ABSTRACT

Title of Dissertation: CREEP CORROSION OVER PLASTIC ENCAPSULATED MICROCIRCUIT PACKAGES WITH NOBLE METAL PRE-PLATED LEADFRAMES

Ping Zhao, Doctor of Philosophy, 2005

Dissertation Directed By: Dr. Michael Pecht, Professor, Department of Mechanical Engineering

Field failures were observed to be caused by the bridging of corrosion products across lead fingers. This phenomenon was identified as creep corrosion and was the motivation for this work.

This dissertation advances the state of knowledge on the creep corrosion process and the strategies for mitigation. A range of plastic encapsulated packages with noble metal pre-plated leadframes, from different vendors, with different package attributes, were used in this study. Creep corrosion on the mold compound surface was reproduced in an accelerated manner using mixed flowing gas (MFG) testing in laboratory conditions. Of the three most widely-used industry-standard MFG testing conditions, Telcordia Outdoor was found to be the most effective environment to induce and promote creep corrosion over the mold compound; Battelle Class III environment can also induce the similar effects of creep corrosion on mold compound, but in a limited rate on selective packages; Telcordia Indoor was found to induce no creep corrosion on the mold compound over a 30 day test time. In both Telcordia Outdoor and Battelle Class III environments, packages attributes and applied pre-conditionings were found to have no significant influence on the creep corrosion effect.

Creep corrosion over the mold compound showed a dendritic formation. The thickness of the corrosion product layer on the mold compound tended to increase with increased exposure time. Creep corrosion products were electrically conductive and were able to bridge the adjacent leads, thereby causing electrical shorts. The corrosion products were found to consist primarily of copper oxides, copper chlorides, and copper sulfides. No distinct differences in corrosion products composition was observed on the lead versus the mold compound surfaces. Conformal coating was identified as an effective mitigation strategy to eliminate creep corrosion on noble metal pre-plated leadframe packages.

CREEP CORROSION OVER PLASTIC ENCAPSULATED MICROCIRCUIT PACKAGES WITH NOBLE METAL PRE-PLATED LEADFRAMES

By

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1 Introduction

This chapter focuses on the background and fundamentals for the dissertation work. First, introductions are given about plastic encapsulated microcircuit (PEM) packages and noble metal pre-plated leadframes. Second, field failure due to corrosion migration external to the PEM package is discussed, which is the motivation for this study. Third, previous works in the literature about creep corrosion are reviewed; a refined definition of creep corrosion is presented. At last, the scopes and objectives for this work are defined.

1.1 Plastic encapsulated microcircuit packages

Electronic packages can be categorized in one of two broad classifications, namely hermetic and non-hermetic or plastic packages. Plastic packages were devised in the 1970s to improve upon the weight, size, and cost of traditional hermetic packages. Tremendous efforts were made in the 1980's to try and improve plastic package reliability. PEM packages now dominate the market share of microcircuit sales worldwide due to several significant advantages over their hermetic counterparts in the areas of size, weight, cost, and availability [1]. PEM packages can be roughly divided into two groups, grid array package and leadframe-based package. Leadframe-based packages are the most frequently used package format and account for the major portion of PEM packages.

To understand the function of leadframes in PEM packages, it is necessary to put some words on electronic packaging for integrated circuits (ICs). Figure 1.1 shows the cross-section view of a typical IC package with leadframe. Semiconductor die usually sits in the center of the package, on which the circuitry performs the pre-designed functionalities. Die is attached by die attach materials on die paddle, which is part of the leadframe. The electrical connection is realized by bonding wires from the contact bump over the die to each extended lead fingers of the leadframe. Molding compound acts as the encapsulant of the package.

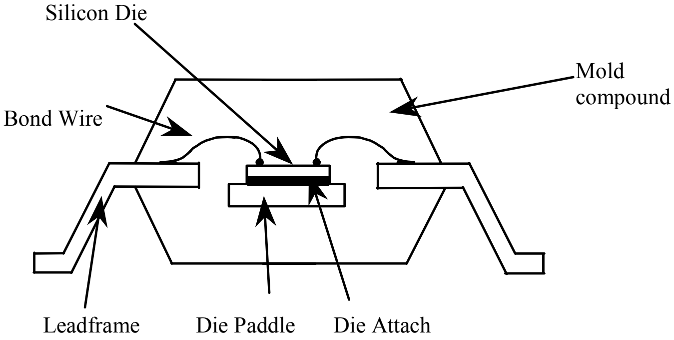


Figure 1.1 A typical PEM package with leadframe

There are four primary functions of the leadframe in an IC package. First, it is the carrier strip for package assembly. Second, it provides mechanical support for die during handling of wire bonding and assembly. Third, the leads of the leadframe serve as contacts of electrical connections to the outside circuitry. Last but not least, it can be regarded as the natural heat sink for dissipating heat generated by the operation of components. Figure 1.2 shows the schematic diagram and the photo of a piece of leadframe separated from the strip. The captions on Figure 1.2 show the terminology for each specific part of the leadframe. Some portion of the leadframe will be removed after encapsulation and each lead will be mechanically separated from each other.

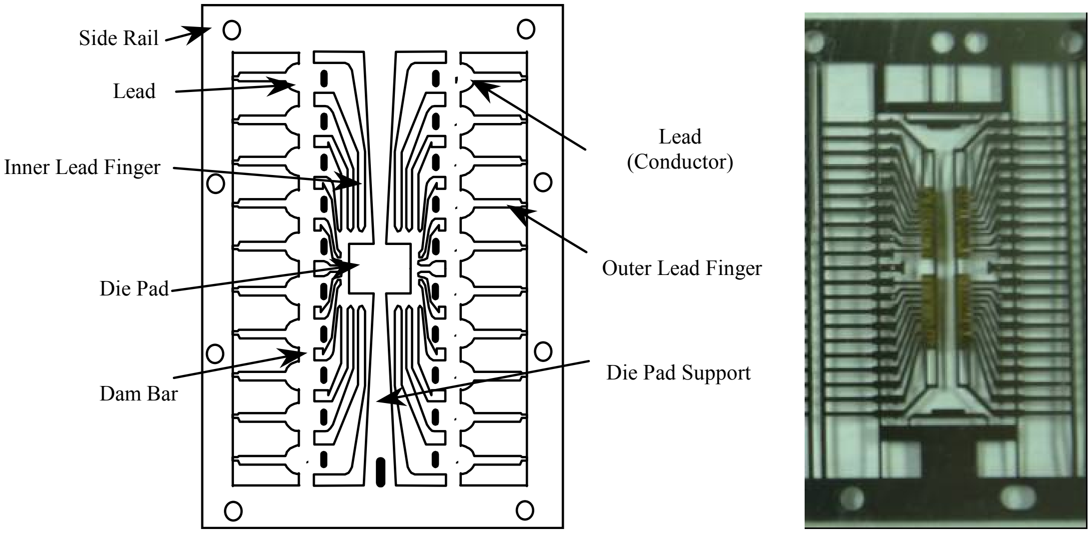


Figure 1.2 The schematic diagram of a standard leadframe and the photo of a piece of leadframe separated from the strip

An ideal leadframe should have the following properties listed in Figure 1.3.

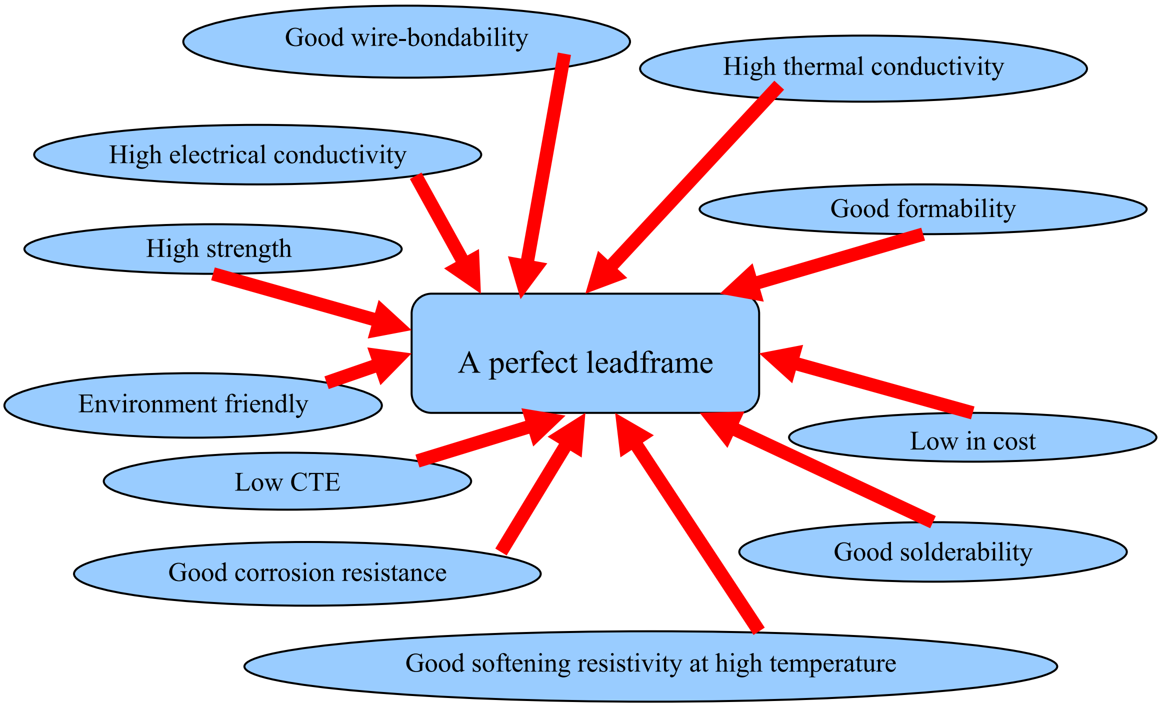


Figure 1.3 Properties for an ideal leadframe

However, in the real world, there is always trade-offs to consider for choosing the appropriate materials for specific application. Commonly used leadframe materials are listed in Table 1.1. Copper alloy based leadframe has the biggest market share, followed by Alloy 42 (42%Ni/58%Fe).

Table 1.1: Commonly used leadframe materials

Alloy	Designation	Nominal composition (%)
Cu-Fe	C19400	2.35Fe-0.03P-0.12Zn
	C19500	1.5Fe-0.8Co-0.05P-0.6Sn
	C19700	0.6Fe-0.2P-0.04Mg
	C19210	0.10Fe-0.034P
Cu-Cr	CCZ	0.55Cr-0.25Zr
	EFTEC	0.3Cr-0.25Sn-0.2Zn
Cu-Ni-Si	C70250	3.0Ni-0.65Si-0.15Mg
	KLF-125	3.2Ni-0.7Si-1.25Sn-0.3Zn
	C19010	1.0Ni-0.2Si-0.03P
Cu-Sn	C50715	2Sn-0.1Fe-0.03P
	C50710	2Sn-0.2Ni-0.05P
Other	C15100	0.1Zr
	C15500	0.11Mg-0.06P
Fe-Ni	ASTM F30 (Alloy 42)	42Ni-58Fe
Fe-Ni-Co	ASTM F15 (Kovar)	29Ni-17Co-54Fe

1.2 Noble metal pre-plated leadframes

For electronic packages produced with leadframes, it is necessary to protect the exposed leads from oxidation and corrosion, so that the part can be soldered with high quality onto a printed wiring board (PWB). Component lead finishing is used to enhance solderability and the electrical contact, and to provide an acceptable cosmetic appearance [1].

Leadframe finishing can be accomplished by pre-encapsulation or post-encapsulation processes. The differences between those two processes are shown in Figure 1.4. In the post-encapsulation process, generally a coating of tin-lead or other tin-based alloys is applied by hot dipping or electroplating after mold compound encapsulation. Due to the up-coming European lead-free legislation, any coating material containing lead will be prohibited, with some minor exemptions [2]. As a result, pure tin coating has gained wide industry support as a lead finish, in spite of its potential for tin-whiskering [3]. In the pre-encapsulation process, metals are plated over the entire leadframe prior to die bonding, wire bonding and encapsulation. In most cases, a noble metal such as palladium and/or gold is used in pre-encapsulation plating, often over a layer of nickel.

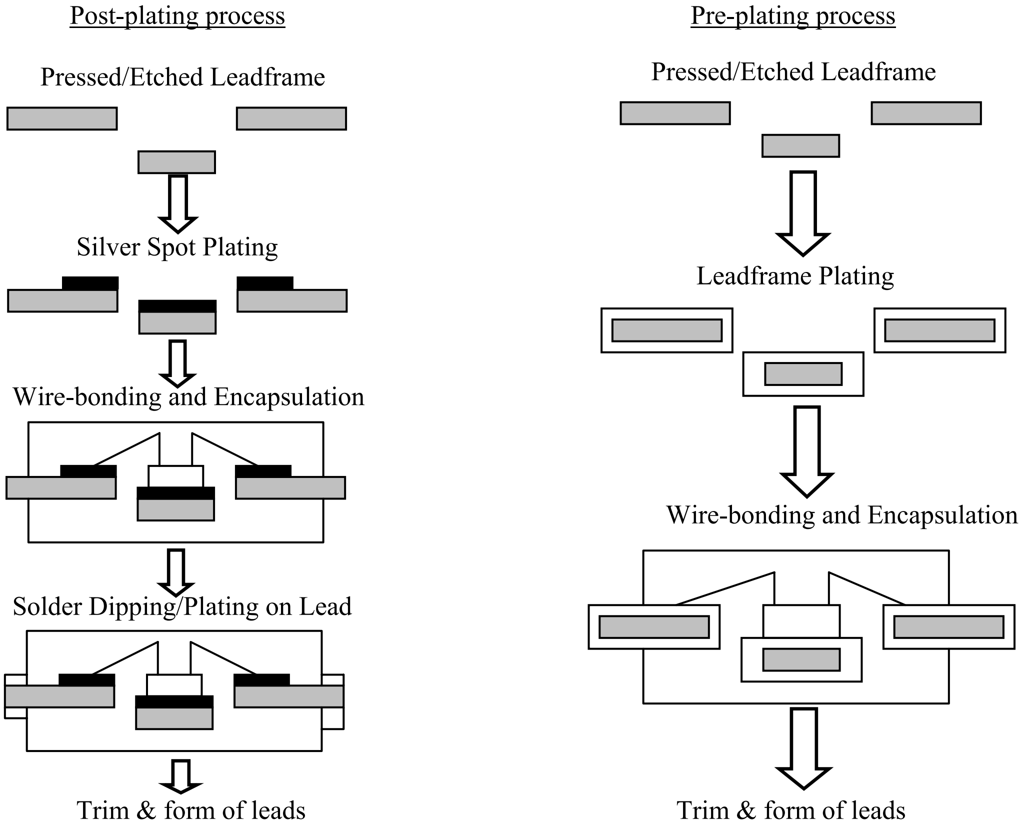
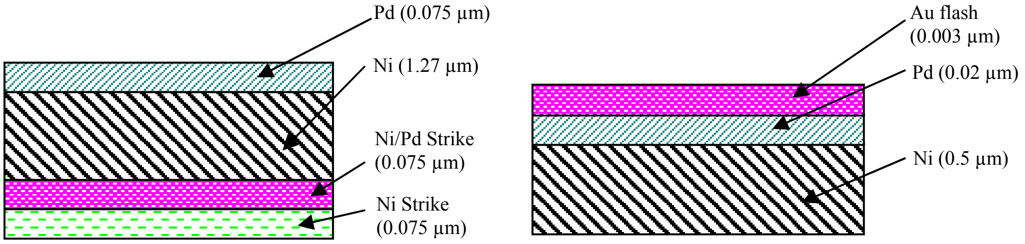


Figure 1.4 Differences between post-encapsulation and pre-encapsulation process

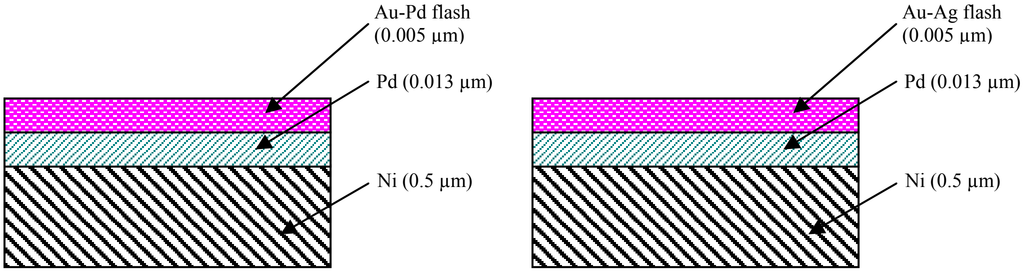
Using palladium as the plating material for electronic products was first proposed in the mid 1970's for contacts and connectors [4]. An electrolytic plating of pure palladium over nickel was found to provide corrosion resistance and wear properties similar to that of hard gold. The success of palladium-plated contacts and connectors eventually led to its consideration for replacement of solder finishing of leadframes in the semiconductor industry. Texas Instruments (TI) first introduced the palladium-over-nickel leadframe technology as a pre-encapsulation practice for their small outline, low pin-count integrated circuit (SOIC) devices in 1989 [5]. By 1999, TI reported that it had fielded more than 30 billion IC packages with this type of finish [6], including fine-pitch (0.64mm or less) high pin-out surface-mount packages.

Palladium plated leadframes (also called pre-plated leadframes) used in the pre-encapsulation process, have many advantages over conventional solder-coated leadframes [6]. The palladium pre-plated leadframe eliminates the solder coating process in manufacturing, and reduces cycle time and overall production costs in semiconductor assembly. Lead in solder dipping and cyanide in silver spot plating process are removed from the process, eliminating health and safety concerns associated with exposure to these hazardous materials in the work place and on products. Palladium pre-plate also avoids issues associated with lead and cyanide disposal. Component quality is reported to be improved due to higher IC planarity and lower solder bridging, compared to post-plated methods [7][8][9][10][11]. In addition, tin whisker doesn't occur on such components. TI qualification studies [7][8][9][10][11] have found that the palladium lead finish provides at least equivalent protection capability, solderability, and product shelf life, compared to that of the standard tin-lead solder coating. However, pre-plated leadframes' disadvantages include the high cost of noble metal and concerns with visual inspection criterion of the solder joint. According to Benedetto [12], it was suggested that palladium lead finish parts cannot be utilized as a drop-in replacement for tin-lead plated parts based on their solderability and reliability test results.



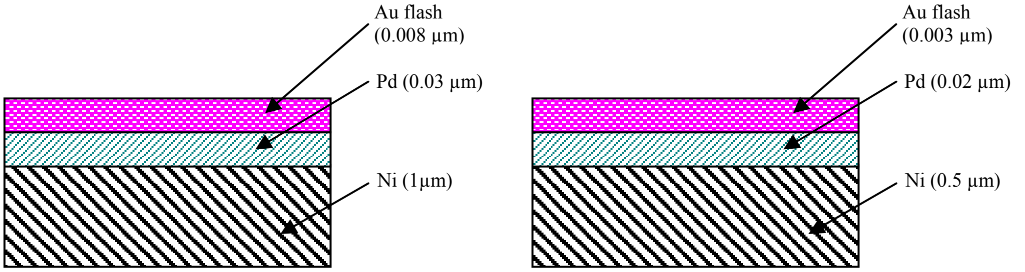
(a) TI Conventional 4-layer Ni/Pd

(b) TI 3-layer Ni/Pd/Au plating



(c) Samsung Techwin "μ-PPF"

(d) Samsung Techwin "upgrade μ-PPF"



(e) Mitsui 3-layer Ni/Pd/Au plating

(f) Shinko updated 3-layer Ni/Pd/Au plating

Figure 1.5 Plating structures and nominal thickness values for pre-plated leadframes

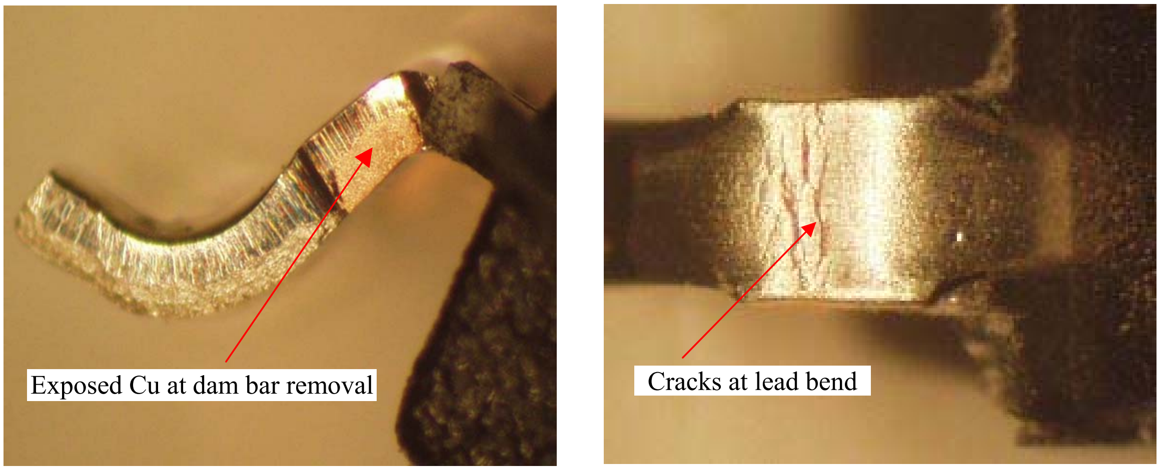
Initially, the leadframe plating was 4-layer Ni/Pd plating (Ni strike/NiPd strike/Ni/Pd) and 2-layer Ni/Pd plating [6]. Since the late 1990s, due to the increase in the price of palladium, the plating structure has been modified to include the reduction of the palladium thickness and the addition of a gold flash over the palladium. Now, TI has chosen Ni/Pd/Au finish as the preferred lead-free finish for all their leadframe-based packages [13]. Other companies also developed their own plating metallurgy and structures. Selective examples with the structure and nominal plating thickness values are shown in Figure 1.5.

1.3 Creep corrosion on PEM packages with noble metal pre-plated leadframes

Electronics usually work in atmospheric environments with many kinds of corrosive contaminants. For PEM packages with noble metal pre-plated leadframes, failures due to creep corrosion are identified and the field failure due to this failure mechanism has been located. Previous studies on the topic of creep corrosion are reviewed and a refined definition is presented.

1.3.1 Corrosion and noble metal pre-plated leadframes

In the plastic IC component packaging process, after transfer molding, dam bars connecting the adjacent leads are removed and the extended leads are bent to a pre-designed shape. This process is called “trim and form” [1]. On pre-plated leadframes, the base metal of the leadframe is exposed during the dam-bar removal. Cracks which extend to the base metal may also occur at the arc of lead bend. The dam-bar removal area and cracks at the lead bent are shown in Figure 1.6. Since the barrier layer of nickel and the noble metal plating is thin, typically less than 1μm for nickel and less than 0.05μm for noble metal plating, surface porosity is inevitable. Thus, the plating does not completely eliminate the exposure of base metal and barrier metal to the surrounding environment.



(a) (b)

Figure 1.6 Areas of exposed base metal on a SOIC package with pre-plated leadframe after “trim and form”

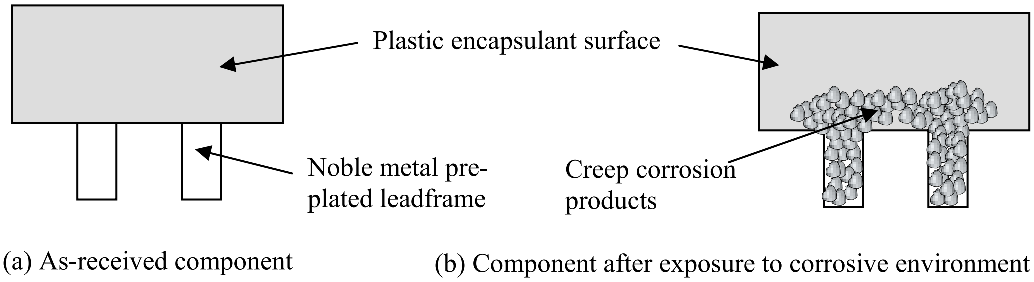
Sites of base metal exposure can corrode in pollutant environments. For noble metal plated materials, the most deleterious effect of the base metal corrosion is that the generated corrosion product may migrate over the surface of noble metal plating without attacking it [14], which is later defined as creep corrosion over the metallic surface.

1.3.2 Field failure due to corrosion products migration external to the package

In a Telecom application, field failure due to corrosion products migration external to the package was found. Figure 1.7 is a SEM picture of a field failure component [15]. This is a component with a palladium pre-plated leadframe. This photo highlights the conductive material growth onto the molding compound surface of the plastic package. The corrosion products have completely bridged the adjacent leads and have advanced over the plastic package. Electrical short and current leakages have been verified on this component.

Figure 1.7 SEM overview of a failed component with creep corrosion over package

The molding compound for IC package is the inert material, which usually does not induce direct chemical reaction with the atmospheric contaminants. For this field failure case, it is believed that the corrosion products initiate from the leadframe material, and eventually migrate onto the molding compound surface to cause the bridging of leads. This hypothesized process is illustrated in Figure 1.8. This phenomenon is similar to the effect of corrosion migration behavior on noble metal plated materials. However, the surface over this the migration occurs is not only metallic plating but also non-metallic molding compound surface. This phenomenon is defined as creep corrosion over plastic encapsulated microcircuit packages with noble metal pre-plated leadframes.



(a) As-received component (b) Component after exposure to corrosive environment

Figure 1.8 Hypothesized process for the field failure

1.4 A review of the previous work on creep corrosion and the refined definition for creep corrosion

Creep corrosion was first reported on noble metal plated metallic materials. In 1958 [14], Egan and Mendizza observed that when gold plated silver coupon was exposed to sulfur vapors, silver sulfide spread radically and rapidly on the gold surface and adhere it strongly. In 1966 [16], Antler discussed the growth pattern and morphology of sulfide tarnish films which creep across the interface between gold plat and silver or copper alloys. The test samples were exposed to the flow of H_2S and electrical properties in terms of contact resistance was evaluated. In 1978 [17], Abbott studied gold electroplates on silver, copper, and nickel substrates, and focused on the kinetics of tarnish film creep. In 1981 [18], Tierney tested gold plated copper coupon in H_2S flow, and demonstrated the protective nature of copper oxidizing layers for creep corrosion. In addition, the humidity dependence of the rate and maximum distance of the creepage have been studied. In 1982 [19], Conrad *et al.* conducted comparative studies of creep corrosion over gold, palladium, and tin-lead electroplated films exposed to H_2S flows. A combination of electrochemical and molecular mechanisms was proposed to explain why non-precious substrate corrosion products spread over precious metal coatings. In 1987 [20], Williams subjected two precious metal inlays, in combination with four kinds of base metals, to mixed flowing gas (MFG) environments. The effect of base metal on creep corrosion was evaluated and two mitigation strategies against creep corrosion were demonstrated, namely surface lubrication and shielding. In 1991 [21], Geckle and Mroczkowski made use of mixed flowing gas chamber to test noble metal plated copper coupons. Chemical composition of copper creep corrosion products was investigated and found to be a complicated mixture. In 1994 [22], Haynes and Baboian observed copper corrosion product creep on stainless steels. The creep corrosion rate for different stainless steels was defined and a mechanism of creep over stainless steel surface was described. In 2001 [23], Xie and Pecht extended the concept of creep corrosion to the electronic packages. It was exhibited that creep corrosion could pose a potential risk for the reliability of electronic components.

In general, there are limited quantities of publications primarily focused on the study of creep corrosion. Among them, the following points can be generalized:

- Creep corrosion was first reported on noble metal plated metallic surfaces.
- Creep corrosion products contain sulfides and chlorides of base metal materials.
- Base metal materials, plating materials, and environmental conditions have effects on the creep corrosion rate.
- The proposed mechanisms of creep corrosion on metallic surface usually involve the usage of galvanic corrosion theory.
- Creep corrosion poses a risk to the reliability of PEM packages with noble metal plating.

Although many researchers have conducted study for the phenomenon, a concise and accurate definition for creep corrosion is not available in the literature for a long time. In a paper by Conrad [19], the phenomenon is defined as “Corrosion products spread over the protective coating with or without attacking it”. It was wise not to specify the coating material only as metal. However, the migration effect is not necessary to occur on a coating or a protective coating surface. Later, Xie (2001) introduced the concept about the risk of creep corrosion on electronic package materials and described the phenomenon as “Creep corrosion is a physical process during which solid corrosion products migrate over a surface”. This definition does not cover the chemical aspect of the phenomenon.

In the new definition, the term of “physical process” is replaced by “mass transport process”, which emphasizes the effect of this phenomenon instead of its process or mechanism.

1.5 Scopes and objectives for this work

From the practical point of view, especially the perspective of reliability, this phenomenon of creep corrosion over plastic packages is of considerable importance. However, throughout the literature, there are few studies and findings about creep corrosion; even less for the discussion of this phenomenon over plastic surfaces. Taking consideration of all these, the scope and objectives for this work will be: to investigate creep corrosion on plastic encapsulated microcircuit packages with noble metal pre-plated leadframes; to provide a phenomenological understanding of the creep corrosion process; and to identify mitigation strategies.

2 Accelerated testing for creep corrosion on IC packages

The environments for the operation of electronics are introduced. Mixed flowing gas (MFG) environment in laboratory conditions is chosen as the accelerated testing environment to simulate the corrosion effect on electronic packages.

2.1 Atmospheric environments for electronics

Electronics usually work in indoor or sheltered outdoor environments. There is no precisely defined indoor and outdoor environmental conditions because a wide range of atmospheric variables are present because of seasonal, geographical, natural, and human influences. The concentration of indoor pollutants in a facility is a function of outdoor pollutant levels and indoor generation rates, so that the indoor values can be greater or less than the outdoor values depending on local sources and air-handling facilities. The interaction of those airborne contaminants, together with the ambient temperature and relative humidity levels contributes to the process of atmospheric corrosion.

Corrosive contaminants in the atmosphere are reactive elements in the corrosion process. Corrosive gases include CO_2, SO_2, NO_X, H_2S, Cl_2, NH_3, ozone, and mineral or organic acids [24][25]. Table 2.1 lists concentrations of selected contaminants found both in densely populated, urban, outdoor environments and in environmentally controlled indoor facilities [26].

Table 2.1 Outdoor and indoor contaminant levels for Telecom equipments

Contaminants	Concentrations (outdoor)	Concentrations (indoor)
Airborne Particles	90 μg/m3	20 μg/m3
Coarse Particles	50 μg/m3	<10 μg/m3
Fine Particles	50 μg/m3	15 μg/m3

Water Soluble Salts	30 μg/m3	10 μg/m3
Sulfate	30 μg/m3	10 μg/m3
Nitrites	12 μg/m3	5 μg/m3
Volatile Organic Compounds	1600 μg/m3	5000 μg/m3
Sulfur Dioxide	150 ppb	50 ppb
Hydrogen Sulfide	40 ppb	40 ppb
Ammonia	50 ppb	500 ppb
Oxide of Nitrogen (NO)	500 ppb	500 ppb
Oxide of Nitrogen (NO_2)	250 ppb	200 ppb
Nitric Acid (HNO_3)	50 ppb	15 ppb
Ozone	250 ppb	125 ppb
Gaseous Chlorine ($HCl + Cl_2$)	6 ppb	5 ppb

2.2 Mixed flowing gas test

Creep corrosion occurs in the atmospheric surroundings. As it has been mentioned before, atmosphere, no matter indoor or outdoor, is full of corrosive elements, such as corrosive gases and particles. In addition, the corrosion process is always a lengthy process. Usually, it has to wait for months or even years to see the effect of material degradation in field due to corrosion. In order to simulate and accelerate the corrosion effect in the laboratory environments, especially for atmospheric corrosion on electronics, the test system named mixed flowing gas (MFG) testing system has been developed since late 1980s. The mixed gas environments represent the state of the art for realistic environmental simulation in corrosion studies. In such a system, a minimum of three corrosive gases involving H_2S+NO_2+Cl_2 in various levels is used, while some methods use a four-gas combination, with the addition of SO_2. All of them operate at relative humidity levels in the range of 70-80% and temperatures in the range of 25-50 degree C.

2.2.1 Introduction to Mixed Flowing Gas Testing

Mixed Flowing Gas (MFG) test is a laboratory test in which the temperature (ºC), relative humidity (%RH), concentration of gaseous pollutants (ppb level), and other critical variables (such as volume exchange rate and airflow rate) are carefully defined, monitored and controlled [27]. The purpose of this test is to simulate corrosion phenomenon due to atmospheric exposure.

Test samples that have been exposed to MFG testing have ranged from bare metal surfaces, to electrical connectors, and to complete assemblies. In regards to noble metal plated connector applications, MFG testing has been widely accepted as a qualification test method to evaluate the corrosion resistance performance of these connectors.

Since 1970's, researchers at Battelle Labs (Columbus, OH), Telcordia (previously Bellcore), and IBM, carried out tests or published data on the use of MFG to accelerate atmospheric corrosion and its effect on electronic applications. In early 1990's, professional organizations, including American Society for Testing and Material (ASTM), Electronic Industries Association (EIA), International Electrotechnical Commission (IEC), and Telcordia, began to standardize these test methods and issued corresponding documents as test guidelines. Among them, ASTM provides the most comprehensive list of documents, covering almost every aspect to perform a well-controlled MFG testing. These documents include:

- ASTM B827-97—Standard Practice for Conducting Mixed Flowing Gas Environmental Tests
- ASTM B845-97—Standard Guide for Mixed Flowing Gas Tests for Electrical

Contacts

- ASTM B810-01a—Standard Method for Calibration of Atmospheric Corrosion Test Chambers by Change in Mass of Copper Coupons
- ASTM B825-97—Standard Test Method for Coulometric Reduction of Surface Films on Metallic Test Samples
- ASTM B826-97—Standard Test Method for Monitoring Corrosion Tests by Electrical Resistance Probes
- ASTM B808-97—Standard Test Method for Monitoring of Atmospheric Corrosion Chambers by Quartz Crystal Microbalances

The nature of ASTM is to publish voluntary consensus standards for materials, products, systems, and services. Therefore, ASTM standards are more likely a review of existing MFG practices, rather than a mandatory procedure for individual situations. ASTM B845 provided a comprehensive list of available MFG test conditions for the time being [28]. For industrial applications, Battelle Labs MFG Test Methods [29], Telcordia GR-63-CORE section 5.5 Indoor/Outdoor MFG Test Methods [26], EIA-364-TP65A [30], and IEC 68-2-60 Part 2 [31] are generally followed. To have a better understanding for those standards, it is necessary to understand the background and the industrial coverage information of the above-mentioned organizations. ASTM International, which grows from US industry, is an organization that provides a global forum for the development and publication of voluntary consensus standards for materials, products, systems, and services. The Electronic Industries Alliance (EIA) is a US national trade organization that includes the full spectrum of U.S. electronic products manufacturers. The International Electrotechnical Commission (IEC), primarily based on European electronic industry, is the international standards and conformity assessment body for all electrical, electronic and related technologies.

