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SURFACE MOUNT COUNCIL WHITE PAPER

PWB Surface Finishes



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The Surface Mount Council (SMC) is made up of key industry representatives from EIA, IPC and SMTA. The SMC is dedicated to promoting the use of surface mount and advanced electronic packaging technology in the design and production of electronic hardware.

Council Members represent user, supplier and equipment manufacturing companies engaged in surface mount implementation for automotive, telecommunication, computer, instrument, government, consumer and medical electronics.

The mission of this Council is to facilitate, coordinate and promote the orderly implementation of surface mount technology through standardization, the development of technical documents and other means.

At the request of the SMC, this collection of papers was developed by seven PWB fabrication experts. This group reviewed surface finishes available for printed boards and the needs of surface mount assembly. The surface finish technology drivers are fine pitch packaging for components with lead spacing of 0.5 mm or less, direct chip attach for pitches at 0.2mm or less, flat solder lands for solder paste application and multiple reflow operations to achieve high first pass yields, cost effective assembly, and the limitations of HASL and tin/lead reflow. Additional technology drivers would include solderability, compatibility with electrical test, applicability to thin PWBs, wire bondability and process availability from multiple suppliers. One surface finish method is not likely to satisfy all these requirements. The PWB designer and the system assembly engineer must become much more knowledgeable about all the surface finish options in order to make the most cost effective choice for his particular product. The topics covered include:

- Organic Solderability Protection (OSP) methods such as Imidazole and Substituted Benzimidazole coatings
- Metallic Coatings Directly over Copper such as Tin/Lead Hot Air Solder Level process (HASL), Immersion Silver and Immersion Bismuth
- Metallic Coatings over Nickel over Copper such as Gold, Palladium Tin and Tin-Nickel

All the above approaches surface finish approaches were tested during the recent NIST/NCMS PWB Interconnect Program and the detailed test results are reported. Process engineers, PWB electrical designers, electronic system assembly designers and managers who have the responsibility for defining SMT processes will benefit from the information in this compendium. Knowledge of the SMT assembly process will be helpful in reading and understanding these papers.

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ORGANIC SOLDERABILITY PRESERVATIVES: BENZOTRIAZOLES AND SUBSTITUTED BENZIMIDAZOLES

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INTRODUCTION

The acceptance and use of Organic Solderability Preservatives (OSPs) as replacements for Hot Air Solder Leveling (HASL) continues to grow. OSPs selectively protect and maintain the solderability of a PCB's copper features (i.e. SMT pads, through-holes) by providing thermal protection against degradation during assembly. Historically one class of OSP, the benzotriazole inhibitors, has been successfully used by a number of major OEMs in select assembly applications requiring a single heat excursion. During the past five years a new upgraded class of OSP, the substituted benzimidazole, has proven to yield additional benefits to PCB fabricators while addressing a diversity of processing challenges encountered by PCB assemblers and OEMs.

Environmental and economic factors, as well as advancements in PCB technology are the three major drivers which have ignited the change from HASL to OSPs. Environmental concerns include the desire to eliminate hazardous materials (e.g. lead) from the fabrication production environment, as well as the need to address potential legislation restricting the use of lead on the local, state, and national levels. Since OSPs are aqueous-based and do not produce hazardous waste, environmental compliance is made easier.

Economically, the OSP process is substantially less expensive than HASL, which is a labor intensive and a high maintenance process. When one considers that the HASL process produces solder dross (considered a hazardous material), the disposal of the dross is both an economic and environmental burden that the PCB fabricator would welcome the opportunity to eliminate. When one compares actual processing cost, rework/repair cost, and the cost of rejects, current users of substituted benzimidazole-based OSPs have experienced a total cost savings of 25 to 50% versus HASL. For benzotriazole-based coatings the savings are even more impressive.

Finally, technology advancements evidenced by the advent of new and complex packaging designs such as fine-pitch, ball grid arrays (BGAs), chip scale, and flip chip have necessitated flat, planar surfaces. Another processing concern is the trend towards thinner PCBs. HASL has limited success in processing PCMCIA cards

and thin PCBs. It is not uncommon for HASL to produce boards with inconsistent solder coating thicknesses, thus causing "crowned" SMT attachment areas and reduced clearance of through-holes. These deficiencies result in subsequent rework and rejects at assembly and reduce first-pass assembly yields. Conversely, OSPs are known to consistently produce thin coatings. Other problems associated with the HASL process include: intermetallic compounds formation (Cu/Sn) and the potential for poor solderability; warpage due to changes in temperature; and thermal shock which jeopardizes PCB integrity while escalating the potential for increased ionic contamination levels.

This article will examine the considerations required in selecting benzotriazole and substituted-benzimidazole OSPs for implementation in PCB manufacturing.

OSPs IN PCB FABRICATION

By implementing OSP technology the PCB fabricator replaces a hazardous, difficult to control process (HASL) with a lead-free, easy to control, aqueous process. Figures 1 and 2 outline typical benzotriazole and substituted benzimidazole process cycles.

The front end of each process, referred to as the "pre-clean cycle", is quite similar. During this cycle the PCB is first immersed in a cleaner (typically an acid cleaner) to remove any finger oils or other contaminants. Some copper oxide removal also occurs. During the microetching step the copper oxide is fully removed and a total of 20-40 microinches of copper is etched away. The resultant copper topography has an increased surface area due to the microroughened surface. This surface results in an increased number of attachment/bonding sites for the OSP. Additionally, the associated high surface energy of the copper will result in a high solderability level. The result of poor or insufficient microetching is a non-uniform, less than ideal coating appearance. This may also negatively affect solderability during wave soldering. The acid rinse step is used to neutralize any microetchant salts not fully rinsed off, as well as a sacrificial bath to inhibit any contaminants from entering the OSP solution. A 5-10% sulfuric acid (H_2SO_4) solution is typically employed for this operation.

After the copper is properly prepared, OSP application can occur. The benzotriazole coating is deposited by immersing the PCB in a 1.0 to 2.5% concentration solution for 60±30 seconds. The solution temperatures can range from room temperature to 49°C. A heated solution will aid in drying the PCB. The most critical coating control parameter is maintaining the solution pH above 3.0. The resultant deposit is a monolayer approximately 50 to 150 Angstroms thick. A thicker deposit is not possible. See Figure 3 for a benzotriazole bonding mechanism onto copper.

