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SOME CAUSES FOR POROSITY AND LEAKAGE IN NON-FERROUS CASTINGS.

BY

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A

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STATEMENT OF PROBLEM

1. Non-ferrous copper base alloys find many applications in industry. Among these alloys one finds the tin bronzes rather widely used for many purposes, and by delving still farther one finds pressure castings as one of their important applications. In many foundries the percentage of rejections due to leakage or porosity is quite high. This is obviously very costly since leakage is generally only found after machining. It is with a view to determine the causes for leakage in pressure castings and to devise methods for its prevention that the work described in this thesis was undertaken. It is not intended to cover the subject completely. Furthermore, the author wishes to direct attention to the fact that the work was conducted primarily to increase the knowledge on the behavior of these alloys under certain controlled conditions and that no attempt was made to adhere to existing specifications other than chemical composition.

2. Porosity in any casting whether ferrous or non-ferrous is undesirable. Its importance depends on the purpose for which the casting is made. For example, castings which are required to withstand steam, hydraulic, or pneumatic pressure must not be porous.

Conversely, a reasonable amount of porosity is not objectionable in structural and other castings which are not used under pressure.

3. This investigation covers non-ferrous pressure castings in which porosity is extremely important. The primary purpose of the study is to establish the reasons for porosity and to devise methods for its prevention. The object of this report is (1) to review the literature on non-ferrous pressure castings and, (2) to present the data, results, and conclusions from work done by the author.

KNOWN FACTS BEARING ON THE PROBLEM (THEORETICAL CONSIDERATIONS)

(a) Introduction

4. There are several non-ferrous alloys commonly used for the manufacture of pressure castings. Two of these alloys seem to be more extensively used that the others, and for the purpose of simplification they shall hereafter be referred to as composition "G" and composition "M". Actually these alloys have many trade names; for example, composition "G" is sometimes called "G" bronze, gun metal, 88-10-2, 88-8-4, etc., and composition "M", leaded tin bronze, steam or valve bronze, commercial 88-10-2, etc. The nominal chemical

composition of composition "G" is 87.25 per cent copper, 9 per cent tin, 3 per cent zinc, and 0.75 per cent nickel. The nominal chemical composition of composition "M" is 88.0 per cent copper, 6.5 per cent tin, 4.0 per cent zinc, 1.5 per cent lead, and 1.0 per cent nickel permissible. These alloys are somewhat similar in chemical composition. Although the lead contained in composition "M" increases machinability, the tensile strength is lowered by the lead in combination with a lower tin content. However, from the standpoint of cost of materials composition "M" is less expensive.

5. An extensive search of the literature failed to reveal any substantiating evidence in regard to which of the two alloys is better for pressure castings. One point of view is that the lead in composition "M" tends to fill the cavities formed during the process of solidification which results in a less porous casting. Although this report covers only composition "G", some investigations are in progress in which an attempt is being made to determine which of the two alloys is preferable for pressure casting purposes.

6. The lack of pressure tightness may arise from a number of causes, such as cracks, cold shuts, blowholes, and sand inclusions. All of these faults

can be avoided by proper foundry technique. However, gas pockets and minute intercrystalline cavities or channels are more difficult to eliminate.

(b) Gas Porosity

7. The possible sources of gas porosity are: (1) absorbed gases may be present in the raw materials or absorption may take place during the melting process; (2) insoluble mold gases may be trapped in the metal during casting; and (3) metallic oxides present in the molten metal when cast may be reduced to form carbon monoxide and carbon dioxide which are trapped during solidification.

8. The solubility of some gases in molten bronze increases with temperature, and during solidification the solubility decreases. Thus it is possible for any precipitated gas to become trapped internally to form gas cavities. Investigations have been made on the effect on porosity of various gases which might be carried in with the raw materials or absorbed during the melting process. Daniels (6) stated that carbon dioxide, nitrogen, and carbon monoxide have no effect on composition "G" and that hydrogen causes unsoundness. Jenkins (18) in his review of the literature on composition "G" suggested that sulphur dioxide, carbon dioxide, and carbon

monoxide are the occluded furnace and melting gases which form cavities. Bolton and Weigand (5) ran a practical foundry test involving over 100,000 castings (composition "G" and similar bronzes) and found that by melting under a neutral or slightly oxidizing atmosphere a greater number of pressure-tight castings were produced than under a highly reducing atmosphere averaging 7 per cent carbon monoxide. Daniels (6) and Jenkins (18) confirmed the work of Bolton and Weigand (5). Bailey (19) suggested that hydrogen and water vapor also might have a deleterious effect on pressure castings. Claus and Bauer (17) studied the influence of gas solubility on inverse segregation in tin bronzes and concluded that neutral gases, carbon monoxide plus carbon dioxide and nitrogen have a normal influence, while hydrogen gives extreme inverse segregation; that hydrogen sulfide, which reacts to form cuprous sulfide and hydrogen, has the same effect as hydrogen; and that sulphur dioxide, which forms cuprous sulfide and stannic oxide, has no effect. They found that phosphorus and lithium tend to reduce the dissolved uncombined hydrogen and decrease the segregation while zinc and aluminum have little influence. High internal gas pressure, developed by the evolution and entrapment of dissolved gases during solidification, was considered to be the cause of inverse segregation. Bailey (19) showed data proving that the hydrogen solubility in molten copper depends not only on the temperature, but also upon the oxygen content of the copper. In other words, the higher the oxygen content, the lower the hydrogen solubility. There is a maximum oxygen content, however, which, if exceeded, lowers the hydrogen solubility but little. When the molten charge contained hydrogen a greater degree of unsoundness was observed in sand castings than in chill castings; the apparent explanation is that a chill casting retains more of the gas in solution than a sand casting.

9. Only those absorbed gases which are soluble in molten bronze and whose solubility increases with temperature are to be considered as sources of trouble. Gases absorbed during the melting process which are soluble in bronze at room temperature naturally will not cause unsoundness or porosity. And, it seems highly improbable that insoluble gases could be held in suspension in molten bronze because of their bouyancy in liquids.

10. Mold gases which are trapped during the casting and solidification process may come from a number of possible sources, for example, steam from green

sand, air held in the pores of the sand, gases from the interstices of chills, carbonic oxides originating from ignition of carbonaceous mold facing materials and core compounds, and gaseous hydrocarbons from the decomposition of organic bonding compounds (18). Some of these gases are dissolved but most of them remain insoluble in the form of distinct bubbles. If the metal is too viscous to allow the gases to escape, they will be retained in the form of blow holes distributed irregularly throughout the casting but often confined to the surface (7).

11. The formation of tin oxide is considered by some writers to be harmful in composition "G" and particularly in "M". The presence of tin oxide is usually accompanied by porosity and low tensile strength. It seems probable that the metallic oxides are reduced by dry core binding material and produce oxides of carbon which are trapped with the freezing metal around the core, under the surface of the casting (18). This trouble is encountered more frequently in bronzes of high lead content (11).

(c) Intercrystalline Shrinkage Porosity

12. Some writers feel that intercrystalline shrinkage porosity is caused by slow or prolonged

freezing with consequent sluggish feeding of sections. The copper-tin equilibrium diagram shows an extremely wide freezing range of approximately 150°C (302°F) for a tin content of 9 per cent. During solidification bronze contracts considerably. Thus the dendrites which are formed occupy less space than the liquid from which they are formed and voids are left around them. If new liquid is available during solidification the spaces tend to fill, but if, for any reason, the supply of liquid is cut off, contraction cavities will result. It is obvious that due to the wide cooling range a considerable depth of metal from the cooling face of the casting will be freezing at the same time and the feeding liquid will have to traverse a long network of dendrites to fill the cavities (7,16). Bolton and Weigand (5) stated that the gas rejected in the crystal interstices during crystallization prevents feed back of the metal and causes shrinkage by preventing feed through back pressure. Dews (7) stated that cavities are formed primarily by contraction and while they may provide lodging places for liberated gases, they are not formed through any action of the gases.

13. It seems logical that even in the absence of dissolved gases intercrystalline shrinkage cavities

may be formed by contraction during solidification, and that intercrystalline shrinkage porosity may be controlled by the rate of solidification. This seems to point to the importance of casting temperature; for example, if the casting temperature is well above normal, the contraction during solidification will be greater than if cast at a normal temperature. Consequently, if it is impossible to feed the contraction cavities with liquid metal the unsoundness of the resultant casting will be increased. Karr and Rawdon (2) and Carpenter and Elam (3) showed that casting temperature has, through its influence on rate of solidification, a greater effect on soundness of composition "G" than any other factor. Primrose (1) and Thews (15) concluded that soundness, ultimate strength, and degree of elongation depend upon the rate of solidification. Smalley (4) showed that casting at too low a temperature results in poor physical properties which may be attributed to entrapped oxides and gas and improper feeding.

14. Since this report is primarily concerned with the causes for porosity in composition "G" and with methods of attack for the elimination of porosity, no attempt is being made to discuss in detail those factors which have only a minor influence on porosity.

However, it seems worthwhile to mention some of the methods employed to produce satisfactory castings. The castings are designed to maintain a cast finish where possible and to allow for a minimum amount of machining when machining is necessary. This procedure does not, by any means, reduce porosity, but it does take advantage of the pressure-tight skin on the surface of the casting chilled by the mold. From the standpoint of design and molding there are several important factors to be considered, for example, the coring of heavy bosses, the maintenance of uniform thickness throughout and the use of ample fillets when changes in sections or right angle bends are necessary, the selection of the proper type and size of gates, and the proper use of chills (9,18). Careful selection of raw materials and scrap are made to avoid possible contamination by undesirable elements, gases, or oxides. Melting and casting procedures are carefully controlled, and permissible elements, such as nickel (10,13) and phosphorus (7,8,14) are added. These alloying elements are considered beneficial to the production of pressure castings when properly used.

EXPERIMENTAL PROCEDURE

(a) Study of Gas Porosity

15. The literature in general agrees that reducing gases are a source of porosity in composition "G" castings, although there is a difference of opinion in regard to the gas or group of gases which may be contained in the raw materials or scrap, or which may be absorbed during the melting process and evolved during solidification. In view of this, the following experiments were performed to determine the effect on porosity in composition "G" of the various gases which might be present in the atmosphere during melting.

16. Some experimental melts were made in vacuo to determine the feasibility of using virgin metals in the proper proportions for composition "G". Considerable difficulty was experienced in retaining the zinc in the molten metal. The zinc which vaporized was carried off through the vacuum system and it was deposited along the way as it became cool enough to condense. In order to avoid this loss of zinc the following procedure was devised which proved to be quite satisfactory for the entire series of experiments.

