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Progress Report

on

# The Causes for Porosity and Leakage in Non-Ferrous Castings (The Effects of Nickel, Zinc and Lead on the Mechanical Properties of Nickel-Tin Bronze Containing Five Percent Tin)

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

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Prepared by: Ralph L. Fox, Ensign, USNR
Ralph H. Brouk, Associate Metallurgist
Blake M. Loring, Metallurgist

Reviewed by: F. M. Walters, Jr., Superintendent
Division of Physical Metallurgy

Approved by: A. H. VAN KEUREN, Rear Admiral, USN
Director

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TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

## ABSTRACT

Three nickel-tin bronzes containing five percent tin and varying percentages of nickel, zinc and lead were found to compare favorably with composition G in pressure tightness and fluidity. Two of the bronzes easily passed the mechanical requirements for composition G (46M6G) provided that contamination by lead was held within limiting percentages. The third alloy did not possess satisfactory mechanical properties unless special care was taken in foundry practice.

## INTRODUCTION

### AUTHORIZATION

1. The development of a nickel-tin bronze having the mechanical properties and corrosion resistance of composition G was requested in Bureau of Ships letter QP/Castings (334) dated 16 December 1943. The base project to which this problem was assigned was authorized under Bureau of Ships P. O. BP/6R entitled "Non-Ferrous Casting Research" dated 22 June 1943.

### STATEMENT OF PROBLEM

2. The desirable characteristics of bronze include not only good mechanical properties and corrosion resistance, but also pressure tightness, high fluidity and a wide pouring range. The primary concern often may be the pressure tightness, which has given considerable trouble in the standard composition G and M bronzes. If other properties were nearly the same as those of G and M and the pressure tightness much superior, there would be considerable advantage in the use of a nickel-tin bronze.

3. Previous work has shown that nickel improves the pressure tightness of G bronze when it is substituted for part of the tin (1.). It has been demonstrated further that the nickel-tin bronze must contain about six percent tin in order to have good resistance to corrosion in moving, brackish Severn River water. The aim of the present investigation was to find the optimum percentages of nickel, and also zinc, in a bronze containing five percent tin. The influences of pouring temperature and lead contamination were investigated for each composition.

### THE EFFECTS CLAIMED FOR VARIOUS ELEMENTS IN BRONZE

(a) Nickel

4. Nickel is generally believed to promote grain refinement, increased tensile strength, and greater hardness when replacing several percent of copper in gun metal (88-10-2) (Cu, Sn, Zn). (2.) The effect of nickel apparently depends on the composition of the bronze as well as the percentage of nickel. Pilling and Kihlgren found 0.5 percent nickel to give optimum properties in (88-8-4) and 2 percent nickel in (88.5-11.5) (Cu, Sn). (3.) (10.) Both bronzes were at maximum tensile strength and ductility at the respective percentages. The 0.5 per cent nickel in the (88-8-4) increased the tensile strength by 15 percent and the elongation by 50 percent. The benefits derived from nickel were not so important in the bronze containing 11.5 percent tin.

5. Nickel also has a favorable influence on mechanical properties if it is substituted for a portion of the tin in bronzes. There is a decrease in intercrystalline shrinkage and an improvement

in pressure tightness (2.). In 88-10-2 gun metal, one half of the tin has been replaced by nickel in the alloy 88-5-5-2. Several investigators (4.)(5.)(6)(12.)(13.) claim that this alloy is slightly better than gun metal in its mechanical properties. At least there is an economic advantage in the use of nickel instead of tin.

(b) Zinc

6. Most commercial bronzes are not pure copper-tin alloys but contain small percentages of zinc. According to Dews (7.) zinc and tin produce similar changes in the microstructure of bronze. The effect of the zinc is approximately half that of tin and an alloy containing eight percent tin and four percent zinc would have the microstructure of a ten percent tin bronze. The proportion of alpha plus delta eutectoid in both bronzes should be the same. The limitations on the percentages of zinc and tin for which the relationship is valid have not been determined.

7. In addition to being a hardening element in bronze, zinc is also a deoxidizer. It is not sufficiently strong in this respect and other deoxidizers must be used at the same time. The fluidity of tin-bronze is increased by the zinc partly as a result of deoxidation.

(c) Lead

8. Lead is practically insoluble in copper base alloys and lowers the mechanical properties of the alloy because of its own low strength. Since lead has a beneficial effect on the machineability and pressure tightness of bronzes, the somewhat lower mechanical properties given by one to two percent can be tolerated in M bronze and five percent in hydraulic bronze. The lead does not solidify until a temperature of 327°C is reached and hence is often associated with the alpha and delta eutectoid as rounded particles of mechanically held lead. With less than seven percent of lead there is little danger of serious segregation. (2.)

(d) The Effect of Nickel on the Constitution of Copper-Tin Alloys

9. The effect of nickel on the constitution of copper-tin alloys is best understood by means of the equilibrium diagram sections. Four of these sections for 0, 2, 5, and 10 percent nickel appear in Plate 6. (8.)(11.) The presence of 2 percent nickel causes a marked narrowing of the alpha field and the appearance of a new phase known as theta. Higher percentages of nickel further decrease the alpha field and increase the theta phase. Although the alloys containing theta are age hardening (9.), they are often used as casting alloys with no heat treatment.

<u>ORIGINAL WORK DONE AT THE NAVAL RESEARCH LABORATORY</u>

10. Fluidity spirals, tensile test coupons and pressure bushings of some nickel-tin bronze alloys were cast at several pouring temperatures. The tensile strength, yield strength, percent

elongation in two inches, pressure tightness and fluidity were determined for comparison with G bronze.

11. The three base compositions of nickel-tin bronze selected for investigation had the following percentages:

| Cu | Sn | Ni | Zn |
|---|---|---|---|
| 88 | 5 | 5 | 2 |
| 88 | 5 | 3 | 4 |
| 88 | 5 | 2 | 5 |

It will be noted that the sum of percent nickel and percent zinc is equal to seven. To each of the bronzes, lead was added from 0 to 2 per cent. The percent of zinc in the three percent nickel bronze was varied from 0 to 6 percent in increments of 2 percent to determine its effect as an alloying element.

EXPERIMENTAL PROCEDURE

12. The charges were melted under a light cover of charcoal in a 210 pound lift coil, high frequency induction furnace in clay graphite crucibles. Electrolytic copper, Straits tin, Horsehead zinc, copper-nickel master alloy and selected Naval Research Laboratory scrap of known composition were used for all heats. The copper was melted first and deoxidized with $2\frac{1}{2}$ ounces of phosphor-copper (10 percent phosphorus) per hundred pounds of melt. Half of the zinc followed by the tin was then charged. When the tin had gone into solution, the remainder of the zinc with 10 percent additional for melting losses was stirred into the bath. For final deoxidation $2\frac{1}{2}$ ounces of phosphor-copper was introduced about 3 minutes before pouring. When lead was charged, the addition was made just prior to the final deoxidation.

13. The heats were removed from the furnace at 1300 to 1340°C and cast at the required temperatures. This temperature range was never exceeded during the melting. At every casting temperature, type 10A tensile test coupon, a Naval Research Laboratory fluidity spiral (Plate 4) and a bushing (Plate 5) for pressure testing were poured into green sand molds. Three corrosion plates $8\frac{1}{2}$" x 2" x $\frac{1}{2}$" were also cast from each alloy (Plate 5). The sand was Albany 00 sand, having A.F.A. permeability of 22, green compressive strength of 4 to 6 psi and a moisture content of 6 to 8 percent. The molds were permitted to air dry for 4 hours before casting.

14. The tensile specimens were 0.505" in diameter with 2" gage length. The yield strength was taken by the 0.5 percent offset method. The bushings for the pressure tests were $4\frac{1}{4}$" long, 2" in inside diameter and 2 3/4" in outside diameter. The bushings were tested first in the as cast condition, then with the inside and finally with the outside surface machined. The final wall thickness was 11/32".

