Requirements for the Filler Material Solder Paste for Combinations of Different Technologies (SMT, COB, FC and LE/PE)

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ABSTRACT
A trend towards miniaturization has been evident since the introduction of SMD technology (SMT). This was extended with chip on board (CoB) and flip chip technology, which is still considered state of the art in back-end production in the semiconductor industry. Furthermore, there is an increasing demand for power electronic (LE/PE) modules in many areas of individual branches of industry and a trend here to develop a combination of the above technologies. To date, filler materials based on solder pastes have been qualified for the respective technologies to meet the respective requirements. The article is intended to show which important requirements are necessary for the respective evaluation. It will also discuss which intersections exist that make it possible to fall back on a filler material. The challenges, possible qualification measures, optimizations and limitations will be presented.

Key words: Miniaturization, Solder Paste, Alloy, Flux, Qualification, Reliability, SMT, Power Electronic, Semiconductor, Environment

INTRODUCTION
In recent years, three key areas have emerged in Europe in the field of assembly and connection technology. On the one hand, classic SMT technology is still in process. The return of the semiconductor industry has opened up a further business area and, in recent years, power electronics has also become a focus.
Electronics production was essentially determined by miniaturization. This means that the semiconductor industry is the determining factor in miniaturization by reducing the pitch distance, expanding the connections, etc. This technology was followed by SMT and power electronics.
The characteristics of the individual technologies are shown below:

Semiconductor:
The semiconductor industry is divided into the so-called front end and back-end package. At the front end, the electroplating process is generally used to create the bumps. In individual cases, however, wafer bumping is also used. In such cases powder type 6 till 9 are the preferred sizes. The back-end package is actually also a form of SMT but with powder type 5 or 6. Here, both active and passive components are placed and connected on substrates, see Figure 1, so-called interposers.

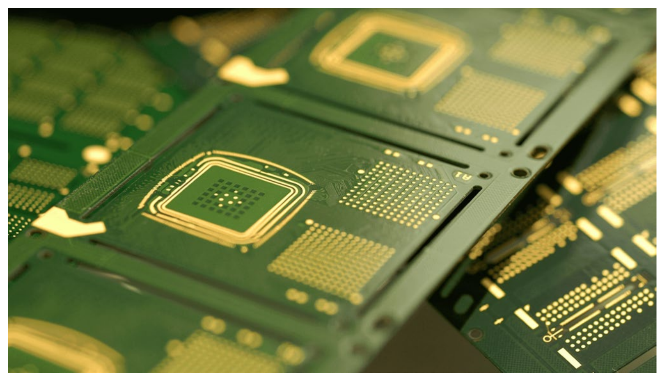

Figure 1. Interposer for Area Array Components

The properties that the connecting material (solder paste) must have are:

- Miniaturization
- Water-washable
- 0 Halogens
- Alloy SnAg, SnCu or SAC based

SMD-Technology (SMT):
SMD technology follows the trend described above. But standard is powder size 4. In some cases, type 5. An example of this technology is shown in Figure 2.

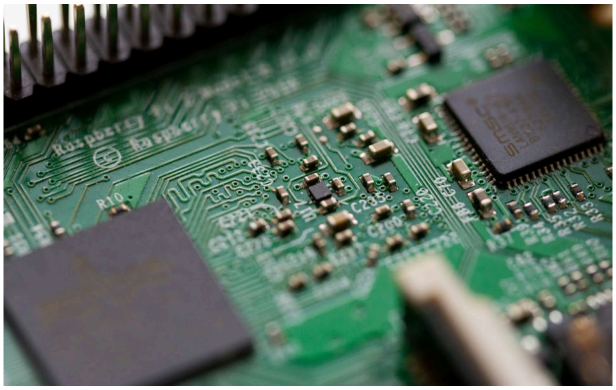

Figure 2. Example of SDM technology

The properties for this connection material (solder paste) are listed below:

- Miniaturization
- No Clean
- L0 or tends to 0 halogens
- Leg. SAC or alternatives with higher reliability e.g. automotive

Power Electronic:
Power electronics can consist of a combination of power semiconductors and passive components. Figure 3 below shows an example of a module with power components only.

