

The Pros of Conformal Coatings

Choosing the right coating to preserve and protect electronics in harsh environments

Introduction

Many chemicals found in the oil, gas, and petrochemical industries can consign electronic components to a short life, creating high failure rates and low reliability. Corrosive agents such as H₂S gas, hydrocarbons, chlorobenzene, and chemical by-products play havoc with components that control and manage processes, or transport vital data between control centers and remote sites. What is required is a protective coating that can isolate the components from the harsh reality of industrial settings.

Conformal coatings, as the name suggests, do just that by conforming to the contours of elements that populate printed circuit boards (PCBs) and other components present in electronic assemblies and systems. Conformal coatings are thin layers of synthetic resins or organic polymers applied to PCBs and electronic components for protection against environmental, mechanical, electrical, and chemical problems including contaminants such as dust, dirt, fungus, moisture, chemicals, thermo mechanical stress, mechanical shock, and vibration. Conformal coating types include urethane, silicone, acrylics, epoxies, and parylene.

This paper will focus on networking products components as they are now heavily migrating into industrial settings, and the protection of these devices is vital in the proper functioning of networks that manage and control various processes. A Harsh Environment Conformal Coating is engineered to resist H₂S gas and other corrosive agents, including humidity. Adding harsh environment conformal coating improves and extends the working life of the industrial networking product and ensures security and reliability of performance. But not all conformal coatings are created equal.

The Environmental Attack

Studies have shown that hydrogen sulfide (H₂S) contaminants in concentrations as low as 10 ppm may attack surface mount (SMT) electronic components. Long filaments of silver sulfide known as "silver whiskers" can form on the surface of the silver electrical contacts of these electronic components, when exposed to environments containing low levels of H₂S.

The presence of heat, chemicals and moisture can accelerated these formations. These deposits can potentially create short or open circuits that can cause a networking product such as an Ethernet switch or other electronic component to ultimately malfunction or fail. Hardened networking boxes are extremely robust, meeting and exceeding IPC/IEC/MIL standards for survivability in power utility and heavy industrial environments. However, specific environmental hazards such as the effects of H₂S gas and other corrosive agents on surface mount electronic components are not specifically addressed by normally hardened networking products.

The issue of excessive heat on components can be partially solved with the use of a thermally conductive conformal coating applied between a heat-generating electrical device and a heat sink in order to improve heat dissipation. It forms a thermally conductive layer on the substrate, either between components or within a finished product.

Conformal Coating Elements and Characteristics

It is important to determine the types of threats a system will be subjected to when deciding on the best conformal coating. The list of chemical systems and filler materials used in conformal coatings is very broad. Some chemical systems contain acrylics, elastomers, natural or synthetic rubbers; epoxy resins, water-based resins, silicone compounds, or volatile organic compounds (VOCs). Others contain bismaleimide (BMI) resins, phenolics, or formaldehyde resins. Commonly used chemical systems also include polybutadiene, polyester, vinyl ester, polypropylene (PP), polysulphide, and polyurethane (PUR). In terms of filler materials, some conformal coatings contain aramid fiber, chopped fiber, carbon powder, or graphite powder. Other products contain glass fillers, metal fillers, or inorganic compounds. Unfilled conformal coatings are also available. Typically, these raw materials are used as starting components in the production of finished coatings.

Once the coating is applied, there are several curing technologies available. Typically, thermo-set plastics and thermo-set resins are cured using heat or heat and pressure. Vulcanization, a thermo-setting reaction, uses heat and/or pressure in conjunction with a vulcanizing agent to produce materials with greatly increased strength, stability, and elasticity. Some polymer resins or compounds cure or vulcanize at room temperature. Others cure with radiation, electron beam irradiation, visible light, or ultraviolet light. Single-component curing systems consist of a resin that hardens through the application of heat or through a reaction with surface moisture. Two-component and multi-component curing systems consist of two or more resins and a hardener, crosslinker, activator or catalyst.

Selecting the Right Conformal Coating

There are several parameters to keep in mind when selecting the right conformal coating. The product's application environment is obviously one of the keys, but so are the physical characteristics of component assembly. To what types of contaminants will the assembly be subjected? What is the severity and duration of contact? Is mechanical stress or heat a factor? How delicate are the mounted component leads and connections on a PCB?

Selecting conformal coatings requires an analysis of physical, mechanical, thermal, electrical, and optical properties. Physical properties include viscosity and gap fill, the space between the material and substrate. Mechanical properties include tensile strength, tensile modulus, and elongation. Thermal properties such as temperature range, thermal conductivity, and coefficient of thermal expansion (CTE) are important considerations also. Electrical properties for conformal coatings include electrical resistivity, dielectric strength, and dielectric constant.

Conformal coatings are not restricted to the environments described here. Many special purpose applications make use of conformal coatings, such as electrical power and high voltage products including generators, transformers, circuit breakers, and motor assemblies. Specialized conformal coatings meet military specifications (MIL-SPEC) MIL-I-46058, IPC-CC-830, IPC-4101, MIL-STD-1188, and are suitable for many applications. Flame retardant materials resist ignition or reduce the spread of flames when exposed to high temperatures. Flexible or dampening materials form layers that can bend without cracking or de-laminating.

In fact, flexibility is of primary concern where PCBs are concerned and where PCB real estate is critical. The differences in coefficient of thermal expansion (CTE) between a non-flexible conformal coating and the PC board and its mounted components may lead to damage of light-gauge leads and connections. This effect is particularly a problem on boards that experience repeated temperature cycling.

In these applications, a rigid coating may cause damage to the substrates it was originally designed to protect. This reason, along with the ongoing miniaturization of electronics, supports the need for more flexible conformal coating materials to prevent stress on fine-pitch leads and very small components.

