

UNDERSTANDING SOLDER DROSS: CAUSES AND CONTROL STRATEGIES

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Dross formation is an inevitable consequence of wave soldering. It occurs when molten solder comes into contact with oxygen, forming metal oxides that float on the surface of the solder bath. Over time, this oxidation byproduct accumulates and must be removed to maintain solder quality and process consistency. While the presence of dross is expected, the rate at which it forms—and the effort required to manage it—can vary widely depending on several process and material variables.

A common question from manufacturing teams is: How much dross is normal? The reality is that there is no universal benchmark. Drossing rates are influenced by a combination of factors including the solder alloying process, the temperature and agitation of the solder bath, the presence of contaminants from the assembly, and the overall condition of the equipment. What may be acceptable in one process could be excessive in another.

This article outlines the main contributors to dross formation, examines how alloy refining methods play a role, and explores practical ways to reduce dross through process control and equipment optimization. Special attention is given to the use of additives such as phosphorous and the challenges associated with maintaining consistent dross reduction over time.

What Is Solder Dross and Why Does It Form?

When molten solder is exposed to air, it reacts with oxygen to form metal oxides—primarily tin oxide in

most electronic solders. These oxides, often combined with burned organic residue, float to the surface and form dross.

If not removed regularly, dross can disrupt the process, affecting solder flow, and compromising PCB quality.

Dross typically results from normal oxidation, not alloy impurities. However, excessive or rapid drossing can signal issues with alloy oxide content, process temperature, or turbulence.

Dross formation rate is influenced by several factors—most notably alloy composition, solder pot temperature, wave agitation, and contamination from boards or components.

Alloying and Oxide Content

Bar solder manufactured from “virgin” metals is not inherently low-dross. If the alloying process introduces or fails to remove oxides effectively, the resulting solder can exhibit oxidation rates similar to or worse than poorly processed recycled alloys. Oxides that remain suspended in the alloy will contribute directly to early and sustained dross formation once the solder is in use.

On the other hand, bar solder produced using controlled, oxide-minimizing processes tends to dross more slowly and more predictably. The key factor is not whether the metals are new or recycled, but whether oxides and oxidation-prone impurities

have been adequately removed during alloying and casting manufacturing.

Thermal Conditions

Solder pot temperature is one of the most direct contributors to dross formation. As temperature increases, so does the oxidation rate. For eutectic Sn63/Pb37, typical operating temperatures fall in the range of 480°F to 490°F (approximately 250°C to 255°C). For SAC305 and similar lead-free alloys, pot temperatures are generally higher—often between 500°F and 520°F (260°C to 271°C).

Operating above these ranges can significantly accelerate oxide formation. However, reducing pot temperature to limit dross must be balanced against process needs, as too low a temperature can compromise hole fill, wetting, and overall soldering performance.

Wave Characteristics and Agitation

Mechanical agitation of the solder surface, particularly from turbulent wave designs, increases drossing. When the solder is static, less surface area becomes exposed to air, and oxidation proceeds more slowly. In systems that rely on chip waves or generate constant movement at the solder-air interface, the exposed surface area increases, leading to more rapid oxidation.

Wave design, pump condition, and the use of standby modes all factor into how much solder is exposed to air at any given time. Systems equipped with intelligent wave control that reduce agitation when no boards are present typically produce less dross over time.

Contaminants from Assemblies

PCBs and components introduce additional complexity. Copper, gold, nickel, and other surface finishes can dissolve into the solder pot, subtly changing the alloy's behavior and increasing the formation of intermetallics or oxide inclusions.

Organic contaminants, such as flux residues, can also interact with molten solder, creating undesirable byproducts.

Routine solder pot analysis can help identify rising levels of contamination and guide corrective action. Maintaining impurity levels within IPC-recommended limits is essential not only for minimizing dross but also for ensuring joint reliability.

Additives and Approaches to Dross Reduction

Efforts to reduce dross formation typically follow two main paths: altering the solder alloy itself or modifying the environment in which soldering takes place. Both approaches aim to slow oxidation and limit the accumulation of unusable material.

To mitigate oxidation and reduce dross, some operations employ additives such as commercially available solder surfactants. While these can be effective, they also introduce challenges: maintaining an additional material in the process, ensuring proper dosing, and managing potential instability or unintended interactions with the solder alloy or contaminants.

Phosphorous as a Dross-Reducing Additive

One common method of reducing visible dross is the addition of phosphorous. Phosphorous acts as an oxygen scavenger, preferentially oxidizing before the tin in the alloy reducing dross generation. For manufacturers working with higher oxide content material, phosphorous additions offer a relatively simple path to improved appearance and somewhat reduced waste.

