Evaluation of High Temperature Overmold Compounds for Manufacturing of Laminate Based Leadfree System in Package

Mohammed Wasef & Mike Anderson
ANADIGICS, Inc.
141 Mount Bethel Rd, Warren, NJ 07059
Phone: (908) 668-5000; Fax: (908) 791-6009

Keywords: Leadfree, Laminate, modules, Overmold Compounds, Moisture Absorption.

Abstract

The worldwide push for leadfree microelectronics has caused the industry to revamp its design, material selection, and manufacturing processes of its products. However, the needs of industry have surpassed the current lead free standards set up by organizations such as JEDEC. This paper looks into how ANADIGICS defined internal standards, reviewed customer needs, and met them by using unique materials and processes prior to the release of leadfree standards for laminate based modules.

Laminate based system in package products, which combine assembly process and materials, historically, have been limited to meeting Moisture Sensitivity Level (MSL) 3 at 240 °C. It is now possible to achieve this level at 260°C – a temperature requested by customers for leadfree assembly. The use of lead free solders has caused a significant rise in the reflow temperatures of packages and has therefore prompted the need for high-temperature overmold compounds. The high temperature capabilities of several overmold compounds that could be used to encapsulate laminate based modules were evaluated.

Five overmold compounds were subjected to conditions specified for MSL 3 with a reflow peak temperature of 260 °C. Three of the five overmold compounds that provided positive results were subjected to the more aggressive stress test of MSL 2a at 260 °C. Comparison of pre and post stress electrical tests to determine the change in electrical parameters, and comparison of pre and post stress sonoscan images to determine the change in percent delamination were used to judge the performance of the overmold compounds. Failure analysis was also performed on the modules to look for evidence of solder mask delamination and/or solder extrusion.

INTRODUCTION

The worldwide leadfree initiative for microelectronics has caused the industry to revamp the design, material selection, and manufacturing processes of its products. Japan and Europe have launched industry wide campaigns to remove lead from electronic products by end of 2005 and July 1 2006, respectively [1,2]. Japan's lead-free initiatives are driven primariliy by OEM's where as the European Parliament is responsible for the removal of hazardous materials from consumer electronics in Europe. Although the United States does not have any legislation requiring the removal of Lead from electronics, US based industries are following the Japanese and European initiatives in order to remain competitive in this global market.

PROJECT STRATEGY

When subjecting modules to high reflow temperatures, the primary concern was the movement of the melted solders inside the package or solder extrusion. Leadfree solders are used to attach the SMDs on to the laminate board prior to encapsulation. These solders have a liquidus temperature below ~245 °C and melt when the module is subjected to the leadfree reflow temperatures of 260 °C. The pressure generated within the modules at this high temperature can force the melted solder to flow into any open cavities or void. If a large enough cavity is present or if the overmold compound does not adhere well to the other components, the melted solder can flow along delaminated interfaces potentially shorting the module or impacting long-term reliability.

The strategy chosen to overcome this problem involved containing the melted solder by maximizing adhesion between the various interfaces. The approach taken during this project was to use commercially available leadfree overmold materials that have better adhesion to the SMDs and laminate interfaces. Many mold compound suppliers have recently introduced new compounds to meet the high temperature requirements. The choice of materials to be evaluated was based on industry survey and sub-contractors recommendations.

Leadfree mold compounds have their epoxy and hardener resins specially formulated for good adhesion. Various coupling agents and adhesion promoters have been added to ensure better adhesion at high reflow temperatures. In addition adhesion promoters increase the adhesion between the mold compound and the laminate by increasing the wetting and forming chemical/mechanical bonds between the mold compound and the laminate components.

After reviewing available compounds, five overmold compounds were evaluated as potential candidates for replacing the standard encapsulent in order to make the modules' high temperature tolerant. The selected mold compounds were developed specifically for high-temperature applications.

TABLE 1**.** Overmold materials evaluated for high temperature capability

Property	**Standard**	**Compound B**	**Compound C**	**Compound D**	**Compound E**	**Compound F**
Epoxy Resin	Type 1	Type 1 + Type 2	Type 1	Type 2	Type 2	Modified Type 2
Hardener Resin	Type α	Type β	Type δ	Modified Type β	Type β	Type β
Tg (°C)	150	114	130	175	194	185
Flexural Modulus (N/mm^2)		28,000 (22 °C) 980 (240 °C)	26,000 (25 °C) 800 (240 °C)	21,000 (25 °C) 1800 (240 °C)	18,100	22,000 (25 °C) 1400 (240 °C)
α1 (ppm/°C) α2 (ppm/°C)	14 60	8.8 26	9 40	11 36	12 40	11 38
Filler Content (%)	80	89.5	87	84	84	88
Moisture Absorption (%)	0.26	0.24	0.21	0.26	0.36	0.29

The above data was obtained from the Data sheets of the respective compounds.
The moisture absorption data was obtain experimentally in-house (85/85 @ 168 hrs)

MOISTURE ABSORPTION CAPABILITIES

In order to determine if there was a correlation between moisture absorption capabilities and MSL performance, modules from the various overmold material sets were subjected to the Moisture Absorption test as specified by the JEDEC standard J-STD-020B.