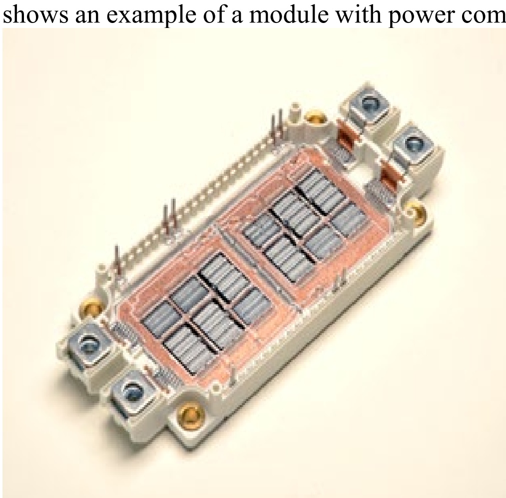

Figure 3. Power Modul from company Danfoss [1]

The properties that the connecting material (solder paste) must have are:

- Change from powder type 2 to 3
- Water-washable or No Clean
- 0 Halogens
- Leg. SAC or SnAg3.5
- Thermal conductivity

SOLDER-POWDER

Nowadays, solder powder is produced in a mass process since the demand should be several thousand tons by now. As a result, powder production (schematic diagram, Figure 4) takes place on several levels and includes (from top to bottom) the following production steps

1) Production of the alloy/melt mostly under protective gas (to avoid oxide formation of the melt = dross)
2) Atomization
3) Sieving (powder size and fractionation)
4) Packing

The most complex manufacturing step is atomization. Three types are distinguished here, e.g.:

• Gas atomization

A molten stream of tin or alloy through an annular nozzle and a gas stream (e.g. with nitrogen) splits the alloy into droplets. These droplets then solidify and are fractionated through several stages of screening.

• Spinning Disk

As the molten tin stream hits a disk rotating at high speed, it is split. The resulting particles form particles/balls which are then spun off the disk. These particles then solidify and are fractionated through several stages of screening.

• Ultrasonic

The molten tin stream is directed onto a sonotrode and broken down into particles according to the drive frequency. These particles then solidify and are fractionated through several stages of screening.

An alternative:

• Dispersion in a liquid (dispersion medium), e.g. Welco process

In this process, the alloy is melted in a temperature-stable medium and rotating tools break down this melt into particles, which in turn are enclosed by the dispersion medium and, in combination with the surface tension, form high-quality fine powder particles. However, this process is a batch process, thus quantitatively limited and only suitable for ultra-fine particles.

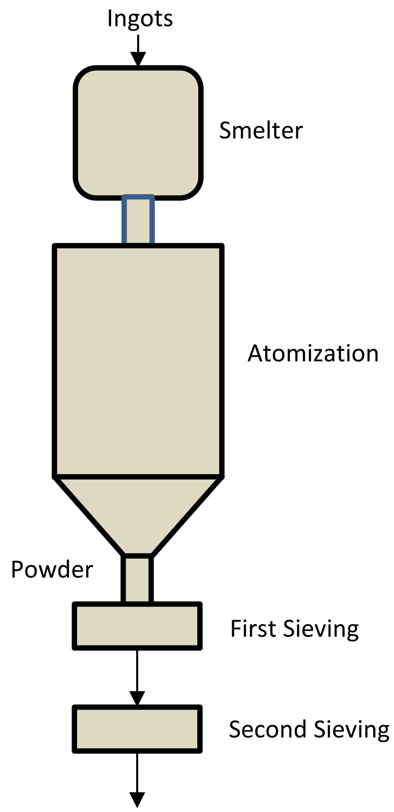

Figure 4. Schematic representation of a powder production plant

The size of the powder particles is fractionated according to international and national standards, such as J-STD-005 (IPC-TM-650) and DIN 32513, Table 1. The size value shown in Table 1 is the range of the particles of at least 90%. However, the ranges above and below this range are also clearly standardized. Important is the measuring method to determine the size distribution. Here, both transmitted light (thus measuring the individual diameters) and determination of the weight are possible. Type 7 and 8 are currently not standardized. They are still in the industrial development stage.