2.2.2 Existing MFG Testing Standards and Specifications

In this section, the existing MFG testing standards are generalized. Their detailed specifications are listed in tables as well.

Battelle Labs MFG Test Methods

The classification and parameters for the Battelle Labs MFG Test Methods are listed in Table 2.2 [29]. The operational environments for electronic equipments in atmosphere are divided into four classes, from least corrosive (Class I) to most corrosive (Class IV). Class I refers to well-controlled office environment with continuous adjustment. Class II stands for light industrial environment, such as business offices where there is no effective or continuous environment control. Class III means moderate industrial environment, such as storage areas with poor environment control. Class IV represents heavy industrial environments, such as locations adjacent to primary sources of atmospheric pollutant gases.

Since available data for Class I indicate no precedent for environmental effects on reliability, there is no accelerated testing for Class I. The other three classes use three corrosive gases, NO_2, H_2S, and Cl_2, to accelerate corrosion.

Table 2.2: MFG test methods developed by Battelle labs

Class	Temp (ºC)	RH (%)	H_2S (ppb)	Cl_2 (ppb)	NO_2 (ppb)
I	----	----	----	----	----
II	30±2	70±2	10+0/-4	10+0/-2	200±25
III	30±2	75±2	100±10	20±5	200±25
IV	50±2	75±2	200±10	50±5	200±25

Telcordia MFG Test Methods: Telcordia GR-63-CORE Section 5.5

Telcordia, previously known as Bellcore, is a center for technological expertise and innovation that provides the driving force for standardization within the telecommunication industry. Based on this nature, the MFG test methods developed by Telcordia primarily focus on electronic equipment in Telecommunication applications. Since these kinds of equipments may operate inside or outside the room, two MFG test conditions are available from Telcordia, which are known as indoor and outdoor. The parameters for these two methods are listed in Table 2.3 [26]. Compared with Battelle MFG test methods, the major difference is that a fourth corrosive gas of SO_2 is included.

Table 2.3 MFG test methods developed by Telcordia

Conditions	Temp (ºC)	RH (%)	H_2S (ppb)	Cl_2 (ppb)	NO_2 (ppb)	SO_2 (ppb)
Indoor	30±1	70±2	10±1.5	10±1.5	200±30	100±15
Outdoor	30±1	70±2	100±15	20±3	200±30	200±30

EIA MFG Test Methods: EIA-364-TP65A

EIA published its own specifications for MFG testing as seen in Table 2.4 [30]. Class II, III and IV parameters come directly from Battelle research. Class IIA and IIIA are essentially the same conditions as Telcordia Indoor and Outdoor MFG test methods.

Table 2.4: MFG test methods developed by EIA

Class	Temp (ºC)	RH (%)	H_2S (ppb)	Cl_2 (ppb)	NO_2 (ppb)	SO_2 (ppb)
I	----	----	----	----	----	----
II	30±2	70±2	10±5	10±3	200±50	----
IIA	30±1	70±2	10±5	10±3	200±50	100±20
III	30±2	75±2	100±20	20±5	200±50	----
IIIA	30±1	70±2	100±20	20±5	200±50	200±50
IV	40±2	75±2	200±20	30±5	200±50	----

IEC MFG Test Methods: IEC 68-2-60 Part 2

Table 2.5 shows the parameters for MFG testing from IEC [31]. Test method 1 is for testing of with gold-plated contacts to be used in mild environments. Methods 2 and 4 are appropriate for electronic products to be used in moderate corrosive environments. Such environments may be found in telecommunication centers, most office environments and some industrial instrument rooms. Test method 3 is appropriate for more corrosive environments.

Table 2.5: MFG test methods developed by IEC

Methods	Temp (ºC)	RH (%)	H_2S (ppb)	Cl_2 (ppb)	NO_2 (ppb)	SO_2 (ppb)
1	25±1	75±3	100±20	----	----	500±100
2	30±1	70±3	10±5	10±5	200±50	----
3	30±1	75±3	100±20	20±5	200±50	----
4	25±1	75±3	10±5	10±5	200±20	200±20

IBM MFG Test Methods: G1 (T)

IBM has worked on accelerated corrosive gas testing extensively since the late 1960's. They classified the working conditions for electrical equipments into three classes, which are G1 (business office), G2 (industrial) and G3 (harsh industrial). In order to simulate the accelerated corrosive effect of equipment in G1 environment, IBM designed and verified the G1 (T) MFG test environment, where they used four corrosive gases. Unlike other test methods, IBM's recommended gas concentrations, see Table 2.6 [32], are very different from those from Battelle MFG testing. According to the literature, the IBM MFG test method does not gain much popularity in the industry. In the last 10 years, almost no paper is available concerning or citing the application of IBM G1(T) method.

Table 2.6: G1(T) MFG Test Method Developed by IBM

Temp (ºC)	RH (%)	H_2S (ppb)	Cl_2 (ppb)	NO_2 (ppb)	SO_2 (ppb)
30±0.5	70±2	40±5%	3±15%	610±5%	350±5%

2.2.3 Selected test conditions for this study and test facility

According to the section above, three most popular MFG test conditions are chosen for this study, which are Telcordia Indoor MFG environment, Telcordia Outdoor MFG environment, and Battelle Class III environment, listed in Table 2.7. The test facility is shown in Figure 2.1, while its schematic diagram is shown in Figure 2.2.

Figure 2.1: MFG Chamber Located in CALCE Center at the University of Maryland

Table 2.7 Selected test conditions for this study

Conditions	T (ºC)	RH (%)	H_2S (ppb)	Cl_2 (ppb)	NO_2 (ppb)	SO_2 (ppb)

Telcordia Indoor	30±1	70±2	10±1.5	10±1.5	200±30	100±15
Telcordia Outdoor	30±1	70±2	100±15	20±3	200±30	200±30
Battelle Class III	30±2	75±2	100±10	20±5	200±25	---

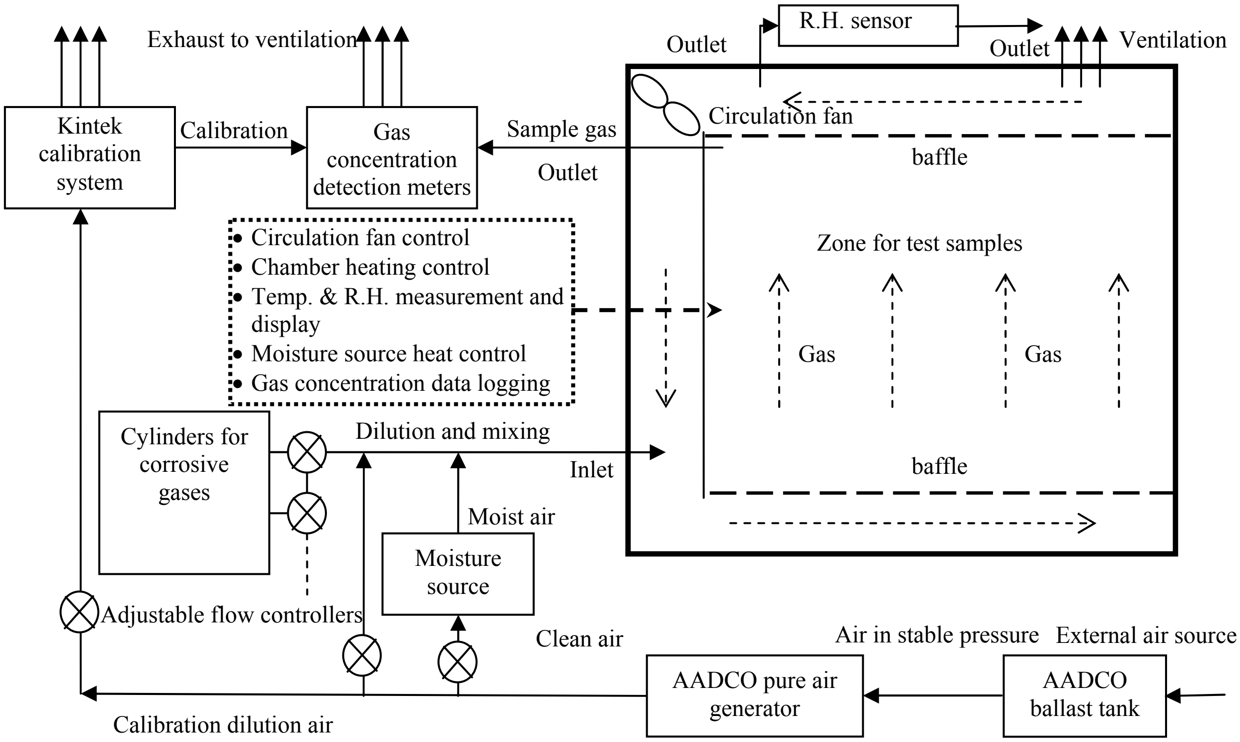


Figure 2.2 Schematic diagram of CALCE MFG test system

2.3 Test samples and set-up

A range of components with pre-plated leadframes having different package types, plating structures, encapsulant materials, and base metals were tested. Noble metal pre-plated coupons were tested as well. Tin-lead coated samples were tested at the same time for comparison purposes. Table 2.8 lists the types of samples used in this study with respect to different test conditions. For component type samples, unless specially pointed out, they all have noble metal pre-plated leadframes. The exact number of samples for each test run will be provided in the next chapter along with the interpretation of the test results.

Table 2.8 Test samples investigated in this study

Sample Types	A	B	C
Un-mounted components from TI	√	√	√
Un-mounted dummy QFPs from Motorola	√	√	√
Dummy components from Topline (to apply with/without bias)	√	√	√
TI components mounted on TI boards		√	
Components from various vendors mounted on Telcordia boards		√	
Plated Cu coupons from TI and Telcordia		√	
Plated Cu or Alloy42 coupons from Samsung Techwin	√	√	√
Components in strips with Shinko or Mitsui leadframes	√	√	√
Bare leadframes in strips with Shinko or Mitsui leadframe	√	√	√
Un-mounted components provided by Philips			√
Un-mounted and mounted components from Samsung Techwin			√
SnPb dipped and electro-plated components	√	√	√

Notes: A – Telcordia Indoor, B – Telcordia Outdoor, C – Battelle Class III

The MFG test process follows the guidelines provided by ASTM B827 [27]. As for the set-up of test samples inside the MFG chamber, for most cases, epoxy thin thread was used to tie the samples with the wood rode, then the wood rode was placed on the stainless steel racks inside the chamber. In this way, the flow of the gas mixtures inside the chamber would not be restricted and shielding effect was minimized. Figure 2.3 shows a typical set-up of test samples for a MFG test during this study.

Figure 2.3 Test samples set-up for a MFG test during the study

3 Results and interpretation for standardized MFG tests

In this chapter, results from various MFG tests are presented and explanations are provided to interpret the data.

3.1 Telcordia Outdoor MFG tests

Test conditions for Telcordia Outdoor MFG environments are listed in Table 3.1. Three test runs were conducted following the conditions.

Table 3.1 Test conditions for Telcordia Outdoor MFG environment

Conditions	T (ºC)	RH (%)	H_2S (ppb)	Cl_2 (ppb)	NO_2 (ppb)	SO_2 (ppb)
Telcordia Outdoor	30±1	70±2	100±15	20±3	200±30	200±30

3.1.1 Test 1

The first test run tested one type of component in un-mounted conditions [33]. Information about the test samples is listed in Table 3.2. During the test, one sample was removed after 8, 16, 24, 32, 64, 96, 112, 120, and 240 hours of exposure and was not put back. Visual inspection with the aid of optical microscopy was applied to identify the creep corrosion on the package and micrograph was taken to document the corrosion sites.

Table 3.2 Information on samples used for Telcordia Outdoor MFG test 1

Part No.	Package	Pins	Pitch (mm)	Plating	Pre-treatment	Resin	Base metal	Sample size
TI CD4001BM	SOIC	14	1.27	Ni/Pd/Au	No	Cresol Novolac Epoxy	Cu alloy	9

It was observed that after 64 hours of MFG exposure, creep corrosion products was found over mold compound, see Figure 3.1. As the exposure time increased, creep corrosion products were expanding in coverage on the surface of molding compound. After 240 hours of exposure, many leads of the test samples had corrosion products migrated onto the vicinity area of the molding compound surface near the lead. Some lead pairs were visibly bridged by the corrosion products, see Figure 3.2.

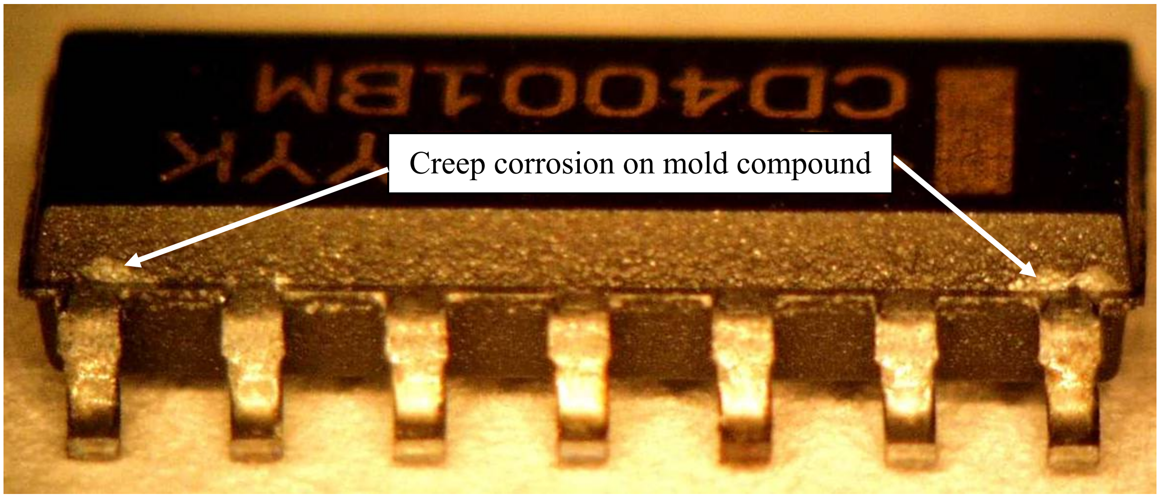


Figure 3.1 Creep corrosion over mold compound after 64 hours of Telcordia Outdoor MFG exposure

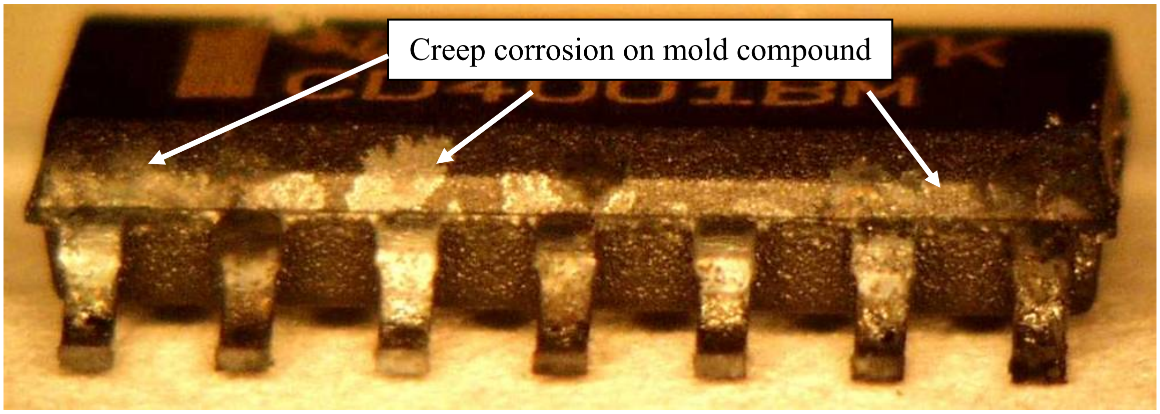


Figure 3.2 Creep corrosion over mold compound after 240 hours of Telcordia Outdoor MFG exposure

This test confirmed that creep corrosion can be reproduced in the similar effect as the field failure via the approach of MFG testing in laboratory conditions.

3.1.2 Test 2

Test samples for this test run can be divided into three groups. Group 1 were printed circuits boards populated with plastic encapsulated components. Group 2 included 8 kinds of loose components, among which various packaging styles and plating materials are intentionally selected for the test. Group 3 consisted of test coupons, whose base metal was copper and all of which are plated with various metals, including both non-noble and noble materials. The test exposure lasted for 15 days.

Test boards and their results

The first group included 4 PCB boards, 2 from Texas Instruments and the other 2 from Telcordia. On each of the TI board, there were totally 32 surface mount dummy components, single-side mounted and having 6 distinct types. Two kinds of plating structure were available on the board, both four-layer Ni/Ni-Pd/Ni/Pd plating and Ni/Pd/Au plating. The number of leads on each component was either 16 or 20, and their pitch was uniform as 1.27mm. All those components were produced by Texas Instruments. The overview of the test board is shown in Figure 3.3 with component-mounted side. The schematic diagram about the location of test samples is shown in Figure 3.4, in which capitalized letters stand for components with Ni/Ni-Pd/Ni/Pd pre-plated leadframes and letters in lowercase represent components with Ni/Pd/Au pre-plated leadframes.

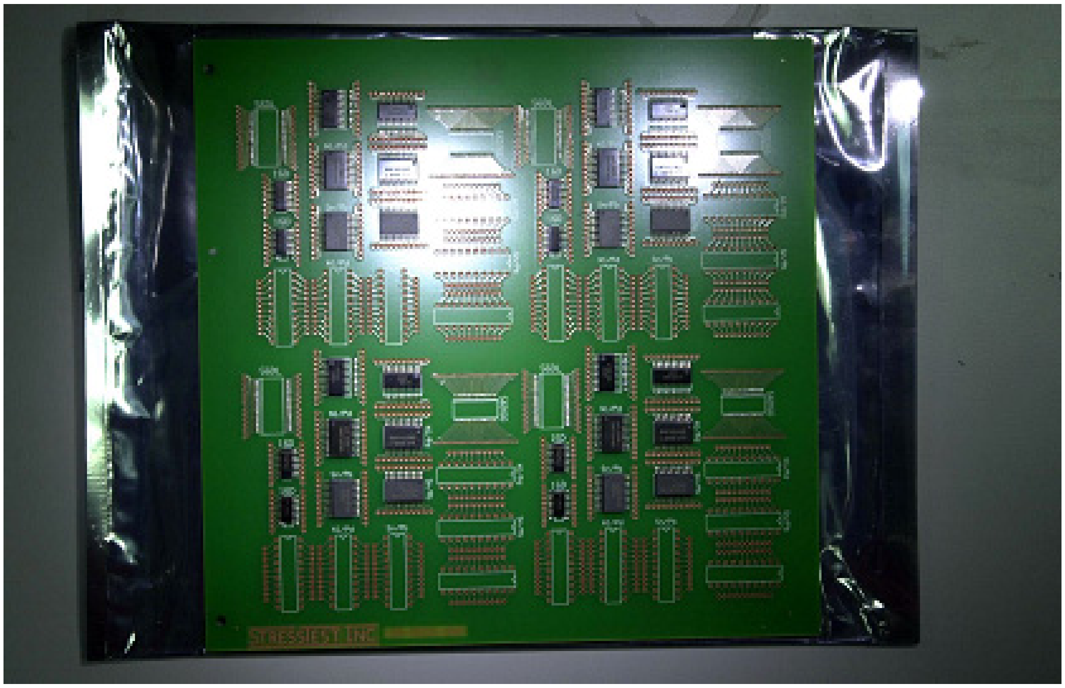


Figure 3.3 Test board with mounted components from Texas Instruments

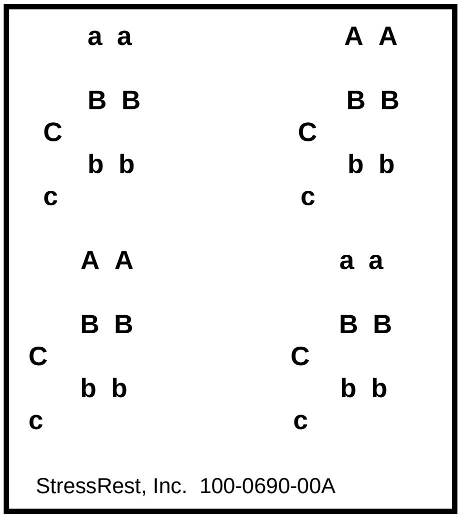


Figure 3.4 Schematic diagram for component locations on TI board

Telcordia board is shown in Figure 3.5. On each board, there were totally 53 surface mount components, single side mounted onto the board. The packaging style included SOIC, J-lead, and QFP, and their pitches were different from each other. Components mounted on the board came from various manufacturers, including TI, Motorola, Philips, Fairchild, etc. All TI components had noble metal pre-plated leadframes.

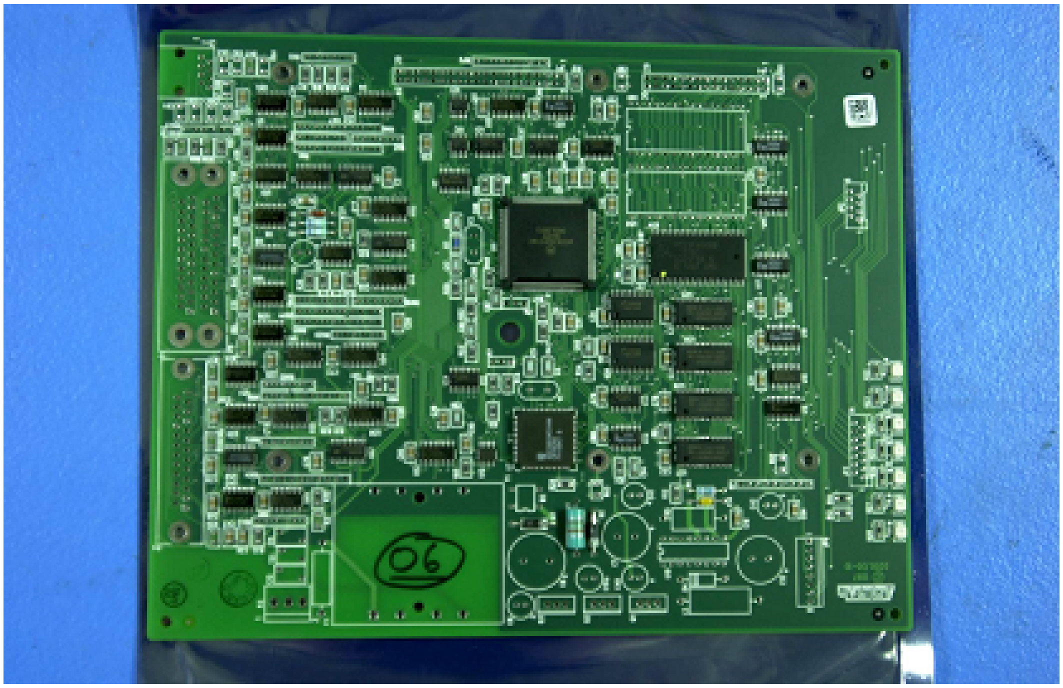


Figure 3.5: Test board with mounted components from Telcordia

On TI boards, after 10-day test, creep corrosion over mold compound was observed on almost all components (see an example in Figure 3.6). On TI board I, 25 out of 32 components had electrical short, while on TI board II, 18 out of 32 components had electrical short. Using a multi-meter, the resistance between the bridged lead pairs ranged from 5MΩ to 15MΩ. On the TI boards, there were two kinds of leadframe plating structures, Ni/Pd and Ni/Pd/Au plating. However, no significant difference in corrosion behavior was found over those two groups of components (see Figure 3.7).

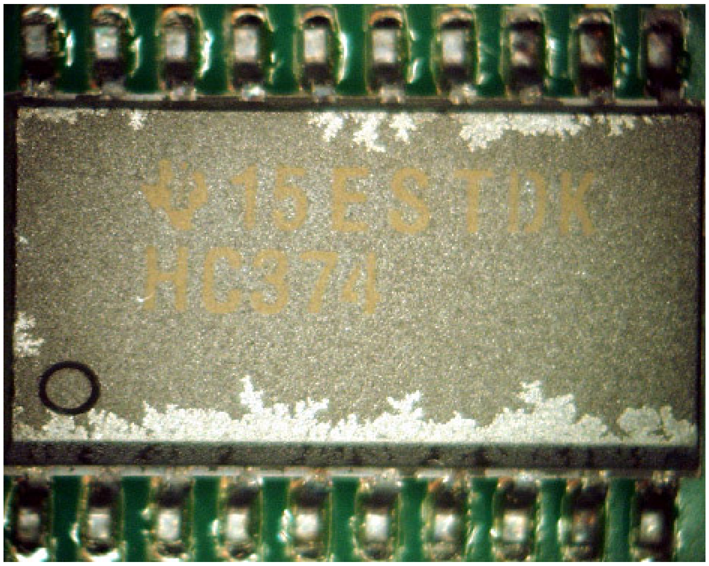
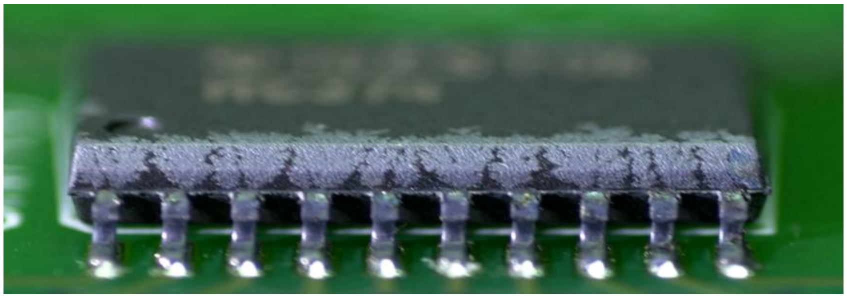
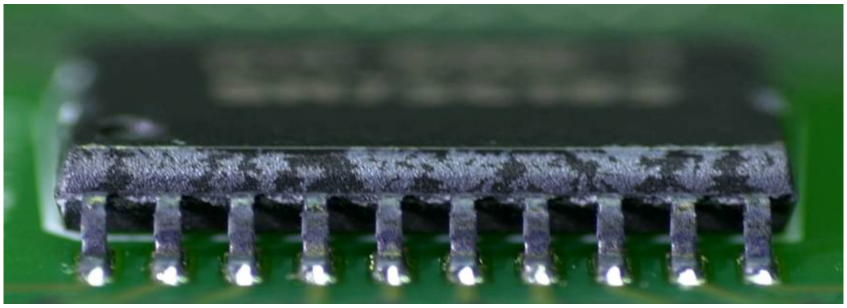


Figure 3.6 Mounted components on TI board with creep corrosion over mold compound



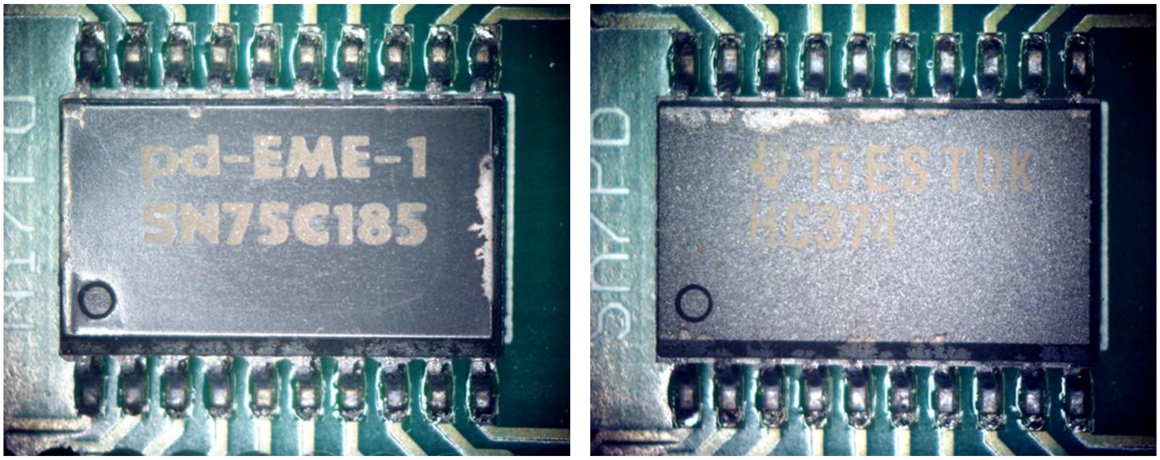
(a) Ni/Pd/Au pre-plated components after the 10-day Telcordia Outdoor MFG test



(b) 4-layer Ni/Pd pre-plated components after the 10-day Telcordia Outdoor MFG test

Figure 3.7 Creep corrosion over components with different platings on TI boards

Because creep corrosion occurred on the surface of mold compound, surface roughness was suspected to have the effect on this phenomenon. However, on two types of components with different surface roughness values (RMS at 0.4 microns and 1.0 microns respectively), no significant difference on creep corrosion behavior was found after the 10-day test, see Figure 3.8.



(a) TI SOIC with RMS about 0.4 μ m

(b) TI SOIC with RMS about 1.0 μ m

Figure 3.8 Creep corrosion on components with different surface roughness values

On Telcordia test boards, all TI components were found with creep corrosion over mold compound. One example of creep corrosion on TI component is shown in Figure 3.9. On board I, 6 out of 8 TI components had lead pairs bridged by creep corrosion products; while on board II, 7 out of 8.

Figure 3.9 Creep corrosion on TI component over Telcordia board after 10-day test

Un-mounted test components and their results

Un-mounted components were selected for simulation of components in storage and for comparison to assembled components. For components with noble metal pre-plated leadframes, altogether 6 kinds of components were chosen, 5 of which came from Texas Instruments and the last one came from Motorola. For comparison purposes, components with tin-lead dipped and electroplated leads were tested as well. The detailed information about those test components is listed in Table 3.3.

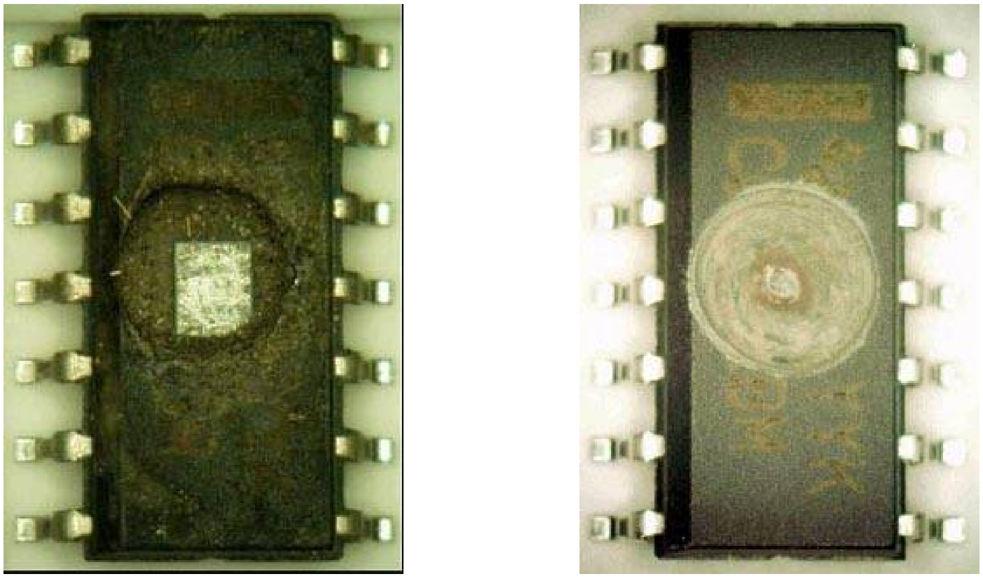
Table 3.3 Un-mounted test components for Telcordia Outdoor MFG test 2

Part No./Description	Package	Pins	Pitch (mm)	Plating	Resin	Base metal	Sample conditioning	Sample size
TI CD4001BM	SOIC	14	1.27	Ni/Pd/Au	Cresol Novolac Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received	7
							Ultrasonically cleaned	7
							Mechanically decapsulated	6
							Chemically decapsulated	9
TI SN74TVC3010DGVR	TVSOP	24	0.4	Ni/Pd/Au	Cresol Novolac Epoxy and Biphenyl Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received	3
							Ultrasonically cleaned	3
TI SN74TVC3010DBQR	SSOP	24	0.64	Ni/Pd/Au	Cresol Novolac Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received	3
							Ultrasonically cleaned	3
TI SN74LV4066AN	DIP	14	2.54	Ni/Pd/Au	Cresol Novolac Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received	3
							Ultrasonically cleaned	3
TI CD4001BE	DIP	14	2.54	Ni/Pd/Au	Cresol Novolac Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received	3
							Ultrasonically cleaned	3
Motorola A441YP04AA (dummy sample)	QFP	144	0.5	Ni/Pd		Cu alloy	As-received	2
							Ultrasonically cleaned	2

Conventional packages	DIP	14	2.54	SnPb plating		Cu alloy	As-received	3
							Ultrasonically cleaned	3
Conventional packages	DIP	14	2.54	SnPb dipped		Cu Alloy	As-received	3
							Ultrasonically cleaned	3

For some of the un-mounted components in test, two kinds of pre-conditioning methods were applied, namely decapsulation and cleaning. Decapsulation was the method to create dummy components facilitating the insulation resistance measurement. Cleaning was for the evaluation of component surface residue contaminants' effect on creep corrosion.