## DISCUSSION OF RESULTS

(a) The Combined Effects of Nickel, Zinc and Lead on the Mechanical Properties

15. In this discussion the following identification has been adopted:

5-5-2 = 5% tin; 5% nickel; 2% zinc; 88% copper
5-3-4 = 5% tin, 3% nickel; 4% zinc; 88% copper
5-2-5 = 5% tin, 2% nickel, 5% zinc, 88% copper

16. The effects of the various percentages of nickel and zinc in a bronze containing 5 percent tin are shown in Plate I. The open triangles represent the lead-free alloys.

17. The lead free alloys have a range of tensile strength of about 9000 psi, the range lying just above the minimum tensile strength (40,000 psi) for G bronze. The lowest tensile strength, 40,300 psi was that of the 5-2-5 alloy poured at 1250°C and the highest, close to 50,000 psi, a 5-5-2 bronze poured at 1150°C. The elongation of both bronzes was about 40 percent. However, it is possible for a G bronze produced with good melting practice to have a tensile strength of more than 50,000 psi and elongation better than 50 percent. The mechanical properties of the nickel-tin bronzes therefore, fall in the same range of properties as G bronze. The 5-2-5 bronze is not far from the bottom of the range with an average of 41,500 psi tensile strength. The 5-3-4 bronze is nearer the middle of the range and averages 43,500 psi in tensile strength. The 5-2-5 alloy, even when free of lead, is too close to the minimum specifications of G bronze to be considered. The 5-5-2 and 5-3-4 alloys which differ by only about 3000 psi in tensile strength have a sufficient margin in mechanical properties so that impurities or poor melting practices would be less likely to cause serious impairment.

(b) The Effects of Lead and Pouring Temperature

18. Plate 2 is based on the same data as Plate 1 with the intention of showing more clearly the influence of lead. Referring to both plates, lead and high pouring temperature will be observed to have similar effects in lowering the mechanical properties. Several 5-2-5 alloys containing 1 to 2 percent lead when poured at 1250°C fell below 40,000 psi in tensile strength, the lower limit for G bronze. The 5-3-4 alloy showed the least sensitivity to lead contamination and pouring temperature. It may contain 1.8 percent lead and be cast from 1100° to 1300°C with only plus or minus 2000 psi variation in tensile strength. The elongation under the same conditions varies from 30 to 50 percent. Compared to the 5-3-4 alloy, the 5-5-2 has the same trend in mechanical properties due to pouring temperature. The 5-5-2, however, is somewhat more affected by lead contamination as shown by the fact that 1.9 percent lead lowered the tensile strength by 4000 psi. It is believed that the 5-5-2 bronze should not have more than 0.5 percent lead if the best mechanical properties are to be

obtained, whereas the 5-3-4 bronze is not damaged seriously by almost 2 percent. The latter composition has the percentage of lead and tin of an M bronze and the mechanical properties of composition G.

19. Several heats of bronzes with 0.2 to 0.4 percent lead had slightly better tensile strength than the corresponding lead free alloys. The variations normally encountered in cast metals could easily account for a spread of plus or minus 1000 psi in the mechanical properties. The trend of the 5-5-2 and 5-3-4 alloys to slightly lower properties at higher pouring temperatures is of the same order as the average trend in G bronze. The harmful effect of high pouring temperatures may be somewhat worse for the 5-2-5 alloy.

(c) The Effect of Zinc on the 5 Percent Tin, 3 Percent Nickel Alloy

20. In Plate 3 the increase of zinc from 0 to 6 percent is shown to increase both tensile strength and elongation while the yield strength is practically unaffected. The tensile strength increases from 40,000 to 44,000 psi and the elongation from 32 to 42 percent. This would indicate that zinc has both deoxidizing and strengthening effects. In the alloy without the zinc addition, two heats fell below the minimum specifications of 40,000 psi. Within the pouring range of 1310° to 1160°C, the variation of tensile strength is about 4000 psi.

(d) Pressure Tightness

21. The test for pressure tightness indicated that all of the nickel bronze alloys would withstand pressure of at least 750 pounds provided that the pouring temperature was not too low and the metal sufficiently deoxidized before casting. The test apparently was not sufficiently sensitive to distinguish important differences in pressure tightness in the three compositions of nickel bronze alloys. These alloys, however, were much superior to G bronze cast under similar conditions.

22. Previous pressure tests of Composition G indicated that leakage would occur at pressures less than 750 lbs. particularly when the bushings were poured at temperatures in excess of 1150°C. Rejections were often more than 75 percent on bushings of these dimensions. The type of leakage was in most cases classified as sweating.

(e) Deoxidation Practice

23. For superior mechanical properties, good deoxidation practice was necessary in these alloys. Partial deoxidation by the addition of zinc was followed by the introduction of phosphorus as phosphor-copper. If, however, a crust of oxides formed on the surface after skimming, more phosphor-copper was added until these oxides were reduced.

24. A slight excess of phosphorus is desirable for its effect on fluidity. The amount of phosphor-copper will vary depending on the type of charge and the melting conditions. The residual phosphorus in the alloy was from 0.005 to 0.01 percent. Too much phosphorus in heats poured at high temperatures caused penetration of the molding sand.

CONCLUSIONS

25. The nickel-tin bronzes show pressure tightness superior to composition G.

26. The nickel bronze containing 5 percent nickel, 5 percent tin and 2 percent zinc has the most favorable mechanical properties provided it contains not more than 0.5 percent lead. The best range of pouring temperature is 1200°C to 1300°C.

27. The 3 percent nickel, 5 percent tin and 4 percent zinc alloy has slightly lower tensile strength than the 5 percent nickel bronze. It may contain up to 1.8 percent lead without excessive loss in mechanical properties, and may be poured over a wide range of temperature (1150°C - 1300°C). This alloy could be made from scrap metals.

28. The nickel bronze with 2 percent nickel, 5 percent tin, and 5 percent zinc does not have sufficiently high mechanical properties to be of special interest.

29. Before the final evaluation of the 3 percent nickel bronze can be made, the results of the corrosion tests in moving seawater at Wilmington, North Carolina will have to be considered. (These tests are now in progress)

RECOMMENDATIONS FOR FUTURE WORK

30. The effect of impurities on the corrosion resistance, pressure tightness and mechanical properties of nickel bronze should be investigated.

31. The five percent nickel bronze should be compared to the three percent nickel bronze under typical foundry conditions in a Navy Yard.

REFERENCES


1. Naval Research Laboratory Report to the Navy Department M-2013 dated 20 February 1943.

2. Non-Ferrous Foundry Practice. J. Laing and R. T. Rolfe.

3. Some Effects of Nickel on Bronze Foundry Mixtures. N. B. Pilling and T. E. Kihlgren. Trans. A.F.A., Page 93 (1931).

4. AIME Transactions. G. K. Burgess and R. W. Woodward. Vol. 60, Page 179 (1919).

5. AIME Tech. Publ No. 523 (1934). E. M. Wise and J. T. Eash.

6. Metallurgia. F. Hudson. Vol. 17, Page 13 (1937).

7. Metallurgy of Bronze. H. C. Dews. (London) (1932)

8. The Copper Rich Alloys of the Copper-Nickel-Tin System. J. T. Eash and C. Upthegrove. AIME Transactions(1933).

9. Strength and Aging Characteristics of the Nickel Bronzes. E. M. Wise and J. T. Eash. AIME Tech. Pub. No. 523, February (1934).

10. Casting Properties of Nickel Bronzes. N. B. Pilling and T. E. Kihlgren. Trans. American Foundryman's Association (1932).

