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A Study of the Effect of Third Metals on the Wetting Properties of Solders

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MONTANA SCHOOL

OF MINES

BUTTE, MONT.

THE EFFECT OF THIRD METALS ON THE WETTING PROPERTIES OF SOLDERS

BY

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A THESIS

IN PARTIAL FULFILLMENT

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IN METALLURGICAL ENGINEERS

A STUDY OF THE EFFECT OF THIRD METALS ON THE WETTING PROPERTIES OF SOLDERS

By
William L. O'Brien

A Thesis
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in Partial Fulfillment of the
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MONTANA SCHOOL OF MINES
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A STUDY OF THE EFFECT OF A THIRD METAL ON THE WETTING PROPERTIES OF SOLDERS

Introduction

Solders are not new alloys, since they were known in late Roman times when they were mentioned by Pliny*. These solders differed very little from our modern ones. Tertiarium, consisting of one part of tin to two parts of lead, is known today as plumbers solder; and argentarium, consisting of equal parts of lead and tin, is still extensively used for many purposes.

Soldering methods were at a standstill for several centuries. It was not until a few years before 1432 (when the Bayswater lead circuit was installed) that wipe soldering was invented. This eliminated the necessity of sand casts which were previously used in soldering operations, and allowed the workmen to reach more inaccesible portions.

Lately, a modern machine was developed which is capable of manufacturing 300 tin cans per minute. Since tin cans require much solder, the solderers were forced to develop a machine which would not fall behind the other operations in their manufacturing.

In 1936, 20,500 short tons of tin were consumed in solders with 22,00 short tons of lead#.

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*D. J. MacNaughtan & Ernest S. Hedges, "Solders" Page 2
International Tin Research & Development Council
#"Minerals Year Book" U. S. Bureau of Mines 1938 PP. 119, 617

Definitions

A solder is any easily fusible alloy (usually lead or tin), which is used to join metallic surfaces, or to mend broken metal.

The flux is that substance which is used to prevent the surfaces of the plate metal, and the solder from oxidizing, and to clean the existing oxides from these surfaces.

The plate metal is the metal to be soldered.

Wetting (liquid on solid) is that property of a liquid to completely contact the solid, and to spread over its surface. Any liquid which does not wet a solid contracts into the shape of a globule.

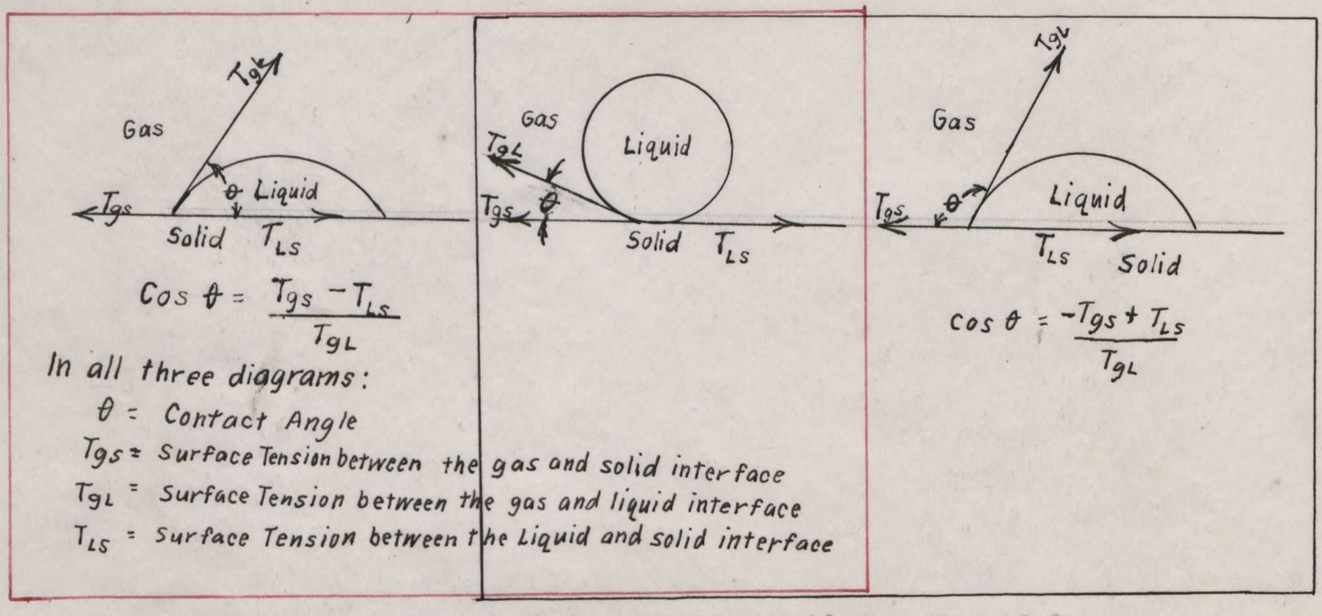
The angle of contact is the angle by which the molten solder contacts the plate metal. It is best defined the diagrams which will follow shortly. It has been satisfactorily proved that you measure the amount of wetting which has taken place, when you measure the angle of contact between two substances. It has been suggested by T. B. Crowe*that alloying is accompanied by wetting, and that alloying always follows wtting. Therefore, if the angle of contact can be determined, the amount of alloying is automatically determined, provided of course that Mr. Crowe is right.