Two decapsulation methods were applied, which were chemical decapsulation and mechanical decapsulation. Chemical decapsulation used fuming acid to etch away the mold compound over the die area of the package. Then, the bonding wires were broken to cut off the electrical connection through the die. For mechanical decapsulation, a small drilling device was used to drill away the molding compound over the die. During this process, the bonding wires were mechanically damaged to isolate leads from each other. In all decapsulated components, half of them were chemically decapsulated and the other half mechanically decapsulated. The effects of these two methods were monitored and then one of them would be recommended for future tests. Figure 3.10 shows the chemically decapsulated sample and mechanically decapsualted sample respectively.



(a) Component after chemical decapsulation (b) Component after chemical decapsulation

Figure 3.10 Components after chemical decapsulation and mechanical decapsulation

In the lab, the Cole-Parmer 8890 ultrasonic cleaner was used to clean some of the test samples. The components to be cleaned were placed in the glass beaker filled with de-ionized water, and then kept the beaker in ultrasonic cleaner rinsing for 10 minutes. When samples were removed from the beaker, they were dried in ambient environments. After the cleaning procedures, the samples were stored in a vacuum desiccator until the start of MFG exposure.

After the 10-day test, components with creep corrosion products over the package were found on almost all un-mounted components with noble metal pre-plated leadframes. Figure 3.11 shows creep corrosion on an un-mounted component. No evidence was found for the dependence of creep corrosion behavior on the package styles. Surface cleaning of samples was not found to have significant influence on creep corrosion over the encapsulant surface, see Figure 3.12.

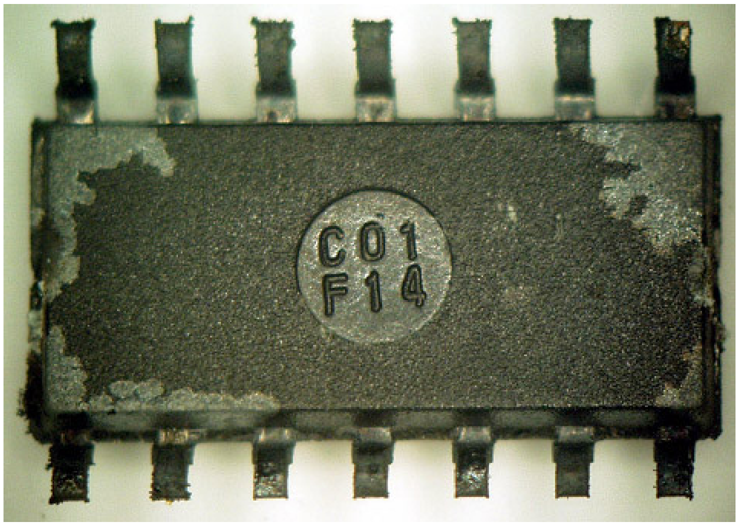
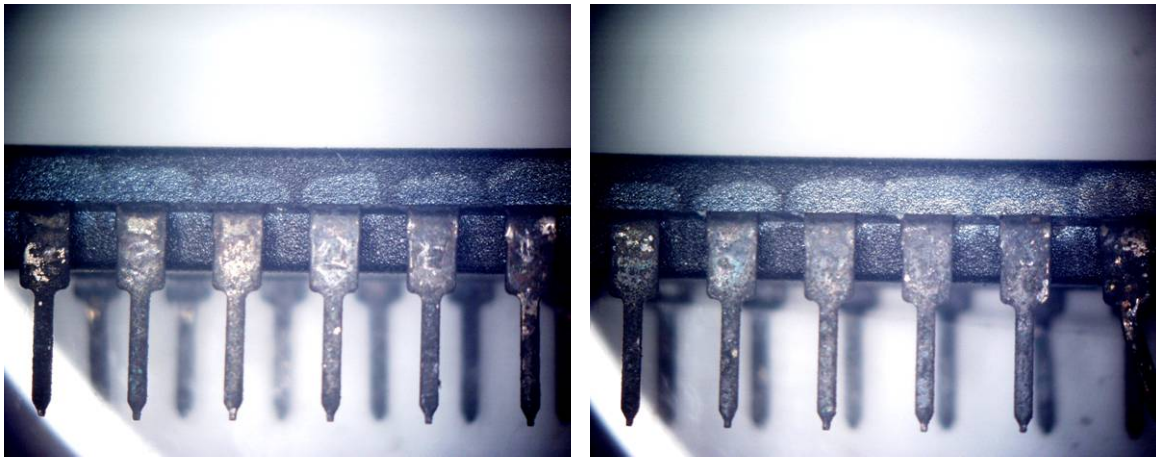


Figure 3.11 Creep corrosion on un-mounted TI SOIC in as-received conditions



(a) TI DIP without surface cleaning

(b) TI DIP with surface cleaning

Figure 3.12 Creep corrosion on TI DIP with and without surface cleaning

Chemical decapsulation was found to increase the severity of the migration of corrosion products. This may results from the surface damage and excessive chemical contamination caused by fuming acid in chemical decapsulation. On decapsulated components with creep corrosion bridged lead pairs, insulation resistance between adjacent leads decreased down to the range of 8MΩ to 20MΩ.

The components with tin-lead coated leads for comparison purposes were not found with creep corrosion on mold compound, which showed that solder coated leads were resistant to creep corrosion phenomenon.

Plated coupons and their results

Test coupons were used to monitor and to compare corrosion behaviors on various plating structure and plating materials.

Texas Instruments provided the group of test coupons. There were a total of 6 kinds of test coupons with various plating materials and plating structures. The base metal for all the test coupons was CDA194 alloy. Table 3.4 lists the details about coupon plating material structures and nominal plating thickness for each layer. In fact, all coupons containing Pd plating layers had the same or similar plating structure and thickness as the lead frame applications. During the test, test coupons were divided into two groups. Each group stayed in the chamber for 5 days.

Table 3.4 List of test coupons from Texas Instruments

Plating structure	Nominal plating thickness (μm)	Sample size
Ni/Au	1.27/0.75	4
Ni	1.02	2
Ni/Pd/Au	0.5/0.02/0.003	2
Ni/Ni-Pd/Ni/Pd/Au	Flash/flash/1.02/0.075/0.003	2
Ni/Pd	1.27/0.075	2
Ni/Ni-Pd/Ni/Pd	Flash/flash/1.02/0.075	2

On Ni/Au plated coupons, apparent pore corrosion effect was found, see Figure 3.13. Creep corrosion effect was found on Ni/Au plated coupons from cutting edges of the coupon, where base metal was exposed, see Figure 3.14. On Ni plated coupons, gross corrosion effect was observed. On Ni/Ni-Pd/Ni/Pd/Au plated coupons, creep corrosion effect was observed starting from the cutting edges and introduced centerline scratches, see Figure 3.15. On all other coupons, gross attach of corrosion was found on the majority area of the coupon surface, while slight creep corrosion effect was sometimes found near the cutting edges.

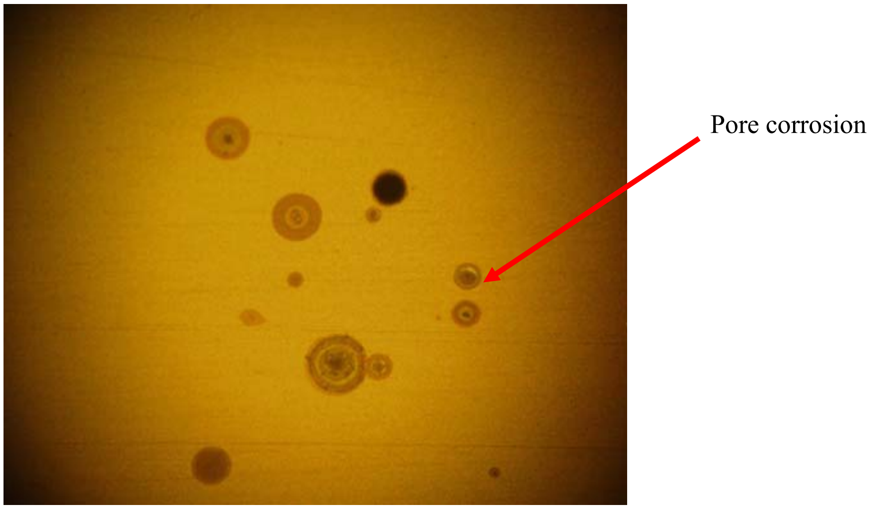


Figure 3.13 Pore corrosion on Ni/Au plated coupon after 5-day Telcordia Outdoor MFG exposure

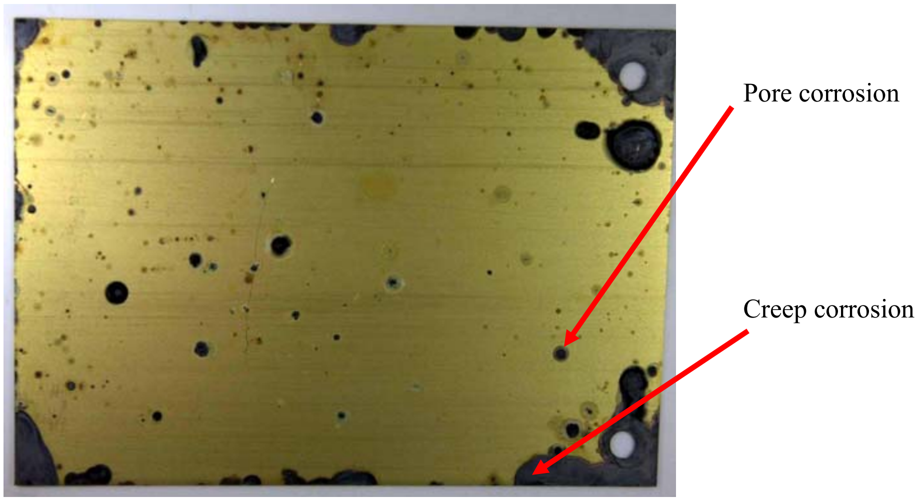


Figure 3.14 Pore corrosion and creep corrosion effect on the Ni/Au plated coupon after 5-day Telcordia Outdoor MFG exposure

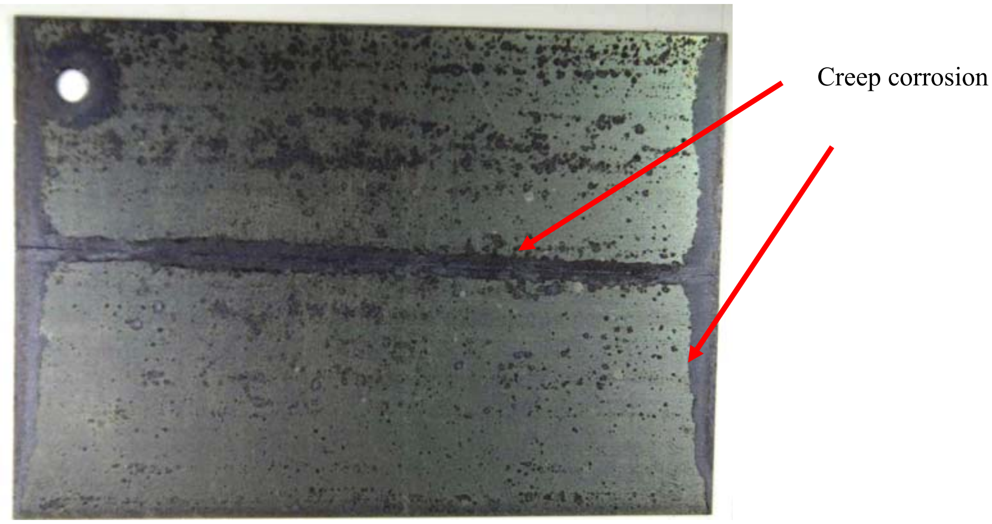


Figure 3.15 Creep corrosion effect on the Au/Pd/Ni/Ni-Pd/Ni plated test coupon

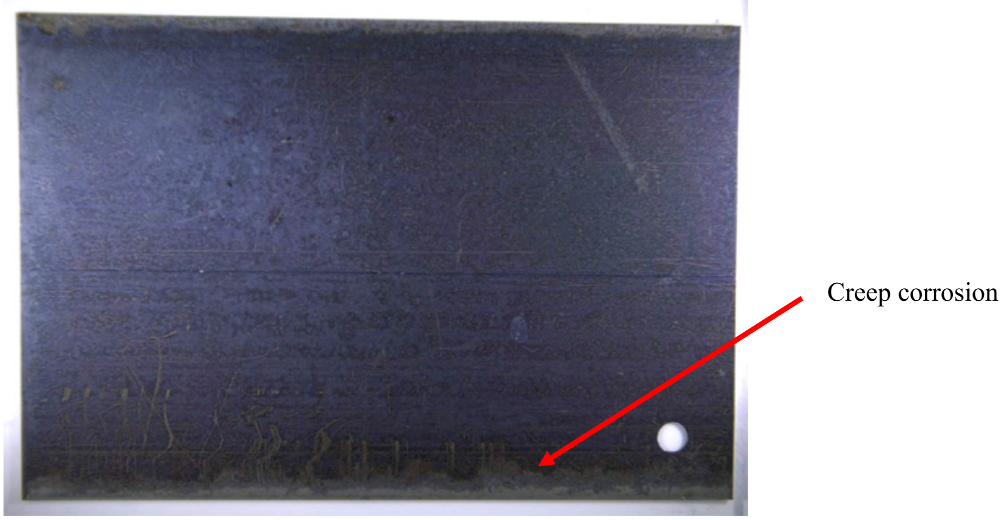


Figure 3.16 Gross corrosion and creep corrosion effect on the Ni/Ni-Pd/Ni/Pd plated test coupon after 10-day Telcordia Outdoor MFG test

It is appeared that pore corrosion and creep corrosion are competitive processes on the noble metal plated coupons. If the noble plating is relatively thick, like the Ni/Au plated coupons, majority of the plating surface is well protected by noble metal except the cutting edges and some scattered pores. When those openings provide path for environmental contaminants to react with the base metal, corrosion products grow from there and migrate over the Au surface, which creates the effect of pore corrosion and creep corrosion. However, for most other noble metal plated coupons, since noble metal plating is thin, numerous mini-pores would expose enough base metal material for corrosion attack. When corrosion products move out of their initiation sites, not much clean noble plating surface is available for migration. Therefore, slight indication of creep corrosion or no apparent creep corrosion effect was observed on them.

This test displayed that Telcordia Outdoor MFG environment is an effective environmental to reproduce creep corrosion over PEM packages with noble metal pre-plated leadframes. Package style and mounting configuration (un-mounted versus printed circuit board mounted), noble metal pre-plating structure, surface roughness, and component ultrasonic cleaning, were found to have no significant influence on the occurrence and progression of creep corrosion over the encapsulant surface. Since chemical decapsulation brings excessive contamination to the test samples, mechanical decapsulation or the use of dummy samples are recommended in the future tests to create electrically isolated lead pairs on the test sample.

For noble metal plated copper coupons, both pore corrosion and creep corrosion may occur. However, for coupons with comparable plating structure and thickness with leadframe applications, no apparent pore corrosion and creep corrosion effect was observed.

3.1.3 Test 3

Test samples for this test run can be divided into three groups. Group 1 included

10 kinds of un-mounted components, with or without pre-conditioning. Group 2 were leadframe strips with or without mold compound. Group 3 consisted of coupons with plating. Duration for this test exposure was 15 days.

<u>Un-mounted test components and their results</u>

For components with noble metal pre-plated leadframes, a total of 10 types of components were chosen. Among them, 6 came from Texas Instruments, one from Motorola, one from Topline, all of which had noble metal pre-plated leadframes. The other two types of components were packages with tin-lead dipped and electroplated leads. Details for those test samples are listed in Table 3.5. During the test, all components were taken out of MFG chamber for visual inspection after 5-day exposure, and then were put back into the chamber. After 10-day exposure, all test samples were taken out of MFG chamber for the visual inspection. One sample for each type was withheld and all the rest samples were returned back into the chamber. After 15-day exposure, the test was terminated.

Table 3.5 Un-mounted test samples for Telcordia Outdoor MFG test 3

Part No./Description	Package	Pins	Pitch (mm)	Plating	Resin	Base metal	Sample conditioning	Sample size
TI CD4001BE	DIP	14	2.54	Ni/Pd/Au	Cresol Novolac Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received	5
							Coarse surface	3
							Smooth surface	3
TI CD4001BM	SOIC	14	1.27	Ni/Pd/Au	Cresol Novolac Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received	5
TI CD4001BPWR	SOP	14	0.64	Ni/Pd/Au	Cresol Novolac Epoxy and Biphenyl Epoxy	Cu-Fe-P	As-received	5
TI	TQFP	64	0.50	Ni/Pd	Cresol	Cu-	As-received	5

							Coarse surface	3
							Smooth surface	3
TI SN74GTLP1395DGVR	TVSOP	20	0.40	Ni/Pd	Cresol Novolac Epoxy and Biphenyl Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received	5
TI SN74ABTE16245DGGR	TSSOP	48	0.50	Ni/Pd	Cresol Novolac Epoxy and Biphenyl Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received	5
							Coarse surface	3
							Smooth surface	3
Motorola A441YP04AA (dummy sample)	QFP	144	0.5	Ni/Pd		Cu alloy	As-received	1
							Coarse surface	1
							Smooth surface	1
Dummy samples bought from Topline	SIP	15	2.54	Ni/Pd/Au			As-received	2
							Biased at 5, 10, 15, 20v	2
Conventional packages	DIP	14	2.54	SnPb plating		Cu alloy	As-received	3
Conventional packages	DIP	14	2.54	SnPb dipping		Cu Alloy	As-received	3

Two kinds of pre-conditioning methods were applied for part of the test samples, namely surface roughness change on mold compound surface and applying electrical bias between adjacent lead pairs.

Because mold compound surface is the media over which the migration of corrosion products occurs, there is a belief that surface roughness of the mold compound surface may be a dominant factor to determine the migration speed and coverage. For TI samples in this test, the RMS surface roughness values were measured prior test on as-received components, see Figure 3.17.

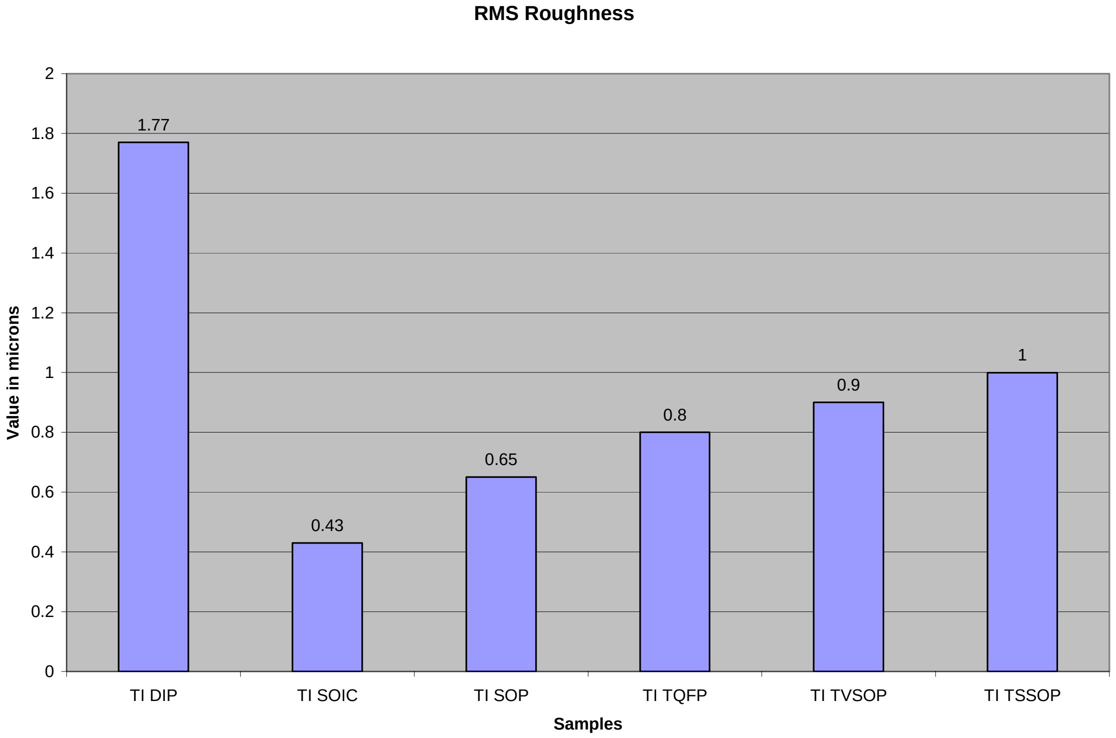
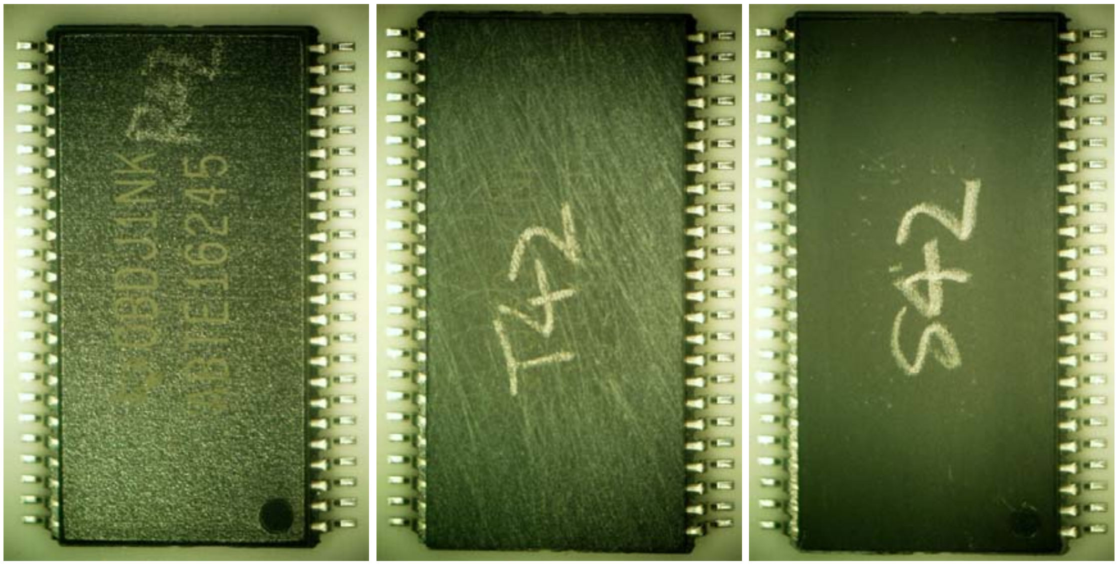


Figure 3.17 Surface roughness (RMS) values for TI un-mounted samples in Telcordia Outdoor test 3

From Figure 3.17, it was noticed that the surface roughness values were not dramatically different. To manually create the molding surface with different surface roughness values, sanding paper was used. Sanding paper for cross sectioning was used to change the surface roughness of the molding compound. 120-grit sand paper was used to make a rough surface on molding compound on top of package. 1200-grit sand paper was used to make a smooth surface on molding compound on top of package. Using a KLA Tencor Alpha-Step 500 surface profilometer, the surface roughness of RMS value for rough surface was found to be close to 2 μm, while for smooth surface around 0.3 μm. Figure 3.18 shows the photo of three TI TSSOP components with different surface roughness.



(a) As-received (b) Smooth surface (c) Coarse surface

Figure 3.18 TI SOP components with different molding compound surface roughness

Since creep corrosion products over the mold compound surface had the dendritic formation, which was similar to the dendritic formation in electro-chemical corrosion process [34], it was suspected that electrical bias may play a roll in this process. To evaluate this effect, electrical bias was applied on the components lead pairs during the MFG test. Based on the information found in Telcordia Outdoor MFG test 2, dummy samples should be the best choice for this purpose. 15-pin single-inline-packages (SIP) with Ni/Pd/Au pre-plated leadframes were purchased from Topline, in which no functional die existed and some lead pairs were internally connected by wire-bonding and others intentionally left electrically-open. The diagram to apply voltage bias to the package is shown in Figure 3.19. Voltage biases at 5, 10, 15, and 20v were applied to the specific lead pairs.

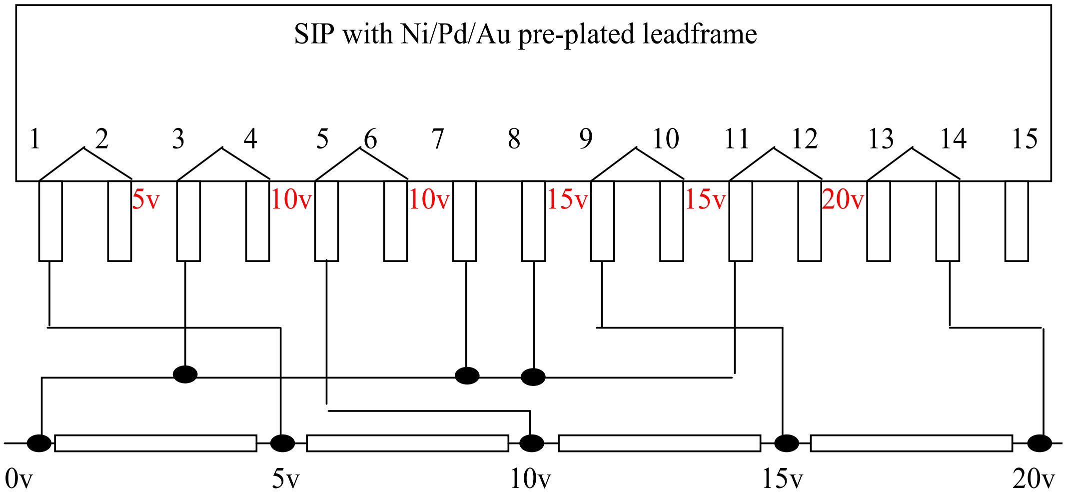
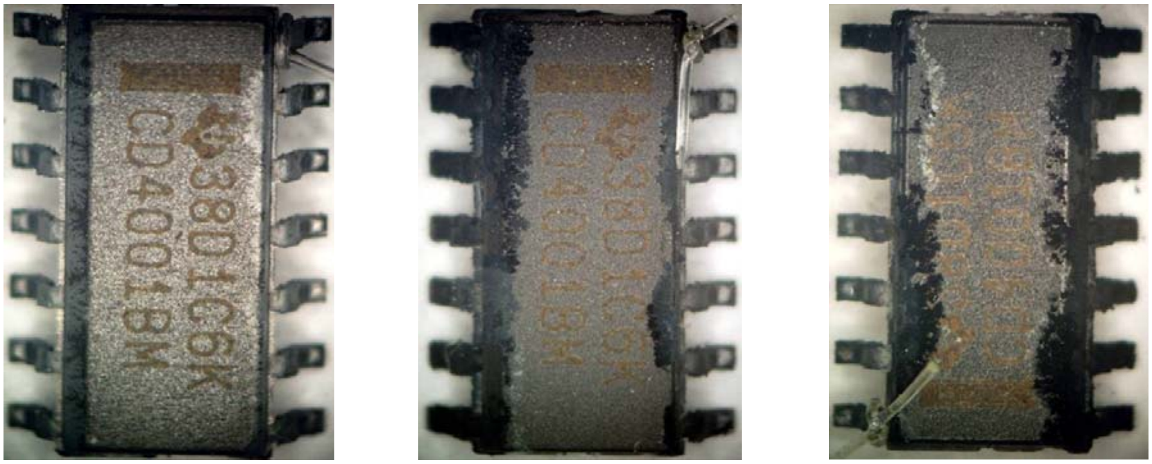


Figure 3.19 Diagram to apply electrical bias to SIP with Ni/Pd/Au pre-plated leadframe

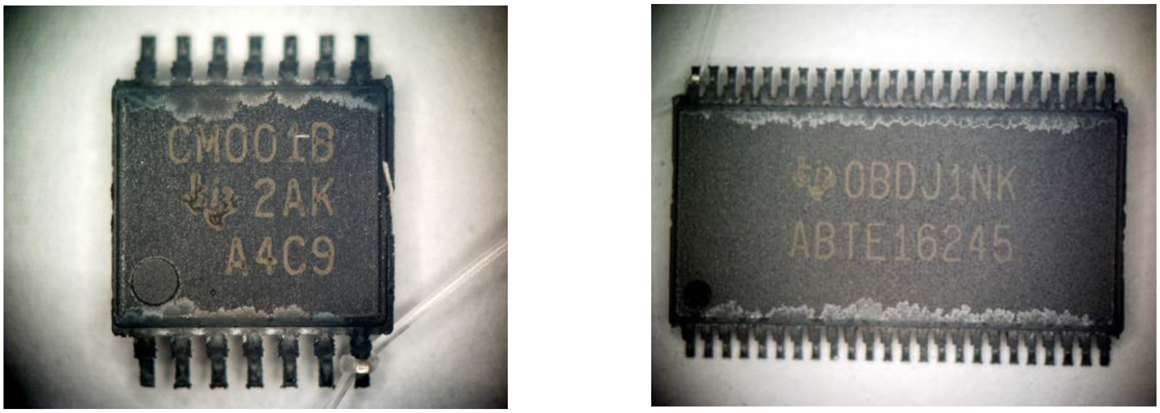
After 5-day MFG exposure, creep corrosion on mold compound surface was found on all components with noble metal pre-plated leadframes. On most packages, creep corrosion products still stayed on the side walls of package. Bridging was found on some packages, and insulation resistance was measured at the level of kilo-ohms. After 10-day exposure, the coverage of creep corrosion products on mold compound surface increased. Corrosion products from different leads tended to merge with each other and move forward on top of the package molding surface. Insulation resistance was further dropped to the level of hundreds of ohms. After 15-day exposure, no significant change of coverage of creep corrosion products was noticed. Corrosion products appeared to be thicker and after the packages were taken out of MFG chamber, the layer of corrosion product might peel and fall off from the mold compound surface. The change of appearance of creep corrosion on packages during the 15-day test is shown in Figure 3.20.

The effect of some package attributes on creep corrosion were evaluated, including leadframe base metal material effect, mold compound resin system effect, and surface roughness effect. Creep corrosion occurred over the mold compound on samples with different leadframe base metal materials. There was no significant difference in corrosion products morphology and coverage on those two types of packages, see Figure 3.21. The same trend went for components with different resin systems and different surface roughness values, see Figure 3.22 and Figure 3.23.