However, phosphorous use carries notable drawbacks. It tends to plate out on iron components in the solder pot, such as pumps and baffles, often leading to clogging or surface buildup. In some systems, this buildup can lead to flow disturbances

or wave instability. Moreover, phosphorous is easily removed from the pot during dross removal, which means its concentration may fall over time unless carefully monitored and replenished.

At elevated concentrations, phosphorous can also interfere with wetting. Research has shown that phosphorous levels above 0.01% by weight can contribute to dewetting and solder joint cracking. This presents a long-term risk in high-reliability assemblies, especially when phosphorous levels are not routinely analyzed, as conventional solder pot analysis does not typically include this element.

Atmospheric Modification (Nitrogen Inerting)

Another approach is to reduce the oxygen available for oxidation in the first place. This is done by inerting the soldering environment with nitrogen. Reducing ambient oxygen levels to 50–100 ppm significantly slows the rate of oxide formation and, by extension, dross accumulation.

Nitrogen inerting has been shown to reduce dross generation by up to 90% in some wave soldering systems. It also improves wetting by lowering the surface tension of the molten solder. The benefits, however, come with added complexity: inerting systems require gas handling infrastructure, flow control equipment, and in some cases, modifications to the soldering machine itself.

Minimizing Dross Through Process Stability

In many cases, the most effective way to reduce dross is not to add something new, but to control what is already in place. Maintaining proper solder pot temperatures, minimizing wave turbulence, and keeping equipment in good mechanical condition can all have a significant impact on dross levels. Additionally, ensuring that assemblies are clean and compatible with the solder alloy in use helps reduce the introduction of extraneous materials that can drive oxidation.

Advanced bar solder formulations that are manufactured with low suspended oxide content—rather than those relying on chemical treatments post-production—tend to exhibit more stable long-term behavior with respect to dross. These materials are less reactive, less prone to oxide regeneration during use, and generally easier to maintain across extended production runs.

Managing Dross and Solder Pot Health

Even under optimal conditions, some dross formation is inevitable. For this reason, regular maintenance of the solder pot and surrounding equipment is essential. Effective dross management isn't just about removing surface oxide—it also involves monitoring contamination levels, identifying early signs of instability, and maintaining consistent operating parameters.

Dross Removal and Equipment Conditioning

Dross removal should be performed carefully to avoid removing excessive amounts of good alloy along with the oxide layer. In some cases, particularly after a solder changeover or when new bar solder is added, residual oxides or surface buildup on pot walls, pump shafts, or baffles can mix back into the solder. A controlled “burn-in” period—where the solder pot is held at operating temperature in a static state overnight—can help settle and separate any suspended oxides from the new solder charge.

Following this conditioning step, a thorough but gentle removal of accumulated dross helps stabilize the pot and reduce the risk of premature oxidation during startup.

Solder Pot Analysis and Alloy Integrity

While dross is a visible indicator of oxidation, many chemical changes occur in the solder bath long before they're noticeable on the surface. Regular solder pot analysis—typically conducted monthly or quarterly—provides insight into the accumulation of

contaminants such as copper, gold, zinc, aluminum, and iron. These elements can enter the pot from component terminations, board plating, or even the alloy itself.

Standards such as IPC J-STD-001 and IPC J-STD-006 define acceptable levels for these contaminants. Exceeding these limits can lead to a range of issues including:

- Reduced wetting or flow
- Joint defects (e.g., voids or incomplete fill)
- Changes in solder alloy melting behavior

In lead-free systems, elements such as nickel and bismuth are of particular concern due to their low solubility and effect on intermetallic formation. When contaminant levels approach threshold values, corrective actions may include dilution with fresh alloy, removal of dross with high contaminant content, or in more severe cases, a full pot dump and recharge.

Dross Recycling and Reclaim Programs

Because dross contains a significant amount of usable metal, recycling is an important part of cost control in wave soldering operations. A well-managed reclaim program allows manufacturers to recover value from what would otherwise be considered waste. Collected dross can be processed by specialized metal recovery services to extract reusable solder, which is then credited back or returned in usable form.

While some facilities attempt to implement internal recycling systems—such as on-site dross reduction equipment—these setups can introduce new challenges. In many cases, such systems rely on chemical or thermal treatments that generate fumes, increase maintenance demands, or introduce variability into the recovered solder. If not tightly controlled, internal recycling can lead to inconsistent alloy quality and contamination risks.

For most operations, working with a qualified external reclaim partner offers a more consistent and cost-effective solution, ensuring recovered solder meets quality standards and minimizing disruption to the production process.

Conclusion

Dross formation is an inherent part of wave soldering, driven primarily by oxidation at the solder surface. Ultimately, consistent process control, appropriate alloy selection, and regular maintenance offer the most reliable path to minimizing dross and preserving solder quality. A well-managed soldering system doesn't just reduce material waste—it also supports long-term stability, product reliability, and manufacturing efficiency.