The angle of contact taken by me, varies from that taken by Mr. Crowe, and by many other investigators.

T. B. Crowe, "Fluxes for Soft Soldering" Faraday Society And the Institude of Metals. (April 1924)

My reasons for taking a different angle of contact will be explained immediately following the accompanying diagrams. It will be noted that in both cases the trignometric functions used correspond to the angle taken.

Theory



Note: The angle used by Mr. Crowe*is enclosed by a **red** rectangle, while that one used by me is enclosed in a black rectangle.

My reasons for using this contact angle instead of the other are: 1. It is easier to compare the comparative wettability (alloyability) of one solder and base metal with another solder and the same base metal. As my angle of contact increases, the wettability of the metal by the solder increases, Mr. Crowes angle, on the other hand is always acute, so it is necessary to mention whether the solder spread, or contracted into

*T. B. Crowe "Fluxes for Soft Soldering" Faraday Society and the Institude of Metals (April 1924) the shape of a globule. 2. It does not matter which angle you take, as long as you are consistent, and you tell the reader which one you take, provided that the equation is made to comply with the angle taken.

Properties of Solders

All solders have two primary requirements.

1. They must have a low melting point
2. They must adhere readily to the surfaces of the metals to be soldered.

Most solders are alloys of lead and tin, since these alloys fill the first requirement, and with a few exceptions such as aluminum, they fill the second requirement better than other alloys.

A study of the equilibrium diagram of lead and tin* shows the effect of temperature on several of the physical properties of them, and their alloys. The diagram will be found on page , and it shows the following things. The eutectic mixture contains 61.9% tin, and 38.1% lead. It freezes at 183.3° C, while pure lead freezes at 327°C, and pure tin freezes at 232°C. The metallic compositions between this eutectic mixture, and the pure metals do not melt or freeze at any one temperature, but over a range of temperatures, during which time it is in a mushy condition. This latter condition is very important in practice. Without it

Mr. von Hansen, "Der Aufbau der Zweistofflegierungen". Page 994 wipe soldering (its development was previously mentioned in this report) would be impossible. The best mixtures for wipe soldering are between 27% and 36% tin, and the rest lead. This gives the best wiping consistency, and remains mushy over a sufficient range of temperatures to give the solderer time to complete the operation.

The same equilibrium diagram shows the following information about the solders used by me.

