# Lead-Free Soldering

## Objectives

* Define lead-free soldering.
* Define lead-free solder.
* Describe flux used for lead-free soldering.
* List the advantages of switching to lead-free soldering.
* List the disadvantages of switching to lead-free soldering.
* Describe the impact of lead-free solder on hand soldering.
* Describe the thermal profile for lead-free soldering.
* Describe proper heat transfer for lead-free soldering.
* Describe the effect of lead-free solder on iron tips.
* List characteristics of a good joint.
* Describe common lead-free soldering defects.

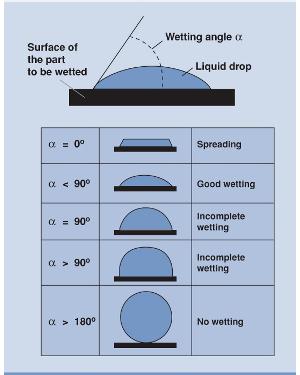


## What is Lead-Free Soldering?

Probably the most significant trend in soldering applications is the increase of **lead-free soldering**. Lead-free soldering refers to soldering with metal **alloys** that contain only trace amounts of **lead** or no lead at all. Because lead has been identified as a highly **toxic** substance, it has already been eliminated from paint and gasoline. As you can see in Figure 1, if landfills fill up with old TVs, radios, and electronic games containing **lead-based solder**, there is concern that lead will seep into the **water table** and contaminate it.   
  
In light of these concerns, Europe and Japan are currently taking serious measures to phase out lead-based solders completely within the next few years. The U.S. will also likely follow suit. In fact, the transition to lead-free solder is one of the most significant industrial changes since the banning of **chlorofluorocarbons** (CFCs) from products like hairspray and air conditioners. The current shift to lead-free technology will affect household appliances like the washer and refrigerator shown in Figure 2, computers, lighting equipment, electrical tools, electronic toys, and more.  
  
In this class, you will learn the specific characteristics, flux requirements, and thermal profile of lead-free solders. You will also learn the proper techniques to apply when using these new solder materials.

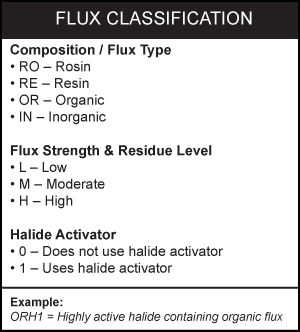
## What is Lead-Free Solder?

**Lead-free solder**, also known as **Pb-free solder**, is basically any solder that contains less than 0.2% lead. This is such a small amount that it is almost the same as having no lead at all. Because there is no single substitute for lead, lead-free solders must be developed from **alloys** in various combinations of tin, silver, copper, antimony, bismuth, indium, or zinc. Figure 1 shows a joint made with a lead-free alloy.  
  
Each alloyed metal is suitable for different production requirements. Consequently, numerous lead-free solders are available. Some of the more common lead-free alloys are **SAC** (tin, silver, and copper) and **SnCu** (tin and copper). Of the two, SAC is usually preferred for its lower melting point. Since there are many possible formulations, the melting point of lead-free solder varies depending on the type of alloy. However, all lead-free solders have a significantly higher melting point than lead-based solder.  
  
Lead-free solder is duller and grainier in appearance than lead-based solder. It also has higher **surface tension**, which leads to reduced **wetting** capability. This means that the solder spreads out more slowly, and the finished joint is shaped differently from one created with lead-based solder. Solder with poor wetting does not flatten and covers very little surface area, as shown by the examples of incomplete wetting and no wetting at the bottom of Figure 2. The top portion of Figure 2 shows how a solder with good wetting flattens and spreads out over a surface.



## Flux for Lead-Free Soldering

**Flux** is the most important factor to consider when choosing lead-free solder wire due to its influence on wetting. Most types of wire already contain flux at the core, as illustrated in Figure 1. When using lead-free solder, the flux at the core of the solder wire should be organic, highly active, and contain a **halide**. This type of flux would be classified **ORH1**. Figure 2 shows how different types of flux are classified.  
  