The substituted benzimidazole coating is deposited by immersing the PCB in a 100 ± 10% concentration solution for 45 to 90 seconds. The solution temperature is set at ~43°C and the pH at ~2.7. The resulting coating thickness is 0.35 ± 0.15 microns (3500 ± 1500 Å). The protective layer is formed initially through a complexing reaction with copper to form an organometallic bond, followed by a build-up of the benzimidazole to the requisite final thickness. The deposition process is controlled via the coating thickness. The solution temperature and dwell time are kept constant during operation. The solution concentration and pH/total acidity will change over time, and thus are monitored and replenished accordingly. See Figure 4 for a substituted benzimidazole bonding mechanism onto copper.

The final step in the OSP application process is PCB drying. Drying should be performed in an in-line dryer and should be of sufficient temperature (60-80°C), air reflow and duration to ensure that all PCB holes and vias are free of water. This step is critical for achieving maximum shelf life and solderability of the OSP-coated PCBs.

These OSP coating processes can be performed either in a vertical dip line or in an automated horizontal line. For maximum consistency and throughput, especially of small PCBs or PCBs containing small holes ($\leq 0.015''$), a horizontal process is recommended. Horizontal processing equipment for both types of OSPs is quite similar. The only major difference is that benzotriazoles can be applied via spray technology, whereas substituted benzimidazoles, due to their long molecular structures, can not. Benzimidazoles are successfully being deposited in production via a horizontal flood immersion module being used in the OSP coating step. See Figure 5 for an example of a typical horizontal immersion processing line.

Unlike HASL, and other metallic PCB surface finishes, OSP-coated PCBs are reworkable by simply re-processing them through the original application process. If necessary, rework of the OSP coatings can occur several times without concern for the integrity of the PCB. The only critical parameter to monitor is the total

amount of copper removed during the microetch steps. Once a total of 60 to 80µ inches has been removed it is best to skip the microetch step if subsequent reworks are required. This should suffice since the copper PCB surface topography originally created will remain intact over time.

The recommended procedures for packaging OSP-coated PCBs for shipping to the assembler are quite similar to those for HASL. The PCBs should be stacked 10 to 25 high, depending on size, without individual slip sheets between each PCB. An outer slip sheet, made from sulfur-free materials, should be placed on the top and bottom PCBs in the stack. A "shrink wrap" should be applied to tightly seal the PCB stack. The PCB stacks should be placed in a box which includes desiccant. During the packaging step operators should wear impermeable gloves in order to eliminate the possibility of ionic contamination and coating degradation (especially for benzotriazole - coated PCBs).

RELIABILITY OF THE OSP COATINGS

The reliability of OSP coatings can be defined by how durable they are prior to assembly (i.e. shelf life, handling, robustness, etc.) and by their long term electrical insulative properties.

Durability

Historically one of the main concerns with the use of OSPs has been their limited shelf life and low tolerance to being handled. The benzotriazole coating is a thin, monolayer deposit that is quite fragile. This coating is susceptible to high humidity conditions and the best case storage/shelf life is typically 3 to 6 months. Finger prints or other similar handling soils will adversely affect the benzotriazole coatings. Furthermore, the coating's protective properties are severely diminished when exposed to temperatures exceeding 100°C. After one soldering heat excursion (e.g. SMT reflow) this coating rapidly degrades and severe oxidation of the remaining copper surfaces follows, thus rendering assembly of the PCB's second side improbable.

Over 20 years of industry production experience has well documented the limitations of the benzotriazole coatings. Despite these limitations, numerous OEMs/assemblers have successfully used these coatings as HASL alternatives by optimizing their assembly processes to compensate for these shortcomings. These coatings have been most widely used in the computer and telecommunications sectors in conjunction with single soldering assembly processes, highly active soldering materials and/or inerted soldering processes.

Through six years of worldwide production experience the substituted benzimidazoles have been demonstrated to be substantially more robust than previous OSPs.

Accelerated aging, along with actual production experience, has found that these coatings maintain solderability for a minimum of twelve months, at typical assembly shop conditions (e.g. $\leq 35^{\circ}\text{C}$, $\leq 80\%$ R.H.).¹ Companies that have performed accelerating type tests have learned not to use steam aging, but rather more moderate conditions.

For many years, steam aging has been used to artificially accelerate the storage/shelf life conditions of solder coated PCBs. The steam conditions ($90\text{--}96^{\circ}\text{C}$) were ideal for inducing the growth of the non-solderable Cu-Sn intermetallic compounds (IMCs) found on PCBs coated with solder. In a relatively short time (8 - 24 hours) a shelf life period of more than one year could be simulated. Companies looking to use this method on OSPs have found that it is not suitable. Since IMCs are not present in a OSP coated PCB, the steam aging only serves to degrade the organic coating and oxidize the copper. Therefore other means of accelerated testing are necessitated. Testing has been reported with 35°C , 95% R.H. for 96 days, 65°C , 95% R.H. for 24 hours and 40°C , 90% R.H. for 1000 hours.^{2,3} These conditions all simulated 12 to 24 months of storage life.

Although metallic PCB surface finishes tend to be more robust to handling than OSPs, the substituted benzimidazole coatings are significantly more tolerant than the benzotriazoles. Production experience at numerous contract assemblers in the U.S. has shown that these coatings can withstand the routine handling that PCBs are subjected to during assembly without the need for gloves. Of course proper handling of PCBs by their edges should always be stressed, regardless of PCB surface finish, in order to minimize the potential for ionic contamination. This is most important for PCBs to be used in no-clean assembly processes.

Long Term Electrical Reliability

To date, numerous reliability tests have been performed to characterize the effect of the presence of the substituted benzimidazole coating on the long term electrical properties of the PCB. These tests were performed to determine the reliability of the coating "as deposited" as well as after one or more heat excursions (soldering operations). Following is a summary of some of these tests:

- JIS Z-3197 Surface Insulation Resistance

JIS Z-3197 Type 2, interlocking comb patterns with 12.5 mil lines/spaces and a 0.62" overlap length of the fingers were coated with a substituted benzimidazole coating and subjected to 1000 hours at 40°C , 90% R.H. Insulation resistance measurements were taken at 100 VDC test voltage every 200 hours. After 1000 hours the final

insulation resistance was 2×10^{13} ohms. See Table 1 for actual readings.⁴

- Bellcore TR-NWT-000078 Surface Insulation Resistance

IPC-B-25 comb patterns with 25 mil lines/50 mil spaces were coated with a substituted benzimidazole coating and subjected to 96 hours at 35°C , 85-90% R.H. and a 45-50 VDC bias. Insulation resistance measurements were taken every 24 hours at a 100 VDC test voltage. After 96 hours the final insulation resistance was $> 3 \times 10^{12}$ ohms (Pass = 1.2×10^{11} ohms). See Table 2 for actual readings.

