THE EFFECT OF SOLDER MASK AND SURFACE MOUNT ADHESIVE TYPES ON A PCB MANUFACTURING PROCESS

James A. Serenson Jr.
Loctite Corporation

Steven Marongelli
Universal Instruments

Introduction

A high volume manufacturer of printed circuit boards (PCBs) had attempted for many years to locate an adhesive that was robust enough to meet their manufacturing needs. This proved to be a challenge because they needed the adhesive to accommodate a wide range of different dispensing equipment and board designs. The two key performance criteria required from the adhesive were dispensability and adhesion. If the adhesive could not dispense consistently at high speed (40M+ dph), the process throughput would be unacceptable due to excessive maintenance and down time. If the adhesion was not acceptable on all of the different solder masks which were utilized in their various board designs, the chip loss during subsequent processing would result in excessive rework.

Over time, adhesives from all of the reputable surface mount adhesive (SMA) suppliers had been evaluated. From the evaluations, adhesives had been identified that excelled in certain arenas and would perform well for specific production lines. An adhesive could not, however, be identified which would perform well with all production lines. The two adhesives that had exhibited the best performance of the SMAs evaluated were Loctite® Chipbonder® 3609 and Hereaus® PD955M. The 3609 provided trouble free dispensing but did not have good adhesion to one of the six solder masks (Dexter Hysol SR8200R). The PD955M had sufficient adhesion to the SR8200R solder mask but was difficult to dispense. In particular, stringing and maintaining consistent dot dimensions proved to be problematic.

The primary objective of the study was to identify an adhesive that would dispense robustly on, and have acceptable adhesion to, the six different solder masks utilized across all their production lines. The solder mask types used were Ciba Giegy Probimer 52, Ciba Giegy Probimer 65M, Dexter Hysol SR8200R, Enthone DSR3241MD, Taiyo PSR4000DM and Taiyo PSR4000MP. To accomplish that, a three phase joint study was conducted by Universal Instruments, Loctite Corporation and the PCB manufacturer. The first stage of the study was an in depth surface characterization of each solder mask. Once that was completed, the second and third phases were to determine how Loctite Chipbonders 3615 and 3618 dispensed on and adhered to each of the solder mask types. These were recently developed SMAs that were designed for improved performance in difficult SMA applications.

A second, long term objective of the PCB manufacturer was select one solder mask which would be utilized for all their PCB designs. To assist in this selection process, a relative rating was of compatibility with the best SMA candidate was give in terms of adhesion and dispensability.

Solder Mask Surface Characterization

Surface Topography

The first evaluation performed to characterize the surface of each of the solder mask types was to visually observe differences in their surface topography. As can be seen in Figure 1A of the appendix, the topography of each solder mask type was examined using an Olympus BH-2 microscope in reflectance mode at 50X magnification. Substantial differences between the surface topography of the six solder masks were observed. The six solder masks could be divided into two groups. The Dexter Hysol SR8200R, Enthone DSR3241HD, Taiyo PSR4000DM and Taiyo PSR4000MP had fine granular surfaces while the Ciba Giegy Probimer 52 and Probimer 65M solder masks had ridges of polymer surrounding particles that were embedded in the polymer.

Although many different factors will influence the performance of a SMA, the rough surface finish of the Probimer solder masks was hypothesized to be advantageous. The higher surface roughness was anticipated to promote adhesion by providing sites for mechanical interlocking. The increased surface area and irregularity of the solder mask would also be expected to increase the force required to pull the adhesive from the printed circuit board decreasing the tendency for stringing and/or missing adhesive dots.

Organic Content

The type and amount of polymeric material that comprises the surface of the solder mask will strongly influence its compatibility with SMAs. To better understand the composition of the solder masks, a FT-IR spectra was generated for each solder mask type using a Biorad UMA-500 FT-IR microscope equipped with a SpectraTech ATR adapter. The ATR adapter had a penetration depth of approximately 1 μm and allowed for the spectra to be directly acquired from the solder mask. The organic content of the solder masks varied significantly (See Figure 2A in the Appendix). To confirm that the variation was not due to different analysis locations, spectrums were acquired from several locations on the PCB. The spectrum for a particular solder mask was shown to be consistent regardless of the sampling location on the PCB.

The Taiyo PSR4000DM and PSR4000MP solder masks were essentially glass (or silica). The “MP” solder mask had a slightly higher organic content than the “DM” material, but both solder mask surfaces had an extremely low organic content. In fact, the amount of organic material present on the surface was too low to identify a polymer type for the solder mask. The low organic content is due to a high filler content. Since highly filled materials are general very strong and, in comparison to unfilled polymers, easier to bond, the Taiyo solder masks would be expected to have good mechanical properties and be relatively easy to bond. The Dexter Hysol SR8200R and Enthone DSR3241HD had a higher organic content than the Taiyo solder masks but were still had more inorganic filler at the surface of the solder mask than organic polymer. The Probimer 52 and 65M solder masks were identified as organic epoxy. No glass filler could be detected on the surface. The high polymeric content of these materials agrees with the surface topography noted in the previous section. Since most surface mount adhesives bond well to epoxies, the Probimer materials would be expected to be relatively easy to bond. The unfilled epoxy solder mask surface would be expected to fail at lower strengths than the other four highly filled solder masks which were evaluated.