The flux in the solder core should account for at least 2% of the solder wire by weight. This is twice the amount of flux used in traditional lead-based solder wire. In fact, some lead-free solders have as much as 3.3% flux. Given this increase in flux quantity, you should not apply additional flux from a **flux pen** or a squeeze bottle when using lead-free solder wire.   
  
You should also keep in mind that, in addition to being present in larger amounts, fluxes used in lead-free solder are also more potent than those used for lead-based solder. Therefore, it is more important than ever to protect yourself by wearing protective glasses and using a **fume extractor** like the one shown in Figure 3 when soldering.



## Advantages of Lead-Free Soldering

In the United States, lead-free technology is still relatively new compared to Japan and Europe, but it has already shown several advantages:

* Using lead-free solder eliminates the risk of lead poisoning from exposure while soldering (Figure 1), or from lead-based products in landfills leaching or seeping into the water and the environment.
* Transitioning to lead-free technology has led to the creation of new industries for analyzing and testing lead-free solder and training manufacturers to use it effectively.
* Producing lead-free products offers a wider choice to consumers who wish to "buy green" and help the environment (Figure 2).

Of these advantages, environmental safety still remains the primary and most important reason for switching to lead-free soldering.

## Disadvantages of Lead-Free Soldering

As with any transition, there are still difficulties with lead-free soldering that must be resolved before manufacturers can fully embrace this new technology. For example:

* The higher temperatures required for lead-free soldering can damage the soldering equipment or cause defects in the end product (Figure 1).
* There is still some concern about the reliability of lead-free solder. Companies may have to divert additional resources to research and testing before switching.
* Many electronic products are still manufactured with lead-based components. Manufacturers have yet to catch up with the growing demand for lead-free technology.
* Lead-free solder has a different appearance and consistency than lead-based solder, and therefore much of the existing criteria for visual inspection cannot be applied. New inspection methods and standards must be created (Figure 2).
* Lead-free solders often use much higher amounts of silver, making lead-free solders more expensive than lead-based solders and more prone to **whiskers** (Figure 3).

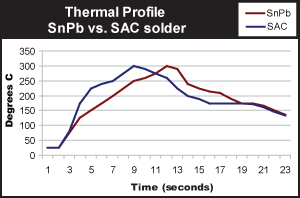
Despite these disadvantages, most scientists, governments, and industry leaders agree that the health and environmental benefits of switching to lead-free solder outweigh the difficulties of using it.

## Hand Soldering with Lead-Free Solder

Only 10-20% of all soldering is done by hand. However, because the switch to lead-free solder applies to hand soldering as well as automated soldering, technicians must adopt new methods and procedures when using lead-free solder.   
  
Lead-free solder has higher **surface tension** than lead-based solder. This means that lead-free solder spreads out more slowly. Technicians must be patient and allow more time for joints to form. In addition, the reduced **wetting** capability of lead-free solder requires a lower **contact angle**. Contact angle refers to the angle at which a liquid meets a solid surface. A liquid hitting a surface from directly above would have a high contact angle, while a liquid hitting a surface from the side or at a slant would have a lower contact angle. The lower the contact angle of a liquid, the greater its wetting capability. The top of Figure 1 shows a drop of liquid that has hit a surface at a slant.   
  
You may be tempted to "max out" the temperature of your soldering iron to improve wetting and speed up the process, but this is not recommended. Fluxes for lead-free solders tend to be more active, meaning they are more **corrosive** and react to heat more quickly. In fact, a hotter iron can cause flux to stick to the iron tip and blacken, as you can see in Figure 2.