The same test was performed but after the test coupons were coated they were subjected to one SMT reflow in an IR/convection oven in an air atmosphere. The final insulation resistance for the "soldered" coupons was $> 7 \times 10^{12}$ ohms (Pass = 1.2×10^{11} ohms).⁵

- Modified Bellcore TR-NWT-000078 Surface Insulation Resistance

IPC-B-25 comb patterns with 12.5 mils lines/spaces were coated with a substituted benzimidazole coating and were subjected to various reflow/wave soldering conditions prior to electrical testing. The SIR test conditions were 35°C , 85-90% R.H. 45-50 VDC bias for 28 days. Insulation resistance measurements were taken at 100 VDC test voltage every two days. The minimum acceptable insulation resistance is 2×10^{10} ohms.

Condition 1: Coating subjected to one SMT reflow.
Final I.R. was $> 3 \times 10^{12}$ ohms.

Condition 2: Coating subjected to five SMT reflows.
Final I.R. was $> 4 \times 10^{12}$ ohms.

Condition 3: Coating subjected to one SMT reflow plus wave soldered with a low solids, no-clean flux.
Final I.R. was $> 3 \times 10^{11}$ ohms.

Condition 4: Coating subjected to five SMT reflows plus wave soldered with a low solids, no-clean flux.
Final I.R. was $> 3 \times 10^{11}$ ohms.

See Table 3 for actual readings.

Through the use of numerous SMT reflows it was proven that the coating is highly inert even after exposure to elevated temperature excursions. The introduction of the low solids flux demonstrated the suitability of the no-clean system, which incorporates the use of the substituted benzimidazole coating in a no-clean, mixed technology assembly.

Furthermore, Condition 4 simulates the worst case scenario of having exposed/non-wetted copper present with tin-lead along with no-clean flux residues, which could occur when full wetting is not achieved during wave soldering. The test results prove this to be an inert system and probably most dependent on the activity of the no-clean flux used.

- Bellcore TR-NWT-000078 Electromigration Resistance

IPC-B-25 comb patterns with 25 mil lines/50 mil spaces were coated with a substituted benzimidazole coating. Half of the coupons were subjected to one SMT reflow. All of the samples were stabilized at 85°C, 85% R.H. for 96 hours. Initial insulation resistance measurements were made using 100 VDC test voltage. The coupons were then subjected to 500 hours at the 85°C, 85 R.H. and 10 VDC bias conditions. The final results showed no decrease in the insulation resistance as a result of the applied bias. Additionally, at 10X magnification there was no evidence of electromigration or dendritic growth.⁶

<u>Coupon</u>	<u>Initial I.R.</u>	<u>Final I.R.</u>
Control	$6.4 \times 10^8 \Omega$	$3.6 \times 10^8 \Omega$
As Coated	$3.8 \times 10^8 \Omega$	$1.2 \times 10^9 \Omega$
Reflowed	$7.2 \times 10^8 \Omega$	$1.1 \times 10^9 \Omega$

- Modified Bellcore TR-NWT-000078 Electromigration Resistance

IPC-B-25 comb patterns A, B and C were coated with a substituted benzimidazole coating and subjected 85°C, 85% R.H. for 1000 hours at three different applied voltages. Each group of coupons had their own uncoated copper control comb patterns.

<u>Test Board</u>	<u>Combs</u>	<u>Applied Voltage Bias</u>
Pattern A	6 mil lines/spaces	50 VDC
Pattern B	12.5 mil lines/spaces	100 VDC
Pattern C	25 mil lines/50 mil spaces	500 VDC

Initial insulation resistance for all comb patterns, including controls, were $\sim 1 \times 10^{14}$ ohms. After 1000 hours all the coated coupons were measured at $> 5 \times 10^9$ ohms, with the control coupons all within less than a decade difference. At 10X magnification no evidence of any electromigration or dendritic growth was reported. See Table 4 for actual readings.⁷

- Moisture and Insulation Resistance - MIL-STD-202E, Method 106D

Per MIL-STD-202E IPC-B-25 comb patterns were prepared with a liquid photoimageable solder mask. Half were coated with a substituted benzimidazole and the

remainder with HASL. The coupons were first cycled from 25°C, 90% R.H. to 65°C, 95% R.H. for ten 16 hour cycles. Once pre-conditioned the comb patterns were measured for initial insulation resistance and then subjected to 65°C, 95% R.H. for 139 hours with a 100 VDC bias. The specification requirement is that the final insulation resistance must be $> 5 \times 10^8$ ohms.

<u>Coating</u>	<u>Initial I.R.</u>	<u>Final I.R.</u>
HASL	$2.0 \times 10^{12} \Omega$	$6.0 \times 10^7 \Omega$
OSP	$1.3 \times 10^{13} \Omega$	$4.0 \times 10^{11} \Omega$

No failures were attributed to solder mask degradation. The failure analysis did suggest that the presence of the solder mask was responsible for entrapping some constituents from the HASL flux during the high temperature coating operation. As the solder mask softened at the elevated temperature, cycling and bias of the test, these potentially ionic materials were released.

Although the benzotriazole coatings have been used for many years, the volume of published reliability data is not substantial. Most large users have determined the coating to be reliable via similar tests to the ones described above, but have never released the results into the public domain. See Table 2 for the results of one Bellcore SIR test.

OSPs IN PCB ASSEMBLY

The SMT Process

The major benefit of OSPs to the assembler is the flat PCB soldering pads. Unlike HASL-coated PCBs there is no solder bump on these pads to interfere in solder paste deposition and component placement. The flat surface allows the assembler maximum control in depositing an accurate, consistent volume of solder paste. This results in a higher transfer efficiency of the solder paste especially for stencils with small apertures (i.e. FPT, UFPT, BGA, micro-BGA, flip chip). This “cleaner” solder paste deposit significantly reduces the incidence of lateral smear of the solder paste on the underside of the stencil and of solder paste bridging of tight pitch soldering pads. With finer pitches ($< 0.020''$) this will minimize the need to reduce stencil apertures, which will aid printability, without concern for bridging. If minimizing the amount of exposed/non-wetted copper on the periphery of an SMT pad is important, then the stencil aperture/SMT pad ratio should be maintained at 1:1. The recommended maximum reduction for FPT apertures (in air reflow) is 20% (i.e. 8 mil wide paste deposit on a 10 mil wide pad). Aperture reductions in the lengthwise direction are unnecessary and not recommended.