(a) 5-day tested (b) 10-day tested (c) 15-day tested

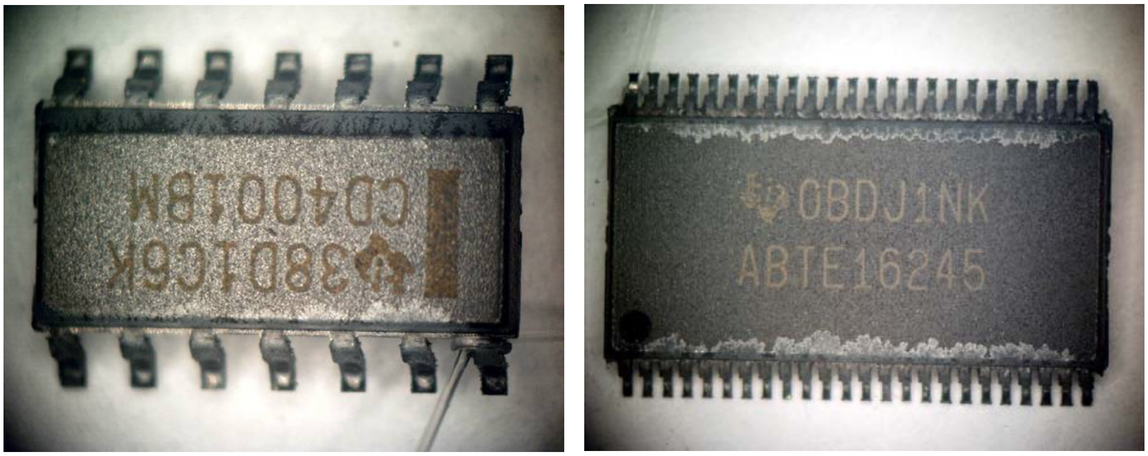
Figure 3.20 Creep corrosion on TI SOIC along with increased test exposure



(a) Base metal Cu
(Alloy 0.1Fe-0.03P)

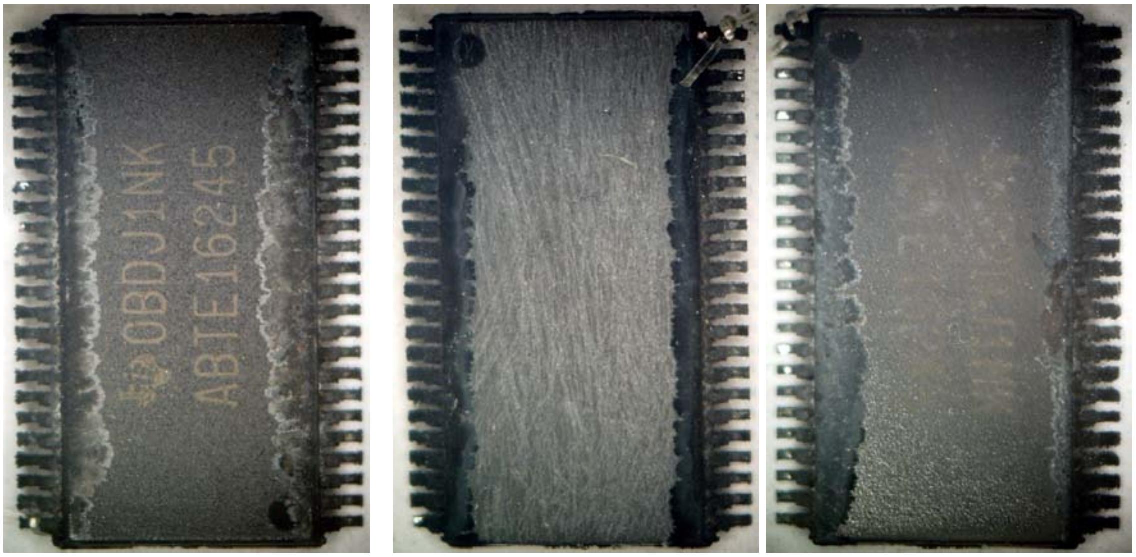
(b) Base metal: Cu
(Alloy 2.4Fe/0.03Pb/0.015P/0.03Sn/0.1Zn)

Figure 3.21 Creep corrosion over mold compound on components with different base metals after the 5-day Telcordia Outdoor MFG exposure



(a) Resin: Cresol Novolac Epoxy
(b) Resin: Cresol Novolac Epoxy and Biphenyl Epoxy (ratio 8:1)

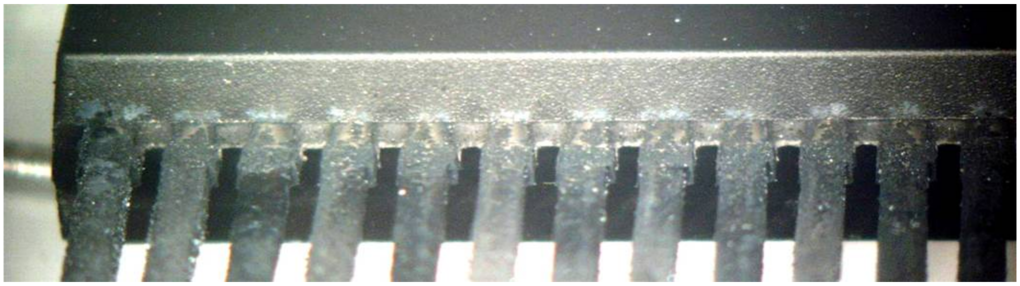
Figure 3.22 Creep corrosion over mold compound on components with different resin system after the 5-day Telcordia Outdoor MFG exposure



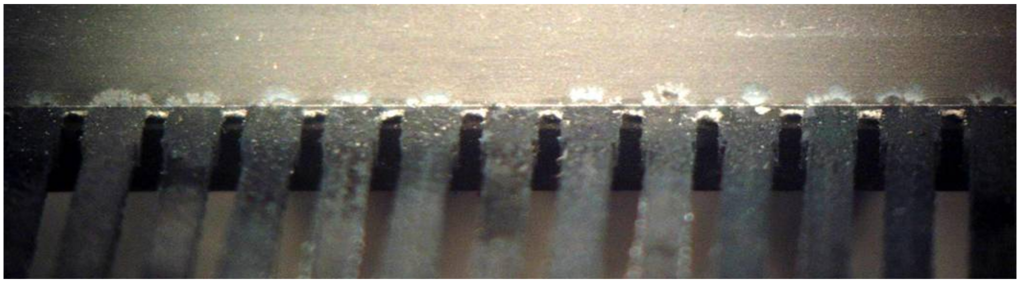
(a) As-received (b) Smooth surface (c) Coarse surface

Figure 3.23 Creep corrosion over mold compound on components with different surface roughness values after the 10-day Telcordia Outdoor MFG exposure

The voltage bias effect was also evaluated. Creep corrosion occurred over the mold compound on components with and without applied voltage biases. There was no significant difference in corrosion products morphology and coverage on those two types of packages, see Figure 3.24.



(a) Unbiased Topline dummy sample after a 10-day Telcordia Outdoor MFG test



(b) Biased Topline dummy sample after a 10-day Telcordia Outdoor MFG test

Figure 3.24 Creep corrosion over mold compound on components with and without electrical bias after the 10-day Telcordia Outdoor MFG exposure

Sn-Pb coated component also had corrosion products over the lead surface. However, no creep corrosion over mold compound surface was found.

<u>Components on leadframe strips and their results</u>

Components provided in leadframe strips were included in the test. They were either QFP with Shinko pre-plated leadframe or SOIC with Mitsui pre-plated leadframe, see Figure 3.25 and Figure 3.26. Details about those samples on strips are provided in Table 3.6 Those components were molded packages on leadframe strip. That is to say, no “trim and form” was conducted on the components, so that there was no exposed copper in dam-bar removal area and cracks at lead bend.

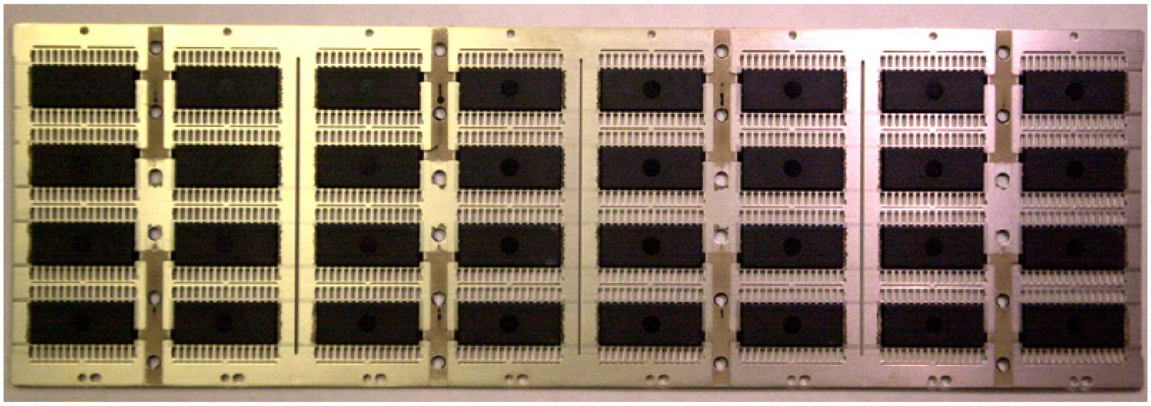


Figure 3.25 Components on leadframe strip with Mitsui noble pre-plated leadframes

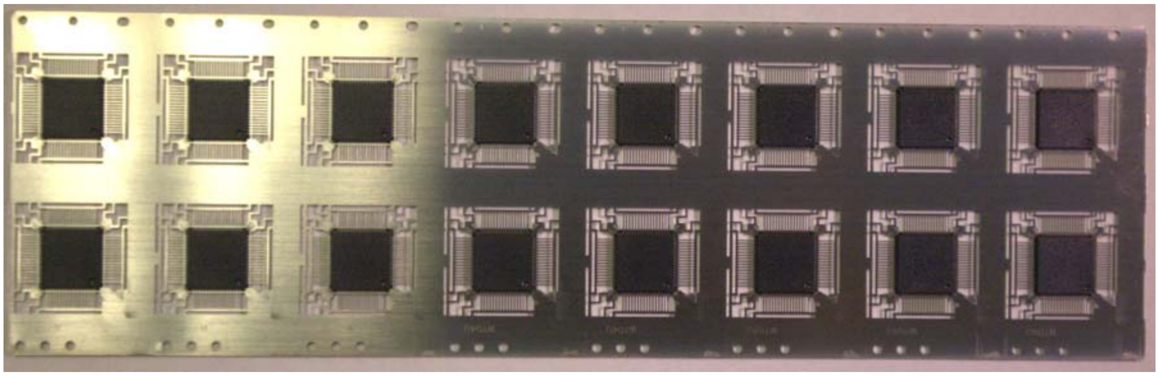


Figure 3.26 Components on leadframe strip with Shinko noble pre-plated leadframes

Table 3.6 Information about the test samples on strips

Description.	Package	Pins	Pitch (mm)	Plating	Base metal	Sample conditioning	Sample size
Components in strip with Mitsui pre-plated leadframes	SOIC	28	1.27	Ni/Pd/Au	Cu alloy	As-received	4
						Coarse surface	4
						Smooth surface	4
Components in strip with Shinko pre-plated leadframes	QFP	64	0.5	Ni/Pd/Au	Cu alloy	As-received	4
						Coarse surface	4
						Smooth surface	4

Before the test, each component was sigulated by cutting it from the strip. Part of the test samples were tested in as-received conditions, while others were pre-conditioned by changing the mold compound top surface roughness. Similar to the approach to TI samples, sanding papers of 120-grit and 1200-grit were used to create coarse and smooth top surface.

After exposure to Telcordia Outdoor MFG environment, creep corrosion products were observed on mold compound surface after 5, 10, 15-day test, see Figure 3.27. It appeared that bulk area of exposed copper is not necessary to be the initiation source for creep corrosion over mold compound surface. Those corrosion products may start from the porosity of the plating on leadframe surface.

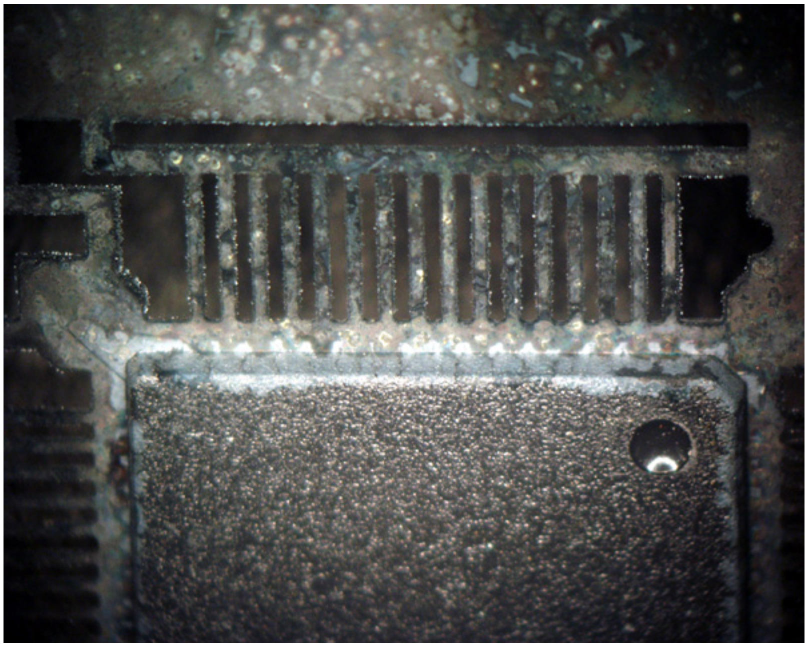


Figure 3.27 Creep corrosion over mold compound on QFP with Shinko noble pre-plated leadframe

<u>Plated coupons and their results</u>

Coupons with various platings provided by Samsung Techwin were included for this test. Plating structure and nominal thickness are listed in Table 3.7.

Table 3.7 Coupon plating structure and nominal thickness

Group	Structure	Ni (μm)	Pd (nm)	Au (nm)	Sample size
A	Cu/Ni/Pd/Au-Pd	0.64	12.7	7.6	2
B	Cu/Ni/Pd/Au-Ag	0.64	12.7	25.4	2
C	A42 PPF Type I	2.56	12.7	25.4	2
D	A42 PPF Type II	1.02	12.7	25.4	2
E	Ref 1 (Cu/Ni)	0.64	---	---	1
F	Ref 2 (Cu/Ni/Pd)	0.64	12.7	---	1

After 5, 10, 15-day Telcordia Outdoor MFG exposure, gross corrosion was observed on the majority area of the coupons. In some locations near the cutting edges and the introduced centerline scratches, slight indication of creep corrosion was noticed, see Figure 3.28. The reason is likely that in such a corrosive environment, thin noble metal plating did not protect the majority area of base metal in an effective way, so that gross attack appeared a dominant effect.

Figure 3.28 Corrosion on sample B after 10-day Telcordia Outdoor MFG test

3.1.4 Summary and conclusions

From the Telcordia Outdoor MFG tests, the following conclusions could be made:

- Telcordia Outdoor MFG environment is an effective environment to reproduce creep corrosion over PEM packages with noble metal pre-plated leadframes.
- Package style and mounting configuration (un-mounted versus printed circuit board mounted), leadframe base metal and noble metal pre-plating structure, mold compound resin system and surface roughness, electrical bias, and component ultrasonic cleaning, were found to have no significant influence on the occurrence and progression of creep corrosion over the mold compound surface.
- Creep corrosion over mold compound surface may occur in less than 5 days exposure to Telcordia Outdoor MFG environment.
- Beyond 5 days of exposure, there is an increase of the coverage of mold compound surface by creep corrosion. However, no significant difference of coverage is noticed between 10-day tested and 15-day tested samples.
- For coupons with comparable plating structure and plating thickness, gross attack by corrosion is observed on coupon surface. On selective samples, a limited effect of creep corrosion is noticed.
- Exposed base metal and cracks at lead bend are not necessary to be the initiation source for creep corrosion over mold compound surface. Plating porosity might have been the adequate source for creep corrosion.
- Sn-Pb coated components did not have creep corrosion over the mold compound surface up to 15-day exposure in Telcordia Outdoor MFG environment.

3.2 Battelle class III MFG tests

Test conditions for Battelle Class III MFG environments are listed in Table 3.8.

Two test runs were conducted following those conditions. This test is intended to simulate industrial locations, where moderate amounts of pollutants are present in poorly controlled environments [28].

Table 3.8 Test conditions for Battelle Class III MFG environment

Conditions	T (ºC)	RH (%)	H_2S (ppb)	Cl_2 (ppb)	NO_2 (ppb)
Battelle III	30±2	75±2	100±10	20±5	200±25

3.2.1 Test 1

Duration for this test was 10 days. Two groups of samples were tested in this Battelle Class III environment. Group 1 included components provided by Philips. They had noble metal pre-plated leadframes either from Mitsui or Samsung. The second group included samples from TI, Motorola, and conventional Sn-Pb coated components.

<u>Components provided by Philips and their results</u>

Information about the components from Philips is shown in Table 3.9. One out of each type of samples was removed for inspection after a specific period of exposure time, and was not put back. The time interval is illustrated in Figure 3.29.

Table 3.9 Package information for samples from Philips

Type	Leadframe source	Package	Number of Pins	Pitch (mm)	Base metal	Sample size
1	Mitsui (Pd-0.6”)	SOIC	14	1.27	Cu alloy	10
2	Mitsui (Pd-1.0”)	SOIC	14	1.27	Cu alloy	10
3	Samsung (Pd-0.5”)	SOIC	14	1.27	Cu alloy	10
4	Samsung	TSSOP	56	0. 5	Cu alloy	10

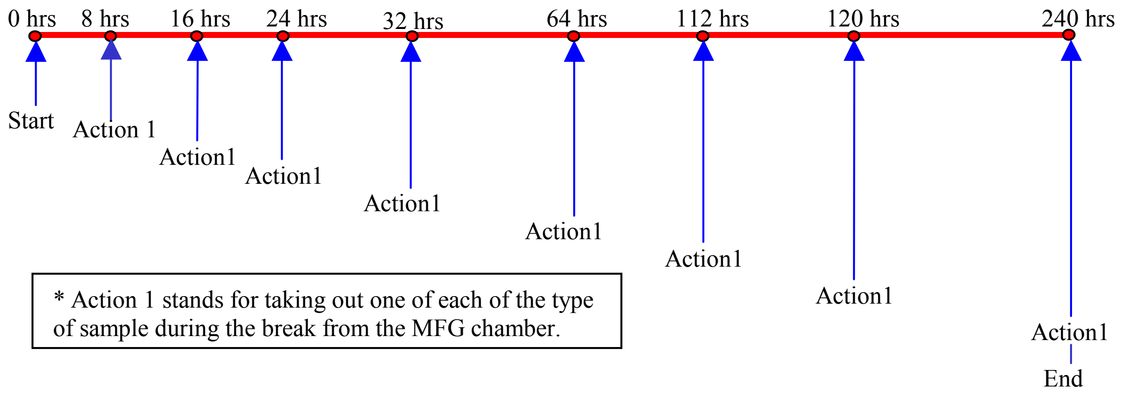


Figure 3.29 Removal intervals for Philips samples

Altogether, there were 10 samples for each type. To follow the process specified in Figure 3.29, 8 samples for each type were required. In this test, 3 samples for each type were tested for a total of 240 hours in MFG exposure. All those samples were tested in as-received conditions. In addition, those samples were dummy sample, which means no functional die inside, so that insulation resistance can be measured in an accurate manner as a signature of bridging by creep corrosion products. After 10-day Battelle III exposure, extensive corrosion on lead surface was observed for the component, see Figure 3.30.

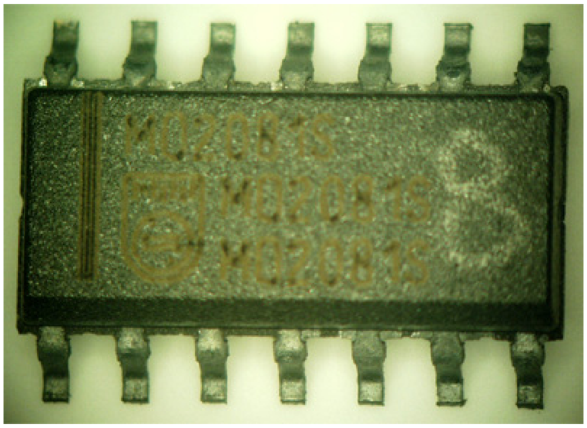
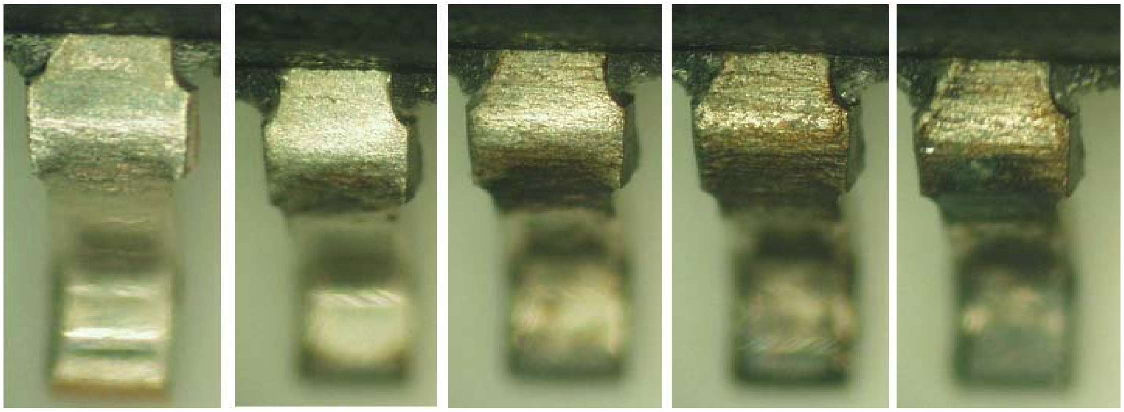
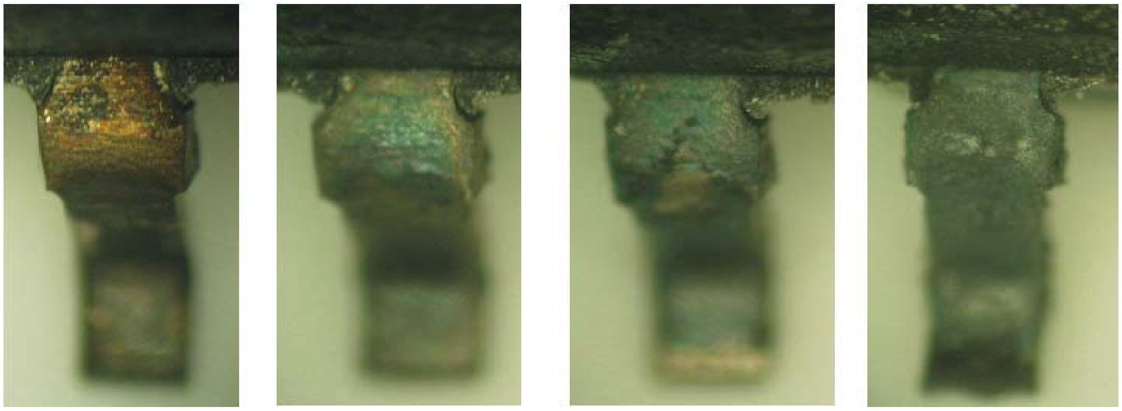


Figure 3.30 Overview of type 2 component after 10-day Battelle Class III MFG test

During the exposure period, continuous increase of corrosion on leads was found on all 4 types of components, see Figure 3.31.



No exposure 8 hrs exposure 16 hrs exposure 24 hrs exposure 32 hrs exposure



64 hrs exposure 112 hrs exposure 120 hrs exposure 240 hrs exposure

Figure 3.31: Corrosion on component type 1 leads after specific exposure period in Battelle Class III MFG environment

Creep corrosion over mold compound surface was only found on several components after 10-day exposure. It usually appeared as small spots on mold surface adjacent to the lead fingers, see Figure 3.32. Altogether, there were 7 sites of creep corrosion over mold compound surface located on 10-day tested Philips components. There was no apparent difference in corrosion behavior between the 4 types of samples. The insulation resistance between adjacent leads did not have a drop.

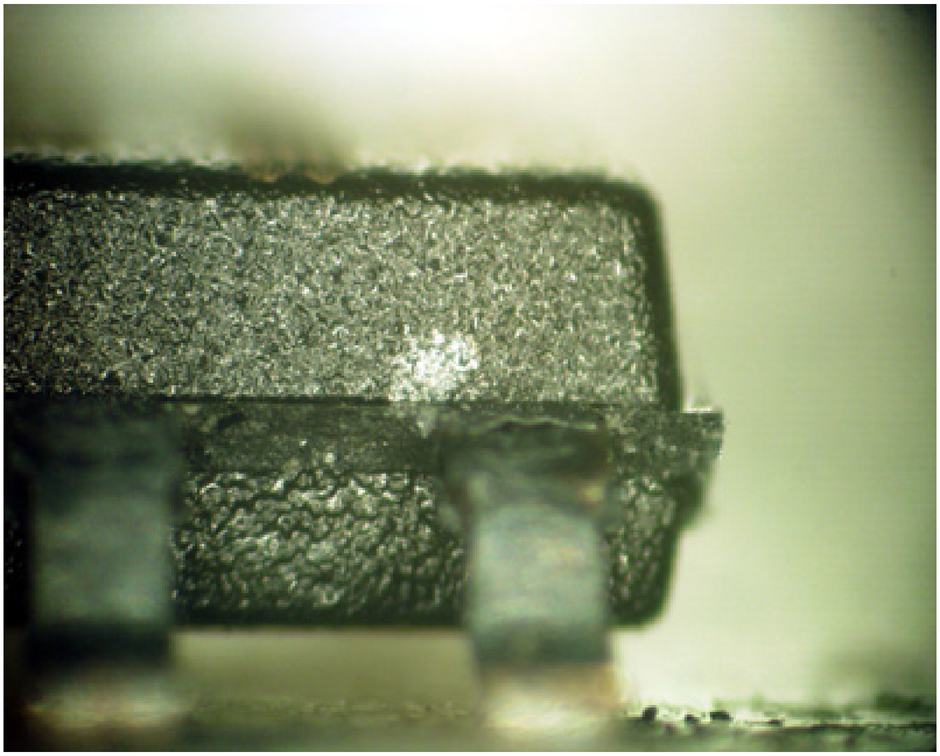


Figure 3.32 Creep corrosion over mold compound surface on 10-day Battelle III tested Philips type 1 components

Other components and their results

Components from TI and Motorola with noble metal pre-plated leadframes were included in the test. Conventional Sn-Pb coated components were tested as well. Information about those test samples is shown in Table 3.10.

Table 3.10 Information about the test samples for Battelle Class III 10-day MFG test

Part No./Description	Package	Pins	Pitch (mm)	Plating	Resin	Base metal	Sample conditioning	Sample size
TI CD4001BE	DIP	14	2.54	Ni/Pd/Au	Cresol Novolac Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received with one side of leads scratched	4
							Surface roughened	4
							Surface smoothed	4

							Polyurethane conformal coating	4
							Acrylic conformal coating	4
							Mechanically decapsulated	2
TI CD4001BM	SOIC	14	1.27	Ni/Pd/Au	Cresol Novolac Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received with one side of leads scratched	4
							Surface roughened	4
							Surface smoothed	4
							Polyurethane conformal coating	4
							Acrylic conformal coating	2
							Mechanically decapsulated	2
TI CD4001BPWR	SOP	14	0.64	Ni/Pd/Au	Cresol Novolac Epoxy and Biphenyl Epoxy	Cu-Fe-P	As-received with one side of leads scratched	2
							Surface roughened	2
							Surface smoothed	2
							Polyurethane conformal coating	2
							Acrylic conformal coating	2
TI SN74ABTH18652APM	TQFP	64	0.50	Ni/Pd	Cresol Novolac Epoxy and Proprietary Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received with one side of leads scratched	2
							Surface roughened	2
							Surface smoothed	2
							Polyurethane conformal coating	2
							Acrylic conformal coating	2

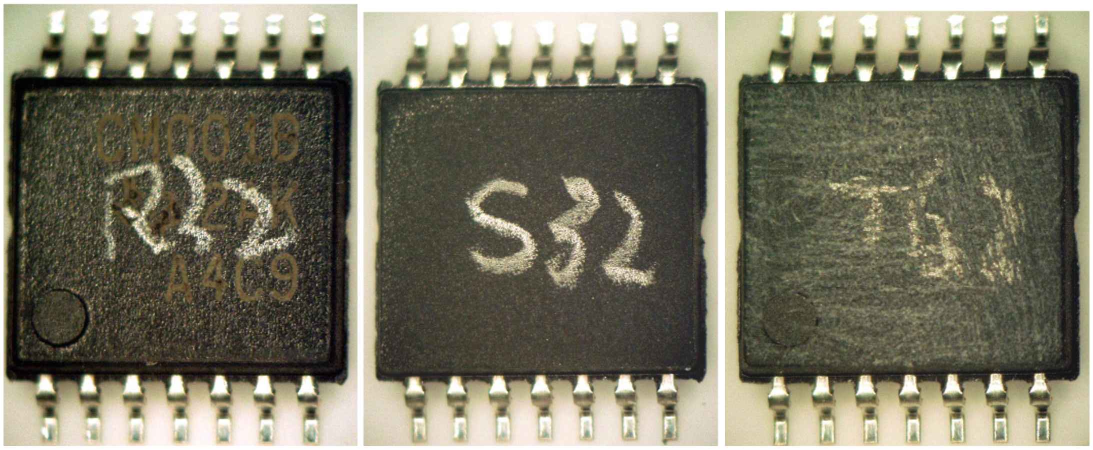
TI SN74GTLP1395DGVR	TVSOP	20	0.40	Ni/Pd	Cresol Novolac Epoxy and Biphenyl Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received with one side of leads scratched	2
							Surface roughened	2
							Surface smoothed	2
							Polyurethane conformal coating	2
							Acrylic conformal coating	2
TI SN74ABTE16245DGGR	TSSOP	48	0.50	Ni/Pd	Cresol Novolac Epoxy and Biphenyl Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received with one side of leads scratched	2
							Surface roughened	2
							Surface smoothed	2
							Polyurethane conformal coating	2
							Acrylic conformal coating	2
TI SN74TVC3010DGVR	TVSOP	24	0.4	Ni/Pd	Cresol Novolac Epoxy and Biphenyl Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received with one side of leads scratched	2
							Surface roughened	2
							Surface smoothed	2
							Polyurethane conformal coating	2
							Acrylic conformal coating	2
TI SN74TVC3010DBQR	SSOP	24	0.64	Ni/Pd/Au	Cresol Novolac Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received with one side of leads scratched	2
							Surface roughened	2
							Surface smoothed	2
							Polyurethane conformal coating	2

							Acrylic conformal coating	2
Motorola A441YP04AA (dummy sample)	QFP	144	0.5	Ni/Pd		Cu alloy	As-received with one side of leads scratched	1
							Surface roughened	1
							Surface smoothed	1
TI SN74FB2031RC	QFP	48	0.64	SnPb plating	Epoxy and Proprietary Resin	Cu alloy	As-received	2
							Surface roughened	2
							Surface smoothed	2
Conventional package	DIP	14	2.54	SnPb plating		Cu alloy	As-received	3
Conventional package	DIP	14	2.54	SnPb dipping		Cu Alloy	As-received	3

Parts of the components were tested in as-received conditions, while other components experienced several forms of pre-conditioning before the MFG exposure. The pre-conditionings included surface roughness change of molding compound on top of package, conformal coating on the whole package, and additional scratch on the leads near the mold compound surface. The aim to do those pre-treatments was to compare their behaviors in terms of creep corrosion with the as-received components.

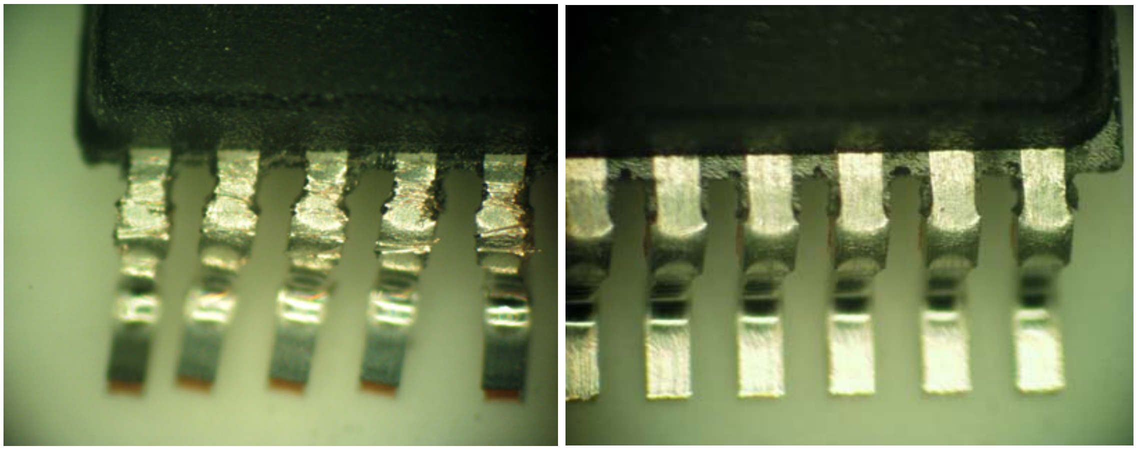
Sanding paper was used to change the surface roughness of the molding compound. 120-grit sand paper was used to make a rough surface on molding compound on top of package. 1200-grit sand paper was used to make a smooth surface on molding compound on top of package. Figure 3.33 shows the three samples with different surface roughness.

Since pre-plated leadframe is more susceptible to surface damages in handling, it is necessary to evaluate the effect of surface damages on creep corrosion. Although there was already cracks and dam-bar removal on the leads, some additional scratches were applied near the lead bend by a sharp needle-like tool. The appearance of leads before and after scratching is shown in Figure 3.34. The additional scratches were not only applied on original as-received samples, but also on samples with surface roughness change and with conformal coatings.



(a) As-received (b) Smooth surface (c) Coarse surface

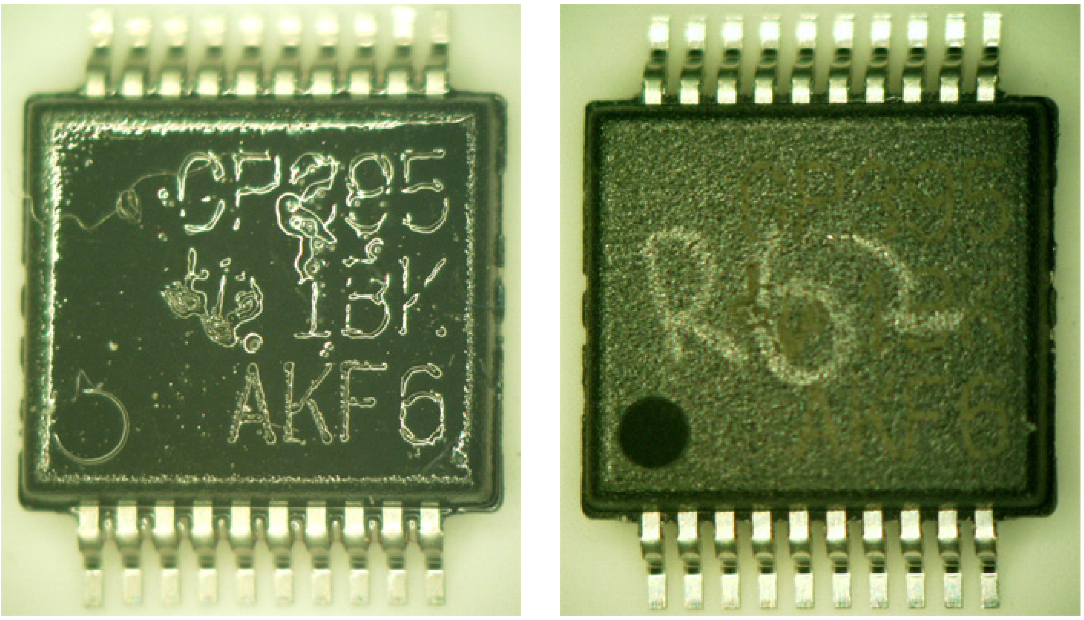
Figure 3.33 TI SOP components with different molding compound surface roughness



(a) Leads with scratches (b) Leads without scratches

Figure 3.34 Packages with and without intentional introduced scratches

Conformal coating is a protective, dielectric coating designed to conform to the surface of an assembled printed circuit board. It functions primary as the protection layer against moisture, water vapor condensation, corrosive chemical vapor, salt spray, and dust from the environment. In order to find out the effect of conformal coating on creep corrosion, two kinds of conformal coating materials, Polyurethane and Acrylic, were sprayed over the top of part of the un-mounted components. After spraying, the components were visually inspected to ensure a full coverage of coating material on molding surface and leads. Figure 3.35 shows the components with and without conformal coating.