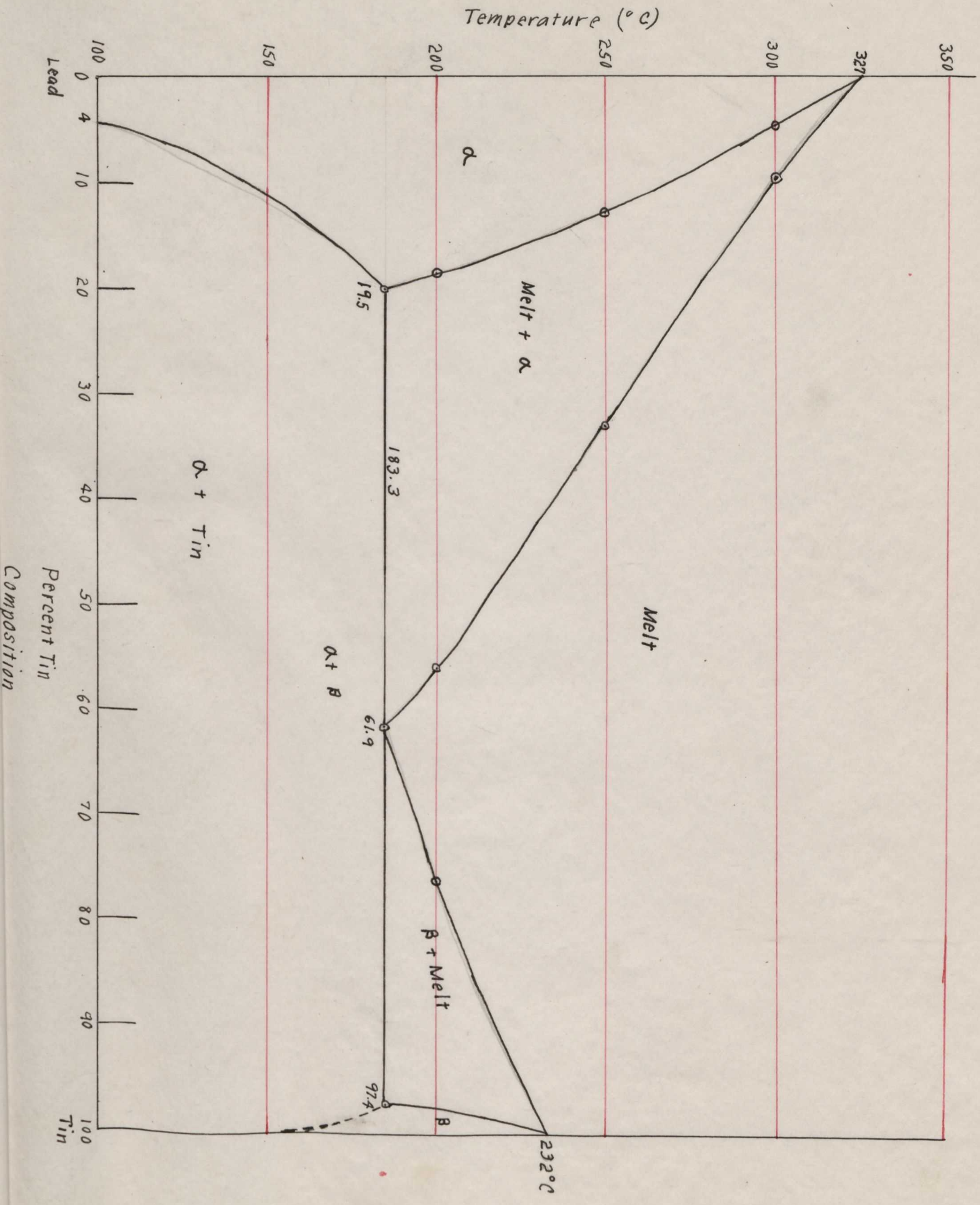
Solder % Sn	%Pb	Temperature at which Completely Liquid	Completely Solid
33	67	250°C	183.3°C
50	50	215°C	183.3°C
67	33	190°C	183.3°C

This diagram also shows that 19.5% tin is soluble in solid lead at 183.3°C, while only about 4% tin is soluble in lead at 100°C. However this fact is of little pracical importance, since most solders range from 25% tin to 67% tin. Lead is not soluble in metallic tin.

Preparation of the Solders

The three solders which were manufactured in the laboratory had the following compositions: 1. One part of lead to two part s of tin, 2. One part of lead to one part of tin, 3. Two parts of lead to one part of tin. These compositions were carefully weighed on

*D. J. MacNaughton and Ernest S. Hedges "Solder" Page 7 International Tin Research and Development Council


Temperature (°C)
100
150
200
250
300
327
350
Lead
0
4
10
20
30
40
50
60
70
80
90
100
Tin
Percent Tin
Composition
α
Melt + α
Melt
α + Tin
α + β
β + Melt
β
19.5
183.3
61.9
97.4
232°C

accurate chemical balances. To get pure, unoxidized lead an excess of test lead was melted, and the oxides were drossed off. This was then weighed with high grade tin shot. The mixtures were melted in clay crucibles, and covered with charcoal to prevent oxidation as much as possible. The molten mixtures were stirred for about five minutes with a carbon electrode.

These three solders were used to prepare other solders containing a third metal as an impurity. The third metals which were used were antimony, cadmium, bismuth, copper, and zinc. They were all added in such an amount that they equaled 10% of the solder. This gave me fifteen solders containing a third metal, three for each of the five, and the three pure solders. Besides this I had another solder containing fifty per cent tin, (plus or minus 1%), and the rest lead. This was made when two different solders accidently got mixed, and melted together. The proportions of lead and tin were known accurately however, so this solder was used as a check for the 50-50 solder which was deliberately made. This solder was also mixed with 10% antimony, cadmium, and bismuth, giving me a good check all the way through the experiment.

The plate metals used for these different solders were nickel, malleable iron, copper, zinc, and aluminum. About one square inch of each metal was used for each solder. This small plate was flattened (so that the final angle of contact could be measured accurately), and thoroughly cleaned with No. 1 carborundum cloth.

