As originally published in the SMTA Proceedings.

VOID-FREE SOLDERING WITH A NEW VAPOR-PHASE WITH VACUUM TECHNOLOGY

Claus Zabel
Asscon
Königsbrunn, Germany
c.zabel@asscon.de

JB Byers
A-Tek Systems Group
Longmont, CO, USA
jb_byers@atekllc.com

ABSTRACT:
Voids in solder joints are largely a function of differential pressure between vapor pressure of the gases inside of the joint and environmental conditions. By entering joints still in their liquid state into decompression chambers, voids can be eliminated. Equipment has been developed to achieve void-free joints under these conditions utilizing modern condensation reflow technology.

Key Words: Condensation reflow, vacuum soldering, multi-vacuum

BACKGROUND:
Studies such as those of Pillar [1] or Lea [2] had also other repercussions, besides demonstrating that visual inspection is of limited value as far as the reliability of the soldered joint is concerned. One of them is the increased use of x-ray technology to analyze the interior of the joint. To nobody's surprise, x-ray is able to show more and perhaps more serious defects than visual inspection ever could. Among such defects, voids have attracted a lot of attention. The sudden concern about voids can only be explained by the concurrent introduction of more critical components, such as the BGA family or CSPs. Anyone who *has been around for some time* would still recall the 'raging war' between wet waves (oil in the wave as an oil intermix) and the dry wave – artificially heightened because of marketing reasons. One of the leading arguments on the 'dry side' was the inclusion of oil in the joint as demonstrated by NASA at that time. Hence, voids and inclusions have been with us for quite some time. Whether they did any harm was – then – largely immaterial, as the argument was a scare tactic rather than proper objective information.

Although some investigations have indicated that voids may, under certain circumstances, actually be beneficial, such statements cannot be universally correct. They may depend on such characteristics as size of the voids, number of voids and their location as well as distribution within the joint. Hence, the majority of engineers would side with those that rather eliminate voids than live with them as the latter case may involve sophisticated decisions on what to accept and what to reject. Barnes [3] sums up the general concern, when he states:

"The presence of voids reduces the reliability and functionality of the devices. Besides, enlarging the probability of component cracking, voids will increase the device operating temperature and weaken the bond area. When exposed to mechanical shock and vibration, the device will ultimately fail."

That voids will increase the operating temperature of a device is true in all those cases where the joint is also used to heat-sink the component. Reducing the cross section by voids will lessen the conduction of heat and thus the temperature of the device may climb. We encountered precisely such a case and that caused us to develop a soldering method that effectively eliminates voids.

CAUSE:
There are a number of suggestions outlining the cause for voids, depending – to some extend - on the affiliation and interest of the writer and investigator. Some blame them on the paste and or the flux constituents, some see a role in the board finish, the reflow profile, metal content of the paste and even powder size [4]. Be this as it may, the voids either contain liquid or gas. Hence they are created in a process where either flux or some other liquid or solvent is entrapped or by solidification shrinkage of the molten metal [3]. Hence, any method that tries to eliminate these voids, must act during the solidification of the joint and ensure that gases and liquids trapped in the molten metal, can escape. This is a particularly demanding task whenever there are large areas to be soldered or the joints are situated under large components such as BGAs.

BASIC CONDENSATION REFLOW:
Several studies carried out in Europe {Wolter, TU Dresden; Siemens; Fraunhofer Inst.) have shown that the technology of Condensation Reflow (formerly referred to as VP) of late greatly neglected, has a number of very positive features when applied to soldering of highly complex boards. Improved self-alignment, very short times above liquidus, a

naturally inert environment, and a well-defined upper temperature, are well known properties. Recently, free parameterization of the pre-heat ramping parameter has been offered by at least one European manufacturer of such equipment. Thus, finally, this very awkward handicap has been eliminated as well, and in a rather elegant way.

