Environmentally Conscious Manufacturing Integrated Demonstration

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Abstract

The Environmentally Conscious Manufacturing Integrated Demonstration illustrated that existing techniques could be successfully used on an electronic assembly to drastically reduce CFC, CHC and other hazardous material usage and the waste generated by their use.

Summary

The objective of the Environmentally Conscious Manufacturing Integrated Demonstration was to show that several of the individually developed materials and processes to reduce hazardous materials and waste could be successfully used on a single assembly.

A methodology was developed that could be used on any product to plan the approach to eliminating hazardous

materials. Sample units of an existing design electronic unit were fabricated applying this methodology and substituting nonhazardous materials and processes.

The results of this project show that total waste can be drastically reduced by at least an order of magnitude and hazardous material and waste can be essentially eliminated in the manufacture of this type of electronic devices.

Discussion

Background

This project was funded as part of FY1992 project AL-4113-01 by the DOE's Environmental Restoration and Waste Management Division's Office of Technology Development (EM50). The objective of the Environmentally Conscious Manufacturing Integrated Demonstration (ECM ID) was to demonstrate that several of the individually developed materials and processes could be used on a single assembly to eliminate, or reduce by orders of magnitude, use of hazardous materials and the hazardous waste generated.

Various contractors within the DOE Nuclear Weapons Complex (NWC) have been, for several years, pursuing initiatives to reduce or eliminate the use of a large number of hazardous substances. The definition of what is hazardous is somewhat nebulous; several agencies of the federal and state governments are in the process of defining what they feel is hazardous and they do not agree. For our purposes, a suitable definition is "any substance that is harmful to personnel or the environment either through its use or disposal." The current high visibility of environment, safety, and health (ES&H) issues nationwide has heightened everyone's awareness of the concerns for hazardous substances. Many of the nation's leading corporations, including all NWC contractors, are dedicating additional resources to these activities because it is the "right thing to do." The DOE headquarters in Washington, D.C., is applying increasing pressure, including funding pressure, to all field offices and contractors within the NWC to reduce our reliance on hazardous substances and thereby reduce the

hazardous elements of our waste streams. The initiatives that are under way have the potential to improve our position; however, at this point they are fragmented and there is insufficient overall coordination of the activity.

Historically, the largest volume of hazardous materials in many manufacturing environments is the waste from solvents used for cleaning. Cleaning of electrical and mechanical parts and assemblies generates a large amount of waste, most of which is hazardous. One of the main thrusts of the ECM ID is to eliminate, or at the very least drastically reduce, our use of CHC and CFC solvents. This is prompted by a concern for our environment as well as compliance with federal, state, and local laws and regulations.

The ECM ID is a first step in bringing many of the past activities together in a single project. The B61-6/8 Programmer was selected as the demonstration unit. This Programmer was selected for several reasons.

1. The technologies involved both in the unit and in the manufacturing processes are typical of a large number of assemblies used in the NWC.
2. A quantity of production units has been built; therefore, test data is available.
3. Pieceparts are available in stores to fabricate ECM ID units.
4. A number of typical hazardous materials are used in the unit and its processes.

We have built three functional and four visual units as part of the ECM ID. These units replace, as far as possible, hazardous materials with benign materials. The complete Programmer is shown in Figures 1 and 2.

The paragraphs below detail the results of ECM changes at the various assembly levels of the Programmer. It should be noted that the evaluations done as a part of this integrated demonstration were not exhaustive and do not negate the need for complete evaluation and compatibility studies before implementation on production hardware. The purpose of this demonstration was to identify promising materials and processes and to try them on a "sample of one."

Methodology

The following methodology was developed as part of the ECM ID project to ensure that all material was considered and hazardous material identified and replaced.

1. Analyze in detail all product drawings and specifications to identify all material used either in the product or as part of the production processes.
2. Identify all hazardous material on this list.
3. Determine purpose and unique characteristics for each of the hazardous materials.
4. Identify prospective replacement nonhazardous materials.
5. Experiment and select a suitable replacement.
6. Identify hazardous materials with no suitable replacement.
7. Determine if an acceptable alternate production process exists that can be made nonhazardous with steps 1 through 5.
8. Select alternate processes with nonhazardous materials.
9. Fabricate sample units with selected nonhazardous materials.
10. Perform "acceptance-type" tests on sample units and compare to results from original design.
11. Evaluate results.

General Results

Printed Wiring Board

The original printed wiring board (PWB) used on the B61-6/8 Programmer was fabricated from Kerimid 601 material. This is shown in Figure 3. This material uses a Polyimide resin and has 4,4'-methylenedianiline (MDA) in the curing agent. MDA is a suspected carcinogen. In the fabrication of multilayer printed wiring boards, the prepreg material between layers is handled in a partially cured state and therefore unprotected personnel could be exposed to MDA. Stringent procedures and equipment are used to prevent exposure. The lamination area is a limited-access area (see Figure 4). All handling of the uncured prepreg is done at a protective workstation (see Figure 5). All waste from the area is treated as carcinogenic waste (see Figure 6). This is expensive in terms of both equipment required and the time penalty.