Due to the high color contrast of the materials in use, (e.g. OSP-coated copper, the solder mask and solder paste), additional in-process benefits are realized. Alignment of the stencil to the PCB during screen printing set-up is

facilitated due to the copper color of the SMT pads. Any missed or skipped solder paste deposits onto the PCB will be easily detected because of the copper pad to solder paste color contrast. This will allow earlier detection of poor printing and will preclude these PCBs from being fully assembled, only to require subsequent rework. Finally, the flat non-reflective topology of OSP-coated fiducial marks allows more consistent recognition by the assembly equipment's machine vision.

Production experience to date has exhibited excellent compatibility of most solder pastes, regardless of the flux vehicle activity (i.e. OA, RMA, no-clean, low residue) with the benzotriazole and substituted benzimidazole coatings.

In converting to the OSP processes there is no need to adjust the thickness of the solder paste deposited. Normally the same thickness used with HASL PCBs will suffice. Most of the solder from the HASL process remains under the SMT leads during reflow and does not contribute to the solder fillets formation.

Existing SMT reflow profiles used for HASL - coated PCBs should work well for both OSP types. Although, some optimization to the profile will enhance second side solderability. Maintaining the peak temperature that the PCB experiences (in air) during first side reflow below 240°C will be beneficial for subsequent soldering operations. Similarly, increasing the post-reflow PCB cool-down rate to reach 100°C as quickly as possible is also advantageous (not to exceed cooldown rate specified for ceramic components). These optimizations will increase the process window for substituted benzimidazole coatings for multiple heat excursion assembly. Unfortunately this beneficial effect does not extend to the benzotriazole coatings. After one heat excursion the second side copper is considerably oxidized. Consistent second side soldering is unlikely, even with highly active soldering materials.

One consideration that is required during SMT assembly of substituted benzimidazole coated PCBs is the selection of solvents used to wipe down misprinted solder paste. These coatings are soluble to varying degrees in most solvents (acidic or basic). Even though some amount of coating may be removed by a chosen solvent, this does not equate to a loss of solderability. Careful selection of an appropriate wipe-down and cleaning solvent will eliminate potential incompatibilities. The benzotriazole coating, as a result of its strong monolayer bond to copper, is not similarly affected.

In most in-line assembly processes all of the soldering steps will occur within a few hours (if not minutes) of each other. At times, due to equipment breakdown or component shortages, partially assembled PCBs may

incur substantial hold times prior to subsequent soldering. Typically, for substituted benzimidazole coated PCBs if these delays are a matter of hours or even days, solderability of the second side will not be compromised. Several variables will impact the maximum hold time allowable:

1. Time at elevated temperature during the first solder paste reflow.
2. Maximum temperature the PCB reached during the first reflow.
3. Reflow environment used (N₂ vs. Air).
4. Cleaning of the PCB and what type of solvent used.
5. Solder paste wipe down for misprint.
6. Activity of soldering material to be used for side two.

Production experience has shown that hold times of one to seven days are typical and should not be of a concern. The variables listed above will dictate the acceptable hold times for PCBs in a particular process. One major OEM has experienced hold times greater than one month without solderability degradation.⁸

The Wave Soldering Process

Production experience to date of single pass through-hole wave soldering of benzotriazole and substituted benzimidazole coatings has exhibited excellent compatibility of most flux types, regardless of activity (i.e. OA, RA, RMA, SA, low solids no-clean, VOC-free no clean) or flux application technique. For mixed technology assembly, where wave soldering occurs after prior heat excursions, the more active flux types will be fully compatible with the substituted benzimidazole coatings. Low activity soldering materials such as low solids and VOC-free no-clean fluxes may require some process optimization. Benzotriazole coatings are not recommended for use in mixed technology processes.

Successful implementation of low activity fluxes requires some scrutiny of the wave soldering process. Typically the major areas to be analyzed are the flux formulation, the effectiveness of the flux application method/equipment and the assembly process parameters. The choice of flux and how it is applied to the PCB's plated through-holes (PTHs) are major factors in determining the level of hole fill and top side wetting achieved. The wetting mechanism for OSPs differs from HASL. In order to achieve good wetting the flux needs to be applied where the solder needs to flow. The flux is instrumental in penetrating the coating ahead of the molten solder. The more complete the flux penetration into the PTHs, the more likely that full hole fill and top

side wetting of the annular ring will occur. Flux application techniques like wave fluxing and foam fluxing are effective at delivering a suitable level of flux transfer to the PTHs. These techniques result in excellent hole fill and top side wetting even with the lowest activity fluxes. Conversely, most spray fluxing equipment is limited in its ability to deliver flux far enough up into the PTHs. Additionally, spray fluxing significantly reduces the quantity of flux applied to the PCBs. For these reasons unoptimized spray processes will typically yield poor top side solder fillets.

Low solids and VOC-free no-clean fluxes specifically formulated for OSPs are now available from numerous flux manufacturers. These fluxes typically offset some of these flux application shortcomings by being slightly more active, having superior capillary action or being more effective at penetrating the OSP. A new flux application technique, the JetFlux® System, uses the principles of ink jet printing to achieve superior flux transfer to the PTHs. The flux is delivered in liquid micro streams that deposit well up into the PTHs to be soldered. This technique helps achieve excellent top side fillets while applying a flux quantity similar to spray fluxing.

In converting to mixed technology assembly of substituted benzimidazole coated PCBs with low solids or VOC-free no-clean fluxes, several process parameters should be reviewed and optimized:

1. Improve PCB first side SMT reflow process control by minimizing the peak reflow temperature and increasing the PCB cooldown rate.
2. Minimize PCB hold times between soldering operations.
3. Maintain wave fluxing PCB top side pre-heat temperature at 100-120°C.
4. Maintain solder pot temperature at 245 to 260°C.
5. Use air knife after flux applicator to assist flux penetration up the PTHs.
6. Use turbulent type wave configuration (e.g. chip wave) to maximize hole fill.
7. Increase wave contact time and PCB depth in solder to maximize hole fill.

