

A NOVEL SOLUTION FOR CIRCUIT BOARD PROTECTION

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Abstract

The use of Circuit Board Protection (CBP) is becoming prevalent for consumer electronics. Traditional dominant methods of CBP are potting, conformal coating and sealing. The polyamide molded in place CBP material offers a novel solution of CBP which is cost effective, environmentally friendly and have much higher output as compared to traditional methods. However traditional polyamide resin have high softening point ($>217^{\circ}\text{C}$) which limits their use for electronics applications. Formulation adjustments result in a low temperature polyamide hot melt which could encapsulate and protect electronics without damage to solder joints and electronic components. In addition, this novel solution of CBP also provides superior waterproof capabilities and excellent low temperature flexibility.

Keywords: Circuit Board Protection, Polyamide molding, Waterproof, Low temperature flexibility

Introduction

CBP is used to protect electronic printed circuit boards (PCB) from dust and the environment. Traditionally, the use of CBP has been limited to critical military and automotive applications. In recent years, CBP use have been extended to the realm of consumer electronics due to the popularity of wearable electronics, RFID devices and tracking sensors, and the improved quality demanded for home appliances. Miniaturization and increased functionalities are trends that dominate the entire electronics industry. As the devices get smaller, the pitch between components become so close that any moisture or dirt can cause failure. There was a dire need for an official guideline for circuit board protection and in 2012, IPC released IPC-HDBK-850 'Guidelines for Design, Selection and Application of Potting Materials and

Encapsulation Processes Used for Electronics Printed Circuit Board Assembly.' [1] Material development for CBP application and process innovation to apply the materials is set to be a major focus for the materials suppliers and manufacturers in the electronics industry.

Current methods of circuit board protection

Potting and conformal coating are two dominant CBP methods in the industry. Potting is defined as the process of partially or completely filling an electronics assembly with a solid compound to protect the assembly from dirt, dust and moisture and to increase the assembly resistance to shock and vibration. The potting materials are normally thermosetting materials and the chemistries used are usually an Epoxy, Urethane, Arcylate or Silicone. Such materials can either be heat cured or moisture cured depending on the chemistries and the cure time varies from about 4 hours to a few days.

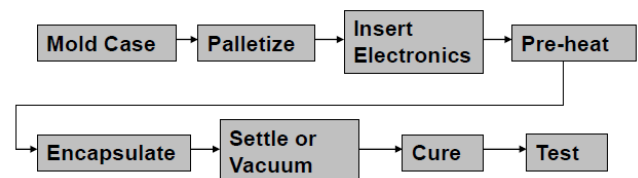


Figure 1: Potting process flow

In the manufacturing process using potting materials, an injection molded mold case has to be produced offline to house the PCB. The entire process flow, which takes between 4 hours to several days to complete, is as shown in figure 1. Conformal coating is a thin dielectric layer applied to protect the PCB from moisture, dust and temperature extreme. The conformal coating materials are normally thermosetting materials and the chemistries used are usually an Epoxy, Urethane, Arcylate or Silicone.

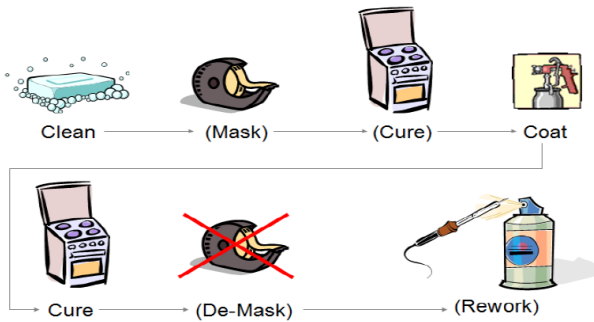


Figure 2: Process flow for conformal coating

The conformal coating material can be applied by spraying, dipping, or dispensing. Most conformal coating materials use solvent systems to aid application of the material and are “cured” by drying off the solvents. The production time for application and curing of the material is between 4 hours and a few days. The high solvent evaporation rate during production is a major health and safety concern. In particular, the Poly-isocyanurates present in urethane conformal coating causes skin sensitization to the operators in the vicinity. As such, the conformal coating process is usually carried out in an isolated room and the operator handling it is equipped with full protective gear.