A strong objective of the surface characterization was to determine the root cause for the incompatibility of the Dexter Hysol SR8200R solder mask with SMAs. By reviewing the FT-IR spectra for the Dexter Hysol SR8200R in Figure 2A, it can be observed that a hydrocarbon material was present in the solder mask in significant quantities. It is known that non-polar, low molecular weight constituents, such as hydrocarbons, can adversely affect wetting if present in appreciable quantities. As a result, this was hypothesized to be responsible for the poor compatibility. After the hydrocarbon constituent was identified, it was further desired to determine if the hydrocarbon material was a surface contaminant or a bulk constituent of the solder mask. To that end, a methylene chloride solvent extraction was performed. The low level of hydrocarbon detected indicated that the hydrocarbon material was most likely a bulk constituent of the solder mask. Subsequent discussions with the board manufacturer confirmed that a hydrocarbon wax had been added to the solder mask to reduce the potential for solder ball formation.

Elemental Composition of Fillers

The type and level of filler used in a solder mask will significantly affect the compatibility of a solder mask with a SMA. For each solder mask, an EDS spectrum was acquired using a Kevex system with a quantum detector for light elements detection. An accelerating voltage of 30 KeV and a sampling scan duration of 300 seconds was used for data collection. Table 1 summarizes the results of the evaluation. Please refer to Figure 3A in the Appendix for a more comprehensive presentation of the experimental data.

Table 1: Elemental Composition of Fillers in Solder Masks, %

Element	Probimer 52	Probimer 65M	Hysol SR8200R	Enthone DSR3241MD	Taiyo PSR4000DM	Taiyo PSR4000MP
Silicon	44	35	83	83	90	67
Aluminum	35	19	3	4	7	29
Magnesium	16	16	5	13	-	-
Calcium	5	31	3	-	-	2
Chlorine	-	-	2	-	-	-
Titanium	-	-	-	-	3	2

All six solder masks contain a large percentile of elemental silicon. This is most likely from glass fiber fillers. Other elements which were detected in significant quantities are aluminum, magnesium, calcium and titanium. These are most likely from alumina, magnesium stereate, calcium carbonate and titanium dioxide fillers, respectively. **(Check with Hank Temme)**. Unfortunately, the specific type of filler cannot be identified using EDS. For example, long glass fibers and ground quartz, two distinctly different fillers, cannot be differentiated using EDS. Since the specific filler type cannot be identified, it is not possible to hypothesize the effect of the filler on the solder mask's compatibility with SMAs. In spite of this, the EDS spectra were still deemed important to provide a better understanding of the variation between the different filler packages used in solder masks.

Dispensability Investigation

The objective of this phase of the study was to confirm the suitability of Loctite 3615 and 3618 for high speed dispensing. At the time that this study was conducted, their dispensing performance had been confirmed in a laboratory environment, but their dispensability had not been proven in a production environment. Since the PCB manufacturer was using a Universal

GDM equipped with a piston pump, the primary focus was to confirm the SMA's dispensing performance on that system. As secondary investigations, the adhesive's compatibility with an Archimedes style pump and nozzles designed with boots to facilitate maintenance were also confirmed.

Abbreviated Dispensability Investigation of the Universal Archimedes Pump

Since it was desired to investigate the compatibility of the SMAs with an Archimedes pump, but that was not the primary focus of the study, an abbreviated dispensability investigation was performed using only Loctite 3615. To evaluate the dispensability, the operating parameters were adjusted on a Universal speed board to set the adhesive dot diameter to approximately 0.020" and 0.027" for spindles 1 and 2, respectively. The Universal speed board is a bare 6" x 6" board which has a 400 dot dispense pattern. The parameters were not optimized for speed, so higher speeds could probably be accomplished by adjusting the operating parameters illustrated in Table 2.

Table 2: Operating Parameters for Feasibility Investigation of Loctite 3615 on Archimedes Pump

Operating Parameter	Spindle 1	Spindle 2
Z-off, microns	20,750	20,750
Z-safe, microns	3,000	4,000
Delay Before, mS	0	0
Delay After, mS	10	10
Operating Speed, dots/hour	+32M	+26M

Once the dot dimensions were set on the speed board, Loctite 3615 was dispensed on each of the six solder masks. For each spindle, a matrix of thirty (30) dummy dots were dispensed in an open area in the center of the mask. Twenty (20) production dots were then placed between solder pads. The dummy dots were run prior to dispensing adhesive between solder pads to minimize the impact of start up effects. Five (5) boards were run for each solder mask type yielding a total of 250 dots per solder mask. The dispensing performance of the adhesives was determined by visually reviewing all the boards for missed dots, stringing and incomplete dots. The dot height and diameter were also measured for random dots on each board using a Production Control Systems optical measurement device with a 0.0001" sensitivity.

The dot diameter remained constant throughout the trial. The Probimer 52 and 65M, Enthone DSR3241HD and Taiyo PSR4000MP solder masks ran without incident. The Dexter Hysol SR8200R and Taiyo PSR4000DM masks had some stringing. Approximately 10 strings were observed in 5 boards (approximately 4%), however, the strings were not sufficient to cause pad contamination.

Comprehensive Dispensability Evaluation using the Piston Pump

To confirm the dispensing performance of the Loctite 3615 and 3618 a more comprehensive evaluation was performed. As with the Archimedes pump, the dot diameters were dialed in to 0.020" and 0.027" for spindles 1 and 2, respectively, using the Universal speed board. The system configuration and operating parameters of the Universal GDM are described in Tables 3 and 4, respectively. Again, the operating parameters were not optimized for speed.