Optimization of the above listed common wave soldering parameters, along with selection of the appropriate flux and application technique will result in successful no-clean, mixed technology assembly with OSPs.

See Table 5 for a summary of OSP compatibility with various assembly process and soldering materials.

Effect of Nitrogen Inerting

Historically, nitrogen inerting of SMT reflow has been used to maximize first-pass assembly yields for processes using low activity soldering (no-clean) solder pastes. Most recently nitrogen, in the form of a “blanket” surrounding the solder pot, has been used in wave soldering with low solids, no-clean fluxes. In this case the benefits stem more from the reduction of dross formation on the solder pot than increased solderability. In the case of OSPs nitrogen inerting of the entire assembly process is beneficial.

Some assemblers have found that by inerting the SMT reflow process they are able to “extend” the effectiveness of benzotriazoles for some multi-heat excursion processes. When inerting is coupled with the use of highly aggressive water soluble wave solder fluxes and short hold times between soldering operations, some success with mixed technology assembly may occur. Only a few companies have ever succeeded in consistently achieving this.

The use of nitrogen (< 500 ppm O₂) in the SMT reflow of substituted benzimidazole coated PCBs will improve the wave soldering hole fill with low activity fluxes. During SMT reflow of the top side of the PCB, the bottom side also experiences the elevated temperature and thus the coating on this side also “opens its pores”, but does not come in contact with the flux vehicle. During this period some oxygen diffusion will occur through the coating. The use of a nitrogen atmosphere will reduce this condition. When the PCB temperature is reduced after reflow, the coating will “close its pores”, and thus not allow any further degradation. By reducing the quantity of oxygen diffused through the coating on PCB side 2 during SMT reflow, the second side soldering operation will experience a wider operating range. For this reason, OSPs retain solderability through more heat excursions in nitrogen versus air. When nitrogen is used in wave soldering, but not during SMT reflow, one will experience some increase in process latitude. This will not be as significant an improvement as when nitrogen is used during SMT reflow alone. OSP-coated PCBs soldered in air will remain effective through 3 to 5 mass heat excursions (depending on the activity of the soldering materials) plus any localized soldering (i.e. hand soldering, rework, etc.). In nitrogen (< 500 ppm O₂), more than 5 mass heat excursions are possible.

Production experience has shown that the use of nitrogen is not required for successful mixed technology assembly of OSP-coated (substituted benzimidazole) PCBs in a no-clean environment. The key is proper process optimization.

APPLICABILITY TO NEW PACKAGING TECHNOLOGIES

In general both types of OSPs will be beneficial to any packaging technology where soldering to a flat attachment area is required. The following is a summary of applicability to various new technologies.

Ultra Fine-Pitch

Ultra fine-pitch is defined as lead-to-lead spacing of 0.016" or finer. Work to date has shown that the pad flatness afforded by the OSPs, in conjunction with finer mesh solder paste powder (-400/+500, -500/+635) makes production level processes feasible below 0.015" pitch. With the recent advances in stencil manufacturing and screen printer accuracy/repeatability, pitches down to 0.010" may be feasible.

Ball Grid Arrays (BGAs)

To date a substantial amount of production work has been performed with various BGA configurations soldered to OSP-coated PCBs. A recent study by a major OEM found that the use of certain types of substituted benzimidazole OSPs resulted in the highest solder joint reliability for BGAs. This test compared HASL, various Ni-Au coatings, Sn-Bi, Ni-Pd, and various OSPs.

The flat pad attachment areas offer the potential for every BGA solder joint to be virtually identical in solder volume. By improving the probability of forming consistent solder joints the opportunities for costly rework are virtually eliminated. For ideal compatibility with OSPs, the BGAs need to have eutectic solder balls which will be attached to the PCB via flux/solder paste or high temperature alloy solder balls which will use solder paste for attachment. Micro-BGAs, mini-BGAs, and other BGA configurations will all benefit similarly.

Flip Chip

Flip chips, due to their low profile solder bumps, will also benefit from consistent, flat pads. Flat pads will tolerate any lack in bump coplanarity better than a poorly controlled HASL deposit. In a similar manner to BGAs, any flip chip configuration where the bump is made of an alloy that will melt during standard reflow will be fully compatible with OSPs.

Tape-Automated-Bonding (TAB)

Soldering of TAB components normally requires that the solder be pre-deposited on the attachment pads (which are typically 0.010" pitch or finer). OSPs are not directly compatible with TAB attachment but they may be of use by creating a flat solderable surface for applying the pre-deposited solder. The solid solder techniques often used in this application would be compatible with the OSPs.

Chip-on-Board Wire Bonding

The OSPs will not be directly compatible with any type of wire bonding. OSPs may be useful for PCBs requiring both wire bonding and solderability. Wire bonding needs to occur to a noble metal like gold, but often the gold thickness employed could be detrimental to the formation of metallurgically sound solder joints. Therefore OSPs can be used for PCBs requiring two surface finishes. Once the PCBs have been gold plated in the wire bond attachment areas they can be processed through the OSP coating operation. Unlike HASL and other metallic finishes, masking of the gold is not necessary.

PCMCIA Cards - Thin Cards

Most PC card designs use a 0.016 to 0.018" thick PCB with numerous fine pitch components. These PCBs are typically fabricated in 18" x 24" panels. It is very difficult to HASL such large, thin panels consistently. The use of OSPs on such designs results in increased first-pass yields of the fine-pitch components by reducing the incidence of bridging. Additionally the mild temperatures of the OSP process will not alter the dimensional integrity of the thin PC Cards. The thermal shock associated with the HASL process can distort the physical dimension of the PC cards in a non-linear manner. This distortion, albeit relatively small (1 to 2 mils), can be enough to affect the screen printer and component placement accuracy, thus impacting fine pitch assembly yields.

SOLDER JOINT RELIABILITY

One of the primary issues in considering new PCB surface finishes is the reliability of the resulting solder joints. Numerous reliability tests have been performed by automotive, computer, and telecommunication OEMs. Several of these tests comparing substituted benzimidazole OSPs to metallic surface finishes are summarized below.

Pull Strength Test

Numerous companies have performed comparative pull tests for solder joints formed OSP and HASL-coated PCBs. A major U.S. computer manufacturer performed the following test:

PCB preconditioning: Thermal cycling from -10° C to 110°C, 30°C/minute ramp rate, 1 minute dwell at extremes for 4000 cycles.