The replacement material used was PY260 manufactured by Norplex/Oak. This is one of a group of laminate materials from various manufacturers that uses a polyimide resin with no free MDA. This material was selected from a group being evaluated prior to completion of testing. It was selected as being representative of the group of non-MDA materials and a sample quantity was available. Although it is not the material recommended as the "standard" material in Appendix A, the

Figure 1. Programmer Final Assembly

Figure 2. Programmer Disassembled View

Figure 3. Polyimide Multilayer Printed Wiring Board

Figure 4. PWB Lamination Area Warnings

Figure 5. PWB Lamination Area Protective Workstation

Figure 6. PWB Lamination Area Carcinogenic Waste

results on the ECM ID are equally valid with the selected material. Preliminary evaluation indicates that these materials can be used with the same processing parameters as Kerimid 601. Although not optimized, these parameters will yield acceptable results.

Two processing lots of PWBs were fabricated using Norplex/Oak PY260 material. Standard phototools and processing parameters were used for both lots. The only processing difference was that the PY260 was not confined to processing in the Bio-cabinet system in the PWB production department but was processed as a nonhazardous material. No difference was seen in fabrication or next assembly use between the K601 and PY260. (See Appendix A for further details.)

Cables

Two identical pigtail cables are used on each unit. Several changes were made to the cable materials and processing to eliminate hazardous and undesirable materials. The complete cable is shown in Figure 7. All cables were fabricated using Kester SM950E "no-clean" flux and non-cored solder (see Figure 8). (See Appendix E for further details on no-clean fluxes.) The only cleaning solvent used was alcohol. Cleaning was done to enhance bonding of the encapsulant and not to remove flux residue.

Fabrication techniques using the no-clean flux were somewhat different from standard flux/solder; however, assembly operators reported that only a short time was needed to become familiar with the new flux and then it did not hamper them. The no-clean flux was more inclined to leave solder spurs on the back of solder cups than the standard flux. A significant portion of these spurs would not meet the requirements of solder specifications but they did not bridge a significant percentage of the

distance between cups. Some additional time was required to reduce these solder spurs. The soldered connections were rejected by Visual Inspection for excess flux as expected but no other defects were noted that could be attributed to the flux. The excess flux residue was removed in the alcohol cleaning before potting. Figure 9 shows a completed connector.

These cables were originally encapsulated with EN-7, which contains toluene diisocyanate (TDI), a carcinogen. A low free-TDI replacement encapsulant, PET 90A was selected as a replacement (see Figure 10). PET 90A contains less than 0.1% free TDI and thus is not classed as a carcinogen by the Environmental Protection Agency (EPA) or Department of Transportation (DOT). This material was used without color paste for visual units and with a black color identical to the production definition for the functional units. The production tooling was used with no changes to encapsulate both the connector backshell and mounting feature on the cable. No problems were found. This material appears to act very similar to EN7. (See Appendix B for further information on Polyurethane encapsulants.)

Printed Wiring Assemblies

Printed wiring assemblies (PWAs) were fabricated per the drawing set except for solder fluxes and/or cleaning. Two Visual and two Functional units (two PWA for each unit) were fabricated using aqueous processes. Two Visual and one Functional unit were fabricated using d-Limonene cleaning. Figure 11 shows a completed PWA before removal from the panel.

For the aqueous processed units, a change was made to the flux used in the drag solder fabrication of the PWAs. On the Visual units, Kester 2120 flux was used followed by cleaning with deionized water in the Hotpack "dishwasher" (see Figures

Figure 7. Pigtail Cable

Figure 8. Cable Soldering with No-Clean Flux

Figure 9. Completed Cable Connector

Figure 10. Polyurethane Elastomer Potting

Figure 11. Completed Printed Wiring Assembly

12 and 13). Cleanliness testing on the Omegameter indicated that this flux did not clean adequately with water only. Recleaning with the addition of a saponifier to the deionized water resulted in zero residue with the Omegameter. For the Functional units, a saponifier was used in a cascade type aqueous cleaner, shown in Figure 14. This again produced "clean" PWAs. All aqueous cleaning was followed by an alcohol spray shown in Figure 15 to aid in drying the unit. (Additional information on Aqueous fluxes is given in Appendix D.)

The PWAs slated for cleaning with d-Limonene were soldered using the standard flux and solder processes. Cleaning was accomplished using a d-Limonene bath agitated with an air driven impeller pump. This was followed with an alcohol spray. Cleanliness was within acceptance limits using the Omegameter but not as low as the water/saponifier cleaning.

Baseplate/PWA Subassembly

This subassembly consists of the PWA mounted on an aluminum baseplate with a cable attached. Attachment of the cable is a hand soldering operation. All Visual and Functional units were fabricated using Kester SM950E no-clean flux in this operation (see Figure 16). This flux was chosen for several reasons. First, it eliminates the need for CFC/CHC cleaning and is therefore environmentally friendly. Second, by the elimination of the solvent cleaning, there is less wicking of the flux residue under the insulation of the wire where it could be a long-term reliability factor. Results using this procedure were acceptable with the exception that the small amount of white residue remaining after soldering is not acceptable per the current solder specifications. The comments noted above in the cable section concerning performance of the flux

also applies here. The completed baseplate/PWA subassembly is shown in Figure 17.