Table 1. Solder powder fractionation according to J-STD-005 and DIN 32513

Type	Powder Size
1	150 to 75 µm
2	75 to 45 µm
3	45 to 25 µm
4	38 to 20 µm
5	25 to 10 µm
6	15 to 5 µm
7	11 to 2 µm
8	8 to 2 µm

A comparison between the standard procedures and the Welco process is shown in Figure 5.

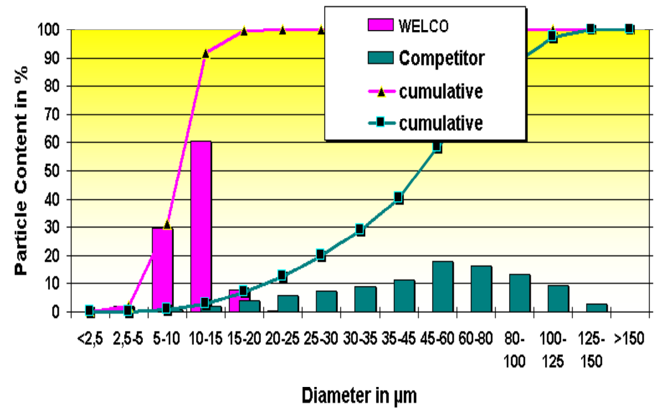

Figure 5. Yield during powder production [2]

The diagram shows that the Welco process gives a very high yield, whereas screening is essential for the standard processes.
The powder is the most important component in the soft solder pastes. The quality of the powder determines:

- Formation of the intermetallic phases.
- Alloy composition
- Liquidus and solidus temperature
- Surface tension
- Oxides and O2 uptake

Defects or insufficient qualities due to roughness in the powder surface, satellite formation, partial re-melting, contamination and the oxide layer leads to quality variations in the paste in terms of rheology, which can have a negative effect during application (e.g. printing), in the soldering properties, e.g. too much oxide reduces the solderability, and in the stability of the pastes, e.g. during storage, i.e. the long-term stability. Figures 6 and 7 show corresponding erros.

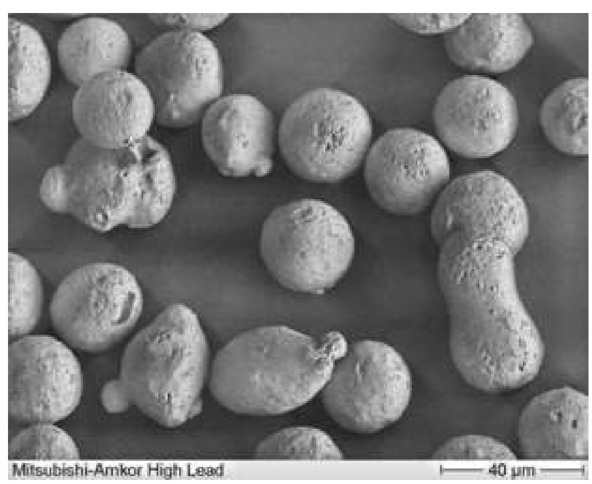

Figure 6. Defects in powder production due to conglomerates (dog bones) [2]