The need for increased production speed in CBP

As discussed in the earlier section, the current production speeds for CBP are limited to the slow application and curing time of the potting material. The potting material takes time to flow and fill up the casing. In addition, the curing time of the potting material could be anywhere from two hours to a day. In addition, the current supply chain needs to be managed well as the casings are normally outsourced and produced offline. In order to keep up with the exponentially increasing demand of CBP for consumer electronics, there is a need for material development and process innovation to reinvent the CBP process.

Ideology

Injection molding has been the cornerstone for plastic engineering, providing ultra-high production speeds and flexibility for engineering plastics. [2] Every year,

billions of mobile phone cases, refrigerator housing, washing machine housing etc. are produced by injection molding. The process advantages of injection molding is so dominant that even metal manufacturers have invested in liquid metal in the bid to process metal the injection molding way. In fact, the cases used to house the potting compound are also produced using the injection molding process. It would be ideal if the injection molding method can be used for CBP as it can potentially improve the process UPH and improve the supply chain efficiency.

Why is the current method of injection molding not suitable for CBP?

The current engineering plastic injection molding makes use of an extruder screw to push a polymer melt through an orifice at high temperatures and pressures. This combination of temperature and pressure would cause solder joints to reflow and components to be damaged.

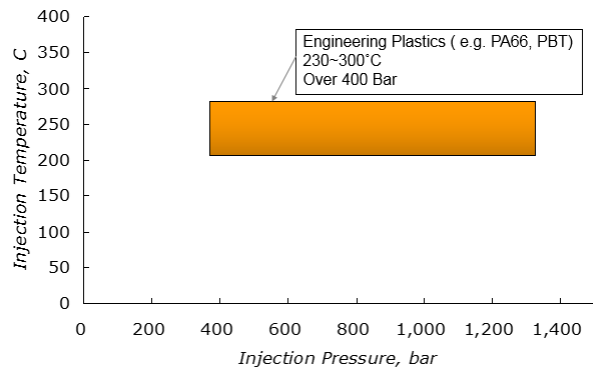


Figure 3: Injection pressure vs Temperature for engineering plastics

The process advantages of injection molding is so alluring that some manufacturers have decided to use it for CBP purposes despite significant incompatibilities in temperature and pressure. In a particular case, one of the sensor manufacturers used the polypropylene melt to protect a circuit board, setting the temperature in the barrel to about 230 degrees, just enough to melt the material and reducing the extruder screw speed to the lowest possible setting on the machine. This resulted in a partial success molding process with a yield of about 70%. This yield,

however is not acceptable in the consumer market where high yields are demanded because margins are low. In order to develop a sustainable and stable injection molding process for CBP purposes, a material that can be molded at temperatures below the reflow temperature of solder and at pressures gentle enough not to damage the PCB must be developed.

Material Development

Basic chemistry

Polyamides, invented by Carothers have very excellent mechanical properties, have great strength and toughness, and have excellent self-lubricating properties [3]. The polyamide is formed through a condensation reaction of a polybasic acid and a polyamine.

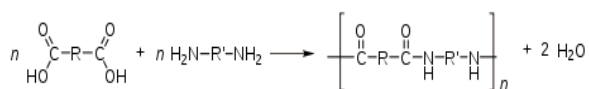


Figure 4: Condensation reaction between a polybasic acid and polyamine

Depending on the constituent mixture of the polybasic acid and polyamine, the resulting polymer chain can either be linear or branched. The linear polyamide has high molecular weight, resulting in high strength and toughness, and is better known as Nylon 6/6. 6/6 means that it has an equal number of polybasic and polyamine. By varying the constituent mixture of the precursor prior to the condensation reaction, it is possible to form a branched polyamide. Branched polyamides have lower molecular weight, as such, it has lesser strength but it exhibits excellent flexibility. In addition the viscosity of branched polyamides are greatly reduced.