Polyurethane Foam Potting

The potting material chosen for the ECM ID version of the Programmer is the new formulation designated BKC44307. This foam has been thoroughly characterized in experiments both at AlliedSignal, Kansas City Division (KCD) and Sandia National Laboratories (SNL). The unit was potted using the same processing steps as the original polyurethane foam except that the hand mix option (see Figure 18) was chosen over the automatic machine mix and dispense (see Figure 19). This method reduces the amount of waste and cleanup. For small batches of material, hand mixing is less wasteful of material and cleanup solvents. (Additional information on BKC44307 Polyurethane Foam is given in Appendix C.)

Monitoring

Monitoring of emissions of volatile organic compounds is an important part of efforts to reduce solvent usage. Monitoring provides a quantitative measure of the success or failure of different approaches. To be most effective, a monitoring system should be both accurate and rapid, preferably real-time. Appendix F describes one type of monitoring system, the Portable Acoustic Wave Sensor (PAWS) system being developed by Sandia National Labs. This system is shown in operation in Figure 20.

Marking

Part marking within the NWC is primarily by ink stamp. While this yields an acceptable marking from the standpoints of readability and durability, it uses high-VOC inks and thinners. This is further compounded by

Figure 12. Hotpack Dishwasher Exterior View

Figure 13. Hotpack Dishwasher Interior View

Figure 14. Cascade Aqueous Cleaner

Figure 15. Alcohol Spray Booth

Figure 16. No-Clean Flux Soldering

Figure 17. Completed Baseplate/PWA Subassembly

Figure 18. Hand-mix Polyurethane Foam

Figure 19. Automatic Mix & Dispense Polyurethane Foam

Figure 20. PAWS Monitoring System

the difficulty in marking some parts due to surface conditions or configuration, such as curved or rough surfaces. Under these conditions, the marking may be cleaned off and remarked several times using CHC solvents. Several methods were evaluated to replace the ink stamp marking method.

On Visual units, clear and black background labels were pre-printed with the information and attached to the housing and cables. On functional units, laser marking was used on the aluminum housing and UV cure ink stamp was used on the polyurethane potting on the cables. All of these methods have been used sparingly in the past with varying success. Laser marking of metal parts is in general a good choice and is cost effective, especially if larger lots of material can be marked at one time. The drawback is that it is not possible to change once the part is marked. UV cure inks, while appearing initially to be good choices, have characteristics that present processing difficulties when used in a production environment. The primary problem is the film thickness. To cure with the UV source, the ink film must be no more than 0.0003 inch thick. This thin film is difficult to ensure in a hand stamping operation.

An ink jet marking system has recently been developed at KCD. This system has considerable promise to reduce waste. At the present time, only black ink is available; however, white should be available in the future. Since this is a computer controlled process, rework should be minimal. This will further reduce the use of CHC solvents.

Conclusions

This Integrated Demonstration project has shown that alternative materials exist for many of the hazardous materials that we currently use. It has also shown that these materials appear on the surface to be

compatible with each other. Further work must be done to assess the long-term compatibility and reliability of these materials. To take full advantage of the alternate materials and processes will require a culture change within the NWC. We cannot expect, nor should we want, the new materials to be "just like what we are using now." Rather, we must set realistic standards and evaluate the new materials just as we did for the current materials. In many cases we may find that a material is now available that will function better in addition to being less hazardous. Potential users must evaluate the suitability of these materials for each application.

The potential reduction in the waste streams by using this type of methodology is illustrated in Figures 21 and 22. Figure 21 illustrates the types of waste generated and an indication of the quantities involved in the standard manufacturing processes used in the past. Note that a large portion of this waste is hazardous, including CFCs and CHCs as well as materials contaminated with carcinogens. The waste shown in Figure 22 represents the types and quantities of waste generated by the "ECM" process. In addition to the drastic quantity reduction, this waste contains no CFCs, CHCs or carcinogens. Alcohol containing small amounts of organic fluxes, dust, and skin oils are the major wastes.

As a part of this project, a videotape entitled "Environmentally Conscious Manufacturing: An Integrated Demonstration" was produced in September 1992 summarizing this work. Copies are available in EM50, SNL/NM and the ECM organization at AlliedSignal, Kansas City Division.

Future Work

Evaluation of the results of this effort is continuing. An electrical and environmental test program is under way to

Figure 21. "Existing Method" Waste

Figure 22. "ECM Method" Waste

subject the units fabricated on this project to the same type of environmental and electrical test as the production definition. The data gathered will be compared with the results of similar tests on previous production definition units to identify any changes in performance.