(a) Package with conformal coating

(b) Package without conformal coating

Figure 3.35 Packages with and without acrylic conformal coating

After 10-day exposure to the Battelle Class III environments, creep corrosion on mold compound surface was found on selective packages in a limited fashion. In most cases, creep corrosion appeared as spots over the mold compound surface, not yet able to bridge the adjacent leads, see Figure 3.36. In some cases, creep corrosion products bridged adjacent leads and did induce the drop of insulation resistance, see Figure 3.37. Since most of the creep corrosion products were not able to migrate onto the top surface of mold compound, the effect of surface roughness was not demonstrated.

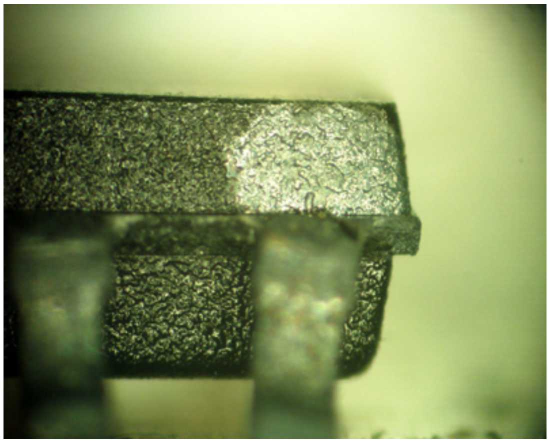


Figure 3.36 Creep corrosion over mold compound but not yet bridged the leads after 10-day Battelle Class III test

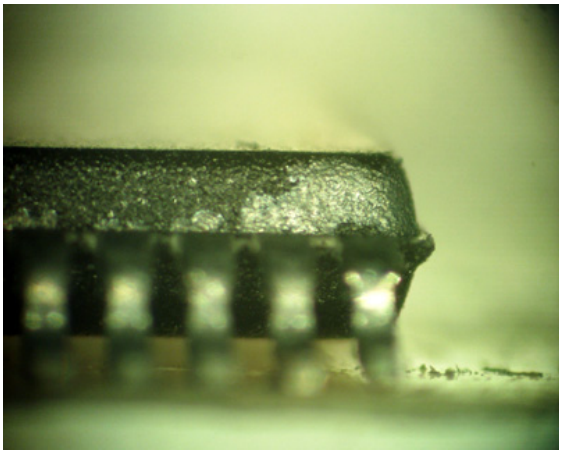
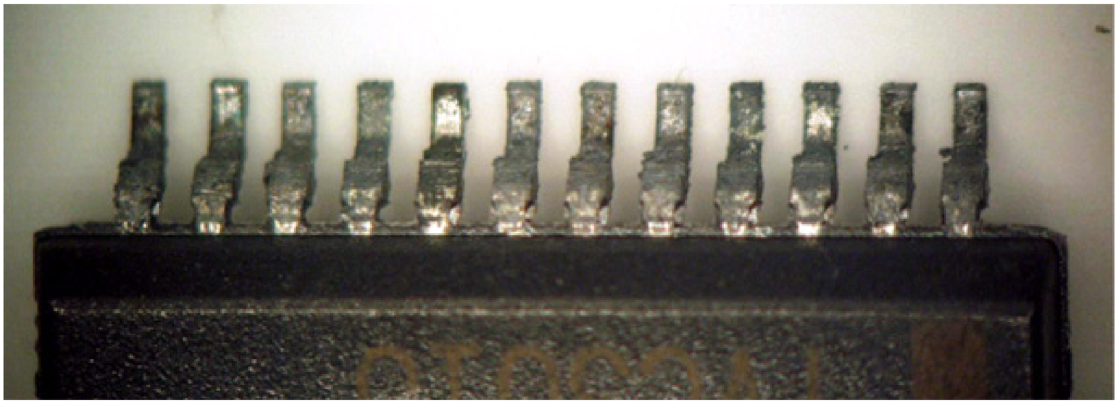
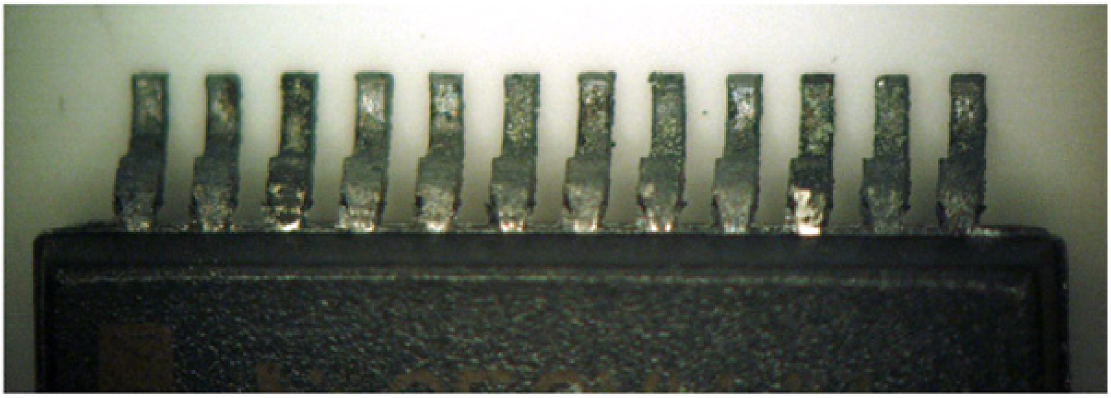


Figure 3.37 Creep corrosion over mold compound and bridged the leads after 10-day Battelle Class III test

It appeared that additional scratches on the lead did not promote lead corrosion or creep corrosion in a 10-day Battelle Class III MFG test. In Figure 3.38, the visual appearance of leads with scratches and without scratches was similar. In this case, both of them did not have creep corrosion over the top surface of the molding compound.



(a) Corrosion on leads with scratches after 10-day Battelle Class III test



(b) Corrosion on leads without scratches after 10-day Battelle Class III test

Figure 3.38 Comparison of corrosion with and without introduced scratches on leads

It was observed that samples with conformal coating, no matter what kind of coating material the component was covered by, the conformal coating did a good job to protect the component from creep corrosion as well as corrosion on leads. It can be shown in Figure 3.39 that the leads were still free from corrosion products and exposed copper at toe area looked in original color. For the conformal-coated components with introduced scratched, after 10-day exposure, the sites on leads with scratches was corroded, but there was no migrated corrosion products onto the top surface of the molding compound via the conformal coating surface.

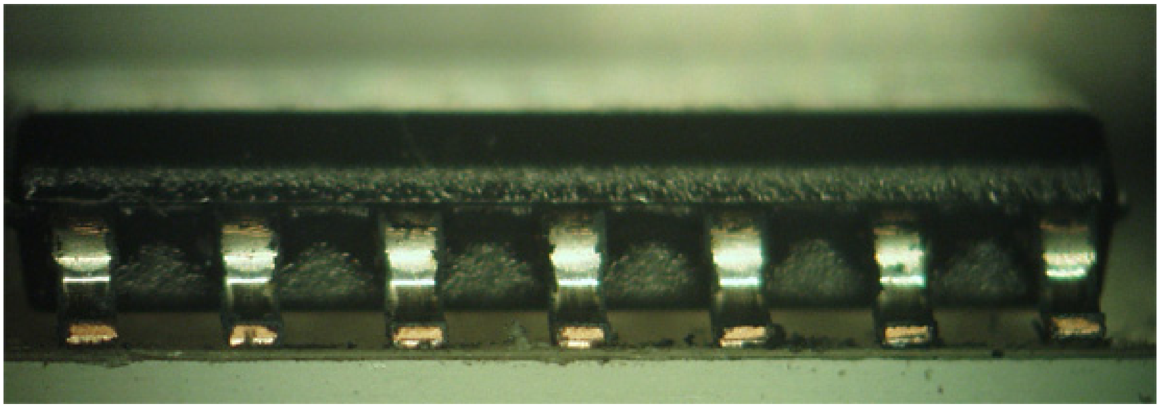


Figure 3.39 Component well protected from corrosion after 10-day Battelle Class III test

3.2.2 Test 2

Duration for this test was 15 days. Four groups of samples were tested in this Battelle Class III environment. Group 1 included components provided by Samsung Techwin. They had noble metal pre-plated leadframes and either in un-mounted or board mounted configuration. The second group included components from TI and conventional Sn-Pb coated components. Group 3 were leadframe strips with or without mold compound. Group 3 consisted of coupons with plating.

<u>Samples from Samsung Techwin and their results</u>

Table 3.11 lists test samples of this study. The experiment included un-mounted and assembled components, with different package styles, different base metals, and different plating structures. In this study, two pre-plating compositions, called “μ-PPF” and “upgrade μ-PPF” manufactured by Samsung Techwin, were investigated. For “μ-

PPF", a nominal thickness of 0.013 μm of Pd is plated over a nominal thickness of 0.5 μm of Ni. A nominal thickness of 0.005 μm of Au-Pd alloy is plated over Pd as the surface flash. For "upgrade μ-PPF", all the nominal values are the same, but the surface flash is an Au-Ag alloy. Compared to type 1 components, type 2 components have an additional heat treatment. This was also true for components type 4 in contrast to components type 3.

Table 3.11 List of test samples from Samsung Techwin

Type	Test Status	Package	Base metal	Plating	Sample size
1	Un-mounted component	SOP32	C194	Upgrade μ-PPF	13
2	Un-mounted component	SOP32	C194	Upgrade μ-PPF	13
3	Un-mounted component	SOP32	C194	μ-PPF	13
4	Un-mounted component	SOP32	C194	μ-PPF	13
5	Un-mounted component	TSSOP56	C7025	Upgrade μ-PPF	13
6	Un-mounted component	TSSOP56	C7025	μ-PPF	13
7	Un-mounted component	QFN48	C194	Upgrade μ-PPF	13
8	Un-mounted component	QFN48	C194	SnPb	13
9	Un-mounted component	TSOP66	Alloy42	Upgrade μ-PPF	13
10	Component on PCB	TSSOP56	C7025	Upgrade μ-PPF	1
11	Component on PCB	TSSOP56	C7025	μ-PPF	1
12	Component on PCB	QFN48	C194	Upgrade μ-PPF	1
13	Component on PCB	QFN48	C194	SnPb	1
14	Component on PCB	TSOP66	Alloy42	Upgrade μ-PPF	1

For all un-mounted components (type 1 through 9 listed in Table 3.11), nylon line was used to suspend the No. 1 lead of each component to a wood rod, and then the rod was put onto the rack inside the MFG chamber. The quad flat no-lead (QFN) components were tied in the center of the package. A set of samples were taken out after 12-hr, 1-day, 2, 3, 4, 5, 6, 7, 8, 9, 10-day exposures and were not put back into the chamber. After 15-day exposure, the test was terminated and the last two sets of samples were removed from the chamber.

For board mounted test samples (types 10 through 14 listed in Table 2), only one board for each type was tested. Those boards were hung by nylon line inside the chamber. After 7 and 10 days of exposure, the test boards were taken out of test chamber for a visual inspection and then put back into the chamber.

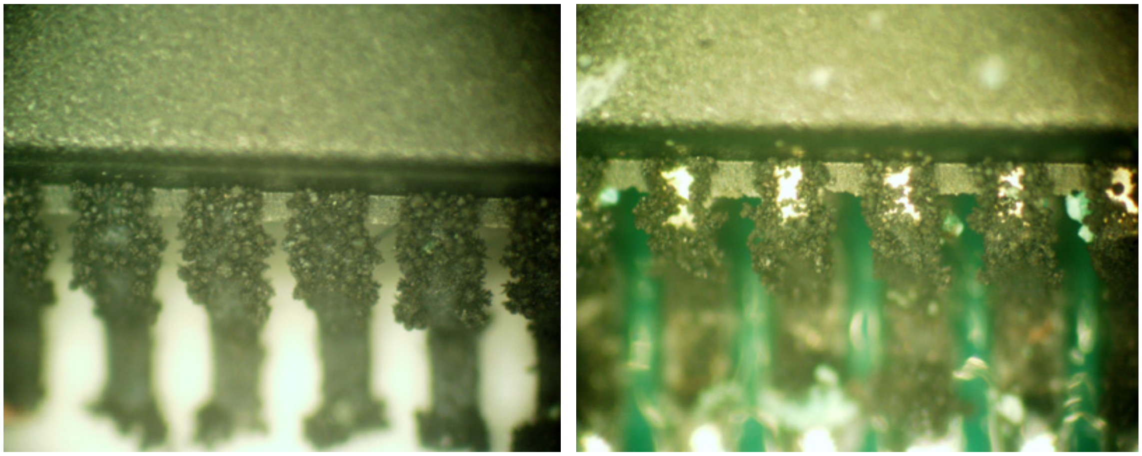
Corrosion of the leads was observed on all the tested components. Figure 3.40 shows the evolution of corrosion over leads on the type 1 samples. Board mounted samples showed a similar corrosion behavior to un-mounted samples, see Figure 3.41, which meant the heat treatment during reflow for leadframes on board mounted components did not change their corrosion behavior. Base metal materials and package styles seemed not to influence the property of corrosion over leads. Figure 3.42 shows the corrosion over leads on components with copper and alloy42 base metal materials. The Alloy 42 (42% Ni and 56% Fe) component showed different color of corrosion products under the optical microscope. This is probably due to the content of iron corrosion products. The two plating structures, “upgrade μ-PPF” and “μ-PPF”, showed similar corrosion behavior. On QFN packages, the SnPb coated sample visually showed less dramatic corrosion effects on exposed pad and die paddle than the “upgrade μ-PPF” plated samples, see Figure 3.43.

Corrosion products with a different morphology (see Figure 3.44), which were found in many locations on un-mounted QFN packages, were observed on some leads of tested samples. Those materials appeared green, have the very porous morphology and always started from the bulk area of exposed copper before the MFG exposure.

(a) No exposure (b) 12 hours

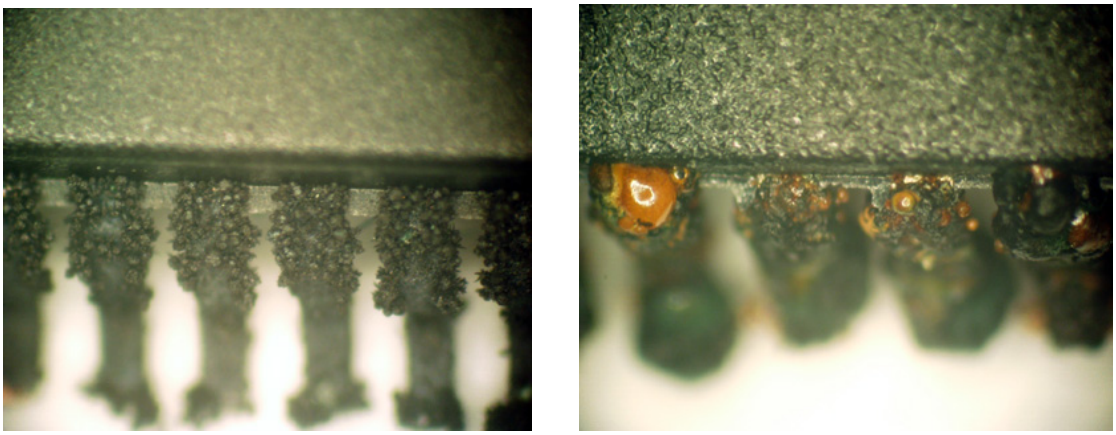
(c) 5 days (d) 8 days (e) 15 days

Figure 3.40 Evolution of corrosion over leads on sample type 1



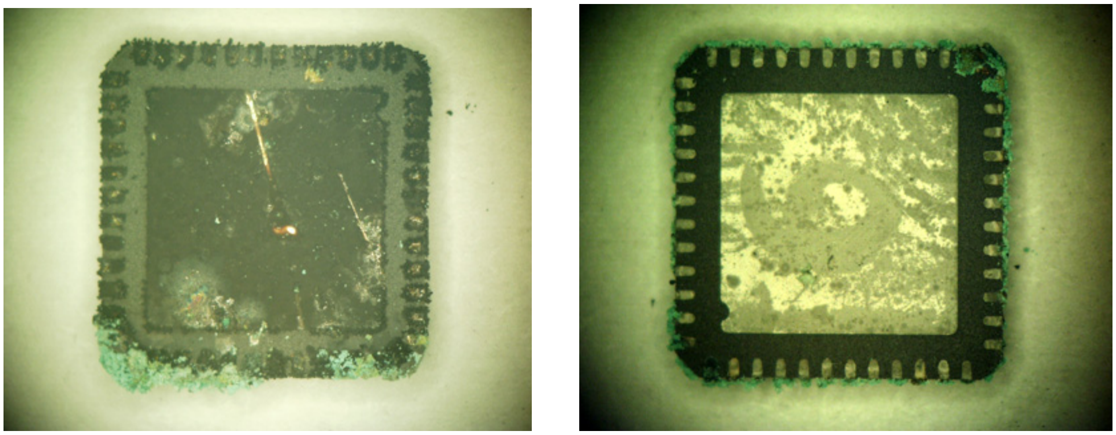
(a) Un-mounted component (b) Board mounted component

Figure 3.41 Comparison of un-mounted sample and board mounted sample after 15-day Battelle Class III MFG exposure (type 6 and type 11)



(a) TSSOP56 with base metal C7025 (b) TSOP66 with Base metal alloy42

Figure 3.42 Corrosion over leads on components with different base metals after 15-day Battelle Class III MFG exposure (type 6 and type 9)



(a) QFN with upgrade μ-PPF (b) QFN with SnPb plating

Figure 3.43 Corrosion over QFNs with different platings after Battelle Class III 15-day MFG exposure

Creep corrosion was observed on the molding surface of the un-mounted QFN packages with the "upgrade μ-PPF" plating after 15-day MFG environment exposure. Figure 3.45 shows that location of creep corrosion on the mold compound surface by optical microscopy and ESEM. Since the tested QFN package was a "dummy sample", which meant no functional die and wire-bonding inside the package, the insulation resistance was measured between the adjacent leads. For the adjacent lead pairs with visible creep corrosion bridging effect, the insulation resistance was measured to be around 6MΩs.

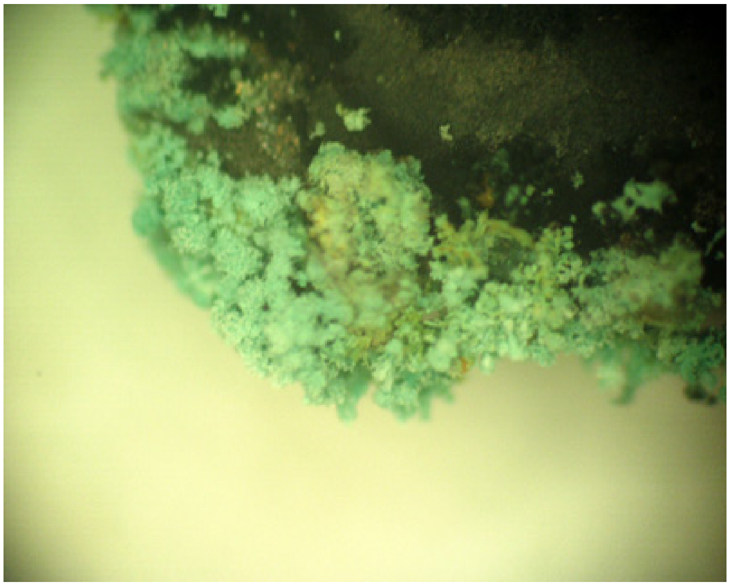
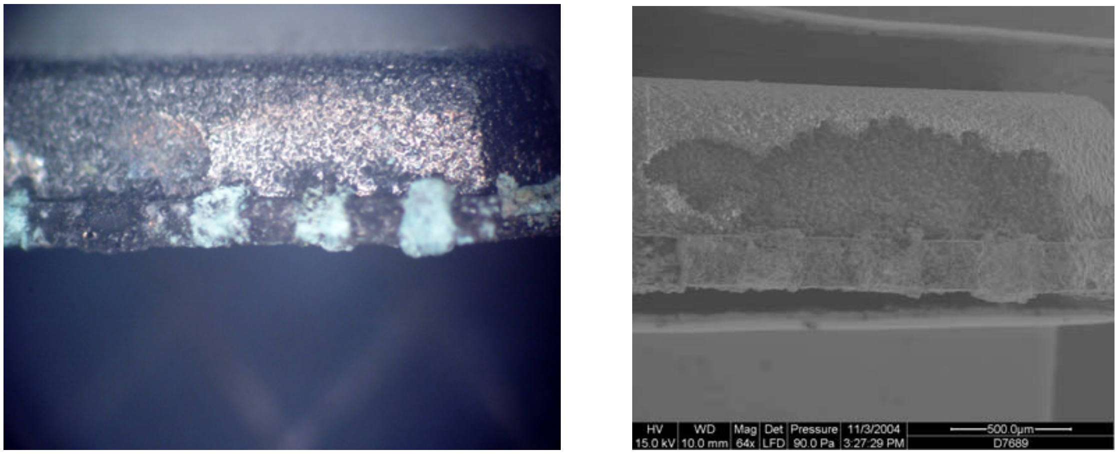


Figure 3.44 Porous corrosion products on un-mounted QFN package after Battelle Class III 15-day exposure



(a) Optical view of creep corrosion

(b) ESEM photo of creep corrosion

Figure 3.45 Creep corrosion on 15-day MFG exposed QFN package with "upgrade µ-PPF" (type 7)

Leadframe corrosion was found on all test samples in this study after exposure to Battelle Class III environment of 15 days. There was corrosion behavior for various package styles, base metal materials, noble metal plating structure, and sample test status (un-mounted or mounted). SnPb plated QFN showed less corrosion than “upgrade μ-PPF” plated QFN. Creep corrosion on the molding surface was only located on 15-day exposed QFN packages with “upgrade μ-PPF”. Creep corrosion products were electrically conductive to bridge the adjacent leads.

Other components and their results

Table 3.12 shows the information about TI components and conventional SnPb coated components. Parts of the components were tested in as-received conditions. Others experienced various kinds of pre-conditioning, including surface cleaning, decapsulation, conformal coating, additional scratches on leads, and applying electrical bias. Those pre-conditioning procedures are explained in previous sections of this dissertation. In this case, the conformal coating was applied by dipping the components into the Acrylic material produced by Humiseal. For most of the TI components, a set of components were taken out after 12-hr, 1-day, 2, 3, 4, 5, 6, 7, 8, 9, 10-day exposures and were not put back into the chamber. After 15-day exposure, the test was terminated and the last two sets of components were removed from the chamber. For SnPb coated conventional components and decapsualted TI DIP, one component was removed from chamber after 5 days and 10 days. When test was terminated after 15 days, the rest two were removed. For the dummy components from Topline, one component of each in biased and unbiased test mode was removed after 10-day exposure, and the other two components were taken out after 15-day exposure.

Table 3.12 Information about TI components and conventional SnPb coated components

Part No./Description.	Package	Pins	Pitch (mm)	Plating	Resin	Base metal	Sample conditioning	Sample size
TI CD4001BE	DIP	14	2.54	Ni/Pd/Au	Cresol Novolac Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received	13
							Ultrasonically cleaning	13
							Chemically decapsulated and rinsed	4
TI CD4001BM	SOIC	14	1.27	Ni/Pd/Au	Cresol Novolac Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received	13
							Conformal coating with one side scratched	13
TI CD4001BPWR	SOP	14	0.64	Ni/Pd/Au	Cresol Novolac Epoxy and Biphenyl Epoxy	Cu-Fe-P	As-received	13
							Additional bending on one side and scratches on the other	13
TI SN74ABTH18652APM	TQFP	64	0.50	Ni/Pd	Cresol Novolac Epoxy and Proprietary Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received	13
							Additional bending on one side and scratches on the other	13
TI SN74GTLP1395DGVR	TVSOP	20	0.40	Ni/Pd	Cresol Novolac Epoxy and Biphenyl Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received	13
							Ultrasonically cleaning	13
TI SN74ABTE16245DGGR	TSSOP	48	0.50	Ni/Pd	Cresol Novolac Epoxy and Biphenyl Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received	13
							Conformal coating with one side scratched	13
Dummy parts from Topline	SIP	15	2.54	Ni/Pd		Cu alloy	As-received	2
							Biased with 5, 10, 15, 20V	2
Conventional packages	DIP	14	2.54	SnPb plating		Cu alloy	As-received	4
Conventional packages	DIP	14	2.54	SnPb dipping		Cu Alloy	As-received	4

It was observed that corrosion on leads occurred on all test components. For TI components, after 8 days of MFG exposure in Battelle Class III environment, limited quantity of creep corrosion on mold compound surface was produced, see Figure 3.46. The occurrence of creep corrosion did not have any preference towards to the package styles, introduced scratches on leads, and pre-test cleaning. Conformal coating protected leads from corrosion except the lead toe area, which may result from the non-full coverage of leads by conformal coating. Scratches on the conformal coated leads had localized corrosion products, but did not migrate over the coating surface or bridge the lead pairs, see Figure 3.47. No creep corrosion over mold compound surface both on Topline components and conventional SnPb coated components.

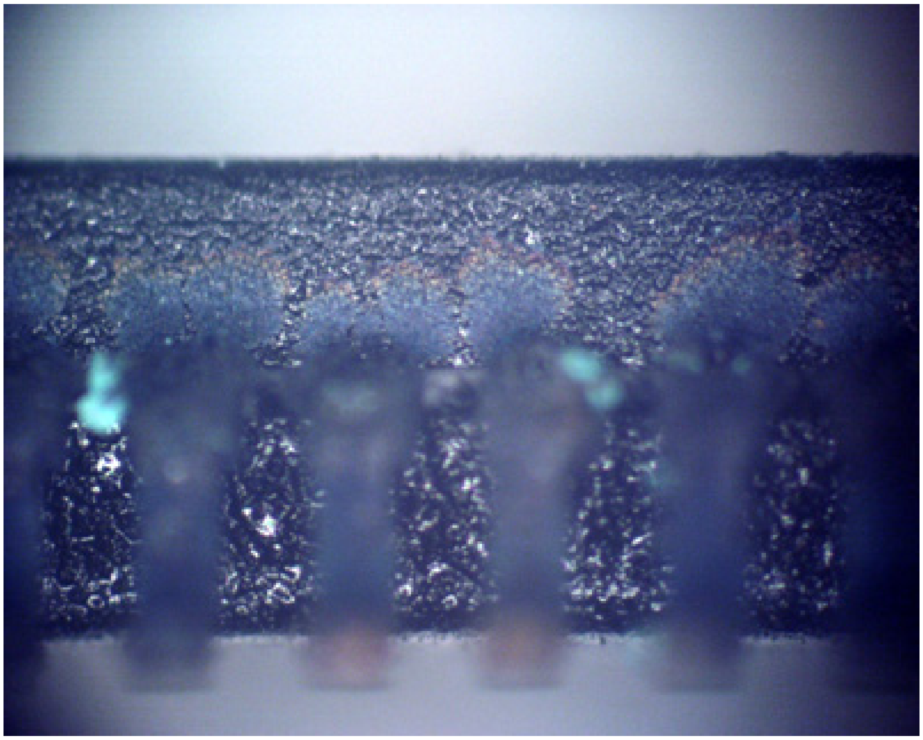
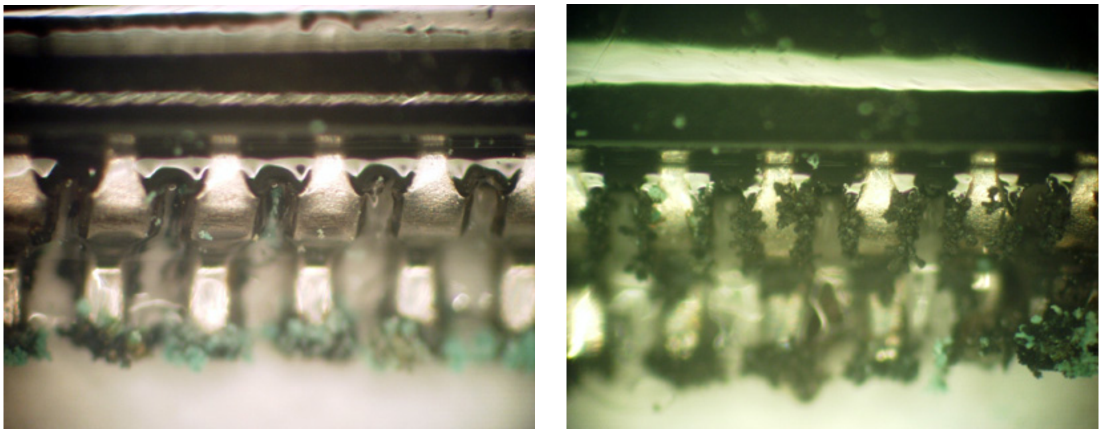


Figure 3.46 Creep corrosion over mold compound after the 15-day Battelle Class III test



(a) Conformal coated leads (b) Conformal coated leads with scratches

Figure 3.47 Conformal coated leads after 15-day Battelle Class III test

<u>Leadframe strips with or without mold compound and their results</u>

Samples in leadframe strips with and without mold compound also joined this test, see details in Table 3.13. The components with mold compound in the form of packages were separated from the leadframe strip and tested in as-received mode. On one side of those packages, scratches were introduced on the leads surface close to the mold compound. Two components, one for each type, were taken out after 12-hr, 1-day, 2, 3, 4, 5, 6, 7, 8, 9, 10-day exposures and were not put back into the chamber. After 15-day exposure, the test was terminated and the rest 4 components were removed from the chamber. For bare leadframe samples, each leadframe for test was cut from the strip. 6 of them were test in as-received mode and were removed respectively after 12-hr, 1, 2, 3, 4, and 5-day exposure. The other 4 were conformal coated then scratched to expose base metal at the middle of die paddle. They would be removed after 5, 10, 15, and 15-day exposure.

Table 3.13 Information about samples on leadframe strips

Descriptions	Package	Pins	Pitch (mm)	Plating	Base metal	Sample conditioning	Sample size
Components in strip with Shinko pre-plated leadframes	QFP	64	0.5	Ni/Pd/Au	Cu alloy	As-received with one side of leads scratched	13
Shinko pre-plated leadframes in strip	QFP	64	0.5	Ni/Pd/Au	Cu alloy	As-received	6
						Conformal coated with a deep scratch at die paddle	4
Components in strip with Mitsui pre-plated leadframes	SOIC	28	1.27	Ni/Pd/Au	Cu alloy	As-received with one side of leads scratched	13
Mitsui pre-plated leadframes in strip	SOIC	28	1.27	Ni/Pd/Au	Cu alloy	As-received	6
						Conformal coated with a deep scratch at die paddle	4

After 15-day exposure to Battelle Class III environment, although corrosion on leads was quite common, no creep corrosion was found on the components from leadframe strips. Pore corrosion effect was evident on the bulk surface of bare leadframes after the first several days of exposure, see Figure 3.48. Conformal coating on the bare leadframes did protect the leadframe from corrosion except the location with scratches Figure 3.49.

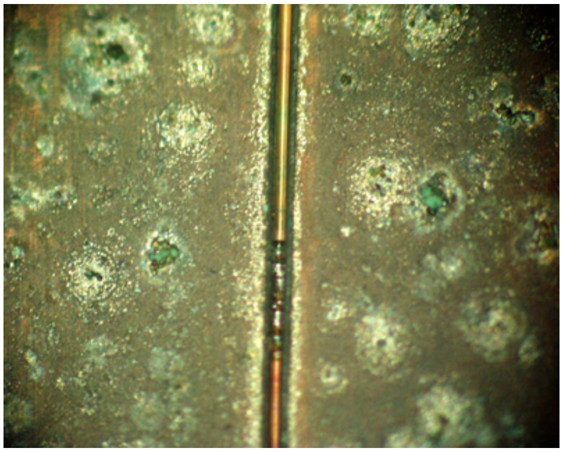


Figure 3.48 Pore corrosion effect on Shinko leadframe at die paddle area after 2-day Battelle Class III MFG test

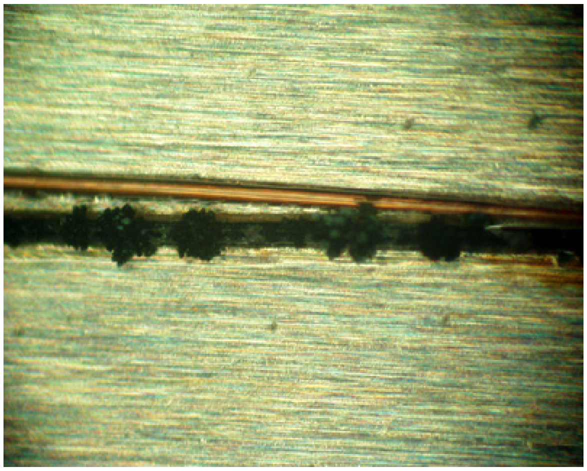


Figure 3.49 Conformal coated Shinko leadframe at die paddle area after 15-day Battelle Class III MFG test

Plated coupons and their results

Coupons with various platings from Samsung Techwin were included for this test. Plating structure and nominal thickness are listed in Table 3.14. Three coupons for each type were tested in the environments. One of each type was removed from the chamber after 5, 10, and 15 days.

Table 3.14 Coupon plating structure and nominal thickness

Type	Structure	Ni (μm)	Pd (nm)	Au (nm)	Sample size
A	Cu/Ni/Pd/Au-Pd	0.64	12.7	7.6	3
B	Cu/Ni/Pd/Au-Ag	0.64	12.7	25.4	3
C	A42 PPF Type I	2.56	12.7	25.4	3
D	A42 PPF Type II	1.02	12.7	25.4	3
E	Ref 1 (Cu/Ni)	0.64	---	---	3
F	Ref 2 (Cu/Ni/Pd)	0.64	12.7	---	3

After 5, 10, 15-day Battelle Class III MFG exposure, gross corrosion was observed on the majority area of the coupons. On noble plated coupons, in some locations near the cutting edges, slight indication of creep corrosion was observed, see

Figure 3.50. It appeared that the very thin nature of noble plating did not do a good job to protect the underlying metal in such environments. Therefore, both gross corrosion and localized corrosion (pore corrosion and creep corrosion) occurred but gross attack was dominant.

