

# **THE EFFECT OF METALLIC IMPURITIES ON THE WETTING PROPERTIES OF SOLDER**

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## Abstract

Since the development of wave soldering machines about forty years ago, the electronics industry has become more aware that certain metallic impurities have an effect on the wetting properties of solder. Traditionally the maximum amounts of contaminating metals -- such as copper, gold, antimony, iron, zinc, aluminum and cadmium -- have been established by trial and error over many years. There is a need in the industry for substantiated data so specifications can be established for replacing contaminated solder at the proper time.

This paper is a report of a study made to determine the maximum allowable impurities in solder used for wave soldering applications. This report concludes with a list of impurities compiled from actual analyses of solder which caused production problems. A list of recommended maximum allowable impurities will assist in establishing reliable quality controls on the purity level of the solder in a wave soldering machine.

With the introduction of wave soldering machines in the late fifties, the printed circuit industry moved into the age of automation and high productivity. Like any new process, there was a period of trial and error which extended over several years to determine the operating parameters of the equipment. The technician or assembler using a hand soldering iron had much better control over the soldering situation since he could control join-to-join heating to complete properly soldered connections. Heating on the wave soldering machine, however, could not be variable if automation and productivity were to be accomplished. All joints were exposed to the same amount of heat, and only the mass of component parts being soldered determined the temperatures to which the surfaces were heated. The wave soldering machines and the problems associated with them helped advance soldering technology since the speed of soldering required more careful control of the other parameters for soldering. Studies began and still continue on the solderability of surfaces, the proper application of flux, faster acting fluxes, types of

preheating and conveyor mechanics. The temperature of the solder pot rather quickly was established at 60°-80°C higher than the melting point of the solder. This, like other parameters, was by experimentation. By far the most commonly used solder alloys were, and still are, 63/37 and 60/40 tin/lead. These alloys are low melting, bond to copper surfaces most readily, and melt over a narrow temperature range. There are many soldering fluxes to select, but after the choice is made, control is fairly simple by checking density or acid number and adding the correct amount of thinner.

At that time, twenty years ago, experience started to dictate that certain metallic and non-metallic impurities in the solder had an effect on the wetting properties of the solder and the amount of reworking of defective joints. Automatic wave soldering machines incorporate large amounts of molten solder which picks up contamination by a washing action of parts being soldered. Assuming that solderability and flux are under control, the only other factor that can have a serious effect on soldering quality is contamination in the solder. The speed of wetting is the single most important factor in automatic wave soldering since as many as 200 joints can be completed in one second. Any impurities which cause the solder alloy to become sluggish could result in icicles and shorts since the solder does not properly drain off the board as it exits the solder wave. Impurities which form intermetallic compounds with the tin or lead can cause gritty looking solder and make solder too sluggish to properly fill plated through holes in circuit boards.

Investigations have been made to determine the metallurgical changes made on bulk solder by adding large amounts of impurities. These studies, however, were very generalized and not specifically related to wave solder. Reports vary considerably as to the permissible amount of contamination contained in solder before soldering problems might occur. These investigations were done before wave soldering developed into the scientifically designed process that it is today. Original machines soldered at speeds less than a meter/minute, while today it is not unusual to see conveyors moving 4-6 times that fast. The report by the Tin Research Institute<sup>4</sup> in 1975 was very comprehensive and provided valuable information on the effects of impurities on the wetting ability of solder. Nevertheless, this study was not specifically directed to wave soldering and the results do not entirely agree with the percentages of impurities established over the years by trial and error.

The purpose of this paper is to summarize the traditionally accepted "trial and error" maximum allowable impurities, and then by testing under laboratory controlled conditions to establish maximum allowable percentages of contamination in solder used by the electronics industry.

The effects of adding certain metallic impurities to 60/40 Sn/Pb solder will be reported in terms of wetting ability, spread, appearance and the amount of solder being used to complete soldered joints by wave soldering.

SOURCE OF IMPURITIES

The solder used for this investigation was all from one batch with the following analysis:

<u>Element</u>	<u>Weight %</u>	<u>Element</u>	<u>Weight %</u>
Sn (tin)	60.1	Fe (iron)	0.006
Sb (antimony)	0.02	Bi (bismuth)	0.006
Cu (copper)	0.004	As (arsenic)	<0.01
Au (gold)	<0.002	In (indium)	0.005
Cd (cadmium)	0.0003	Ni (nickel)	<0.001
Zn (zinc)	0.0002	P (phosphorous)	<0.001
Al (aluminum)	<0.001	S (sulfur)	<0.001
Ag (silver)	0.001	Pb (lead)	balance

Though the purpose of this testing was to determine the effect of impurities dissolved during the soldering process, it is important to note that national specifications for solder are not strict enough to assure obtaining high purity metal. Secondary or refined metal could contain excessive impurities and shorten the usable life of the solder bath. Impurities such as copper, antimony, zinc and aluminum have an effect on soldering quality and should be kept to a minimum.

Assuming that high purity solder is being used, the impurities are introduced into the solder from parts being soldered, from holding fixtures and from the solder pot itself.