Follow-on activity planned for FY1993 includes extending the techniques developed in this project to the next higher level of assembly. This will include additional materials and processes not used on the B61-6/8 Programmer.

Two areas were not addressed during this integrated demonstration project that need further attention and should be considered for follow-on work. These are corrosion resistant coatings for aluminum and steel and an alternative for lead bearing solder for electrical connections. Both of these add significant quantities of hazardous materials to the waste streams.

Appendix A

Printed Wiring Board Laminants

by J. W. Lula, AlliedSignal Inc, Kansas City Division

The majority of printed wiring boards manufactured at the Kansas City Division of AlliedSignal are made from a high-temperature polyimide material. The high temperature material is necessary to achieve the high reliability and quality level required of subsequent KCD electronic assemblies over the life of the product.

The multilayer printed wiring boards we produce at KCD consist of copper-clad core layers laminated together with adhesive bonding layers. Both the core layers and the adhesive layers are made from the same high-temperature polyimide material. The difference between them is that the core layers have already been fully reacted chemically, while the adhesive layers have only been partially reacted. During the lamination process, the adhesive layers fully react.

In recent months, however, a concern has arisen because the polyimide prepreg, used for the adhesive bonding layers, contains a small amount of methylenedianiline, or MDA, a suspected carcinogen.

Because of the MDA, new prepreg handling procedures have been implemented in the PWB lamination area. All work done in preparation for lamination must be done within a Bio-cabinet, which contains any dust particles generated during handling. In the Bio-cabinet, the prepreg is removed from the shipping package, dried to remove moisture, and then placed between the core layers in preparation for lamination. At this point the lay-up is placed within a separate bag for transfer to the lamination press. All these precautions have been implemented to prevent skin contact or breathing of any dust particles containing MDA. Once the lamination cycle is complete, the MDA has chemically reacted, and there is no further hazard.

In addition to prepreg handling, there have been other changes in the lamination area to deal with the presence of MDA, such as the following:

- The lamination room is a restricted area, with login and logout procedures.
- Protective clothing is required, which is disposed of as hazardous waste.
- Personnel are subjected to mandatory, annual physical exams.
- All materials used in housekeeping are disposed of as hazardous waste. This includes everything from the air filters in the ceiling to the water that is used to mop the floor.

None of these precautions are required for MDA-free printed wiring boards. A project is currently under way to evaluate several new PWB materials that do not contain MDA.

Through this project, new PWB materials have been characterized to determine their suitability for high-temperature, high-reliability PWB applications at KCD. Of primary importance is the thermal characterization. The table below is a brief summary of some of the thermal characterization.

Table A-1. PWB Material Thermal Characteristics

	T _g (°C)	T _d (°C)	TCE (ppm/°C)			Delamination Resistance	
			x axis	y axis	z axis	min	@ °C
ARLON 85N	> 240	426	16.5	18.9	62.1	10.6	305
Hitachi 67N	232	354	14.7	15.3	55.5	15.6	260
NELCO N7000		378	15.0	15.5	43.9	9.6	305
Norplex PY260	224	337	14.8	19.3	56.5	> 20	260
Polyclad 702	243	352	16.7	18.2	59.9	3.1	305
ARLON 63N	243	387	15.6	16.8	29.3	11.2	305
Fortin T80	248	391	14.8	16.6	45.6	> 20	305

This data plus other considerations have enabled the selection of new materials to be narrowed down to ARLON's 63N cyanate ester and ARLON's 85N MDA-free polyimide. Both of these materials have shown extremely good high-temperature properties, can be processed similar to our current material, and are supplied by a company that has provided KCD other high technology PWB materials (polyimide/quartz) in the past. Process characterization of this material is currently under way at KCD.

Appendix B

Polyurethane Encapsulants

by M. H. Wilson, AlliedSignal Inc., Kansas City Division

Polyurethane prepolymers are used at KCP for several products and processes. Primarily they are used to encapsulate electronic assemblies and cable connectors to provide environmental and high-voltage protection and structural support for components. They are also used for certain adhesives applications. The polyurethane encapsulants used at KCP contain approximately 0.2-12% of free toluene diisocyanate (TDI). TDI participates in the curing reaction and is an acute and chronic sensitizer. TDI is listed as a carcinogen by both the NTP and IARC.

A new product, AIRTHANE PET-90A, manufactured by Air Products and Chemicals, contains a much lower level of free TDI. It is a toluene diisocyanate and polytetramethylene ether glycol (TDI-PTMEG) based polyurethane with a nominal NCO content of 3.5% that differs from conventional cast elastomers of this type. Conventional prepolymer technology produces not only the desired 2:1 TDI/PTMEG adduct, but also a number of uncharacterized higher oligomers (typically > 25% of 3:4, 4:3, 5:4,...). The AIRTHANE prepolymers are manufactured to give a very high percentage of the 2:1 adduct of the isometric mixture of 80:20, 2,4-:2,6-TDI and PTMEG. This manufacturing technique produces prepolymers that have very low oligomer content (> 90% 2:1 adduct) and a residual TDI content of approximately 0.04 to 0.08%.