Figure 3.50 Corrosion on coupon type A after 15-day Battelle Class III test

3.2.3 Summary and conclusions

From the Battelle Class III MFG tests, the following conclusions could be made:

- Compared with Telcordia Outdoor MFG environment, Battelle Class III MFG environment is the less effective environment to reproduce creep corrosion over PEM packages with noble metal pre-plated leadframes.
- Package style, leadframe base metal and noble metal pre-plating structure, mold compound resin system and surface roughness, electrical bias, and component ultrasonic cleaning, were found to have no significant influence on the occurrence and progression of creep corrosion over the mold compound surface.

- Creep corrosion over mold compound surface may occur in 8-day exposure to Battelle Class III MFG environment.
- For coupons with comparable plating structure and plating thickness, gross attack by corrosion is observed on coupon surface. On selective samples, a limited effect of creep corrosion is noticed.
- Sn-Pb coated components did not have creep corrosion over the mold compound surface for the 15-day Battelle Class III test.

3.3 Telcordia Indoor MFG tests

Test conditions for Telcordia Indoor MFG environments are listed in Table 3.15. Two test runs were conducted following those conditions.

Table 3.15 Test conditions for Telcordia Outdoor MFG environment

Conditions	T (ºC)	RH (%)	H_2S (ppb)	Cl_2 (ppb)	NO_2 (ppb)	SO_2 (ppb)
Telcordia Indoor	30±1	70±2	10±1.5	10±1.5	200±30	100±15

3.3.1 Test 1

The first test run lasted for 10 days. Only components were used for this test, see Table 3.16. Additional bending was imposed on leads of half of the TI test components to aggravate the cracks at the lead bend. Test components were taken out for inspection after 5-day exposure, and were removed from the chamber after 10-day exposure. Corrosion on leads was found on all test samples. No creep corrosion on molding surface was found for any samples. Intentionally introduced lead bending did not make the components more susceptible to creep corrosion over mold compound within the 10-day exposure to Telcordia Indoor MFG environment. SnPb coated component did not show as much corrosion attack on leads as the components with noble metal pre-plated leadframes.

Table 3.16 Components used for Telcordia Indoor MFG test 1

Part No./Description	Package	Pins	Pitch (mm)	Plating	Resin	Base metal	Sample conditioning	Sample size
TI CD4001BE	DIP	14	2.54	Ni/Pd/Au	Cresol Novolac Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received	2
							Additional bending of leads	2
TI CD4001BM	SOIC	14	1.27	Ni/Pd/Au	Cresol Novolac Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received	2
							Additional bending of leads	2
TI CD4001BPWR	SOP	14	0.64	Ni/Pd/Au	Cresol Novolac Epoxy and Biphenyl Epoxy	Cu-Fe-P	As-received	2
							Additional bending of leads	2
TI SN74ABTH18652APM	TQFP	64	0.50	Ni/Pd	Cresol Novolac Epoxy and Proprietary Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received	2
							Additional bending on leads	2
TI SN74GTLP1395DGVR	TVSOP	20	0.40	Ni/Pd	Cresol Novolac Epoxy and Biphenyl Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received	2
							Additional bending on leads	2
TI SN74ABTE16245DGGR	TSSOP	48	0.50	Ni/Pd	Cresol Novolac Epoxy and Biphenyl Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received	2
							Additional bending on leads	2
Conventional packages	DIP	14	2.54	SnPb plating		Cu alloy	As-received	3
Conventional packages	DIP	14	2.54	SnPb dipping		Cu Alloy	As-received	3

3.3.2 Test 2

In the test 2 following Telcordia Indoor MFG conditions, a longer duration of 30 days was used and more variety of test samples were included.

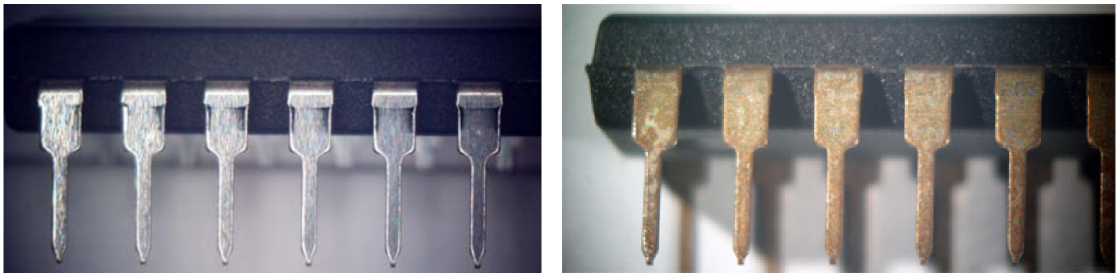
<u>Components and their results</u>

Six types of TI components were tested for this condition, see details in Table 3.17. Most of them were tested in as-received conditions. In the first 10 days, one component of each type was removed everyday from the chamber and did not put back. After 15, 20, and 30-day exposure, two components of each type were removed from the chamber and did not put back. 5 TI DIP packages were decapsulated and subjected to electrical bias of 5, 10, 15, and 20v. Each of them was removed after 5, 10, 15, 20, and 30 days of exposure. Dummy samples from Topline with and without electrical bias were tested as well. One sample for each type of them was removed after 10, 20, and 30-day exposure. Conventional SnPb dipped and electro-plated components were tested for comparison purposes. Each of them was removed after 5, 10, 15, 20, and 30 days of exposure.

Table 3.17 Components for Telcordia Indoor MFG test 2

Part No./Description	Package	Pins	Pitch (mm)	Plating	Resin	Base metal	Sample conditioning	Sample size
TI CD4001BE	DIP	14	2.54	Ni/Pd/Au	Cresol Novolac Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received	18
							Decapsulated and subjected to bias 5, 10, 15, and 20v	5
TI CD4001BM	SOIC	14	1.27	Ni/Pd/Au	Cresol Novolac Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received	16
TI CD4001BPWR	SOP	14	0.64	Ni/Pd/Au	Cresol Novolac Epoxy and Biphenyl Epoxy	Cu-Fe-P	As-received	16

TI SN74ABTH18652APM	TQFP	64	0.50	Ni/Pd	Cresol Novolac Epoxy and Proprietary Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received	16
TI SN74GTLP1395DGVR	TVSOP	20	0.40	Ni/Pd	Cresol Novolac Epoxy and Biphenyl Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received	16
TI SN74ABTE16245DGGR	TSSOP	48	0.50	Ni/Pd	Cresol Novolac Epoxy and Biphenyl Epoxy	Cu-Fe-Pb-P-Sn-Zn	As-received	16
Motorola A441YP04AA (dummy sample)	QFP	144	0.4/0.5	Ni/Pd		Cu alloy	As-received	3
Dummy samples from Topline	SIP	15	1.27	Ni/Pd/Au		Cu alloy	As-received	3
							Biased at 5, 10, 15, 20v	3
Conventional packages	DIP	14	2.54	SnPb plating		Cu alloy	As-received	5
Conventional packages	DIP	14	2.54	SnPb dipped		Cu Alloy	As-received	5


(a) Before exposure (b) After 1-day exposure

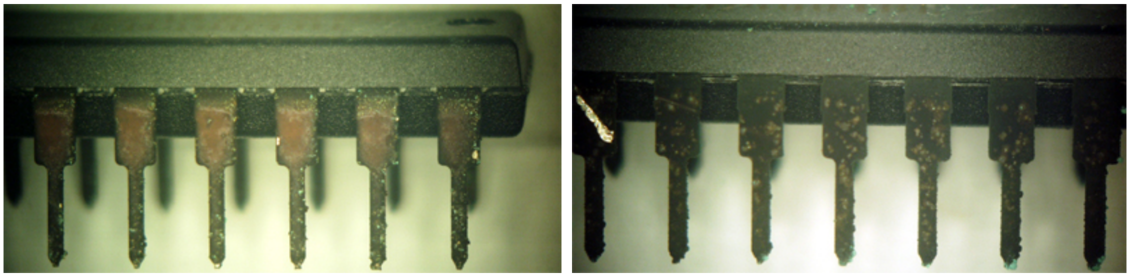

(c) After 10-day exposure (d) After 30-day exposure

Figure 3.51 Corrosion on TI DIP before and after Telcordia Indoor MFG test

Corrosion on leads was observed on all tested components, but no creep corrosion over mold compound surface was found on any of them, see Figure 3.51. SnPb coated leads had far less visually dramatic corrosion effect compared with leads with noble metal pre-plating. Electrical bias between leads did not show the promotion of corrosion on leads.

__Samples on leadframe strips and their results__

Samples on leadframe strips were included in this test. Those samples were either packages with mold compound or bare leadframes. The information about them is listed in Table 3.18. Corrosion on leads and leadframe surface was observed on those samples, but no creep corrosion was found even after 30-day exposure. On the surface of bare leadframes, pore corrosion was identified, see Figure 3.52.

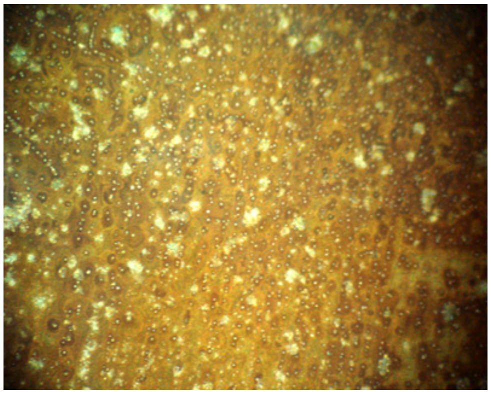


Figure 3.52 Pore corrosion identified on Shinko leadframe after 5-day exposure to Telcordia Indoor MFG test

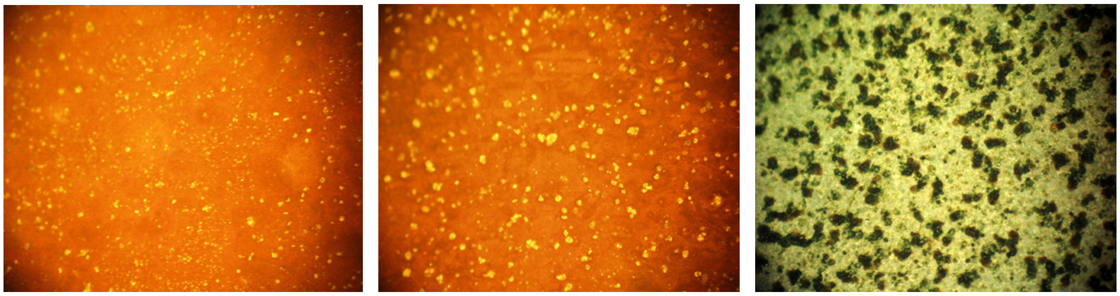
Table 3.18 Information about samples on leadframe strips

Descriptions	Package	Pins	Pitch (mm)	Plating	Base metal	Sample conditioning	Sample size
Components in strip with Shinko pre-plated leadframes	QFP	64	0.5	Ni/Pd/Au	Cu alloy	As-received	16
Shinko pre-plated leadframes in strip	QFP	64	0.5	Ni/Pd/Au	Cu alloy	As-received	16

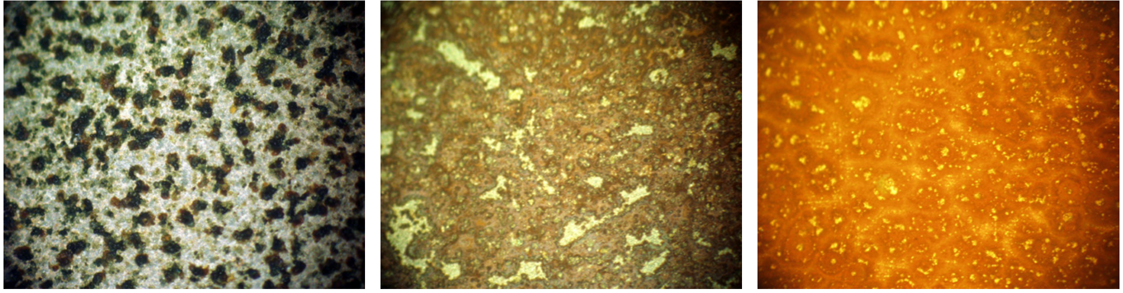
Components in strip with Mitsui pre-plated leadframes	SOIC	28	1.27	Ni/Pd/Au	Cu alloy	As-received	16
Mitsui pre-plated leadframes in strip	SOIC	28	1.27	Ni/Pd/Au	Cu alloy	As-received	16

Coupons with plating and their results

Coupons with various platings from Samsung Techwin were included for this test. Plating structure and nominal thickness are listed in Table 3.19. 3 coupons for each type were tested. One coupon of each type was removed after 10, 20, 30 day exposure. In the first 10 days, one coupon of each type was taken out for the micrograph then put back. On all coupons throughout the 30-day test period, pore corrosion was observed see Figure 3.53.



(a) Coupon A (b) Coupon B (c) Coupon C



(d) Coupon D (e) Coupon E (f) Coupon F

Figure 3.53 Pore corrosion effect on coupons after 10-day Telcordia Indoor MFG test

Table 3.19 Coupon plating structure and nominal thickness

Type	Structure	Ni (μm)	Pd (nm)	Au (nm)	Sample size
A	Cu/Ni/Pd/Au-Pd	0.64	12.7	7.6	3
B	Cu/Ni/Pd/Au-Ag	0.64	12.7	25.4	3
C	A42 PPF Type I	2.56	12.7	25.4	3
D	A42 PPF Type II	1.02	12.7	25.4	3
E	Ref 1 (Cu/Ni)	0.64	---	---	3
F	Ref 2 (Cu/Ni/Pd)	0.64	12.7	---	3

3.3.3 Summary and conclusions

From the Telcordia Indoor MFG tests, the following conclusions could be made:

- Corrosion on leads occurred on all test samples in Telcordia Indoor MFG environment.
- No creep corrosion was found on mold compound surface for the 30-day exposure to Telcordia Indoor MFG environment.
- For coupons with comparable plating structure and plating thickness, pore corrosion was identified on coupon surfaces.
- Compared with leads with noble metal plating, Sn-Pb coated leads show less attack of corrosion in the Telcordia Indoor MFG environment.

3.4 Interpretation of the three standardized MFG tests in terms of creep corrosion on packages

Three standardized MFG tests, including Telcordia Outdoor, Battelle Class III, and Telcordia Indoor tests, were conducted for the study of creep corrosion over electronic packages with noble metal pre-plated leadframes. Among them, both Telcordia Outdoor test and Battelle Class III test are capable of producing creep corrosion over mold compound surface, and Telcordia Outdoor is the more effective environment to induce and promote creep corrosion over mold compound surface. Telcordia Indoor did not induce creep corrosion within the 30-day exposure.

In the three standardized MFG environments, effects of different kinds of sample conditioning methods were also evaluated. It was found that package style and mounting configuration (un-mounted versus printed circuit board mounted), leadframe base metal and noble metal pre-plating structure, encapsulant resin system and surface roughness, electrical bias, component ultrasonic cleaning, and intentionally introduced lead surface scratches, did not have significant impact on the occurrence and progression of creep corrosion over the mold compound.

It was determined that environmental conditions are the dominant factors inducing and promoting creep corrosion over the encapsulant surface of PEM packages.

4 Analyses on the creep corrosion products

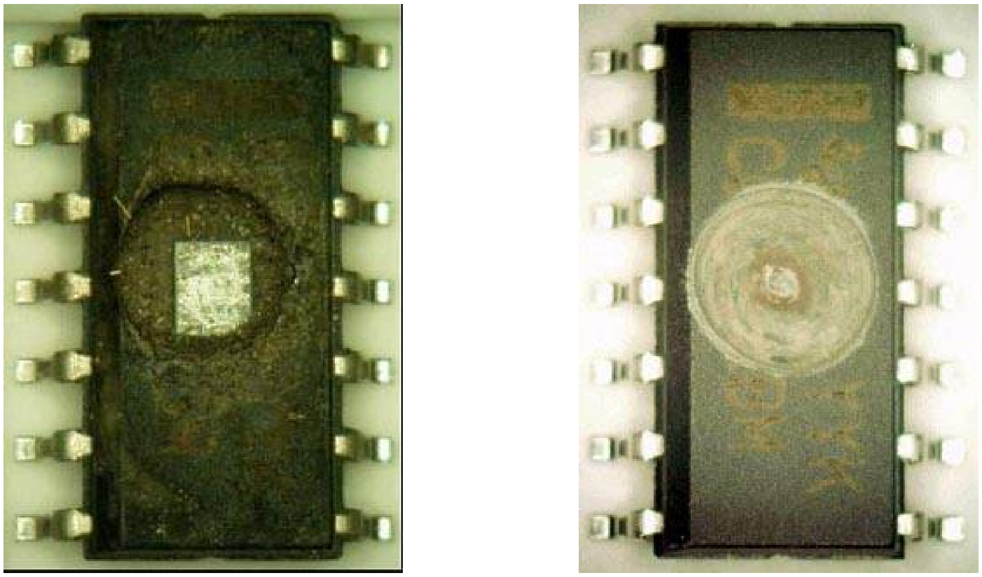
In this chapter, various properties of creep corrosion products over mold compound were characterized, including the electrical conductive nature, surface morphology and structure, and information about elemental and chemical compositions.

4.1 Electrical conductive nature of creep corrosion products

In the field failure due to creep corrosion over mold compound surface [35], electrical short was found on the failed components. This might result from the conductive nature of creep corrosion products. To evaluate and characterize the conductive nature of creep corrosion products, insulation resistance measurement was used for MFG tested components.

To find out the initial value for insulation resistance between adjacent leads, dummy components or decapsulated components should be used. Dummy components refer to packages without functional die or wire-bonding inside, so that each leads are electrically separated. Within the sample population for the MFG exposure, several kinds of samples are dummy samples, including SIP15 from Topline, QFP144 from Motorola with Ni/Pd pre-plated leadframe, and sample group provided by Philips and Samsung Techwin. For TI samples, decapsulation was applied to create samples with insulated lead pairs.

Two decapsulation methods were applied, which were chemical decapsulation and mechanical decapsulation. Chemical decapsulation used fuming acid to etch away the molding compound over the die area of the package. Then, the bonding wires were broken to cut off the electrical connection through the die. For mechanical decapsulation, a small drilling device was used to drill away the molding compound over the die. During this process, the bonding wires were mechanically damaged to isolate leads from each other. In all decapsulated components, half of them were chemically decapsulated and the other half mechanically decapsulated. The effect of these two methods was monitored and then one of them would be selected during future tests. Figure 4.1 shows the chemically decapsulated sample and mechanically decapsualted sample respectively.



(a) Component after chemical decapsulation (b) Component after chemical decapsulation

Figure 4.1 Components after chemical decapsulation and mechanical decapsulation

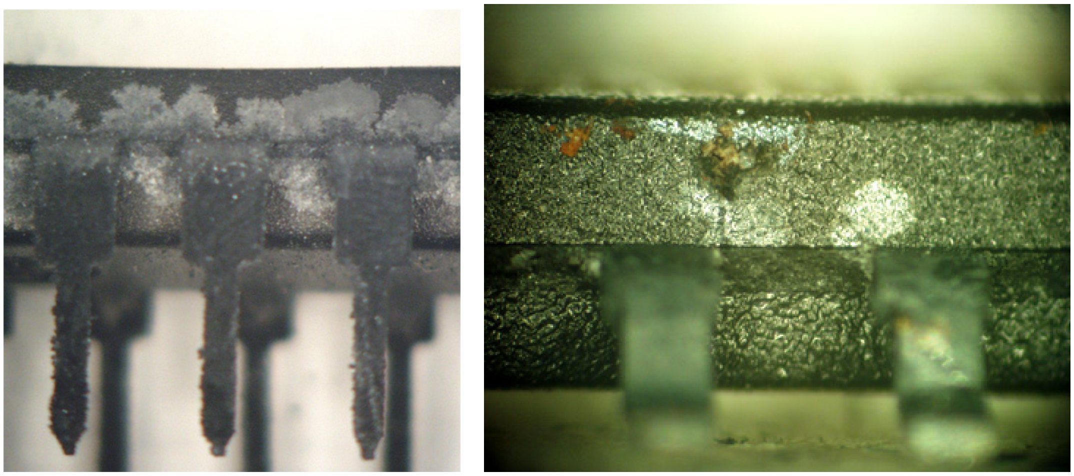
Aglient 4155C semiconductor parameter analyzer, see Figure 4.2, was used to measure the initial insulation resistance between electrically separated lead pairs. Table 4.1 shows the insulation resistance values on a TI DIP. The measurement was taken at room temperature over the ceramic substrate holder with relative humidity about 50%. It appeared that the initial insulation resistance was over the level of $10^{10}\Omega$.

Figure 4.2 Agilent 4155C semiconductor parameter analyzer

Table 4.1 Insulation resistance on a decapsulated TI DIP by Agilent 4155C

Leads pair	1-2	2-3	3-4	4-5	5-6	6-7
Insulation resistance (Ω)	$6*10^{15}$	$7*10^{12}$	$3*10^{14}$	$1*10^{13}$	$2*10^{16}$	$5*10^{12}$
Leads pair	8-9	9-10	10-11	11-12	12-13	13-14
Insulation resistance (Ω)	$9*10^{10}$	$4*10^{13}$	$4*10^{12}$	$6*10^{15}$	$7*10^{15}$	$4*10^{16}$

After the exposure to MFG environments, creep corrosion may move over the mold compound surface. If the corrosion products visually bridged the adjacent leads, see Figure 4.3(a), insulation drop was found. However, if the corrosion products did not merge with each other, see Figure 4.3(b), no insulation drop was found. The insulation resistance values for visually bridged lead pairs ranged from several hundreds of ohms to several mega ohms. An example is given in Table 4.2 to show the insulation resistance between lead pairs on decapsulated TI DIP after 10-day Telcordia Outdoor MFG test.



(a) With bridging (b) Without bridging

Figure 4.3 Lead pairs with or without bridging by creep corrosion products

Table 4.2 Insulation resistance of lead pairs on decapsualted TI DIP after 10-day Telcordia Outdoor MFG test

Leads pair	1-2	2-3	3-4	4-5	5-6	6-7
Insulation resistance (Ω)	$6*10^{15}$	$7*10^{12}$	$3*10^{14}$	$1*10^{13}$	$2*10^{16}$	$5*10^{12}$
Leads pair	8-9	9-10	10-11	11-12	12-13	13-14
Insulation resistance (Ω)	$9*10^{10}$	$4*10^{13}$	$4*10^{12}$	$6*10^{15}$	$7*10^{15}$	$4*10^{16}$

The variation of insulation resistance between lead pairs was due to several microscopic characteristics of the creep corrosion products, including conduction path, thickness of conduction film, absorbed moisture in corrosion products, etc.

4.2 Surface morphology and structure of corrosion products

Creep corrosion initiated from the individual leads but did not take the shortest path to bridge the adjacent lead over the encapsulant, and the initiation of creep corrosion over mold compound surface was not uniform in time frame even for the leads on the same components, see Figure 4.4.

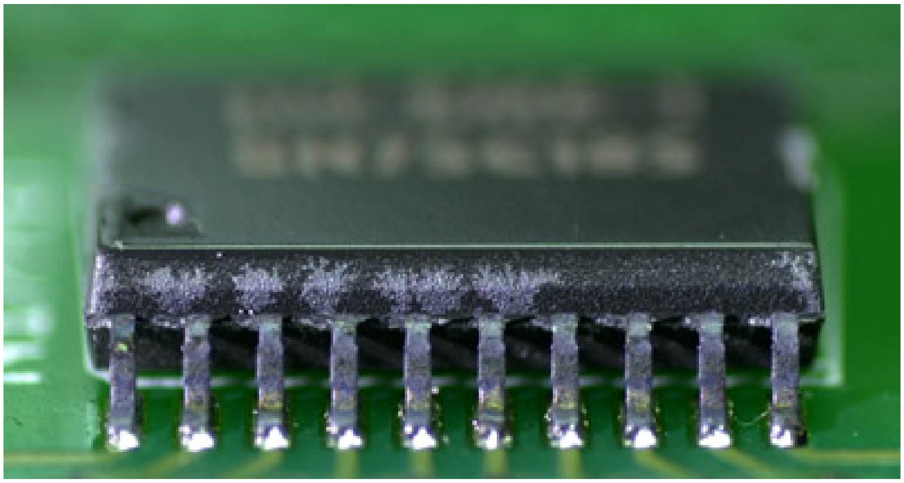
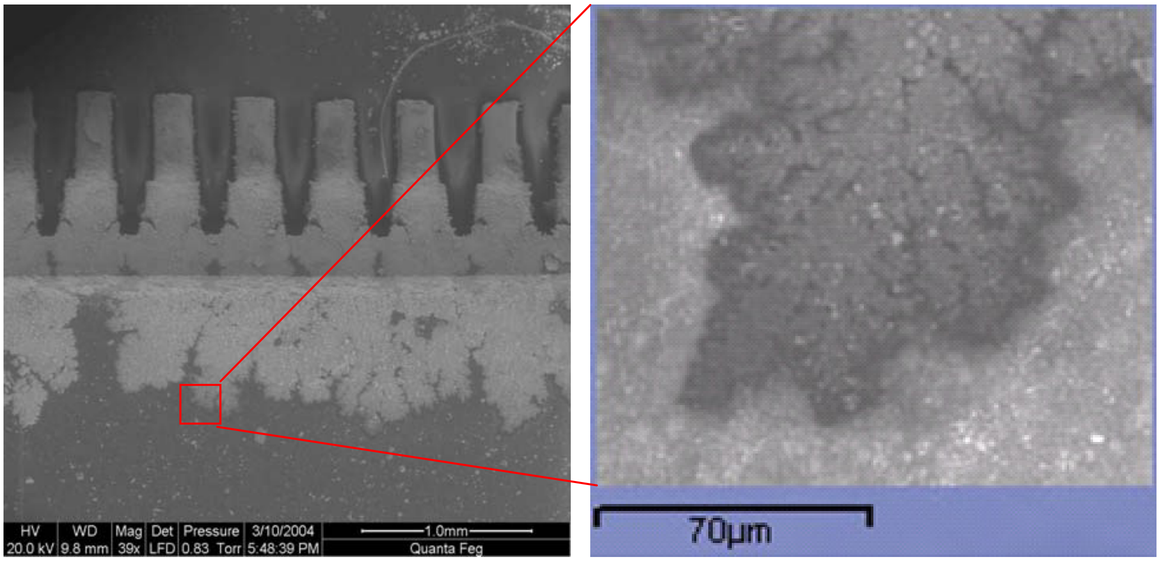


Figure 4.4 Creep corrosion on TI SOIC after 10-day Telcordia Outdoor test

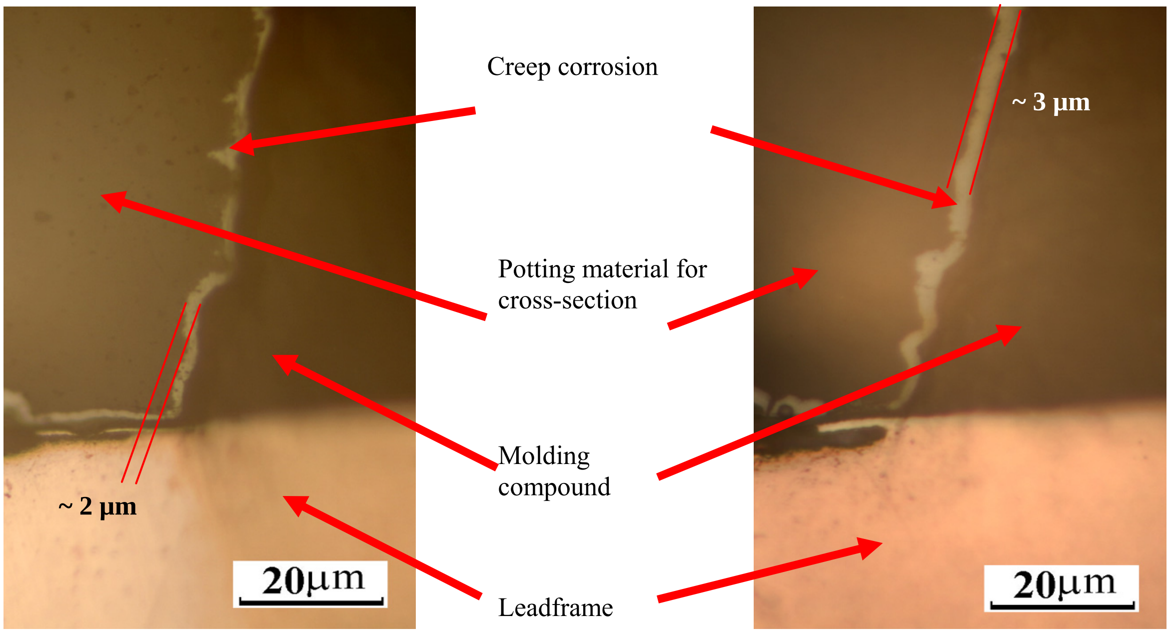
Creep corrosion products usually migrated over and adhere to the mold compound surface, rather than protruded from the molding surface. In addition, creep corrosion products had apparent dendritic formation near the leading edge of the corrosion products, see Figure 4.5.



(a) SEM overview (b) SEM local view

Figure 4.5 Dendritic formation at the leading of creep corrosion on TI TSSOP after 10-day Telcordia Outdoor MFG test

Creep corrosion products over mold compound might appear in different colors, from light shiny, to dull gray, even to dark black. It might be indicating the thickness change of the corrosion layer. For components tested in Telcordia outdoor, after 15-day exposure, the layer of corrosion products could separate from the encapsulant surface and fall off spontaneously. This might result from the evaporation of moisture from the corrosion products. Thickness of the creep corrosion products layer was evaluated by cross-sectioning the components after exposure to MFG environments. It was found out that the layer thickness increased with increased exposure duration to the test environments, see Figure 4.6.



(a) 10-day tested (b) 15-day tested

Figure 4.6 Evaluation of creep corrosion layer thickness on TI TSSOP after Telcordia Outdoor MFG exposure

From Figure 4.7, it was noticed that there was more attack by corrosion at the lead bend area. For the cross-section view of corrosion products on lead surface in Figure 4.8, the Ni plating layer was still visible, but in a disrupted manner.

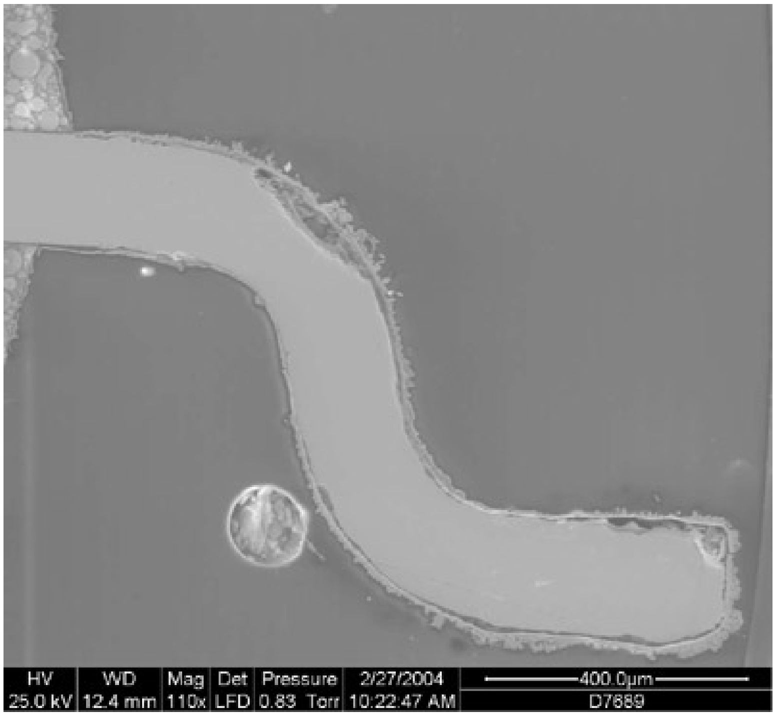


Figure 4.7 SEM overview of the cross-section of TI SOIC lead with corrosion after 15-day Telcordia Outdoor MFG test

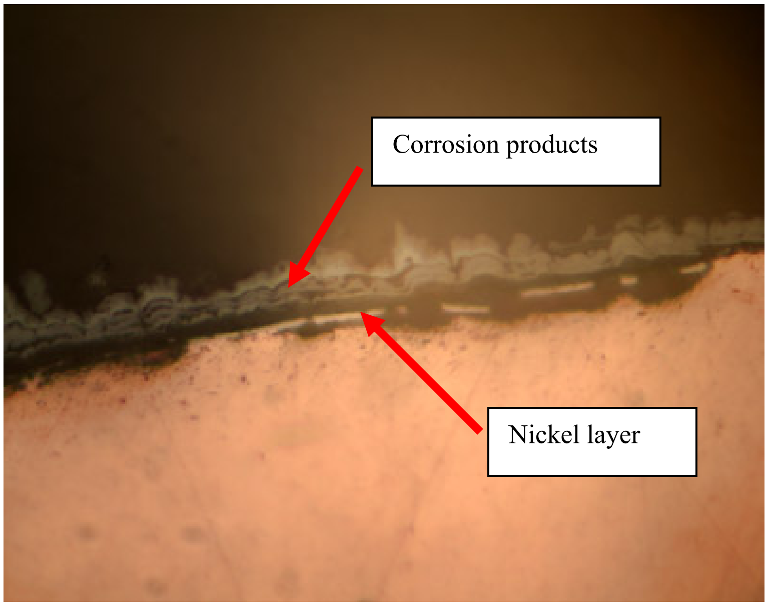


Figure 4.8 Optical view of corrosion products on lead surface of TI SOIC after 15-day Telcordia Outdoor MFG test

The corrosion products residing over the surface of the lead could be mechanically brushed off. After that, the shiny plating surface was exposed again, see Figure 4.9, which was similar to the original luster. Elemental analysis by energy dispersive spectroscopy found elements similar to the original surface.