17. A preliminary melt which contained more than the desired amount of zinc was sand cast. Three-pound specimens cut from the preliminary melt were vacuum melted in a graphite crucible and remelted in a graphite crucible under certain controlled gas atmos-

pheres. A different specimen was melted under each of the following gas atmospheres: hydrogen, water vapor, air, sulphur dioxide, carbon dioxide, nitrogen, oxygen, and carbon monoxide. The excess zinc was purposely added to the preliminary melt to compensate for zinc losses which occurred during vacumm melting. It is to be noted that the specimens cut from the preliminary melt were melted in vacuo before melting under controlled gas atmospheres. This procedure was followed because it was felt that the sand cast specimens might contain certain gases or oxides which would influence results when melting under controlled gas atmospheres. In other words, by following this procedure all specimens were brought to a standard quality and thus the results obtained after melting under different gas atmospheres were comparable.

18. The preliminary melt was made of virgin metals in a high frequency lift coil induction furnace using a No. 60 semi-conducting crucible having a capacity for 180 pounds of bronze. The metal was cast at 1140°C (2084°F) into a green sand mold. The resultant casting weighed approximately 117 pounds including gates and risers. The main body of the casting consisted of three cylinders, each 1-3/4 inches in diameter and 30 inches long. The casting was sand-blasted, thoroughly

cleaned, and cut into lengths each weighing about 3 pounds. The chemical analysis of a representative sample of the alloy showed that it contained 85.52 per cent copper, 8.71 per cent tin, 0.75 per cent nickel, and 4.73 per cent zinc.

19. In order to arrive at the desired zinc content (3 per cent) the specimens were weighed before and after vacuum melting and the loss in weight taken as loss of zinc. By this method the approximate zinc content could be calculated. The charge was remelted if the zinc content was too high and discarded if too low.

20. Melting in vacuo and under controlled gas atmospheres was done in graphite crucibles machined out of Acheson graphite electric arc furnace electrodes, four inches in diameter. The crucibles were 2-1/2 inches outside diameter, 5 inches overall length, 2 inches inside diameter at the top, tapered 4-1/2 inches in length to 1-3/4 inches inside diameter at the bottom. A graphite hopper 5 inches overall length was placed over the crucible so that the entire charge could be loaded at once, thereby preventing interruptions when melting. A graphite lid was placed over the hopper. Both the lid and the hopper also served to eliminate drastic temperature gradients during solidification. The crucible, hopper, and lid were

placed in a quartz tube closed at one end, 12 inches long, 3-1/2 inches outside diameter, and 1/8 inch wall thickness. A water-cooled bronze cap was fitted to the open end of the quartz tube and sealed with a rubber gasket. The cap had two convenient openings, one of which was closed when melting under vacuum, and when melting under gas atmospheres one opening was used as an inlet and the other as an outlet. A high frequency induction furnace was used for melting and a Beach-Russ two-stage rotary oil pump was used to produce the vacuum. The total time for a vacuum melt was 60 minutes - 30 minutes for evacuating the furnace, 25 minutes to melt the charge, and the charge was held 5 minutes in the molten condition after which the power was cut off and the metal allowed to cool to room temperature in vacuo.

21. The procedure for melting under gas atmospheres was as follows. Commercial grades of hydrogen, sulphur dioxide, carbon dioxide, nitrogen,and oxygen were employed. In order to insure their purity the gases were chemically treated to remove those impurities which might influence results. Hydrogen was passed over palladiumized pumice at 100°C (212°F) to convert oxygen to water vapor. It was then passed through concentrated sulphuric acid and calcium chloride to remove the water vapor before

entering the enclosed heating chamber. Sulphur dioxide received no special treatment. Carbon dioxide was passed over calcium chloride. Nitrogen was passed over copper filings at 600°C (1112°F), through concentrated sulphuric acid, and over calcium chloride in the order named. Oxygen was bubbled through a cuprous chloride solution to remove carbon monoxide, and then over calcium chloride to remove water vapor. Water vapor was produced by running steam generated by boiling water through the heating chamber. Carbon monoxide was produced by continuously dropping concentrated formic acid into concentrated sulphuric acid. Any acid fumes and water vapor carried with the carbon monoxide were removed by passing through concentrated sodium hydroxide and calcium chloride. In all cases, excepting the melt in air, the exhaust gas was bubbled through water to maintain a constant pressure and to prevent suction of air into the system should a drop in internal pressure occur.

22. The flow of gas was maintained for at least thirty minutes before starting the furnace and was continued until the metal cooled to room temperature. The metal was held molten for thirty minutes reaching a maximum temperature of approximately 1100°C (2012°F). It solidified in about fifteen minutes and cooled to

room temperature in three hours. The resultant specimens were halved lengthwise through the diameter, polished, and photographed. Density determinations and chemical analyses were made.

(b) Study of Intercrystalline Shrinkage Porosity

Effect of alloying elements

23. In studying gas porosity, cavities were observed even in specimens melted in vacuo prior to melting under controlled gas atmospheres. Assuming that by melting in vacuo no gases would be present, it seems reasonable to deduce that some other factor caused the porosity. Therefore, it was felt that this type of porosity might be natural for cast composition "G" and that some alloying element or elements were the contributing factors.

24. To prove this, the following experiments were performed. Five vacuum melts were made using the set-up described in paragraph 20. Virgin metals of high purity were used for a 3-pound charge of each composition shown in Plate 2. It is to be noted that in each successive charge copper is substituted for by one or more elements comprising composition "G", and that the last charge is the alloy itself. The specimens were processed in the manner outlined in paragraph 20.

Influence of pouring temperatures

25. The inportance of pouring temperatures, often referred to as casting temperatures, was emphasized in the literature. Some experiments were undertaken to confirm statements in the literature, while others were made to determine the relationship between pouring temperatures and soundness, tensile strength, and elongation.

26. Five heats, numbered from 22 to 26 inclusive, were run. Two were composition "G" containing no nickel, two were composition "G" containing the nominal nickel percentage, and one was a modification of composition "G" in which 6 per cent nickel was substituted for 6 per cent tin. The composition of each heat is shown in Figure 3. The melting was done in an Ajax-Northrup lift coil type induction furnace having a capacity for a No. 70 crucible. Seventy-pound charges were melted in a No. 40 crucible. Each charge consisted of 30 per cent scrap and the balance virgin metal. Nickel was added in the form of a 50 per cent copper and 50 per cent nickel master alloy. The scrap metal, copper-nickel master alloy, and virgin copper were melted first. The molten metal was covered with charcoal and heated above the initial pouring temperature. The tin was added

followed by zinc. The crucible was removed from the furnace, the metal cooled to the desired pouring temperature, and cast.

27. Details of the casting are shown in Plate 11 and Plate 12, Figure 1. The molds were made of No. 0 Albany green sand containing from 7 to 8 per cent moisture. The tensile test specimens were cut from each casting and density determinations were made on each specimen before maching to 0.505 inch diameter.

(c) Hydraulic Pressure Testing

28. An attempt was made to correlate pressure tightness with density by first determining densities of hollow cylinder castings as cast and as machined to size and then subjecting them to hydraulic pressure. Two melts were made in a No. 60 semi-conducting crucible, using the same equipment and following the same melting and casting procedure outlined in paragraph 26. Composition "G" containing no nickel was used. The details of the hollow cylinder casting are shown in Plate 10 and 12, Figure 2. The hollow cylinders were machined to 2-1/2 inches outside diameter, 2-1/4 inches inside diameter, and 4 inches length for testing, the excess length being cut off the top section of the cast cylinder. Plate 13 shows the device used for hydraulic pressure testing.

(d) Density Determinations, Voids and Soundness Calculations

29. Observed density values were determined by the conventional displacement of water method. The values obtained were at 20°C (68°F). It was found that densities of small samples taken from various sections of a casting varied considerably. Therefore, in all cases observed densities of the entire specimens were measured. In other words, in determining the density of a tensile test specimen the whole specimen was weighed in air and in water and the density computed. This gave an average observed density value for the tensile test specimen. The same procedure was followed in density determinations of hollow cylinder castings, and specimens obtained from vacuum and controlled gas atmosphere experiments. In order to calculate per cent voids or per cent soundness, it was necessary to determine the maximum densities of the alloys studied. Specimens of each alloy were cut into one-inch cubes, and cold compressed and annealed until maximum and constant density values were obtained. Three methods of determining density were used: (1) displacement of water, (2) weighing a known volume in air, the volume determined by measuring the dimensions with a micrometer

caliper, and (3) X-ray diffraction. The results obtained from the latter were used, since they were more consistent than the results obtained from the others. Table 4 lists the alloys studied and the corresponding maximum density values.

30. Before leaving the subject of density determinations, a few words should be included in regard to density as a measure of porosity or unsoundness. If a casting or specimen has a density equal to the maximum density, it can be said that the specimen is 100 per cent sound or contains zero per cent voids. On the other hand, if the density is less it is obvious that the specimen is not 100 per cent sound and necessarily contains a certain percentage of voids to make up for the volume occupied. In other words, the observed density of a specimen is an indication of its soundness or porosity. The maximum density varies, of course, with the composition. Thus in presenting data showing the effects of variations in composition or the effects of other variables on porosity, observed density values must be compared with the maximum density obtainable for the particular composition. The percentage of voids may be computed from the following formula.

$$\text{Voids, per cent} = \frac{D_{max.} - D_{obs.}}{D_{max.}} \times 100$$

$D_{max.}$ is the maximum density and $D_{obs.}$ is the observed density as described in paragraph 29. The figures shown as soundness (per cent) were determined by subtracting voids (per cent) from 100. Thus a perfectly sound casting would be 100 per cent sound, and a casting containing 10 per cent voids would be 90 per cent sound.

DISCUSSION OF RESULTS

(a) Study of Gas Porosity

31. The chart in Plate 1 represents the data obtained from the study of gas porosity described in preceding paragraphs. Hydrogen and water vapor caused the most porosity, sulphur dioxide and air followed with a decided drop in porosity, and carbon dioxide, nitrogen, oxygen, and carbon monoxide caused porosity in the order given with carbon monoxide causing the least. It is interesting to note the relative positions of the two bars marked "Leaky Castings." They represent hollow cylinder castings having the least porosity of 24 tested which leaked when subjected to the hydraulic pressure test. In other words, a further reduction of porosity seems necessary to obtain pressure-tight castings.

