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Correlation between Surface Texturing on Pre-Plated Leadframe and Delamination Phenomenon in Automotive Packaging

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ABSTRACT

Poor adhesion between mold compound and leadframe in integrated circuit packaging for automotive devices can cause serious reliability issue and degrade the package quality. This study aims to evaluate and understand the correlation between surface texturing procedure (roughening) on pre-plated leadframe (PPF) and delamination phenomenon in integrated circuit packaging. The pre-plated leadframe with textured surface was prepared by the leadframe supplier. Four major evaluations were conducted which based on morphology analysis, contact angle measurement, mold shear strength test and reliability test. For morphology analysis, textured PPF possessed higher surface roughness (284nm) compared with standard leadframe (174nm). The highest contact angle value was observed for textured PPF at room temperature (71°). Conversely, the lowest contact angle value was observed for textured PPF at 175°C (55°) which was simulated according to inline manufacturing condition. High shear strength test was obtained for textured PPF compared with standard leadframe. Furthermore, reliability test proved that no delamination was detected for PPF sample. However, this phenomenon was observed for standard leadframe. All the observations agreed that the interfacial adhesion between mold compound and leadframe was significantly improved by surface texturing procedure on the leadframe. The improvement of adhesion helps to eliminate delamination and improve package reliability.

Keywords: Automotive packaging, Delamination, Pre-plated leadframe, Reliability, Surface texturing

1. INTRODUCTION

The improvement of integrated circuit (IC) package reliability without high additional cost is desirable in line with high demand of automotive products in the semiconductor market. A reliable IC package without imperfection can be realized by process improvements and new materials development which satisfy the current standards of automotive sector [1]. Poor adhesion between leadframe and mold compound leads to a serious problem which influences the quality, reliability and safety performance of the IC package in automotive devices [2-3]. Delamination in IC package is a phenomenon of weak or loss of film adhesion from the substrate due to the dissimilarity in coefficient of thermal expansions (CTE) between different material interfaces. This phenomenon leads to the package reliability issue, affects the product quality and limits the device performance [3-4]. Adhesion occurs due to the adhesive penetration into cavities, pores or other surface non-uniformities which take over the place of trapped air at the substrate surface. Adhesives usually have better attachment with abraded surfaces rather than smooth surfaces. Adhesion between two different surfaces can be improved by various

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techniques such as mechanical interlocking, establishment of continuous contact surface area and formation of clean or highly reactive surface. The improvement of adhesion can be achieved either by one or combination of these techniques [5]. Therefore, good adhesion between leadframe and mold compound surfaces is important in order to eliminate defects and produce high quality and reliable IC package for automotive devices [3].

1.1 Pre-plated Leadframe

In IC packaging, a leadframe (LF) serves as a mechanical support for chip mounting and also for electrical connection between mounted chips and external package leads [6]. Nowadays, pre-plated leadframe (PPF) has been used as an alternative to the conventional leadframe which offers numerous advantages to the semiconductor packaging industry. This PPF helps in improvement of leadframe solderability and enhances the adhesion of die attach, wire bonds and mold compound [7]. Specifically, copper alloy (Cu-alloy) base plated leadframe are widely used in IC packaging due to their benefits such as low cost compared to gold (Au), high conductivity in terms of electrical and thermal, better in mechanical stability and fewer issue on intermetallic growth [8-9]. Cu-alloy base plated leadframe consists of multi-layer metal plating such as NiPd (nickel/palladium), NiPdAu (nickel/palladium/gold), NiPdAu-Pd (nickel/palladium/gold-palladium alloy) and NiPdAu-Ag (nickel/palladium/gold-silver alloy) [9].