To prevent reoxidation, I used the cleaned metal within two hours. A small piece of solder was cut off of the larger piece, and placed in the center of the plate metal, which was held perfectly horizantal. The solder and the metal were covered with an excess of NH_4Cl, which is an effective acid flux. The solder was melted by the flame from a Fischer burner, with the flame shooting downward to the flux. Part of the flux would melt, and part would volatilize, but in both cases it would clean the solder and the plate metal, and keep the furfaces from reoxidizing. As the surface of the solder was cleaned, the molten solder would contract into a globule, and then when perfectly clean the globule would break and the solder spread out.

Early in the experimentation, I tried to check the angles of contact found by Mr. Prater* last year. We both used the same compositions of pure solders (no third metal), several of the same plate metals, and NH_4Cl as a flux. I discovered that by using the same quantity of flux each time, I could get a reasonably good check, but if I varied the amount a flux used the angle of contact would be materially changed. Therefore, my procedure varied slightly from his. Instead of using the same amount of flux each time, I would used a large enough excess to give the maximum angle of contact.

A Study of Solders, John D. Prater, A Thesis at the Montana School of Mines, 1939

That is I would attempt to the same final condition between the solder and the plate metal, instead of use the same amount of flux each time. If necessary I would flux the material several times to get this maximum. My experiments always showed the same maximum angle between the plate metal and the same solder, and in most cases the maximum angle approached perfect wetting or 180°, or 0°C using the same angle other investigators used. Thus, my angles of contact averaged much higher than did Mr. Prater's*, using the same plate metals, solders, and flux.

Ammonium chloride was chosen as the flux because it did not hydrolyze as readily as zinc chloride, and therefore it would remain solid if left open to air. The chief reason, of course, for using ammonium chloride is that it is one of the best solder fluxes available, being very slightly inferior to zinc chloride. When the joint was completed, the ammonium choloride would usually be eliminated by volatilization. If not it would be washed away after the solder solidified.

Experimentation

I carried on six different series of experiments.

1. The study of the wettability of the plate metals by the three pure lead-tin solders.

2. The effect of adding 10% (of total weight of solder) antimony on their wettabilities.

A Study of Solders, John D. Prater, A Thesis at the Montana School of Mines, (Bachelor of Science) 1939

3. The effect of adding 10% Cadmium.

4. The effect of adding 10% Bismuth.

5. The effect of adding 10% Copper.

6. The effect of adding 10% Zinc.

In this work the only variables used were the plate metals and the solders. The purpose of this experimentation was to find the effect of metallic impurities on the wettability of several plate metals by the impure solders. Therefore, all of the solders were tested on all of the plate metals. The effect of the impurities on each plate metal is given in tabulated form later on in the report.

Once after measuring the angle of contact made by a 50% tin, and 50% lead solder on zinc, the author decided to examine the surface of the zinc. To do this he carefully remelted the solder, and turned the plate upside down, thus pouring out the molten solder. To his surprise, the surface of the zinc had not been tinned, but some of the zinc had been melted with the solder, and a shallow pit was left. Apparently, the solder had formed a eutectic with the zinc,since none of the zinc showed thefaintest sign of being melted, except that which was directly beneath the solder. This pit is drawn to size below, and the depression was about 1/64 of an in inch at its maximum depth.

Pit in zinc (left by solder)

In melting the solders on the plate metals, I soon discovered that I could melt them at as high a temperature as desired on the nickel, steel, and copper plates, so I used the maximum heat given by the flame. More finesse was required to melt the solders on the zinc and aluminum plates, since they were easily melted at the higher temperatures. Any time the aluminum, or the zinc showed signs of being melted, I would repeat on a new specimen.

This work could be done slightly more accurately by using a neutral atmosphere of CO_2, N_2, or H_2, but since these atmosphere are not used in commercial practice, I did not even attempt to do this.

Observations

In the first series of experiments, I discovered that the lead-tin solders (all three of them) wetted the zinc and the copper completely, wetted the nickel and iron <u>very</u> slightly less, and practically refused to wet the aluminum. The solder appeared to sit on the aluminum, without contacting it, but since a slight force was necessary to free it from the plate metal, it did adhere slightly. Since it seemed to be sitting on the aluminum, the angle couldn't be accurately measured. It approximates 5°, plus or minus 3°.

In the second series of tests, the same solders with an addition of 10% antimony were used. In no case did the antimony change the angle of contact more than one

or two degrees. The flux was again NH_4Cl, the plates were again cleaned with No. 1 carborundum paper, and all the other conditions under which the experiments were carried out, were kept as constant as possible.
This shows that up to 10% antimony could be used in solders without any detrimental effects on their wetting properties. It was noted that the solder was harder to cut from the main piece, and that it was more brittle, than when it was pure lead and tin alone. This probably means that it would have a greater tensile strength than when pure, unless it became too brittle. However, since these examinations were outside the field of my experimental work, I did not make any precise measurements. These observations are borne out in a statement that up to 10% antimony, or up to 10% cadmium greatly increases the strength of tin-lead solders.*

In the third series of experiments, the solders contained 10% Cadmium. These solders very slightly lowered the wettability of nickel by solders, but had no effect on the other angles of contact. No difference could be noticed in the hardness of these solders from the originals, but apparently they are stronger (see the above paragraph).

