ABSTRACT

Title of Document:	EFFECTS OF SOLDER-DIPPING AS A TERMINATION RE-FINISHING TECHNIQUE
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Solder-dipping may be used to replace tin-rich finishes with eutectic tin-lead for tin-whiskering risk mitigation purposes. However, re-finishing also subjects electronic parts to new risks, including damage from the thermal re-finishing profile, finish non-uniformity, incomplete replacement of the pre-existing finish and poor solderability from re-finishing. This study overviews solder-dipping as a re-finishing technique and identifies key process and part parameters that could result in risks.

A physical analysis procedure was developed and implemented to assess these risks on electronic parts. A quantitative metric was established to assess propensity for thermo-mechanical damage for solder-dipping parts. Surface mount dipped parts were prone to exposure of base-metal or interfacial intermetallics at termination corners, knees and heels. Solder-dipped insertion-mount parts showed regions of low finish thickness and possible deviations from eutectic tin-lead composition at portions close to the part-body.

EFFECTS OF SOLDER-DIPPING AS A TERMINATION RE-FINISHING TECHNIQUE

By
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Dedication

To my parents for their support and guidance all through my life, and also to my friends who stood by me, in even the most difficult of times

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Finally, I thank my parents, my uncle and other family members, friends and colleagues at UMD for their support and company all through and particularly, during the difficult times that I underwent owing to the accident I suffered from, while midway into this work. I am personally indebted to Dr. Diganta Das, Prof. Abhijeet Dasgupta, Sony Mathew, Anshul Shrivastava, Rajeev Mishra, Sanjay Tiku, Anupam Choubey, Gayatri Cuddalorepatta, Joseph Varghese, Dr. Keith Rogers, Dr. Peter Rodgers, Dr. Valerie Eveloy, Dr. Ji Wu, Kapil Sahasrabudhe and Jagan Sankaranarayanan for their invaluable assistance without which, this study could not have been complete. I also thank Bo Song, Haiyu Qi, Yan Liu, Nikhil Vichare, Yuki Fukuda, Yuliang Deng, Sheng Zhan, Reza Keimasi and others for their inputs towards completion of this study.

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Chapter 1: Introduction

Electronic part manufacturers are eliminating lead from the part termination-finish for compliance with lead-free legislations such as RoHS[1] and WEEE [2][1]. Pure-tin and other tin-rich alloy finishes such as tin-bismuth, tin-copper and tin-silver are being considered as lead-free replacements, in terms of solderability, compatibility with pre-existing tin-lead or lead-free systems, easy process control and cost-effectiveness [2]. Tin whiskering, however, is a major reliability concern for these pure-tin or other tin-rich finishes. This has led to a recent drive to replace pure-tin and tin-rich finishes with a eutectic tin-lead finish using solder-dipping, in industries with long-term and high reliability applications that have exemptions from the lead-free legislations. The effects of solder-dipping electronic parts as an intermediary step between part manufacture and/or distribution and assembly and subsequent use has however not yet been extensively investigated.

1.1 Overview of tin whiskering and risks associated

Tin is a ductile material with excellent corrosion resistance and good electrical conductivity. However, tin has a high potential for whisker formation. Tin whiskers are generally thin, single crystal filaments growing out-of-plane from finished metal surfaces [2]. Tin whiskers are a major reliability concern not only for pure-tin but also for many tin-rich alloy finishes [3]. Tin whiskers have been known to cause costly field failures in military, avionics, telecommunications, medical and consumer electronics applications [4]. For instance, Boeing reported the loss of a $200 million communications satellite due to tin-whisker induced failure of a space control processor [5]. Assessment of reliability risks due to tin-whiskering can be found in the literature [6]-[11]. High density electronic

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[1] The restriction of the use of certain hazardous substances in electrical and electronic equipment
[2] Waste electrical and electronic equipment

systems with fine-pitch components and long-term reliability requirements are at the highest risk of component lead-to-lead shorting due to tin-whiskering.

The most common failure modes associated with thin whiskers include short circuits, metal vapor arcing, contamination and plasma at low pressures. Whiskers being conductive in nature, can cause bridging between two conductors at different potentials, and thus lead to shorting. These shorts may be permanent or intermittent in nature depending on the amperage and current carrying capabilities of the whiskers. Intermittent shorts occur when the current through the short overheats the whisker and causes fusing. When these whiskers break off from their original site, these may still float about on airflow, due to their extremely small size and low weight and, cause shorting again in locations where they fall off. Ruptured whiskers can also be a source of contamination. They may contaminate optical surfaces or interfere with the operation of micro-electro-mechanical systems (MEMS) [12].

1.2 Solder-dipping as a tin whiskering risk mitigation technique

Some organizations, whose products are exempt from lead-free legislation, have mandated that pure tin finished parts cannot be used in their products, in order to reduce the risk of tin whisker induced failures [13]. An industry standard, GEIA-STD-0005-2 [14], has been proposed that defines conditions by which one may restrict or ban the use of tin finished parts. Solder-dipping is a method of replacing pre-existing tin-rich finishes with eutectic tin-lead, which is known to be resistant to tin whiskering [12], for the purposes of meeting the requirements of GEIA-STD-0005-2 [14] .

1.3 Brief history of solder-dipping and plating

Popular use of plated bright tin for part-termination finishing can be traced back to the 1950s. Bright tin finishes used organic additives which were responsible for imparting a shiny appearance to termination surfaces, which was one of the major reasons for the popularity of the bright tin in finishing operations. However, these organic additives caused outgassing which caused porosity in the finish material leading to corrosion related reliability problems. Further in the late 1970s, when the US military initiated accelerated burn-in tests to screen for premature electrical failures, the elevated time and temperatures resulted in loss in solderability due to excessive outgassing of the organic material in bright tin finishes. From the early 1980s, the trend was to move towards lower organic content matte tin platings as the solution for part-termination finishing. However, revision of the MIL-M-38510 in 1985 stipulated leadframe finishes should contain a minimum of 5% lead. This made tin-lead solder plating and eutectic (tin-lead) solder-dipping the two most prevalent finishing techniques at that point of time. Each technique had its on advantages. Eutectic tin-lead solder-dipping provided for lower porosity in resulting finishes and lesser probability of occlusion of organic additives within the finish, over plating. However eutectic solder-dipped finishing was also known to risk parts to thermal shock during dipping and was, further unsuitable for high-temperature burn-in because the eutectic melting point was too low. With increasing pin-count and decreasing pitch dimensions, it was no longer viable with existing technology to solder-dip fine-pitch parts with pitch dimensions below 0.050 inch. The industry thus gradually migrated to plated finishes over eutectic solder-dipped finishes. However, recent lead-free drives have led to the adoption of solder-dipping to replace pure-tin and tin-rich finishes with a eutectic tin-lead finish by certain sectors of the industry.

1.4 Overview of solder-dipping process

Solder-dipping has been used to “finish” the exposed leadframe of packaged electronic parts, including pin grid arrays (PGA), plastic dual inline packages (PDIP), transistor outline (TO) cans, ceramic quad flatpacks (CQFP), leadless ceramic chip carriers (LCCC) and connectors [15]. The purpose is to ensure that the leadframe, which is usually copper or alloy 42, is coated to prevent oxidation and enhance solderability in circuit card assembly.

Solder-dipping has been used as a “re-finishing” technique to replace parts with finishes that have exceeded their shelf life, to change the finish if it is incompatible with the assembly process, such as gold plated finishes with tin-lead, and is a mandated re-work procedure, per J-STD-001D [16], for parts which fail solderability testing [17]. Solder-dipping performed for these purposes involves sufficient immersion of the device terminations to ensure that the regions at and near the solder joint are re-finished. Immersion does not typically cover the entire termination, particularly the portion immediately adjacent to the package. This area is of key concern in the formation of tin whiskers that can bridge between adjacent terminations.

The solder-dipping process, when used as a re-finishing technique, consists of five stages: fluxing, preheating, dipping, water rinsing and drying. Fluxing aids in improving wettability through removal of oxide films. Preheating activates fluxing action and reduces the thermal shock experienced during dipping. Dipping dissolves the original finish and replaces it with a eutectic tin-lead finish. Rinsing cleanses residues on the part due to the process. The part is finally dried to remove residual rinsing agent.

1.5 Goal of the study

Electronic parts after manufacture and distribution will be reflowed on to printed circuit boards for assembly before use. Electronic parts with tin-rich finishes on terminations may have to undergo an intermediary solder-dipping step, for re-finishing terminations with eutectic tin-lead when they are required to be used in high reliability, long-term applications (see Figure 1). Electronic parts will however, be exposed to new risks from the solder-dipping process. For instance, an electronic part packaged as a Plastic-Quad-Flat-Pack (PQFP) will be exposed to 4 thermal shocks from the solder-dipping process, since full lengths of the terminations on each of its 4 sides will be dipped in the hot solder one after the other.

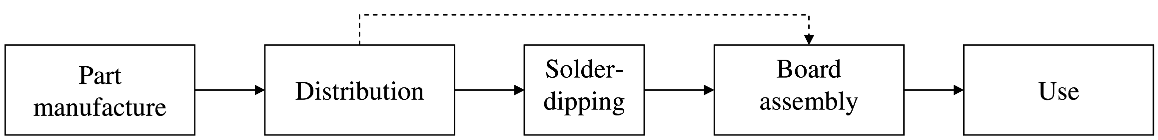


Figure 1: Solder-dipping as an intermediary step

Inspections and/or screening performed on electronic parts when solder-dipping is used as a conventional method for finishing or re-finishing terminations are very limited. Inspections typically performed on solder-dipped parts include magnified (10X) inspection on random production samples, as per requirements established in J-STD-001D [16] and 100% non-magnified inspection of the entire production lot. These inspections are aimed at verifying that the solder-dipped finish exhibits smooth, continuous solder coverage without evidence of dross, icicles, or excessive solder build-up. Electronic part users will commonly perform electrical tests of their own on an initial qualification batch of solder-dipped parts to verify that there are no negative effects from the solder-dipping process. In few cases, standard dip-and-look solderability tests and/or seal leakage tests (for hermetic parts) may also be performed by the solder-dipping service provider, upon request from their customers. Under very rare circumstances, composition and thickness of the solder-dipped finish may be analyzed by the service provider. There however, exist significant variations in procedures and techniques to assess the same within the industry [17].

There are no stress tests such as those that have been used in this study, performed on electronic parts after solder-dipping. Since solder-dipping is now being proposed as a tin-whiskering risk mitigation strategy for electronic parts which will be used in long-term, high reliability, harsh environment applications, the need for stress testing solder-dipped parts gains significance, particularly from the point of view of assessing risk of thermo-mechanical damage.

The goal of this study was to demonstrate an extensive, systematic and organized procedure for assessment of parts re-finished by solder-dipping. This was aimed to investigate the major risks of thermo-mechanical damage from thermal shock, finish non-uniformity and potential for exposure of underlying base-metal or interfacial intermetallics, incomplete replacement of the pre-existing finish and potential poor solderability of the re-finished terminations, from solder-dipping parts.

Chapter 2: Experimental Study for Analysis

2.1 Test flow and part-types for physical analysis

A total of 23 part-types (see Table 1) were used to assess the finish profile resulting from solder-dipping. These 23 part-types underwent a robotic solder-dipping process (see Figure 2) performed by Corfin Industries LLC, Salem, NH, USA, an organization specializing in part-termination finishing operations. The parts were initially baked for 24 hours at 150°C, based on the most stringent conditions provided in J-STD-033B [18], intended to remove any moisture within the package. Parts were maintained at conditions of ≤ 30°C and ≤ 60%R.H. for a maximum period of 48 hours, in accordance with MSL (Moisture Sensitivity Level) 5 of J-STD-020C [19]. All parts were then fluxed under constant specific gravity control using an organic-acid, water-soluble flux with an amino-acid halide activator (for 1.0 sec), forced hot air preheated at 150 ±3˚C (for 4.0 sec), dipped in Sn63Pb37 solder at 245 ± 1˚C (for 3.0 sec) under a nitrogen blanket, hot water washed at 60˚C, and forced air dried.

In contrast with traditional solder-dipping, the full lengths of the terminations, up to the package ends, were immersed in the solder bath. Robotic motion was programmed according to the part-type to handle the angles of immersion and withdrawal from the solder bath. Rates of immersion were around 3.25 inches per second and that of withdrawal were approximately 0.7 inches per second [17]. Typically, the flux material may be selected based on the original finish and the conditions of the finish. However, in this study, a single flux was used for all the parts.

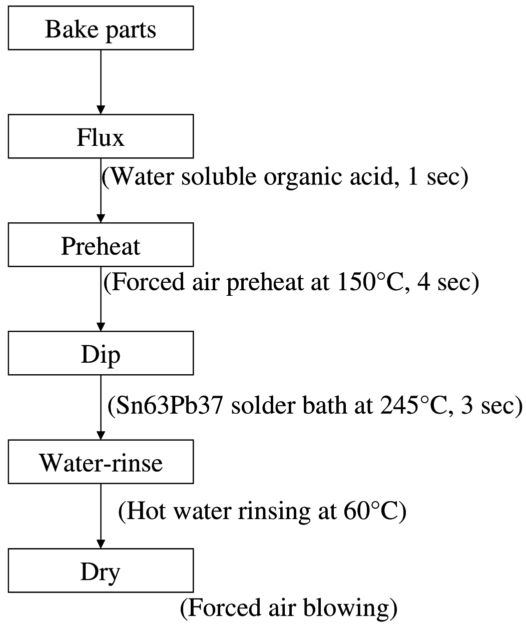


Figure 2: Solder-dip process steps.

A total of 23 part-types (see Table 1) were used in this study. A total of 45 parts of each part-type underwent a test flow that was categorized into three stages: as-received, post-dipped and after-environmental exposure. A set of 4 parts were set aside at each of these 3 stages for studies on potential risks that may arise out of solder-dipping (see Figure **3**).