11. American Society for Metals Handbook (1939).

12. The Improvement of Bronze with Nickel. International Nickel Company, Bulletin No. 303.

13. A General Utility Non-Ferrous Casting Alloy. A. Dunlop. Foundry Trade Journal. Page 397. 30 May 1940.

14. Production and Properties of Age Hardenable 5% Nickel Bronze Castings. T. E. Kihlgren. Trans. A.F.A. (1938) Page 41.

TABLE 1 CHEMICAL COMPOSITION AND PROPERTIES

| Heat No. | Composition* Sn | Ni | Zn | Pb | P | Pouring Temp. °C. | Y.S. psi | T.S. psi | % El. 2" | ** | Fluidity Inches |
|---|---|---|---|---|---|---|---|---|---|---|---|
| G43 | 4.53 | 5.08 | 1.59 | | 0.001 | 1290 | 23100 | 47100 | 43.5 | a | 24 |
| | | | | | | | 23400 | 47400 | 37.5 | | |
| | | | | | | 1240 | 23200 | 47100 | 50.0 | | 18 |
| | | | | | | | 23100 | 46500 | 44.5 | | |
| | | | | | | 1190 | 23900 | 50600 | 49.5 | b | 10 |
| | | | | | | | 23400 | 47300 | 50.0 | | |
| | | | | | | 1140 | 23800 | 48800 | 34.0 | c x | 4 |
| | | | | | | | 23800 | 47900 | 31.5 | c | |
| G43 | 4.72 | 5.02 | 1.70 | | 0.001 | 1310 | 23100 | 47100 | 43.5 | | 27 |
| | | | | | | | 23400 | 47400 | 38.5 | | |
| | | | | | | 1260 | 23200 | 47200 | 43.5 | c | |
| | | | | | | | 23100 | 47100 | 38.5 | c | 20 |
| | | | | | | 1210 | 23200 | 47500 | 50.0 | | |
| | | | | | | | 23100 | 48100 | 41.5 | | 14 |
| | | | | | | 1160 | 23700 | 50200 | 42.5 | w | |
| | | | | | | | 23700 | 50800 | 48.5 | w | 10 |
| G37 | 4.85 | 4.50 | 1.99 | 0.23 | 0.006 | 1310 | 20000 | 46500 | 37.5 | | 30 |
| | | | | | | | 19600 | 45200 | 36.0 | | |
| | | | | | | 1260 | 19400 | 46500 | 40.5 | | 20 |
| | | | | | | | 20000 | 47100 | 45.5 | | |
| | | | | | | 1210 | 20400 | 47800 | 42.0 | | 12 |
| | | | | | | | 20100 | 49100 | 40.5 | | |
| | | | | | | 1160 | 20800 | 44900 | | | 7 |
| | | | | | | | 21400 | 48800 | 31.0 | y | |
| G36 | 4.74 | 5.46 | 2.14 | 0.36 | 0.007 | 1310 | 20100 | 47880 | 36.0 | | |
| | | | | | | | 19800 | 47600 | 37.0 | | 35 |
| | | | | | | 1260 | 20400 | 47700 | 35.0 | | |
| | | | | | | | 20500 | 48400 | 36.0 | | 30 |
| | | | | | | 1210 | 20300 | 46000 | 28.5 | a | |
| | | | | | | | 20300 | 44600 | 26.0 | c | 21 |
| | | | | | | 1160 | 20800 | 48100 | 34.0 | | |
| | | | | | | | 20800 | 47000 | 28.0 | | 14 |
| G41 | 4.71 | 4.68 | 1.43 | 0.87 | 0.013 | 1310 | 20200 | 43600 | 26.5 | | 37 |
| | | | | | | | 20170 | 44300 | 23.0 | | |
| | | | | | | 1260 | 21600 | 47100 | 28.0 | | 28 |
| | | | | | | | 21400 | 47800 | 31.5 | | |
| | | | | | | 1204 | 21900 | 46800 | 24.5 | | 15 |
| | | | | | | | 21100 | 47300 | 27.0 | d | |
| | | | | | | 1150 | 21200 | 47900 | 22.0 | d | 8 |
| | | | | | | | 22100 | 48500 | 29.0 | | |
| G42 | 4.85 | 5.00 | 1.76 | 1.90 | 0.001 | 1310 | 20600 | 44600 | 27.5 | | 38 |
| | | | | | | | 20600 | 44200 | 26.0 | c | |
| | | | | | | 1260 | 21100 | 43700 | 22.5 | | 30 |
| | | | | | | | 20700 | 43900 | 22.5 | | |
| | | | | | | 1210 | 20800 | 44000 | 21.5 | | 22 |
| | | | | | | | 20700 | 45700 | 23.5 | | |
| | | | | | | 1160 | 21000 | 42900 | 19.0 | d | 14 |
| | | | | | | | 21200 | 43800 | 17.5 | d | |

TABLE 2 - MECHANICAL PROPERTIES OF A MODIFIED TIN BRONZE CONTAINING 3% NICKEL AND SMALL AMOUNTS OF LEAD

| Heat No. | Composition* | | | | | Pouring Temp. °C | Y.S. psi | T.S. psi | 2 In. % El | | Fluidity Inches |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sn | Ni | Zn | Pb | P | | | | | | |
| G24 | 5.06 | 2.98 | 3.88 | | 0.014 | 1310 | 17900 | 43400 | 42.9 | a | 39 |
| | | | | | | | 18000 | 41800 | 37.5 | | |
| | | | | | | 1260 | 17800 | 42300 | 45.3 | | 30 |
| | | | | | | | 17900 | 43100 | 46.9 | | |
| | | | | | | 1210 | 18500 | 44600 | 54.7 | | 25 |
| | | | | | | | 17700 | 43600 | 50.0 | | |
| | | | | | | 1160 | 18700 | 46300 | 53.9 | z | 14 |
| | | | | | | | 18000 | 44600 | 50.0 | | |
| G16 | 4.57 | 2.95 | 3.76 | 0.25 | 0.007 | 1260 | 16800 | 43800 | 50.4 | | 33 |
| | | | | | | | 18400 | 43900 | 50.7 | | |
| | | | | | | 1210 | 18200 | 43900 | 53.1 | | 24 |
| | | | | | | | 19500 | 44100 | 52.0 | | |
| | | | | | | 1160 | 16100 | 44500 | 45.7 | | 16 |
| | | | | | | | 21000 | 43300 | 37.0 | | |
| | | | | | | 1110 | 18800 | 45200 | 39.0 | | 9 |
| | | | | | | | 19500 | 45500 | 38.5 | | |
| G17 | 4.74 | 2.99 | 3.53 | 0.58 | 0.005 | 1310 | 17000 | 42300 | 37.0 | | 40 |
| | | | | | | | 18200 | 42300 | 25.0 | | |
| | | | | | | 1260 | 17800 | 42900 | 48.0 | | 32 |
| | | | | | | | 18300 | 43200 | 55.0 | | |
| | | | | | | 1210 | 16800 | 43500 | 53.5 | | 24 |
| | | | | | | | 18200 | 43500 | 51.0 | | |
| | | | | | | 1160 | 18000 | 45100 | 42.0 | c | 18 |
| | | | | | | | 18200 | 45300 | 44.0 | | |
| G18 | 4.66 | 2.96 | 3.51 | 1.08 | 0.008 | 1310 | 17700 | 42200 | 38.0 | | 37 |
| | | | | | | | 17900 | 40400 | 30.0 | | |
| | | | | | | 1260 | 19000 | 42800 | 42.0 | | 29 |
| | | | | | | | 19400 | 43400 | 45.5 | | |
| | | | | | | 1210 | 19600 | 43400 | 43.5 | | 20 |
| | | | | | | | 20300 | 43200 | 39.0 | | |
| | | | | | | 1160 | 20000 | 45100 | 39.5 | | 14 |
| | | | | | | | 20000 | 43500 | 34.5 | | |
| G19 | 4.55 | 2.93 | 4.04 | 1.80 | 0.007 | 1260 | 18300 | 42600 | 50.0 | | 24 |
| | | | | | | | 18600 | 42900 | 53.5 | | |
| | | | | | | 1210 | 18700 | 43100 | 50.0 | | 23 |
| | | | | | | | 18800 | 42500 | 36.5 | | |
| | | | | | | 1160 | 18400 | 44400 | 43.0 | | 18 |
| | | | | | | | | 43800 | 47.5 | | |
| | | | | | | 1110 | | 45200 | 36.0 | | 9 |
| | | | | | | | | 45900 | 42.5 | | |