The fourth series of experiments were made with the original solders plus 10% bismuth. Bismuth acted

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*Second General Report, International Tin Research and Development Council Page 38 like antimony. It did not effect the angles of contact, and therefore the wettability, but it did make the solders definitely harder and brittler, although not quite as noticeably so as did the antimony. From this fact, I believe that it would increase the strength of the solder if not added to excess, but since it is slightly more rare than antimony, would not displace it.

The fifth series of experiments were conducted on solders containing 10% copper. These solders were unsatisfactory, because much of the solder had too high a melting point. I believe that this is because lead and copper are practically immiscible in the solid state. The free lead would melt at a fairly low temperature, but the copper, tin, and a small portion of lead, were more difficult to melt. I believe that all three components were mixed as thoroughly as possible when molten, since I only had about fifteen grams of any one of these solders, and they were stirred for five minutes. They were readily melted in the crucibles, but probably too much heat was radiated away from them when they were placed on the plate metals. Lower percentages of copper would bear investigation, since the solder which did melt wetted all the plate metals, including aluminum.

The final set of experiments, studied solders containing 10% zinc. These solders like the others wetted the copper, nickel, zinc, and iron plates very readily, but unlike the others it wetted the aluminum almost as readily. The angles of contact ranged from

170° 40' with the solder containing equal parts of tin and lead with 10% zinc, to 164° with the solder containing one part of tin to two of lead, plus 10% zinc. According to the equilibrium diagram in Dr. von Hansen's "Der Aufbau der Zweistofflegierungen" on page 164, aluminum and zinc form two mixtures of alpha and beta crystals in the solid state, and they also form a hidden miximum compound at 83% zinc at 380° (beta), which is stable at room temperatures. Therefore, it is the zinc in the solder which wetted the aluminum, and not the tin and lead. This fact is borne out by the other experiments. None of them, with the exception of the copper one (which also forms compounds with aluminum) had any wetting effect on the aluminum, even though they all contained lead and tin. Because of this, I would recommend that any solder to be used on aluminum sould contain zinc. This has been corroborated by several other experimenters*. *They say that typical solders for aluminum contain from 50 to 80% tin, 15 to 50% zinc, and 0 to 15% aluminum. Since they contain no lead, lead must have a detrimental effect on the joint which is made. From my experiments, I do not think that this is in their wetting properties, but others such as strength, hardness, heat and electrical conductivity, etc.

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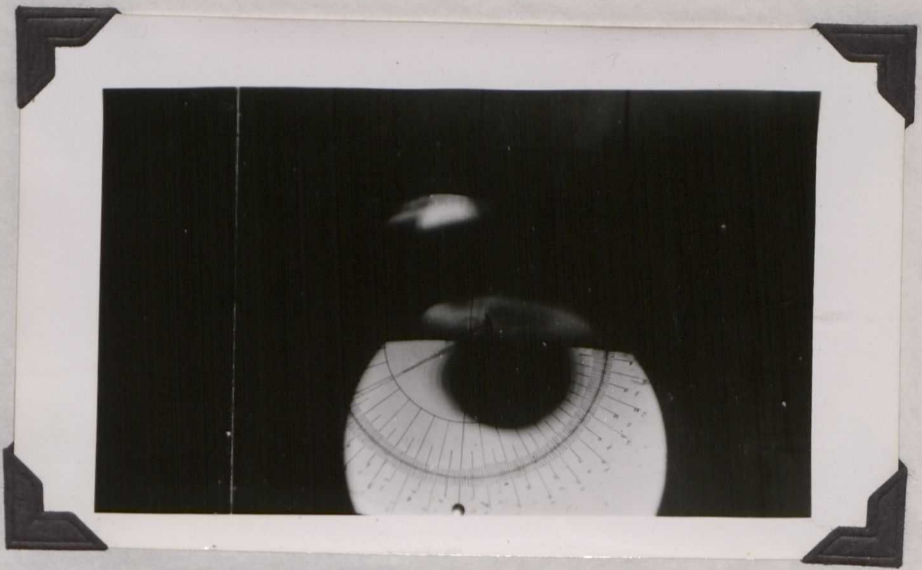
*"Notes on Soldering of Lead Pipes and Sheet Metals" Publication 93 of the International Tin and Research Council Page 18

Equipment

No No special equipment was used in preparing or soldering the plate metals. I had a Fischer burner, some No. 1 carborundum cloth, tin snips, clay crucibles, a burner stand complete with rings and triangles, and a note book.