The environmental exposure, in the test flow consisted of 150 thermal shocks (-55 to 125°C with dwell time of 10 minutes) followed by temperature-humidity conditions of 85°C/ 85% R.H. for 500 hours. These conditions were designed to increase any thermo-mechanical damage that may have been caused by dipping. Electrical tests were repeated at the end of each of the 3 stages.

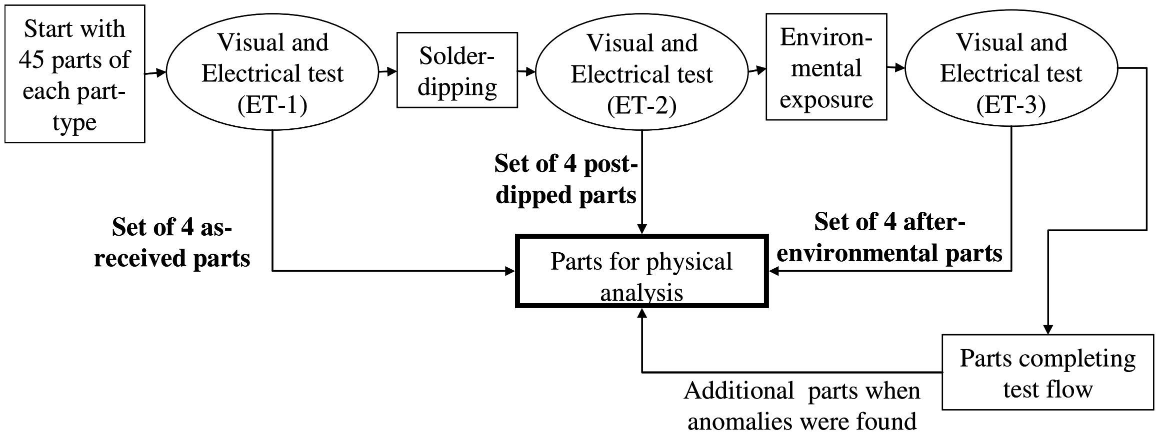
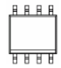
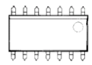
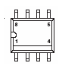
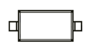
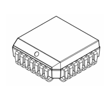
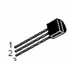


Figure 3: Test flow showing parts (for each part-type) set aside for physical analysis

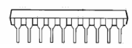
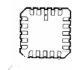
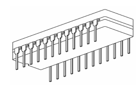
This study was part of a project sponsored and funded by the US Navy. The primary focus of the project was to assess the thermo-mechanical damage related effects of solder-dipping electronic parts. The part-types selected in the study, were provided by the Navy from the inventory of one of its missile programs and, were representative of a wide variety of commonly used leaded electronic parts. Although, a large majority of the part-types studied were not pure tin or highly tin-rich finish based, this was deemed to not cause any significant difference in results from the thermo-mechanical damage standpoint. Electronic parts with original finish material different from the part-types covered in this study however, could yield results slightly different from what is presented here in terms of finish uniformity, residual pre-existing finish material and solderability of the re-finished terminations.

Table 1: Description of the 23 part-types used for the study

Identifier	Part-type	Pin count	Part schematic[3]	Manufacturer	Function	Leadframe	Original finish[4]
1	SOP	8		Siliconix	Transistor	Copper	Tin 90 lead 10
2	SOP	14		Fairchild	Hex inverter	Copper	Tin 90 lead 10
3	TSSOP	16		Analog Devices	Multiplexer	Copper	Tin 85 lead 15
4	SOIC	8		Analog Devices	Operational amplifier	Copper	Tin 85 lead 15
5	SOIC	28		IDT	Memory buffers	Copper	Tin 80 lead 20
6	SOT-23	3		On-Semi	Bipolar transistor	Alloy 42 with copper underplating	Tin 70 lead 30
7	SOD-123	2		Diodes Inc.	Diode	Alloy 42	Tin 70 lead 30
8	PQFP	208		Altera	PLD	Copper	Tin 85 lead 15
9	PQFP	208		Altera	PLD	Copper	Tin 85 lead 15
10	PQFP	32		IDT	FIFO memory	Copper	Tin 80 lead 20
11	TQFP	100		Altera	PLD	Copper	Tin 95 lead 5
12	PLCC	28		Analog Devices	Quad DAC	Copper	Tin 85 lead 15
13	PLCC	32		IDT	FIFO logic	Copper	Tin 80 lead 20
14	Plastic TO-92	3		On-Semi	PNP transistor	Copper	Tin 60 lead 40
15	Plastic TO-220	3		Fairchild	MOSFET	Copper	Pure tin

[3] Part schematics shown are not to scale

[4] These compositions were as per part manufacturer provided information (wherever possible) and were confirmed with energy dispersive spectroscopy analysis on the surface of the terminations.

Identifier	Part-type	Pin count	Part schematic[3]	Manufacturer	Function	Leadframe	Original finish[4]
16	PDIP	14		Fairchild	NAND gate	Copper	Nickel-palladium
17	PDIP	20		Fairchild	Inverting buffer	Copper	Nickel-palladium
18	LCCC	20		Fairchild	NAND gate	Not applicable	Tin 60 lead 40
19	CERDIP	16		Texas Instruments	Line receiver	Alloy 42	Pure tin
20	CERDIP	16		National Semiconductor	Line receiver	Alloy 42	Tin 60 lead 40
21	CERDIP	14		Linear Tech	Operational amplifier	Alloy 42	Tin 60 lead 40
22	CERDIP	14		Analog Devices	Operational amplifier	Alloy 42	Tin 85 lead 15
23	CERDIP	16		Texas Instruments	Line receiver	Alloy 42	Tin 60 lead 40

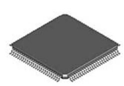
2.2 Description of physical analysis

The sets of as 4 as received, 4 post dipped and 4 after environmental parts that were separated out from the test flow as indicated in Figure **3** were further subjected to a physical analysis flow as depicted in Figure 4 . This physical analysis was organized into 4 different studies: i) Thermo-mechanical damage study ii) Finish thickness study iii) Finish composition study and iv) Solderability assessment to investigate the risks from solder-dipping.

The thermo-mechanical damage study and the finish thickness study were performed on the 23 part-types as described in Table 1: Description of the 23 part-types used for the study . Of all these 23 part-types, part-types 15, 16 and 19, which had their pre-existing finish material different from tin-lead combinations, were selected for the finish composition study. 2 additional part-types, as described in Table 2 were also used to provide additional results in the finish composition study. While part types 15, 16 and 19 underwent the complete test flow as described in Figure **3**, part types 24 and 25 underwent similar solder-dipping with visual inspection only, without any environmental exposure or electrical tests. All part-types that were selected for the finish composition study were further used in the solderability assessment.

The effects of the environmental exposure were only investigated in the thermo-mechanical damage study. The finish thickness study, finish composition study and solderability assessment did not differentiate between post dipped and the after environmental parts. After environmental parts were considered to be equivalent to post dipped parts, for the purpose of analyses in these studies.

Table 2: Additional part-types for finish composition and solderability assessment

Identifier	Part-type	Pin count	Part schematic	Manufacturer	Function	Leadframe	Original finish
24	100-pin TQFP	0.5		Practical Components	Dummy component	Copper	Sn/Cu
25	100-pin TQFP	0.5		Practical Components	Dummy component	Copper	Pure Sn

2.2.1 Thermo-mechanical damage study

Scanning Acoustic Microscopy (SAM) was performed on all parts that were set aside for the thermo-mechanical damage study to identify any delamination within the part at various critical intra-package interfaces such as the die-top and molding compound, die paddle top and lead (termination) fingers and molding compound. A combination of C-Scans and A-Scans using pulse-echo transmission techniques, employing both peak-amplitude and phase inversion modes (as applicable) was used to investigate the possibility of delamination at these interfaces.

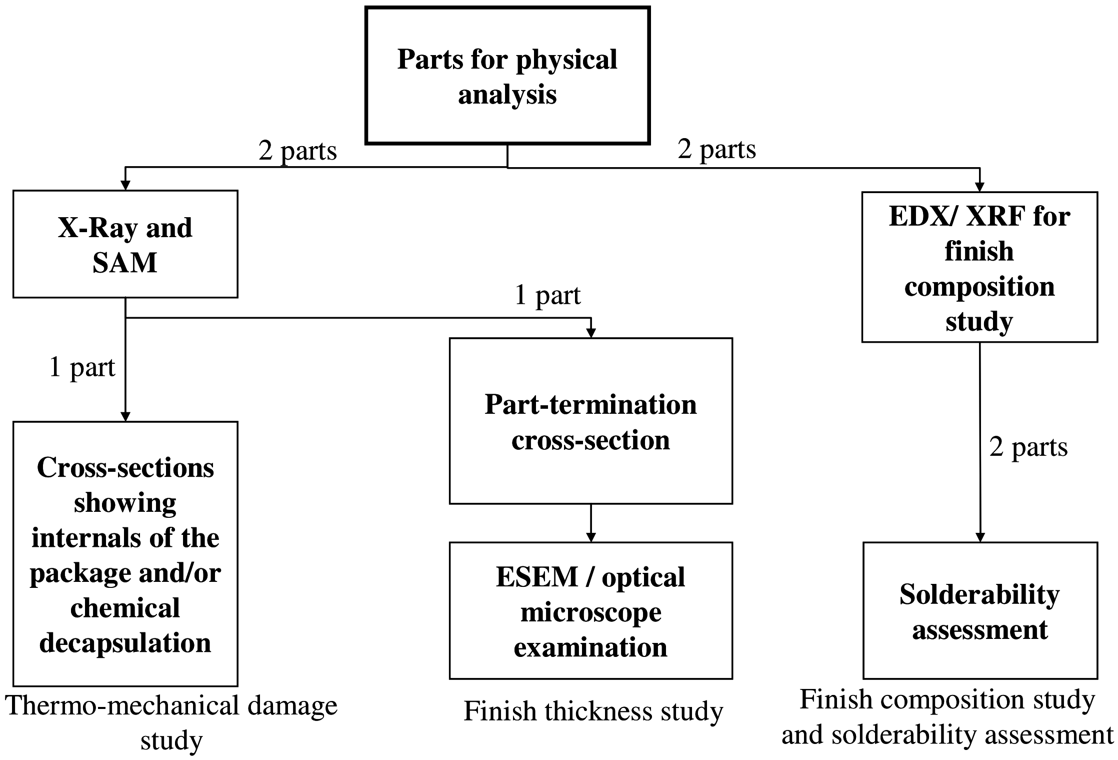


Figure 4: Physical analysis flow

X-Ray scans were then obtained to reveal the internal structure of the package to assist Destructive Physical Analysis (DPA), which was performed on the parts next. The X-Ray scans were also used to provide information to characterize package and die geometry, as explained in Section 3.3. During DPA, a planar cross section through the center of the part was obtained revealing the die, die-attach, die paddle, lead (termination) fingers and the molding compound. All visible interfaces were examined using optical microscopy to examine any signs of gross delamination. Chemical decapsulation was performed using hot fuming nitric acid on additional parts obtained from the test flow to examine the die-surface for metallization or passivation cracks, as necessary.

2.2.2 Finish thickness study

All parts were first visually inspected using low magnification (25X) optical microscopy. Parts used in the study for cross-sectioning, were potted using standard solution of 10 parts of resin and 3 parts (by weight), of cross linker epoxy mount hardener. Curing time was in excess of 6 hours to ensure completeness of the curing process. The terminations were then cross-sectioned and etched. Cross sectioning was performed through a combination of rough grinding using 120, 240, and 400 micron sand papers; fine grinding using 600 ,800 and 1200 micron sand papers and finally, fine polishing using alumina powder. A combination of methanol and hydrochloric acid was used for etching, based on the original finish of the part-terminations. The cross-sectioned and etched terminations were then examined using optical microscopy and/or Environmental Scanning Electron Microscopy (ESEM).

2.2.3 Finish composition study

X-Ray Fluorescence (XRF) was used to determine the finish composition and thickness of each part. Readings were obtained for the as-received and post-dipped parts for each part-type. Measurements were obtained separately from termination feet and termination heads. Termination feet refer to portions of termination sufficiently away from the part body that are expected to form a part of the solder-joint fillet. Termination heads refer to portions located immediately adjacent to the part body (see Figure 5).

2.2.4 Solderability assessment

Dip-and-look tests have been the most widely accepted method to assess part-termination solderability [20] [21] [22] . Dip-and-look tests based on JEDEC Standard JESD22-B102D [23] were performed to assess the solderability of the post-dipped parts of each part-type. Parts were first preconditioned to simulate package storage by dry baking at 150 °C for duration of 16 hours ± 30 minutes. The part-terminations were then immersed in standard activated rosin-based flux at ambient temperature. Excess flux was allowed to drain-off for 15-20 seconds; part-terminations were then dipped in molten tin-lead eutectic solder maintained at 215 ± 5 °C in a solder pot for 5 seconds. Full lengths of terminations were immersed both during fluxing as well as dipping. Residual flux was removed from the terminations using sequential rinses in isopropyl alcohol.

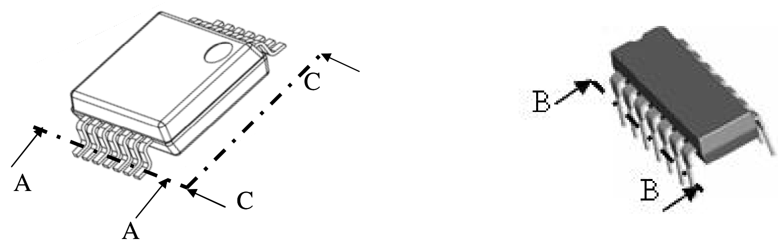


Figure 5: Part schematic showing plane of cross-section for terminations

Parts were then visually inspected using the optical microscope/ SEM as per standard inspection criteria. The area to be inspected for each part was dependent upon package configuration and was determined as per standard guidelines as per JEDEC Standard JESD22-B102D [23]. As per this standard, the inspected area for dual-inline-package (DIP) extends from the termination tip to a plane 0.51 mm (0.020 inch) above the seating plane (see Figure 6). The critical area to be inspected for a gull-winged package is defined as the underside 'A' (see Figure 7) of the lead and all edges 'B' normal to the underside of the lead.

