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RoHS War Stories

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Abstract
The following article is a series of “from the trenches” stories, taken both from the perspective of an electronics manufacturer and an environmental compliance consultancy. The accounts below provide a library of RoHS compliance scenarios that illustrate the extremes of building an RoHS compliant product and the pitfalls of assuming that a declaration of compliance is iron-clad.

Unlike most papers, portions of this one are written in first person. In order to preserve both the confidentiality of our sources and the integrity of this paper, all external stories provided to us have been copied into the paper and kept anonymous. This allows for a non-biased and often humorous accounting of RoHS.

Introduction

Companies that are in the throes of testing for RoHS[1] compliance are having some major headaches. Since its implementation in 2006, the EU environmental directive 2002/95/EC (RoHS) has had manufacturers grappling with the management of restricted substances in their products. While RoHS impacts almost every electronics manufacturer and most areas of the supply chain, there are several different classification scenarios under which companies can be placed:

1. In scope of EU RoHS and are actively restricting the hazardous substances contained in their products (PCs, Cell Phones, Video Game Consoles, etc.)

2. Out of scope from EU RoHS and are not concerned with restricting substances in their processes (Industrial Equipment, Military, etc.)

3. Out of scope from EU RoHS but are forced to become compliant through supply chain pressure (Fasteners, Plastics, and Hardware etc.)

4. Exempt from certain or all aspects of EU RoHS and are trying to keep lead free and pure tin solders out of their process (Medical Devices, Telecomm Industry)

5. In scope of EU RoHS, with no intention of selling into the EU (or China or South Korea for that matter) but are opting to achieve some levels of compliance for their environmental due diligence (Above examples from 1-4 but not sold into EU)

While supply chain management and declarations of conformity (DOC) play a large part of a company’s RoHS compliance program, testing has also become an essential aspect of RoHS accepted due diligence. Test methods range from portable X-Ray Fluorescence to Inductively Coupled Plasma (ICP) and beyond. Testing is a very time consuming and costly undertaking, whether it is done in-house or is subcontracted to a 3rd party laboratory. This paper will not delve into the advantages and disadvantages of one over the other but simply assume that one of the scenarios is applicable to each company attempting to attain and maintain RoHS compliance.

RoHS Substances and Thresholds:

Lead (Pb)	> 1000 ppm
Mercury (Hg)	> 1000 ppm
Hexavalent Chromium Cr(VI)	> 1000 ppm
Polybrominated Biphenyls (PBB)	> 1000 ppm
Polybrominated Diphenyl Ethers (PBDE)	> 1000 ppm
Cadmium (Cd)	> 100 ppm

Of the six elements/compounds being tested for, lead (Pb) is the most ubiquitous. It is therefore no surprise that it is the material mostly likely to be tested for and the one most likely to be exposed during an audit or inspection.

It is for this reason that most of the stories below are based on this particular element. Some of the stories would be funny if this was not such a serious issue and liability for so many manufacturers and Sony certainly knows this, as most people in this industry are very aware.

A few years back Sony sent pallet loads of an early Play Station™ module into the Netherlands for the Christmas rush. The following is the likely enforcement scenario:

A Dutch customs inspector cut open a shrink wrapped pallet with their box knife, took a unit back to their inspection area, opened it, used a screw driver to remove the cover and then used wire cutters to remove one particular plastic sheathed wire, which was then sent to a lab for testing as per their country-specific legislation that pre-dated RoHS. There was a provision for a cadmium (Cd) ban in that legislation and the lab testing found high levels of the substance in the plastic. The cadmium was presumably there as either a colorant or as part of a plastic stabilizer. Regardless of its purpose, the discovery was made public and as a result, Sony was fined and the delay cost Sony the Christmas market. At some point, on their website, Sony admitted that this single event can be pinpointed as having cost them the equivalent of $100,000,000 (US). One can wonder whether the discovery was purely accidental or whether the Dutch authorities were tipped off.

About a year ago Swedish authorities were considering renting two handheld XRF spectrometers for RoHS testing[2]. This would certainly lead one to believe that any instance of non-compliance is more likely to be exposed because a competitor or NGO has the ability to expose these infractions to enforcement authorities. Once a claim of non-compliance has been made, the enforcement bodies can then proceed to use their analytical instruments to verify them against the possible offender. The practice of manufacturers conducting independent analysis on their competitor's products and reporting any infractions to EU enforcement authorities is becoming commonplace and is even being encouraged in some EU member states.

Aside from being ever-present, lead also has the largest number of application exemptions. These are understandable, as lead has had multiple areas of use and has been a staple in the electronics industry for decades and even longer in other industries. Finding safe, reliable replacements (if ever) will take some time. However, these exemptions result in a very big problem – false positives.

