CASE STUDIES IN THE EVALUATION OF MOISTURE SENSITIVE LEVEL (MSL) AND RELIABILITY OF DEVICES FOR HIGH RELIABILITY (HIGH-REL) APPLICATIONS

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ABSTRACT

The reality of today's economic environment is that many companies rely on Sub-contractors and are forced to "Uprate" commercially available devices. The problem is; "How can you confirm that you are getting what you paid for?" This is especially true for quality and reliability issues, such as the Moisture Sensitivity Level (MSL) and the long-term reliability outside of the recommended temperature range or other environmental conditions for the device.

Over the past year we have seen several cases of PCB manufacturers (User) "checking" the MSL of the devices after experiencing unacceptable damage to the devices during their reflow process. Upon laboratory testing, the claimed MSL was not passed per J-STD-020, which led to some obvious questions. Typically, a discussion between the User and Supplier of the device reveals that the supplier has done one of several things. Either their manufacturing process has recently changed or that the devices are now actually manufactured by a sub-contractor.

Unfortunately, the supplier may not always be aware of any changes the sub-contractor may have done to their device. Some changes may be small in the mind of the sub-contractor, but could have a big affect on the MSL of that device. Any changes to the molding compound, die attach or lead frame finish, as a few examples, can have a big impact on the device's MSL. A generic case study representative of several actual investigations that have gone through this process will be presented.

High reliability (High-Rel) users' of devices in the automotive, aero-space and military industries were able to purchase devices that met their specific environmental needs in the past. Unfortunately the economics have also turned against these industries, forcing them to purchase commercially available devices and screening them for reliability at the operating temperatures and other environmental conditions they expect to experience. "Uprating" the devices typically invalidates the warranty from the supplier and places the user in a quandary. Without any valid reliability data, they cannot guarantee the operation of the device and they destroy the warranty in the process. High-Rel users' have also utilized J-STD-020 as a basis for their accept/reject analysis, even though they may be testing the devices under much harsher conditions. A case study showing the typical analysis that a High-Rel User has gone through to qualify a device will be presented.

Key words: MSL, J-STD-020, PEMs, High-Rel, Uprating

BACKGROUND

In 1989 the first standard, IPC-SM-786 [1], was published concerning the phenomena of "Popcorn Cracking" of surface mountable plastic overmolded ICs during the reflow process. Based on the limited knowledge of the problem at the time, a maximum level of moisture absorption, less that 0.11% by weight, was allowed to prevent damage during the reflow process.

Published with the standard in 1989 was a preliminary version of Test Method 2.6.20: Assessment of Plastic Surface Mount Components for Susceptibility to Moisture Induced Damage [2]. The purpose of the Test Method was to determine the maximum RH (Relative Humidity) that a part type could be exposed to at 85 degrees C with no failures during exposure to VPS (Vapor Phase Soldering) at 220 degrees C for a period of 60 seconds. The failure criteria included any surface crack or a crack in the molding compound exceeding 2/3 the distance from the initiation site to bond fingers or the package surface. As surface mount packages evolved from their through hole designs, it was determined that limiting moisture absorption alone was not solving the problem of "Popcorn Cracking".

In 1995, IPC-SM-786A [3] was published with a series of factory floor life conditions, known as levels 1 through 6, were established to simulate the maximum absorption of moisture by a surface mount device (SMD) to just hours of exposure. The moisture exposure conditions were meant to simulate the worst case factory floor conditions, 30 degrees C at 60% relative humidity (RH) from unlimited time periods to hours of exposure.

The criteria for moisture sensitivity classification was added into the standard and expanded upon based on the knowledge gained since the original publication in 1989. In addition to the original failure criteria the following were added:

- Internal cracks intersecting a bond wire, ball bond or wedge bond.
- Internal cracks extending from any lead finger to any other internal feature.
- Measurable delamination change on the top surface of the die.
- Measurable delamination change on any wire bonding surface of the leadframe/die paddle.
- Measurable delamination change along any polymeric film bridging any metallic features designed to be isolated.
- Measurable delamination change through the die attach region.
- Any surface breaking feature delaminated over its entire length.