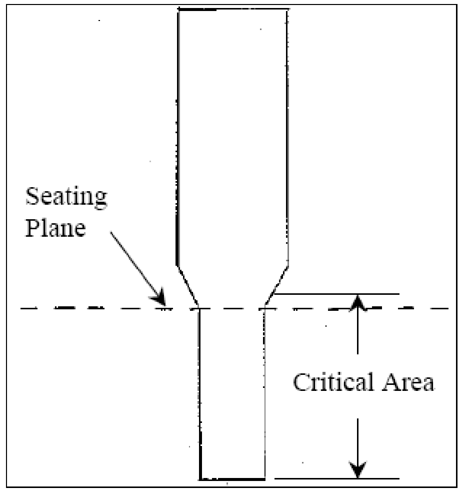


Figure 6: Area to be visually inspected for DIP [23]

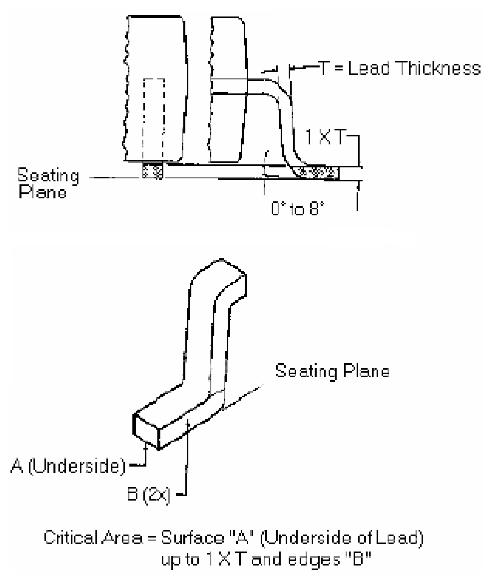


Figure 7: Area to be visually inspected for gull-winged package [23][23]

Chapter 3: Thermo-Mechanical Damage in Electronic Parts from Solder-Dipping

3.1 Observations

There was no evidence of thermo-mechanical damage for 19 of the 23 part-types studied. However, these results were not surprising as 15 of these 19 part-types were coarse-pitch devices (> 1 mm). Nine of these 15 part-types belonged to package configurations that have been successfully subjected to solder-dipping in the past (TO, PDIP and CERDIP package configurations). On the other hand, 4 (part types 3, 8, 11 and 15) of the 23 part-types, exhibited behavior attributable to thermo-mechanical damage. Of these, part types 3, 8 and 11 were fine-pitch (≤ 0.65mm) and their package configurations (TSSOP, PQFP, and TQFP) are not regularly solder-dipped.

Two parts of the 16-pin TSSOP (part type 3) from the test flow (see Figure **3**), showed parametric shifts in the electrical tests performed after the environmental exposure, although no problems were observed for these parts immediately after dipping. One part showed an increase in the forward voltage, while the other exhibited an abnormal reduction in the on-resistance. SAM for these parts indicated delamination at the interface between the die-paddle and mold-compound, although the relation between the parametric shifts and the observed delamination could not be conclusively established.

The 208-pin PQFP (part type 8), was the only part-type of all 23 analyzed, to exhibit pre-existing delamination at the interface between the die-surface and mold compound (see Figure 8, Figure 9 and Figure 10). Parts that underwent the environmental exposure after dipping showed a large increase (~650%) in the percentage of the die surface area found delaminated (see Table 3). DPA and chemical decapsulation of the after-environmental exposure parts however, showed no evidence of passivation-cracking and/or bond-pad deformation.

A further study was conducted on 24 “new” parts of the 208-pin PQFP (part type 8) from the same production lot. These 24 parts again showed similar pre-existing die-surface delamination. These parts were then, exposed to the environmental test exposure conditions without undergoing any solder-dipping. SAM of these parts showed an increase of 525% in the die-surface delamination from the as-received value. These results suggest that the increase in delamination seen in the 208-pin PQFP (part type 8) was due to the environmental exposure conditions and that this was not directly attributable to the dipping process. However, the possibility that the thermal re-finishing profile caused latent damage to this particular part-type could not be completely ruled out.

Table 3: Increase in pre-existing die surface delamination for the 208-pin PQFP (part type 8)

	As received	**Post-dipped**	**Environmental only**	**Post dipped + environmental**
Avg. % of die-surface area delaminated	4	5	25	30
Range of avg. delaminated area (%)	1	1	16	16
% increase from as received value	**--**	**35**	**525**	**640**
No. of parts used for analysis	4	2	4	4

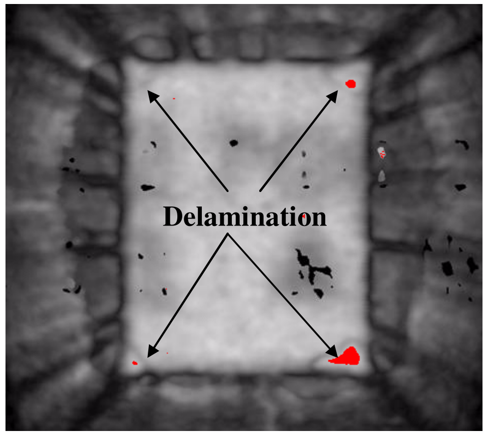


Figure 8: As received part for the 208-pin PQFP (part type 8)

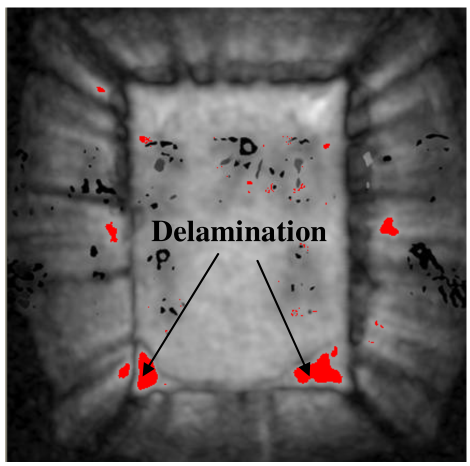


Figure 9: Post dipped part for the 208-pin PQFP (part type 8)

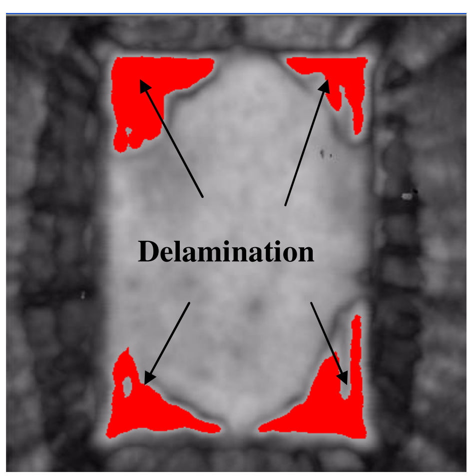


Figure 10: After environmental part for the 208-pin PQFP (part type 8)

In the case of the 100-pin TQFP (part type 11), SAM did not show any thermo-mechanical damage for any of the parts examined. However, one of the parts subject to the test flow (see Figure **3**) indicated an open-pin failure in the electrical tests after the environmental exposure. This pin was located at the corner of the package. Chemical decapsulation of this part exposed passivation cracks around the bond-pad corresponding to the pin (see Figure 11). The passivation cracks were found to extend onto the bond-pad corresponding to the pin.

With the 3-pin TO-220 (part type 15), 25 parts exhibited an increase in gate-channel leakage current beyond specifications, after the environmental exposure. Energy dispersive spectroscopy analysis of the terminations of these parts did not detect any presence of contaminants. The increase in leakage was attributed to thermo-mechanical damage within the package and/or moisture ingression during the test flow.

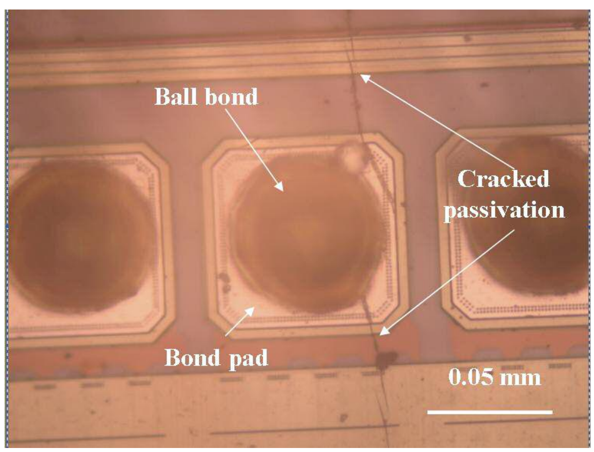


Figure 11: Passivation crack observed for 100-pin TQFP (part type 11)

3.2 Discussion

Although there is a long history of use of solder-dipping for coarse-pitch insertion-mount parts, the applicability of solder-dipped finishes for surface-mount-technology (SMT) parts has been limited due to their fine pitch requirements [24]. Electroplating has been more commonly used for part-termination finishing of SMT parts as there is no risk of thermal shock compared to solder-dipping [25]. Although solder-dipping is now being considered on electronic parts, many of these parts may not have been assessed by the part manufacturer to provide reliable operation after undergoing the thermal profile during dipping. Thus, there is a need for guidelines for certain packaging configurations in terms of the propensity for any such damage.

The thermal re-finishing profile used will expose electronic parts to thermal shocks due to temperature increases during preheating (ΔT ~125 °C) and dipping (ΔT ~100 °C). Furthermore, parts will be exposed to a temperature drop (ΔT ~200 °C) after the dipping to the rinsing step. Exposure to this thermal profile can degrade adhesion strength at interfaces within the package, lead to delamination and result in subsequent package cracking. Moisture absorbed during shipping and storage by the organic materials (mold compound and die attach) in plastic encapsulated microelectronics collects at the voids resulting from the interfacial delaminations. The moisture will further vaporize at the high temperatures experienced during life-cycle conditions, such as those during board reflow [26] [27]. The steam pressure generated due to evaporation of the moisture can result in popcorn cracking during the reflow process [28]. Delamination can also lead to shearing or lifting of ball bonds, metallization/bond-pad corrosion and passivation cracking [29].

Thermo-mechanical residual stresses due to the thermal expansion mismatches between silicon, the mold compound, the die attach and the leadframe material come into play not only during the thermal shocks experienced during solder-dipping but also during subsequent cooling down to room temperature. In the worst case, stress related failures such as cracked passivation and metallization deformation may result. The possibility of such thermo-mechanical damage is generally higher at the die edges than towards the center of the die, as has been noted by prior studies on silicon chips in molded plastic packages [30].

Various process and part parameters may be attributed to failures related to thermo-mechanical damage from solder-dipping electronic parts. These process and part parameters are graphically presented in the fishbone diagram in Figure 12. An explanation of these process and part parameters follows.

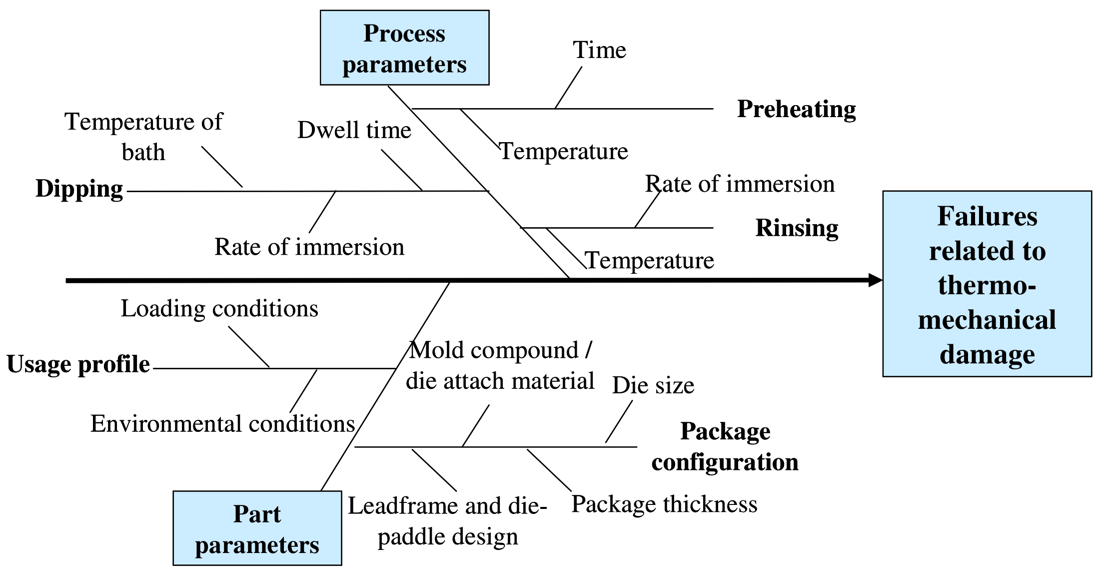


Figure 12: Cause and effect diagram for failures related to thermo-mechanical

3.2.1 Process parameters

Preheating is conducted to reduce the thermal shock to a part. Insufficient preheating may not reduce the effects of the thermal shock during dipping and thereby increase risk of damage. However, excessive preheating times are economically wasteful.

Since terminations of electronic parts will be immersed upto the package body in the solder bath, there exists risk of thermo-mechanical damage to the part from the thermal shock experienced. Faster rates of immersion and longer dwell times than what were used in our process, could accentuate the chances of thermo-mechanical damage from this high temperature exposure.

Electronic parts are further subjected to thermal shock when they are plunged in the hot water wash maintained at 60 °C after dipping at 245 °C, instead of allowing the part to gradually cool to room temperature. Slower rates of immersion in the water bath and higher water bath temperatures could decrease the effect of the thermal shock due to the rinsing step.

3.2.2 Part parameters

Life cycle environmental loading conditions will play a key role in influencing the propensity for thermo-mechanical damage in the solder-dipped parts. The thermal profile experienced during dipping can induce latent damage to electronic parts. Use of solder-dipped parts in harsh environments with unfavorable loading profiles could aggravate the latent damage and result in thermo-mechanical reliability concerns.