This multi-layer plating has been introduced and sequentially applied on the Cu leadframe for several reasons, which are ability to remove post-plating process of the finished package's leads, as an alternative to Pb (lead)-based plating which is hazardous material to the environment, key for Sn (tin) whisker issue in tin-based plating and used for robust IC package [10]. Each metal layer serves different purpose in the formation of robust Cu-alloy base plated leadframe. The Ni layer is plated on the base material (Cu) which serves as solder joint, resistance for oxidation and corrosion at the LF surface and to prevent Cu diffusion into the next plated layer (Pd). The Pd layer is plated on top of Ni layer helps to avoid oxidation on Ni surface and prevents Au diffusion into the Ni layer. Besides, the Pd and Au flash layers ease the wire bonding and soldering processes. In addition, the combination of Au and Ag at the top layer of PPF helps to lower down the surface hardness for effective bondability [6,11].

1.2 Surface Texturing

Surface texturing or roughen the plating layer is one of the alteration methods that helps in improvement of adhesion between different interfacial surfaces (mold compound – leadframe and mold compound – chip). Rough PPF is not only keeps the thermal path but also tends to lower down the stress on the stitch bonds and ball which deters broken stitch bonds or lifted ball of the package [7]. PPF with rough surface enhances the effect of mechanical interlocking resulted in stronger adhesion between different interfacial surfaces hence controls the delamination problem for better IC package reliability [3,7-9]. However, optimum roughness is necessary to warrant the adhesion between different interfacial surfaces. This is because a smooth surface reduces the adhesion tendency while a very rough surface does not correspond to the adhesion standpoint [4]. Therefore, in this paper, the correlation between surface roughness of PPF and delamination problem in IC packaging for automotive devices was studied in terms of wetting property, shear strength and package reliability.

2. MATERIAL AND METHODS

2.1 Leadframe Material

In this study, commercial C194 (STW, 97.0%Cu-2.6%Fe-0.15%P-0.25%Zn) Cu leadframe and fully roughened Ni/Pd/Au-Ag alloy-plated Cu leadframe with dimension 31.5mm x 219.6mm x

0.127mm (width x length x thickness) was used as substrate. The first layer of Ni (thickness ~0.5μm) was electroplated on the Cu base substrate (thickness 127μm). Then, the second layer of Pd with a thickness of ~12nm was electroplated on the Ni layer. The top layer of PPF consists of Au-Ag alloy with the thickness of ~5nm was electroplated on the Pd layer. The schematic diagram of metal layer configuration for PPF and surface texturing is presented in Figure 1. For the roughened Ni/Pd/Au-Ag alloy-plated Cu leadframe, surface texturing (roughening) process was performed on the Ni layer which is the topside of the leadframe. All the multi-layer electroplating processes and surface alteration were carried out by the leadframe supplier.