Pull and peel tests were performed on 7000 solder joints. All recorded strengths for the OSP formed solder joints were equal to or greater than for the HASL ones.

Vibration Test

The same computer manufacturer fabricated test vehicles that incorporated daisy chained devices. The test vehicles were subjected to a vibration stress range of 10 to 2000

hertz on 3 axes at 12G's for 20 hours. No opens were found for either the OSP or HASL-formed solder joints.⁹

Bend Flex Test (3 Point)

A major telecommunications company performed the following test to compare HASL, Ni-Au and OSP-coated PCBs.

Test Vehicle: A 41 I/O ceramic BGA (0.52" x 0.47") with 0.30" solid spheres (Sn62/Pb36/Ag2) was reflowed onto an 0.045" thick FR-4 PCB.

Pre-Conditioning: The assembled PCBs were then subjected to an additional SMT reflow to simulate second side assembly. The PCBs were then artificially aged for 24 hours at 100°C.

Test: A known load (force) was placed on the PCBs and increased until a fracture of the joints was detected.

Results:

Type	Load (lbs)	
	Mean	Standard Deviation
HASL	87	11
OSP	107	6
Ni/Au	62	24

The solder joints formed from OSP coated SMT pads were significantly stronger than those joints formed with HASL or Ni/Au. The standard deviation results showed that OSP formed solder joints were also most consistent. During HASL, a thick, non-uniform Cu-Sn intermetallic compound (IMC) layer is formed at the copper-solder interface, an area prone to solder joint fracture. In the case of Ni/Au, the failure occurred at the copper-nickel interface. The nickel deposit exhibited poor ductility and was the weak point in the solder joint. Solder joints formed from OSP-coated pads have seen only one thermal cycle (that during reflow). This cycle is well controlled in time and temperature and thus allows formation of IMCs with a fine, homogenous crystalline structure. This leads to stronger, more ductile solder joints.

Thermal Shock Test

The same telecommunications company performed a thermal shock test comparing HASL, various Ni-Au finishes, Sn-Bi, Ni-Pd and two OSPs.

Test Vehicle: Same BGA vehicle as used in the 3 Point Bend Flex Test.

Pre-Conditioning: Same

Test: PCBs were subjected to a liquid to liquid thermal shock from -55 to 125°C with a 5 minute dwell at extremes.

At 250 cycles 3 of the Ni-Au finishes and the Ni-Pd all had experienced some level of joint cracking. Anywhere from 4 to 12% of these solder joints had experienced cracks which covered 50% of the joint area. They were removed from further cycling. At the end of the test (450 cycles) the fourth Ni-Au finish exhibited 30% of the joints as cracked, Sn-Bi had 12%, one of the OSPs had 13%, HASL had 6% and the second OSP had none. This OSP was the same one that excelled in the 3 point bend flex test.

All reliability testing performed to date has exhibited substituted benzimidazole OSPs as being equal to or better, in solder joint strength and consistency than HASL and other metallic surface finishes.¹⁰

OSP IN PRODUCTION

Benzotriazoles

Benzotriazoles have been successfully used as a HASL-alternative for nearly 25 years by the computer, telecommunications and consumer electronics industry. Products as diverse as laptop computers, telephones and television remote controls are manufactured with PCBs coated with benzotriazoles. The manufacturing limitation with benzotriazole coated PCBs is that the design must involve only one heat excursion or that soldering be performed in an inert atmosphere with high activity fluxes for double sided or mixed technology designs.

Substituted Benzimidazoles

Substituted benzimidazoles have been successfully used in all major sectors of the electronics industry including: computers, telecommunications, automotive, consumer electronics, instrumentation and business equipment. Some of the high volume manufacturing processes currently using these OSPs include:

- A major instrumentation OEM has been assembling network display monitor PCBs for 2 years in a mixed technology process using a no-clean solder paste and a low solids, no-clean flux in an air atmosphere. The flux is applied via a spray fluxer.
- A major manufacturer of industrial controls for automation is assembling PCBs in a mixed technology process using no-clean solder paste and a VOC-free, no-clean flux in an air atmosphere. The flux is applied via foam and wave fluxers.
- A major contract assembler has been manufacturing lap top computers for 4 years in a double sided SMT process using water soluble solder pastes in an air atmosphere.

- A major contract assembler has been manufacturing desk top computers for 2 years in a mixed technology process using a no-clean solder paste and a VOC-free, no-clean flux in an air environment. The flux is applied via foaming.
- A major automotive electronics OEM is manufacturing control modules in a mixed technology process using a no-clean solder paste and a low solids, no-clean flux. The flux is applied via wave fluxing and the solder pot uses a nitrogen blanket.
- A major telecommunication OEM has been manufacturing personal pagers for 4 years in a double sided SMT process using no-clean solder paste in a nitrogen atmosphere.
- A major computer disk drive manufacturer has been using OSPs for 2 years in a mixed technology process using a no-clean solder paste and a low solids no-clean flux in an air atmosphere. The flux is applied via foam or spray.

SUMMARY

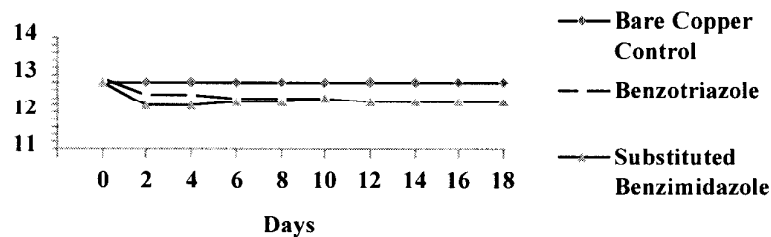
Organic coatings such as benzotriazoles and substituted benzimidazoles have been successfully used for a number of years in the electronics industry. They have proven to be not only reliable alternatives to HASL but down right essential for achieving acceptable first-pass yields for certain complex packaging technologies. The benzotriazoles will probably always have a niche in the industry. Meanwhile many satisfied users predict that the best of the substituted benzimidazoles will be the high volume, low cost coating alternative to HASL for years to come.