32. This discussion covers only the possibility of porosity caused by gases absorbed from the

materials or during the melting process and precipitated during solidification. There is another type of gas porosity which may occur during the casting and solidification processes. This is in the form of occluded gases which appear near the skin of the casting only and are probably a result of insoluble gases formed by hot metal contacting the sand mold surfaces and which are trapped during solidification. These may be almost any of the gases discusses, and although such blowholes are undesirable, they are not too serious a defect if other factors governing porosity are properly controlled, since this type of porosity is usually found near the casting surface only and not throughout the casting. Thus, if the balance of the casting is sound, it would be difficult to force liquid through the casting if the channels formed by a series of cavities are absent.

33. Porosity found throughout a casting might result from precipitated gas which was dissolved prior to casting, and obviously can cause leakage, particularly if the porosity is of such magnitude to provide convenient channels for the liquid or gas. It is interesting to consider in detail some aspects of absorbed gas porosity which are included in Plate 1. The melt represented by the bar marked "Vacuum" (melted only under

vacuum) can be assumed to be free of gas. By melting under vacuum in a graphite crucible metallic oxides would be reduced to oxides of carbon, and these gases and others, if present, would be removed through the vacuum system. Even though the "Vacuum" melt is gas-free it has a certain amount of porosity (indicated by the per cent voids or per cent soundness of the metal) due to some other cause. Since the specimen was prepared under carefully controlled conditions all variables, including gas, were eliminated. Therefore, the other cause for porosity can only be attributed to intercrystalline shrinkage which will be discussed later. If it is assumed that "Vacuum" has zero gas porosity, then a line drawn parallel to the horizontal axis in Plate 1 through the uppermost point of the bar marked "Vacuum" will be the zero point for gas porosity for all of the gas melts. The bar "Vacuum" has two uppermost points one shaded and the other unshaded which were determined by using maximum density values obtained by different methods mentioned above. If a line is drawn through either point, comparisons must be made with corresponding points on bars representing soundness of the various gases. If the dotted line AA' is considered as the zero gas porosity line the effect of the various gases on porosity is more noticeable. Carbon monoxide seems to have no effect and can be considered as either insoluble or soluble from room temperature to 1100°C (2012°F). The former is probably correct. Oxygen, nitrogen, carbon dioxide, sulphur dioxide, and air show gradual increases in porosity due to gas. The per cent voids of specimens melted under water vapor and hydrogen is more than twice that of the vacuum melted specimen, indicating a marked influence of these two gases on porosity. Water vapor probably breaks down to form oxygen and free hydrogen, and it is quite likely that hydrogen alone is dissolved in the molten metal and precipitates during solidification to cause porosity.

34. Table 1 shows the chemical composition and heat numbers of the specimens charted in Plate 1. Plates 7 and 8 show cross-sectional photographs of the specimens charted in Plate 1. The effect of hydrogen and water vapor on porosity is obvious. A number of small cavities are evident in the specimens melted under air and sulphur dioxide. There is no apparent effect of carbon monoxide, oxygen, nitrogen, and carbon dioxide on porosity. The chemical analysis of the specimen melted under sulphur dioxide shows 0.10 per cent sulphur which was picked up during the melting process.

Examination under the microscope revealed the presence of sulphides which seemed to have no bearing on porosity.

35. Before leaving the discussion of gas porosity, a short discussion of the practical application of these findings to foundry practices is in order. Virgin metals and scrap used in making the alloys are possible sources of gases, which may be carried over from previous refining or melting operations. Furthermore, they may come from moisture, oil, or corrosion products on the surface of the materials, Some or all of these, when heated, may ultimately break down to water vapor or hydrogen or both, and become absorbed by the molten metal. Furnace atmospheres in coal or coke fired natural draught pit type furnaces, oil, gas, or induction furnaces, may have hydrogen or water vapor present. Bailey (19) presented a chart showing gas atmospheres for a number of different types of copper melting furnaces including some of those mentioned above which showed that in most cases the hydrogen content varied between 0.0 and 2.0 per cent, but the water vapor was much higher, in one case having as much as 20.7 per cent. If the fluxes, deoxidizers, or charcoal contain moisture, they also may be sources of gas porosity.

36. In view of the similarity in chemical com-

positions between compositions "M" and "G" it is very probable that the results obtained from the study of gas porosity on composition "G" can be applied to composition "M".

(b) Study of Intercrystalline Shrinkage Porosity

Effect of alloying elements

37. Plate 2 shows the per cent voids and per cent soundness of a series of five alloys melted, solidified, and cooled in a graphite crucible in vacuo. The relatively low percentage of voids found in the first three alloys from the left side of the chart is worthy of note. These alloys do not contain tin. The percentage of voids found in the fourth and fifth alloys from the left side of the chart ranges from 4 to 30 times as much as the first three alloys. It is to be noted that the fourth and fifth alloys contain tin and that the fifth is composition "G".

38. Cross-sectional photographs of these alloys are shown in Plate 9. The alloys having low percentage of voids and no tin show a pipe in the center of the specimen, while the alloys containing tin and having a high percentage of voids show no pipe whatsoever. It is obvious that the shrinkage in the alloys showing the pipe is external as evidenced by the pipe, whereas in the alloys

containing tin, no external shrinkage is evident. Consequently, since some shrinkage has to take place, it can be assumed to be internal in the form of minute cavities. This is verified by the fact that the percentage of voids is relatively high and that minute cavities are discernible under the microscope.

39. In view of the results obtained from these data it seems that regardless of precise foundry control, it is impossible to manufacture castings entirely free of voids or porosity. It remains to be proved by hydraulic testing whether or not it is necessary for castings to be free of porosity if they are to be pressure-tight. However, it must be borne in mind that this factor is a natural phenomenon which cannot be easily controlled and presents a considerable handicap in the manufacture of pressure-tight castings.

Influence of pouring temperatures

40. Plate 3 shows the influence of pouring temperature on soundness for three compositions. Two are essentially composition "G", one with and one without nickel. The third composition is a modification of composition "G" in which 6 per cent nickel is substituted for 6 per cent tin. Since the element tin has been shown to be a cause of intercrystalline or internal porosity in composition "G", it was felt that by substituting some

other element for tin, internal porosity could be reduced. The substitution of nickel was made primarily to decrease intercrystalline shrinkage porosity and at the same time retain or improve all of the physical and corrosion resistant properties for which composition "G" is noted.

41. There are further advantages in substituting other elements for tin. In view of the present war conditions a satisfactory substitute for tin, a strategic material, would be an important development. In the case of the modified composition "G" in which 6 per cent nickel was substituted for 6 per cent tin the cost of the alloy would be lowered since tin costs roughly twice as much as nickel.

42. From the two curves in Plate 3 representing composition "G" two important observations can be made: (1) soundness increases rapidly as the temperature decreases to 1150°C (2012°F) and is constant at lower temperatures; (2) the presence of 0.6 to 0.7 per cent nickel shows higher soundness at 1150°C and under, although the pouring temperatures above 1150°C seem to be more critical. Pouring temperature has little influence on soundness of the modified composition "G" alloy containing 6 per cent nickel.

43. In Plate 4 pouring temperature is plotted

against physical properties. Again the drastic effect of pouring temperatures is to be noted on composition "G". As the temperatures drop to 1150°C, the physical properties increase sharply, and as the temperature drops below 1150°C, the physical properties decrease. The physical properties of the modified composition "G" decrease with pouring temperature, but the change is not sharp, nor is there a critical pouring temperature.

44. Plate 3 and Plate 4 are combined in Plate 5 with soundness plotted versus tensile strength and the pouring temperatures inserted at each point on the curves. The curves representing composition "G" show maximum tensile strength and soundness at a critical pouring temperature. Composition "G" containing from 0.6 to 0.7 per cent nickel shows improvement in soundness over composition "G" containing zero per cent nickel with no apparent change in tensile strength. The modified composition "G" alloy shows relatively little change in soundness with pouring temperature, although some loss in tensile strength is to be noted with lower pouring temperatures. However, the tensile strength values on the whole are equivalent to or higher than the maximum tensile strength values obtained on composition "G". Table 2 shows the data used for preparing Plates 3, 4, and 5. In addition,

the average density of each specimen is included.

45. From the observation made on the curves (Plates 3, 4, and 5), the importance of accurately controlling pouring temperatures of composition "G" in the foundry can be appreciated. In order to obtain maximum soundness and maximum physical properties a casting has to be poured within a very narrow temperature range. In view of the similarity of composition "G" and composition "M" it would seem that pending further investigation of the latter alloy, the effect of pouring temperatures would be relatively the same. The modified composition "G" containing 6 per cent nickel does not seen to be affected by pouring temperatures. This may be due to the lower tin content of the alloy. An alloy of this type would be of considerable help to the foundry since it would eliminate one of the important factors in the manufacture of pressure-tight castings by removing the critical relationship between porosity and pouring temperature.

(c) Hydraulic Pressure Testing

46. Table 3 shows the data obtained from the hydraulic pressure tests. It is to be noted that only one specimen, 10A, satisfactorily withstood pressure. The balance leaked at 100 pounds pressure or less. Some

of the other specimens had a higher soundness value than 10A but leaked when tested. Because of the deviation of results no definite conclusions were drawn. Further work is contemplated on this type of testing with a view to the correlation of per cent soundness with pressure tightness. It is felt that some changes in the design of the test casting will be necessary before satisfactory results can be obtained. Gardner and Saeger (20) conducted similar hydraulic pressure tests on cast red brass (85 per cent copper, 5 per cent zinc, 5 per cent tin, and 5 per cent lead) with fairly good results. Plate 6 shows the effect on soundness of two differently shaped and designed castings of identical composition.

SUMMARY AND CONCLUSIONS

47. Tin causes intercrystalline shrinkage porosity in composition "G". This obviously suggests a change in composition or perhaps even a substitution of other alloying elements for tin.

48. Hydrogen and water vapor cause gas porosity in composition "G". Sulphur dioxide seems to have a minor deleterious effect, while carbon dioxide, nitrogen, oxygen, and carbon monoxide cause little, if any, gas porosity.

49. Improper pouring temperatures cause porosity in composition "G". Maximum soundness and physical prop-

erties can only be obtained within a very narrow pouring temperature range, which is difficult to control in actual foundry practice.

50. Modified composition "G", in which 6 per cent nickel is substituted for 6 per cent tin, decreases the effect of pouring temperature on soundness and physical properties. In other words, high soundness values and good physical properties can be obtained over a wide pouring temperature range, which should aid considerably in the production of pressure castings.