To measure the angles of contact of the various solders with the different plate metals other equipment was necessary. The fundamental idea of this equipment was the projection of a large enough image of the plate metal and solder to give an easily measured, accurate angle of contact. To do this I used a high powered picture projector, although an ordinary light would do almost as good, a screen with a protractor drawn on it (accurate to about 15 minutes), and an occular lens (power 6.4). The solder on the metal was held as close to the ocular lens as possible by a ring stand holding a glass plate. When the metal was placed on the glass plate, it showed as a dark shadow, while the glass transmitted a greenish light to the screen. Thus you could see if the screen and image was horizantal. If not the the screen could be leveled, or raised and lowered, until the image was properly lined up on the screen. At the bottom of the protractor, corresponding to the diameter of a circle, a long needle was placed directly at the center. This could be rotated, and when placed tangent to the image of the solder, (at the point where the solder contacted the plate), it would hold the position indefinitely, until moved. This is the angle of contact, and it could be measured directly on the screen, without the necessity of drawing the tangent to the image and then measuring the angle with a separate protractor. No light could get around the ocular lens, but all had to get through it. Therefore the sides of the lens were screened with the aid of a piece of cardboard. A picture of the projector, and the box in which is the ocular lens (shown screened), and the stand on which the glass plate, and the soldered metal is in position, is shown on next page. Also a picture of the screen in use is also shown. The shadow of the globule of solder, the plate metal, the light showing through the glass, the protractor, and the needle is shown very clearly. My notes show that this is the only globule of solder which partially contacted the aluminum, enough to measure the angle of contact. This angle averaged 52° 15', and was made by 1 part of tin, to one part of lead, containing 10% bismuth. Note that in all cases where practical the average of the angle of contact was taken, by taking a number a readings in different positions and averaging them.

Projector, Ocular Lens, Specimen Holder



Protractor & Pointer on Screen is Plainly Shown
Note Inverted Image of
Solder on Screen

Aluminum Plate

Fluxed with NH_4Cl

Cleaned with No. 1 Carb. Cloth

Solder	Angle of Contact	Remarks
Sn 67% Pb 33%	$5^o \pm 3^o$	Round globule of solder sat on plate, adhered enough to require a force to free it. Tangent inaccurate hence $5^\circ \pm 3^\circ$
Sn 50% Pb 50%	$5^o \pm 3^o$	
Sn 50% Pb 50%	$5^o \pm 3^o$	
Sn 33% Pb 67%	$5^o \pm 3^o$	
Sb 10% Sn 60% Pb 30%	$5^o \pm 3^o$	Antimony had no effect on wettability of plate metal. Gives strength to solder
Sb 10% Sn 45% Pb 45%	$5^o \pm 3^o$	
Sb 10% Sn 45% Pb 45%	$5^o \pm 3^o$	
Sb 10% Sn 45% Pb 45%	$5^o \pm 3^o$	
Bi 10% Sn 60% Pb 30%	$5^o \pm 3^o$	Repeated the second solder so often trying to get another result showing good wetting
Bi 10% Sn 45% Pb 45%	150^o	
Bi 10% Sn 45% Pb 45%	$5^o \pm 3^o$	
Bi 10% Sn 45% Pb 45%	$52^o 15'$	
Bi 10% Sn 45% Pb 45%	$5^o \pm 3^o$	Fluxed 5 times.
Bi 10% Sn 30% Pb 60%	$5^o \pm 3^o$	Couldn't repeat reading

Aluminum Plate

Fluxed with NH_4Cl

Cleaned with No. 1 Carb. Cloth

Solder	Angle of Contact	Remarks
Cd 10% Sn 60% Pb 30%	$5^\circ \pm 3^\circ$	No effect on the
Cd 10% Sn 45% Pb 45%	$5^\circ \pm 3^\circ$	wettability of the
Cd 10% Sn 45% Pb 45%	$5^\circ \pm 3^\circ$	solder and plate
Cd 10% Sn 30% Pb 60%	$5^\circ \pm 3^\circ$	metal. Strengthens solder
Cu 10% Sn 60% Pb 30%	90°	Unsuitable solder.
Cu 10% Sn 45% Pb 45%	110°	Melting point too
Cu 10% Sn 30% Pb 60%	Special case (solder diffused through plate)	high. Lower percent Cu worth trying.
Zn 10% Sn 60% Pb 30%	167°	First successful
Zn 10% Sn 45% Pb 45%	$170^\circ 40'$	Aluminum solder.
Zn 10% Sn 30% Pb 60%	164°	