Package configuration is another key parameter which influences the propensity for thermo-mechanical damage. Die size, package thickness, material of molding compound and the die-attach and leadframe/paddle design are key parameters that can affect the risk of thermo-mechanical damage from solder-dipping parts [31] [32]. In particular, as IC chips grow larger, they become increasingly sensitive to stresses resulting due to moisture ingression [33] [34]. Use of larger and thinner surface mount plastic encapsulated micro-electronics (PEM) may increase risk of moisture induced package delamination and cracking during reflow soldering [35]. It has been found that variables such as the thickness of the package and the size of the silicon die, affect the threshold moisture level at which cracking occurs [36]. Other studies have confirmed that the probability of package cracking increases with increase in die size and decreases with increase in package thickness [37]. Popcorn cracking has been reported to be an observed failure mechanism for TQFP and TSSOP type packages [38].

PEMs with large die have also been reported to show an increased tendency for stress related thin film cracking failures such as passivation cracking, typically seen at die corners resulting in failure modes such as electrical parametric shifts, opens and shorts [31]. Prior studies have reported that large silicon chips in molded plastic packages suffer from physical damage to die surface regions when subjected to repetitive thermal excursions such as thermal shock cycling [39].

The thermal conductivity, adhesion strength and coefficient of thermal expansion (CTE) of the materials of the molding compound, die attach, leadframe and die-paddle play a critical role in determining the thermo-mechanical stress levels that the part will be exposed to. Furthermore, special leadframe/paddle design features such as incorporation of an integral heat spreader can provide for more efficient heat dissipation during the thermal profile experienced and can thus reduce risk of thermo-mechanical damage that would have otherwise been observed.

3.3 Package and die geometry characterization

The assessment for thermo-mechanical damage that was performed on the 23 part types as described in this study was time-consuming and expensive. It is therefore desirable to identify a method of leveraging the results from these tests so that a larger number of part types may be considered for solder dipping. Based upon the factors discussed in Section 3.2 our attention focused upon: package configuration and in particular: die area and package thickness as the critical parameters in assessing the vulnerability of a particular package to thermo-mechanical damage.

Package and die geometries were characterized for all 23 part-types of various package configurations. Results from package and die geometry characterization were used to provide guidelines for a basis for comparison with other part-types not covered in this study. Table 4 provides package and die dimensions and, package mass for all 23 part-types. The ratio of die-area to package thickness was calculated in each case, to provide a metric to analyze the combined effect of die-area and package thickness on the vulnerability of part types to thermo-mechanical damage due to dipping.

Table 4 : Package and die geometry characterization data

Part-type number	Part-type	Pin count	Approx. mass (g)	Pitch (mm)	Package dimensions			Die dimensions			Ratio of die-area to package thickness (mm)
					Length (mm)	Width (mm)	Thickness (mm)	Length (mm)	Width (mm)	Thickness (mm)	
1	SOP	8	0.09	1.27	5.2	4.1	1.6	2.5	1.9	0.3	2.97
2	SOP	14	0.13	1.27	8.7	4.0	1.8	2.0	0.9	0.4	1.00
3	TSSOP	16	0.06	0.65	5.1	4.5	1.0	2.4	1.6	0.4	3.84
4	SOIC	8	0.08	1.27	5.0	4.0	1.6	2.8	2.1	0.3	3.68
5	SOIC	28	0.98	1.27	18.5	8.9	2.7	3.2	0.8	0.5	0.95
6	SOT-23	3	0.01	2.00	3.0	1.4	1.1	0.5	0.4	0.4	0.18
7	SOD-123	2	0.01	NA	2.9	1.7	1.4	0.3	0.3	0.4	0.06
8	PQFP	208	5.71	0.5	28.1	28.1	3.6	7.9	4.8	0.4	10.53
9	PQFP	208	10.81	0.5	28.1	28.1	3.6	6.7	5.1	0.5	9.49
10	PQFP	32	0.16	0.8	7.0	7.0	1.5	2.2	1.8	0.3	2.64

Part-type number	Part-type	Pin count	Approx. mass (g)	Pitch (mm)	Package dimensions			Die dimensions			Ratio of die-area to package thickness (mm)
					Length (mm)	Width (mm)	Thickness (mm)	Length (mm)	Width (mm)	Thickness (mm)	
11	TQFP	100	0.49	0.5	14.5	14.5	1.1	4.8	4.8	0.3	20.95
12	PLCC	28	0.98	1.27	11.6	11.6	3.9	5.8	4.6	0.5	6.84
13	PLCC	32	1.10	0.8	14.1	11.5	1.7	2.5	2.0	0.5	2.94
14	Plastic TO-92	3	0.20	1.4	5.3	5.2	4.2	0.3	0.3	0.2	0.02
15	Plastic TO-220	3	2.10	2.54	16.1	10.4	4.9	6.0	6.3	0.3	7.71
16	PDIP	14	1.04	2.54	19.6	6.6	3.6	1.6	0.9	0.3	0.40
17	PDIP	20	1.54	2.54	26.4	6.7	3.4	2.4	1.5	0.2	1.06
18	LCCC	20	0.46	1.27	8.9	8.9	1.9	1.1	1.1	0.5	0.64
19	CERDIP	16	2.20	2.54	19.9	7.9	3.6	1.8	1.8	0.5	0.90
20	CERDIP	16	2.30	2.54	19.9	7.9	3.6	2.0	1.7	0.4	0.94
21	CERDIP	14	2.11	2.54	19.9	7.9	3.6	2.7	2.0	0.5	1.50
22	CERDIP	14	2.05	2.54	19.9	7.9	3.6	3.8	3.3	0.4	3.48
23	CERDIP	16	2.20	2.54	21.3	7.6	3.6	2.3	2.0	0.3	1.28

When the ratio of die-area to package thickness was plotted against each of the part-types, as indicated in Figure 13, the PQFP's (part types 8, 9 and 11) were found to have the largest values of this ratio. It was also found that the part-types that had shown behavior attributable to thermo-mechanical damage (part types 3, 8, 11 and 15) also had the largest ratios among other part-types of similar package configuration. For example, the 16-pin TSSOP (part type 3) had the largest ratio among all small surface mount part-types (SOP/SOIC and SOT/SOD part-types). Similarly, the 208-pin PQFP (part type 8) and 100-pin TQFP (part type 11) had the largest value among all Plastic Quad-Flat-Packs. Again, the 3-pin TO-220 (part type 15) had the larger value of this ratio among the 2 plastic TO part-types used in the study.

The 208-pin PQFP that was packaged with an integral heat spreader (part-type 9) did not exhibit any behavior attributable to thermo-mechanical damage, inspite of a comparatively large ratio (see Figure 13). It is believed that the integral heat spreader was responsible for more efficient heat dissipation for this part-type which allowed solder-dipping with no evidence of thermo-mechanical damage. It may also be noted that the 3-pin SOT 23 (part type 6), 2-pin SOD 123 (part type 7) and the 3-pin TO-92 (part type 14) had particularly small die, with die dimensions less than or equal to 500 μm, in each case. The 8-pin SOIC (part type 4) and 28-pin PLCC (part type 12) on the other hand, had reasonably large die sizes (as compared to the corresponding package size). In each of these part-types no evidence of thermo-mechanical damage was observed.

The ratio of die-area to package thickness for all PEM part-types studied, was categorized by the package configurations (see Figure 14), and proposed as a guideline for electronic part users to assess propensity for thermo-mechanical damage due to solder-dipping of PEM part-types. X-Ray imaging of PEM part-types is recommended to obtain die and package dimensions and calculate the die-area to package thickness ratio. This value can be compared with the ratios indicated in Figure 14 for the appropriate package configuration.

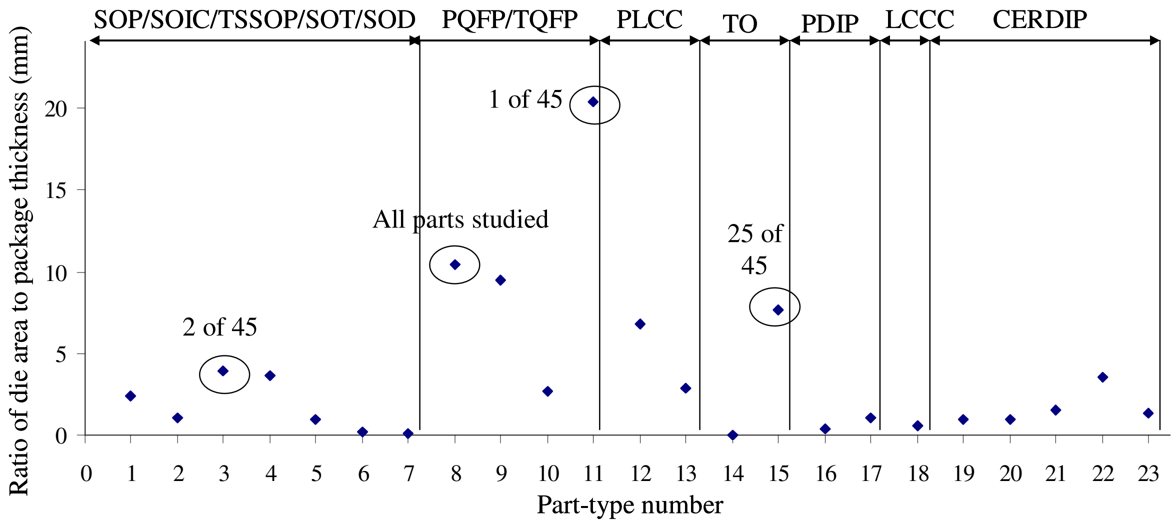


Figure 13: Ratios of die-area to package thickness for each part-type. Encircled part-types showed behavior attributable to thermo-mechanical damage. Figure also shows number of parts with such behavior for each part-type

For any ratio that lies below the maximum of the range of values assessed for no thermo-mechanical damage, as shown in Figure 14 (upper limits of the hatched bars, for e.g ~3.8 for SOPs), the part-type is not expected to suffer from any thermo-mechanical damage from dipping. For part-types, where the ratio of die-area to package thickness exceeds this maximum value, caution needs to be exercised before solder-dipping. Tests may be required on those part-types to assess thermo-mechanical damage from dipping. When part-types show ratios which are less than but close to these maximum values, the necessity of extensive physical analysis will depend on factor-of-safety considerations determined by the application and life-cycle environment of the electronic parts.

This study did not impose any controls on other part parameters that could influence propensity for thermo-mechanical damage such as the material of the mold-compound and die-attach, or the leadframe and die-paddle design. The implications of variations in these part parameters must be considered prior to the use of the guidelines discussed above for critical applications.

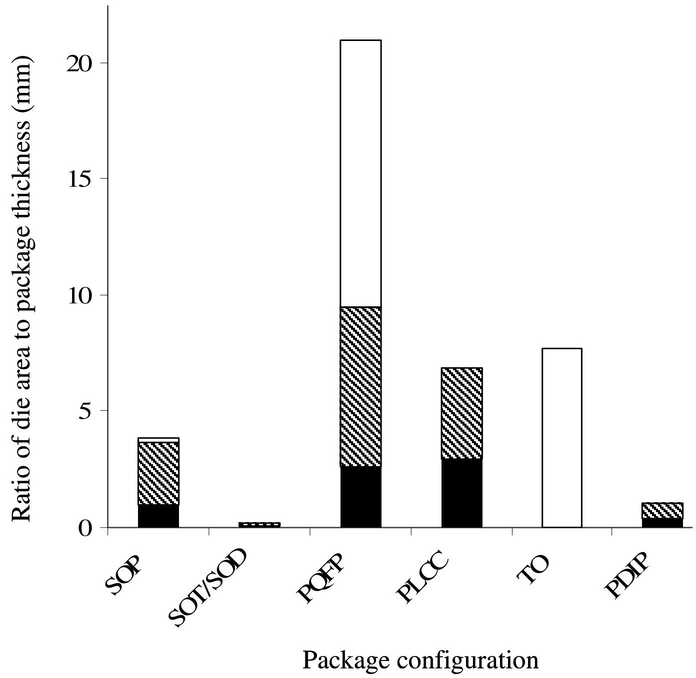


Figure 14 : Ratios of die-area to package thickness assessed for various plastic package configurations. The hatched bars indicate the range of values assessed for part-types that showed no thermo-mechanical damage. The hollow bars indicate the range of values assessed for part-types that showed behavior attributable to thermo-mechanical damage. No part-types were assessed in the range of values indicated by the solid bars.

3.4 Conclusions

The ratio of die-area to package thickness is a metric to assess the role of thermo-mechanical damage before solder-dipping electronic parts. In general, we found that for a given package configuration, part-types with larger ratios of die-area to package thickness are at higher risk of thermo-mechanical damage from solder-dipping than those with a smaller ratio, other part parameters remaining invariants. In addition, we found that package configurations that exhibit inherently large ratios of die-area to package thickness are more likely to suffer from thermo-mechanical damage than those with smaller ratios. Thus, part-types with large die housed in thin packages (such as TQFP, TSSOP) are more vulnerable to thermo-mechanical damage and are possibly inappropriate for solder-dipping. Suitability of large-die, thin, plastic packages for solder-dipping needs to be assessed by physical analysis similar to that performed in this study.

The die-area to package thickness ratio can be used to leverage results from this assessment to other part-types within a given package configuration for suitability to the solder-dipping process. Successful assessment of a part-type may be used to infer a successful outcome for other part-types of the same package configuration, that exhibit a ratio of die-area to package thickness that is less than or equal to the part-type that was assessed.

Thermo-mechanical damage can be induced into packages not only from solder-dipping, but also from subsequent environmental exposure. The combination of these exposures can produce more damage than either alone. Environmental exposure conditions, on solder-dipped parts were found to increase the magnitude of pre-existing defects, such as die-surface delamination. Efforts must thus, be undertaken to ensure that electronic parts are free from any pre-existing defects prior to solder-dipping electronic parts.