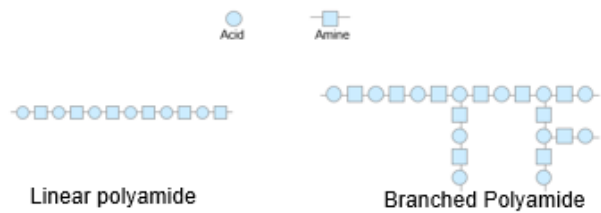


Figure 5: Differences between branched and linear polyamide

A material with a low viscosity is exactly what is needed, however, there has to be a compromise between low viscosity, which is essential for processing the material as a CBP material, and the strength of the material, which determines part of its reliability as a CBP material. By careful control of the ratio of polybasic acid and polyamine, and also the processing variables such as temperature, pressure and time in the polycondensator, the material that could be molded at low temperature and provide gentle encapsulation for PCB was produced. The properties of the new material are tabulated against Nylon 6/6 in figure 5 and key attributes to take note of are the much reduced softening point and viscosity. The reduced softening point of about 80°C results in a processing temperature that is within the range of temperature where lead free solder will not melt.

Property	Nylon 6/6	New material
softening point	255-265°C	165-175°C
Viscosity	1.5-5.0 mfi	3500 cps @ 210°C
% elongation	150-300	400
specific gravity	1.15	0.98
processing temp.	260-327°C	190-210°C
molding pressure	1000-25000psi	50-250 psi

Figure 6: Comparison between Nylon 6/6 and new material

The viscosity of the new material is reduced so drastically

that it is measured on a completely different scale when compared to Nylon 6/6. Viscosity of Nylon 6/6 is measured on the Melt Flow Index (MFI) scale as stipulated by ASTM D 1238 test method, Melt Flow Rates of Thermoplastic by Extrusion Plastometer. [4] This test method is used to test thermoplastic melts which have viscosity so high that it could only flow when an extruder screw is used to push it. The new material, however, is measured on a Brookfield viscometer scale and the viscosity is a low 3500cps at the processing temperature.

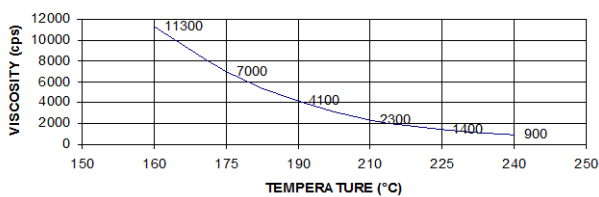


Figure 7: Viscosity measurement of the new material with a Brookfield Viscometer

Material properties

The new material has flexibility that surpasses that of Nylon. Mandrel bend testing revealed that the material remain very flexible even at deep-freeze temperatures of -40°C. In addition, the material is UL 94V-0 capable. By varying the precursors and process conditions, and also by adding in some non-functional additives during the polymerization step, variants from the initial material can be produced. The purpose is to produce material that can withstand varying operating temperatures and materials with different toughness and hardness. The operating temperature value is derived by carrying out a creep test. Figure 7 shows a snapshot of the material properties of four variants of the new material.

Properties	Material Variant 1	Material Variant 2	Material Variant 3	Material Variant 4
Color	Amber / black	Amber / black	Amber / black	Amber / black
Chemical Base	Polyamide	Polyamide	Polyamide	Polyamide
Operating Temperature	-40/+100 °C	-40/+125°C	-40/+140°C	-40/+140°C
Cold flexibility	-40 °C	-40 °C	-40 °C	-40 °C
Applying Temperature	180-220 °C	200-230 °C	210-230 °C	200-230 °C
Shore hardness	A 77	A 90	A 90	D 40
Elongation at rupture	400 %	400 %	400 %	800 %
Flammability	UL94-V0	UL94-V0	UL94-V0	UL94-V0

Figure 8: Material property table of several variants of the new material

Process to apply the new material

Insert molding process

Insert molding is a process where a partially finished part is placed in mold and the partially finished part and the molding material are molded together to become the final product. The new material is pelletized into pellets as shown in figure 9. The pellets could come in any shape or color depending on the pelletizers or dyes used. The pellets are placed in a melt tank capable of melting the material and an integrated displacement pump in the melt tank pushes the material through an orifice into the mold where the PCB is placed.