Insulation Resistance (Ω)

TABLE 1 - Surface Insulation Resistance (SIR) - JIS Z 3197

Test Board	Initial	200 Hours	400 Hours	600 Hours	800 Hours	1000 Hours
OSP	1×10^{14}	4×10^{13}	4×10^{13}	3×10^{13}	2×10^{13}	2×10^{13}
Control	1×10^{14}	6×10^{13}	6×10^{13}	5×10^{13}	5×10^{13}	4×10^{13}

TABLE 2 - Surface Insulation Resistance (SIR) - Bellcore
Average Log (Ω)



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1. Banerji, K. And Bradley, E. "Manufacturability and Reliability of Products Assembled with New PCB Finishes," Proceedings Surface Mount International, 1994, pp. 584-595
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 3. Parker, J.L. and Horton, J.S., "Assembly Performance of Printed Wiring Boards Coated with an Organic Solderability Preservative," Proceedings Surface Mount International, 1992, pp. 499-513
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 5. Trace Laboratories Test Report for Enthone-OMI, October 1993
 6. Ibid 5
 7. Tamura Kaken Internal Report, 1992
 8. Platt, S. and Brantingham, J., "Determination of Product Characteristics and Process Configuration for Organic Solderability Preservatives," 1994, pp. P13-4-1 through P13-4-8
 9. Ibid 2
 10. Ibid 1
- ® JetFlux is a registered trademark of Precision Dispensing Equipment, Inc., Bay Village, Ohio

**TABLE 3 - Surface Insulation Resistance (SIR) Bellcore With Low Solids, No-Clean Flux
Average Log (Ω)**

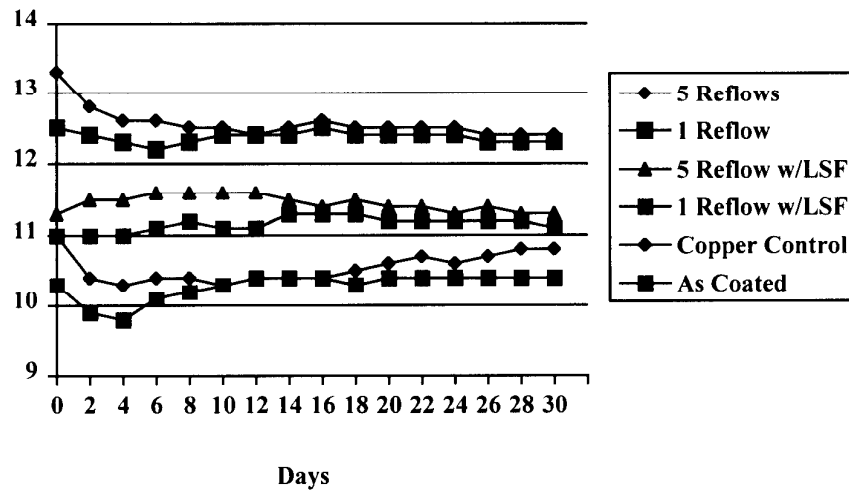


**TABLE 4 - Electromigration Resistance - Various Voltages
Insulation Resistance (Ω)**

Test Board	Initial	250 Hours	500 Hours	1000 Hours
OSP Pattern A *	7.5×10^{13}	1.0×10^{10}	7.5×10^9	5.3×10^9
Control A	8.1×10^{13}	5.0×10^9	3.8×10^9	2.9×10^9
OSP Pattern B*	9.3×10^{13}	1.2×10^{10}	1.1×10^{10}	9.2×10^9
Control B	1.2×10^{14}	1.3×10^{10}	1.0×10^{10}	9.3×10^9
OSP Pattern C*	2.7×10^{14}	1.0×10^{10}	8.2×10^9	6.0×10^9
Control C	2.4×10^{14}	1.0×10^{10}	8.9×10^9	6.7×10^9

No evidence of electromigration

TABLE 5 - Organic Coatings - Assembly Compatibility

Assembly Type ↓	Soldering Flux Type →	Benzotriazoles	Substituted Benzimidazoles
Single	Rosin	E	E
Sided	No-Clean	E	E
SMT	Water Soluble	E	E
Single	Rosin	E	E
Sided	No-Clean	G	E
Wave	Water Soluble	E	E
Double	Rosin	P	E
Sided	No-Clean	P	E
SMT	Water Soluble	F	E
Mixed Technology	Rosin	P	E
	No-Clean	P	G
	Water Soluble	F	E