The advertised processing advantages of using the AIRTHANE system are lower toxicity, lower viscosity, longer pot life, quicker demold, and broad processing latitude. Other advantages include improved dynamic behavior, adhesion, and high-temperature performance. Lower toxicity is especially touted because of the < 0.1% TDI level. TDI cancer warning labels do not appear on the AIRTHANE MSDSs or on the prepolymer containers. In addition, the Airthanes are considered to be TDI-free by both OSHA and DOT standards. The free TDI content of L-100/RN1501 has been measured at 0.12%. On a lot-to-lot basis, the L100/RN1501 technology can not consistently produce levels below 0.1% free TDI.

The polyurethane prepolymers can be reacted with short chain diamine curatives such as MOCA, Cyanacure, and Ethacure 300. Table B-1 contains property comparisons between the encapsulants with different curing agents. The PET-90A prepolymer compares favorably with the presently used polyurethane encapsulants.

Table B-1. Encapsulant Property Comparison by Curing Agent

Prepolymer Curative	RN1501 MOCA	L-100 Cyana	EN-7/EN-8 n/a	PET90A Cyana	PET90A E-300
Stoichiometry, %	95	85	100	95	95
Mixed viscosity @ 71°C, cps	5000	5000	5500	2800	2800
NCO content, %	4.2	4.2	3.0	3.8	3.8
Free TDI content, %	<0.2	0.12	12.5	0.05	0.05
CTE, ppm/°C					
-53°C to 23°C	245	212	155	238	226
23°C to 74°C	214	193	181	215	230
Hardness, Shore A	95	95	90	92	87
Tensile strength, psi	4571	3539	2200	3245	4363
Elongation, %	381	507	425	523	468
Tear strength, ppi	420	469	305	405	435
Dielectric strength, vpm	335*	356	440	351	395
T _g , °C	-44	-42	-77	-64	-64

*Tested on 85% stoichiometry sample

Appendix C

Polyurethane Foams

by T. E. Neet, AlliedSignal Inc., Kansas City Division

Toluene diisocyanate (TDI) is the primary component in the BKC 44402 series of rigid polyurethane foams used at KCD and throughout the DOE Nuclear Weapons Complex to encapsulate electronic assemblies. While these foams have served us faithfully for many years, they do present a potential health hazard to our workers. For example, exposure to TDI in its vapor phase can cause severe, asthma-like reactions in sensitized individuals. In addition, TDI may soon be classified as a potential carcinogen. Providing environmental controls to minimize operator exposure to and atmospheric release of this chemical is becoming increasingly more expensive. Therefore, toluene diisocyanate was targeted for replacement.

The prime candidate for this replacement material is polymeric isocyanate (PMDI). While the dangers associated with both types of isocyanates may ultimately be the same, PMDI is inherently safer than TDI because its vapor pressure is 3000 times lower, thus making it that much easier to keep isocyanate concentrations below the 0.005 ppm Threshold Limit Value (TLV). Also, TDI is classified as a "Poison B" for transportation and disposal purposes while PMDI is treated as only a "Plastic Resin". Consequently, waste disposal and shipping of PMDI is cheaper and easier.

Having selected the replacement material, the next goal was to develop a series of PMDI-based, rigid polyurethane encapsulation foams that would be equivalent to the TDI-based materials in both physical properties and processability. Since there is usually very little difference in the physical properties of most rigid polyurethane foams, initial efforts were concentrated on generating PMDI formulations that closely matched the BKC 44402 series foams in rise-rate characteristics.

The BKC 44402 foams are unique in that they are designed to react very slowly so that operators have sufficient time to inject the correct quantity of material into the molds. With the PMDI formulation, achieving a low reaction rate while avoiding material separation was difficult because this crude isocyanate is not readily compatible with most polyols. Success was eventually accomplished by using a PMDI prepolymer and sucrose-based, polyether polyol (ARCO's LS-490) catalyzed with tetramethylethylenediamine. The final formulations for the five, free-rise densities of this new material, designated BKC 44307, are shown in Table C-1.

Rise-time comparisons between the new formulations and the baseline foam are shown in Figures C-1 through C-5. There is little difference in reactivity, especially in the more important, lower densities. Also, the R-component for the PMDI is considerably less viscous than the TDI system polyol (1000 cps versus 40,000 cps). This is an advantage for both foam machine and batch mixing operations.

Once the new, PMDI formulations were established, physical property testing was conducted to determine what differences, if any, existed between the two materials.

Table C-1. Formulations, Parts by Weight

Parts	LS-490	Water	TMBDA	DC-197	1231 Prepol
44307-4	100.0	2.4	0.2	1.0	172.4
44307-6	100.0	1.6	0.2	1.0	158.9
44307-10	100.0	1.0	0.2	1.0	148.9
44307-14	100.0	0.8	0.2	1.0	145.5
44307-20	100.0	0.5	0.2	1.0	140.5

With one exception, all results are essentially the same. The compressive, flexural and tensile data are shown in Figures C-6 through C-13. As can be seen, both foams have equivalent compressive properties. Tensile and flexural moduli for the two materials are also the same, but the strengths are different. This has been related to a difference in "toughness". That is, the TDI foam deflects further before it breaks. This may or may not represent a significant difference, depending on the degree of movement the foam might experience in the unit.