51. Design and shape of casting influences soundness.

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TABLE 1

Chemical Analysis of Alloys
Melted Under Gas Atmospheres
(See Plate 1)

Gas Atmosphere	Heat Number	%Cu	%Sn	%Zn	%Ni	%S
Vacuum	9	87.15	9.15	2.76	0.75	
CO	16	87.35	9.16	2.63	0.75	
O_2	18	87.43	9.00	2.59	0.75	
N_2	19	87.41	8.96	2.79	0.75	
CO_2	13	87.09	9.03	2.98	0.75	
SO_2	14	87.09	8.96	2.80	0.75	0.10
Air	15	86.89	9.27	2.83	0.74	
H_2O	17	87.23	8.89	2.78	0.75	
H_2	12	87.36	9.14	2.70	0.75	
Leaky	20	87.23	8.81	3.66		
Castings	21	87.78	8.95	2.84		

TABLE 2

Effect of Pouring Temperature on Various Physical Properties

Specimen No.	Heat Number	Pouring Temperature °C	Average Density gms./c.c. at 20°C*	Percent Soundness	Tensile Strength lbs/sq. in*	Elongation % in 2 in.*
1	22	1240	8.536	95.6	33,100	10.2
2	"	1150	8.639	96.8	41,700	25.8
3	"	1050	8.623	96.6	30,300	4.7
4	23	1280	8.331	93.3	24,900	8.6
5	"	1175	8.531	95.6	36,400	-
6	"	1050	8.674	97.2	33,200	6.3
7	24	1290	8.014	90.1	26,300	7.0
8	"	1160	8.597	96.6	40,500	15.6
9	"	1050	8.780	98.7	31,000	6.3
10	25	1300	7.928	88.9	27,400	5.5
11	"	1140	8.795	98.6	41,800	18.8
12	"	1050	8.762	98.2	26,400	4.3
13	26	1325	8.728	97.8	42,500	38.6
14	"	1200	8.736	97.9	41,500	30.1
15	"	1100	8.704	97.5	37,800	24.2

Note: * represents average of two specimens tested.

TABLE 3

Hydraulic Pressure Testing Data on Hollow Cylinder Specimens (Composition "G")

Chemical Analysis:

	% Copper	% Tin	% Zinc
Heat No. 20	87.2	8.8	3.7
Heat No. 21	87.8	9.0	2.8

Pouring Temper- ature °C	Speci- men No.	As Cast		Machined		Pressure Test	
		Density at 20°C gms./c.c.	Percent Sound- ness	Density at 20°C gms./c.c.	Percent Sound- ness	100 lb.	600 lb.
1300	1A	8.148	91.3	7.958	89.2	NG	
"	1B	8.170	91.6	8.080	90.6	NG	
"	6A	7.761	87.0				
"	6B	7.753	86.9	7.464	83.7	NG	
1210	2A	8.309	93.1	8.129	91.1	NG	
"	2B	8.285	92.9	8.023	89.9	NG	
1200	8A	8.493	95.2				
"	8B	8.465	94.9	8.340	93.5	NG	
1125	10A	8.531	95.6	8.319	93.2	OK	OK
"	10B	8.534	95.7	8.346	93.5	NG	
1110	3A	8.463	94.9	8.389	93.8	NG	
"	3B	8.471	95.0	8.284	92.9	NG	
1050	4A	8.440	94.6	8.366	93.8	NG	
"	4B	8.428	94.5	8.428	94.3	NG	
"	12A	8.572	96.1	8.374	93.9	NG	
"	12B	8.549	95.8	8.343	93.5	NG	

* Only specimens withstanding 100 lb. per sq. in. pressure were tested at 600 lb. per sq. in. pressure.

NOTE: Specimens numbered 1A, 1B, 2A, 2B, 3A, 3B, 4A and 4B were taken from Heat No. 20, and specimens numbered 6A, 6B, 8A, 8B, 10A, 10B, 12A, and 12B were taken from Heat No. 21.

TABLE 4

Maximum Density Values

Chemical Compositions				
% Cu	%Zn	%Sn	%Ni	Max. Density X-Ray Diffraction Method
87.4	2.9	9.6	0.0	8.928 gms./c.c.
87.4	3.1	9.5	0.0	8.928 " "
85.8	3.3	10.2	0.7	8.900 " "
87.4	2.9	9.1	0.6	8.922 " "
88.2	2.8	3.1	5.9	8.928 " "