Table 3: System Configuration for Piston Pump		
Equipment Component	**Spindle 1**	**Spindle 2**
Piston	0.025" (2D31), Universal P/N 42346504	0.040" (2C15), Universal P/N 42346503
Adapter	0.025", Universal P/N 46891002	N/A
Boot	0.010" ID, Universal P/N 46891206	N/A
Nozzle	10/6 Single Dot, Universal P/N 46890801	12/8 ID Dual Dot, Universal P/N 42346313

Table 4: Operating Parameters for Study with Piston Pump and Loctite 3615		
Operating Parameter	**Spindle 1**	**Spindle 2**
Z-off, microns	21,000	21,000
Z-safe, microns	4,000	4,500
Delay Before, mS	25	25
Delay After, mS	10	15
Syringe Pressure, psi	17	19
Operating Speed, dots/hour	+38M	+35M

As a control, six (6) speed boards were then run with each spindle for a total of 2400 dispense cycles. No missing dots, stringing or incomplete dots were observed. It was visually perceived that the dot profile of the piston pump was sharper and better defined than the Archimedes pump. Once the dot diameters were dialed in, five (5) boards were run through forty (40) dispense cycles with each solder mask type. After each dispense cycle, the boards were wiped clean with a lint free cloth and cleaned with isopropyl alcohol. The dispense pattern remained thirty (30) dummy dots followed by twenty (20) dots which were placed between solder pads. This yielded a total of 2000 dots per solder mask per adhesive.

The Probimer 52 and 65M, Enthone DSR3241HD and Taiyo PSR4000DM ran without incident. The Dexter Hysol SR8200R and Taiyo PSR4000MP had some stringing. The strings observed were very slight tails that moved away from the dot. The strings were not large enough to cause pad contamination, but were noted to differentiate the dispensing performance of the different solder masks.

When the piston pump was originally evaluated, severe stringing occurred. The stringing occurred, however, in very consistent board dispense locations. This led us to believe that the stringing was caused by improper board support. When additional board support was added, the stringing was eliminated. This indicates that the Archimedes pump is less sensitive to board fixturing than the piston pump and is hypothesized to be due to the smoother operation of the Archimedes pump.

After completing the dispensability study with the Loctite 3615, both nozzles were left uncapped for 13.5 hours (6:00 pm to 7:30 am) at ambient conditions. Three (3) Dexter Hysol SR8200R and three (3) Ciba Giegy Probimer 65M boards were then run. These were selected due to the extreme differences in their composition and surface finish. No change in dot diameter or stringing was observed.

The entire dispensability study was then repeated using Loctite 3618. In general, the Loctite 3618 proved less suitable for high speed dispensing. Initially, severe stringing was noted on the Probimer 52 and 65M and Enthone DSR3241HD masks--all masks which previously ran very well with the Loctite 3615. The stringing was eliminated by adding additional board support. Even though it was possible to eliminate the stringing, the Loctite 3618 was still considered to have a higher propensity for stringing than either Loctite 3615 or 3609.

Effect of New Universal Nozzle with Boot

For the adhesion study, the nozzle on Spindle 2 was replaced with a "new" Universal nozzle which contained the boot to facilitate maintenance. To investigate the effect of the new nozzle, ten (10) Universal speed boards were run to confirm consistent performance (4000 dots). The dot diameter remained consistent with no tails or missing dots observed. The first dispense did tend to be abnormally high, however, tailing or stringing was not sufficient for pad contamination to occur and all subsequent dots were acceptable.

Adhesion Investigation

The PCB manufacturer correlated the chip torque strength to performance in their process. For their manufacturing process, it had been determined that if a 1206 capacitor consistently achieved a torque strength of 4 in-oz or greater that chips would not be lost during processing. To evaluate the effect of the adhesive and solder mask type on the chip torque strength, adhesive was dispensed onto the boards using a Universal GDM dispenser. Philips 1206 capacitors were then placed using a Universal GSM chip shooter. The delay between adhesive dispense and chip placement was typically 20 to 60 minutes. Once the chips were placed, the board was immediately transferred into a Magnatherm 1030N cure oven and the adhesive was cured. The cure profile of the oven had a ramp rate of 1 C/sec and a 90 second hold at 150 C. The cured assemblies were allowed to acclimate to room temperature for several hours before testing. The torque strength was determined using a Data Instruments Torque Gauge that had a 2 to 40 in-oz range and a 1 in-oz sensitivity. Thirty (30) data points were taken per adhesive per solder mask type. Three different operators randomly tested the torque strength in groups of six (6) from five (5) different PCB's to minimize the effect of operator bias and substrate inconsistencies.

The system configuration and operating parameters used for the adhesion study are detailed in Tables 5 and 6, respectively.