Figure 9: New material in Pellet form

The final molded part can take any shape and size and is determined by the mold. In electronic assembly with cables, a strain relief can be designed into the molding process so that the protection of PCB, waterproofing of PCB and strain relief all takes place in one step. Figure 8 shows the flexibility of the insert molding process to mold PCB of different shapes and sizes.

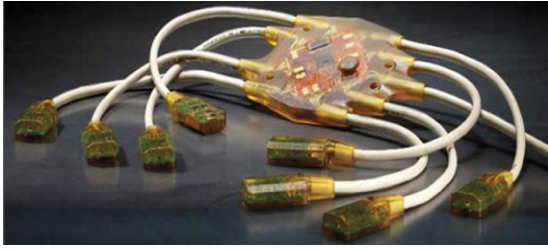


Figure 10: Robot arm controller PCB protected by new material (Amber color)

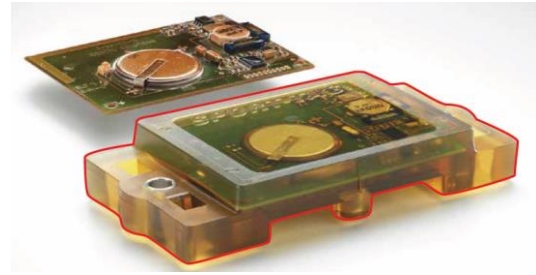


Figure 12: PCB with battery molded with the new material

Application Temperature and Pressure

i) *Application temperature would not affect solder joints*

In order to ensure that the application temperature would not affect the solder joints, thermocouples are placed on the PCB during the molding process. From figure 9, it could be seen that the temperature of the board decreases rapidly upon contact to about 175 °C with the new material and quickly tapers down as it moves away from the injection spruce into the mold.

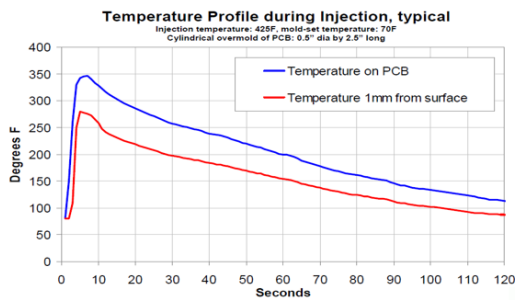


Figure 11: Temperature profile during injection

The peak temperature is well below the lead free reflow temperature (217 °C) of solder, which indicates that this process is suitable for molding assemblies with solder joint. Another point to note is the rapid reduction of temperature as the material moves into the mold. This seems to open up the possibility of using this process for temperature sensitive boards with liquid crystal displays and batteries. This is done by careful control of the injection points to be away from the temperature sensitive components. A PCB with both a battery and LCD was molded with this technology and the mold part has been proven to be functional and pass all relevant reliability tests.

ii) *Application pressure will not affect the solder joints*

In order to verify that solder joints on the boards are not damaged/affected by the application pressure of the material, we molded some printed circuit boards and did cross sectional analysis to check for intermetallic growth caused by the molded process. Cross sectional pictures in figure 13 showed that the thickness of IMC are not affected by the molding process.

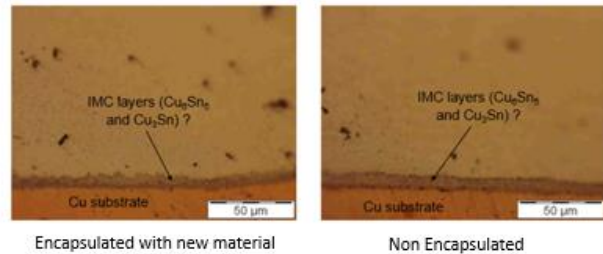


Figure 13: Comparison of solder joints

Process Advantages

There are many process advantages that a manufacturer can reap in utilizing this new material for circuit board protection. One obvious advantage is the massive reduction in production step and the ability to achieve CBP and strain relief function in one step.