These new, PMDI-based foams are defined by material specifications 2170425 through 2170429.

Figure C-1. BKC 44402-4/BKC44307-4 Rise Time Comparison

Figure C-2. BKC 44402-6/BKC44307-6 Rise Time Comparison

Figure C-3. BKC 44402-10/BKC44307-10 Rise Time Comparison

Figure C-4. BKC 44402-14/BKC44307-14 Rise Time Comparison

Figure C-5. BKC 44402-20/BKC44307-20 Rise Time Comparison

Figure C-6. Room Temperature Compressive Strength Comparison

Figure C-7. Room Temperature Compressive Modulus Comparison

Figure C-8. Room Temperature Flexural Strength Comparison

Figure C-9. Room Temperature Flexural Modulus Comparison

Figure C-10. Room Temperature Flexural Tests, Deflection at Break

Figure C-11. Room Temperature Tensile Strength Comparison

Figure C-12. Room Temperature Tensile Modulus Comparison

Figure C-13. Room Temperature Tensile Tests, Deflection at Break

Appendix D

Aqueous Solder Fluxes

Several types of Aqueous Solder Fluxes were evaluated on this unit to gauge solderability and cleanability. These were Kester 2120 and 2224-25, Alpha 260HF and Hughes HF1189. None of the four were cleanable in plain deionized water. Addition of 1% of Kester 5768 Bio-Kleen saponifier yielded acceptable results with Kester 2120 and Hughes HF1189. The remaining two fluxes were not evaluated with the saponifier. Cleanliness was judged initially with the Omegameter. Using DI water only, all four fluxes failed the 0.01mg NaCl/in² limit although they required approximately 15 minutes or longer to exceed this limit. This indicated that the ionic contamination was only slightly soluble in water and alcohol. Further tests using Mass Spectrometer and Scanning Electron Microscope revealed that the ions were tin and lead salts.

All four fluxes yielded acceptable solderability, although the HF1189 was improved by the addition of a surfactant. It is believed that Hughes is still in the process of 'tweaking' the formulation of the HF1189 Citric Acid based flux and the final formulation may include a surfactant.

The Kester 2120 was used on the aqueous cleaned functional MC4138 units in preference to the HF1189 for the following reasons:

1. 2120 is chemically less active than the HF1189.
2. The supply of 2120 at KCD is larger. HF1189 is not readily available from Hughes.
3. Both fluxes yield equivalent solder joints.
4. The formulation of 2120 is more stable, therefore results are more transferable to other units.
5. KCD has prior experience with 2120 and it is much more thoroughly characterized.

The following report details a series of experiments that were performed to evaluate various aqueous fluxes and cleaning methods.

Aqueous Flux Cleaning Evaluations On ECM ID Unit

by R. D. Carter, AlliedSignal Inc., Kansas City Division

Summary

A series of evaluations were conducted in order to determine an acceptable aqueous flux/cleaning process to be used to fabricate the ECM ID units. None of the aqueous fluxes evaluated cleaned adequately using a DI water rinse alone. The best process was to drag solder with an eight second contact time using a Kester 2120 flux. Acceptable cleaning results were obtained by using a heated pressure spray of 1% Kester 5768 saponifier and DI water for four minutes. Following pressure spray, the units were cascade rinsed in hot DI water for three minutes, followed by spray clean with IPA. Using this process there were no visible residues on the test samples and ionic contamination levels were non-detectable.

Evaluation

The intent of these evaluations were to identify an aqueous flux and cleaning process that minimizes the use of hazardous materials without affecting the functional reliability of the ECM ID units. The test samples used were the Programmer PWBs which are a multilayer laminate of Norplex/Oak PY260 with a dry film solder mask.

The test samples were drag soldered with a preheat of 200°F, a solder temperature of 490°F, and a solder contact time of 10 seconds. After drag soldering the test samples were cleaned in the Hotpack dishwasher using a hot DI water recirculating wash followed by a cascade rinse at 43°C. Each test sample was dried using a vortex gun at approximately 150°F. The specific processing parameters and results of ionic cleanliness testing are listed in Table D-1.

All of the fluxes left a visual white or yellow residue of some kind, either on the PWB lands and/or the laminate and solder mask areas. All of the samples tested above the specification limits for ionic cleanliness (0.01mg NaCl per square inch). Analysis showed that the residues were tin and lead salts, which are difficult to remove and very slowly soluble in water.

It should be noted that soldering with the Hughes HF1189 flux did not meet our specifications. The HF1189 tended to bead-up during application on the PWB causing inadequate flux coverage. The experiment was repeated after adding a wetting agent to the HF1189 to improve flux coverage across the test sample. This greatly improved the soldering performance; however, the cleanability of the flux was not improved resulting in unacceptably high ionic contamination levels.