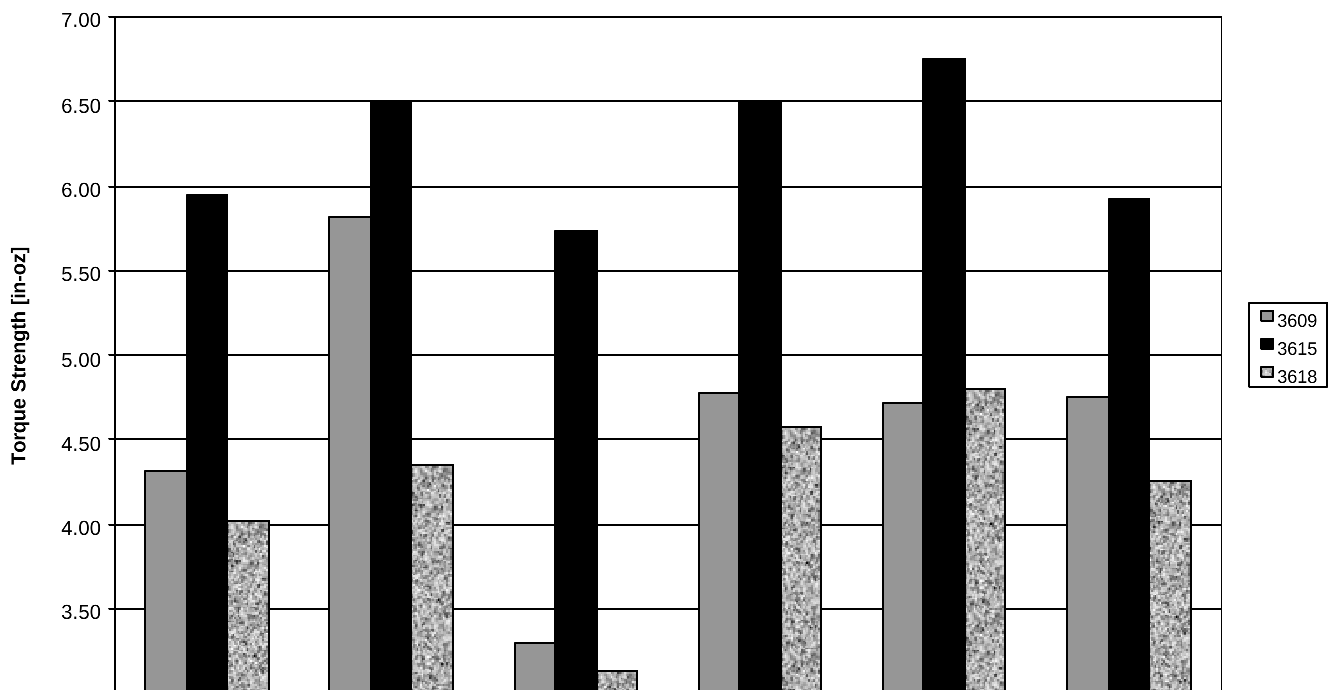
Table 5: System Configuration for Adhesion Study

Equipment Component	Spindle 1	Spindle 2
Piston	0.025" (2D31), Universal P/N 42346504	0.040" (2C15), Universal P/N 42346503
Adapter	0.025", Universal P/N 46891002	N/A
Boot	0.010" ID, Universal P/N 46891206	0.032" ID
Nozzle	10/6 Single Dot, Universal P/N 46890801	12/8 ID Dual Dot

Table 6: Operating Parameters for Adhesion Study		
Operating Parameter	**Spindle 1**	**Spindle 2**
Z-off, microns	21,000	20,850
Z-safe, microns	4,000	4,500
Delay Before, mS	25	25
Delay After, mS	10	15
Syringe Pressure, psi	17	19
Operating Speed, dots/hour	+38M	+35M

As can be seen by reviewing Figure 1, Loctite 3615 achieved higher strengths on all solder mask types than Loctite 3609 and 3618. The mean torque strength of Loctite 3615 ranged from approximately 5.75 to 6.75 in-oz. As expected, the lowest strength was achieved on the Dexter Hysol SR8200R solder mask. Of the one hundred and eighty (180) 1206 components that were bonded using the six different solder masks with Loctite 3615, only one capacitor on the SR8200R solder mask had a torque strength equal to 4 in-oz. No components were observed with a torque strength below 4 in-oz when using the Loctite 3615.

Figure 1: Torque Strength of 1206 Capacitor
Two 0.027" Diameter Dots Dispensed Using Piston Pump and 12/8 Nozzle
Philips 1206 (RC01 10K 5%) Capacitor



	Ciba Giegy Probimer 52	Ciba Giegy Probimer 65M	Dexter Hysol SR8200R	Enthone DSR3241HD	Taiyo PSR4000DM	Taiyo PSR4000MP
3609	4.32	5.82	3.30	4.78	4.72	4.75
3615	5.95	6.50	5.73	6.50	6.75	5.92
3618	4.02	4.35	3.13	4.57	4.80	4.25

Solder Mask Type

For a more comprehensive presentation of the experimental data, please see Tables 1A through 3A in the appendix.

When comparing Loctite 3618 to 3609, no gain in adhesion was realized. On the Taiyo PSR4000DM, Ciba Giegy Probimer 52, Dexter Hysol SR8200R and Enthone DSR3241HD solder masks, no statistically significant difference in torque strength was observed within 95% confidence limits. On the Taiyo PSR4000MP and Ciba Giegy Probimer 65M, Loctite 3618 achieved statistically significant lower torque strengths than Loctite 3609.

More than just the mean bond strength must be considered when determining how well an adhesive bonds to a solder mask. The failure mode must also be considered. For all three adhesives on the two Taiyo masks, the adhesive failed almost exclusively to the chip. This indicates that the adhesion to the solder mask exceeded the adhesion to the chip, consequently, the adhesion to the chip was the limiting factor. The mean torque strength for Loctite 3609 and 3618 when the adhesive failed to the chip was approximately 4.5 in-oz. Loctite 3615 had improved adhesion to chip at a mean torque strength of 6.3 in-oz.