* Balance copper

TABLE 3 - MECHANICAL PROPERTIES OF A MODIFIED TIN BRONZE CONTAINING 3% NICKEL WITH VARIOUS AMOUNTS OF ZINC

| Heat No. | Composition* | | | | | Pouring Temp. °C | Y.S. psi | T.S. psi | 2 In. % El | Fluidity Inches |
|---|---|---|---|---|---|---|---|---|---|---|
| | Sn | Ni | Zn | Pb | P | | | | | |
| G12 | 4.53 | 2.98 | | | | 1310 | 19700 | 37500 | 37.0 | 34 |
| | | | | | | | 18500 | 38500 | 34.4 | |
| | | | | | | 1260 | 17700 | 37400 | 36.0 | 32 |
| | | | | | | | 19600 | 32500 | 24.0 | |
| | | | | | | 1210 | 19800 | 37600 | 28.4 | 20 |
| | | | | | | | 19900 | 42600 | 37.4 | |
| | | | | | | 1160 | 18800 | 41800 | 29.0 | 8 |
| | | | | | | | 21400 | 43700 | 32.8 | |
| G23 | 5.00 | 2.91 | 1.95 | | | 1310 | 18300 | 40600 | 32.8 | 39 |
| | | | | | | | 17700 | 40200 | 41.4 | |
| | | | | | | 1260 | 17400 | 41900 | 39.1 | 33 |
| | | | | | | | 18300 | 40300 | 35.9 | |
| | | | | | | 1210 | 20000 | 43600 | 40.6 | 24 |
| | | | | | | | 19200 | 44300 | 47.7 | |
| | | | | | | 1160 | 18400 | 44200 | 49.2 | 19 |
| | | | | | | | 18800 | 44600 | 51.6 | |
| G24 | 5.06 | 2.98 | 3.88 | | 0.014 | 1310 | 17900 | 43400 | 42.9 | 39 |
| | | | | | | | 18000 | 41800 | 37.5 | |
| | | | | | | 1260 | 17800 | 42200 | 45.3 | 30 |
| | | | | | | | 17900 | 43100 | 46.9 | |
| | | | | | | 1210 | 18500 | 44600 | 54.7 | 25 |
| | | | | | | | 17700 | 43600 | 50.0 | |
| | | | | | | 1160 | 18700 | 46300 | 53.9 | 14 |
| | | | | | | | 18000 | 44600 | 50.0 | |
| G25 | 5.00 | 2.85 | 6.08 | | 0.018 | 1310 | 19000 | 42300 | | |
| | | | | | | | 18900 | 42200 | 50.0 | |
| | | | | | | 1260 | 19800 | 43700 | 52.0 | 32 |
| | | | | | | | 18400 | 44000 | 51.5 | |
| | | | | | | 1210 | 19700 | 44600 | 51.5 | 25 |
| | | | | | | | 19700 | 44500 | 60.5 | |
| | | | | | | 1160 | 18800 | 45000 | 40.5 | 18 |
| | | | | | | | 18500 | 46200 | 40.5 | |

* Balance copper

TABLE 4 - MECHANICAL PROPERTIES OF A MODIFIED TIN BRONZE CONTAINING 2% NICKEL AND SMALL AMOUNTS OF LEAD

| Heat No. | Composition* | | | | | Pouring Temp. °C | Y.S. psi | T.S. Psi | 2 In. % El | | Fluidity Inches |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sn | Ni | Zn | Pb | P | | | | | | |
| G31 | 4.87 | 2.02 | 4.88 | | 0.003 | 1260 | 15800 | 39900 | 45.0 | | 37 |
| | | | | | | | 16200 | 40600 | 47.0 | | |
| | | | | | | 1210 | 17300 | 42400 | 54.0 | | 29 |
| | | | | | | | 17100 | 41500 | 52.0 | | |
| | | | | | | 1160 | 16600 | 41700 | 53.0 | | 25 |
| | | | | | | | 16800 | 42600 | 58.5 | | |
| | | | | | | 1110 | 17400 | 44400 | 59.0 | | 11 |
| | | | | | | | 17200 | 45200 | 56.5 | | |
| G39 | 4.96 | 2.01 | 4.51 | 0.43 | 0.008 | 1316 | 16400 | 41800 | 45.0 | | 41 |
| | | | | | | | 16900 | 40700 | 39.0 | | |
| | | | | | | 1265 | 17600 | 42900 | 54.0 | | 37 |
| | | | | | | | 17700 | 42600 | 54.0 | | |
| | | | | | | 1214 | 16400 | 43200 | 49.0 | | 29 |
| | | | | | | | 16800 | 42400 | 46.5 | | |
| | | | | | | 1163 | 17400 | 42600 | 39.0 | | 19 |
| | | | | | | | 17100 | 43200 | 50.0 | | |
| G32 | 4.86 | 1.91 | 4.80 | 0.48 | 0.005 | 1260 | 16900 | 40400 | 37.0 | | 36 |
| | | | | | | | 16300 | 41100 | 47.0 | | |
| | | | | | | 1210 | 17400 | 40000 | 36.0 | | 35 |
| | | | | | | | 16000 | 41700 | 52.0 | | |
| | | | | | | 1160 | 17300 | 42100 | 56.5 | | 25 |
| | | | | | | | 17100 | 42400 | 60.5 | | |
| | | | | | | 1110 | 16700 | 42500 | 36.5 | | 14 |
| | | | | | | | 17200 | 41000 | 33.5 | | |
| G29 | 4.96 | 1.94 | 5.11 | 1.01 | 0.003 | 1250 | 17600 | 38400 | 32.0 | | 36 |
| | | | | | | | 16500 | 39900 | 37.0 | | |
| | | | | | | 1210 | 16900 | 41200 | 49.5 | | 34 |
| | | | | | | | 16600 | 38600 | 34.0 | | |
| | | | | | | 1160 | 17700 | 41900 | 46.0 | | 26 |
| | | | | | | | 16900 | 40700 | 38.5 | | |
| | | | | | | 1110 | 17400 | 43800 | 43.5 | | 17 |
| | | | | | | | 17800 | 43100 | 40.5 | | |
| G30 | 4.85 | 1.93 | 4.85 | 1.95 | 0.011 | 1250 | 16300 | 36700 | 27.5 | x | 35 |
| | | | | | | | 15900 | 38600 | 35.0 | | |
| | | | | | | 1210 | 15700 | 40500 | 43.0 | | 30 |
| | | | | | | | 16500 | 39700 | 36.0 | | |
| | | | | | | 1160 | 17300 | 41700 | 49.0 | | 22 |
| | | | | | | | 17300 | 41500 | 50.0 | | |
| | | | | | | 1110 | 17500 | 42600 | 38.0 | | 12 |
| | | | | | | | 17500 | 41600 | 37.5 | | |

* Balance copper

TABLE 5 - MECHANICAL PROPERTIES OF COMPOSITION G

| Spec. No. | Composition* Sn | Zn | P | Pouring Temp. °C | Y.S. psi | T.S. psi | 2 In. % El | Fluidity Inches | Hydraulic Pressure Pounds |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 8.91 | 2.36 | 0.001 | 1200 | 18500 | 44300 | 38.5 | 39 | 700 |
| | | | | | 18900 | 43700 | 37.0 | | |
| | | | | 1210 | 19300 | 37200 | 41.0 | 33 | 500 |
| | | | | | 18600 | 45400 | 41.0 | | |
| | | | | 1170 | 19000 | 48700 | 48.0 | 29 | 750 |
| | | | | | 18900 | 46900 | 44.0 | | |
| | | | | 1110 | 20600 | 48500 | 42.0 | 12 | 600 |
| | | | | | 19600 | 46900 | 39.5 | | |