EFFECT ON SOUNDNESS OF MELTING AND SOLIDIFYING COMPOSITION "G" UNDER VARIOUS GAS ATMOSPHERES

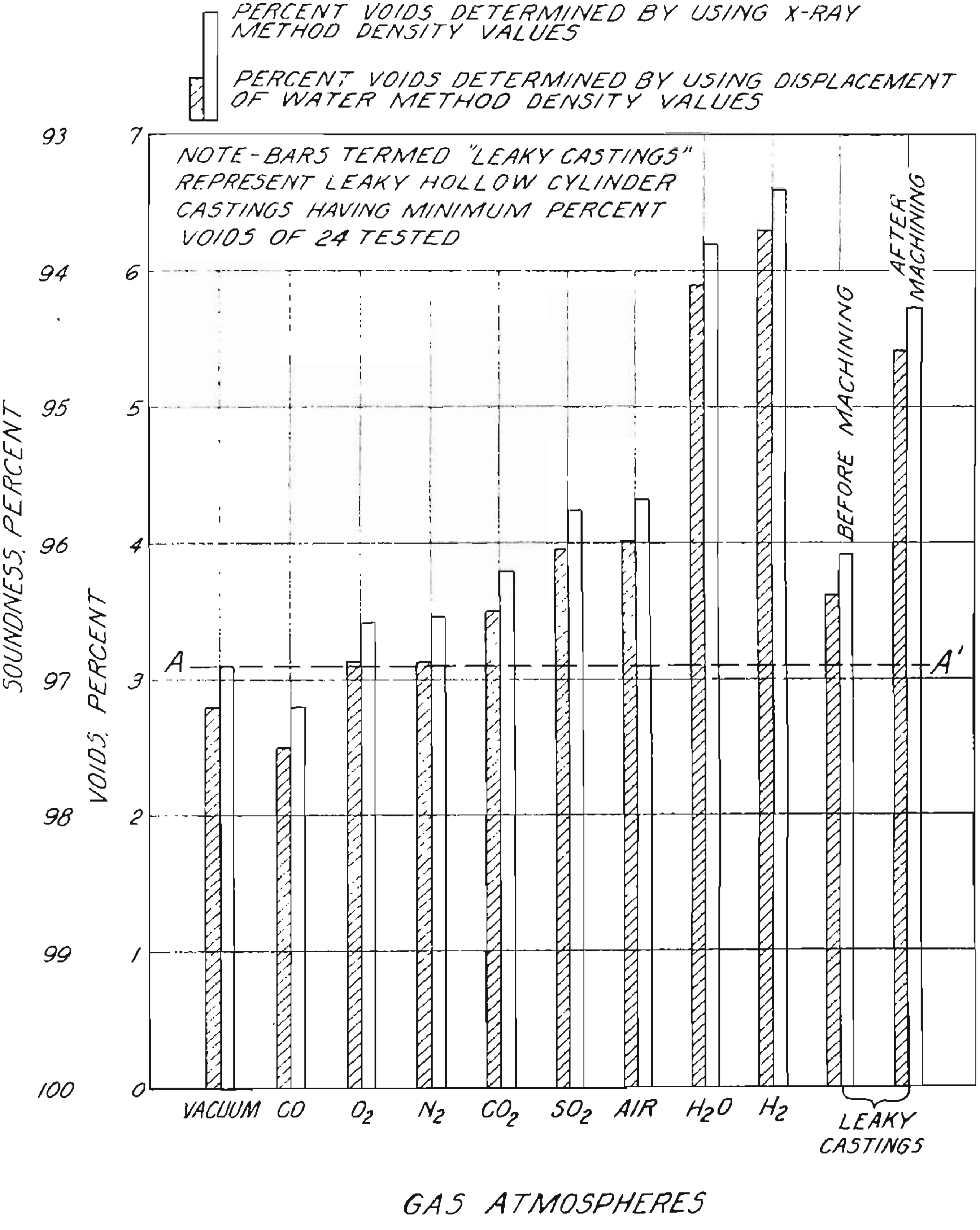


PLATE 1

EFFECT OF ELEMENTS USED IN COMPOSITION "G" ON SOUNDNESS

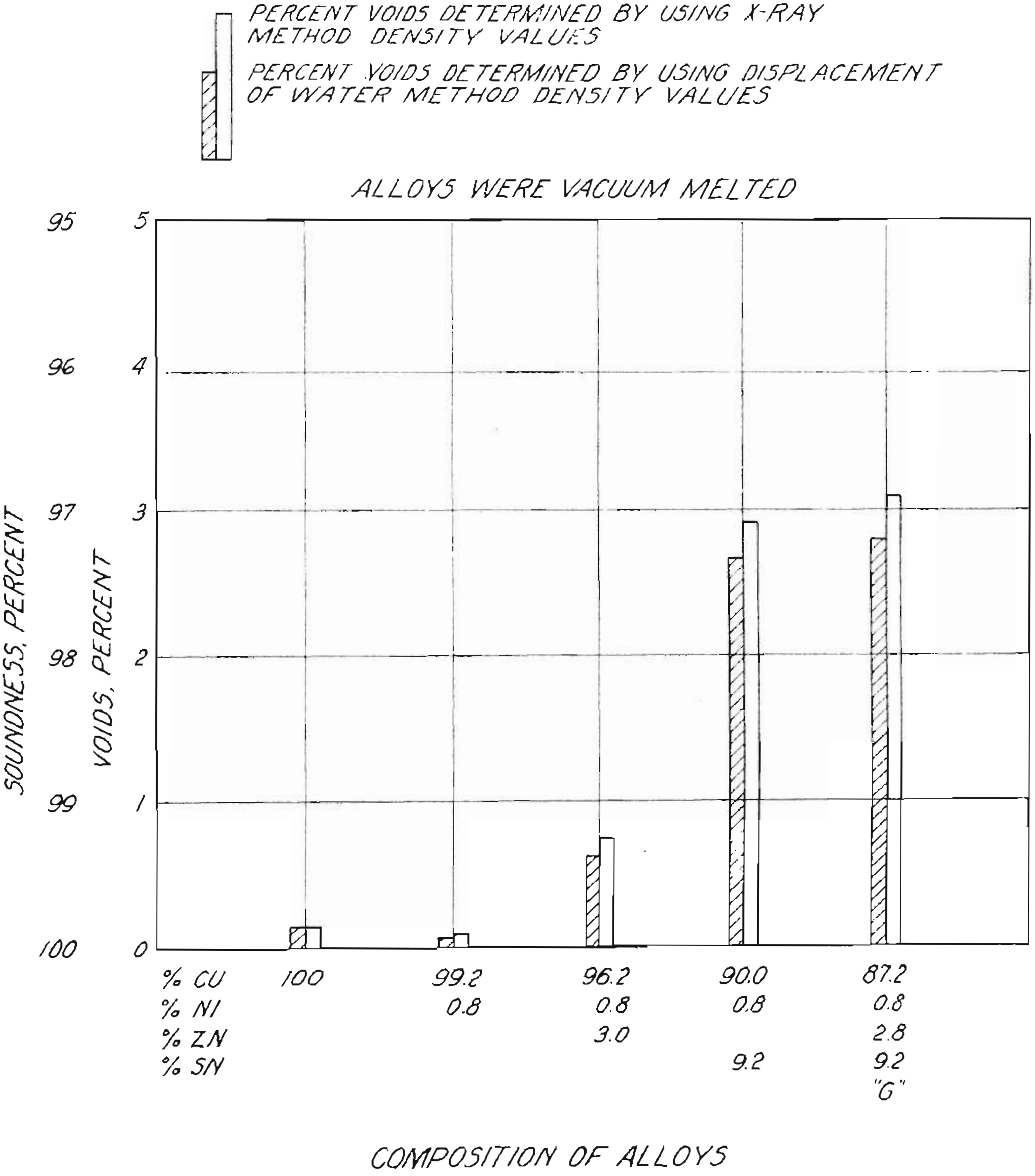
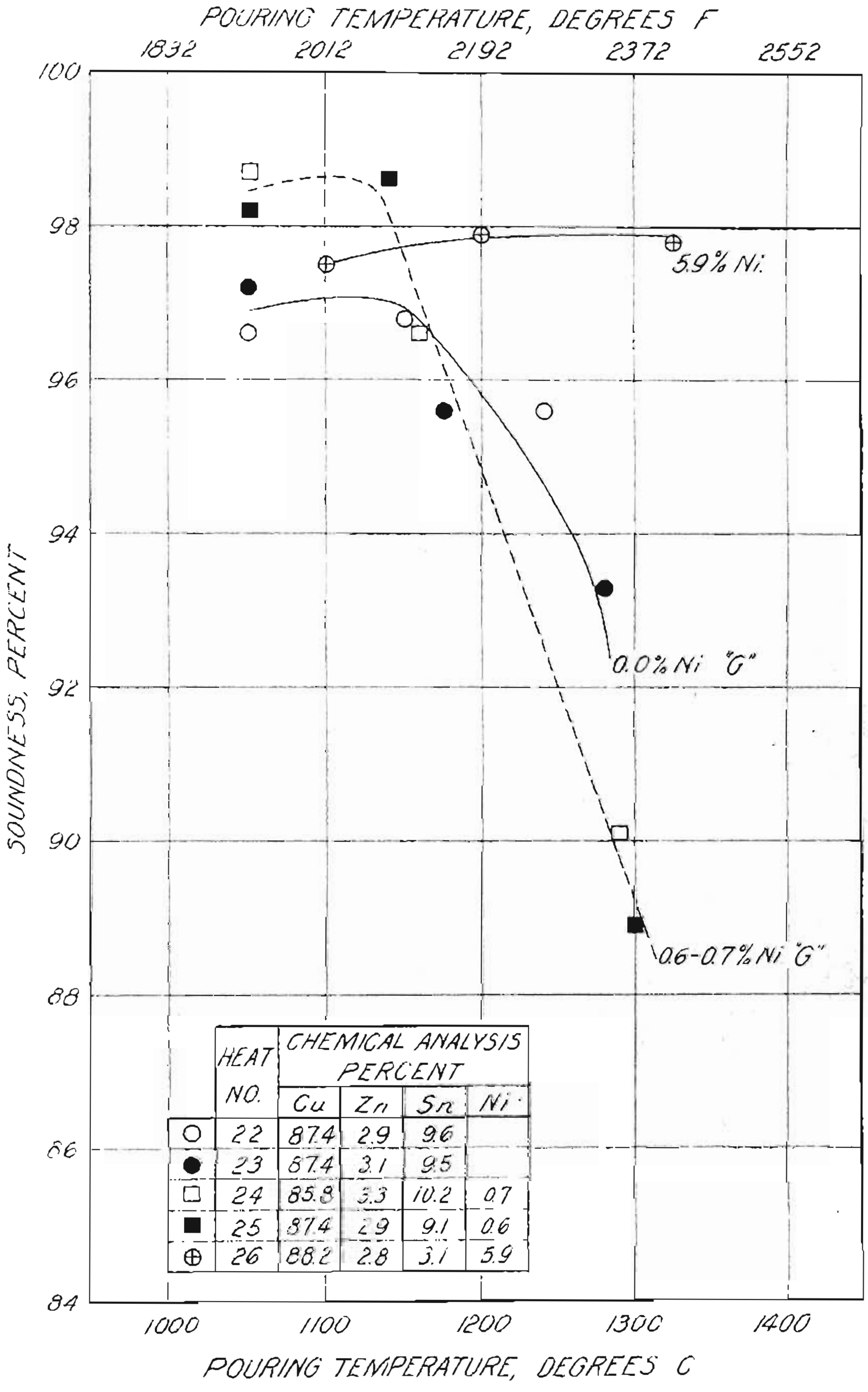


PLATE 2

EFFECT OF POURING TEMPERATURE ON SOUNDNESS OF COMPOSITION "G" AND THE INFLUENCE OF NICKEL.



	HEAT NO.	CHEMICAL ANALYSIS PERCENT			
		Cu	Zn	Sn	Ni
○	22	87.4	2.9	9.6	
●	23	87.4	3.1	9.5	
□	24	85.8	3.3	10.2	0.7
■	25	87.4	2.9	9.1	0.6
⊕	26	88.2	2.8	3.1	5.9

PLATE 3

EFFECT OF POURING TEMPERATURE ON PHYSICAL PROPERTIES OF COMPOSITION "G" AND THE INFLUENCE OF NICKEL

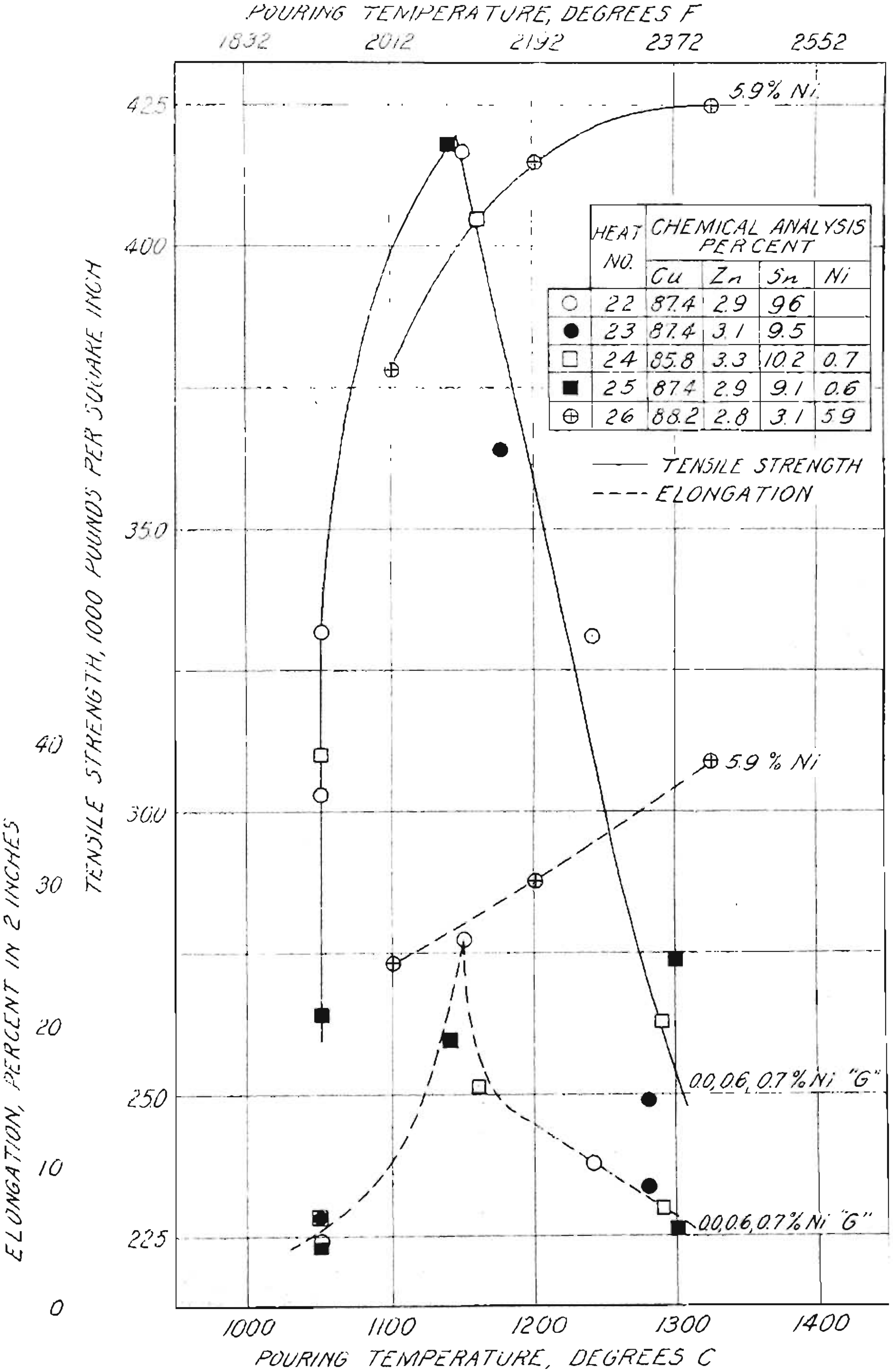
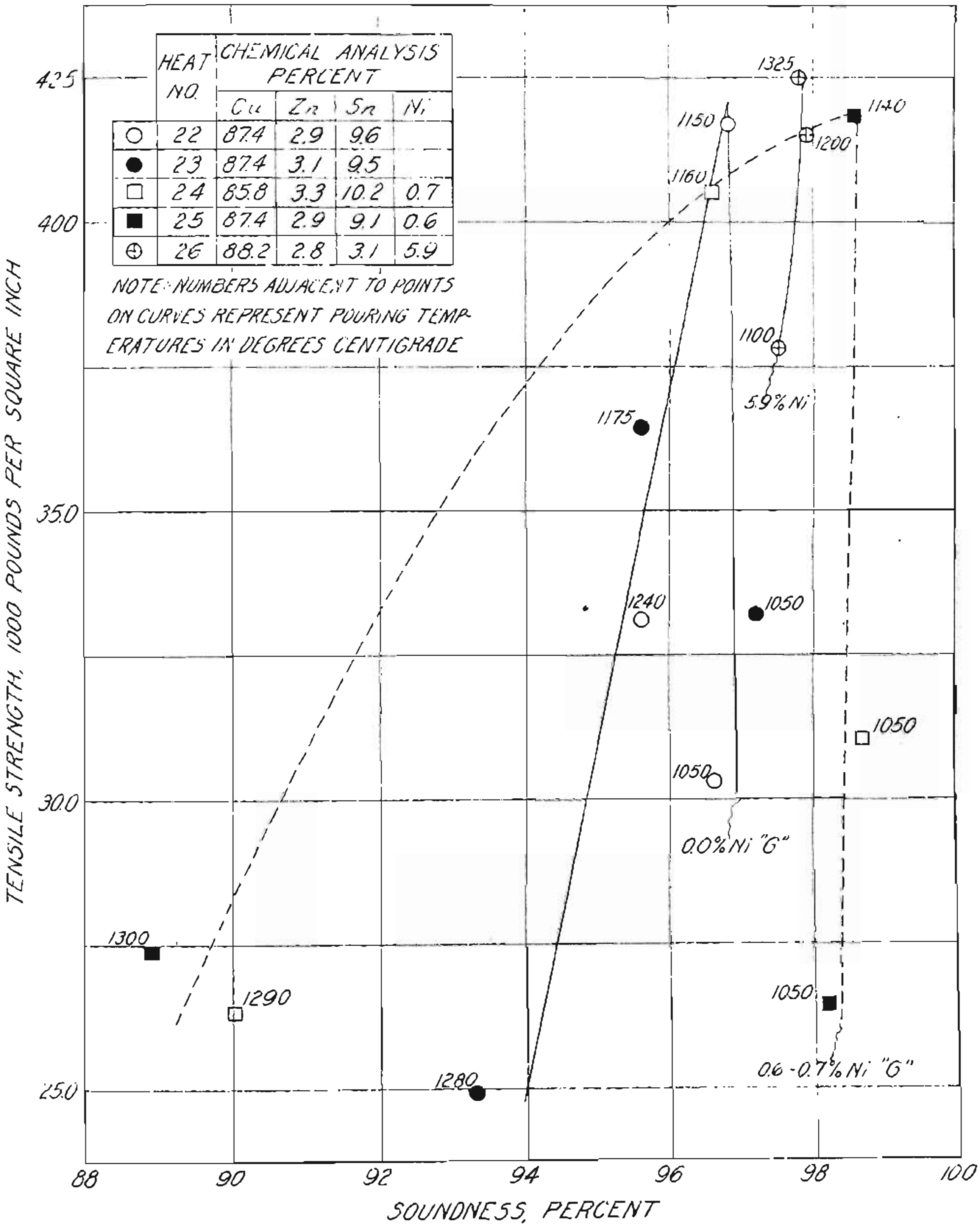