When bonding the two Ciba Giegy Probimer solder masks, the failure mode was typically a combination of the solder mask mechanically failing and the adhesive failing to the chip. In this case, the forces required to de-bond the adhesive from the chip and to cause mechanical failure of the solder mask were similar. The Probimer 65M solder mask failed at higher strengths than the Probimer 52 with all three adhesives, although some adhesive failures were noted with the latter which were not observed with the former. The Probimer solder masks were essentially unfilled at the surface, while the Taiyo masks were composed primarily of glass fibers. As a result, the Ciba solder mask was typically “lower strength” because the mask failed before the adhesive, however, adhesion to the mask was still exceptional. The Enthone DSR3241HD performed very similarly to the Ciba Giegy Probimer masks.

The only mask which proved to be problematic was the Dexter Hysol SR8200R. This was the only solder mask where torque strengths were consistently under 4 in-oz (as low as 2 in-oz) and the adhesive consistently failed to the solder mask. The uncharacteristically low adhesion of the SR8200R has been attributed to a hydrocarbon wax that was added to the solder mask to reduce solder balling.

Relative Solder Mask Rating

The PCB manufacturer desired to select one solder mask which would be used across all board designs. Once the Loctite 3615 was identified as the best adhesive candidate for the application, the compatibility of the solder mask with an SMA process were rated to facilitate selection. The mean torque strength achieved on the six different solder mask ranged from 5.75 to 6.75 in-oz with an approximate standard deviation of 1 in-oz. There was no statistically significant difference within 95% confidence limits although differences in failure mode were prevalent. In terms of adhesion, all solder masks were deemed to be acceptable with the exception of the Dexter Hysol SR8200R which is known to have a hydrocarbon constituent in the bulk solder mask that had an adverse effect on adhesion and dispensability. When considering the dispensability of the boards the Dexter Hysol SR8200R, PSR4000DM and PSR4000MP solder masks had a higher tendency to form strings than the first Ciba Giegy Probimer 52 and Probimer 65M and Enthone DSR3241HD solder masks. Although the stringing was not severe enough to cause pad contamination or low bond strengths, it was observed and differentiated the latter group from the former. Based on this, the solder masks were rated as high or low for adhesion and excellent or moderate dispensability in Table 7.

Table 7: Relative Rating of Solder Masks with Loctite 3615						
Performance Attribute	**Solder Mask**					
	Ciba Giegy Probimer 52	**Ciba Giegy Probimer 65M**	**Dexter Hysol SR8200R**	**Enthone DSR3241HD**	**Taiyo PSR4000DM**	**Taiyo PSR4000MP**
Adhesion	High	High	Low	High	High	High
Dispensability	Excellent	Excellent	Moderate	Excellent	Moderate	Moderate

Summary

- Loctite 3615 offers much improved adhesion when compared to previous generation chipbonders.
- Loctite 3615 is suitable for high speed dispensing with both the piston and Archimedes type pumps as well as the new Universal nozzle design which incorporates the removable boot to facilitate pump maintenance.
- The addition of a hydrocarbon wax to solder masks has a strongly adverse effect on the compatibility of that solder mask with SMAs. Other methods should be pursued for reducing the tendency for solder balling.
- The Archimedes pump is much less sensitive to board fixturing when compared to the piston pump.

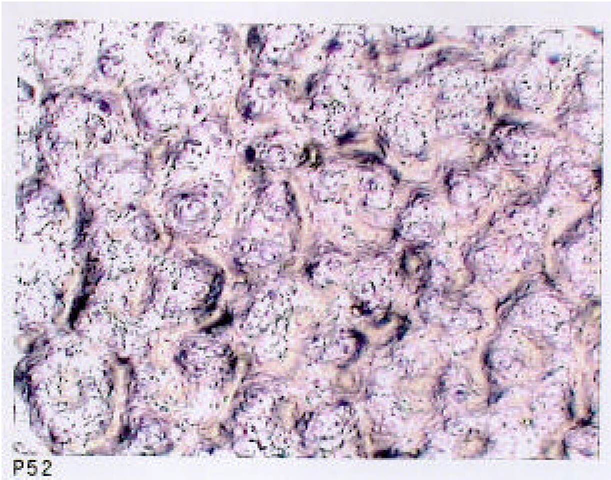
Conclusion

New generation chipbonders have been developed which offer dispensing and adhesion characteristics which were not previously available. By working with your adhesive supplier and equipment vendor, even the most difficult manufacturing challenges can be resolved. It should be noted that after this study was concluded, the PCB manufacturer changed to Loctite 3615. The process has run trouble free for the last 9 months.

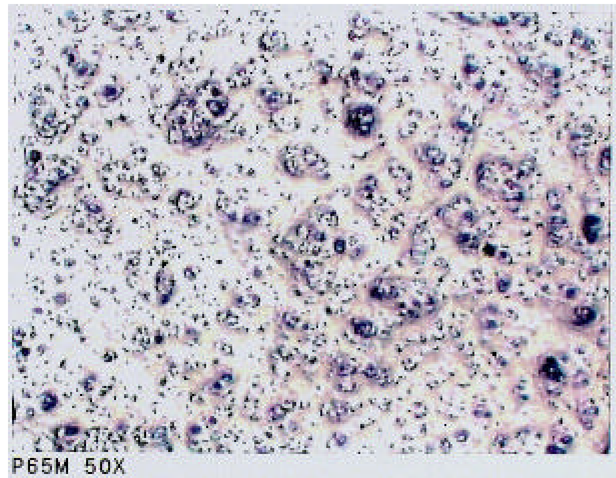
Acknowledgement

This paper would not have been possible with the expertise, time and resources which were generously committed by Dr. Hank Temme of the Surface Science Department of the Loctite Corporation and Mr. Sergio Porcari and Mr. Doug Dixson of the Application Engineering Department of Universal Instruments. I would like to take this opportunity to thank them for their invaluable assistance.