* Balance copper

## EXPLANATION OF SYMBOLS

a - Surface Cracks

b - Fine Grains

c - Oxide Inclusions

d - Porous Fracture

w - Not tested by pressure because of flaws in casting

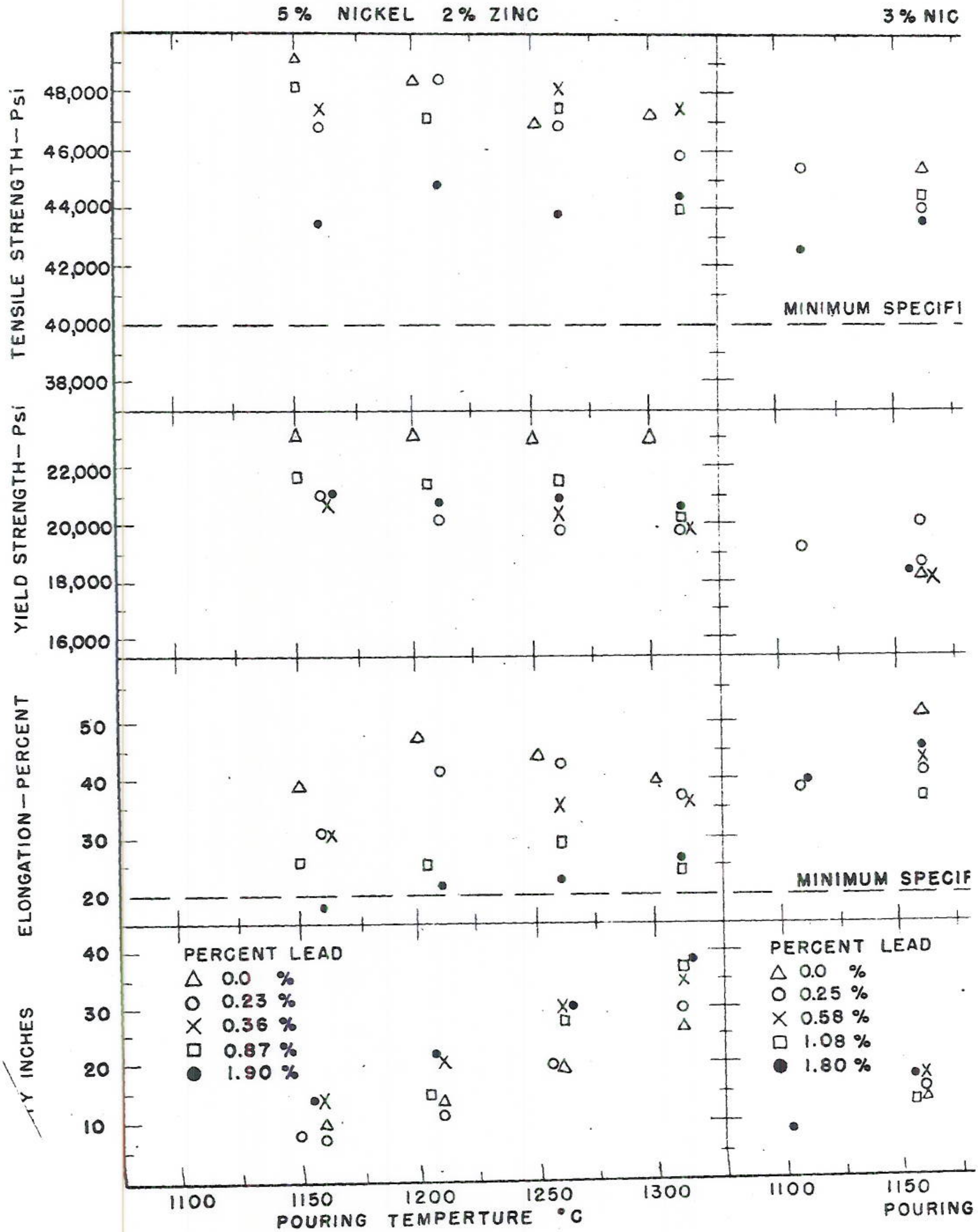
x - Bushing leaked at 400 lbs. when machined