Because none of the fluxes evaluated were removable in water alone, it was decided to evaluate the use of Kester 5768 saponifier. Kester 2120 flux was selected for the rest of the evaluations because it is halide-free and appears to solder approximately as well as the other fluxes.

Table D-1. Flux Cleaning Evaluation Using DI Water

Flux	Saponi- fier (%)	Pressure Spray		DI Rinse		IPA Spray (min)	Ionic Contamination (mg NaCl/in ²)	Residue?
		Time (min)	Temp (°C)	Time (min)	Temp (°C)			
Kester 2120	0	6	50	1	50	2	0.0111	Residue
Hughes HF1189	0	10	50	1	50	2	>0.0400	Gross residue
Kester 2224-25	0	10	50	1	50	2	0.0143	Residue
Alpha 260 HF	0	10	49	3	32	2	0.0106	Residue

An experiment was designed to analyze the effects of soldering contact time on the cleanability of PWBs soldered with Kester 2120 flux and cleaned with Kester 5768 saponifier. Test samples were fluxed with Kester 2120 and drag soldered at various solder contact times ranging from 6 seconds to 14 seconds. Each sample was cleaned using a 1% saponifier solution and the parameters listed in Table D-2.

Table D-2. Flux Cleaning Evaluation Using Saponifier

Run	Pressure Spray		Saponi- fier (%)	Cascade Rinse		IPA Spray		Solder Contact (seconds)	Ionic Cleanliness (mg NaCl/in ²)
	Time (min)	Temp (°C)		Time (min)	Temp (°C)	Pres- sure (psi)	Time (min)		
1	4	43	1	3	43	35	2	6	0.0000
2	4	43	1	3	43	35	2	8	0.0000
3	4	43	1	3	43	35	2	10	0.0000
4	4	43	1	3	43	35	2	12	0.0000
5	4	43	1	3	43	35	2	14	0.0000

Ionic cleanliness testing showed no ionic residues were detected on any of the test samples regardless of solder contact time. In addition, there were no visual residues on any of the test board surfaces.

Conclusions

Results of the evaluations showed that none of the water soluble fluxes were adequately removed using hot DI water alone. Cleaning results were much improved by using a 1% solution of Kester 5768 saponifier. Acceptable ionic

cleanliness results were obtained regardless of soldering contact time when using Kester 2120 flux and Kester 5768 saponifier.

From these evaluations the ECM ID aqueous functional units were processed using the following soldering and cleaning processes.

1. Drag Solder

Flux: Kester 2120
Preheat: 200°F
Solder Temp.: 490°F
Contact Time: 8 seconds

2. Cleaning

- a. Clean for 4 minutes in Hotpack dishwasher using 43°C DI water and a 1% solution of Kester 5768 saponifier.
- b. Cascade rinse in DI water for 3 minutes at 43°C.
- c. Dry with vortex gun at 150°F.
- d. Spray clean with IPA at 35 psi for 2 minutes.

Appendix E

No-Clean Solder Flux

by F. M. Hosking, Sandia National Laboratories/New Mexico

An alternative to fluxless microelectronic soldering is the use of water soluble or low solids ("no-clean") fluxes. Water soluble fluxes are generally excellent choices for environmentally conscious soldering, but require aqueous-based cleaning to remove flux residues. There are times, however, when material is sensitive to water or may become trapped in parts of the assembly and consequently limit the use of water soluble fluxes. A low solids, "no-clean" flux is an excellent choice under such circumstances. A good example of this is the attachment of cable wires to the connector of the B61 programmer cable. "No-clean" fluxing helps to minimize the entrapment of flux residues under the wire insulation, reduce subsequent cleaning, and produce sound, reliable solder joints that are functional over long periods of time. These fluxes are environmentally conscious manufacturing (ECM) materials which offer the best option for soldering cable assemblies without significant cleaning.

The composition of a "no-clean" flux is typically based on an isopropyl alcohol carrier with small additions of acid activators and other surfactants that enhance solder wettability. Flux solids are generally less than 4%. When hand soldering, the effectiveness of "no-clean" fluxing is strongly dependent on operator technique and experience. Preliminary solder wettability experiments were conducted at AlliedSignal and Sandia with several commercial low solids fluxes to identify which gave the best wetting characteristics. The test results were used to develop a "no-clean" fluxing and hand soldering operation for soldering the B61 programmer cable assembly. This procedure is currently being used at AlliedSignal to fabricate prototype hardware.

The same conditions are true for the Baseplate/PWA subassembly level as found at the cable attachment level. ECM soldering of wires can be accomplished by selecting a low solids, "no-clean" flux. Since the process is a hand soldering operation and is very operator dependent, it presents the greatest challenge for applying "no-clean" fluxing. Care must be taken to restrict the volume of flux used, otherwise excess residues result on the soldered component and cleaning becomes necessary. Controlling the heat input during soldering is also critical, since the flux chemistry is formulated to activate closer to the soldering temperature. The lower solids content also presents a wetting problem if the flux is not uniformly applied (or activated). Although these processing limits are more restrictive than those required with mildly activated, rosin-based fluxes, the result is an improved ECM process that yields consistently reliable solder joints. With the increasing demand to phase out CFC compounds, it has become even more critical to quickly implement these alternative soldering technologies into production use.