Ten samples from each overmold set were dry baked at 125 °C for 48 hours and weighed to get the "dry weight". The modules were placed in a humidity chamber for 168 hours at 85 °C and 85% RH and weighed after 24, 48, 96 and 168 hours. Four brass standards were also weighed at the beginning and end of each weighing session to ensure that the microscale was properly calibrated. Table 5 shows that Compound C absorbed the least amount of moisture. Figure 2 shows that compound C also had the slowest absorption rate. According to the vendors, the resins of compound C are also designed to be hydrophobic to reduce the amount of moisture absorbed. The resulting properties minimize moisture penetration into the mold compound.

TABLE 2. Ranking of the various overmold compounds

Ranking	**Compound**	**Moisture Absorbed (%)**
1	C	0.21
2	B	0.24
3	Standard	0.25
4	D	0.26
5	F	0.29
6	E	0.36

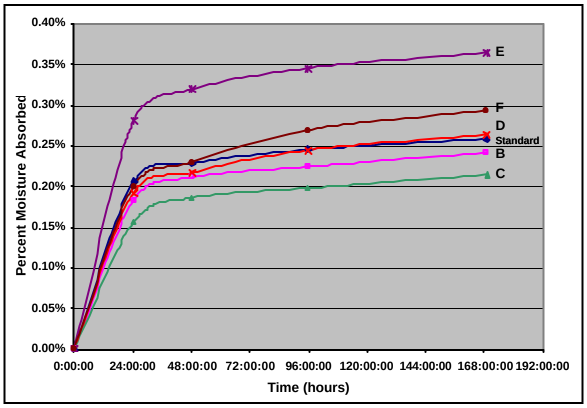

FIGURE 1 Moisture absorbed at 85/85 by modules with various overmold compounds

MSL EXPERIMENTAL PROCEDURE

All samples of each mold compound were tested in accordance to the JEDEC standard J-STD-020B titled “Moisture/Reflow Sensitivity Classification for Non-hermetic Solid State Surface Mount Devices”. For high-temperature applications, the J-STD-020B standard specifies a peak temperature of 250 °C. Since industry expectations for leadfree applications are at peak temperatures of 260 °C, the reflow profile recommended by the J-STD-020B standard was modified to accommodate this peak temperature.

The MSL test procedure is summarized in the previously mentioned MSL process flow. Thirty 4x4 CDMA-PA modules from each material were used for the test. The JEDEC standard J-STD-020B states that the modules have to be subjected to reflow temperatures three (3) times within four hours but not sooner that fifteen (15) minutes of removal from the humidity chamber. Table 6 is representative of a reflow profile. It is seen that when compared to table 3, the profiles are in accordance to the JEDEC specifications.

TABLE 3. Breakdown of Leadfree Reflow Profiles

	Run 1	**Run 2**	**Run 3**
Average Ramp-up (°C/s)	0.91	0.92	0.90
Dwell Time (sec)	109	104	110
Ramp-up 200 to 217 (°C/s)	1.89	1.94	1.98
Time above 217 °C (s)	68	68	69
Time within 5 °C of peak (s)	22	23	25
Peak Temperature (°C)	259.3	260.6	260.7
Average Ramp-down (°C/s)	1.35	1.45	1.47

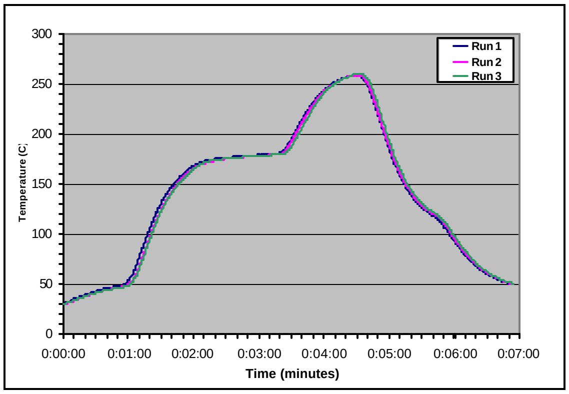

FIGURE 2 Graphical Representation of Anadigics 260 °C Profiles

After being subjected to leadfree reflow temperatures the modules were electrically tested, sonoscanned and then de-encapsulated. The results of the MSL test are given below.