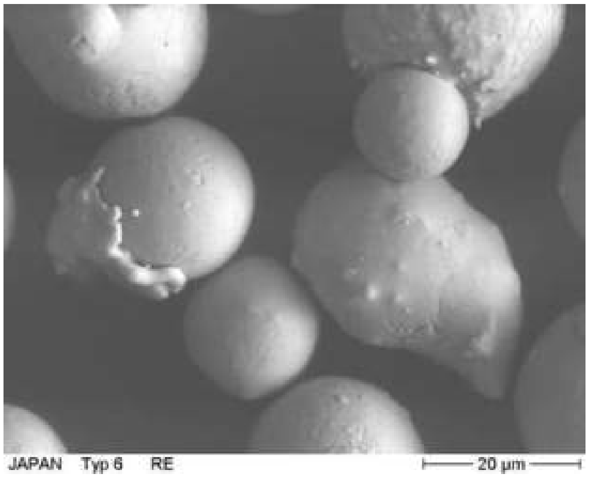

Figure 7. Satellites and contamination with residual melt [2]

A decisive factor with the powder is the oxide formation as the surface or the metallically bound oxide on the powder surface. An increase in the tin content has resulted from the conversion of lead-containing alloys to lead-free alloys and was already described in 2004 [3], Figure 8.

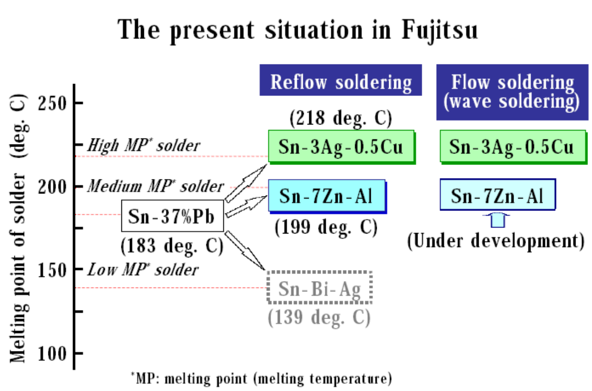

Figure 8. Change in paste viscosity due to a reaction of tin (Sn) and the flux by intensive tin salt formation [3].

The tin salt formation shows up in pitting of the powder and is shown in Figure 9.

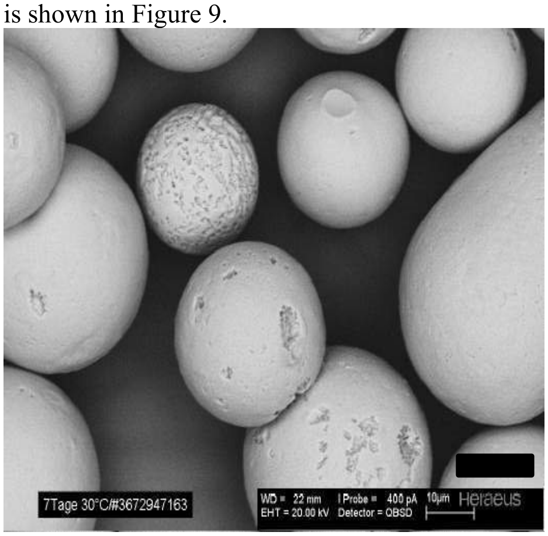

Figure 8. Pitting of SAC powder due to reaction of the flux with the powder. [2]

This results in a minimum for the metal-bonded oxide, which must protect the powders for interaction with the flux (like the anodizing of aluminum), but this oxide must also not be too large, so that no wetting inhibition builds up during subsequent soldering. The flux can only chemically reduce these oxides, since thermal reduction is not possible due to the required temperatures of more than 400 °C in soft soldering (soft soldering < 450 °C, brazing > 450 °C).
In summary, the oxide influences the storage stability, the so-called voiding, i.e. gas inclusions and thus three-dimensional defects in the solder joint, the viscosity of the paste and the wetting properties.

Alloy
As already mentioned, the use of soft solder alloys is mostly covered by lead-free alloys. These differ due to the product requirements. For example, in standard applications (printed circuit boards), the alloy SAC305 (with 3% silver and 0.5% copper) is the most widely used. In power electronics, where high currents and voltages are expected, the eutectic SnAg3.5 (3.5% silver). SnBi58 is also used as a so-called low-temperature alloy. For a higher temperature range, the so-called Innolot has become widespread, especially in the automotive sector. Table 2 shows an overview of the most important alloys, based on SAC.