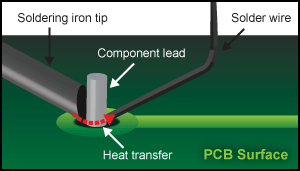
## Lead-Free Soldering: Thermal Profile

A **thermal profile** is the range of temperatures involved in a heating process. The thermal profile for soldering is divided into three stages. First, the iron reaches temperatures above 392°F (200°C), which activates the flux. Then the iron must reach a temperature that is 104°F (40°C) above the **eutectic point** for solder wetting to occur. After soldering takes place, the heated tip is removed and there is a brief cooling period, during which the joint solidifies.   
  
Lead-free solder has a different thermal profile than lead-based solder, as illustrated in Figure 1. Lead-free solder heats faster, takes a few seconds longer to achieve full wetting, and cools sooner than lead-based solder. Technicians must understand the differences of lead-free thermal profiles and adjust their soldering techniques to ensure proper flux activity, solder wetting, and joint cooling.



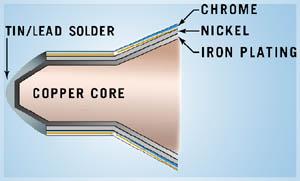
## Lead-Free Soldering: Proper Heat Transfer

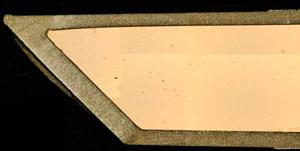
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| |  | | --- | | When a soldering iron is heated, the heat is stored in the iron’s tip. As you touch the tip to a metal surface, **heat transfer** occurs. As you can see in Figure 1, the heated joint is what actually causes solder to melt and not the iron itself. However, repeated heat transfer from soldering multiple joints with an iron causes the soldering iron tip to cool over time. Technicians may have to wait for the tip to fully reheat before soldering the next joint.  Technicians tend to compensate for this cooling tendency by keeping their irons at the maximum temperature all the time. This is not a good practice when using lead-free solder because it can increase **oxidation** and decrease solder efficiency. In addition, because flux burns at a much lower temperature than solder, the flux will burn off and evaporate before it has had a chance to work if too much heat is applied too quickly. Therefore, your soldering iron should not be set above 750°F (400°C) unless absolutely necessary. | |

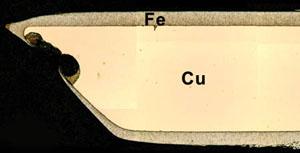


## Effects of Lead-Free Solder on Soldering Tips

Although it may be small, the standard soldering iron tip consists of many layers and materials. At its core, the tip is made of copper to enable **conductivity**. A protective layer of iron plating surrounds the core. At the sides of the tip, plates of nickel and chrome are applied to prevent solder from **wicking** away from the tip. Finally, the tip of the iron is **pre-tinned** with a coating of solder. Figure 1 shows the inner and outer layers of a soldering iron tip.  
  
Despite these multiple protective layers, lead-free solders can be damaging to the soldering iron. This is due to the corrosive nature of lead-free alloys and fluxes, coupled with higher soldering temperatures. Once the iron plating breaks down, the copper core of the tip rapidly dissolves, causing tip failure. Tip life is often drastically shortened. For example, a tip that lasted three months with lead-based solder might wear out in three weeks with lead-free solder. Figures 2 and 3 show a cut-away view of a new soldering iron tip, and what happens to that tip after it has been corroded.  
  
For maximum efficiency, you should use a tip that has been specifically manufactured to work with lead-free solder. Furthermore, the tip should be cleaned, well-tinned, and similar in size and shape to the object being soldered. Never use the same tip for lead-free solder after using it for lead-based solder, or you will contaminate the lead-free solder.