APPENDIX

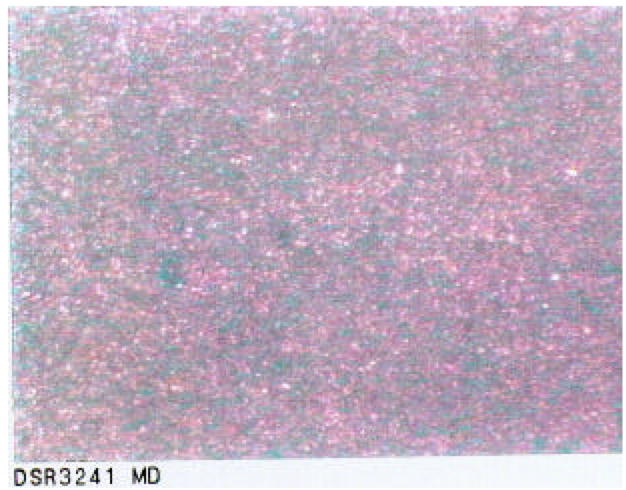


Ciba Giegy Probimer 52

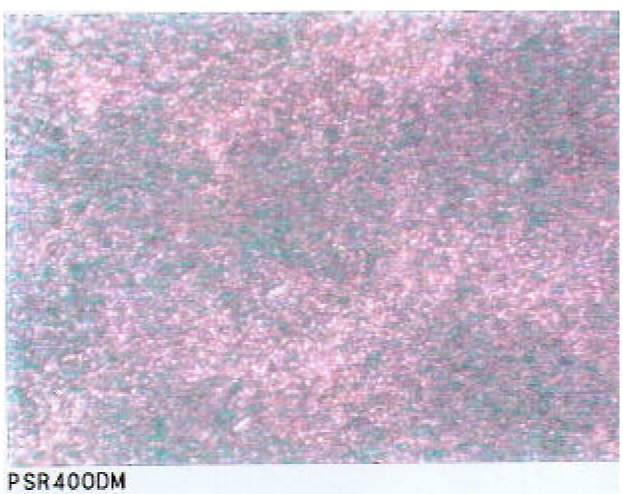


Ciba Giegy Probimer 65M

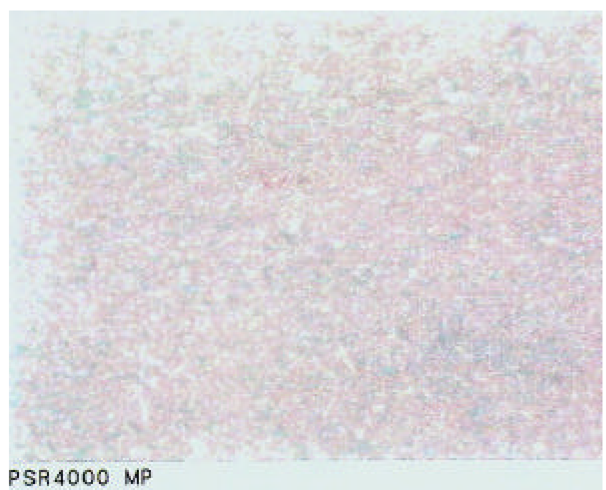
Dexter Hysol SR8200R



Enthone DSR3241MD

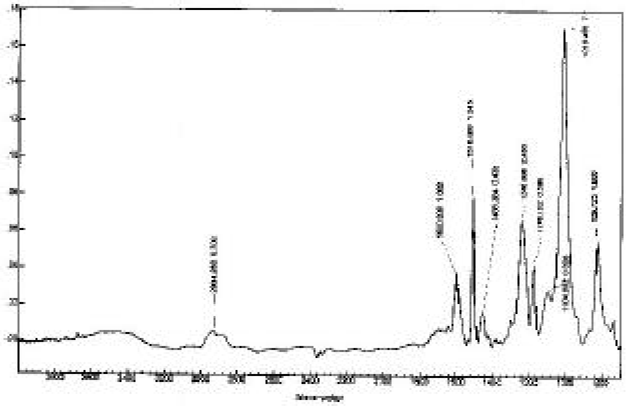


Taiyo PSR4000DM

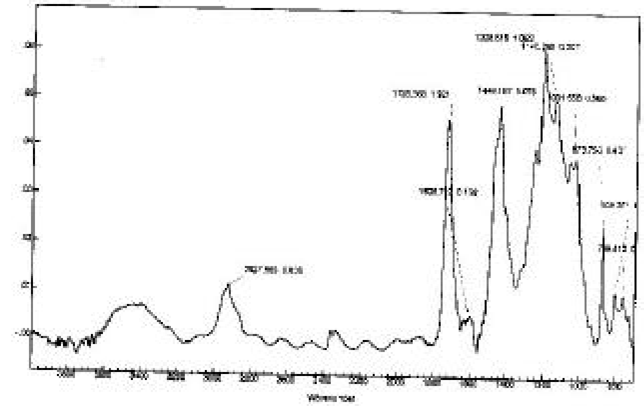


Taiyo PSR4000MP

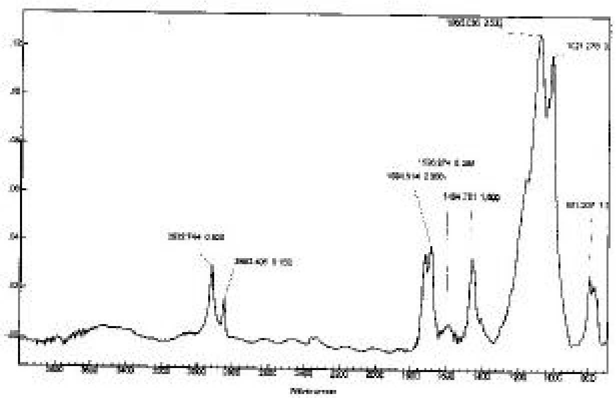
Figure 1A: 50X Magnified Picture of Solder Masks Surface Topography