Nickel Plate

Fluxed with NH_4Cl

Cleaned with No. 1 Carb. Cloth

Solder	Angle of Contact	Remarks
Sn 67% Pb 33%	178°	Nickel very thoroughly
Sn 50% Pb 50%	180°	wet by tin-lead solder.
Sn 50% Pb 50%	180°	
Sn 33% Pb 67%	178°	
Sb 10% Sn 60% Pb 30%	179°	Antimony had no effect
Sb 10% Sn 45% Pb 45%	179°	on the wettability of
Sb 10% Sn 45% Pb 45%	180°	solder on nickel.
Sb 10% Sn 30% Pb 60%	178°	Strengthens solder
Cd 10% Sn 60% Pb 30%	173°	Cadmium very slightly
Cd 10% Sn 45% Pb 45%	179°	lowered the solders
Cd 10% Sn 45% Pb 45%	180°	wetting of nickel.
Cd 10% Sn 30% Pb 60%	177°	Strengthens solder

Nickel Plate

Fluxed with NH_4Cl

Cleaned with No. 1 Carb. Cloth

Solder	Angle of Contact	Remarks
Bi 10% Sn 60% Pb 30%	177°	Bi decreased the wetting power of solder on nickel slightly, but probably strengthens solder.
Bi 10% Sn 45% Pb 45%	172°	
Bi 10% Sn 45% Pb 45%	170°	
Bi 10% Sn 30% Pb 60%	163°	
Cu 10% Sn 60% Pb 30%	180°	Don't leave angle fool you. Solder unsatisfactory. Melting point too high
Cu 10% Sn 45% Pb 45%	180°	
Cu 10% Sn 30% Pb 60%	180°	
Zn 10% Sn 60% Pb 30%	180°	Zinc had little effect on wetting property of solders. Melting point slightly higher.
Zn 10% Sn 45% Pb 45%	175°	
Zn 10% Sn 30% Pb 60%	177°	

Copper Plate

Fluxed with NH_4Cl

Cleaned with No. 1 Cloth

Solder	Angle of Contact	Remarks
Sn 67% Pb 33%	179° 30'	Copper wetted
Sn 50% Pb 50%	180°	practically
Sn 50% Pb 50%	180°	perfect by
Sn 33% Pb 67%	179°	tin-lead solder
Sb 10% Sn 60% Pb 30%	180°	No evil effects
Sb 10% Sn 45% Pb 45%	180°	on wettability of
Sb 10% Sn 45% Pb 45%	180°	copper by solders
Sb 10% Sn 30% Pb 60%	180°	containing antimony
Cd 10% Sn 60% Pb 30%	180°	Cadmium acts on
Cd 10% Sn 45% Pb 45%	180°	plate like the
Cd 10% Sn 45% Pb 45%	180°	antimony did
Cd 10% Sn 30% Pb 60%	180°	

Copper Plate

Fluxed with NH_4Cl

Cleaned with No. 1 Cloth

Solder	Angle of Contact	Remarks
Bi 10% Sn 60% Pb 30%	180°	Bismuth did not lower the
Bi 10% Sn 45% Pb 45%	180°	wetting power of solder
Bi 10% Sn 45% Pb 45%	180°	on copper plate metal
Bi 10% Sn 30% Pb 60%	180°	
Cu 10% Sn 60% Pb 30%	180°	Don't leave angle fool
Cu 10% Sn 45% Pb 45%	180°	you. Solder no good.
Cu 10% Sn 30% Pb 60%	180°	Melting point too high.
Zn 10% Sn 60% Pb 30%	180°	Spread the fastest, so
Zn 10% Sn 45% Pb 45%	180°	wettability the best.
Zn 10% Sn 30% Pb 60%	180°	

Malleable Iron Plate

Fluxed with NH_4Cl

Cleaned with No. 1 Carb. Cloth

Solder	Angle of Contact	Remarks
Sn 67% Pb 33%	179°	Suprisingly good
Sn 50% Pb 50%	178°	contact between
Sn 50% Pb 50%	179°	solder and iron plate.
Sn 33% Pb 67%	179° 30'	
Sb 10% Sn 60% Pb 30%	179°	Antimony did not
Sb 10% Sn 45% Pb 45%	179°	effect the angle of
Sb 10% Sn 45% Pb 45%	179°	contact. Strengthened
Sb 10% Sn 30% Pb 60%	177°	the solder.
Cd 10% Sn 60% Pb 30%	179°	Cadmium had no effect
Cd 10% Sn 45% Pb 45%	178°	upon the angle of
Cd 10% Sn 45% Pb 45%	179°	contact. Strengthened
Cd 10% Sn 30% Pb 60%	179°	the solder.