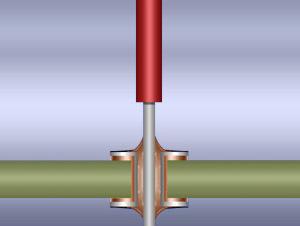


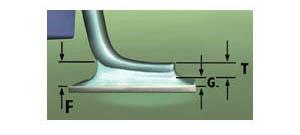
## Characteristics of a Good Joint

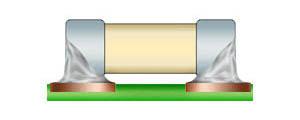
Because lead-free solder looks and behaves differently than lead-based solder, a good lead-free joint has its own unique characteristics. A good lead-based joint appears smooth and shiny, but since lead-free solder is dull and grainy by nature, this standard does not apply. However, it is safe to say that a good joint is created with:

* Flux, solder, and materials that match the job's specific requirements.
* Methods, materials, and environment appropriate to the quality standards of end product.
* Sufficient heat and appropriately controlled time, temperature, and heat distribution.
* Skilled technicians and product inspection according to industry standards for procedures and quality control.

The finished joint should appear relatively smooth with a convex slope, as well as adequate solder coverage that conforms to the size and shape of the joint. Figures 1 through 3 illustrate examples of good joints that exhibit these traits. However, given the complexity of the soldering process and the special requirements of lead-based solder, defects can still occur along the way. Badly soldered joints are always a risk with lead-free materials.



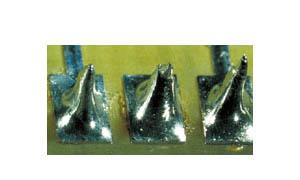




## Common Lead-Free Soldering Defects

In a quality joint, the solder should cover the entire pad, which is the metal area on the circuit board to which you are soldering the part. The solder should slope evenly down from both sides of the part at a low angle. You might have a defect if the solder does not completely cover the pad, if the solder looks like droplets or balls, or if the solder slopes down from a large angle.  
  
Lead-free soldering demands a delicate balance between process time, flux activity, and heat in order to create a good joint. For instance, although raising the temperature on your soldering iron may improve solder **wettability**, it could negatively affect flux activation or even cause damage to the object you are soldering. On the other hand, if the iron is too cool, you may end up with defects such as cold joints or icicles.  
  
Figure 1 shows a **cold joint**, also known as a dull joint, which has poor wetting and a dull, grainy appearance. In the case of lead-free solder, which is already somewhat dull and grainy, the joint would be even duller and grainier than normal. **Icicles**, shown in Figure 2, are jagged extensions or spikes protruding from a soldered joint. They are caused by soldering at too low a temperature, or transferring heat too rapidly to the metal surface.  
  
Another soldering defect is poor wetting, which is shown in Figure 3. This occurs when there is insufficient solder to surround the joint. One possible cause of poor wetting is oxidation. Solder will not wet metals that are badly oxidized or have grease or dirt on the surface. Some possible solutions to poor wetting are adjusting your iron temperature or choosing a more active flux.







## Summary

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| |  | | --- | | Lead-free soldering uses metal alloys that contain only trace amounts of lead, or no lead at all. The transition to lead-free technology is a significant industrial change that will affect many consumer products.  The primary advantage of switching to lead-free solder is environmental safety. However, because lead-free technology is still relatively new, there are still problems with lead-free soldering that must be resolved before manufacturers can fully embrace this new process.  Lead-free solder is also known as Pb-free solder, and it must contain less than 0.2% lead. Because there is no single substitute for lead, lead-free solders must be developed from various other alloys, with SAC and SnCu solders being the most common. Lead-free solder is duller and grainier than lead-based solder and has reduced wetting capability.  Most types of lead-free solder wire use no-clean flux. Ideally, the flux at the core of your solder wire should be classified ORH1 and account for at least 2% of the solder wire by weight. Because of the increased quantity and potency of flux used for lead-free soldering, you should always wear protective glasses and use a fume extractor when soldering.  Lead-free solder has a different thermal profile than lead-based solder. Therefore, you will have to adjust your soldering technique. Improper iron temperature, flux strength, or soldering technique can lead to defects such as cold joints, icicles, or poor wetting. | |