Table 2. Summary of the most important lead-free alloys

In the automotive sector in particular, the requirements for assembly and joining technology (eAVT) are increasing, which includes the expected temperature range and the number of cycles that can lead to early failure. In this context, it is precisely the shear strength that has proven to be an indicator. After a temperature test, which can consist of a shock or alternating test, the assemblies to be tested are cycled, e.g. in a range from -40 °C up to +125 °C with a certain test frequency. By regularly removing the test subjects, shearing off the components, the shear force is determined and the difference to the initial shear force value is determined. The 50% value has become accepted as the error here, i.e. the shear force drop should not be more than 50% of the initial value. A comparison of different alloys [4] is shown in Figure 10 and 11.

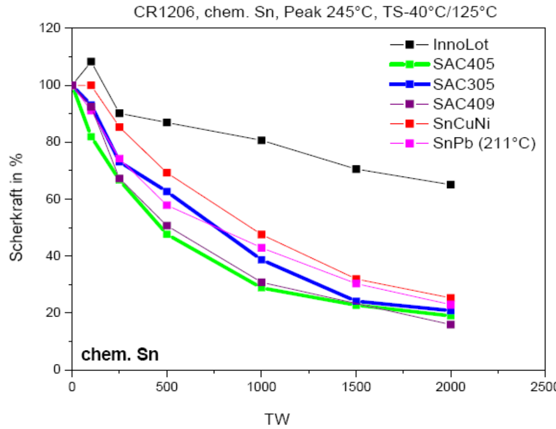

Figure 10. Investigation of the shear strength of different alloys [4]

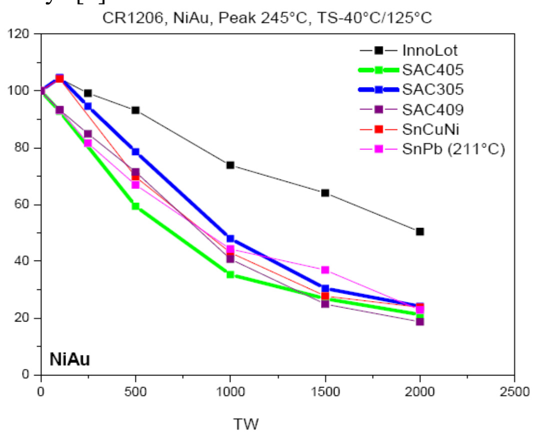

Figure 11. Investigation of the shear strength of different alloys [4]

Irrespective of an increase in reliability through the targeted selection of the alloy, faults can occur in components, for example, Figure 12.

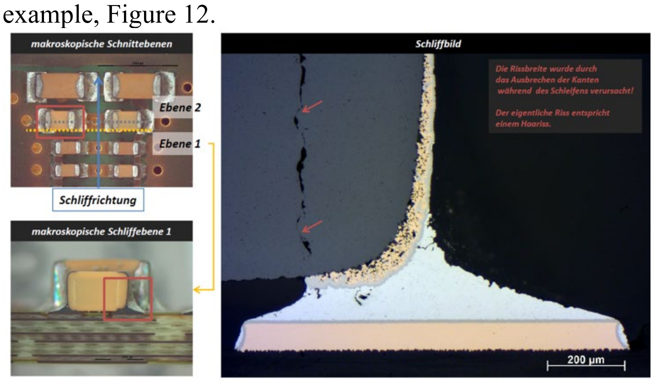

Figure 12. Ceramic crack of a 0805 component after 1000 TS -40/150°C [5]

Another aspect is the use of area array components, especially with BGAs that already have a ball alloy. Due to the solder paste application using a stencil, the ratio between ball and solder paste alloy is approximately 10:1, which means that even when using highly reliable alloys, the ball alloy will always be the dominant factor. The test result in Figure 13 shows that it is worth considering solution aspects.