The simulated solder reflow procedure was not changed and followed the guidelines previously used per Test Method 2.6.20 [2], now an officially published standard, also.

Another significant addition to the revision was a clause about reclassification. Since most component manufactures did not want to spend the time and money to reclassify all of their parts, a statement was added that would <u>not</u> require them to re-characterize the part if they met the following criteria:

- Manufactured with the same dimensions, materials and processes.
- The same or lesser degree of robustness noted on the label.
- Production quality and field reliability data acceptable to the customer.

If any of these conditions were not met, the parts would need to be reclassified to one of the levels, 1 through 6.

The first joint IPC/JEDEC version of the standard was published in 1996, which combined and updated IPC-SM-786 and JESD22-A112 into Joint Standard 020 (J-STD-020). Within J-STD-020 [4] the levels 1 to 6 were referred to as Moisture Sensitivity Levels (MSL) for the first time. The soak requirements were almost the same as previously published, with the exception that a default time of 24 hours was now standard for the Manufacturer's Exposure Time (MET).

The reject criteria did not change for the most part. There was only a clarification of the surface crack and electrical testing as follows:

- External crack visible under 40X optical microscope.
- Electrical room temperature dc or functional failure.

However there was recognition of the changes coming in solder reflow technologies for SMDs. For the first time the performer of the test could choose between VPS, IR/Convection or Convection solder reflow simulations, with a maximum temperature of 220 +5/-0 degrees C, 225 degrees maximum.

The one item missing from the first joint document, which was in IPC-SM-786A, was the subject of device reclassification. There is a small mention of the subject in the purpose section of the document, but that was geared towards limiting the devices to one improved level (longer floor life) before requiring additional reliability testing.

The next big leap for J-STD-020 came with its April 1999 revision, J-STD-020A [5]. The MSLs were expanded to include one new level, MSL 2a (Four weeks floor life) and the clarification of MSL 5 into two separate levels. MSL 5 would become 48 hours and MSL 5a would be 24 hours of floor life. Also added to the MSL table were "Accelerated Equivalent" soak requirements for MSLs 2a through 5a, using 60 degrees C and 60 % RH, which greatly reduced the soak times for the higher levels, especially.

All the previous reject criteria were retained with additions for warpage, cracking within the die attach region and for Ball Grid Array (BGA) package specific criteria. The following reject statements were added:

- Changes in package body flatness caused by warpage, swelling or bulging visible to the naked eye. If the parts still meet coplanarity and standoff dimensions they shall be considered passing.
- No measurable delamination/cracking change through the die attach region in thermally enhanced packages or devices that require backside electrical contact.

For BGAs specifically:

- No measurable delamination change on any wire bonding surface of the laminate.
- No measurable delamination change along the polymer potting or mold compound/laminate interface for cavity and over molded packages.
- No measurable delamination change along the solder mask/laminate resin interface.
- No measurable delamination/cracking change between underfill resin and chip or underfill resin and substrate/solder mask.

For solder reflow there were changes to the preferred method, from VPS to Convection, and adding higher temperature requirements for thin and small volume packages. Packages under 2.5 mm thick and less than 350 mm^3 in volume would need to be tested at 240 degrees C maximum.

A section on "Reclassification" was added. The main statement was that if any of the following attributes were changed, they could affect the moisture sensitivity of the device and may require reclassification. Those attributes were:

- Die attach material/process

- Number of pins
- Mold compound material/process
- Die pad area and shape
- Body size
- Passivation/die coating
- Leadframe and/or heat spreader design/material/finish
- Die size/thickness
- Fab process
- Interconnect
- Lead lock tape

Which is a fairly extensive list of attributes for a SMD package.