P = Poor F = Fair G = Good E = Excellent

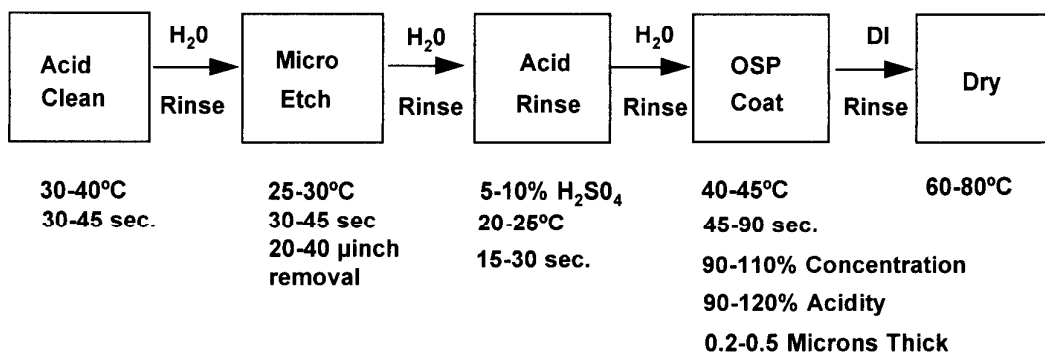


FIGURE 1 - Typical Substituted Benzimidazole Application Process

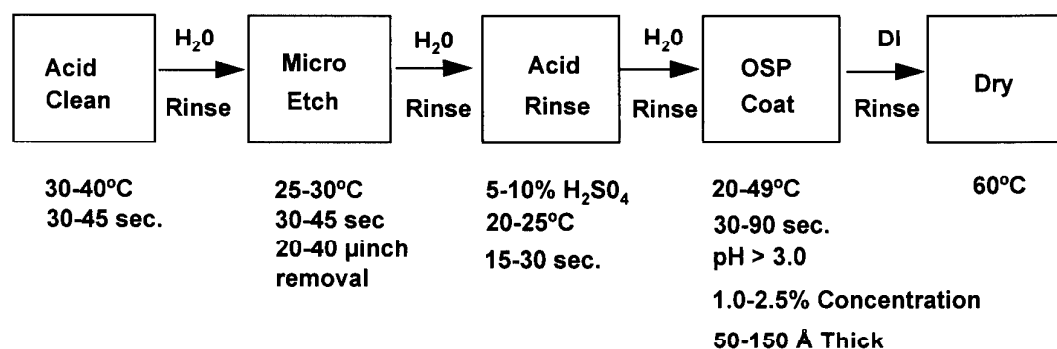


FIGURE 2 - Typical Benzotriazole Application Process

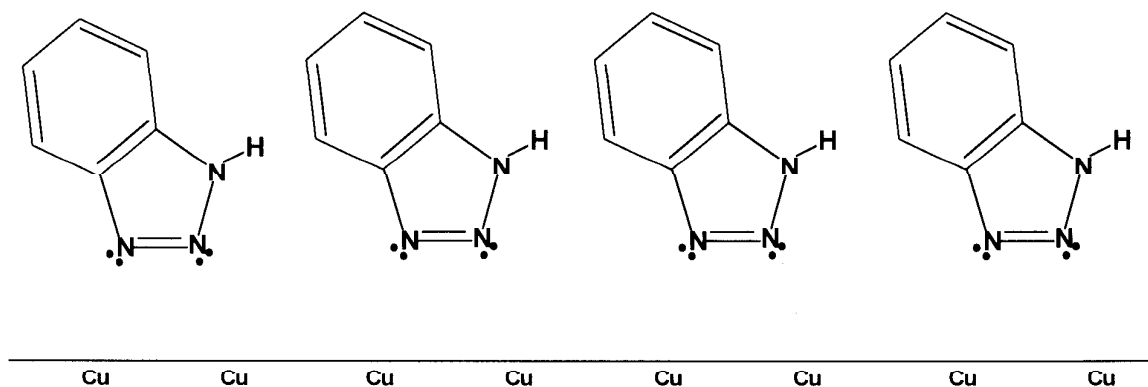


FIGURE 3 - Benzotriazole Coating On Copper

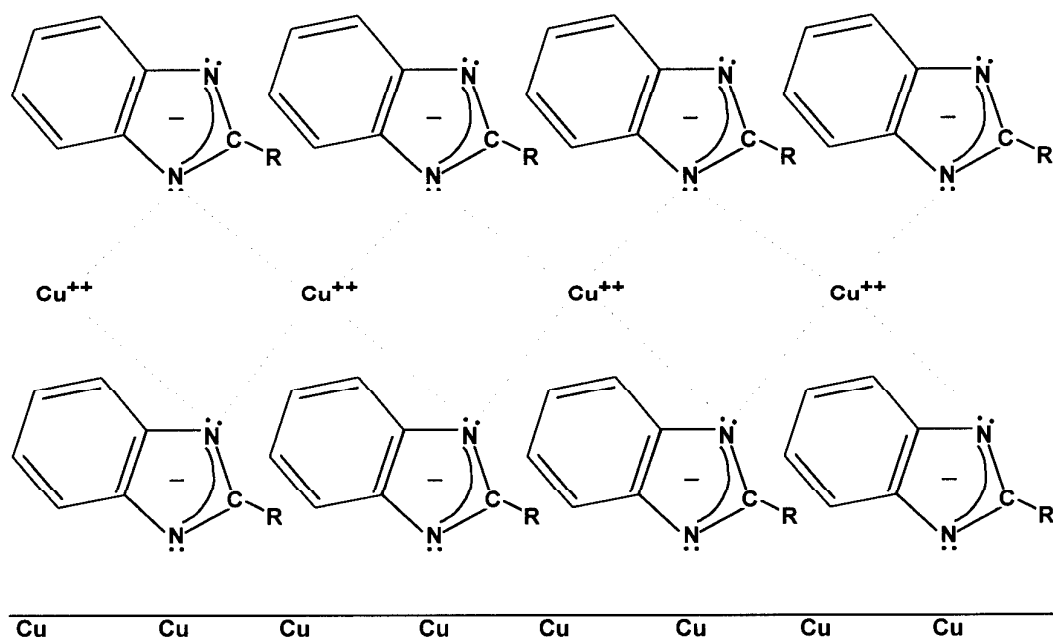


FIGURE 4 - Substituted Benzimidazole Coating On Copper

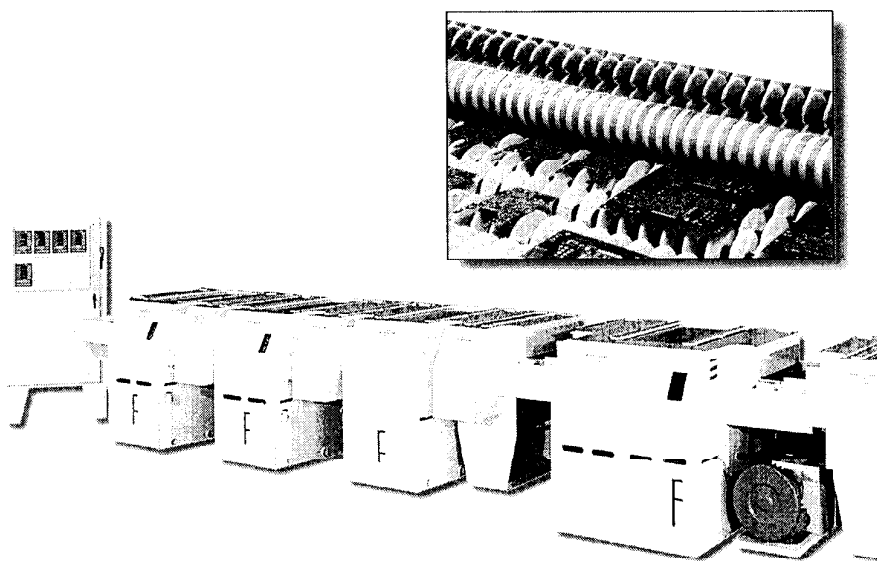


FIGURE 5 - Horizontal Immersion Equipment For OSPs

APPLICABILITY/CAPABILITY MATRIX

Surface Finish	THT	SMT	FPT	UFPT	BGA	Micro BGA	TAB	Flip Chip	Wire Bond
Benzotriazole	5	5	5	5	5	5	3	4	0
Substituted Benzimidazole	5	5	5	5	5	5	3	4	0