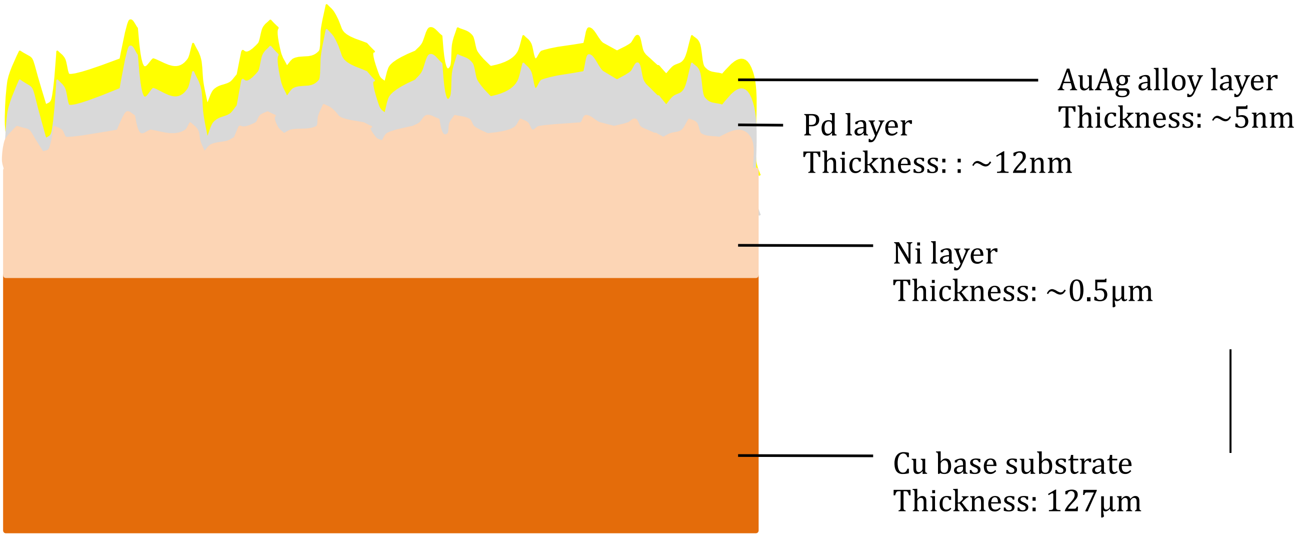


Figure 1. Configuration of metal layer plating and surface texturing for PPF.

2.2 Morphology Analysis

The surface morphology and elemental composition of standard Cu LF and textured (roughened) PPF was characterized by Field-Emission Scanning Electron Microscope, FESEM (Ziess, Merlin) and Energy Dispersive Spectroscopy, EDS (Bruker, Quantax System), respectively. In addition, the surface roughness measurement was performed by optical profiler (Bruker, ContourGT).

2.3 Contact Angle Measurement

The wetting property for both standard Cu LF and textured PPF was obtained through self-fabricated contact angle tool. Two sets of temperature condition were set up for both samples. One set of samples was exposed to the air at room temperature. Meanwhile, another set of samples was exposed at 175˚C (time: 120s) in effort to simulate the molding process for inline manufacturing condition. Water droplet (~5μL) was placed onto the samples surface and the contact angle was measured to obtain the liquid disperse characteristic on the solid surface.

2.4 Mold Shear Strength Test

The mold shear strength test was performed in order to understand the effect of post stress on the adhesion. Samples were molded into a circular truncated cone shape button on the leadframe with the LF dimension of 20mm x 20mm. The diameter of truncated cone was 4mm x 4.37mm (top side x bottom side) with the thickness of 5mm. Samples were prepared for both standard Cu leadframe and pre-plated leadframe. G770 mold compound was used in this study. The molded shear samples underwent post mold cure (PMC) for 5hrs at 175˚C to simulate inline manufacturing condition. After that, samples were analyzed with pre-conditioning MSL (moisture sensitivity level) level 1 (85˚C, 85RH (relative humidity), 168hrs) with 3 times of infra-red (IR) reflow. This condition was to simulate surface mount manufacturing condition. The shear strength test was conducted at room temperature using DAGE 4000 Shear Tester (Nordson). Figure 2 depicts the schematic diagram of sample for this shear test.

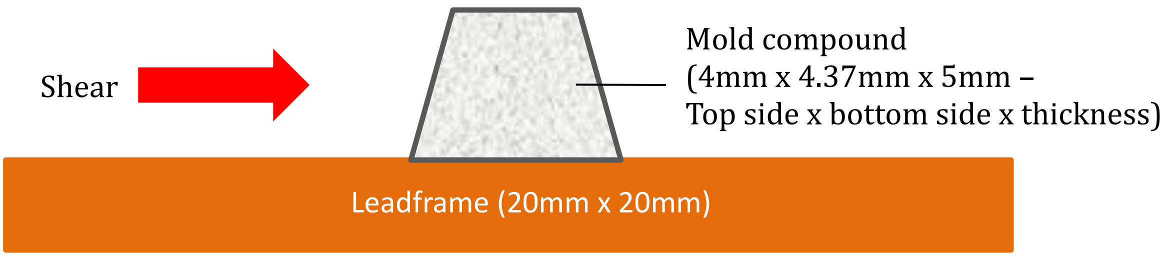


Figure 2. Schematic diagram of sample for mold shear strength test.

2.5 Reliability Test

Samples for standard Cu LF and PPF underwent all the assembly processes and became a complete semiconductor package prior to reliability test procedure. Complete IC package was exposed to pre-conditioning MSL level 1 as presented in Figure 3.