Of the few dozen listed RoHS exemptions[3], 21 are for lead. Of these the most commonly used by the electronic industry in general are:

- Lead-containing ceramic (e.g. lead titanate)
- Lead present in the form of high lead solder (>85% Pb), usually for die attach
- Lead added to copper, steel and aluminum for machining purposes
- Lead in glass frit
- Lead in flip chip attachments
- Lead in solder of network infrastructure products (often referred to as being "RoHS 5 of 6 compliant")

Cadmium poses yet another major problem for RoHS testing. With a pass/fail limit is 100 ppm (per homogeneous, mechanically separable material), it is debatable whether all XRF units (especially portable XRF) being used can accurately detect cadmium at this level. Cadmium testing with XRF is further complicated due to false positives. Unlike lead, the false positives are not instances of exempted cadmium presence, but the result of spectral overlap. If there is any significant presence of tin or antimony in a sample, spectral overlap can artificially raise the cadmium detected by the spectrometer.

Chromium is often present in alloys as a base metal, a component of an alloy (1-57% in stainless steel), decorative purposes or as an alloy finish. The latter cause's issues because zinc chromate and anti-rust finishes are also used in the same types of situations. Even if Cr(VI) can be found and measured, the question becomes "what is the actual weight of the homogeneous material that contained the Cr(VI) and the weight of the Cr(VI) itself?". For this reason, enforcement scenarios typically rely on wet-chemical spot testing for its detection and most failures are determined by conclusively identifying whether or not the substance was intentionally added or not.

PBB and PBDE have been and will continue to be the most difficult aspect of RoHS to control and enforce against. Very few labs have gas chromatography/mass spectrometers (GC/MS), even fewer are accredited with a governing body, and fewer still can competently test for the two families of banned brominated fire retardants. Companies requiring this testing must be very careful in picking their suppliers for this service.

Component Specifications, Certificates of Compliance (CoCs) and Lab reports

1. A component specification sheet lists on the first page a component as RoHS compliant, showing a simple part number. However, moving to the second page, one sees that the part of that designation is actually not RoHS compliant, and contains lead in a non-exempted form. Another component with additional letters added to the part number is the actual lead-free version! If one ordered as per the first page thinking one was getting a compliant part, they would be in for a shock when it arrived – assuming the labeling was correct and/or incoming testing was carried out.

2. "This part is lead-free, there is no lead in the part, all the lead is in the balls under the part." – CoC shipped with a BGA

3. "This part is RoHS compliant. We have done no testing to prove this and do not intend to."

4. "This part does not contain any of the 7 [SIC] RoHS substances."

5. "The hexavalent chromium plating on the below parts is RoHS compliant." – CoC shipped with a plated steel bracket

6. "The parts listed are lead free, except for the plating on the lead frame" – CoC shipped with an IC package

7. "All RoHS substances are below the allowable thresholds on a homogeneous level" – This was accompanied by a test report that clearly indicated that the part had been ground into a single powder, destroying any chance at obtaining homogeneous data

8. "This part is RoHS 5 of 6 compliant" – The declaration was a metal fastener that contained hexavalent chromium plating. 5 of 6 compliance relates to lead solder allowed for network infrastructure devices.

9. A material testing report was received from a well known lab, proving the compliance of a connector. However the description of a material contained in the report was "Red liquid".

10. A client of ours sent a small box made of 7 separate pieces of steel to a well known test lab. The metal pieces for the box were sourced from overseas and not all from the same place. Seven reports were duly returned from the lab, 3 pieces being compliant and 4 non-compliant. However the description on each report was "Shiny Metal part". There was no way of knowing or tracking which parts of the box were compliant and which were not. - We now ensure that all our test requests to Labs contain .jpgs of the part to be tested and ensure the report from the lab also contains the .jpg.

Components

1. During one audit we had suspicions on a lock mechanism - in fact it is the mechanism from the above example where the CoC mentioned the 7 RoHS substances, so we obtained a physical part to visually check. Low and behold, the tongue of the lock appeared to be chromated. We checked it with a spot test of diphenylcarbizide solution that we had handy and it proved to be hexavalent chromate. We phoned the supplier from the audit "Hot Room" and the supplier said "Yes, we know it's not compliant, you've caught us now haven't you." Needless to say they are now an ex- supplier.

2. We had found Pb contaminated PCB's delivered by our sub-contractors. They questioned our XRF results & commissioned their own, but their lab didn't use the correct equipment (XRF collimator, which is far too big). We finally exposed the non-compliance by identifying enough effected [sic] boards & scrapping off a sufficient amount of solder for AAS testing which confirmed the XRF results. A subsequent audit found operators using spatula's from Sn/Pb solder pots in Pb-Free solder pots & un-cleaned squeegee's swapped between Sn/Pb & Pb-Free jobs.

3. A stacked die component was tested for RoHS compliance. Everything was fine when the overmold and BGA balls were tested. However, once the top IC of the stacked part was tested the balls were found to be eutectic tin/lead. The supplier's representative was very surprised. These parts were from a very large company, a company from which one would not expect this sort of mistake to occur, let alone escape. And then it happened again.

4. Virgin chip components from a very large supplier of these components were tested using an XRF. Lead was found. Cross-sectioning and subsequent SEM/EDX testing showed that the lead was present in the plating SnPb 63/37. The supplier was contacted. They insisted that the components were compliant. Eventually it was determined that the manager of the plant that manufactured the components had read the RoHS directive in English, not his native language and misinterpreted it. His understanding was that because his component contained lead in an exempt form (a lead containing ceramic) the whole component was therefore exempt and he had his plant go ahead and use eutectic solder for the terminations.