Chapter 4: Non-Uniformity in Finish Thickness from Solder-Dipping

4.1 Observations

Visual inspection of post-dipped parts showed smooth, shiny surfaces and evidence of good wetting. There were no visible areas of de-wetting, solder-bridging, dross accumulation or solder-flakes over terminations for 22 of the 23 part-types studied.

Figure 15 shows schematics of termination cross-sections at planes A-A or B-B, obtained on as-received parts (with plated finish) and post-dipped parts. As-received parts with plated finishes exhibited uniform thickness around the leadframe. Post-dipped finishes were less uniform than plated finishes, and had minimum finish thickness typically occurring at the termination corners. The maximum finish thickness typically occurred midway along the termination edges.

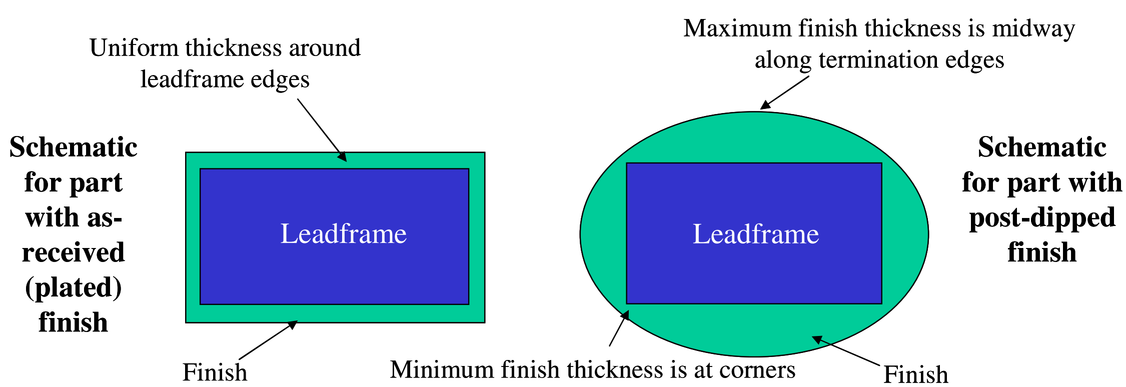


Figure 15: Schematics of part-termination cross-sections performed at planes A-A (or B-B). The as-received (plated) part shows uniform finish thickness. The post-dipped part shows non-uniform finish thickness.

Part-termination cross-sections at planes A-A (or B-B) showed two kinds of part-types among all 23 analyzed: those with straight leadframe edges (see Figure 16 and Figure 17) and those with concavity in the leadframe edges (see Figure 18 and Figure 19). Four part-types (#s 3, 6, 8 and 16) were selected from the 23 under study for a dimensional assessment of finish thickness at the termination corners. The selected part-types were representative of the general post-dipped finish profile seen for all of the 23 part-types. Part-types #3 and #8 were representative of those with concavity in leadframe edges while #6 and #16 were representative of those with straight edges.

Table 5 provides a summary of the findings from the dimensional assessment. Measurements of finish thickness at the termination corners indicated a greater number of cases of exposed base-metal and/or interfacial IMC and, lower mean finish thickness for the part-types with concave leadframe edges as compared to those with straight edges. This suggests that part-types with concave leadframe edges are at higher risk of exposure of base-metal or interfacial IMC, compared to those with straight edges.

Table 5: Part-types selected for dimensional assessment of finish thickness at part-termination cross-section corners

Part-type #	Part-type	Leadframe type	Number of cases of base-metal or IMC exposure observed/ number of total observations	Average finish thickness at corner (μm)*
3	16-pin TSSOP	Concave edges	6/24	0.6 ± 0.1
6	3-pin SOT-23	Straight edges	0/16	1.6 ± 0.1
8	208-pin PQFP	Concave edges	4/24	0.9 ± 0.1
16	14-pin PDIP	Straight edges	3/24	1.4 ± 0.2

All surface-mount part-types among the 23 studied, indicated propensity for variation in the maximum finish thickness between the top and bottom surfaces upon solder-dipping. The maximum finish thickness at the bottom edge of the part-termination cross-section at planes A-A (or B-B) was found to be typically larger than that at the top edge for post-dipped parts (see Figure 20 and Figure 21).

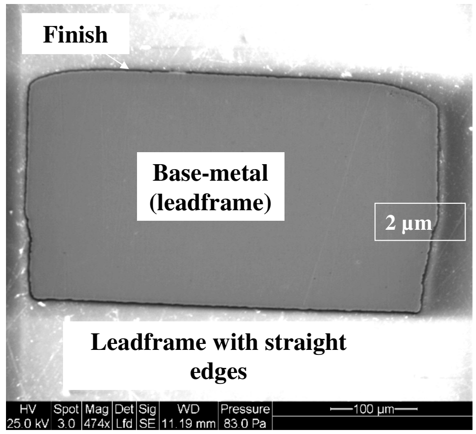


Figure 16: As-received part of 14-pin PDIP (part-type 16) showing uniform finish thickness, for plane of cross-section B-B

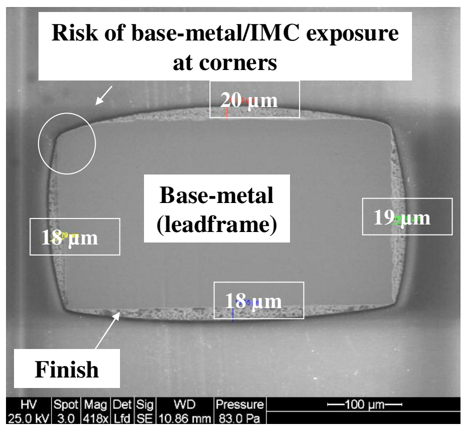


Figure 17: Post-dipped part of 14-pin PDIP (part-type 16) showing variation in finish thickness, for plane of cross-section B-B

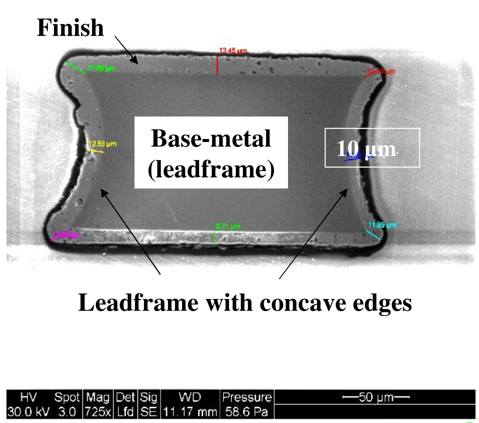


Figure 18: As-received part of 16-pin TSSOP (part-type 3), with concave leadframe edges, for plane of cross-section A-A

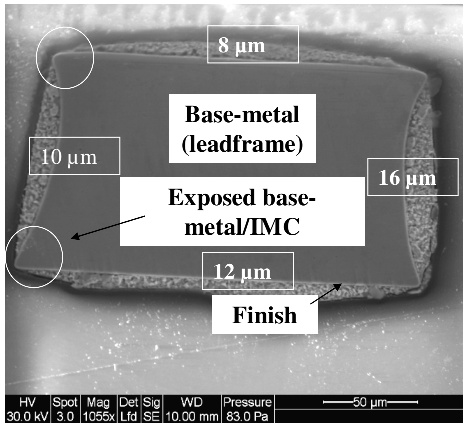


Figure 19: Post-dipped part of 16-pin TSSOP (part-type 3), with concave leadframe edges and exposed base-metal/IMC at the corners, for plane of cross-section A-A

Analysis of Variance (ANOVA) and subsequent Duncan's Multiple Range tests were performed on finish thickness measurements at edges of part-termination cross-sections of part-type 8, 208-pin PQFP to assess the variation in thickness between top and bottom edges. Part-type 8 was arbitrarily selected to represent the general trend that was observed for all surface-mount part-types analyzed. L1 values represented maximum finish thickness at the bottom edge while L3 values represented that at the top edge for post-dipped parts (see Figure 21). L2 and L4 values represented maximum finish thickness along the side-edges for post-dipped parts. L1, L2, L3 and L4 values were recorded from 5 terminations each of 2 post-dipped parts of this part-type. Results from this analysis confirmed that L1 and L3 values for the post-dipped parts belonged to different populations with α (significance level) = 0.01. Normal distribution fits to L1, L2, L3 and L4 values were obtained for a graphical representation (see Figure 22) of populations of each corresponding set of values.

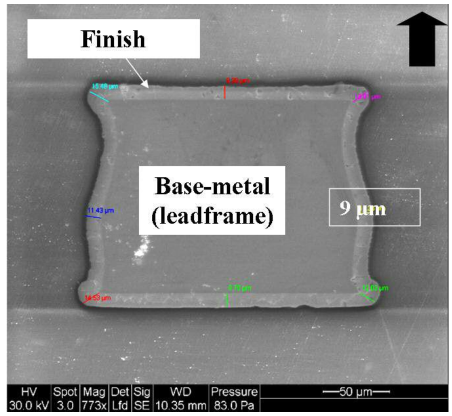


Figure 20: As-received part 208-pin PQFP (part-type 8), for plane of cross-section A-A; arrow points to top side of part

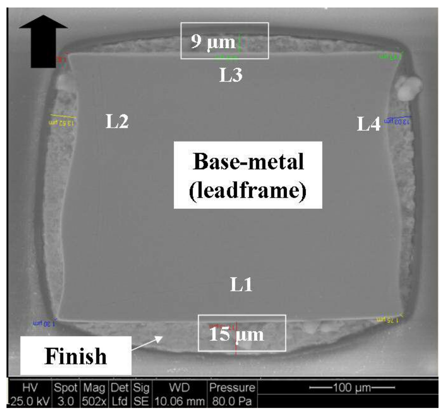


Figure 21: Post-dipped part of 208-pin PQFP (part-type 8), for plane of cross-section A-A; arrow points to top side of part

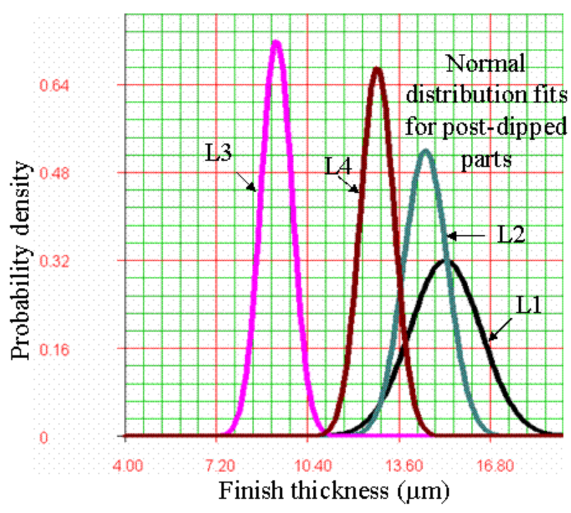


Figure 22: Normal distribution fits for graphical representation of L1, L2, L3 and L4 values

All as-received parts with plated finish, showed uniform finish thickness all along termination edges, including bends such as those at termination knees and heels (see Figure 23) when cross-sections were performed (along plane C-C, in Figure 5). Post-dipped parts however, showed non-uniform finish thickness along termination edges. The maximum thickness was typically found to occur at the insides of the knee and outsides of the heel, with respect to the part body. The outsides of the knee and insides of the heel, with respect to the part body exhibited low (~1.5μm) finish thickness (see Figure 24).

The base-metal was frequently found exposed at termination toes for both as-received and post-dipped parts. Exposed base-metal at termination toes occurs when the leadframe is finished by means of plating, after the encapsulation process and before trim-forming the terminations. After completion of plating, the leadframe is detached from the support that provides electrical contact at the termination toes. This detachment operation thereby results in exposed copper at the toes.

While the IPC A-610D [40] specifies the minimum fillet height required at the heels (F) (see Figure 25) and the minimum solder thickness required at the base of the termination foot (G) for solder-joint assemblies, it does not specify any minimum fillet height required to cover the termination toe. J-STD-001D [16] explicitly permits exposed base-metal at termination toes since the toe is not considered to be a part of the required fillet area.

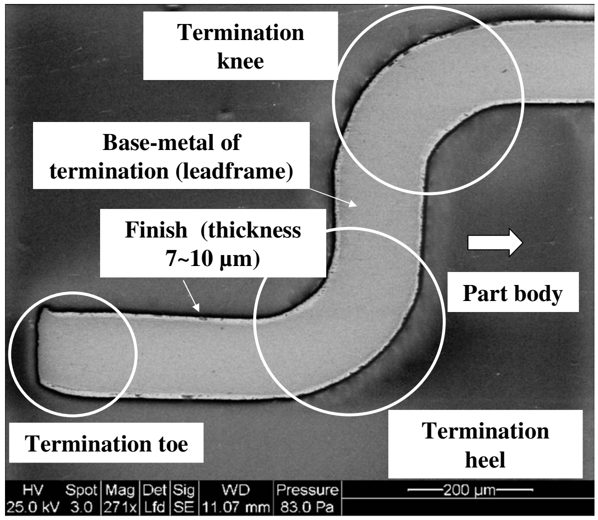


Figure 23: As-received parts (with plated finish) showing uniform finish coverage all along, including knee and heel, for plane of cross-section C-C.