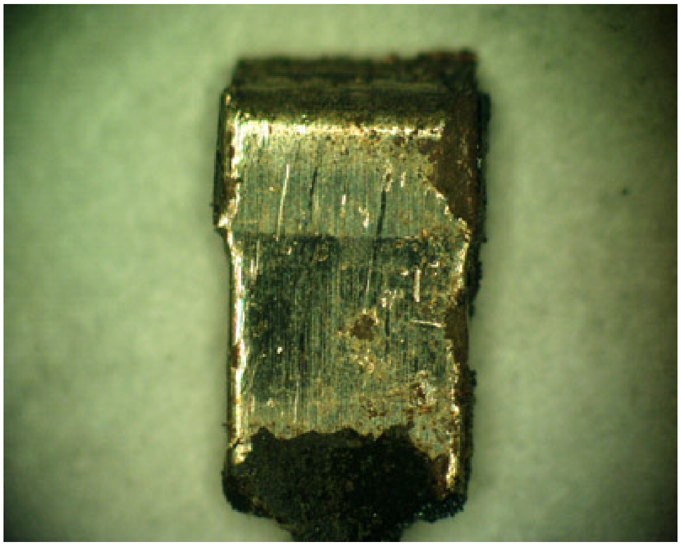


Figure 4.9 DIP lead after the corrosion products mechanically removed

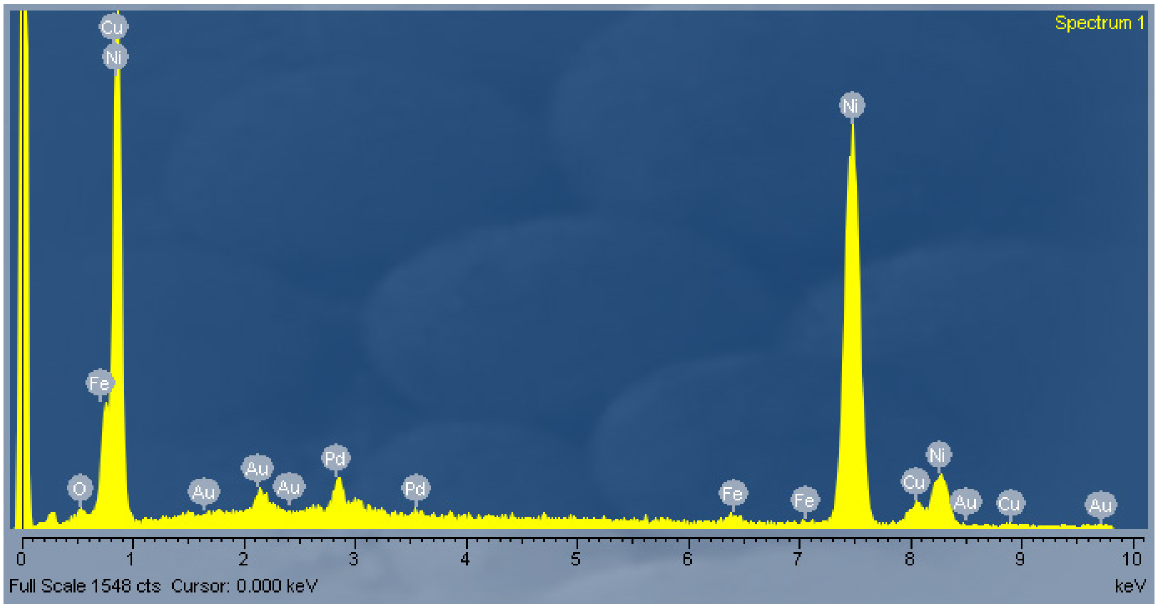


Figure 4.10 Elements on lead surface after mechanically removing the corrosion products

4.3 Elemental composition of corrosion products

High energy electrons that impact the sample yield a variety of by-products, one of which X-rays. The X-rays have characteristic energies and can be detected using a solid state energy dispersive spectrometer detector. Each element has its specific corresponding energies in the spectrum. By analyzing the information from the detector, the elemental information about the sample surface can be secured. This method is usually called energy dispersive spectroscopy (EDS). Depending on the incoming electron energy, the penetration depth varies one to several microns. In practice, EDS is most often used for qualitative elemental analysis, simply to determine which elements are present and their relative abundance.

For corrosion products produced in different MFG environments, no significant difference in elemental composition was found by EDS analysis. EDS analysis on the creep corrosion products on the mold compound surface found elements of O, Cu, Si, S, and Cl, see Figure 4.11. The presence of Si was probably due to the use of silica filler in the mold compound, and analyzing electrons penetrated the thin corrosion products layer to reach the bulk mold compound. No elements of Ni, Pd, or Au were found on the spectrum, which meant those elements or their chemical compounds did not migrate from the lead.

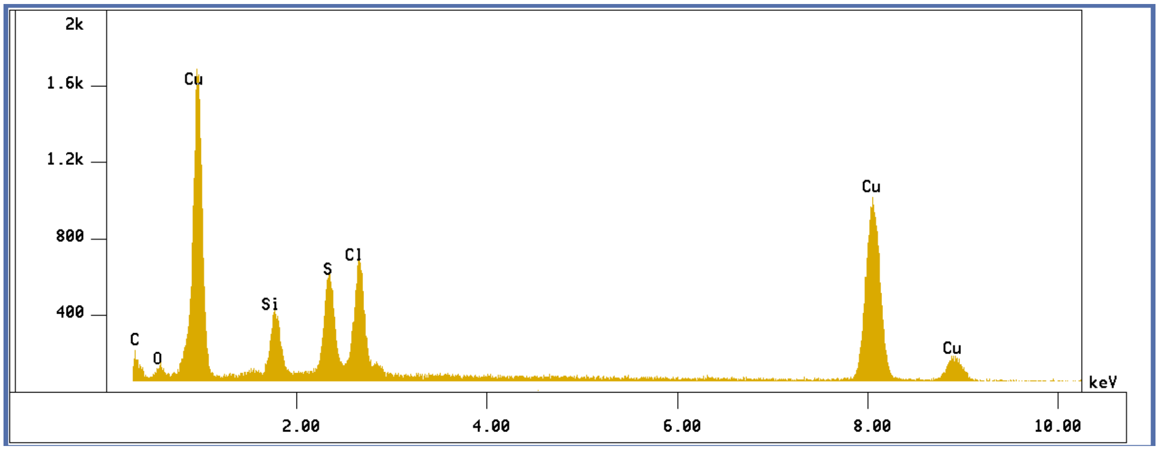


Figure 4.11 EDS analysis of creep corrosion products over molding compound surface

Figure 4.12 shows a typical spectrum for the analysis of corrosion products on lead surface. Ni was found but no Pd or Au is located. That meant Ni corrosion products mixed with the copper corrosion products and cover the underlying noble metal plating. In some cases, Fe was found due to its presence as Cu base metal alloy element.

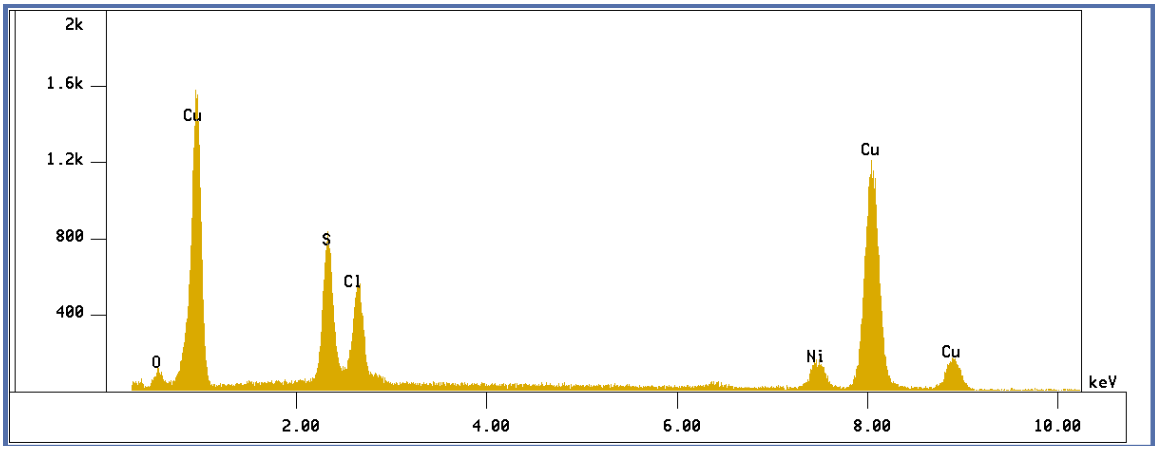
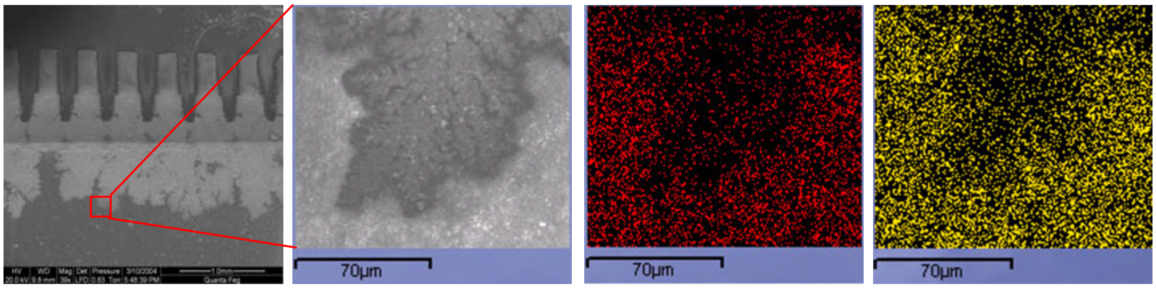
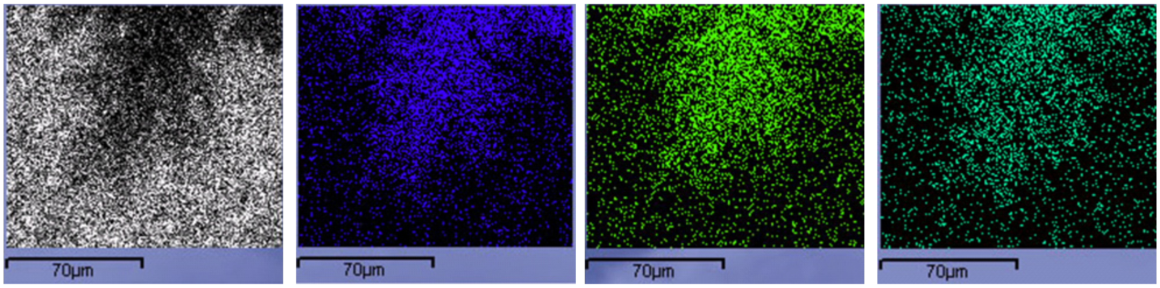


Figure 4.12: EDS analysis of creep corrosion products over lead

EDS analysis not only can do point analysis, but also mapping of elements in two dimensional areas. By this method, it is possible to see if there is a spatial distribution of elements on the specific area of samples. It is shown in Figure 4.13 that the leading edge of creep corrosion products over mold compound does not find significant elemental distribution effect by location.



SEM overview SEM local view EDS mapping: C EDS mapping: O



EDS mapping: Si EDS mapping Cu EDS mapping: S EDS mapping: Cl

Figure 4.13 EDS mapping on a 10-day Telcordia Outdoor MFG tested TI TSSOP

Although EDS is usually trusted as the qualitative analysis approach, if keeping the experimental parameters constant for the analyses, relative quantitative data can be got to interpret the changes on the sample surface. Figure 4.14 and Figure 4.15 show the percentage changes for elements on the lead surface of TI DIP throughout a 30-day Telcordia Indoor MFG test. Plating elements of Ni, Pd, and Au continuously dropped in percentage during the test. Pd and Au elements were not found after 3-day exposure, which meant corrosion products have covered up the noble plating surface. Cu, S, Cl, and O increased but reach the saturation percentage after 3 to 4 days of exposure, which meant Cu corrosion products continued to generate but keep the relatively stable elemental compositions.

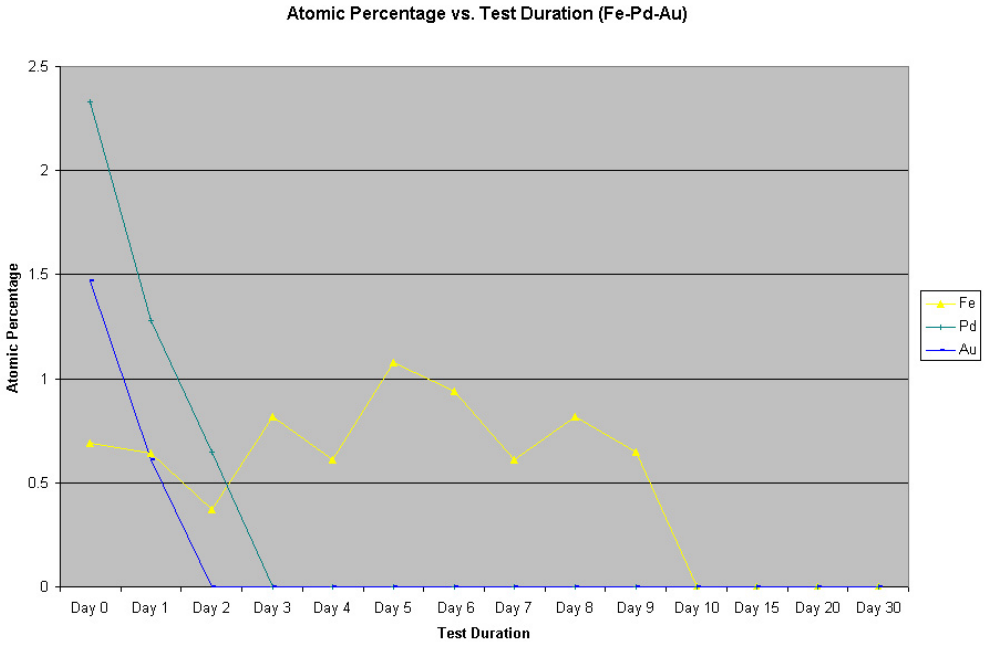


Figure 4.14 Elemental percentage changes on TI DIP lead corrosion products during a 30-day Telcordia Indoor test (part I for low content elements)

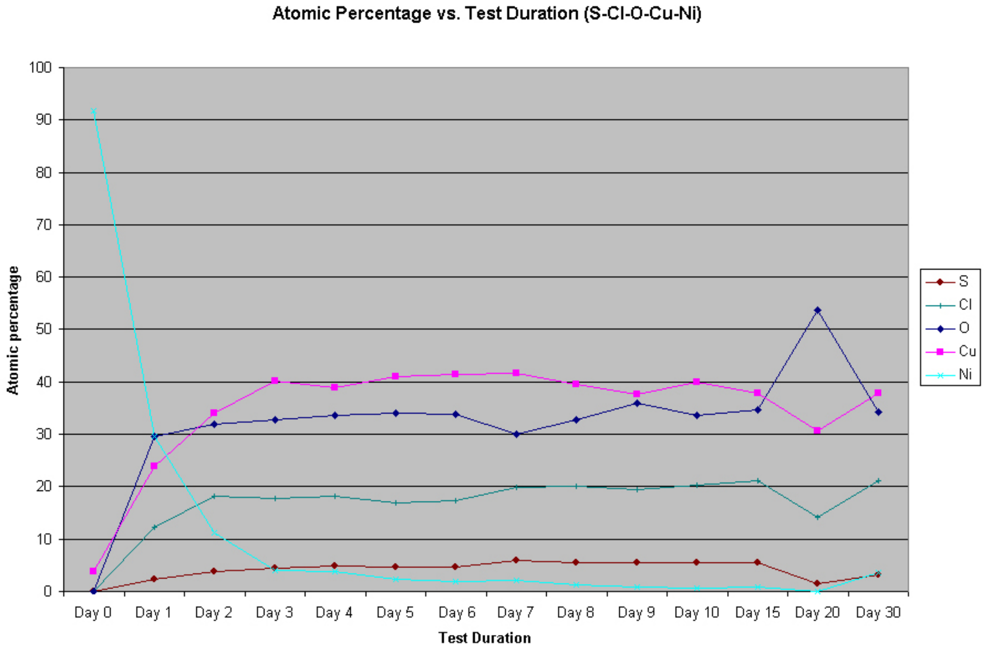


Figure 4.15 Elemental percentage changes on TI DIP lead corrosion products during a 30-day Telcordia Indoor test (part II for high content elements)

4.4 Chemical composition of corrosion products

Although by EDS analysis, elemental composition of corrosion products could be determined, the way how those elements combine with each other was not clear. X-ray photoelectron spectroscopy and X-ray diffraction spectroscopy are the two applicable surface analysis techniques to probe the chemical composition information of materials.

Surface analysis by XPS involves irradiating a solid in high vacuum with mono-energetic x-rays and analyzing the emitted electrons by energy. Because the mean free path of electrons in solids is very small, the detected electrons originate from only the top few atomic layers, making XPS a highly surface-sensitive technique for chemical analysis. The spectrum is obtained as a plot of the number of detected electrons per energy interval versus their binding energy. Variations in the elemental binding energies arise from differences in the chemical potential and polarization of compounds. These chemical shifts can be used to identify the chemical state of the materials being analyzed [36].

The X-ray photoelectron spectroscopic measurements were conducted using Kratos Axis 165 spectrometer at a vacuum of $4x10^{-10}$ Torr with non-monochromatic Mg Kα radiation. The X-ray power used was about 144 W. A wide scan survey, example in Figure 4.16, was used to find out the available elements on the surface. For our case, high resolution scan was conducted for the elements of Cu 2p, C1s, Cl 2p, O1s and S 2p. All measurements are done in hybrid mode using both electrostatic and magnetic lenses, with a step size of 0.1 eV and sweep time of 80 s. Survey spectrum was only 2 scans with pass energy of 160 eV. All individual region spectra were recorded in the FAT (Fixed Analyzer Transmission) analyzer mode with pass energy of 80 eV, and an average of 10 scans. The binding energies were not calibrated and the charge neutralizer was off during the measurements.

Data processing was done using Vision processing software. Binding energies were calibrated by the adsorbed adventitious C1s at 284.6 eV [37]. After subtraction of a linear background, all spectra were fitted using 60% Gaussian / 40% Lorentzian peaks, taking the minimum number of peaks consistent with the best fit. The important parameters used for this fitting are peak position, full width at half maximum, and spin orbit coupling. Figure 4.17 shows an example of Cu high resolution spectrum after fitting, in which two chemical states of Cu are located, with binding energies at 932.945 eV and 935.695 eV respectively.

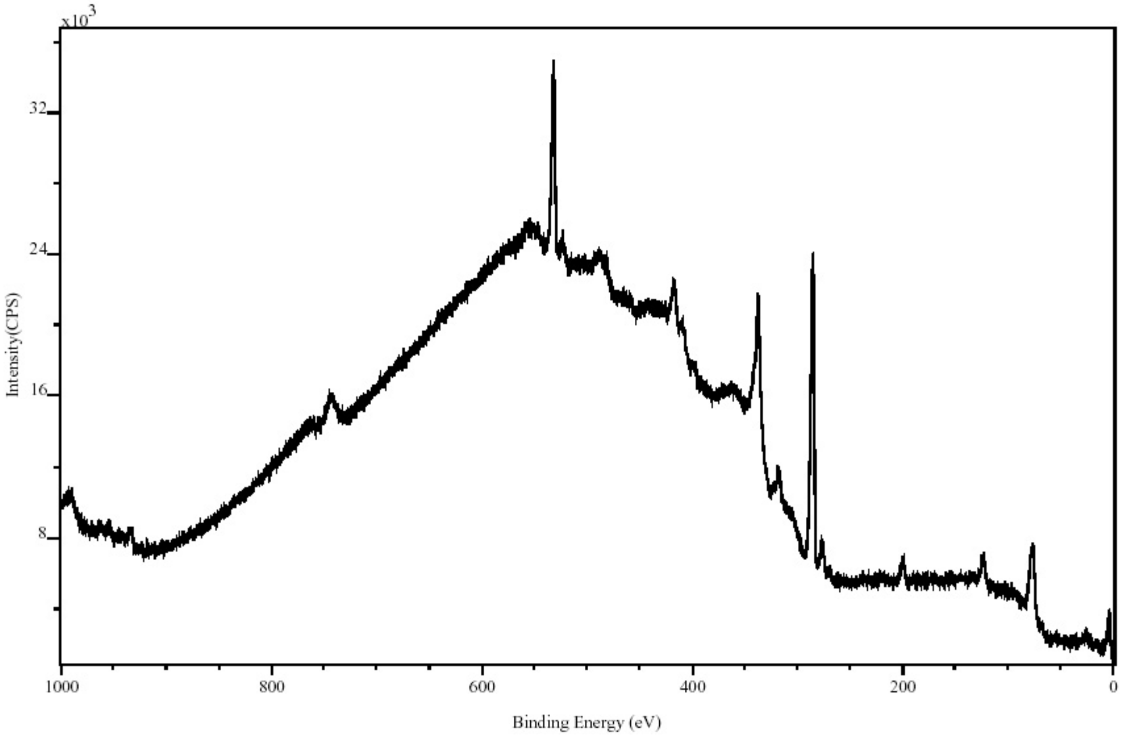


Figure 4.16 A survey scan for corrosion on lead after MFG exposure

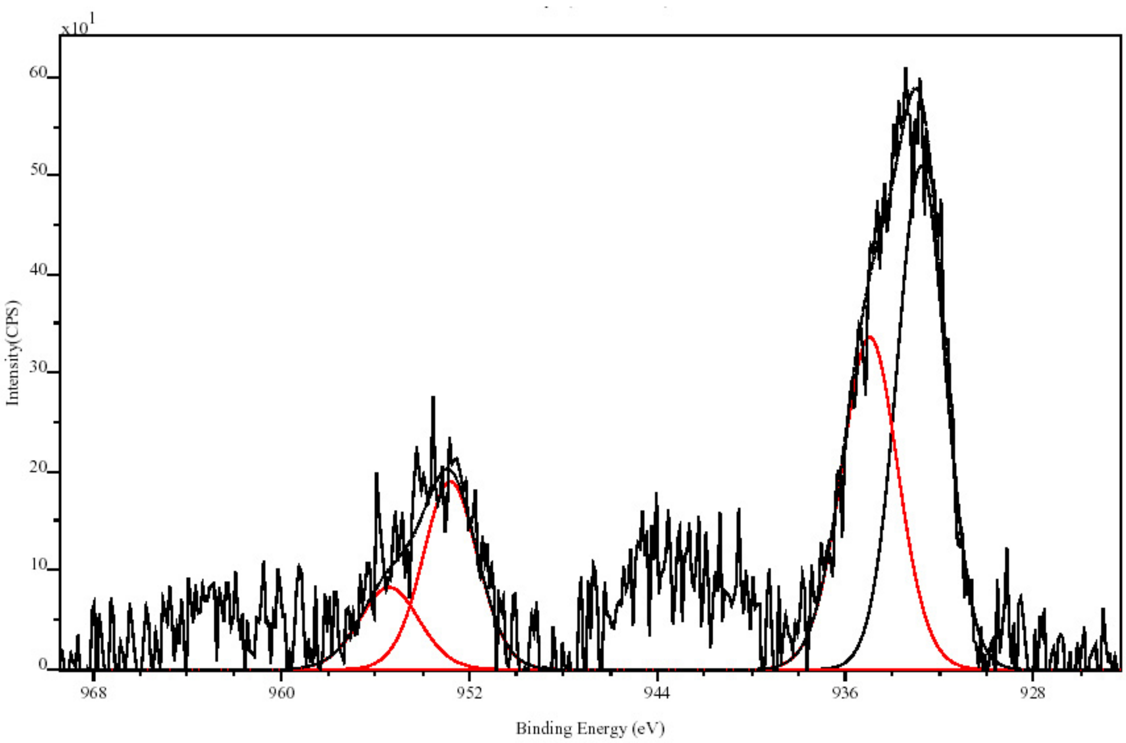


Figure 4.17 High resolution scan for Cu in an XPS spectrum

Data is interpreted using the NIST XPS database at http://srdata.nist.gov/xps/Bind_E.asp [38]. For example, to analyze Cu and Cl for their possible chemical combinations, the binding energies for Cu and Cl should be first located from the high resolution scan. For Cu, there were two chemical states, 932.9eV and 935.7eV. For 932.9eV, considering the variation of +/-0.3eV, possible materials could be CuCl (932.6eV for Cu), Cu2O (932.8eV for Cu), CuO (932.9eV for Cu) and Cu_2S (932.9eV for Cu). For 935.7eV, possible materials could be $CuCl_2$, $CuSO_4.nH_2O$. For Cl, there are two chemical states, 198.2eV and 199.6eV. For 198.2eV, CuCl (198.4eV for Cl) is possible. For 199.6eV, $CuCl_2$ (199.4eV for Cl) was possible. Therefore, the corrosion products might have CuCl and $CuCl_2$ on top surface. Following the same philosophy, the chemical compositions of corrosion products could be interpreted by looking up the high resolution scan data for all available elements.

Ion sputtering can be combined with XPS analysis to get chemical composition information along the depth. For this study, Ar^+ ion at 4Kev under the pressure of $2.8*10^{-7}$ Torr was used for the sputtering process. Ion sputtering was conducted on corrosion products over lead and mold compound after 10-day Telcordia Outdoor tested DIP packages.

Chemical composition of corrosion products after three previous MFG studies (Telcordia Outdoor, Battelle Class III, and Telcordia Indoor), both on the lead and on the mold compound surface if applicable, are listed in Table 4.3

Table 4.3 Chemical composition for corrosion products after the three standardized MFG tests

Test environment	Surface locations	Analysis techniques	Chemical compounds identified
Telcordia Indoor 10-day	Lead	XPS	$CuCl_2$, CuCl, Cu_2S, Cu_2O
Telcordia Outdoor 10-day	Lead	XPS	$CuCl_2$, CuCl, Cu_2S, CuS, $CuSO_4$, Cu_2O, CuO
		XPS depth profiling	$CuCl_2$, CuCl, Cu_2S, CuS, Cu_2O, CuO
	Mold compound	XPS	$CuCl_2$, CuCl, Cu_2S, CuS, $CuSO_4$, Cu_2O
		XPS depth profiling	$CuCl_2$, CuCl, Cu_2S, CuS, Cu_2O
Battelle Class III 10-day	Lead	XPS	$CuCl_2$, CuCl, Cu_2S, CuS, and Cu_2O
	Mold compound	XPS	$CuCl_2$, CuCl, and Cu_2O

According to Table 4.3, there is no significant difference in corrosion product compositions between the three MFG testing environments (Telcordia Indoor, Outdoor and Battelle Class III). There was no distinct difference in corrosion products compositions between on the lead and on the mold compound surface. Creep corrosion products appeared to be a combination of copper oxides, copper chlorides and copper sulfides. Cu oxides might be the major constitutes of corrosion products, as O remained high throughout the XPS analyses (>70%). (However, since Cu_2S and CuS were not found in corrosion products over mold compound after Battelle Class III test, they might not contribute to the corrosion products migration process.)

X-ray diffraction is another way to find out chemical composition of materials. An x-ray beam is produced using a high energy source applied to a vacuum tube, a sample placed in the path of the beam diffracts the x-rays in a signature pattern according to the lattice structure of any crystalline substance present, and the resulting diffracted pattern intensity is counted at specific angles with a rotating detector. Results taken from the detector and compared to analytical standards to determine amount present on each sample. The spectrum is obtained as a plot of the signal strength versus the diffraction angles, example shown in Figure 4.18. According to the spectrum, individual peaks at different angles are located. Based on Bragg's equation, $\lambda=2d\sin\theta$, since diffraction angle "θ"and wavelength "λ"are known, inter-atomic spacing "d" can be calculated. By using the handbook database for XRD analysis [39], the corresponding chemical composition for the specific "d" can be deciphered.

The analysis was conducted on a XRD 3000 system at NIST. Due to the limitation of sample fixture, only corrosion products over TI DIP lead were analyzed. For samples both after Telcordia Indoor test and Telcordia Outdoor test, CuCl and Cu_2O were confirmed to be present in the corrosion products. In addition, a variety of copper sulfide compounds (Cu_2S, CuS, etc.) were possible in the corrosion products with a low concentration. Those results were compatible with the XPS analysis.

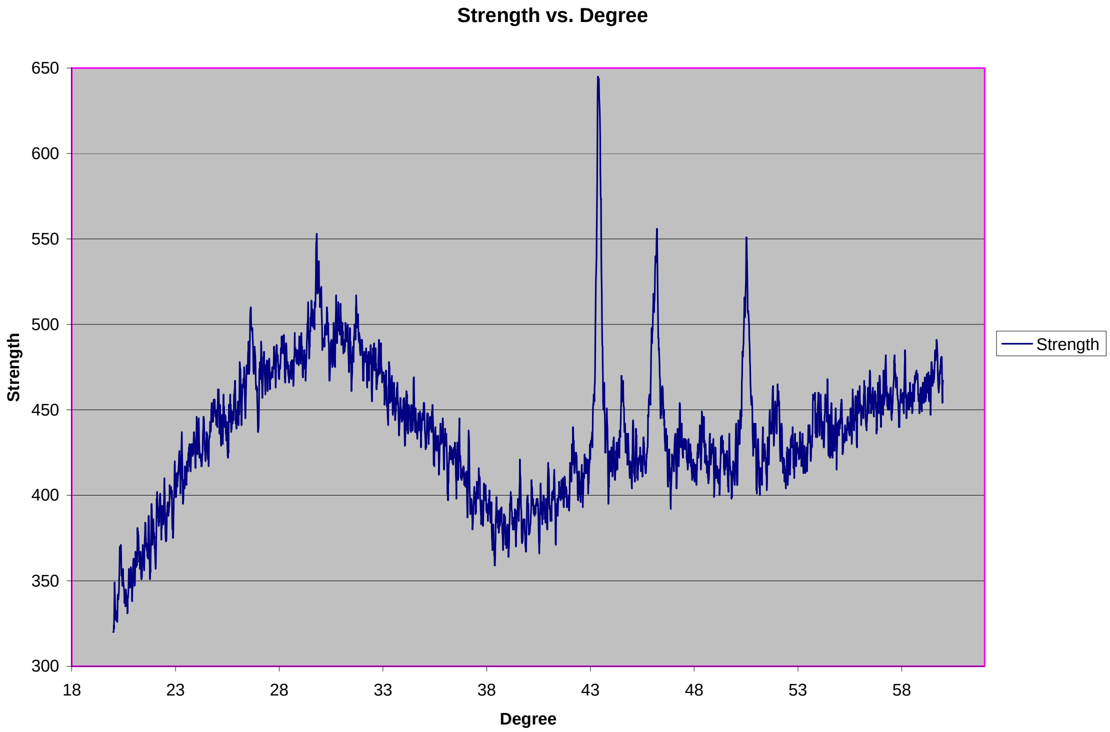


Figure 4.18 A spectrum by XRD for corrosion products on TI DIP after 10-Telcordia Outdoor MFG test

4.5 Summary and conclusions

The characterization of corrosion products on components after MFG exposure demonstrates the following conclusions towards creep corrosion.

- Creep corrosion products are electrically conductive and may bridge the adjacent leads to cause the short.
- Creep corrosion products reside over the surface of package mold compound with dentritic formation and may increase in layer thickness with extended exposure.

- Creep corrosion products appear to be a combination of copper oxides, copper chlorides and copper sulfides. Cu oxides maybe the major constitutes of corrosion products, as O remained high throughout the XPS analyses (>70%).
- There is no significant difference in corrosion product composition between the three MFG testing environments (Telcordia Indoor, Outdoor and Battelle Class III).
- There is no significant difference in corrosion product composition between on the lead and on the mold compound surface.

5 Discussions

In the first part of this chapter, interpretations are provided to explain why the propensity of creep corrosion behaves differently in the three standardized MFG tests. Following that, the mechanism of creep corrosion on packages with noble metal pre-plated leadframes is discussed. After it, the guidelines to conduct MFG testing for evaluation of risk to creep corrosion are developed. In the end, mitigation strategies against creep corrosion in electronic applications are generalized.

5.1 Why the propensity of creep corrosion behaves differently in the three standardized MFG tests?

In contrast to Battelle Class III environment, one obvious difference in Telcordia Outdoor MFG test is the addition of SO_2 in the gas combination. Although SO_2 is believed not to be a dominant factor to drive copper corrosion [29], it has been regarded as the major contaminant to effect the corrosion of nickel [25] [40]. For the case of noble metal pre-plated leadframes, corrosion of Ni barrier layer can be accelerated by adding SO_2 to the gas mixture [25] [32]. This could result in a greater degree of exposure for the Cu base metal, potentially increasing the likelihood of creep corrosion over the lead and mold compound.

Between Telcordia Outdoor and Telcordia Indoor, gas concentrations are the major difference. This difference may results in dramatic different reaction rates even if they have the same mechanism. For the limited test duration, like 30 days, the corrosion kinetics in the Telcordia Indoor environment may not generate comparable amount of corrosion on the lead surface to induce creep corrosion on the mold compound.

5.2 The mechanism of creep corrosion on packages with noble metal pre-plated leadframes

This section firstly gives an overview of previous studies on creep corrosion in the literature. Following that, the mechanism for creep corrosion on packages with noble metal pre-plated leadframes is explained. At last, the experimental results are provided to support the theory.

5.2.1 Overview of creep corrosion studies

Creep corrosion is a mass transport process during which solid corrosion products migrate over a surface [35]. It is a reliability risk for components with noble metal pre-plated leadframes, and has been identified as a cause of failure in fielded devices [35]. Creep corrosion was first reported on gold plating over a silver substrate [14], whereby silver sulfide was observed to spread over the gold plating surface when exposed to 60°C sulfur vapor for a couple of hours. When the exposure period was extended, the maximum creep distance increased.