TABLE 4. Post MSL 3 at 260 ° C Results

	Reflow Temperature: 260 °C		
	Number of Failures		
Material\Test	Post E.T.	Sono-scan	Decapping
Standard	0	N/A	N/A
Compound B	2 (NC)	0	0
Compound C	0	0	N/A
Compound D	0	0	N/A
Compound E	9 (C), 1(NC)	0	Not Decapped
Compound F	1 (NC)	0	Not Decapped

E.T. = Electrical Test
C = Catastrophic failure
NC= Non catastrophic failure

A catastrophic failure refers to failures that cause the modules to not power up. However, the modules that do power up but do not meet the customer specific limits are deemed as non-catastrophic failures. The electrical test results were further analyzed to calculate the average percent shift of critical parameters from pre to post test to determine the stability of the materials. Compound C displayed the least amount of pre to post performance shift followed by Compound D and then Compound B.

MSL 2A CAPABILITY

In order to obtain a more distinct difference in performance of compounds B, C, and D, modules encapsulated with these mold compounds were subjected to the more aggressive test of MSL 2a. Referring to Table 2, Level 2a packages have a floor life of 4 weeks. In accordance to the JEDEC accelerated soaking standards, the modules were soaked at 60 °C and 60 % RH for 168 hours. The regular soak time for MSL 2a is 29 days at 30 °C and 60 %RH.

The modules were subjected to the same process flow as MSL 3 except for the soaking conditions. In order to avoid potential discrepancies caused by differences in reflow profiles, the modules from all three material sets were simultaneously subjected to leadfree reflow temperatures. The results of the MSL 2a test are presented in table 8.

TABLE 5. Post MSL 2a at 260 ° C Results

	Reflow Temperature: 260 °C	
	Number of Failures	
Material\Test	Post E.T.	Sonoscan
Compound B	1 (NC) 8 (C)	0
Compound C	0	0
Compound D	4 (NC) 2 (C)	0

E.T. = Electrical Test
C = Catastrophic failure
NC= Non catastrophic failure

Since the initial test for MSL 2a proved positive only for Compound C, two verification tests were performed using modules overmold with only this mold compound. Two sets of sixty-three (63) modules were subjected to the conditions specified for MSL 2a. Table 9 provides the results.

TABLE 6. Post MSL 2a at 260 ° C Verification Results

	Reflow Temperature: 260 °C	
	Number of Failures	
Verfication Test #	Post E.T.	Sonoscan
Test 1	0	0
Test 2	1 (C)	0

According to the Lot Tolerance Percentage Defective (LTPD) table, at a 20% failure rate, a sample size of 63 modules allows for 8 failures. [7]. Therefore, modules overmolded with compound C can be qualified at MSL 2a. The higher MSL rating was obtained by changing only the overmold compound. Further study is required to determine if this higher level can be maintained after transitioning the product to a new set of green materials.

CONCLUSIONS

Evaluation of the five overmold compounds provided sufficient data with which selecting a suitable material capable of withstanding 2nd level interconnect temperature of 260 °C without degrading MSL performance. The results of the moisture absorption tests along with full moisture sensitivity tests indicated compound C having superior performance over other compounds.

Performance of Compound C is attributed to its hydrophobic properties. These characteristics are a result of polymer design, which incorporate epoxy and hardener resins, along with adhesion promoters and wetting agents. The design balances each of these components to provide a resin system capable of withstanding extreme environmental conditions.

REFERENCES

[1] Soldertec. *Second European lead-free soldering Technology roadmap*. February, 2003.

[2] Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the Restriction of the use of certain Hazardous substances in Electrical and Electronic Equipment.

[3] http://www.kester.com/leadfree_alloys.htm

[4] John H. Lau, *Electronic Manufacturing with leadfree, halogen-free & conductive-Adhesive Materials*. McGraw Hill Publishing. 2003.

[5] Jennie Hwang, *Environment-Friendly Electronics: Lead-free Technology*. Electrochemical Publications Ltd. Isle of Man, 2001.

[6] JEDEC Standard J-STD-020B. *Moisture/Reflow Sensitivity Classification for non-hermetic Solid State Surface Mount Devices*. July 2002.

[7] *General Specifications for Microcircuits*. Military Specifications MIL-M-38510F, October 1983.