PLATE 4

RELATIONSHIP BETWEEN TENSILE STRENGTH, SOUNDNESS, AND POURING TEMPERATURE AND THE INFLUENCE OF NICKEL ON THESE FACTORS IN COMPOSITION "G"

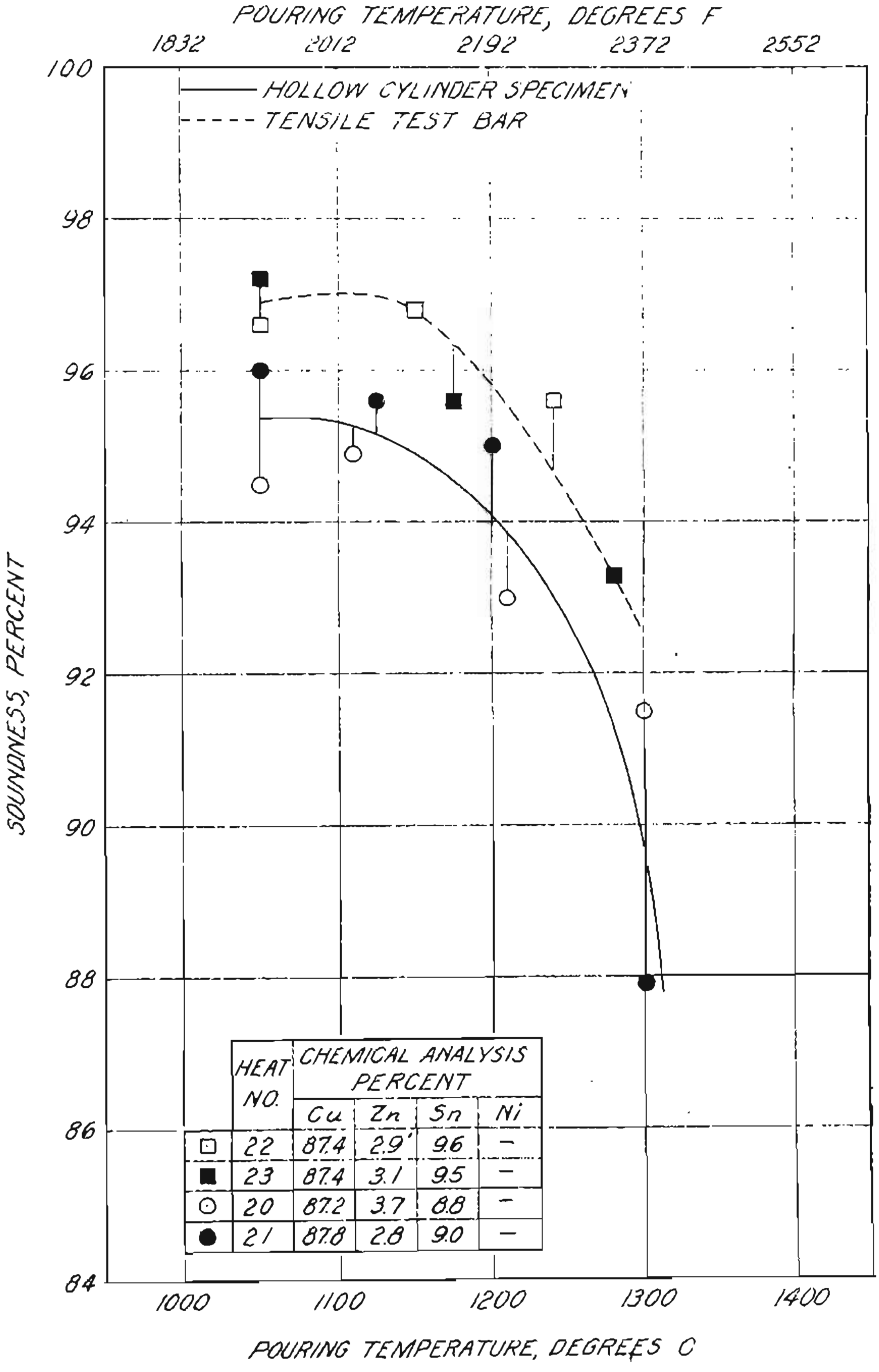


	HEAT NO.	CHEMICAL ANALYSIS PERCENT			
		Cu	Zn	Sn	Ni
○	22	87.4	2.9	9.6	
●	23	87.4	3.1	9.5	
□	24	85.8	3.3	10.2	0.7
■	25	87.4	2.9	9.1	0.6
⊕	26	88.2	2.8	3.1	5.9

NOTE: NUMBERS ADJACENT TO POINTS ON CURVES REPRESENT POURING TEMPERATURES IN DEGREES CENTIGRADE

PLATE 5

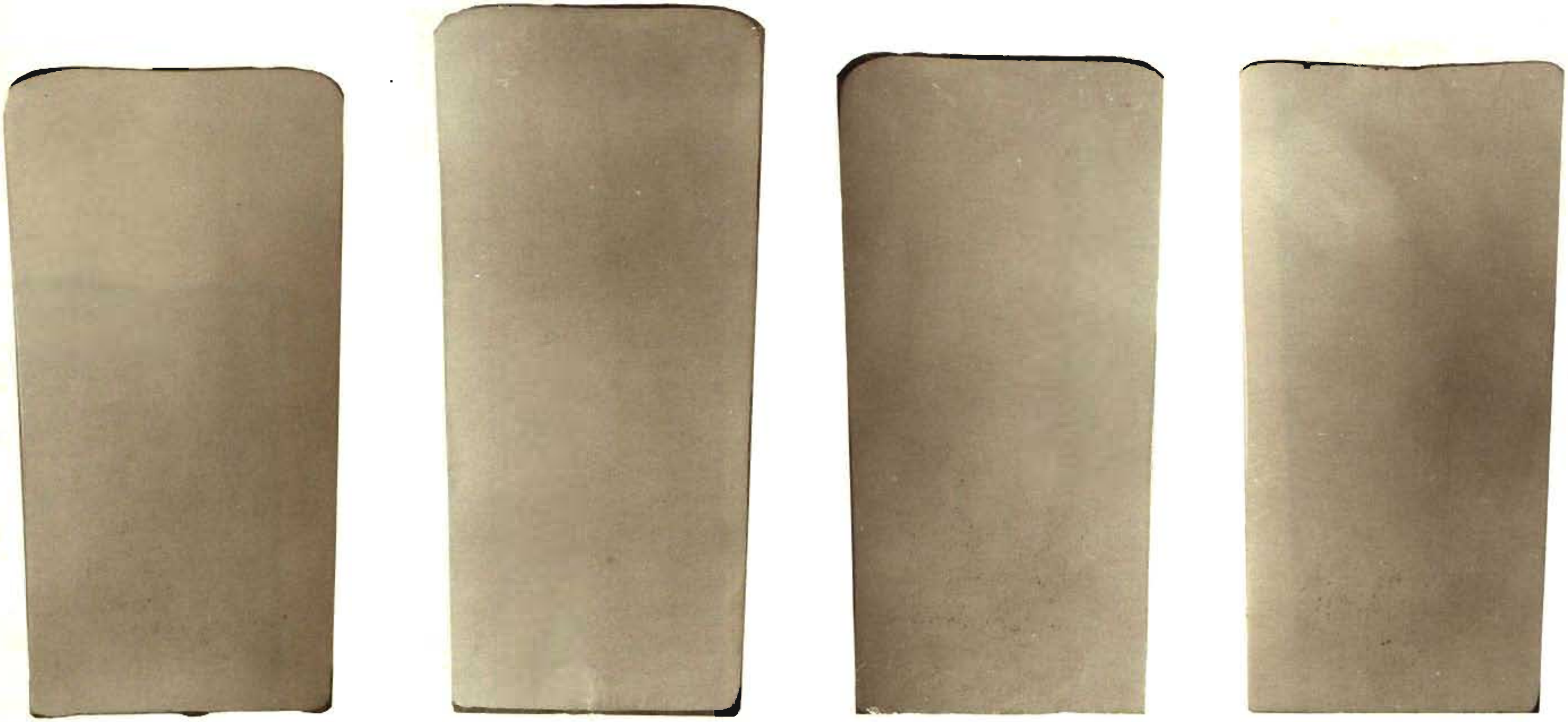
EFFECT OF SHAPE AND DESIGN ON SOUNDNESS OF COMPOSITION "G"