y - Bushing leaked at 200 lbs. when machined

z - Bushing leaked at 350 lbs. when machined

SOME MECHANICAL PROPERTIES OF A MODIFIED TI
NOMINAL COMPOSITION: COPPER 88%,

MECHANICAL PROPERTI



...ONZE WITH VARIOUS AMOUNTS OF NICKEL ZINC & LEAD
5%, BALANCE – NICKEL & ZINC = 7%
VS. POURING TEMPERATURES

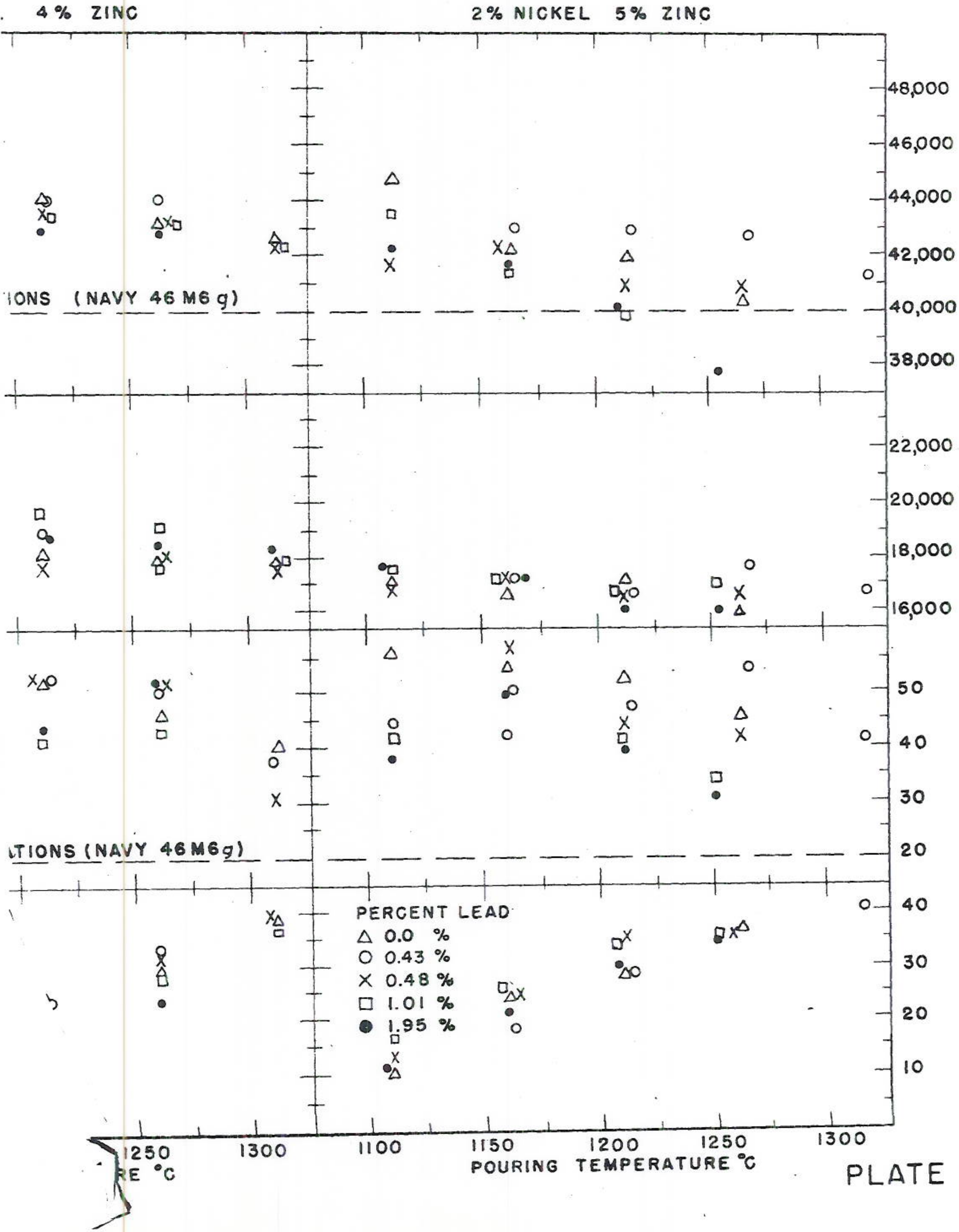


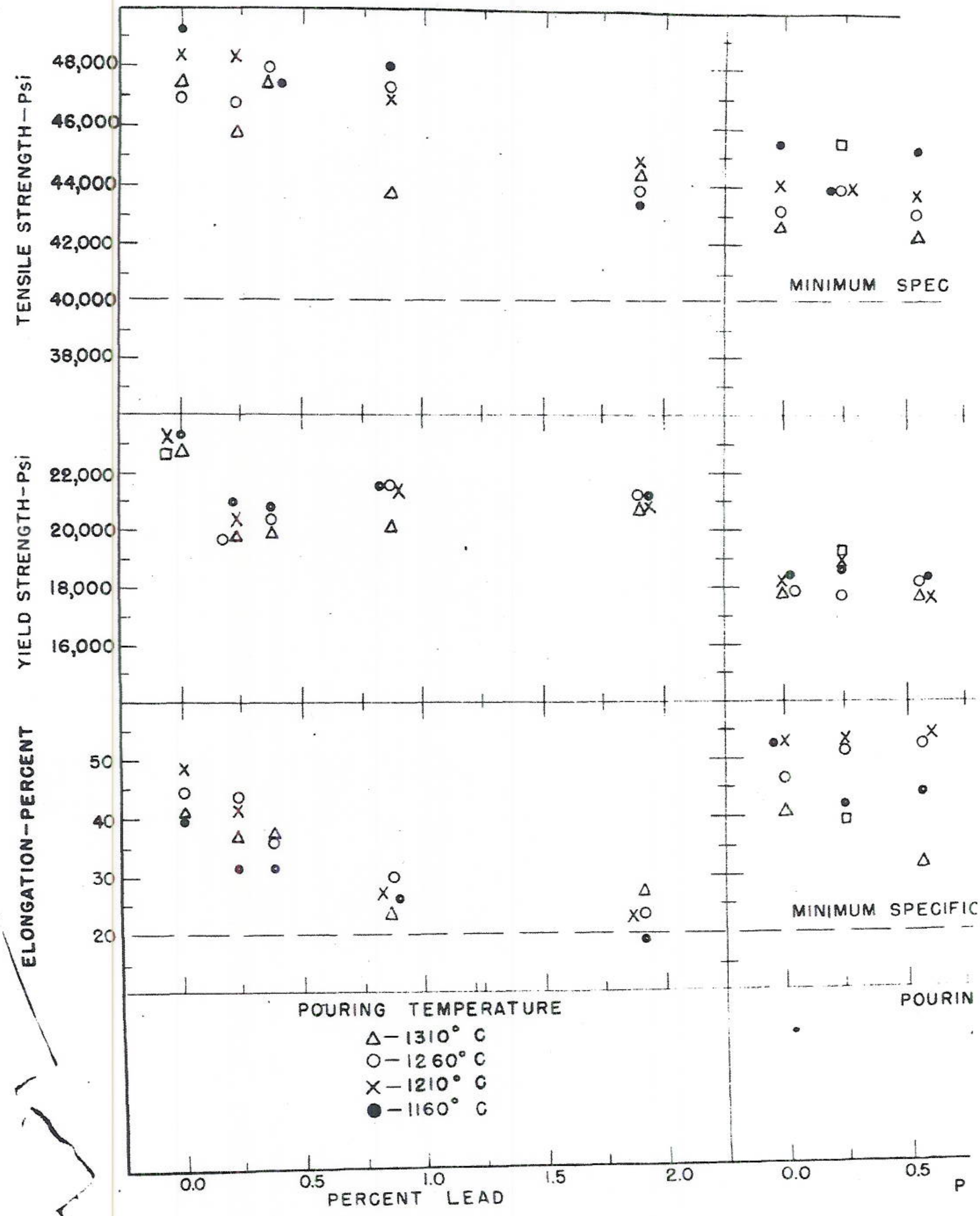

PLATE I

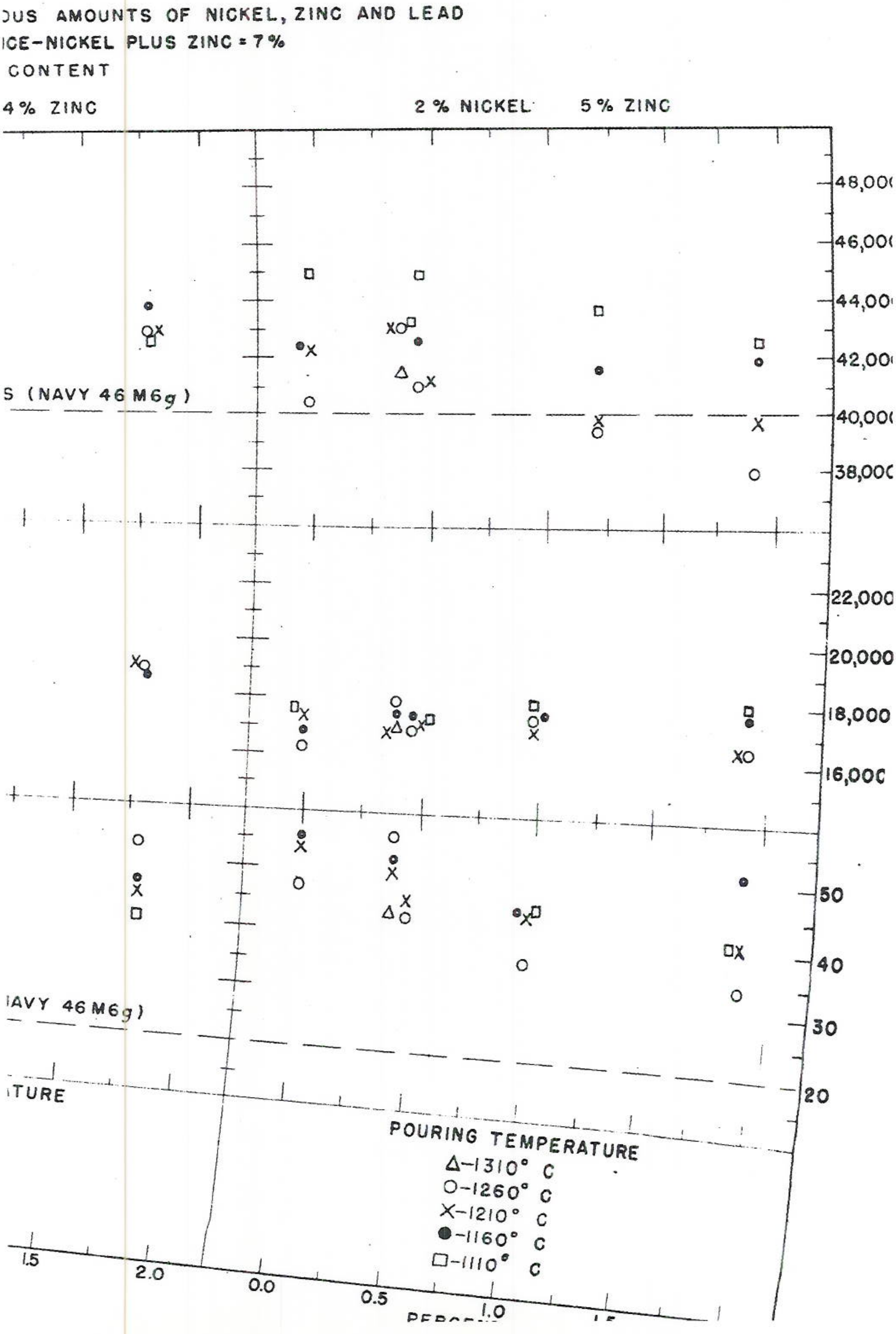
...ECHANICAL PROPERTIES OF MODIFIED TIN-BR

NOMINAL COMPOSITION: COPPER 88

MECHANICAL PROPER

5 % NICKEL 2 % ZINC





OUS AMOUNTS OF NICKEL, ZINC AND LEAD
ICE-NICKEL PLUS ZINC = 7%
CONTENT
4% ZINC
2% NICKEL 5% ZINC
S (NAVY 46 M6g)
48,00
46,00
44,00
42,00
40,00
38,00
22,000
20,000
18,000
16,000
50
40
30
20
AVY 46 M6g)
TURE
POURING TEMPERATURE
Δ-1310° C
O-1260° C
X-1210° C
●-1160° C
□-1110° C
1.5
2.0
0.0
0.5
1.0