The next revision, J-STD-020B [6], was published in July 2002. Within that revision, the MSLs stayed basically the same with some clarification of the tolerances for the hours of soaking required.

The reject criteria was tightened for delamination on the active side of the die and "measurable" change was clarified to be greater than 10% in relation to the total area being evaluated for the delamination. For both metal leadframe and substrate based packages the following reject criteria were revised:

- No delamination on the active side of the die.
- No delamination change > 10% … (for others)

With the push for Pb Free solder, additional reflow conditions for devices being subjected to PB Free processing were added. Small devices, less than 2.5 mm thick and less than 350 mm^3 in volume would need to be tested at 250 degrees C maximum and all other parts at 245 degrees C maximum for Pb Free classification.

The section on Reclassification was slightly modified with the following changes:

- Encapsulation (mold compound or glob top) material/process.
- Leadframe, substrate, and/or heat spreader design/material/process.
- Wafer fabrication technology/process.
- Lead lock taping size/location as well as material.

With the development of J-STD-020 and its predecessors over the years, there has been a strong acceptance by the electronics industry. The MSL rating, also sometimes called Moisture Sensitivity Rating (MSR), of a device has become a critical factor for the proper handling and mounting of surface mounted devices, such as Plastic Encapsulated Microelectronics (PEMs). If a Printed Circuit Board (PCB) manufacturer is not provided with the proper MSL information they are virtually guaranteed a high failure rate for that device and their boards either during the reflow mounting process or in the field.

CASE STUDY #1: SMALL CHANGES COST A LOT

Company A has been purchasing and using PEMs from company B for a couple of years. These specific PEMs have been classified and sold as a MSL 1 (unlimited floor life permitted) device per J-STD-020 by company B. Company A has been handling and reflow mounting these PEMs to their PCBs following the recommendations per J-STD-033 without any problems or failures. Company A places a new order for the same PEMs they have been using for years and puts the new lots of PEMs into their inventory. Production of the PCBs goes on as normal, or at least they thought.

Company A's production department receives one of the new lots of PEMs and handles them using standard procedures. Everything looks fine coming off of the reflow ovens and they are passed on to the QC department for the final checks before delivery to their customers as usual. Unfortunately, the boards do not pass the QC check and everything stops dead. How many of their boards are defective and why?

The QC department needs to narrow down the problem before it becomes a crisis, plus their PCB production is temporarily on hold. PCBs are rechecked from several previous production runs to make sure nothing was missed. After some good detective work is done by company A's QC people the problem is narrowed down to a couple of production runs. Some of the defective PCBs are passed on to the FA department to determine the root of the problem. The FA department narrows the problem down to the PEM manufactured by Company B eventually. Now what?

A corrective action is put in place with several parallel paths to resolve the issues with these defective PEMs as soon as possible. The manufacturer, company B is contacted to obtain their QC reports on the devices received. The production department reviews their handling records for the devices and the reflow profiles for the suspect boards are collected and analyzed for any variations in comparison to known "Good" profiles. Some of the bad PEMs still mounted on the defective boards, along with some unmounted devices from another new lot are gathered together. The group of PEMs are sent to an independent lab for evaluation by Acoustic Microscopy (AM) [7].

Company B checks the records and confirms that the parts passed internal QC evaluations and requests some of the parts back for further analysis. The production department determines that all handling and reflow profiles are within specifications. The independent lab reports back that there is die face, leadframe delamination within the devices that had been mounted on the PCBs and that the unmounted devices do not show any delamination of significance [7]. It could have been a bad lot of devices, but further testing is suggested to check the unmounted devices for their susceptibility to damage during reflow. Figure 1 provides two example images of the delaminations observed within the devices using AM.

Since the PEMs were purchased with an MSL 1 rating, they are tested per J-STD-020 for those specified conditions based on the device thickness, volume and MSL. The devices fail to meet their MSL 1 rating per the internal delamination criteria observed with AM [7]. Data is reported back to company A, who contacts company B. Company B disputes the AM data and does not believe delamination is a major issue. Company A, B and the independent lab have a teleconference to discuss the data and the associated issues. Figure 2 shows one of the unmounted devices after it had completed MSL 1 testing per J-STD-020.