Malleable Iron Plate

Fluxed with NH_4Cl

Cleaned with No. 1 Cloth

Solder	Angle of Contract	Remarks
Bi 10 Sn 60% Pb 30%	179°	Bismuth had very little effect on the angle of contact. Second solder the poorest.
Bi 10% Sn 45% Pb 45%	176°	
Bi 10% Sn 45% Pb 45%	179°	
Bi 10% Sn 30% Pb 60%	179°	
	melted mushy	
Cu 10% Sn 60% Pb 30%	180° 128°	Copper was hard to melt. 128° was only partially melted. Second solder again the worst.
Cu 10% Sn 45% Pb 45%	180° 190°	
Cu 10% Sn 30% Pb 60%	180° 128°	
Zn 10% Sn 60% Pb 30%	179°	Zinc had little effect on the angle of contact of iron, and solder. Middle solder again the worst.
Zn 10% Sn 45% Pb 45%	169°	
Zn 10% Sn 30% Pb 60%	179°	

Zinc Plate

Fluxed with NH_4Cl

Cleaned with No. 1 Cloth

Solder	Angle of Contact	Remarks
Sn 67% Pb 33%	180°	Zinc seems to be the easi-
Sn 50% Pb 50%	180°	est to solder. Solder
Sn 50% Pb 50%	180°	and zinc contacts each
Sn 33% Pb 67%	180°	other perfectly.
Sb 10% Sn 60% Pb 30%	180°	Antimony did not effect
Sb 10% Sn 45% Pb 45%	180°	the angle of contact in
Sb 10% Sn 45% Pb 45%	180°	the slightest. It
Sb 10% Sn 30% Pb 60%	180°	strengthened the solder.
Cd 10% Sn 60% Pb 30%	180°	Cadmium acted on the
Cd 10% Sn 45% Pb 45%	180°	solder exactly like the
Cd 10% Sn 45% Pb 45%	180°	antimony did.
Cd 10% Sn 30% Pb 60%	180°	

Zinc Plate

Fluxed with NH_4Cl

Cleaned with No. 1 Cloth

Solder	Angle of Contact	Remarks
Bi 10% Sn 60% Pb 30%	180°	Did not effect the
Bi 10% Sn 45% Pb 45%	180°	angle of contact the
Bi 10% Sn 45% Pb 45%	180°	slightest, still
Bi 10% Sn 30% Pb 60%	180°	perfect.
	melted mushy	
Cu 10% Sn 60% Pb 30%	180° 133°	Melted portion wet it
Cu 10% Sn 45% Pb 45%	180° 120°	perfectly, mushy por-
Cu 10% Sn 30% Pb 60%	180° 118°	tion fair. Poor
		Solder.
Zn 10% Sn 60% Pb 30%	179°	Seemed to be the worst
Zn 10% Sn 45% Pb 45%	179°	solder made for zinc.
Zn 10% Sn 30% Pb 60%	177°	Seems unreasonable.

Conclusions

The antimony, cadmium, and bismuth had practically no effect on the angle of contact of the plate metals with the solders used. Therefore, other physical properties such as hardness, and tensile strength would determine their uses. They have discovered that a trace of cadmium in the solder does make it slightly more difficult to work with in practice, since their conditions for soldering are not as good as in the laboratory. Careful work in the laboratory however, did not show any decrease in the angle of contact, except very slightly in the case of the nickel plate.

The copper proved unsatisfactory, since there was too high a percentage present for easy melting, and this is one of the prime requisites of a solder. However, this solder as far as seen would work very well on all the plate metals, if there was a smaller percentage of copper present in the solder, except possibly aluminum, and there is reason to believe that it would wet the aluminum better than any other of the solders tested with the exception of the zinc solder.

The zinc solder proved to be the only solder which would effectively wet the aluminum. It would also wet the other metals, if anything, slightly better than the original solders themselves. However, it is thought to be a detriment to good soldering in practice, and it probably is.

Suggestions

This field has been hardly touched so far by experimenters, so a few suggestions may help future workers. 1. If possible clean the plate metals with some etching agent, instead of with a emery or a carborundum cloth. Three fourths of the time was used in cleaning these metals, and over half of this time could have been saved by using a etching reagent, and more profitably used in other work on this experiment. It has been proved by Mr. Prater*that metals cleaned by etching solder better than those mechanically cleaned.
2. A study of the hardness of solders containing impurities would be helpful, especially if a study of their tensile strength could be incorporated with it.
3. I would investigate the measuring of the angle of contace under a low power microscope,, instead of by projecting it onto a screen. This is done in the Mineral Dressing department in the Montana School of Mines, and I believe that it is slightly more accurate. However, the method used here is plenty accurate enough, as is proven by the differences in the angles of contact of the different sides of the same soldered globule.

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*John D. Prater, A Study of Solders A Thesis for his Bachelor of Science Degree 1939

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