Copper - Nearly everything on a printed circuit assembly is made of or plated with copper which dissolves rather rapidly in solder. The circuit board itself, component leads and jumper wires all introduce copper into the solder in a wave soldering machine.

Gold - No longer used as an overall protective plating, gold is used on certain component leads such as nickel-iron alloy used to make transistors, diodes and integrated circuits.

Cadmium - Sheet metal chassis frames and other parts might be cadmium plated to prevent rusting and improve appearance and solderability.

Zinc - Brass is an alloy of zinc and copper; so brass terminals, lugs and bolts are sources of impurities.

Aluminum - Fixturing devices, bolts and fabricated metal parts might be made of aluminum. The tough oxide film on the aluminum will usually prevent solder wetting; but with multiple

solder immersions or if abraded, aluminum can dissolve in the solder. It is doubtful that aluminum will remain in the solder under production conditions since it will dress out when combining with copper, gold or antimony.

Silver - Many parts are silver plated to preserve solderability. Like the other coinage metals, gold and copper, silver will dissolve in the solder.

Iron - Temperatures over 430°C will cause the solder to dissolve iron from the solder pot itself. An improperly alloyed solder using too much heat could contain excessive iron. A new solder pot -- whether cast iron, cold-rolled steel or stainless steel -- will have exposed iron available for dissolution into the solder. Excessive cleaning of the pot walls with a wire brush can also introduce iron into the solder. The problem associated with iron contamination is excessive dressing which usually clears up as the iron compounds are removed with the dress.

Sulfur - It is very unlikely that sulfur would contaminate the solder bath during normal production. Sulfur might be present in secondary metals since it is used to remove copper during the refining process. Sulfur should be limited by national solder specifications to avoid its presence in solder.

Phosphorous - The main source of phosphorous is copper that has been deoxidized with phosphorous.

### PROBLEMS ASSOCIATED WITH IMPURITIES

Phase 1 of the investigations involved a compilation of analyses performed over the last ten years for the specific purpose of solving soldering problems. The amount of impurities in the solder was related to observed defects or solder conditions. These defects, specifically caused by contaminated solder, are noted below with some discussion about the impurities which caused the problem. The table following this discussion shows the percentage range of impurities which seemingly caused the observed soldering defects.

#### Icicles, Shorts, Bridges

Cadmium, zinc and aluminum in trace amounts increase the surface tension of the solder to cause this defect. Copper and gold increase the solder viscosity to cause the same problem.

#### Large Solder Fillets

Copper, gold and antimony increase the melting point of the solder and the intermetallic compounds with tin or lead make the solder more sluggish. The result is larger fillets and more solder consumed to create the solder joint.

#### Unfilled Holes

The speed of wetting is reduced by the presence of copper, gold, antimony and cadmium. Though no instance occurred with zinc and aluminum, these metals are likely to also affect wetting speed because of their ability to increase the surface tension of the solder.

#### Dull Solder, Gritty Solder

Cadmium and zinc in trace amounts make the solder surface dull. Gold also dulls the surface but is quite often indicated by a sparkling, crystalline surface condition. Bismuth or antimony in large amounts above 2.5% also dull the surface. Copper and aluminum contamination result in a gritty-looking solder surface. Both phosphorous and sulfur have caused gritty solder though rarely are these two impurities found in solder samples.

#### Dross Inclusions

Dross inclusions in the solder show up as visible particulate grit or hidden inside a bump or pimple in the otherwise shiny solder surface. Quite often the source of this problem is an unusual amount of iron in the solder.

#### Cracked Joints

Inclusions in the solder such as intermetallics of tin or lead with copper, gold and antimony can provide the nucleus for crack propagation.

#### Dewetting

Zinc, antimony and phosphorous can cause solder to dewet on copper.

By looking at the real world of wave soldering and the ten years of analytical records, we can summarize the impurity levels which traditionally caused problems.

<u>Impurity</u>	<u>% When Problems Occur</u>
Cu (copper)	0.250 - 0.500
Au (gold)	0.005 - 0.200
Cd (cadmium)	0.005 - 0.150
Zn (zinc)	0.001 - 0.010
Al (aluminum)	0.001 - 0.006
Fe (iron)	0.010 - 0.100
Sb (antimony)	0.100 - 1.000
Ag (silver)	0.200 - 2.000
Bi (bismuth)	0.250 - 1.000
As (arsenic)	0.030 - 0.100
In (indium)	no data
Ni (nickel)	0.010 - 0.030
P (phosphorous)	0.010 - 0.100
S (sulfur)	0.002 - 0.030

Immediately obvious by an examination of this list is the fact that the percentages established by experience are not precise numbers. The explanation for this is that the defects cause by the

impurities may be acceptable at one company and cause for rejection at another company. Rigid inspection requirements for aerospace or military products might reject solder joints which are acceptable for consumer products. Difference between fluxes, soldering machines, circuit board density, component layout, hole sizes, solderability and amount of heat all contribute to the quality of soldering.

## REFERENCES

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