Antler [16] reported findings on the growth and morphology of sulfide tarnish films on gold. Gold plating over silver, beryllium copper, and phosphor bronze were subjected to a 1.6ppm H_2S environment with 85% RH at 90°F for 2 weeks. He observed that creep corrosion was rapid at first and then slowed to a negligible rate. Among the three base materials, silver had the most rapid creep corrosion rate.

Abbott [17] studied the kinetics of tarnish film creep for gold electroplates on Ag, Cu, and Ni substrates. He observed high creep rates for silver films, low rates for nickel, and intermediate rates for copper. Effects of gold-plating types were also determined. Gold plating alloys could make a distinction on the creep corrosion rates. For example, he found that Au-1.0In alloy plating produced good inhibition of creep corrosion.

In a later study by Abbott [41], mixed flowing gas was used as the testing environment. He found that sulfide films have a high tendency for creep corrosion, but synergistic effects occurred between chloride and sulfide contaminants. It was shown that both the contact finish and the reactive substrate material had a major influence on the creep process. Among the tested materials, pure gold showed the highest creep corrosion rates.

Tierney [18] exposed gold plated copper coupons in H2S flow. He showed that creep corrosion distance increased linearly with the square root of time for an approximately the first 100 hours of exposure. Thermally produced Cu_2O films can greatly reduce further tarnish of copper surfaces under realistic humidity and temperature conditions. He showed that copper sulfide is a key ingredient for creep corrosion. The morphology of copper creep corrosion over gold plating was described as a progressive band structure, with the edges of bands showing vertical growth.

Conrad [19] studied noble and non-noble metal plating (gold, palladium, and Sn-Pb) over different base metal materials were exposed to the flow of dry and wet H2S. Quantitative measurements of creep corrosion distance showed that Sn-Pb was least susceptible to creep corrosion. The palladium and gold enabled the largest creep corrosion distance. Base metal materials also had the influence on the creep corrosion distance. Among Brass, Bronze, and Copper-Nickel alloy, Brass showed most resistance to creep corrosion, while Copper-Nickel showed least. A model was proposed to explain this phenomenon using galvanic theory combined with the effects of electron transfer and ion diffusion. The driving force for the reaction is regarded as the electron flow resulting from the electrical potential differences between copper and gold.

Rice [42] studied the environmental and material factors that influence creep corrosion on hard gold plating over high purity copper, silver, and nickel. Various mixed flowing gas tests that contained combinations of Cl_2, NO_2, and H_2S were conducted. Copper and silver showed significant product mobility, while nickel corrosion products did not migrate onto the gold surface. The incubation period and creep corrosion distance were found to be dependent upon the Cl_2 concentration. The propensity to creep was observed to directly depend on the relative humidity. Auger spectroscopy showed copper oxide in the corrosion products along with trace amount of Cl and S combined with Cu.

Williams [20] explored creep corrosion over precious metal inlays using Battelle mixed flowing gas tests. His findings about creep corrosion distance were compatible with previous results. Shielding by connector housing and plating surface lubrication were demonstrated to be effective approaches to reduce or eliminate creep corrosion. This is reasonable since less gas would have access to react with the enclosed or underlying surface with plating.

Geckle and Mroczkowski [21] conducted Battelle Class III mixed flowing gas tests to study creep corrosion of copper alloys with a nickel underplate followed by a precious metal surface plating of gold or gold flashed palladium. The base metal corrosion products were found to arise from plating defects, creating films and corrosion mounds on the surface and etch pits in the copper alloy substrate. The creep corrosion products were found to be a complex mixture with elements of copper, nickel, oxygen, chlorine, and sulfur in varying amounts and distributions.

Haynes and Baboian [43] conducted various mixed flowing gas tests to study creep corrosion of gold plated copper with barrier layers of nickel, aluminum, and stainless steel. The corrosiveness of the mixed flowing gas in terms of the thickness and distance of the creep corrosion products decreased in the following order: high-Cl_2-high-H_2S, high-Cl_2-low-H_2S, and low-Cl_2-high-H_2S. Most of the corrosion product creep over gold occurs during the early stages of mixed flowing gas testing. The degree of creep appeared to be influenced by the galvanic relationship of the metallurgy components. Creep corrosion distance with CDA725 was greater than those with pure copper. Both aluminum and type 304 stainless steel were found to inhibit creep corrosion.

In a following study, Haynes and Baboian [22] investigated creep corrosion of copper clad on stainless steels via mixed flowing gas tests. The rate of creep was found to be directly proportional to the alloy content, 321>304=430>409, which was the generally accepted corrosion resistance of the stainless steels.

The authors believed that the driving force for copper ion migration over gold involve the local galvanic cell between the dissimilar metals. The creep corrosion behavior was also observed to be influenced by the degree of corrosion on the stainless steel surface as well as the galvanic relationship.

Xie and Pecht [23] studied creep corrosion of IC packages with noble metal pre-plated leadframes. It was illustrated that the phenomenon of creep corrosion could occur not only on the noble plating surface, but also on the epoxy molding compound, causing electrical short or leakage current between adjacent leads.

5.2.2 The mechanism of creep corrosion

For creep corrosion to occur, there must be some corrosion products. On components with noble metal pre-plated leadframes, exposed copper at dam-bar cut, cracks at lead bend, and plating porosity are initiating sites to be attacked by corrosion. Due to the very thin nature of noble plating, porosity is inevitable and may act as a major source for corrosion initiation. When base copper is exposed to ambient air, surface films would form a two-layer structure, with an inner layer of Cu_2O and an outer layer comprising adventitious hydrocarbon and bound hydroxyl and water [44]. The adsorbed water layers act not only as a medium for electrochemical reactions but also as a solvent for atmospheric constituents, either gaseous or particulate [25]. The layer of Cu_2O is protective for the underlying Cu. However, after gaseous contaminants dissolved into water, the water layer turns into an ionic solution. The protective Cu oxide layer will be disrupted and the dissolution of Cu begins to start. The produced copper ions would combine with the externally dissolved ions to form and deposit as corrosion products.

The migration of corrosion products from the source can be categorized into three effects: volume expansion, electro-chemical reactions, and dissolution/diffusion/redeposition mechanisms. Volume expansion occurs because corrosion products are generally less dense materials than the metals themselves. For example, the density of copper is $8.9 g/cm^3$, while that of $CuCl_2.2H_2O$ is $2.54 g/cm^3$ [45]. The “volcano” looking effect of corrosion products in pore corrosion [21][46] provides supporting evidence for the volume expansion nature in corrosion. However, volume expansion of corrosion products can not explain the non-uniform nature of creep corrosion.

Surface adsorbed water layers are indispensable to the electro-chemical process and are closely related to environmental relative humidity levels. There have been studies to show that number of adsorbed water mono-layers on clean metals increases as the relative humidity level rises [25]. The variation in water adsorption characteristics can be caused by a number of factors, including the hydrophobic or hydrophilic properties of solid surface and its density of defects [25]. Figure 5.1 shows the approximate layers of adsorbed water on clean metals as a function of relative humidity.

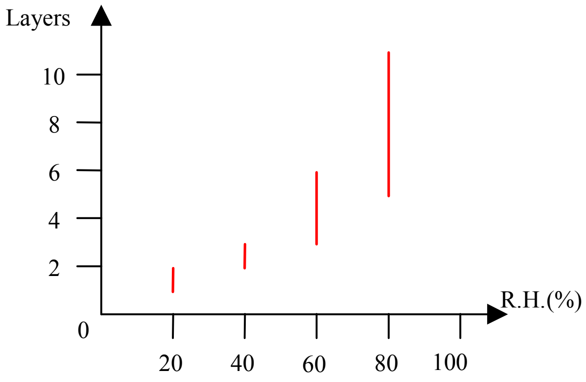
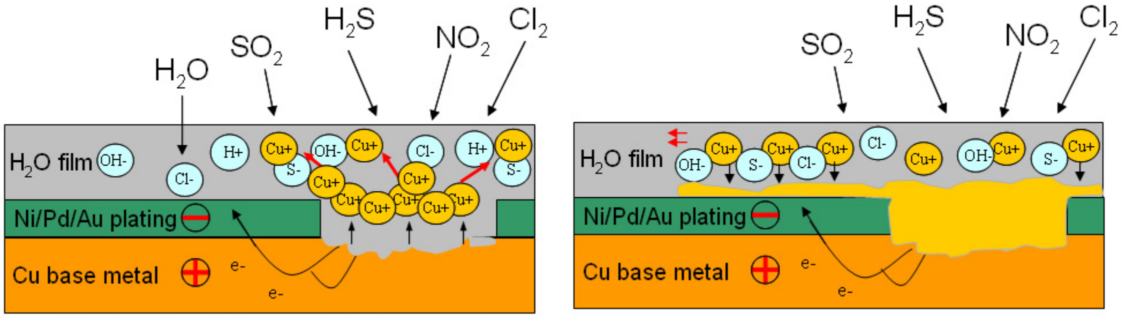


Figure 5.1 Number of adsorbed water mono-layers on clean metals as a function of relative humidity

The electro-chemical reactions are based on galvanic effects to explain creep corrosion over noble metal plating [19][22][43][47]. A potential difference usually exists between two dissimilar metals when they are immersed in a corrosive or conductive solution [48]. The less corrosion resistant metal becomes anodic and the more resistant metal cathodic. There is an electromotive force (EMF) series for difference metals, see Table 5.1 [48]. For example, if Cu is in contact with Au, the potential between would be close to 0.7 volts. This potential accelerates the electro-dissolution of Cu into the ionic electrolyte. Due to the mobility of ions in the electrolyte, Cu ions transport away from its original sites and eventually deposit on the cathodic areas as Cu salts, including copper sulfides and copper chloride. The process of this corrosion initiation and accumulation on the lead surface can be shown in Figure 5.2.

Table 5.1: Standard electromotive force series of metals

	Metal-metal ion equilibrium (unit activity)	Electrode potential vs. normal hydrogen electrode at 25 degree C (volts)
Noble or cathodic	Au → Au^{+3}	+1.498
	Pd → Pd^{+2}	+1.2
	Cu→ Cu^{+2}	+0.788
Active or anodic	H2 → H^{+}	0.000
	Pb → Pb^{+2}	-0.126
	Sn → Sn^{+2}	-0.136
	Ni → Ni^{+2}	-0.250



Electro-dissolution and ion transport

Electro-deposition

Figure 5.2: Schematics for corrosion initiation and accumulation on lead

Electro-chemical reactions may explain the generation of creep corrosion from a metallic source onto a noble metal, but do not explain creep corrosion over a molding compound surface, which is a non-metallic surface free from galvanic effects. The dissolution/diffusion/redeposition mechanism requires high relative humidity, usually above, 70% or 75%, such that multiple mono-layers of water will be adsorbed onto the surface [25][49]. If the corrosion products are soluble in water or ion-filled acidic solutions resulting from gas absorption into surface water layers, those corrosion products can thereby diffuse over the surface in solution down the concentration gradient, and redeposit. The process is schematically shown in Figure 5.3. To verify this hypothesis, additional experiments as described in section 5 were conducted.

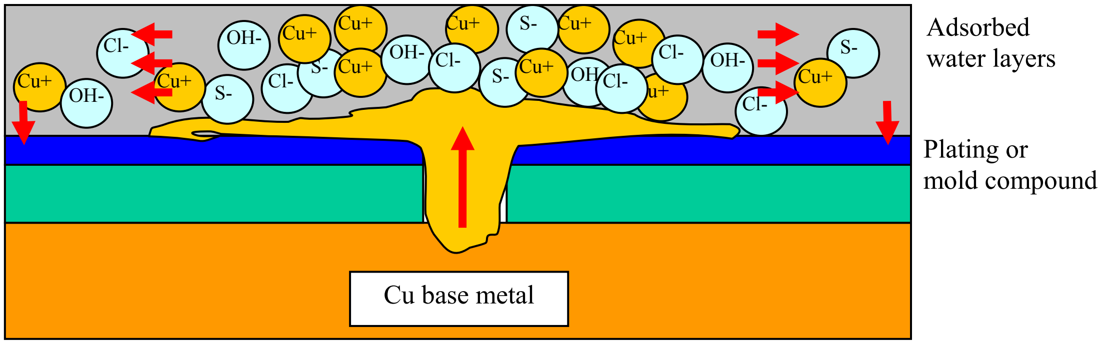


Figure 5.3: Diagram to illustrate creep corrosion by dissolution/diffusion/redeposition

5.2.3 Verification experiments and supporting results

To verify the hypothesis for the mechanism of dissolution/diffusion/redeposition, two sets of additional experiments were conducted. One set were mixed flowing gas tests with relative humidity variations, which demonstrated the effects of relative humidity and corrosive gas concentrations on creep corrosion. The other set of tests were the environmental chamber exposure (temperature/relative humidity), which demonstrates the behavior and process of external deposited corrosion products due to the mechanism of dissolution/diffusion/redeposition.

5.2.3.1 Effects of relative humidity and corrosive gas concentrations

In order to evaluate the role of relative humidity and corrosive gas concentrations in creep corrosion, two non-standard mixed flowing gas environments were investigated. These conditions are described in Table 5.2. Environment D is the modified Telcordia Outdoor MFG environment with RH at 60% instead of 70%. After 10 days exposure, creep corrosion occurred on the lead surface, but not enough to move onto the molding compound surface, as was observed in the 10-day standardized exposure test. This suggests that surface adsorbed water, which is the medium for migration, may not be sufficient to dissolve corrosion products from the source and act as the carrier in this revised environment.

Environment E is the modified Telcordia Indoor MFG environment with RH at 80% instead of 70%. After 10 days exposure, creep corrosion occurred on lead surface, but not yet onto the mold compound surface. This result demonstrated the importance of corrosive gas levels. The gases dissolve into the surface adsorbed water to react with the base metal and assist the dissolution/diffusion of corrosion products from their source.

Table 5.2: Two non-standard mixed flowing gas environments for the study on the effect of relative humidity

Environments	T (ºC)	RH (%)	H_2S (ppb)	Cl_2 (ppb)	NO_2 (ppb)	SO_2 (ppb)	Duration
D	30±1	60±2	100±15	20±3	200±30	200±30	10 days
E	30±1	80±2	10±1.5	10±1.5	200±30	100±15	10 days

5.2.3.2 Temperature/Relative Humidity Exposure Testing

To assess the nature of the creep corrosion process, corrosion products were manually placed on noble metal plating and mold compound and, were then subjected to 85°C/85% RH exposure. In the same experiment, reagent-grade $CuCl_2$ was placed on the noble metal plating and mold compound surface. This material is one constituent of the corrosion products which is always found on samples subject to the three standardized mixed flowing gas tests. Before, during and after the exposure, optical microscopy and SEM analyses were conducted.

The deposit of $CuCl_2$ on Ni/Pd/Au plated copper coupon (see Figure 5.4) spreads out when exposed in the 85°C/85% environment (see Figure 5.5). $CuCl_2$ is highly hydrophilic and readily soluble in water, so that it dissolves into the adsorbed surface water and spreads from its original site. When the sample was removed from the 85°C/85% RH environment, the dissolved CuCl2 formed particulate $CuCl_2$ which was deposited at the border of the drop area (see Figure 5.6). Figure 5.7 and Figure 5.8 showed similar effects on the mold compound surface as that on the noble plated coupon.

The deposit of corrosion products on the mold compound surface exhibited similar but visually less dramatic migration effects compared to the deposit of $CuCl_2$ in the same environment. The initial deposit of material on the noble plated copper coupon (see Figure 5.9) was observed to have some dissociation effect and spread our a little bit after 15-day exposure (see Figure 5.10). In addition, similar to the phenomenon of $CuCl_2$ deposit on noble plated copper coupon, the base metal near the deposit was partially attacked due to the incomplete coverage of noble plating on the coupon. The deposit of corrosion products on the mold compound (see Figure 5.11) was found to show the effect of migration at the border of the deposit after 15-day exposure to the test environment (see Figure 5.12). For the case of deposit on mold compound, no galvanic effect was present. The movement of corrosion products from their original drop site was the behavior of the dissolution/diffusion/redeposition mechanism explained in section 4. Because there are no corrosive contaminants in the 85°C/85% RH chamber, the dissolution process appears to have progressed much more slowly than in Telcordia conditions since no contaminants was present to form the adsorbed ionic solution needed for speeding up the dissolution.

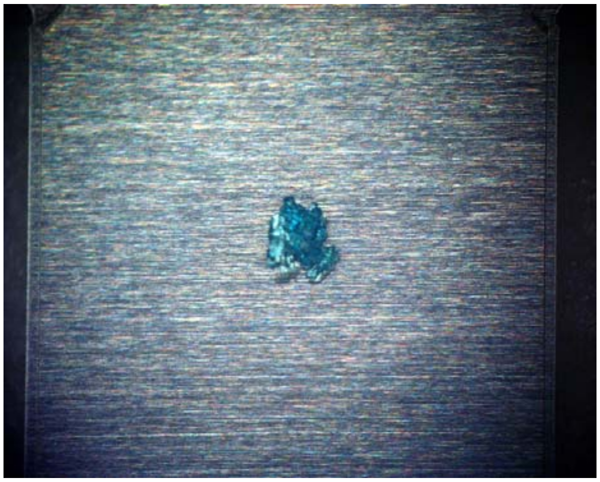


Figure 5.4: Deposit of CuCl2 on Ni/Pd/Au plated copper coupon before 85°C/85% RH exposure

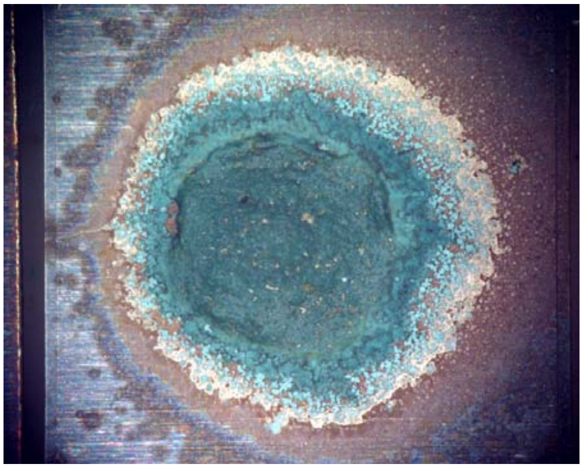


Figure 5.5: Deposit of $CuCl_2$ on Ni/Pd/Au plated copper coupon after 11 day 85°C/85%

RH exposure

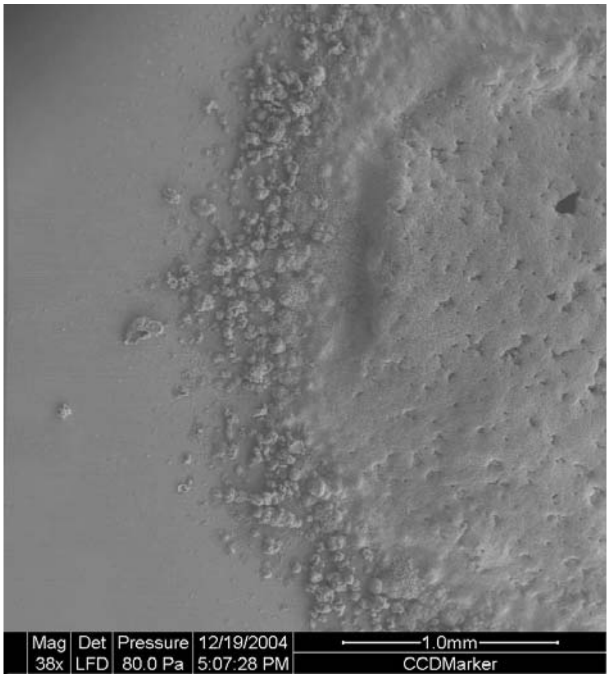


Figure 5.6: SEM at the border of the $CuCl_2$ drop area after 11 day 85°C/85% RH exposure

Figure 5.7: Deposit of $CuCl_2$ on mold compound surface before 85°C/85% RH exposure

Figure 5.8: Deposit of $CuCl_2$ on mold compound surface after 15-day 85°C/85% RH exposure

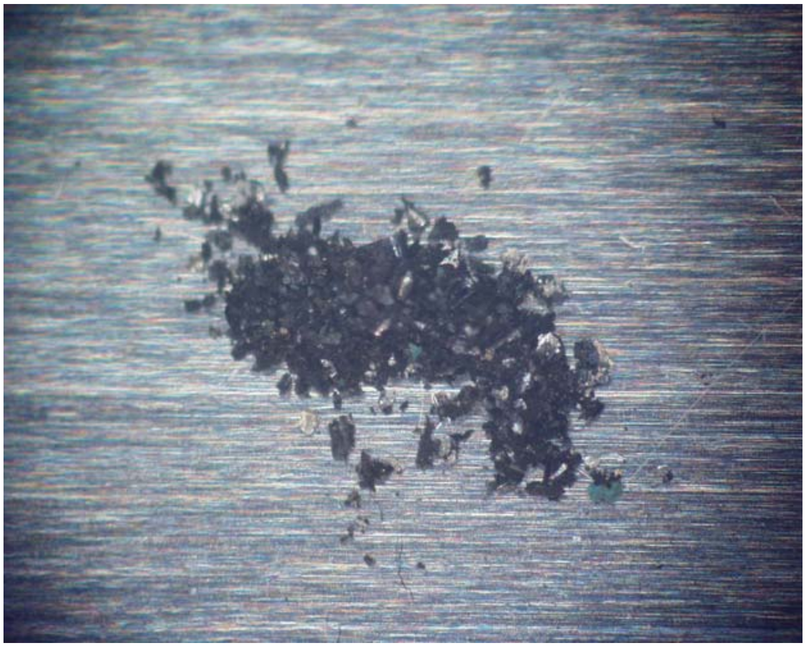


Figure 5.9: Deposit of corrosion product on Ni/Pd/Au plated copper coupon before exposure

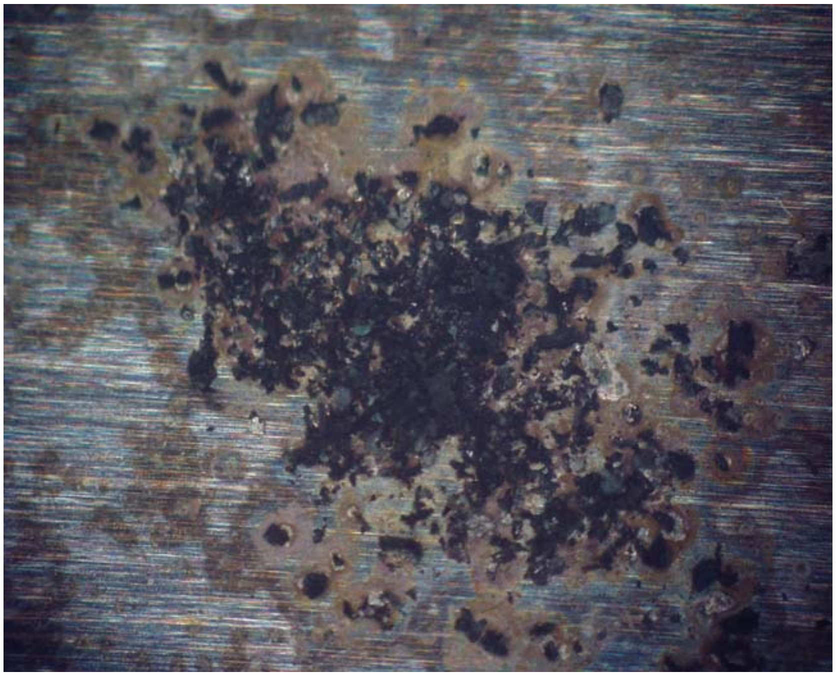


Figure 5.10: Deposit of corrosion product on Ni/Pd/Au plated copper coupon after 15-day 85°C/85% RH exposure

Figure 5.11: Deposit of corrosion product on mold compound before exposure

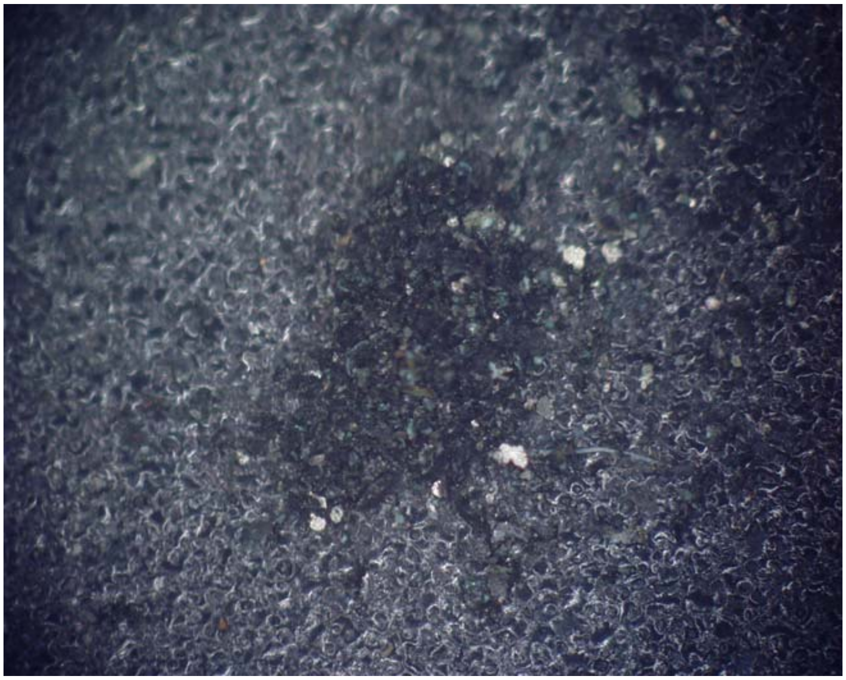


Figure 5.12: Deposit of corrosion product on mold compound after 15-day 85°C/85% RH exposure

5.3 Guidelines to conduct MFG testing for the risk evaluation of packages with pre-plated leadframes to creep corrosion

For the industry, there is an increasing need for realistic tests as a means for evaluating new materials and designs. The results from such testing and the corresponding decisions to be made may have significant economic consequences in the applications. Table 5.3 lists some of the major objectives commonly associated with modern environmental tests. At a technical level, these tests should be designed to reproduce as closely s possible the corrosion mechanisms and chemistries found in the various classes of field environments. At operational level, the ability to reproduce results and verify that the reactions produced are as desired is becoming of increased commercial importance [50].

Table 5.3 Objectives of laboratory accelerated corrosion tests

Technical	• Reproduce corrosion kinetics • Reproduce corrosion mechanisms • Reproduce corrosion chemistries
Commercial	• Reproduce results • Verify test run correctly • Stay within capability or cost of laboratories

For the study of creep corrosion over packages, it has been demonstrated in the previous sections that the process of creep corrosion is pre-dominantly the interaction between the package and the surround environmental conditions. To simulate and accelerate this process, mixed flowing gas testing is a best available approach to choose. This approach is based on the intensive research on the kinetics, mechanisms, and chemical chemistries of various metal materials commonly used in electronics [29]. A bunch of industry wide standards have been formulated to standardize the practice of MFG testing [26][27][30][31], and many researchers have made use of those standardized conditions to qualify or benchmark material performance in terms of corrosion resistance [6][51][52]. Creep corrosion over plastic encapsulated microcircuit packages with noble metal pre-plated leadframes has been reproduced in MFG environment [53].

Based on the experimental results and analyses for this study, the following points of guidelines are formulated in regards to conducting MFG testing for the evaluation of the risk of packages to creep corrosion.

- Test approach and test standards
    - ❑ Telcordia Outdoor MFG test is the appropriate test environment to access

    the risk of creep corrosion on electronic packages with noble metal pre-plated leadframes.

- About the test samples
    - ☐ Un-mounted samples in as-received conditions are adequate for evaluation.
- Failure detection and evaluation
    - ☐ If failure criterion is defined as creep corrosion products found on mold compound surface, optical inspection is the convenient approach to detect failures.
    - ☐ If failure criterion is defined as creep corrosion to electrically bridge adjacent leads, real-time resistance monitoring of dummy samples is recommended for the test.

From the study in previous sections, Telcordia Outdoor MFG environment was found to be the most effective environment to induce and promote creep corrosion over mold compound. By choosing this environment, the package performance with respect to creep corrosion resistance can be benchmarked in an accelerated manner at a reasonable rate. Shorter duration of test compared to Battelle Class III test means faster return of evaluation data and less cost for operation.

As it has been observed, un-mounted components and board mounted component behave similar towards the characteristics of creep corrosion. This provides evidence to use test data on un-mounted samples for the interpretation of field operation performance. This practice eliminates the process to fabricate the test boards and assembly of components, so that it would be more cost-effective. In addition, test with un-mounted components will also provide information about shelf life or long-term storage quality of components. However, use of board mounted components may make the operator to be more convinced about the performance at field.

Failure criterion is important to provide fundamentals for statistical analysis of failure data. The most convenient approach to detect failure as corrosion migration onto the mold compound is simply optical inspection. Unaided eyes plus a low power (up to 100x) microscope may serve this purpose very well. However, if the test population is large and it is preferred to get failure data in an automatic manner, real time monitoring of insulation resistance to detect resistance drops due to corrosion bridging is recommended.

5.4 Mitigation strategies against creep corrosion in electronic applications

The mitigation strategies against creep corrosion are on the same track of conventional corrosion prevention methods. Selective categories of approaches include alteration of environments, material selection and design, and protective coatings [48].

As it has been mentioned, environmental conditions are the dominant factors to induce and promote creep corrosion over packages with noble metal pre-plated leadframes. Therefore, reducing environmental stresses and contaminants is the primary choice. For environmental stresses, temperature and relative humidity should be reduced. For contaminants, concentrations of corrosive gases should be decreased. As it is known, indoor environments usually have less variation in temperature and relative humidity, and contain corrosive gases at the lower level. As the analogy, equipment enclosure would function in the same way to protect components inside. In addition, equipment enclosure may also reduce the air flow velocity, which may affect corrosion rate of materials [54], to limit the corrosion process.

Material properties of components leads and mold compound also have a significant effect for the initiation and migration of corrosion products. Continuous efforts from industry have been being made to refine the quality and reliability of pre-plated leadframe, as well as the package [55]. New structure, metallurgy and process of plating have been in use to increase corrosion resistance without compromising the cost [56]. The design of appropriate mold compound materials may be a feasible inhibiting method against creep corrosion over the mold compound.

Protective coating against creep corrosion has been demonstrated by using commercially available conformal coating materials. It has been proved that conformal coating of component prior to MFG exposure is an effective approach to prevent creep corrosion over mold compound.

6 Conclusions, contributions and possible future work

Major conclusions of this work include:

- Creep corrosion occurs not only on noble metal plating but also on non-metallic surfaces.
- Creep corrosion on PEM packages with noble metal pre-plated leadframes could be reproduced in an accelerated manner using industry-standard mixed flowing gas (MFG) testing.
- Comparing Telcordia Indoor, Telcordia Outdoor, and Battelle class III MFG environments, Telcordia Outdoor was found to be the most effective to induce and promote creep corrosion over PEM packages with noble metal pre-plated leadframes. Telcordia Indoor did not induce creep corrosion on mold compound in the 30-day test.
- Environmental conditions, especially gas concentrations and relative humidity, instead of sample parameters, are the dominant factors for the occurrence of creep corrosion over mold compound.
- Creep corrosion products are identified to be the combination of copper sulfides, copper chlorides, and copper oxides.
- PEM packages with noble metal pre-plated leadframes was carrying potential to reliability risk due to creep corrosion over the mold compound surface, especially for those working in harsh environments.

Contributions of this work include:

1. Reproduced creep corrosion on plastic encapsulated microcircuit packages with noble metal pre-plated leadframes in an accelerated manner using industry-standard mixed flowing gas (MFG) testing. Furthermore, it was shown that the creep corrosion products can electrically bridge the adjacent leads.
2. Showed that as little as 5-day Telcordia Outdoor MFG testing can induce creep corrosion over the mold compound. Battelle Class III and Telcordia Indoor MFG testing are less effective in producing creep corrosion on the mold compound.
3. Demonstrated that the interaction between copper leadframe and environments, especially the gas contaminants and relative humidity levels, is the dominant factor to induce creep corrosion on mold compound surface.
4. Proposed mechanisms to explain the process of creep corrosion on plastic encapsulated microcircuit packages with noble metal pre-plated leadframes.
5. Developed guidelines to evaluate creep corrosion risks on plastic encapsulated packages with noble metal pre-plated leadframes.
6. Proved conformal coating to be an effective mitigation strategy to eliminate creep corrosion on PEM packages with noble metal pre-plated leadframes.

This is the first comprehensive study of creep corrosion over plastic encapsulated microcircuit packages with noble metal pre-plated leadframes. This work was conducted primarily to investigate the phenomena of creep corrosion on plastic encapsulated microcircuit packages with noble metal pre-plated leadframes, to provide a phenomenological understanding of the creep corrosion process, and to identify mitigation strategies.

This study shows that in general, environmental conditions are the dominant factors to affect the occurrence and progression of creep corrosion over mold compound. The reason is mainly due to the interactions between component package materials and environmental contaminants. However, the physics-of-failure based model is not fully understood. Therefore, it may be valuable to investigate the quantitative effect of corrosive gases and relative humidity to the corrosion initiation and migration process.

It is demonstrated in this study that after a period of exposure to certain MFG environments creep corrosion over mold compound can occur and there is risk to have electrical short due to corrosion products bridging the leads. It should be valuable to correlate this phenomenon with component failures in field operation conditions. For this purpose, field failure components should be available for analysis and to make comparisons.

Pore corrosion on noble metal plated materials has been a conjunction topic with creep corrosion for many years. It is also shown in this work that pore corrosion has a kinship with creep corrosion. It should be valuable to investigate the process and mechanism of pore corrosion, and then differentiate it with creep corrosion.

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