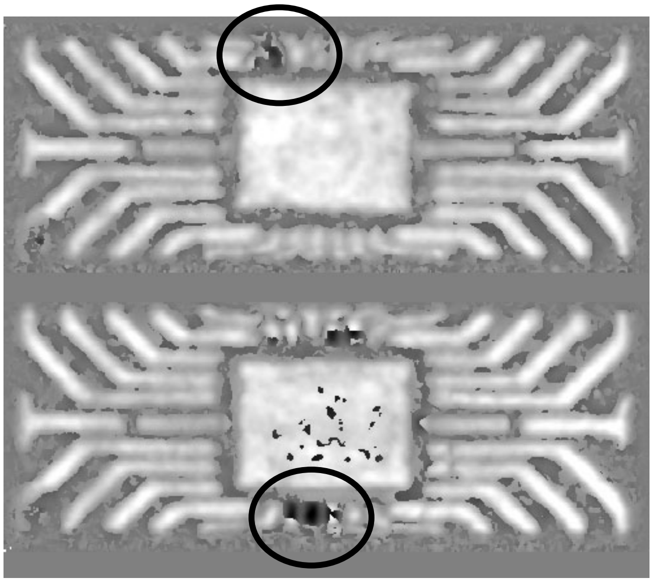

Figure 1. Acoustic Microscopy (AM) images of two process reflowed PEM devices with delaminations along the length of leads as indicated. Some delamination (black areas) within the die region is also shown in the bottom device.

There is agreement that delamination does exist within the PEMs, which is grounds for rejection as a MSL 1 rated device. According to company B, these devices previously qualified as MSL 1 per J-STD-020, therefore if delamination does exist now it does not pose any reliability issues according to their reliability testing data. A good point, but it is a flawed defense.

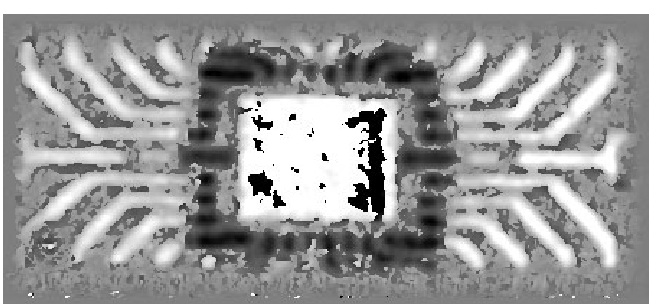

Figure 2. One of the PEM devices subjected to MSL 1 testing per J-STD-020. There is delamination on top of the die, along the length of some leads and at the wire bonding surfaces of all the lead tips. It did not pass MSL 1 testing as specified.

Since the independent lab has an internal expert on J-STD-020 and its associated documents, several questions are asked about the production of the PEMs devices. After several inquiries about the production process and any recent design or material changes, company B sheepishly admits that they don't actually manufacture those specific PEMs anymore. Manufacture of these particular PEMs, and perhaps others, is actually done by a sub-contractor, company C.

At least one attribute of the PEM manufacturing process has been changed and is grounds for "Reclassification" of the device. In its current form it has been proven that the device does not meet the MSL 1 rating as specified. To resolve the immediate problem of meeting production needs, the independent lab ends up screening over 4000 PEMs devices into accept, reject and marginal groups based on delamination criteria for the die surface, leadframe and an inner lead. In the end the problem costs 6 months of time, wasted product and the reputation of the supplier, in addition to the dollars spent.

The following lessons were learned from this experience:

- Incoming QC and testing to confirm specification conformance is becoming more essential with the use of sub-contractors.
- Anytime a process, material or design change of a PEM is made, it needs to be reviewed to see if "Reclassification" is required.