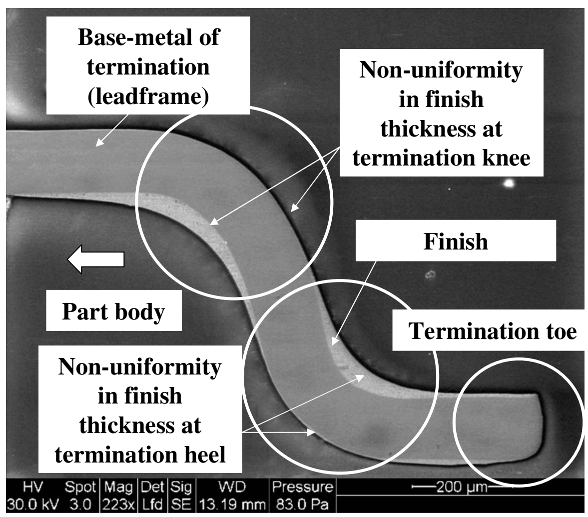


Figure 24: Post-dipped parts showing non-uniform finish coverage with low thickness at outside of knee and inside of heel, for plane of cross-section C-C

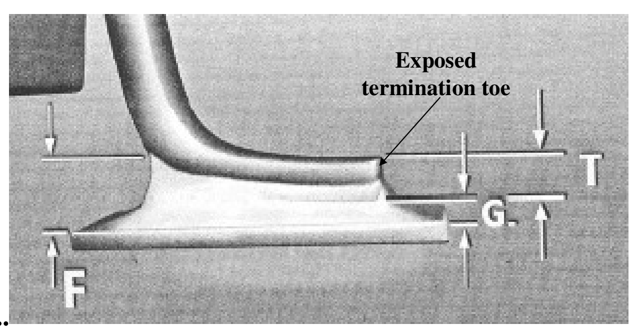


Figure 25: Acceptable solder-joint assembly for class 1, 2 and 3 electronic products, as per IPC-A-610D [40] showing incomplete coverage of the toe by the fillet; F= heel fillet height, G= solder thickness, T= termination thickness

Dimensional assessment was performed on part-type 11 (100-pin TQFP), where the as-received parts had plated finish to demonstrate finish thickness at termination bends in surface-mount parts. Table 6 summarizes the finish thickness measurements recorded at the insides and outsides of termination knees and heels of as-received and post-dipped parts of this part-type. Each value was obtained as an average of 4 readings from 2 terminations of 2 parts. These findings show the large variation (range ~ 30μm) in finish thickness between the insides and outsides of termination knees and heels of post-dipped parts. As-received parts, on the other hand showed uniform finish coverage (range ~ 3μm) all along the terminations, including the insides and outsides of termination knees and heels.

Table 6: Finish thickness measurements at termination knees and heels for 100-pin TQFP (part-type 11)

Termination region (w.r.t. part body)		Finish thickness (μm)	
		As-received part	Post-dipped part
Knee	Inside	10.3	30.9
	Outside	7.9	1.5
Heel	Inside	7.1	2.3
	Outside	10.3	27.9

Figure 26 shows solder blobs on the underside of termination surfaces of one post-dipped part of the 2-pin SOD-123 (part-type 7). Handling due to multiple attempts of insertion into test sockets caused mechanical damage to the solder blobs and led to subsequent failure during electrical testing of this part. Another 14 parts of part-type 7 were reported to have had difficulty in part mounting in test-fixtures due to similar evidence of excess solder over termination surfaces.

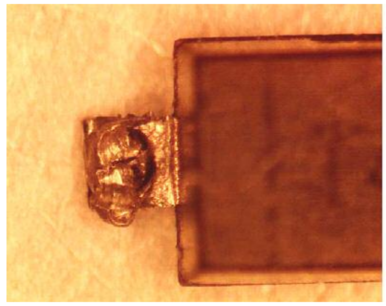


Figure 26: Solder blobs on the underside of termination surface for 2-pin SOD-123 (part-type 7)

4.2 Discussion

Poor wetting of termination portions such as sharp corners and bends discussed in Section 4.1, by the molten solder, causes the base-metal or the IMC at the leadframe-finish interface to be directly exposed. Base-metals such as copper oxidize and corrode when exposed to moisture, high temperatures and environments containing sulphur and chlorine. The wettability of the base-metal is adversely affected due to the formation of corrosion products, which thus deteriorates solderability of the terminations during subsequent reflow [41].

Portions of the termination with low finish thickness can also pose the risk of exposure of the underlying base-metal/IMC. Tin, from the finish is gradually consumed in formation of IMC at the leadframe-finish interface resulting in depletion of the finish with aging of electronic parts [20]. If the finish thickness is sufficiently low, this finish depletion will ultimately result in exposure of the underlying base metal or the interfacial IMC. Prior studies have concluded that solder-dipped parts when aged under harsh conditions show greater loss in solderability as compared to electroplated parts, due to the degradation in solder coverage around the base-metal [20]. Another study concludes that oxidation of the interfacial IMC is the most dominant mechanism for the degradation in solderability performance under accelerated aging conditions [42]. The loss in solderability has further been found to result in premature deterioration in solder-joint reliability under temperature cycling [21].

The solder-dipping process, as used in this study and commonly used in the industry, was performed to comply with finish thickness requirements as per MIL-PRF-38535G [43]. The finish thickness requirements, as per this standard for solder-dipped and tin-lead plated systems, are tabulated in Table 7. The finish thickness measurements, according to the standard record the maximum finish thickness over termination edges at part-termination cross-sections. This standard does not specify any minimum finish thickness requirements.

Table 7: Finish thickness requirements as per MIL-PRF-38535G [43]; NS = Not specified

Finish type	Shape of termination sections	Pitch (mm)	Finish thickness (μm)		Nominal solder-bath composition
			Minimum	Maximum	
Solder-dip	Round	NS	1.52	NS	Tin 60 lead 40 or Tin 63 lead 37
Solder-dip	All shapes (other than round)	≤ 0.64	3.80	NS	Tin 60 lead 40 or Tin 63 lead 37
Solder-dip	All shapes (other than round)	> 0.64	5.08	NS	Tin 60 lead 40 or Tin 63 lead 37
Tin-lead plating	All shapes	NS	7.62	NS	Tin 97 to 50, balance lead

All finish thickness measurements that were made in this study on post-dipped parts complied with the requirements of MIL-PRF-38535G [43]. However, base-metal or interfacial IMC was found exposed at termination corners, especially in parts with concave leadframe edges, as has already been noted in Table 5. Even where base-metal or interfacial IMC was not directly exposed, post-dipped parts were found to have low finish thickness at termination corners. Thus in effect, electronic parts are at risk of being considered as compliant with requirements of the above standard, in spite of exposed base-metal or IMC and/or low finish thickness over termination surfaces.

Solder-dipped finishes have also historically been prone to solder-bridging between adjacent terminations, particularly for fine-pitch packages (for e.g. ≤ 0.65mm) and the collection of dross and flakes of excess solder over termination surfaces [44]. Moreover, solder-dipping is known to result in poor coplanarity due to the inherent difficulty of the process to control the thickness of the finish [45]. The coplanarity problem potential is further aggravated by the risk of bent terminations during additional handling.

Various process and part parameters can influence the uniformity in finish thickness as shown in the fishbone diagram (see Figure 27). All process parameters were maintained as constants in this study for all part-types analyzed, with the exception of the angles of insertion to and withdrawal from the solder-bath, which were selected based on the package configuration. Since the process parameters were maintained as invariants, the analysis of the effects of the process parameters on the observations was beyond the scope of this work. The variations in uniformity of the solder-dipped finish as observed in this study may however, be minimized by means of optimization of the process parameters specific to the part-type. It is therefore, important to understand the role of both process and part parameters in influencing the uniformity of the solder-dipped finish.

4.2.1 Process parameters

Flux material will determine fluxing efficiency which correlates closely to the wettability of the molten solder and thus, to uniform finish coverage around the base-metal. Fluxes typically contain inorganic or organic activators and alcohol or water based solvents. Inorganic fluxes are fast acting, stable over a large temperature range and efficient in terms of oxide removal and thus, promote excellent finish coverage. However, these are corrosive and can result in contamination and corrosion related reliability issues [44]. Organic-acid based fluxes typically have milder fluxing efficiency, although the cleansing action of organic halide-salt based fluxes are comparable to that of inorganic fluxes. Organic components are temperature sensitive and may undergo polymerization and/or decomposition reactions at higher temperatures during preheating or dipping affecting fluxing efficiency [44]. Polymerization or decomposition by-products can leave behind flux residues which adversely affect the wettability of the molten solder. The organic-acid water soluble flux used in this study is reported to be effective for a wide range of tin-based finishes over commonly used base-metals, with a maximum process temperature of around 315 °C [46].

Shorter preheating times and lower temperatures than that specified by the flux manufacturer will not activate fluxing action. On the other hand, preheating time and temperature, beyond manufacturer specified maximum limits can not only be economically wasteful but also set off polymerization reactions for organic fluxes, which will affect the wettability of the termination surfaces.

If the temperature of the solder-bath is not high enough, material of the pre-existing finish may not melt completely. Incomplete dissolution of the pre-existing finish may affect the uniformity of the wetting of the termination surfaces by the molten solder and result in non-uniformities in finish thickness. Solder-bath contamination in terms of accumulation of foreign particles, inclusions and dross with time can also affect the wetting characteristics of the molten solder and thus, wetting of the part-termination surfaces.

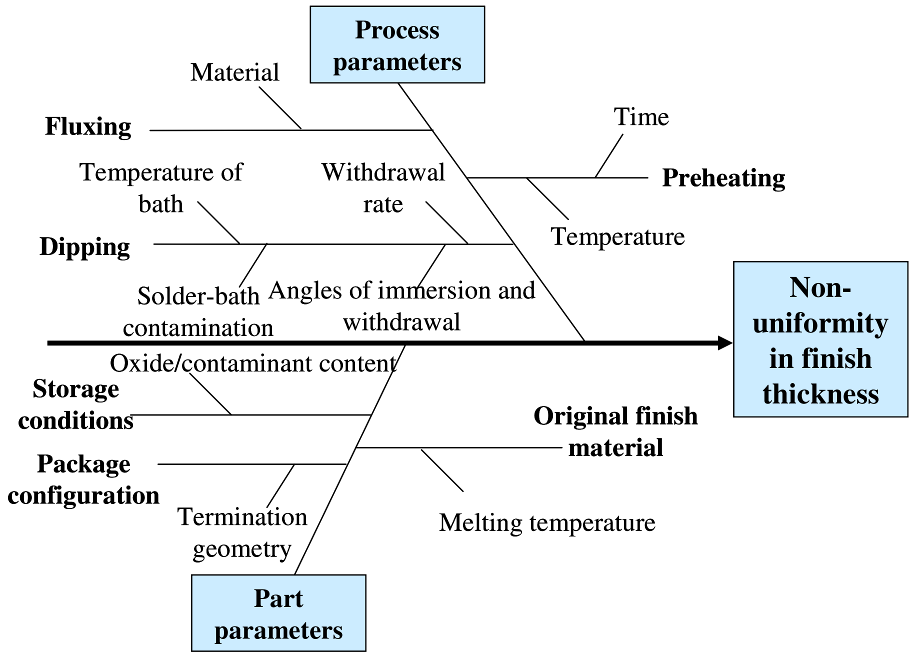


Figure 27: Process and part parameters that influence uniformity in finish thickness for solder-dipped parts.

Other process parameters include rates and angles of withdrawal of the part from the solder-bath. Faster rates of withdrawal from the solder-bath result in shorter times for the molten solder in the finish, to redistribute along the part-termination surfaces, as the solder solidifies under the action of surface-tension and gravitational forces. This can lead to formation of regions of excess solder build-up in the finish over portions of terminations where effects of gravity are weak.

4.2.2 Part parameters

Storage conditions of parts before solder-dipping, will determine the level of contamination and oxide films on the part-termination surfaces. High content of pre-existing contamination or oxide films will degrade efficiency of the flux material and will thus impair wettability of the molten solder, resulting in non-uniformities in the solder-dipped finish thickness. An acid pre-cleaning step may be used to assist fluxing action in case of parts with severe levels of contamination and oxides [17]. Since storage conditions for all part-types analyzed here were identical, none of the observations were attributable to storage conditions of the parts.

The material of the pre-existing finish on part-terminations should be such that they allow for complete melting at the temperatures of the solder-bath. Incomplete dissolution of the pre-existing finish will affect wetting characteristics of the molten solder, as was noted in the discussion for process parameters. Most lead-free tin-based finishes melt in the range of 170 – 227 °C, with others such as Sn-58Bi and Sn-52In melting at lower temperatures. Finishes of Sn-5Sb and Sn-4.7Ag-1.7Cu melt around 240 – 245 °C and this may result in incomplete dissolution for the temperatures of the solder-bath as used in this study, due to localized cooling effects. Some Sn-Ag-Cu formulations however, melt at temperatures of 285 °C or beyond and will necessarily require higher temperatures for complete dissolution. All part-types studied had pre-existing finish material whose melting temperature was well below the temperature of the solder-bath. Thus, none of the observed finish non-uniformities were attributable to the original finish material.

Package configuration will determine termination geometry which, can influence the uniformity of the solder-dipped finish. Gull-winged surface-mount part-types exhibit bends in terminations such as those at the termination knees and heels. Surface-tension and gravitational effects that come into play during the solidification of the solder in the finish, as the part is being withdrawn from the solder-bath (see Figure 28), can lead to poor finish coverage at the knees and heels. All gull-winged surface-mount parts studied here, exhibited low finish thickness at termination bends, as noted in Section 4.1.

Concavity in the leadframe edges as observed in part-termination cross-sections at planes normal to termination lengths, is another factor related to termination geometry, which can affect the wettability of the molten solder. Parts that exhibit concave leadframe edges, as observed at planes of cross-section A-A or B-B, tend to have sharper corners which will be poorly wetted by molten solder, as discussed in Section 4.1.

The concavity in leadframe edges is commonly observed for parts with etched leadframes. Etching is preferred over stamping as a method of leadframe manufacture for high-pin-count (typically > 100 pins), fine-pitch (typically < 0.65 mm) electronic parts. Four (#s 3, 8, 9 and 11) of the 23 part-types analyzed that had the lowest pitch (< 0.65 mm), exhibited concavity in the leadframe edges and also showed evidence of poor wetting at the corners of the part-termination cross-sections. Three (#s 8, 9 and 11) of these 4 part-types had greater than 100 pins and the part-manufacturer confirmed that the leadframe for these part-types had been manufactured by etching.

4.3 Conclusions

Electronic parts re-finished by solder-dipping exhibited finish thickness related non-uniformities in terms of low (less than 1.5 μm) finish thickness at termination corners and bends, variation in finish thickness between top and bottom surfaces for surface-mount parts and evidence of excess solder for some of the parts that were analyzed.