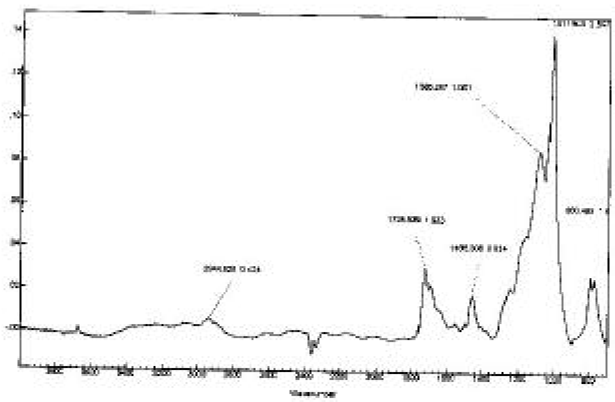
Ciba Giegy Probimer 52



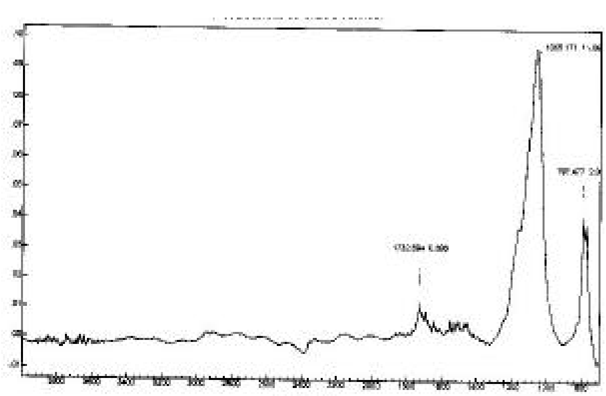
Ciba Giegy Probimer 65M



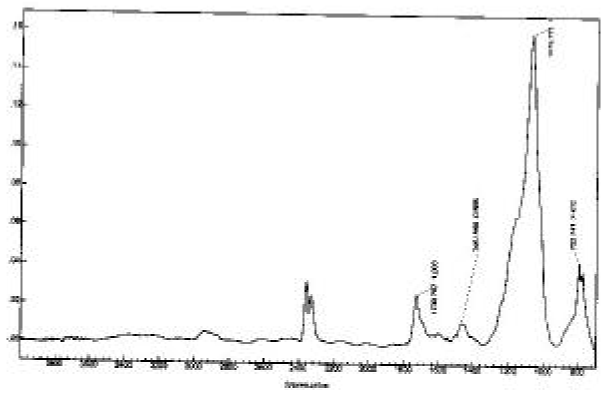
Dexter Hysol SR8200R



Enthone DSR3241MD

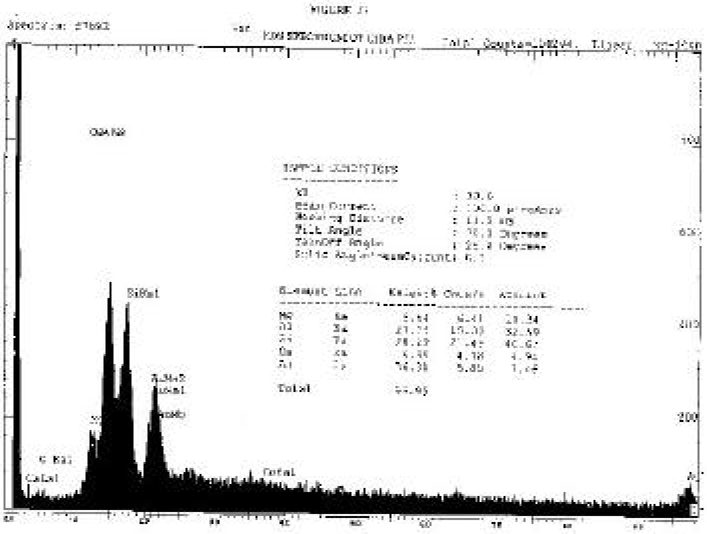


Taiyo PSR4000DM

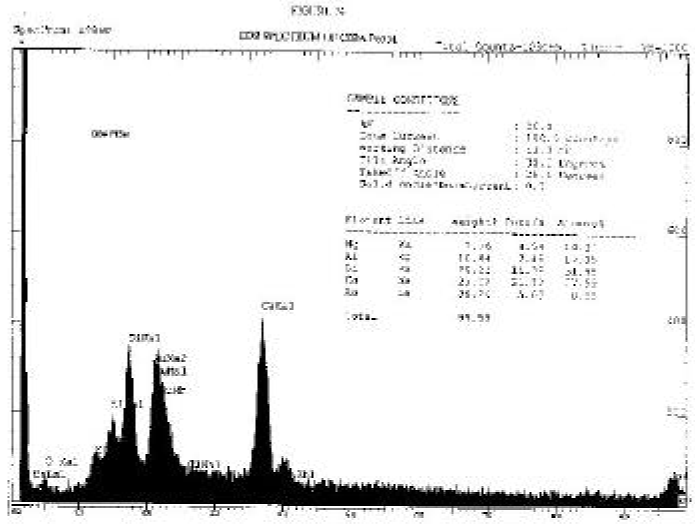


Taiyo PSR4000MP

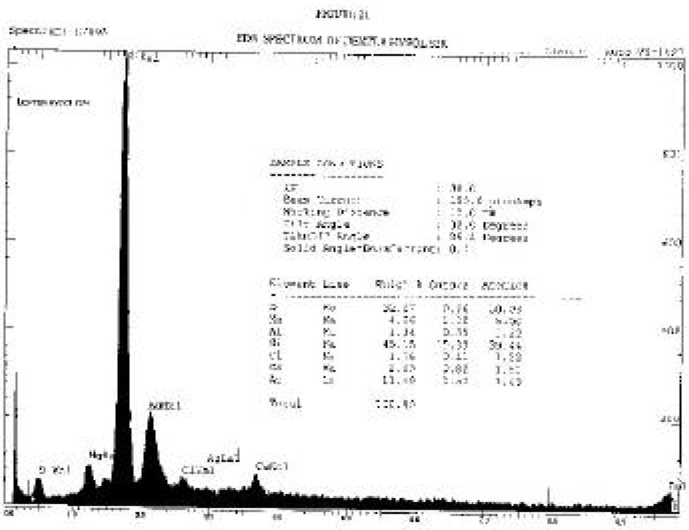