CASE STUDY #2: STRETCHING THE LIMITS

Most PEM type devices are manufactured for and sold to the high volume computer, consumer electronics and telecommunications industries. Therefore the devices are designed to provide the maximum reliability and performance in the environments associated with these industries, more specifically an operating temperature range of -40 to +85 degrees C.

Other industries, such as the automotive, aerospace, military, etc., whom need high-rel parts to operate in temperature ranges beyond the standard are forced to test the limits of commercially available devices. This is commonly known as "Uprating".

Uprating a device typically includes checking all the electrical characteristics of the device over the intended operational temperature range and other environmental conditions, such as RH, radiation, various corrosive conditions, etc. It is a time consuming and costly evaluation, but it is needed to ensure that the devices will perform reliably within the intended use environment.

Unfortunately, most manufactures of a device being uprated do not recommend, support, guarantee and even warn users against using the devices outside of their recommended operating environments for legal and liability reasons [8].

Therefore most companies doing upratings are on their own and looking for guidelines.

In their search for guidelines, they will take an industry standard, such as J-STD-020, and borrow portions of it for their evaluation, even though it does not directly apply. However, they need guidelines and at least it is a start.

In one particular case, company D needed to evaluate company E's devices for an aerospace program that would expose the devices to environments outside of the recommended ranges. Naturally, company E was not willing to provide technical support for the project, so company D hired independent lab F to uprate the parts for them. Part of the evaluation involved exposing the parts to an 85% RH and 85 degrees C environment for a period of time and performing various electrical and physical tests, including AM evaluation.

Devices were sent to independent lab G from lab F for AM evaluation per J-STD-020. Without having any pre-exposure AM images available, the analysis was performed and lab F was informed that the devices did not pass J-STD-020 due to delaminations over the entire length of the leads, even though the leads were small [9]. Both company D and lab F were concerned and a teleconference call to discuss the situation was requested. Figures 3 and 4 provide example AM images of the top and bottom sides of the same device.

Figure 3. AM image of the top side of the PEM device with delamination on the die paddle and on all four leads. Since this device is a "dead bug" configuration, the die is mounted on the bottom side of the device.

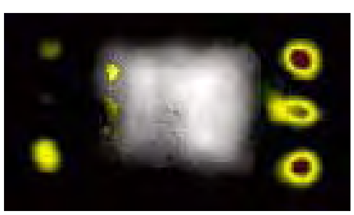

Figure 4. AM image of the bottom side of the PEM device with delamination on three of the four leads, tie bar and the edge of the die.

Company D and lab F were informed that J-STD-020 does not consider or establish any accept/reject criteria for delamination at initial/time zero inspection. Which they understood, but they needed some guideline for their evaluations. In the review of the AM data, they were informed that the PEM device was a "dead bug" configuration, meaning that the die was mounted on the bottom side of the device, which they were not aware of at the time.

Since the leads were completely delaminated over both the bottom and top sides within some of the devices, the devices would not qualify per J-STD-020. However, they were not completely clear why this would cause a problem with reliability. For these particular devices, there were two potential problems associated with the lead delaminations. The most common is that it provided a direct path for moisture and contaminates from the outside environment to the interior of the device. The big concern is premature corrosive failure of the device.

The second concern was that the crack or delamination could intersect a wire bond or wire bonding surface, which could cause premature failure of the wire or the interconnection. Since they did not have any knowledge of the internal configuration of the device, this type of failure mode could not be ruled out.

They would now need to reevaluate their uprating procedures and decide to either ignore the J-STD-020 test data, retest the parts at more favorable environmental conditions or design the final product so that it incorporates some sort of environmental protection for this particular device.

The following lessons were learned from this experience:

- The internal construction of a device needs to be known before any uprating tests of the device are started.
- If you plan to adapt and apply other standards within your uprating process, you need to specify what it will be evaluating and the consequences of that evaluation.

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