The process is easily explained and the principle has not changed since Dr. Pfahl (then Western Electric) invented it in 1974. An inert liquid with a boiling point above the melting temperature of the solder alloy to be used, is boiled in a chamber. As the liquid evaporates, it forms a vapor blanket above the boiling liquid. As the liquids in question (e.g. perfluoronated poly-ethers) are very heavy, the vapor blanket remains well defined above the boiling liquid. Any article entered into it with a temperature lower than the condensation temperature of the vapor will be heated. The heating is a form of convection heating, however, utilizes the condensation of the vapor and thus is more efficient than gas convection (the Reynold's number is much higher).

This efficiency of heating has posed problems in the past during pre-heat. The temperature increase could be as high as 20 K/sec. contributing to such problems as wicking and tombstoning. Lately, methods have been developed that allow variable temperature ramping without the addition of other heating methods such as IR or convection. Furthermore, a new condensation process has been introduced: non-saturated vapor. Systems using non-saturated vapor technology can operate at different vapor temperatures without change of liquid. This is achieved by using non-saturated vapors rather than saturated ones. The former behave more or less like a gas and thus may be heated beyond the boiling point.

THE PROBLEM:

We were confronted with two particularly intractable tasks:

⇒ The soldering – using paste and reflow - of components over their entire large surface area for heat-sinking reasons without any voids, and

⇒ Void-free soldering of high-frequency shielding

So far the user had not been able to produce void-free connections, even though he had experimented with a variety of solder pastes, and had modified his reflow profile with regard to ramping and plateau height as well as length. The best results were still not acceptable, as his testing had indicated.

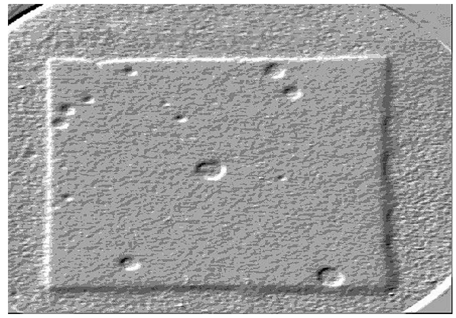

Figure 1. Initial results - voids are clearly visible

APPROACH TAKEN:

Accepting, as a premise, that "Solder joint voids are generally formed by pockets of gas trapped during the creation of solder connections between the component terminals and the Printed Circuit Board (PCB)"[5], we concentrated on the *'creation of solder connection'* issue. I.e. we were searching for a condition during the liquid state of the joint that would facilitate the release of gas from the interior without negative effects on the structure of the joint. Obviously, vapor pressure would be a key clue. As it turned out, it is not so much the vapor pressure of the flux component itself but rather the differential pressure between it and the surrounding atmosphere during the solidification stage that influences the escape of trapped volatiles. In other words, if the vapor pressure on the outside of the joint is high during the molten state of the joint, release of gases from its interior is inhibited. The higher the outer pressure, the more disadvantageous the situation. Turning this argument around, i.e. lowering the gas pressure outside th joint should thus help in eliminating voids in the joint.

In close cooperation with the customer, experiments were carried out in vacuum chambers to determine the appropriate instant at which vacuum would be most beneficial. Applying differential pressure too early would hinder the wetting process as critical activators may escape or be made ineffective by the loss of solvents. During solidification of the metal employing negative pressure would largely be useless as the viscosity of the metal would have achieved a high enough level to inhibit the transport of volatiles out of its interior.

In addition to the correct moment in time the question of the quality of the vacuum had to be answered. Several settings were compared until an optimum between time to create the vacuum and effectiveness as a 'void remover' had been established. The value that we determined for the 'correct vacuum setting' was 30 torr [0.58 psi]. This pressure setting, combined with the proper duration (approximately 10 seconds) yielded virtually void-free solder joints in all samples processed.

The findings from these experimentations were translated into a process that gave surprisingly consistent results. The task now was to conceive of a configuration of the equipment that would permit efficient soldering in a productive environment.