Figure 2A: FT-IR Spectrum of Solder Masks



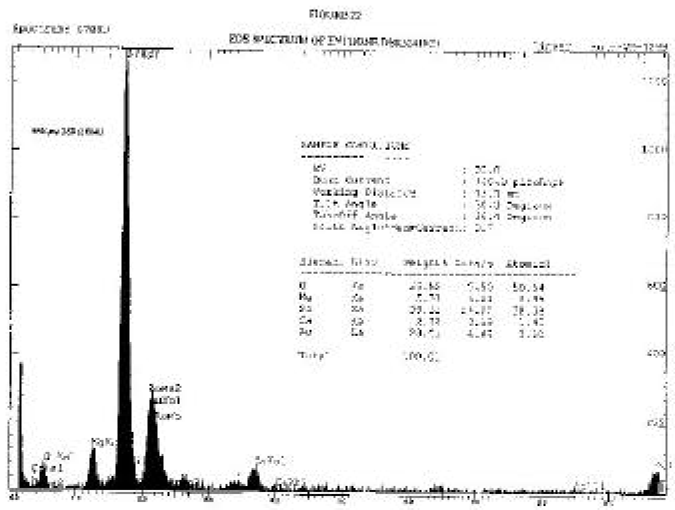
Ciba Giegy Probimer 52



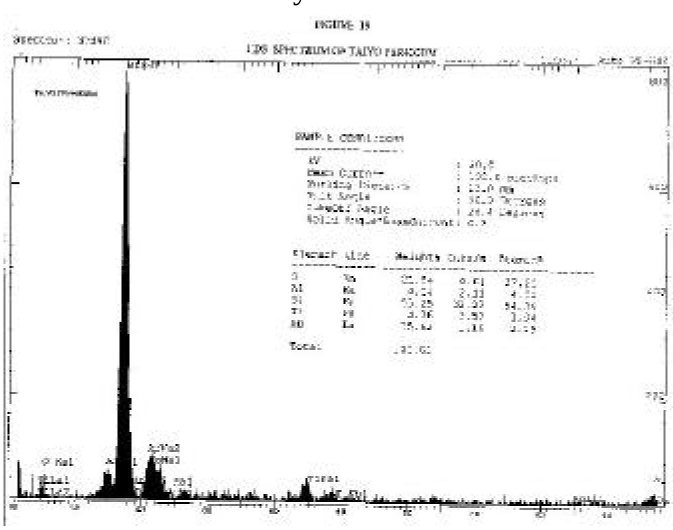
Ciba Giegy Probimer 65M



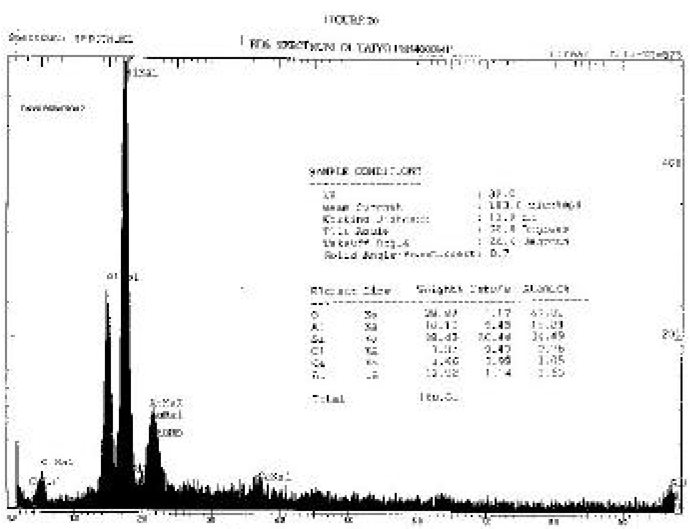
Dexter Hysol SR8200R



Enthone DSR3241MD



Taiyo PSR4000DM



Taiyo PSR4000MP

Figure 3A: EDS Spectrum of Solder Masks