

Failure in Solder Joints

Introduction

Summarising the information in [*Mechanical properties of metals*](#), [*Stress and its effect on materials*](#), and [*Solder materials*](#), we can see that:

- The soft solder alloys used in electronics are rather weak, because joints are operating at a high temperature relative to their melting point
- Data on the tensile and shear strengths of solder alloys will only be of limited use in real situations because:
 - the performance under actual loads will invariably be affected by creep and fatigue
 - material defects will probably also be present and act as stress-raiser

In short, a normal soldered connection on a printed board is not well suited to withstanding a permanent mechanical load.

The combination of low load-carrying capacity and a sensitivity to cyclic stresses of the solder alloys used in electronics implies that the soldered joints have a finite life and, consequently, so does the electronic equipment in which they are used. The key consideration in design and manufacture is therefore to ensure that the expected lifetime of the soldered joints is adequate for the application.

Properly designed joints which have been properly soldered are for most purposes sufficiently reliable. However, in practice, too many joints are potential failure sources as a result of insufficient design or doubtful processing.

Three main causes of solder joint failure may be distinguished, although the mechanisms often work simultaneously, and other causes, such as corrosion, may play a role. These causes are:

- overloading, causing tensile rupture (fracture)
- long-lasting permanent loading (creep)
- cyclic loading (fatigue).

Joint fracture caused by short-term loading

Solder joint cracks caused by overloading are often the result of an accident or harsh treatment. For example, when using too much force to mount a soldered assembly in position in an enclosure, or when dropping a mobile phone. In these cases the shear strength of the solder is exceeded, resulting in fracture of the joint.

The force required to fracture a soldered joint will depend on the type of board and the type of joint and, in many cases, on the amount of solder used. The following comments apply to through-hole components:

- A soldered joint in a **plated through-hole** is capable of withstanding short-term forces of a few hundred Newtons. This gives a very considerable margin of safety for almost all designs

- The solder fillets on printed **boards without hole plating** will support similar loads, provided that the component is loaded in tension and that the solder fillet has sufficient height, since the short-term strength of these joints, which is essentially a shear strength, is proportional to the fillet height
- However, if components on **single sided boards** are loaded in compression or subjected to bending, tearing or peeling forces, then the adhesive bonds between the solder lands and the printed board laminate will yield sooner than the soldered joints, unless the joints have been incorrectly designed¹ or badly manufactured.

1. If a soldered joint has an insufficient quantity of solder, there is a risk of breaking of the joint by forces arising later on during assembly, transport or use of the equipment.

For leadless components, the amount of solder has relatively little effect on the initial strength of the joint, as measured by pull or shear tests. Forces of between 40 and 50 N are usually required to detach a soldered chip component from a circuit, for example, by pushing the component with a rod through a special hole in the substrate. In the shear test the shearing forces are higher, perhaps up to 200 N. Fracture almost always takes place outside the soldered joint proper:

- in the body of the component
- in the bond between the solder land and the laminate material or
- in the substrate material itself (in the case of ceramic material).

Only if extremely small amounts of solder are applied (typically less than 20% of the recommended amount) are the breaking forces noticeably reduced.

Joint fracture caused by creep

Solder joint fracture caused by creep is especially important at temperatures higher than room temperature, but, with common solder alloys, such cracks may be formed even at room temperature. It is therefore necessary to take care that no permanent load is present in the soldered joints (that is, less than 1 N/mm² at 20°C and preferably no more than 0.1 N/mm²).

One potential instance of fracture caused mainly by creep occurs when an assembly has been insufficiently supported during soldering, particularly reflow. After soldering, the board may have a rather large permanent warp, but the joints are in an almost stress free condition. However, if this board is then screwed into an enclosure, whilst being firmly forced flat, very large forces are exerted on the joints. This may cause cracks during the mounting operation (overloading) or soon thereafter.

Fracture caused by fatigue

Having looked at failures caused by short-term overload, and by permanent loading producing creep, we move to the third and largest category of failures, the fatigue failures that result from cyclic loading.

The major cause of such fatigue failure is the cyclic deformation of the joint by the stresses that result from temperature excursions combined with CTE mismatch. The extent of the deformation depends on the design of the joint, and whether or not there is any compliance in the system. Read [Stress caused by thermal mismatch](#) for guidance as to which designs can be expected to be most reliable when temperature cycled.

Usually the deformation of the solder in the joints is rather large, of the order of 1%, and the movements are slow, with typical cycle times measured in hours. Referred to as 'low cycle fatigue', cracking from this type of deformation may be observed in all kinds of soldered joints, and this is the main cause of eventual crack formation in initially good joints.