Low finish thickness at terminations corners and bends such as termination knees and heels can lead to potential exposure of the underlying base-metal or IMC on aging of the electronic parts. High pin-count (> 100 pins), fine-pitch (< 0.65 mm) parts generally have etched leadframes which can exhibit concave leadframe edges at planes of cross-section normal to termination lengths (A-A or B-B in Figure 5). These parts will be more prone to exposure of base-metal or IMC due to the sharper corners of the leadframe geometry, which are poorly wet during the solder-dipping process.

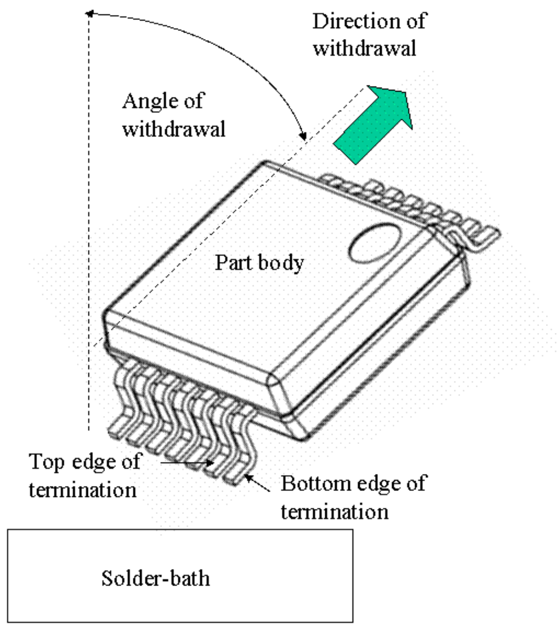


Figure 28: Schematic showing withdrawal of part from the solder-bath

For small parts where termination knees are close to the edges of the molding compound, corrosion of the exposed base-metal or IMC, at knees can reduce leadframe-to-molding compound adhesion and cause interfacial delaminations. This can act as a path for ingress for corrosion products, as also moisture and other contaminants to the internals of the package, resulting in various reliability concerns [47]. Exposed base-metal or IMC and, its subsequent corrosion at termination heels will deteriorate solderability performance resulting in poor wetting during reflow and degrade solder-joint reliability.

We find that the commonly used standards [43] to assess finish thickness for solder-dipped parts may fail to effectively identify parts with regions of exposed base-metal or IMC and, those with low finish thickness. Additional studies that involve accelerated aging of the termination finish (e.g., mixed flowing gas [48][49]) will be necessary to evaluate the effects of the thinness or lack of finish in solder-dipped parts, particularly for long term exposure to uncontrolled, high temperature, high humidity storage and/or use environments.

Solder-dipped surface mount parts can also have larger than normal finish thickness at the bottom surfaces of the terminations. This occurs due to the combined effects of surface-tension of the molten solder and gravity as the part is being withdrawn from the solder-bath. Since, the maximum finish thickness at the bottom edges of part-termination cross-sections was found to be around 30 µm, coplanarity variations were well within established process limits (100 µm) in this study. Co-planarity variations were thus, not considered as a risk for the part-types that underwent dipping in this study. However, efforts must be enforced to ensure that solder-dipped surface-mounts parts conform to coplanarity requirements prior to subsequent processing. Solder-dipped parts must be inspected for the presence of finish non-uniformities, such as the solder blobs observed in this study, before mechanical mounting into test fixtures.

Since the process parameters were maintained as invariants for all part-types analyzed, a study on the effects of the process parameters on the observations was beyond the scope of this work. It would however, be useful for future work to address possibility of minimization of the variations in uniformity of the solder-dipped finish, by means of optimization of the process parameters specific to the part-type

Chapter 5: Incomplete Replacement of Pre-Existing Finish / Poor Solderability

5.1 Observations

The following sections explain the observations from the XRF analysis for the finish composition study and the dip-and-look tests for the solderability assessment.

5.1.1 Finish composition study

Results of analysis of finish composition for the as received and post-dipped parts are summarized in Table 8. These values were obtained as an average of readings from XRF surface analysis of at least 5 terminations of the post-dipped parts. Deviations of the post-dipped finish composition from the eutectic composition were marginal (Sn ±2.1%, Pb ±2.0%, as may be seen from Table 9) at termination feet for all part-types. Larger deviations (Sn -30.3%, Pb -24.5%, as may be seen from Table 10) from eutectic composition were observed at termination heads for the DIP part-types (#16 and #19), which showed the largest deviations among all part-types. Part-types #16 and #19 also showed higher (see Table 8) finish thickness at termination feet compared to termination heads. Elements from the underlying base-metal were detected in larger percentages (see Table 11) at termination heads compared to termination feet in the post-dipped finishes for all part-types.

Table 8: Finish composition study results

#	As received finish, by weight (%)	Lead-frame	Post-dipped finish			
			Termination foot		Termination head	
			Finish thickness (μm)	Composition, by weight (%)	Finish thickness (μm)	Composition, by weight (%)
15	Sn 100	Copper	11.1 (±2.1)	**Sn 59.5, Pb 34.3**, Cu 6.2	2.2 (± 0.9)	**Sn 54.0, Pb 33.0**, Cu 13.0
16	Au/Pd/Ni	Copper	40.0 (±1.6)	**Sn 61.2, Pb 36.7**, Cu 1.6, Ni 0.3, Pd 0.0, Au 0.2	4.9 (±0.6)	**Sn 26.9, Pb 9.2**, Cu 54.3, Ni 9.1, Pd 0.3, Au 0.2
19	Sn 100	Alloy 42	22.7 (±1.1)	**Sn 64.4, Pb 33.9**, Fe 1.1, Ni 0.6	2.7 (±0.4)	**Sn 38.6, Pb 15.8**, Fe 32.8, Ni 12.8
24	Sn 97.6 Cu 2.4	Copper	3.8 (±0.1)	**Sn 62.6, Pb 35.3**, Cu 1.6, Ni 0.5	6.1 (±1.6)	**Sn 57.9, Pb 32.3**, Cu 8.9, Ni 0.9
25	Sn 100	Copper	2.6 (±0.2)	**Sn 59.4, Pb 39.4**, Cu 1.1, Ni 0.1	4.3 (±0.2)	**Sn 56.9, Pb 40.4**, Cu 2.6,Ni 0.1

Table 9: Deviation from eutectic composition at termination feet for all part-types

Part-type #	Sn in post-dipped finish (%)	Deviation from 63% (%)	Pb in post-dipped finish (%)	Deviation from 37% (%)
15	59.5	-3.5	34.3	-2.7
16	61.2	-1.8	36.7	-0.3
19	64.4	+1.4	33.9	-3.1
24	62.6	-0.4	35.3	-1.7
25	59.4	-3.6	39.4	+2.4
Average deviation	**for Sn**	**± 2.1**	**for Pb**	**± 2.0**

Table 10: Deviation from eutectic composition at termination heads for the DIP part-types

Part-type #	Sn in post-dipped finish (%)	Deviation from 63% (%)	Pb in post-dipped finish (%)	Deviation from 37% (%)
16	26.9	- 36.1	9.2	- 27.8
19	38.6	- 24.4	15.8	- 21.2
Average deviation	**for Sn**	**- 30.3**	**for Pb**	**- 24.5**

The XRF analysis of the post-dipped finishes for the 14-pin PDIP (part-type 16) is shown in Table 11. Termination feet showed finish thickness of ~40 µm and finish composition close to tin lead eutectic. Measurements at termination heads were made at two different regions (see Figure 29). Region 1 was just below the termination bend (vertical area) while Region 2 was above the bend and closer to the part body (close to horizontal). These regions clearly belonged to different populations. Region 1 measurements showed higher finish thickness (~ 5µm) and composition as showed in Table 11. Region 2, on the other hand showed lower finish thickness (~ 0.4 µm). XRF analysis gave inconclusive results for composition of the finish material at Region 2.

Table 11: XRF findings for post-dipped finish of the 14-pin PDIP (part-type 16)

Termination region		**Thickness (µm)**	**Composition of post-dipped finish, by weight (%)**
Feet		40.0 (±1.6)	**Sn 61.2, Pb 36.7**, Cu 1.6, Ni 0.3, Pd 0.0, Au 0.2
Heads	Region 1	4.9 (±0.6)	**Sn 26.9, Pb 9.2**, Cu 54.3, Ni 9.1, Pd 0.3, Au 0.2
	Region 2	0.4 (±0.1)	XRF analysis gave inconclusive results for composition of the finish material

5.1.2 Solderability assessment

Post-dipped parts for all part-types passed the dip-and look solderability tests conducted. Terminations showed uniform solder coverage all over termination surfaces including termination portions deemed critical as per inspection and failure criteria provided in the JEDEC Standard JESD22-B102D [23]. In all cases, pinholes, voids, non-wetting, de-wetting and other related defects were well below the maximum limit of 5% of total area inspected, as required by this standard [23]. Figure 30 and Figure 31 show the underside of termination feet of post-dipped parts of the 100-pin TQFP (part-type 4) before and after performing the dip-and-look solderability tests.

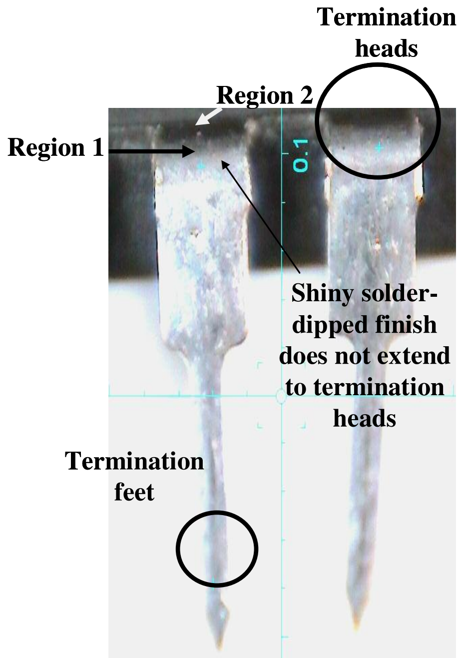


Figure 29: Regions of measurement: Heads and feet for 2 adjacent terminations of the 14-pin PDIP (part-type 16)

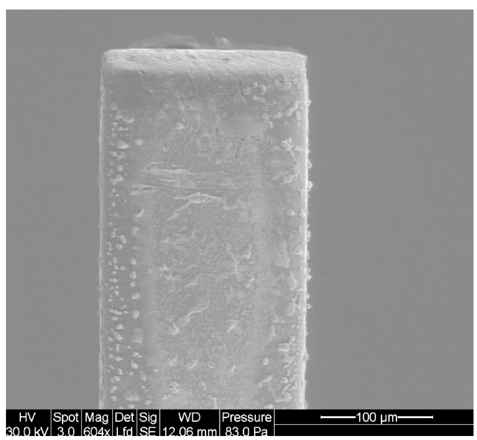


Figure 30: Underside of termination feet of post-dipped parts, after pre-conditioning and before solder immersion

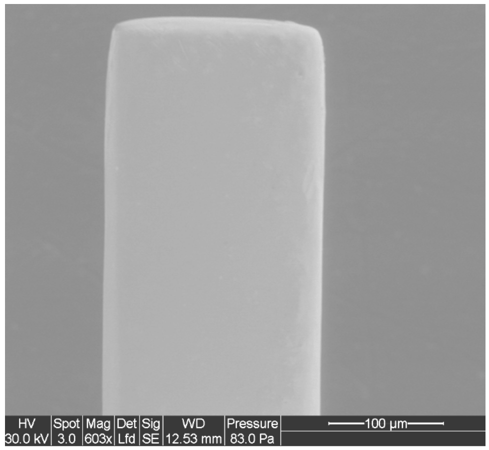


Figure 31: Underside of termination feet of post-dipped parts, after pre-conditioning and solder immersion, showing uniform solder coverage

5.2 Discussion

The low finish thickness and greater percentage of base-metal elements detection in the post-dipped finish composition at the termination heads (see Table 8), were indicative of poor wetting by the molten solder for at least, the DIP part-types (#16 and #19). Poor wetting can result in incomplete replacement of the pre-existing finish which will leave behind residual material and consequently cause the solder-dipped finish to have deviations from the expected tin-lead eutectic composition. Residual pre-existing finish material (Ni/Pd/Au) was detected at the termination heads for part-type 16 (see Table 8). Part-types #2 and #3 also demonstrated large (see Table 10) compositional deviations at the termination heads from the eutectic composition, as has been explained in Section 5.1.1.

Since the solder-dipping process is aimed at replacing tin-rich finishes with eutectc tin-lead, the effectiveness of the process as a tin-whisker risk mitigation strategy will have to be questioned if the resulting composition of the solder-dipped finish deviates sufficiently from the desired eutectic composition. Since the mid 1990s, industries with high reliability applications such as the US military have preferred using tin-lead finishes with at least 3% lead, to mitigate the problem of tin-whiskering [4]. The use of tin containing less than 3% lead has been banned in space-based systems, strategic missile vehicles and implanted medical devices [12]. Alloying pure tin finishes with 3% or more of lead, has thus been believed to effectively reduce tin-whiskering risks. The lead percentage detected in this study, was always greater than 3% for all post-dipped parts analyzed, including the termination heads for the DIP part-types that showed the largest deviations from tin-lead eutectic composition.

Although, a minimum of 3% lead is commonly believed to sufficiently mitigate tin-whiskering risks, whisker formation for finishes containing greater than 3% lead is rare but not impossible. There have been reports of tin whisker formations for 90/10 and 93/7 tin-lead finishes [50] [51] [52]. Since termination surfaces of solder-dipped parts can show variation in tin-lead composition, it will be useful to perform finish composition analysis of such parts in line with the assessment performed here to detect any localized lead-deficient regions. These localized regions can serve as potential sites for tin-whisker formation in spite of solder-dipping. The minimum required lead percentage to be used as the cut-off percentage is an engineering decision and may be selected to range from 3~10%, based on the use environment and the criticality of the part application.