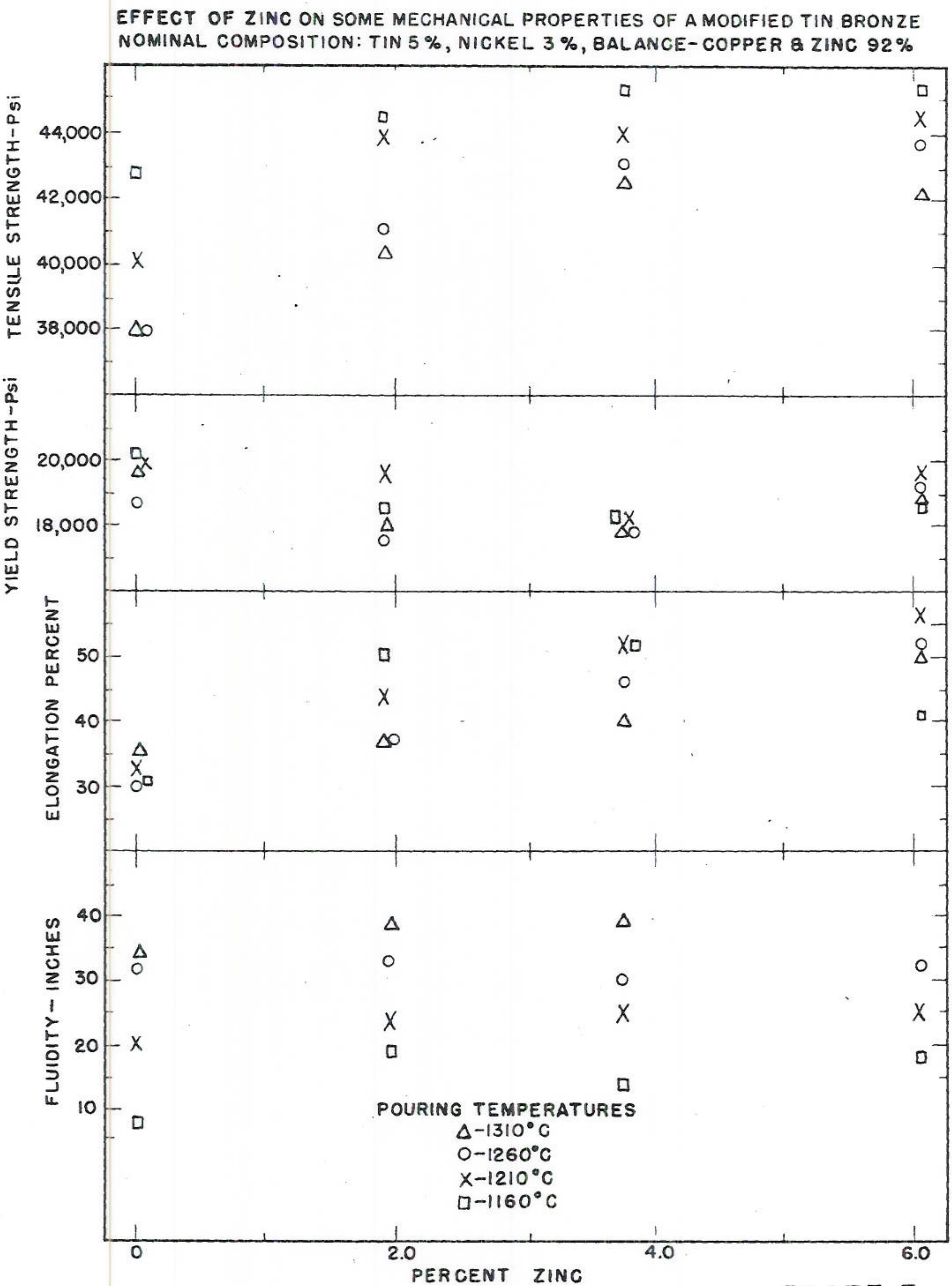

EFFECT OF ZINC ON SOME MECHANICAL PROPERTIES OF A MODIFIED TIN BRONZE
NOMINAL COMPOSITION: TIN 5%, NICKEL 3%, BALANCE-COPPER & ZINC 92%
TENSILE STRENGTH-Psi
44,000
42,000
40,000
38,000
YIELD STRENGTH-Psi
20,000
18,000
ELONGATION PERCENT
50
40
30
FLUIDITY- INCHES
40
30
20
10
POURING TEMPERATURES
Δ-1310°C
O-1260°C
X-1210°C
□-1160°C
0
2.0
4.0
6.0
PERCENT ZINC