Figure 13. Critical strained fraction of the solder joint [6]

Based on the problem of mixing and due to the dominant factor of the BGA ball, an alloy (opt.) was produced that contains oversized elements, so that after the soldering process at a ratio of 1:10 an Innolot is created in the overall composite (solder joint). Another possibility is a mixture of different powders with soft solder alloys, pure elements as well as hard solder alloys in order to achieve a change in the overall structure to a more reliable structure after the soldering process.
Figures 14 to 16 show the first results after soldering tests on Cu substrates.

The tests were carried out on a hotplate at approx. 250°C.

Figure 14. CS poor SAC305

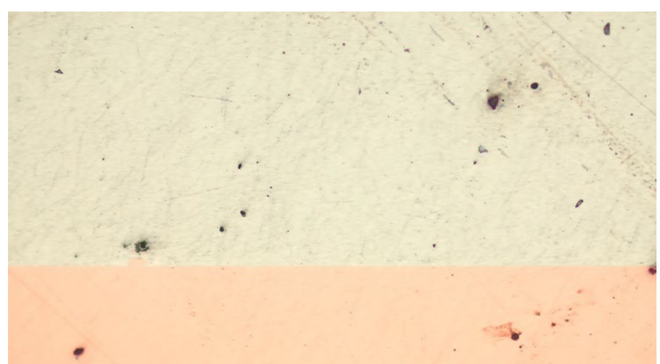

Figure 15. Alloy-Mix and SAC305 1:10

Figure 16. Optimum-Alloy and SAC305 1:10

The micrographs show homogeneous structures and good mixing / diffusion at a ratio of 1:10.
The quantitative analysis by spark spectrometry is shown in Table 3.

Table 3. Spark analyzes

It can be seen that the optimum alloy (opt.) comes very close to the Innolot alloy. Especially when you consider that the solder paste alloy is also changed by the components and PCB surfaces during soldering, it can be assumed that there is potential to increase reliability.

FUXES

The flux consists essentially of a resin, solvent, activators, and auxiliary materials. Together with the solder powder, this produces the solder paste. After soldering, residues of the flux are the resins, small proportions of the activators, and auxiliaries, but these must then be bound in the flux residue to prevent any harmful interactions with the substrate and the components, such as surface resistance (SIR = Surface Insulation Resistor), which leads to unwanted leakage currents and/or corrosion.

The resin, solvent, activators, and auxiliary materials determines the behavior of the flux.

The biggest difference in the choice of flux is its classification. Unfortunately, the various standards differ. For example, an L0 classification can pretend not to contain halogens, but it can also allow a limit. This limit can be uncritical for use in SMT but can lead to failures in power electronics.

However, the biggest difference is still in the area of water-washable and no clean. While SMT and power electronics prefer no-clean in both cases, water-washable is still the preferred flux in the semiconductor industry. Whether synergies can be found here remains to be seen. What is not open, however, is the demand for real halogens.

ENVIROMENT FRIENDLY

In addition to the well-known requirements for technical and commercial conditions when selecting solder pastes, a third condition has been added. This concerns the selection of raw materials that enable both environmentally friendly and humane extraction of these raw materials. When it comes to tin in particular, there are currently only one or two suppliers from whom tin can be purchased with a clear conscience. There is also an increasing demand for recycled raw materials such as tin. Some activities are already underway and will certainly yield even more insights in the future.

SUMMARY

Major trends are addressed. On one hand the minimization from the Semiconductor to the SMT as well as Power Electronic will be based on the quality of powder and for increasing the reliability based on the alloy composition. For the flux there is no discussion about the activity with zero halogens. Also, no clean is already fixed for SMT and LE/PE. About the ww fluxes depends on activities at the semiconductor industry.

Finally, a lot of investigations have to have more and more the focus on environmental point.

LITERATURE

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