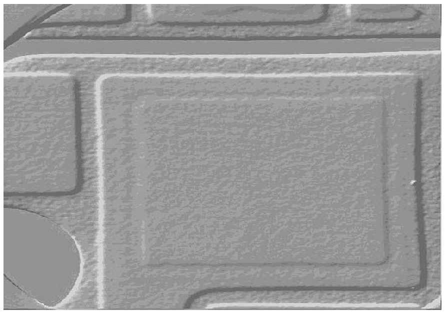

Figure 2. Soldered joint after vacuum treatment

THE SYSTEM:

For the development of the industrial application, we relied upon a proven concept of condensation reflow equipment. The constellation of such a system permitted the introduction of an appropriate vacuum chamber with only minor modification. Its location was chosen such that

a) the travel distances from the reflow area and to the cooling stage was minimized, and
b) the vacuum chamber can be deactivated in those cases where void-free soldering was not a priority. Thus the condensation reflow system could revert back to its original application without any physical modification if needed.

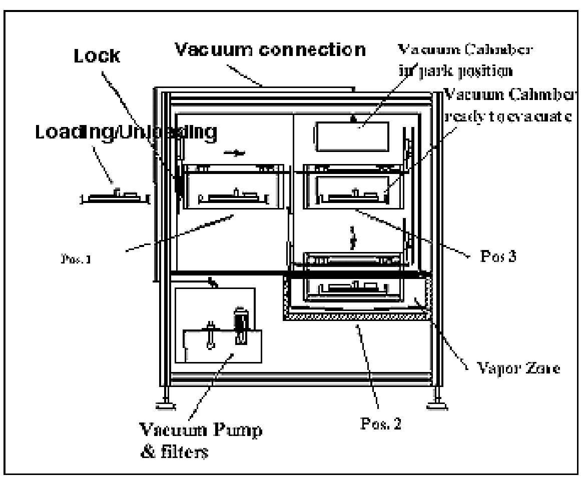

Figure 3. Sketch - condensation reflow system with vacuum chamber

THE PROCESS DEVELOPS AS FOLLOWS:

1. Loading of assembly (pos. 1)
2. Conveying into the vapor zone
3. Heat-up of assembly with free parameterization of the ramping coefficient (pos. 2)
4. Conveying of hot assembly into vacuum chamber (pos.3)
5. Closing of vacuum chamber
6. Establishing vacuum
7. Holding in established vacuum (appr. 10 sec.)
8. Establishing normal pressure in vacuum chamber
9. Opening of vacuum chamber
10. Conveying of assembly to cooling zone (Pos. 1)
11. Exiting and unloading

Figure 4. Vapor phase reflow oven with vacuum chamber

The advantage of void-free soldering is gained at a price: the cycle time is increased. However, the increase is only 25 seconds. This includes the 10 seconds dwell time in the vacuum chamber as well as travel phase and the periods to create the vacuum and bringing the chamber back to normal pressure. Should higher throughput be a prerogative, parallel processing could conceivably be introduced.

REFERENCES:

[1] Pillar, W.O.; SMT Inspection Versus Performance; Proceedings of the Technical Session; Nepcon West 19
[2] Lea, C.; Evidence that Visual Inspection Criteria for Solder Joints are no Indication of Reliability; Proceedings of the Technical Session; Nepcon West 1994
[3] Barnes, P. W.; Pressure Variation Method for Fluxless, Void-Free Ball/Chip Attach; Proceedings of the Technical Session; Nepcon West 1999
[4] Lee, N.-C.; Soldering For Area Array Packages; Proceedings of the Technical Session; Nepcon West 1999
[5] Morrison, G. & K. Lyne; Curtailing Voids in Fine Pitch Ball Gid Array Solder Joints; Proceedings of the Technical Session ;SMI, 1999
[6] Ohara, W. & N.C. Lee, “Voiding Mechanisms in BGA Assembly”; Proceedings of the Technical Session; ISHM, Oct.1995.
[7] Lee, N.C.; “Troubleshooting BGA Assembly”; Proceedings of the Technical Session; Nepcon West [Symposium of BGA]; Anaheim, CA, Feb., 1998.

[8] Rahn, A. & R. Diehm: Theorie, Konzept und Anwendung beim Reflow: Ein Vergleich der Reflow-Methoden Strahlung, Konvektion und Kondensation; Hochschulkolloquim Weichlöten in Forschung und Praxis, 7. Löttagung, 19 & 20. Nov. 1996 Technische Iniversität München