PLATE 3

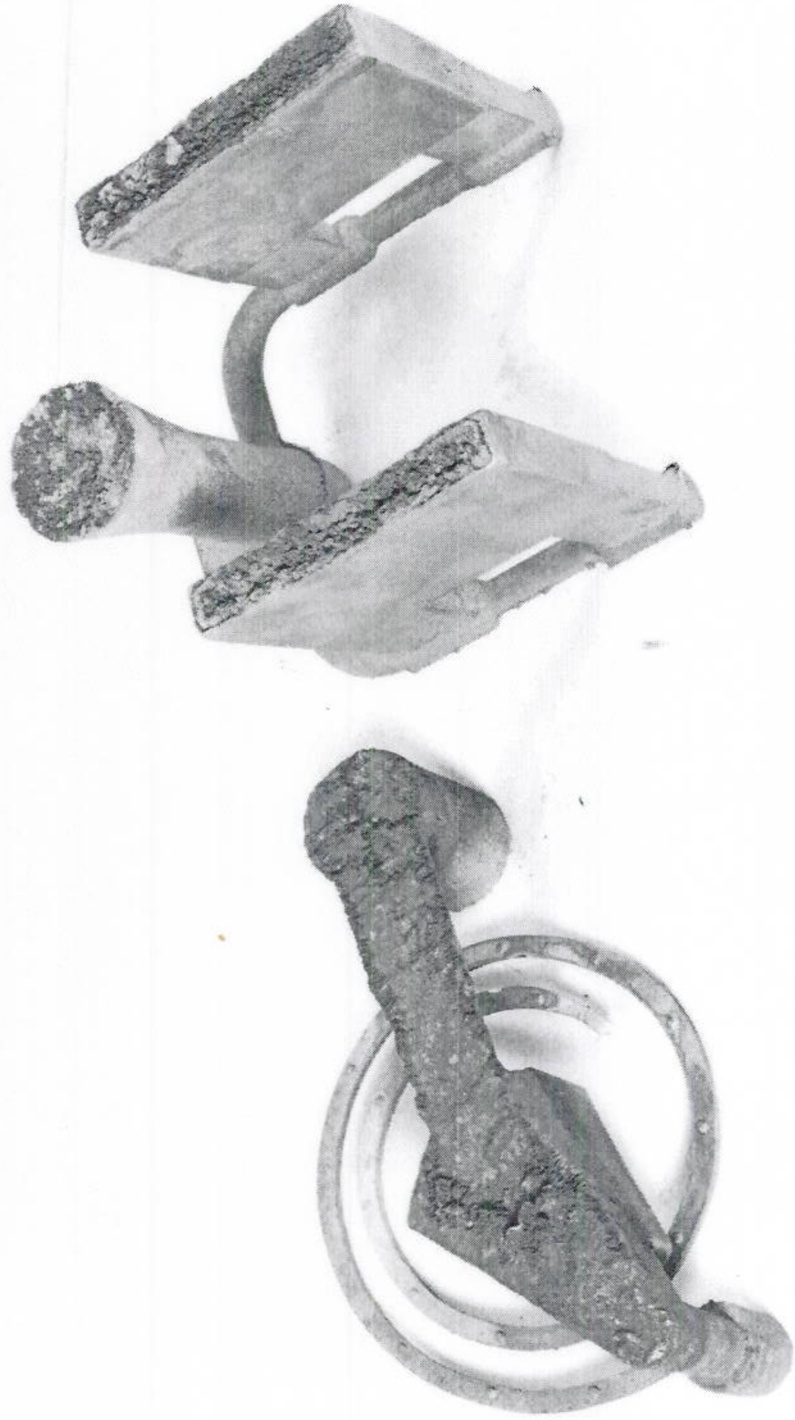


PLATE 4

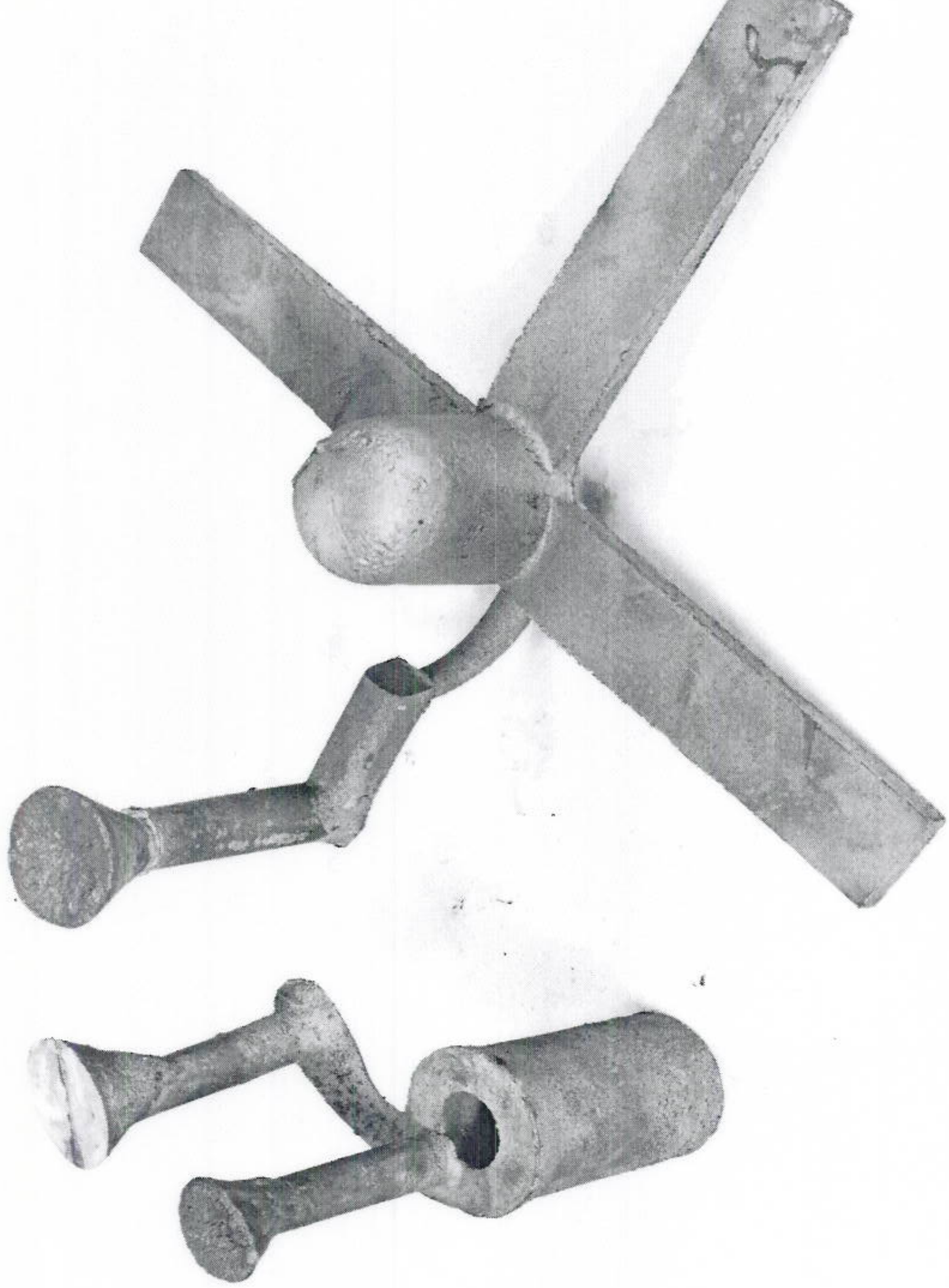


PLATE 5

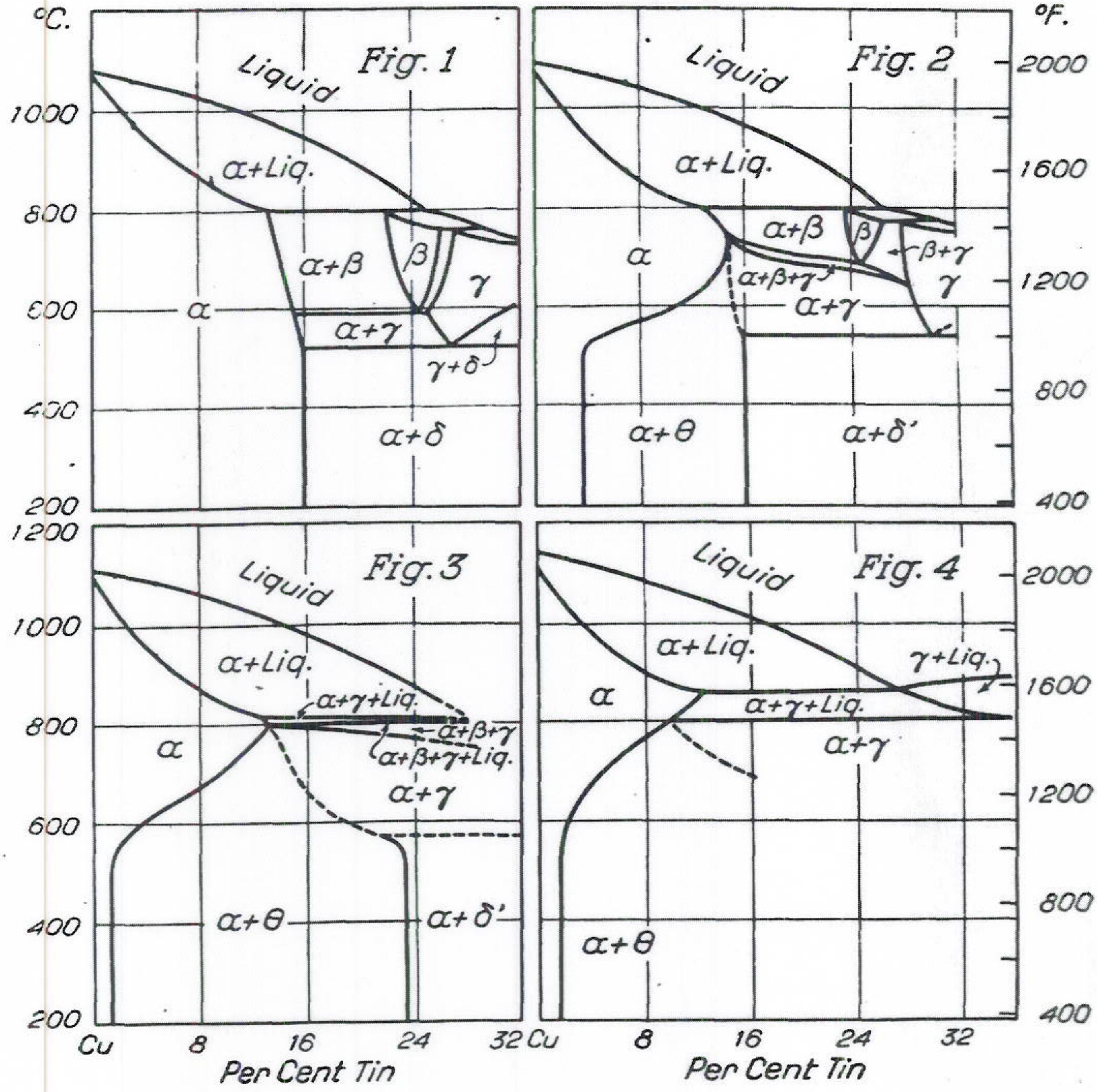



**Fig. 1—The copper-tin constitution diagram. Fig. 2—Constitution diagram for nickel-copper-tin alloy with 2% nickel. Fig. 3—Constitution diagram for nickel-copper-tin alloy with 5% nickel. Fig. 4—Constitution diagram for nickel-copper-tin alloy with 10% nickel.**

PLATE 6