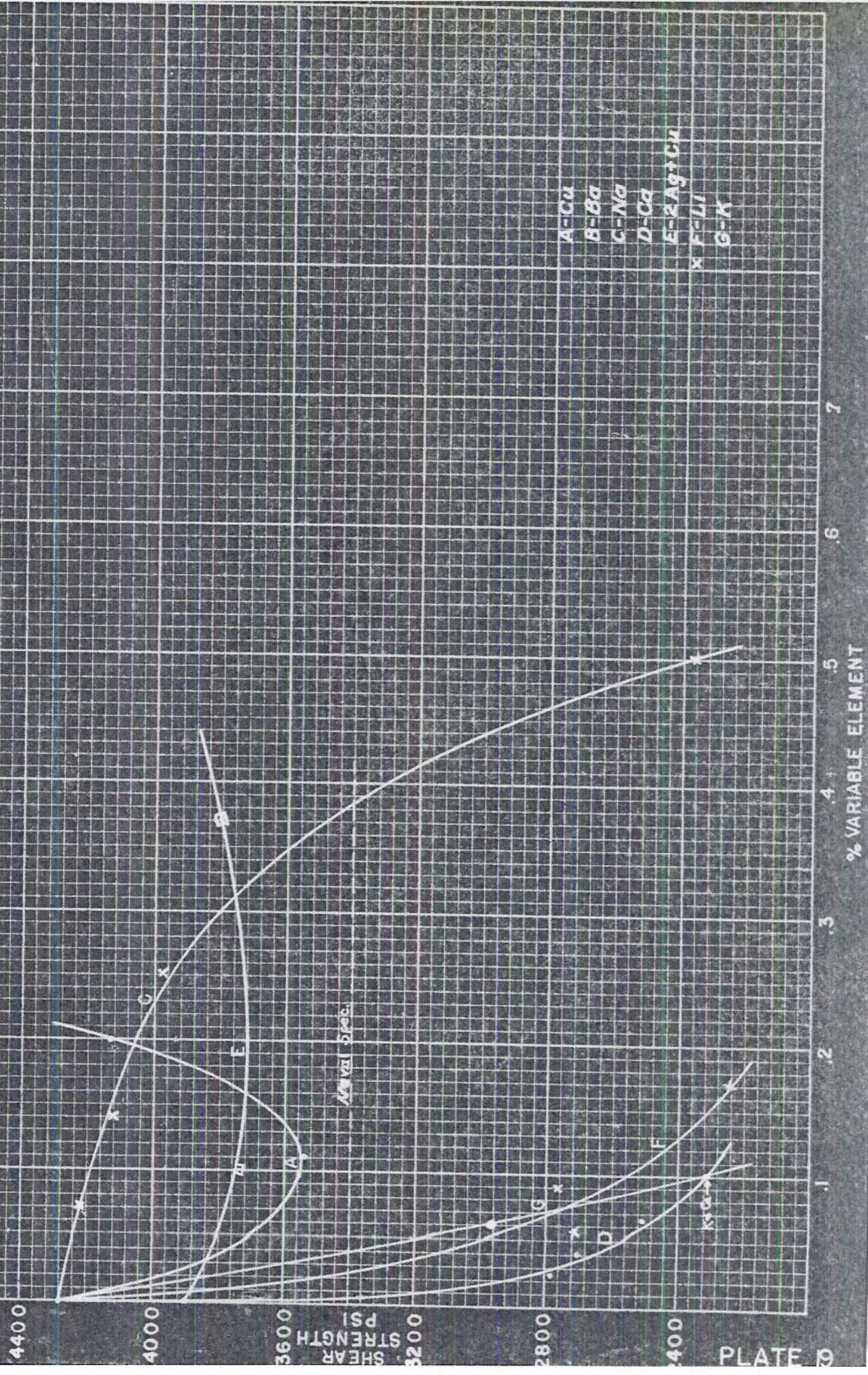
% VARIABLE ELEMENT

EFFECT OF ELEMENT ADDITIONS ON THE JOINT SHEAR STRENGTH OF THE BASIC 15% SN-BAL. PB ALLOY

- A-Ag
- B-Tl
- C-2Ag+1In
- D-2Ag+22Cu+1In
- E-2Ag+5Sb
- F-Sb



EFFECT OF ELEMENT ADDITIONS ON THE JOINT SHEAR STRENGTH OF THE BASIC 5% SN-BAL PB ALLOY



EFFECT OF TEMPERATURE ABOVE
THE LIQUIDUS ON WETTABILITY
OF SOLDERS



- A- 40 Sn, 60 Pb
- B- 13.2 Sn, 50.8 Ag, Bal. Pb
- C- 14.2 Sn, 0.20 Cu, " "
- D- 14.2 Sn, 0.52 Ti, " "
- E- 14.7 Sn, 7.89 Sb, 3.83 Ti, Bal. Pb
- F- 4.58 Sn, 10.25 Sb, 0.07 Cu, Bal. Pb
- G- 15.0 Sn, 9.79 Sb, " "
- H- 15.0 Sn, 14.05 Sb, " "

