Determining Solder Alloy and Base Metal Compatibility

Simple test methods provide important information about solder and base metal interactions

BY ALEXANDER E. SHAPIRO

Compatibility of standard solder alloys, such as Sn-37Pb or Sn-3.5Ag (in wt-%) with common base metals, such as copper or other solderable surface finishes, is well known and understood. As new materials and processes are introduced, however, the compatibility of solder alloy and base metal may not be as obvious and will require further examination. This can be accomplished very effectively and efficiently through several simple compatibility evaluations. The key characteristics to consider are as follows:

- Wetting of the base metal by the liquid solder, typically characterized by the contact angle;
- Spreading the solder along the base metal surface, characterized by the spread area;
- General dissolution of the base metal by the molten solder, characterized by base metal erosion and a change to the solder composition;
- Intergranular corrosion of the base metal, characterized by solder penetration along the base metal grain boundaries; and
- Intermetallic compound (IMC) formation and growth at the solder/base metal interface and within the solder region.

Typical engineering methods that precisely measure the contact wetting angle include the use of both specialized optical instruments and a sufficiently large statistical test population that is representative of the application's materials and processing conditions. Simpler, screening evaluations can also be conducted with fewer test specimens to quickly estimate general process trends. An example of the latter approach is illustrated in Fig. 1. The method is very adaptable to field and shop floor use. The test involves dipping a base metal wire, 0.5–1 mm (0.02–0.04 in.) in diameter, into a molten solder bath to "pretin" the wire. The tinned wire is then placed on a flat 25- × 25-mm (1- × 1-in.) test coupon and chemical flux is applied to the test area prior to heating to the soldering temperature. It is held at temperature for approximately 5–7 s and permitted to cool. After washing to remove any flux residues, the test specimen is sectioned and polished by fine-grade abrasive paper. The contact angle is then measured with a magnifying lens or optical microscope at low magnification. Typical measurement accuracy is ± 2 to 5 deg, depending on the type of instrument used.

Solder spreading can be assessed by

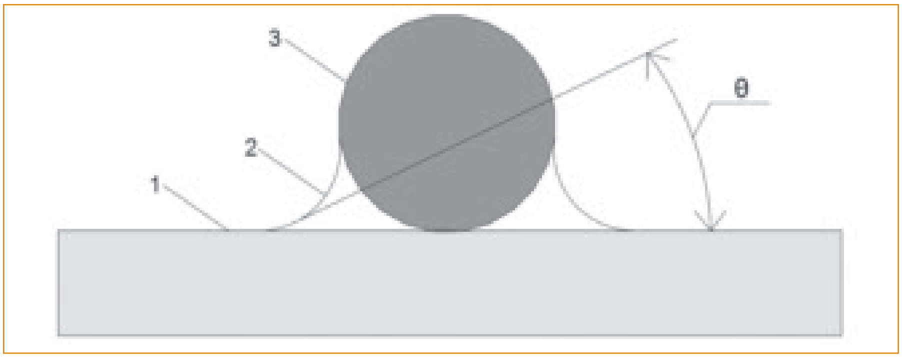

Fig. 1 — Measurement of the contact angle after wetting. Cross section of copper wire soldered to a base metal plate: 1 — Base metal, 2 — solder after wetting, 3 — copper wire, and θ — contact angle.

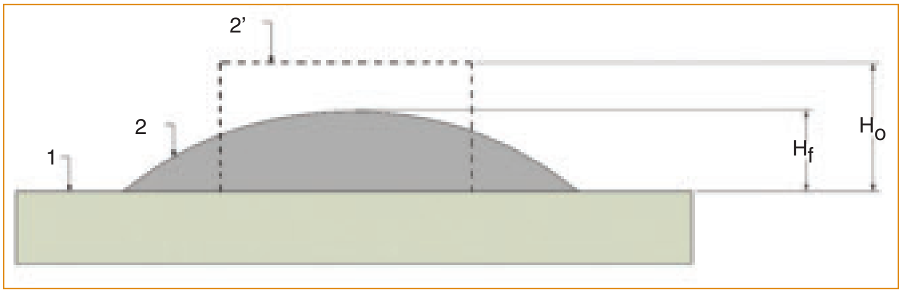

Fig. 2 — Cross section of the solder droplet after wetting the substrate: 1 — base metal; 2 — solder after the wetting test; and 2' — solder before the wetting test.