	HEAT NO.	CHEMICAL ANALYSIS PERCENT			
		Cu	Zn	Sn	Ni
□	22	87.4	2.9	9.6	–
■	23	87.4	3.1	9.5	–
○	20	87.2	3.7	8.8	–
●	21	87.8	2.8	9.0	–

PLATE 6

FULL SIZE LONGITUDINAL SECTIONS OF SPECIMENS OF COMPOSITION "G"
MELTED AND SOLIDIFIED UNDER VARIOUS GAS ATMOSPHERES



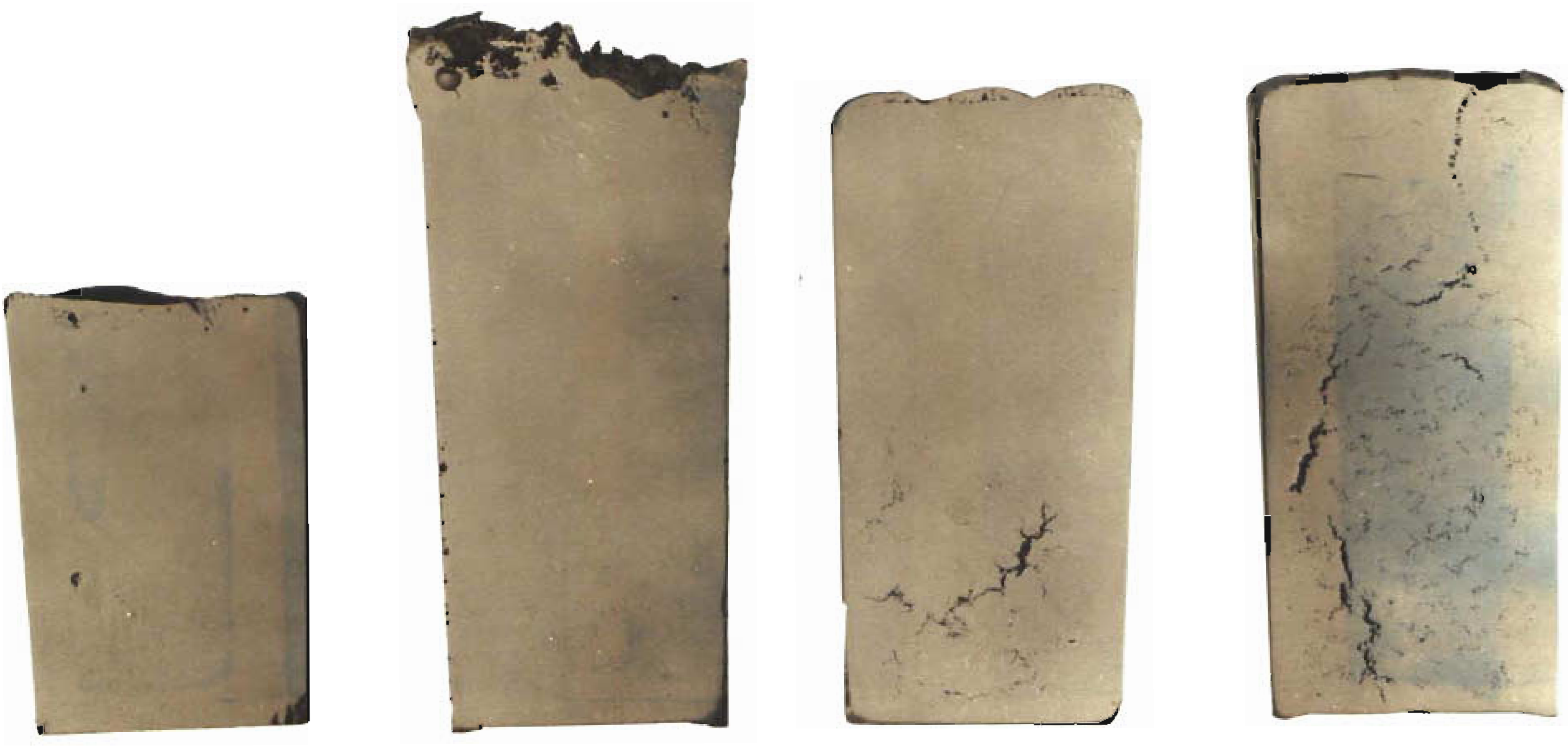
CARBON MONOXIDE

OXYGEN

NITROGEN

CARBON DIOXIDE

PLATE 7



FULL SIZE LONGITUDINAL SECTIONS OF SPECIMENS OF COMPOSITION "G"
MELTED AND SOLIDIFIED UNDER VARIOUS GAS ATMOSPHERES

SULPHUR DIOXIDE

AIR

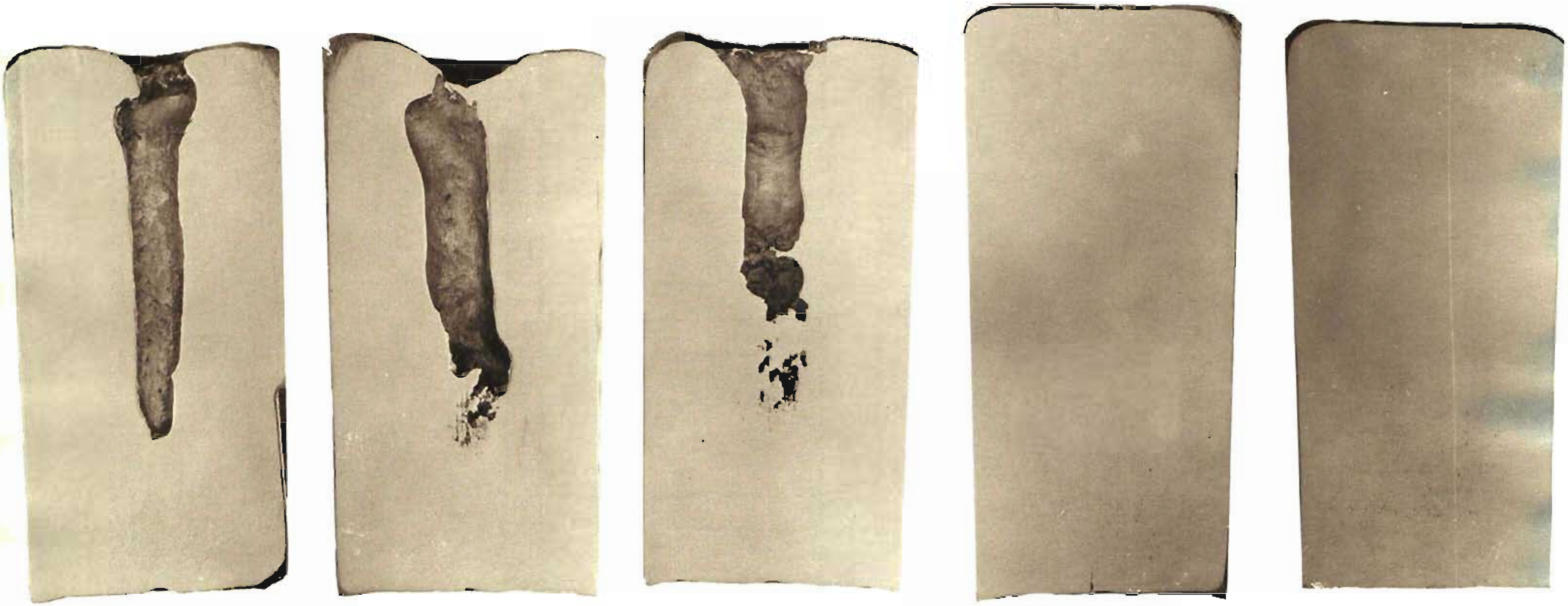
WATER VAPOR

HYDROGEN

PLATE 8

FULL SIZE CROSSSECTIONAL VIEW OF SPECIMENS USED FOR PREPARATION OF CHART, PLATE 2

VACUUM MELTED



% Cu	100	99.2	96.2	90.0	87.2
% Ni		0.8	0.8	0.8	0.8
% Zn			3.0		2.8
% Sn				9.2	9.2
					"G"