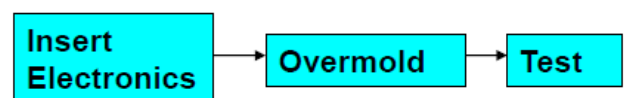


Figure 14: Process steps using new material

In addition the ability of the material to skyline around the PCB as compared to the potting process reduces material use and hence material cost to the manufacturer. It also results in a reduction of material weight which is critical in automotive applications. Other advantages of this process compared to convention process are

- i) Elimination of mixing and curing step
- ii) Elimination of casing
- iii) Reduction of production floor space
- iv) Lower energy waste
- v) Non-toxic process

Performance as a CBP material

The main functions of a CBP material is to protect the material from moisture and harsh environment. Since every device is different in shape, structure as well as reliability requirements, the testing results presented in this section of the paper has been done mainly based on material properties rather than device performance.

Protection against temperature extremes

The material has been subjected to storage and 85°C and -40 °C which are typical temperature ranges required for consumer products. As shown in figure 15, the material properties are not affected by the high and low temperature storage, which from a materials point of view justifies its suitability for use in the temperature range.

	3000h 85°C		3000h -40°C	
	Before -50, after -48		Before -50, after -48	
Cold flexibility, Mandrel °C	2.8,	2.6	2.8,	2.6
Yield N/mm ²	3.0,	3.3	3.0,	3.1
Break N/mm ²	328,	319	328,	335
Elongation at rupture %	105,	108	105,	107
DSC Return max °C	-45,	-49	-45,	-49
DSC 2 run Tg °C	140,	145	140,	144
DSC 2 run Peak max °C	78	80	78	77
Shore A hardness				

Figure 15: Material properties after storage at high and low temperatures

Protection against salt and water ingress

Another important function of the CBP material is to protect the PCB from moisture ingress. In order to quantify this property a simple Light Emitting Diode (LED) was molded in place using the new material and used as a

test vehicle. Molding was carefully done to ensure that there are no voids in the material that could potential affect the results. The solution used was a 5% concentration of sodium chloride at a temperature of 35°C. The LED functionality is checked before the immersion and test again after 1000 hours of immersion.

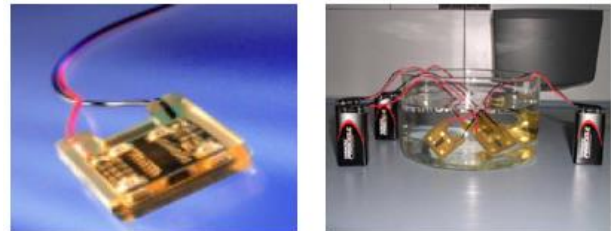


Figure 16: Picture of LED test vehicle and salt water ingress test

All 5 LEDs are tested to be working after the immersion. The condition of this test best simulates conduct to human skin with the salt content coming from perspiration. The success of this material to provide water proofing and salt resistance function indicates its suitability for use in wearable electronics. In addition, the LED has been also tested in accordance to the IP 67 water proof test and have passed the test.

Conclusion

Traditional CBP methods mainly utilize the potting or conformal coating application. An alternative method of CBP is proposed in this paper. This new method makes use of the polyamide chemistry, which is well proven in the mechanical plastics world but relatively new in the CBP industry. This new material can be applied by the process of insert molding, which brings many process advantages to the manufacturers. The success of this alternative method of CBP would require a combined effort between the materials supplier, the manufacturers design team, and the mold maker since every device is different and need a unique set of mold. The numerous unique value propositions that this alternative method of CBP would certainly attract more manufacturers to evaluate it in the near future.

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