Where do the cracks start?

During the fatigue process, successive metallurgical phenomena occur. As the strain in the joint exceeds the plastic limit, the solder will start to creep. However, there is the complication for tin-lead solder that the material consists of two separate phases:

- α -lead has up to 19% of dissolved tin, with a face-centred cubic crystal structure, and its CTE is the same in all three directions
- by contrast, the β -tin phase, containing up to 2.5% of lead, has a body-centred tetragonal structure, where the thermal expansion in the axis of maximum CTE is very close to that of α -lead, but only about half this along the minimum axis.

This anisotropy causes internal stresses in the structure during slow thermal cycling.

As a result of these stresses, the solder exhibits phase segregation and grain growth, and the weaker α -lead phase is where cracks start and propagate during continued thermal cycling. Before the cracks start, there is usually a change in the surface appearance of the joint, which becomes rough, often having the appearance of small steps which usually develop into cracks.

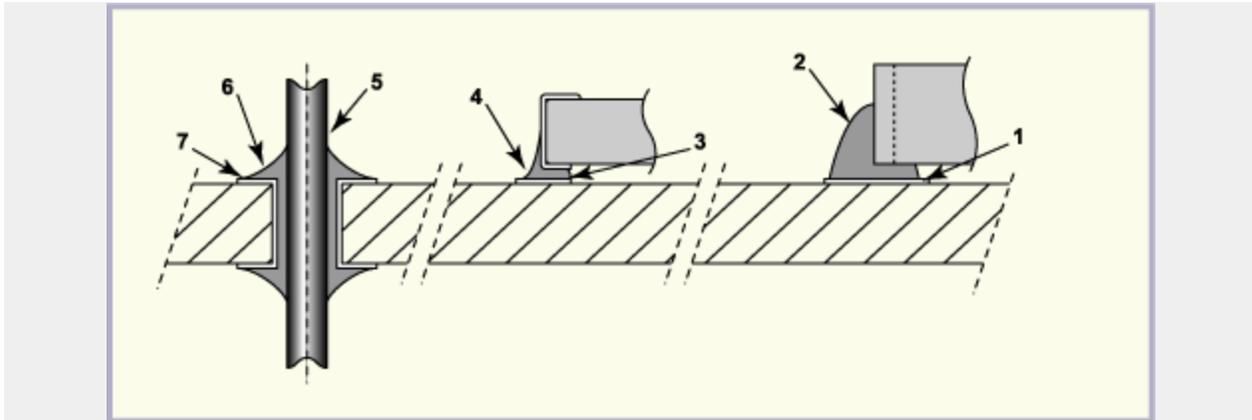
What form does the fracture take?

Slow cycle fatigue has been observed with most solder joints, but in general does not affect through-hole assemblies because of their higher margin of safety. The progress of the fatigue damage of leadless components may be seen as:

- Start of the crack, generally under the component at the edge of the metallisation (difficult to observe in inspection)
- Progression of the crack to the outer surface of the fillet, generally first visible at the corners of the metallisation
- Growth of the visible cracks from the corners of the component to the middle of the joint
- Sometimes, depending on the configuration, the cracks follow the interface between component and solder

The places where cracks will become visible under thermal cycling conditions are indicated in Figure 1 by the numbers 1 to 7.

Figure 1: Fatigue susceptible locations in solder joints



For leadless devices:

1. At the interface between solder and metallisation under large components such as leadless chip carriers
2. At the vertical interface between the solder fillet and end metallisation of SM devices
3. At the interface between solder and foil under chip components such as multilayer capacitors and resistors
4. In the bulk of the solder fillet.

For through-hole devices:

5. Annular cracks at the interface between solder fillet and wire
6. In the bulk of the fillet
7. Between joint and pad.

Cracked through-hole joint



Combined creep and fatigue

The mechanisms involved when fatigue and creep act together are poorly understood, but there is evidence that the sum of their effects is greater than their individual contributions.

Since solders operate at high homologous temperatures, if they have a small stress acting on them they are effectively creeping all the time. Consequently, any form of stress or thermal cycling will introduce the unwelcome phenomenon of combined creep and fatigue. To make matters worse, duty cycles could be:

- fluctuating stress levels at constant high homologous temperature
- fluctuating high homologous temperatures under constant stress
- simultaneous fluctuations in stress and high homologous temperature or
- combinations of these.

Source : http://www.ami.ac.uk/courses/topics/0154_fsj/index.html