COMPOSITION OF ALLOYS

PLATE 9

DETAILS OF HOLLOW CYLINDER TEST CASTING

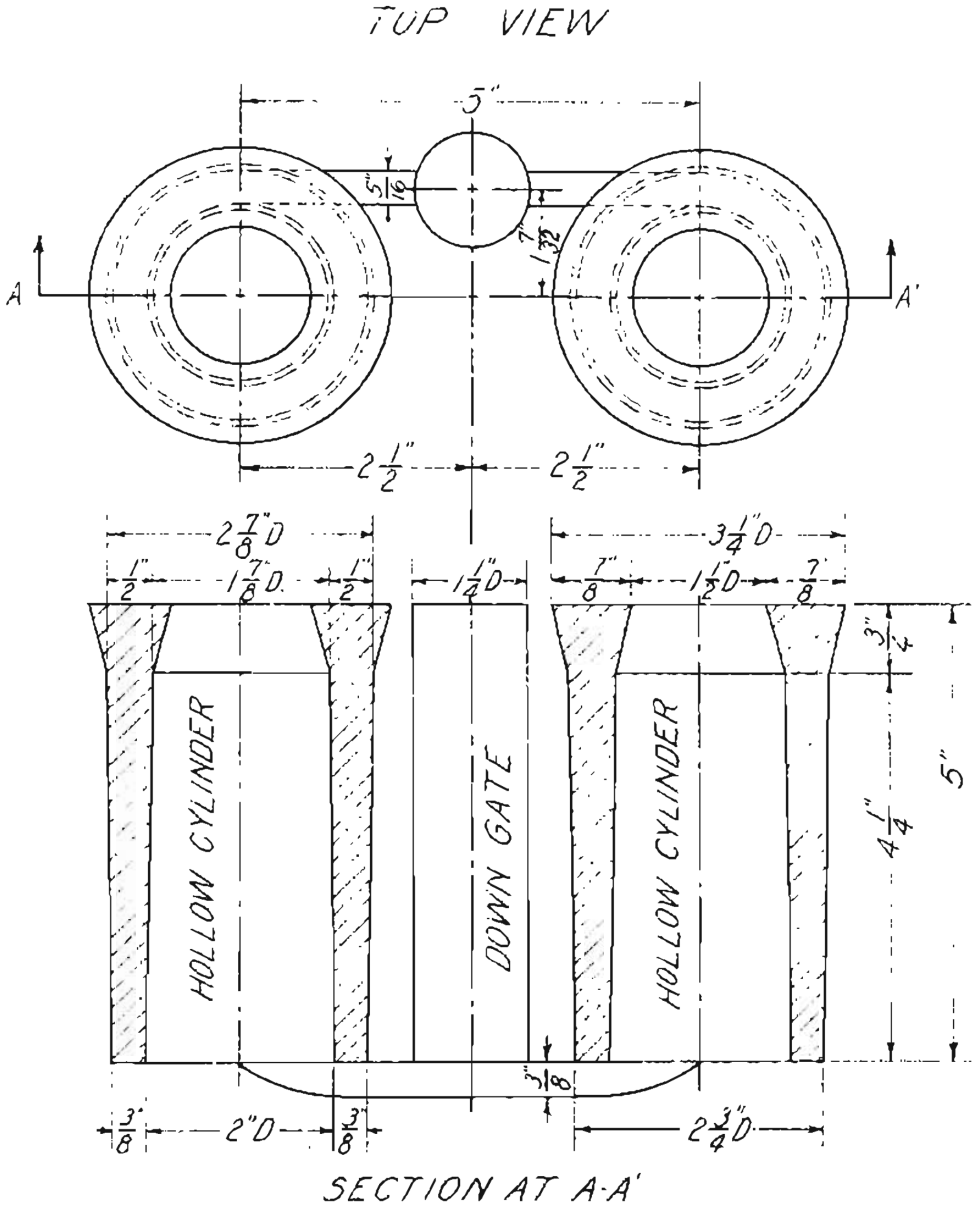
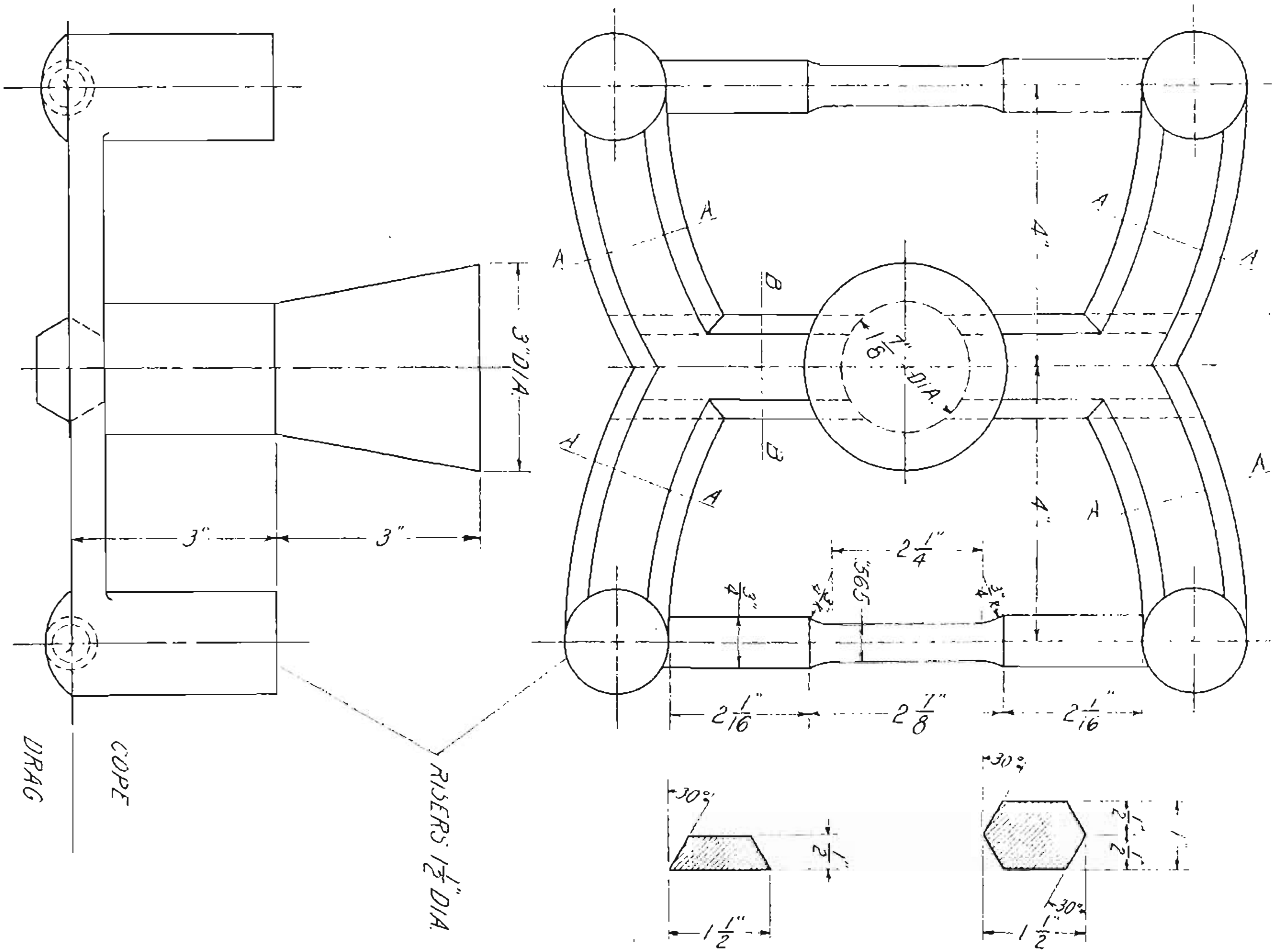


PLATE 10

DETAILS OF TENSILE TEST SPECIMEN CASTING



SECTION ON A-A

SECTION ON B-B

PLATE 11

TENSILE TEST
SPECIMEN CASTING

FIG. 1

HOLLOW CYLINDER
TEST CASTING

FIG. 2

PLATE 12

HYDRAULIC PRESSURE TESTING DEVICE

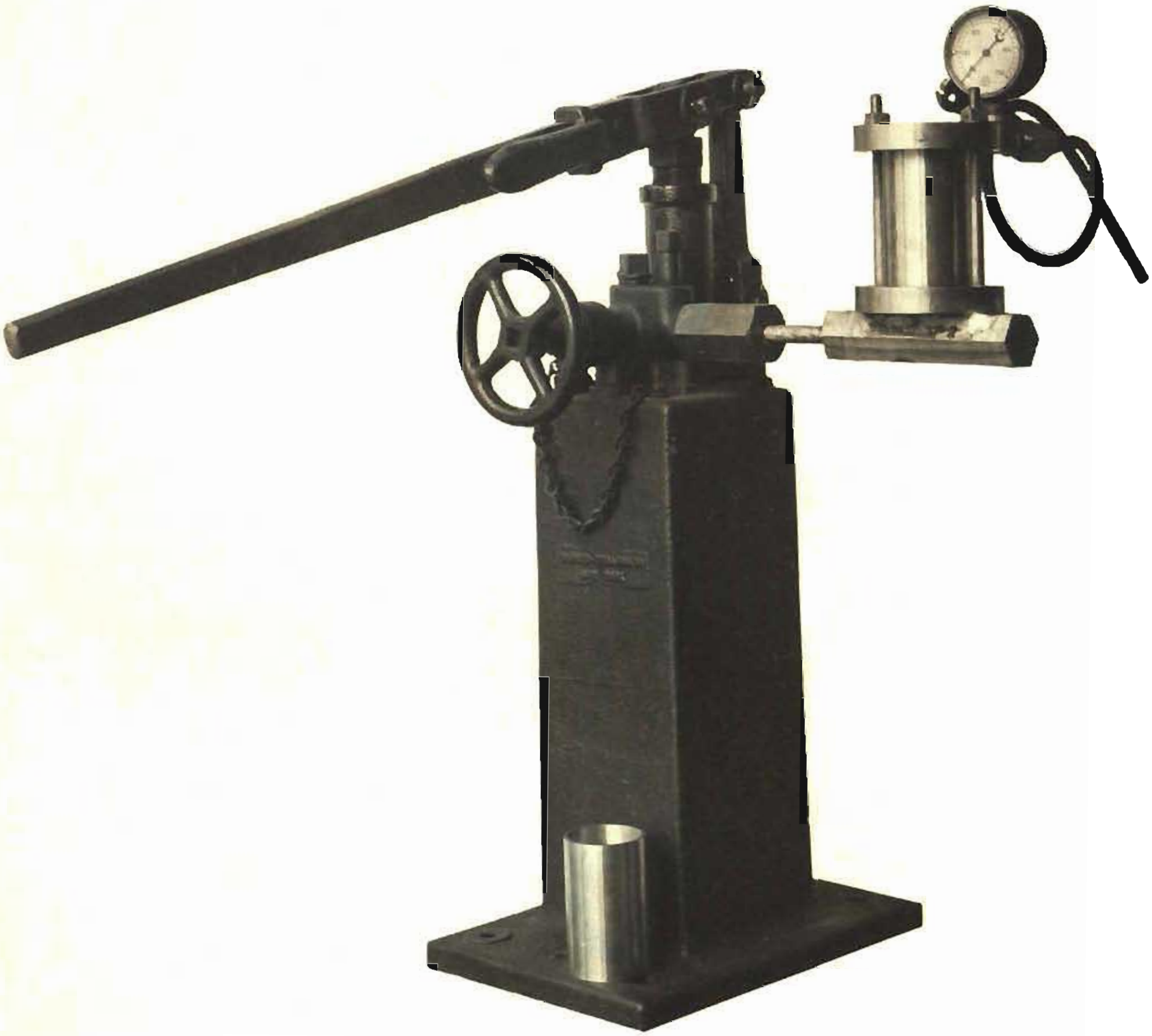


PLATE 13