Appendix F

PAWS Monitoring System

Preliminary Report on PAWS Field Test at AS/KCD

by G. C. Frye & R. W. Cernosek, Sandia National Laboratories/New Mexico and
G. W. Bohnert & T. E. Hand, AlliedSignal Inc., Kansas City Division

The first field test of the Portable Acoustic Wave Sensor (PAWS) system being developed at Sandia National Laboratories (SNL) for real-time, on-line monitoring of volatile organics took place March 9 to 11, 1992. Testing was done on exhaust stacks from spray cleaning booths in the Precision Cleaning Facility at AlliedSignal, Kansas City Division (KCD). A variety of tests were performed to evaluate the system performance as well as to probe how alternative solvents and processes can be used to minimize environmental emissions. The results from the system demonstrate real-time, on-line detection of both trichloroethylene (TCE) and d-Limonene (a substitute solvent being used as part of the environmentally conscious manufacturing integrated demonstration of which this test was a part). Sensor baseline was effectively evaluated on-line using an AmberSorb scrubber and a computer controlled three-way solenoid valve to direct the gas stream to the scrubber on an operator input protocol. Using input calibration coefficients for the chemicals, the frequency response from baseline was used to determine chemical concentration in the exhaust stack with time. These coefficients were determined prior to the test by calibrating the sensor using a new vapor test system. The absolute accuracy of the PAWS system was also verified since the concentration values were in good agreement with those calculated based on the amount of solvent lost (sprayed volume minus recovered volume) with time and the volumetric flow rate in the exhaust stack (calibrated during the test).

Results from a variety of tests demonstrated the utility of this on-line monitoring for evaluating the environmental impact of cleaning processes. These on-line tests generally consisted of a run time of about seven minutes and a one minute spray time starting at about the one-minute mark. A scrub cycle at the beginning and middle of each run was used to demonstrate the ability for on-line evaluation of sensor baseline. For the figures, the dashed lines are the frequency response from the acoustic wave sensor and the solid line is the calculated concentration of the solvent in the stack (no concentration data is shown during the scrub cycles). A comparison of the TCE cleaning process previously used (see Figure F-1) with one using d-Limonene (see Figures F-2 and F-3) demonstrated that emissions were dramatically reduced and solvent recovery was significantly improved with the alternative solvent. Two runs with d-Limonene (Figures F-2 and F-3) performed by the same spray booth operator and with identical settings on the spray gun demonstrated that differences in the spraying technique can result in a doubling of emissions. This demonstrates that use of this on-line monitoring capability could be used to optimize worker protocols to reduce the environmental impact of processes using volatile organics. Another test investigated the advantage of using a non-air atomized spray gun with the air atomized spray guns typically used at

KCD. Figure F-4 shows that changing to this new spraying technique could reduce emissions by a factor of five to ten (comparing to Figures F-2 and F-3).

The PAWS system used in this field test consists of an 8" x 8" x 7.3" sensor module containing a PC board with RF electronics for operating the acoustic wave sensor and a temperature control circuit for maintaining the device test case at a constant and elevated temperature. The acoustic wave device coated with a polyisobutylene coating for absorbing the volatile organics to be detected is held in a 1" x 1" x 0.7" brass test case mounted to the PC board. This case has gas inlet and outlet tubes, a heat exchanger on the gas inlet side to increase the gas temperature to near that of the device, and pressure electrical contacts enabling simple drop-in changing of devices in the field. The sensor module also contains a power supply for operating the electronics and the solenoid valve. For this test, a small external pump was used to continuously pull a gas sample into the sample chamber. The module is connected to a Dolch portable computer running a specially designed software system running in LabWindows. Frequency is monitored using a counter card in the computer and a separate card is used to send out a digital signal to activate the relay which is used to power the three-way valve. The software takes the frequency data, converts the data to chemical concentrations using an input calibration coefficient, activates the scrubber on an input protocol, and displays a plot of the data in real-time. Preliminary hardcopy plots of the data can be obtained from this system using a portable printer. The data is stored in ASCII format enabling final plots to be generated using a plotting package (Figures F-1 to F-4 were generated using SigmaPlot at KCD during the test).

GFC, RWC:ASTCE7.DAT/SPG

Figure F -1. TCE: Air Spraying 19% Recovery

GFC/RWC: ASLIME3.DAT/SPG

Figure F-2. d-Limonene: Air Spraying 84% Recovery

GFC/RWC: ASLIME4.DAT/SPG

Figure F-3. d-Limonene: Air Spraying 30% Recovery

GFC/RWC: ASLIME5.DAT/SPG

Figure F-4. d-Limonene: No-Air Spraying 89% Recovery

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