Solder-dipped electronic parts commonly exhibit exposed base-metal/IMC or low (< 1.5 µm) finish thickness at sharp termination corners and bends such as those knees and heels for surface mount parts. Exposed base-metal will form oxides which will adversely affect wettability of molten solder during board assembly reflow and thus impair solderability. Intermetallic compounds (IMC) at the leadframe-finish interface are necessary for metallurgical bonding between the leadframe and the finish materials.

These IMC will not cause solderability problems as long as they remain covered with the finish material. These IMC however, continue to grow with time and temperature, consuming tin from the finish and gradually depleting the finish. If the finish thickness is sufficiently low, this finish depletion will ultimately result in exposure of the underlying base metal or the interfacial IMC [20]. Exposed IMC will further oxidize effecting loss in part solderability [20] [21] [53] .

A previous study concludes that oxidation of the interfacial IMC is the most dominant mechanism for the degradation in solderability performance under accelerated aging conditions [42]. Other studies have concluded that solder-dipped parts when aged under harsh conditions show greater loss in solderability as compared to electroplated parts, due to the degradation in solder coverage around the base-metal [20] [21][22] . The loss in solderability has further been found to result in premature deterioration in solder-joint reliability under temperature cycling [21].

Various process and part parameters can influence incomplete replacement of the pre-existing finish and possibility of poor solderability of terminations of parts re-finished by solder-dipping (see Figure 32). All process parameters were maintained as constants in this study for all part-types analyzed, with the exception of the angles of insertion to and withdrawal from the solder-bath, which were selected based on the package configuration. Since the process parameters were maintained as invariants, the analysis of the effects of the process parameters on the observations was beyond the scope of this work. The variations in the solder-dipped finish composition, as observed in this study may be minimized by means of optimization of the process parameters specific to the part-type. It is therefore, important to understand the role of both process and part parameters in influencing the incomplete replacement of the pre-existing finish and/or poor solderability of the re-finished terminations.

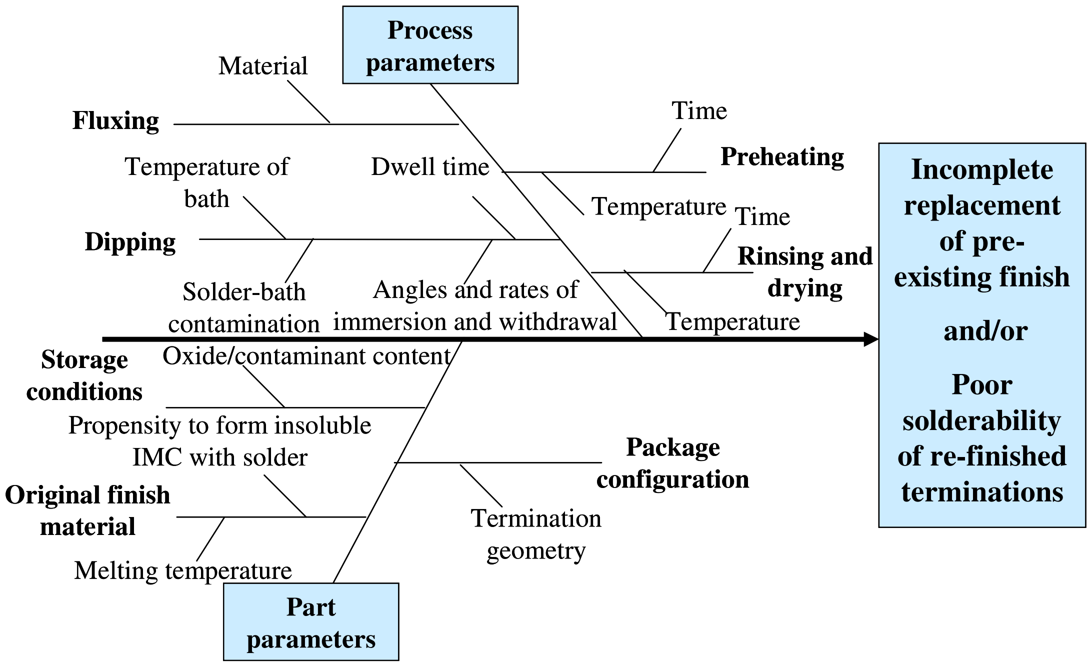


Figure 32: Fishbone diagram for incomplete replacement of pre-existing finish and poor solderability of terminations re-finished by solder-dipping

5.2.1 Process parameters

Fluxing efficiency closely correlates to wettability of the molten solder and thus to complete replacement of the pre-existing finish and uniform finish coverage. Flux materials with lower fluxing efficiency and thus milder cleansing action, will fail to effectively remove oxide films from part-termination surfaces. These oxides may have high melting temperatures, especially when they are ionic in nature. As a result, these oxides will not melt at solder-bath temperatures and will inhibit the replacement of the underlying finish material during dipping. Moreover, poor wetting of the molten solder during dipping due to the presence of these oxide films will cause non-uniform finish coverage over the base-metal. This can result in areas of non-wetting, de-wetting, pinholes, voids and other defects of part-termination surfaces which will adversely affect part solderability.

Fluxes typically contain inorganic or organic activators and alcohol or water based solvents. Inorganic fluxes are fast acting, stable over a large temperature range and efficient in terms of oxide removal and thus, promote excellent finish coverage. However, these are corrosive and can result in contamination and corrosion related reliability issues [44]. Organic-acid based fluxes typically have milder fluxing efficiency, although the cleansing action of organic halide-salt based fluxes are comparable to that of inorganic fluxes. Organic components in these fluxes are temperature sensitive and may undergo polymerization and/or decomposition reactions at higher temperatures during preheating or dipping [44]. Polymerization or decomposition by-products can leave behind flux residues which adversely affect the wettability of the molten solder. The organic-acid water soluble flux used in this study is reported to be effective for a wide range of tin-based finishes over commonly used base-metals, with a maximum process temperature of around 315 °C [46].

Longer preheating time and greater temperature, beyond manufacturer specified maximum limits can not only be economically wasteful but also set off polymerization reactions for organic fluxes, which will affect the wettability of the termination surfaces. On the other hand, shorter preheating times and lower temperatures than that specified by flux manufacturer will not activate fluxing action. This can cause the incomplete removal of oxide films over part-termination surfaces, ultimately resulting in incomplete replacement of pre-existing finish and poor solderability of terminations re-finished by solder-dipping.

If the temperature of the solder-bath is not high enough, material of the pre-existing finish may not completely melt resulting in incomplete replacement of the original finish. Temperature fluctuations of the solder-bath to lower than that required can cause localized cooling which will affect the wettability of the molten solder. Poor wetting of the molten solder will manifest in terms of areas of non-wetting, de-wetting, pinholes, voids and other related defects which will adversely affect solderability of the part. Accumulation of contaminants such as foreign particles, inclusions and dross in the solder-bath can affect heat flow in the molten solder, result in localized cooling and inhibit replacement of the pre-existing finish. Solder-bath contamination can also further hinder the fluidity of the molten solder and consequently deleteriously affect solderability of the part-terminations. Low dwell times in the molten solder, may not provide for sufficient time for complete replacement of the original finish with the new eutectic finish. Angles of insertion into and, withdrawal from the solder-bath depend upon the package configuration and determine the extent of the termination surfaces that will be immersed in the solder-bath. These angles can limit the extent of wetting for difficult-to-reach areas such as termination portions immediately adjacent to the part-body. Rates of insertion and withdrawal can affect the quality of the solder-dipped finish in terms of finish thickness uniformity and, will thus influence solderability of the re-finished terminations.

The process steps of rinsing and drying will not have any role in incomplete replacement of the pre-existing finish. These steps may however, affect the solderability of the re-finished terminations. Insufficient rinsing, in terms of time and temperature will leave behind flux residues which will interfere with the wetting process during assembly reflow of solder-dipped parts and can thus compromise solder-joint reliability. Inadequate drying, on the other hand, will fail to cleanse off excesses of the rinsing agent which will in turn, result in contamination or corrosion related reliability problems in the part.

5.2.2 Part parameters

Storage conditions of parts that will undergo solder-dipping, will determine the level of contamination and oxide films on the part-termination surfaces. Use of parts with high contaminant and oxide content, with mild fluxes will result in incomplete replacement of the pre-existing finish due to oxide (or contaminant) interference. High oxide and/or contaminant content will thus impair efficiency of the flux material, degrade wettability of the molten solder and, result in poor solderability of re-finished terminations. An acid pre-cleaning step may be used to assist fluxing action in case of parts with severe levels of contamination and oxides [17]. None of the observations reported in this study were attributable to the storage conditions as all part-types had identical storage conditions.

The material of the pre-existing finish on part-terminations should be such that they allow for complete melting at the temperatures of the solder-bath to allow for replacement of the pre-existing finish with the new eutectic tin-lead finish. Most lead-free tin-based finishes melt in the range of 170 – 227 °C, with others such as Sn-58Bi and Sn-52In melting at lower temperatures. Finishes of Sn-5Sb and Sn-4.7Ag-1.7Cu melt around 240 – 245 °C and this may result in incomplete replacement for the temperatures of the solder-bath as used in this study, due to localized cooling effects. Some Sn-Ag-Cu formulations however, melt at temperatures of 285 °C or beyond and will necessarily require higher temperatures for replacement of the original finish than what was used in this study. All part-types used for this study had pre-existing finish material whose melting temperature was below the temperature of the solder-bath. Thus, none of the observations reported here, were attributable to the original finish material.

The pre-existing finish material can also result in the formation of insoluble IMC at the leadframe-finish interface between itself and the molten solder, thereby not allowing complete and effective removal of the pre-existing finish material. A prior study conducted to remove gold from gold-plated pads via solder-dipping discusses the possibility of the gold forming insoluble IMC with tin from the eutectic solder, thus inhibiting complete removal of gold from the surface-finish [54]. The brittle nature of the IMC can lead to eventual solder-joint embrittlement. Moreover, when exposed the IMC can oxidize and result in degradation in part solderability.

Package configurations of electronic parts will determine termination geometry which, impose constraints in angles of insertion to and withdrawal from the solder-bath. This can hinder wetting of portions of terminations close to the part body and other difficult-to-reach areas. This can thus result in incomplete replacement of the pre-existing finish in these portions of the termination. As we observed in this study, the DIP part-types (#16 and #19) in particular, showed evidence of poor wetting at termination portions immediately adjacent to the part-body. This is expected to have resulted in the large deviations from the expected tin-lead eutectic composition for the post-dipped parts of these part-types. In comparison, the PQFP part-types (#24 and #25) showed evidence of good wetting and eutectic tin-lead composition all over the termination surfaces. The termination geometry of the PQFP package configuration allows for use of steeper angles as compared to DIPs when full length of the terminations are immersed, thereby yielding better results as compared to the DIP configuration.

5.3 Conclusions

Post-dipped parts exhibited variation in finish composition along different portions of the terminations of the part-types analyzed. Analysis of the post-dipped finish composition indicated that portions of the termination that are expected to be a part of the solder-joint-fillet in reflowed assemblies, always had composition close to eutectic tin-lead (Sn 63 ±2.1%, Pb 37 ±2.0%). However, at least the DIP part-types analyzed, showed evidence of poor wetting at termination portions immediately adjacent to the part-body in terms of lower finish thickness and greater (see Table 8) percentage detection of the underlying base-metal elements. Poor wetting could have further resulted in these termination portions to exhibit deviations from the expected tin-lead eutectic composition. Large deviations from the eutectic composition at specific termination portions can result in localized lead deficient areas which can serve as potential sites for tin-whisker formation even after the solder-dipping process.

The DIP part-types analyzed were found to have very low finish thickness (0.4 µm) at portions of the termination immediately adjacent to the part body. Poor finish coverage at these portions would risk exposure of the underlying base-metal and the interfacial IMC. Oxidation and subsequent corrosion of the exposed base-metal and IMC can reduce leadframe-to-molding compound adhesion in these portions and result in interfacial delaminations [47]. This can then act as a path for ingression for moisture, corrosion products and other contaminants to the internals of the package, leading to various reliability concerns.

Post-dipped parts for all part-types passed the dip-and-look solderability tests with terminations showing uniform solder coverage after the tests. Future work needs to further address investigation of board-level solder-joint reliability of electronic parts, re-finished by solder-dipping and reflowed onto board assemblies, by means of performing suitable temperature cycling and lead pull tests.

Contributions

A procedure was developed in close co-ordination with a university-government-industry collaborated team to assess the effects of solder-dipping for termination re-finishing for tin-whiskering risk mitigation purposes. This procedure was aimed at providing an extensive, systematic and organized approach for the investigation of some of the major problems that were anticipated as a result of solder-dipping electronic parts. The procedure was implemented using physical analysis techniques to demonstrate the approach adopted for investigating each the following problems from solder-dipping electronic parts: thermo-mechanical damage from thermal shocks, finish non-uniformity, incomplete replacement of the pre-existing finish and poor solderability from the re-finishing operation.

Key process and part parameters were identified that can result in the above mentioned problems from solder-dipping electronic parts. Further, the ratio of the die area to package thickness was established as a quantitative metric to assess propensity for thermo-mechanical damage from solder-dipping plastic packaged parts. Ranges of the values that were assessed for this metric were categorized according to various plastic package configurations. This was proposed as guidelines for assessing propensity for thermo-mechanical damage before solder-dipping leaded PEMs. The use of this metric has been adopted in a soon-to-be released US Navy sponsored project document aiming to provide guidelines on the use of solder-dipping as a tin-whiskering risk mitigation technique [55].

It was further demonstrated through analysis techniques that surface mount parts when solder-dipped, are prone to exposure of base-metal or interfacial intermetallics along bends in part-terminations such as outsides of termination knees and insides of termination heels as also, at corners of cross-sections normal to length of terminations. Further, the analysis demonstrated that solder-dipped insertion-mount parts, including DIPs have regions of low finish thickness and deviations from eutectic tin-lead composition at portions immediately adjacent to the part-body.

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