5. During an inspection of a finished PCB subassembly, we were alerted to the possible presence of Pb in the solder. From a visual inspection, the dull finish of Pb-free solder made the one area of shiny solder very easy to identify. After following up with XRF and confirming the result, the manufacturer was contacted and their response was "Oh, I know that we did some re-working of the board with leaded solder but since we worked so hard on the original RoHS conversion, I didn't think anyone would mind."

6. RoHS testing was completed for a stacked die part. The part was failed because the top set of solder balls were SnPb 63/37. It was very embarrassing when the supplier pointed out that the top part was a flip chip and thus the balls were exempt from the directive.

Finished Products

1. We have found Cr+6 as an anti-fingerprint treatment on stainless steel refrigerators. It is transparent in that specific application and came as a complete surprise. As it is applied over stainless steel that has a high Cr(0) content, it is virtually impossible to test by screen testing. This was discovered by querying the supplier.

2. After working with a client who had spent months converting their product to RoHS compliance, we were conducting XRF screening to see if anything failed inside the housing and on the product's extremities. A thorough screening of 100 scans was conducted and the product passed with flying colors. As an afterthought, the label on the product that stated "RoHS Compliant" was screened and found to have had very high lead content. All their work was rendered useless as the label that boasted their work was the area of non-compliance.

3. The same scenario as above occurred with a different client but this time, with cadmium being the substance that negated all the compliance efforts for product conversion.

4. Again, working with a client to screen for RoHS compliance, the XRF scans performed on the product were not producing any significant risks to compliance. It was only when the orange cable ties were prepared for sampling that significant levels of cadmium were exposed. As it turns out, the cable ties were not called out in the product BOM, nor were they part of the product assembly process. After a lengthy investigation, it turns out that a long time assembly line employee, in charge of installing cabling, had taken matters into his own hands. He had purchased a large quantity of cable ties, housed them at his station and added them to the product himself!!

Accessories

1. Not knowing the chemistry of leather, we were very surprised to detect a significant chromium peak on the leather of a holster when carrying out exploratory XRF testing. Why test a holster? It is not an electronic device – no power cord, battery, solar cell, or fuel cell. If it were being sold on its own then there would be no question, however, when it is placed in a box with an electronic device, then is must meet criteria set forth in the RoHS directive.

We have since learned that at least one popular leather tanning process uses Cr(VI). It gives leather a suppleness not found in several other non-Cr(VI) processes. With chromium being detected, what is the next step? XRF cannot tell the difference between chromium metal, Cr(0), Cr(II), Cr(III), Cr(IV) and Cr(VI). The chromium in the leather was further tested using the UV-visible spectroscopic method as detailed in IEC 62321, latest edition[4]. The good news is that for one OEM, the amount of Cr(VI) in a homogeneous material was never found to be greater than 250 ppm.

2. A Bluetooth head set was disassembled and tested for RoHS compliance, using an analytical XRF, as usual. One chip component was found to contain lead. A similar looking component elsewhere on the small PCB did not contain lead. The component was removed from the board and cross-sectioned for examination in a SEM/EDX to determine whether the lead was there is a form that was exempt – high lead solder (unlikely in this application), lead glass frit (possible) or lead based ceramic (most likely). However, the lead was found only on the terminations of the component in the form of eutectic tin/lead solder.

The device supplier was contacted and informed of the discovery. As in a few other cases, it took some convincing to get them to realize that this was real. No root cause was ever found,, but a few may be speculated – a reel ran out on a placement machine and a reel of tin/lead parts was substituted, the reel was a spliced reel or the reel was made up of "sweepings" put together by the supplier or their distributor. An on-site audit of the supplier did find some deficiencies in their processes, which have since been corrected.

3.An LCD was tested for RoHS compliance. Every layer of the LCD was tested, along with each piece of plastic and metal and all components – both the terminations and the body were tested. One chip component was found to contain lead by XRF testing. This was followed by cross-sectioning and SEM/EDX analysis, which confirmed the presence of lead in the form of tin/lead eutectic solder on the terminations. This information was fed by to the supplier, who did not believe the allegation. First the report had to be provided and then the actual assembly had to be provided before they would admit that they had made a mistake.

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References

1) http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32002L0095:EN:HTML
2) Lars-Olof Wallin, "Are Scandinavian Companies Ready for Lead free PCBs?", Proceedings of APEX 2006, Anaheim, California.
3) http://ec.europa.eu/environment/waste/weee/legis_en.htm
4) IEC 62321, 111/99A/RVC, Electrotechnical products - Procedures for the determination of levels of six regulated substances (Lead, Mercury, Cadmium, Hexavalent Chromium, Polybrominated Biphenyls, Polybrominated Diphenyl Ethers) found at: http://www.iec.ch/cgi-bin/procgi.pl/www/iecwww.p?wwwlang=e&wwwprog=pro-det.p&He=IEC&Pu=62321&Pa=&Se=&Am=&Fr=&TR=&Ed=1