Conformal Coating Types

The choice of the right coating requires knowing what threats the assembly will be subjected to and its vulnerability to the coating characteristics. As mentioned above, an inflexible coating can stress mounted components to the point of failure. The ease of application and its removal when components fail are of prime importance.

IPC/MIL specifications classify conformal coatings into types by the cured chemistry of the coating. The types and associated acronyms are:

- Type AR-Acrylic
- Type ER-Epoxy
- Type SR- Silicone
- Type UR-Polyurethane or Urethane
- Type XY-Paraxylylene.

These are listed below with their primary characteristics and considerations.

Acrylic:

Generally the easiest of the conformal coatings to handle. The thermoplastic lacquer base means the coating is easy to apply and easy to remove and repair. Moisture resistance is comparable to urethane and silicone, but it has poor resistance to petroleum solvents and alcohol. Dielectric withstand >1500 volts. Temperature range -59C to 132C.

Silicone:

Good thermal shock resistance due to flexibility. Also easy to apply and repair, although overall removal may be challenging. Moisture resistance is similar to urethane and acrylic. Dielectric withstand may be somewhat lower than for the other coatings (1100 volts/mil), but flexibility of silicone coating allows for much thicker film build than comparable acrylic or urethane coating. Temperature range - 65C to 200C.

Urethane:

Hard, durable coating that offers excellent abrasion and solvent resistance. Similar moisture resistance to acrylic and silicone, but significant shrinkage during curing and extremely hard film may stress components. Urethane is a difficult coating to apply and nearly impossible to remove. Rework may be accomplished by burning through coating with soldering iron (using appropriate safety precautions due to isocyanates in the cured film) on local areas, but stripping of large areas or whole boards is nearly impossible. Temperature range is same as the Acrylic above.

Epoxies:

Excellent resistance to moisture and solvents, usually a two-part thermosetting coating. Coating shrinks during curing, leaving hard, difficult-to-repair film, which may stress components. Due to the extreme solvent resistance of the film, coating is virtually impossible to strip.

Paraxylylene:

Usually a two-part Paraxylylene coating is very uniform and yields excellent pin coverage. Limitations include high cost, sensitivity to contaminants and the need for vacuum application technique.

Silicone on Silicon

Ironically, the best choice for the oil, gas, and petrochemical industry is silicone, the term usually confused with silicon, the heart of the logic chips this coating protects. The reasons for silicone usage are many when this industry's requirements are listed.

Silicone has the ability to function over a wide temperature and humidity range, provides a durable dielectric insulation, acts as a barrier against environmental contaminants such as hydrocarbon and benzene, is effective against gas permeation, and is also a stress-relieving shock and vibration absorber.

In addition to sustaining their physical and electrical properties over a broad range of operating conditions, silicones are resistant to ozone and ultraviolet degradation and have good chemical stability. Most silicones contain significantly less solvent than organic coating and are available in a wide variety of cure systems. Silicones also offer better repair ability and, in the manufacture of electronic devices, allow the option to salvage or reclaim damaged or defective units as they can be removed from substrates and circuitry by scraping or cutting, or by using solvents or stripping agents.

A list of key conformal coating characteristics the industrial networking product should possess are:

- Low viscosity
- Spray, dip, select, or flow-coat application options
- Long pot life
- Rapid cure, no by-product
- Sufficient under-component cure
- Repair ability
- Wide range of operating temperatures
- Non-toxic
- Low cost
- Robust adhesion
- Chemical resistance
- Standards compliant: IPC-CC-830, IPC-TM-650, MIL-I-46058, ASTM-D-1005, UL 94

Conformance to Industry Standards

Emerging standards for conformal coating thickness are being considered by the IEEE. The new standard will define the appropriate thickness range for each coating type, indicating the recommended values for harsh environments.

Under the IPC-CC-830 standard, silicone (SR) coating thickness was defined in the 1.97-7.87 mil range. Accordingly, GarrettCom offered thin film silicone coatings consistent with this standard for protection against moisture. But after much investigation, GarrettCom determined that a thicker silicone coating in the 14 mil range was more appropriate for the oil, gas, and petrochemical industry.

Military applications and standards such as MIL-I-46058C demand a heavy-duty silicone conformal coating to protect electronic equipment from highly corrosive gaseous hydrocarbons. This application

environment is similar to those frequently found in the oil, gas and petrochemical industry. For this, Type SR (Silicone) requires a thickness of 12.50 to 15.87 mils as specified in table 1.

TABLE 1 MIL-I-46058C THICKNESS REQUIREMENTS

Type of Coating	Thickness
AR	[18.98-22.95 mil]
UR	[15.98-18.95 mil]
ER	[14.98-20.95 mil]
SR	[12.50-15.87 mil]
XY	[12.49-15.87 mil]

As can be seen from the table, the traditional MIL standard, MIL-I-46058, provided more stringent standards for the various coating types, which GarrettCom believes are appropriate, considering the invasive effects of H₂S and other gases and chemicals commonly found in the oil and gas industry. GarrettCom is a participating member of the IEEE Standards Committee and hopes it will recommend these conclusions. Nonetheless, GarrettCom will continue to provide the coating thickness it deems best for its customers in the oil and gas industry.

Conclusion

Silicone coatings provide excellent resistance to industrial chemicals, environmental heat and mechanical shock conditions, low stress on mounted components, ease of use and ease of removal, making it the choice for hardened industrial networking products such as Ethernet switches and other electronic products.

Using a thicker 14-mil silicone coating on PCB assemblies and all of the subassemblies inside of networking products, especially highly configurable products, is more time-consuming and costly than the thin coatings commonly being used. But GarrettCom believes the better protection and reliability of networking products in harsh environments demand no less than the right coatings for the right reasons.



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