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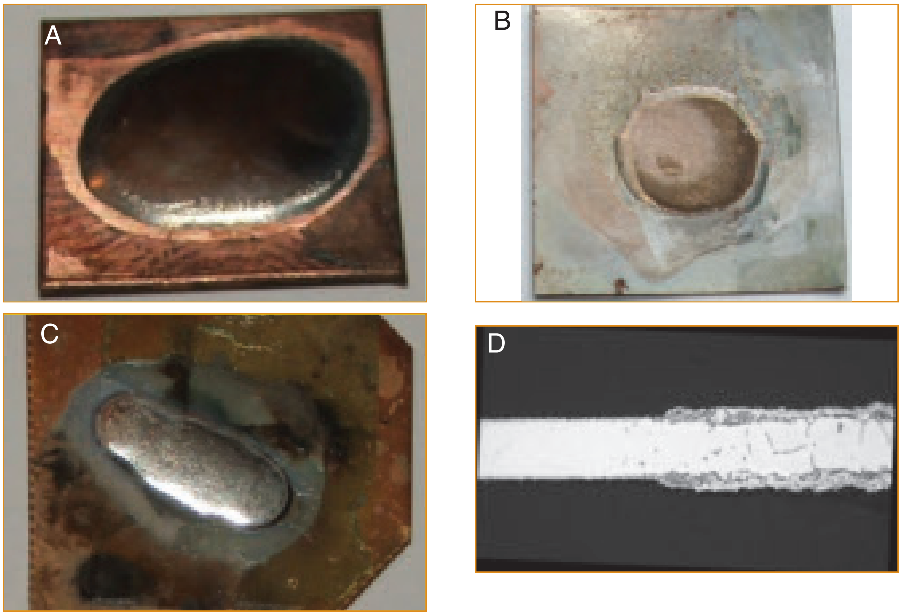

Fig. 3 — Solder spreading patterns: A — Good wetting and flow behavior of Sn-3.5Ag solder on copper; B — "hat brim" spreading of Sn-3.5Ag-0.7Cu on stainless steel; C — "halo" around a mass of Sn-20Zn solder on copper; and D — erosion of base metal after soldering with Zn-8Al-1Mg solder.

two criteria and measured simultaneously on the same test specimen (Fig. 2):

1. Area coefficient of spreading $K_a = S_f/S_o$, where S_o, in.^{2} (mm^2), is the area covered by solder before the test, and S_f, in.^{2} (mm^2), is the area covered by the solder after spreading; and

2. Height coefficient of spreading $K_h = H_f/H_o$, where H_o, in. (mm), is the height of the initial applied solder, and H_f, in. (mm), is the solder height after spreading.

The values of $K_a \geq 2$ and $K_h \leq 0.5$ characterize satisfactory spreading of the solder. The recommended solder volume for the spreading test is 0.0025 in.^{3} (40 mm^3), equivalent to a 0.2-in.- (5.1-mm-) long solder wire with a 0.125-in. (3.2-mm) diameter.

The outer boundary of the solder droplet region and its internal structure can provide additional information about base metal and solder alloy interactions, such as base metal dissolution and erosion, grain boundary penetration, and intermetallic compound formation and growth. All of these reactions can influence subsequent properties and product reliability and are observed through metallographic crosssections of the solidified solder droplet. Typical features include the following:

1. A symmetric, uniform solder droplet with a low contact angle, representative of good wetting and flow behavior (Fig. 3A); this condition is generally indicative of correct soldering materials and processing parameters.

2. A second spreading feature is shown in Fig. 3B. The cross section of the solder droplet is shaped like a hat brim. The shape is usually observed when soldering multicomponent base metals, such as stainless steel, nickel alloys, and cast bronze. This feature is usually not considered a defect unless there are special surface requirements. The profile also indicates good soldering conditions. A very thin copper or nickel coating on the base metal or a slightly higher soldering temperature can reduce or eliminate the effect, if necessary. The phenomenon requires further study to better understand its fundamental cause.

3. A third spreading feature has a "halo" or outer rim appearance (Fig. 3C) and is another example of preferential solder wetting and flow. The pattern is characterized by the presence of an outer thin solder region (i.e., halo) and an inner circle comprising the main mass of the solder droplet. These features can result from differential heating and melting of the solder alloy and preferential wetting by one or more alloy constituents. The effect can also occur during controlled atmosphere soldering, such as in a vacuum. The resulting precursor spreads and forms the outer halo band and is usually not considered a defect, but good wetting.

4. A fourth feature involves the formation of intermetallic compound (IMC) interfacial reaction products between the base metal or its surface finish and the molten solder. The presence of this reaction layer promotes wetting and subsequent solder joint strength. The IMC can sometimes be considered as a defect if it is very thick or observed throughout the solder region, since it is generally brittle and causes premature solder joint failures. Growth of the intermetallic layer can also occur during subsequent thermal aging. The intermetallic effect can be reduced or prevented by applying a solderable barrier coating over the base metal, selecting a different solder alloy that forms a thinner reaction layer, or adjusting the soldering parameters (lower temperature and shorter time).

5. A fifth feature to consider is base metal erosion — Fig. 3D. The effect usually indicates excessive dissolution of the base metal by the molten solder and is considered as a defect if the affected base metal loses its required mechanical and physical properties, such as strength or electrical resistivity. This problem is typical for soldering aluminum or magnesium with Sn-Zn or Zn-Al solders. A potential solution is to adjust the soldering parameters. Another effective method is to coat the base metal with a barrier or protective coating.

6. Besides general base metal erosion, intergranular attack of the base metal grain boundaries can also occur —Fig. 3D. The rapid penetration of these intergranular regions can lead to stress corrosion cracking and premature failures. The effect is usually accelerated by higher soldering temperatures and can be prevented by adjusting the soldering parameters, selecting a different solder alloy composition, and minimizing the amount of cold work in the base metal.

Thus, simple visual and analytical tools are available for relatively quick field analysis of solder wetting and spreading conditions. These simple test methods provide important information about solder and base metal interactions and will help to reduce or prevent manufacturing defects and subsequent service problems in soldered structures and assemblies.◆