The reliability test was conducted in accordance with IPC/JEDEC STD 020 (Moisture/Reflow Sensitivity Classification for Non-Hermetic Solid State Surface Mount Devices) standard. This procedure was conducted in order to simulate the condition of accelerated used. Any adhesion failure or delamination for tested samples would be detected after this testing procedure. The delamination of the package was measured using scanning acoustic tomography, SAT (Sonix, ECHO). The frequency was set to 75MHz C-SCAN with 23.3uS of water path and 55dB of attenuation in accordance to IPC/JEDEC STD 035 (Acoustic Microscopy for Non-Hermetic Encapsulated Electronic Components) standard.

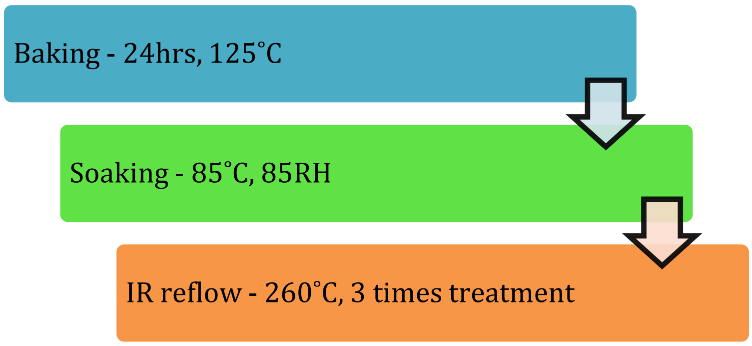


Figure 3. Process flow for pre-conditioning MSL level 1.

3. RESULTS AND DISCUSSION

3.1 Morphology Analysis

Figure 4 shows the FESEM images of leadframe surface for both standard Cu LF and textured PPF, respectively. The difference of surface roughness morphology for both leadframe samples were obviously observed under the same magnification setting (5.00k). The standard Cu LF surface was relatively smooth with the average surface roughness of 174nm. Meanwhile, the textured PPF surface was observed to be rougher than the standard Cu LF surface with the average surface roughness of 284nm.

These observations prove that the surface texturing procedure strikes the surface roughness value of PPF compared with standard Cu LF. The same observation was reported by Anan et al. and Christopher H., respectively [1,7]. In addition, roughened surface is reported to provide better interlocking pattern between different interfacial layers. Consequently, the adhesion of interfacing layers can be improved and become stronger [1].

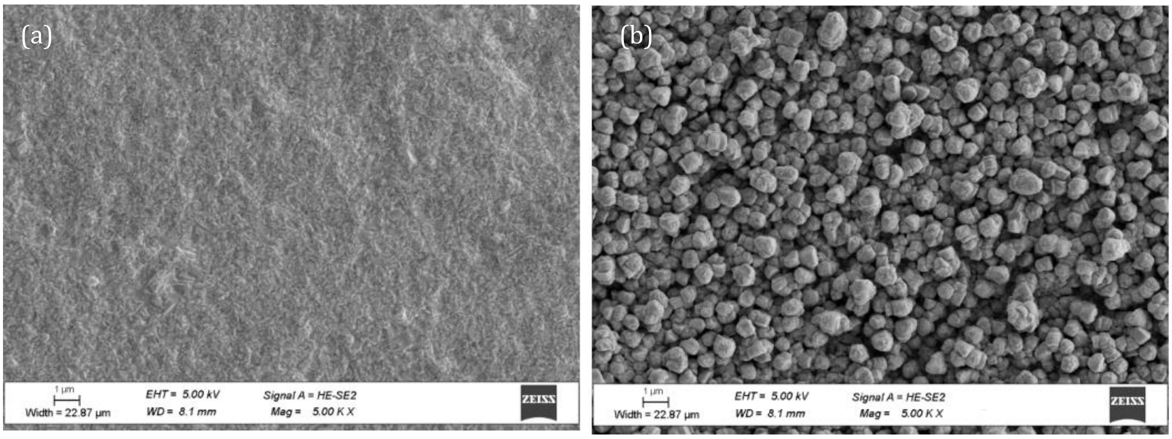


Figure 4. FESEM image of leadframe surface; (a) standard Cu LF; (b) textured PPF.

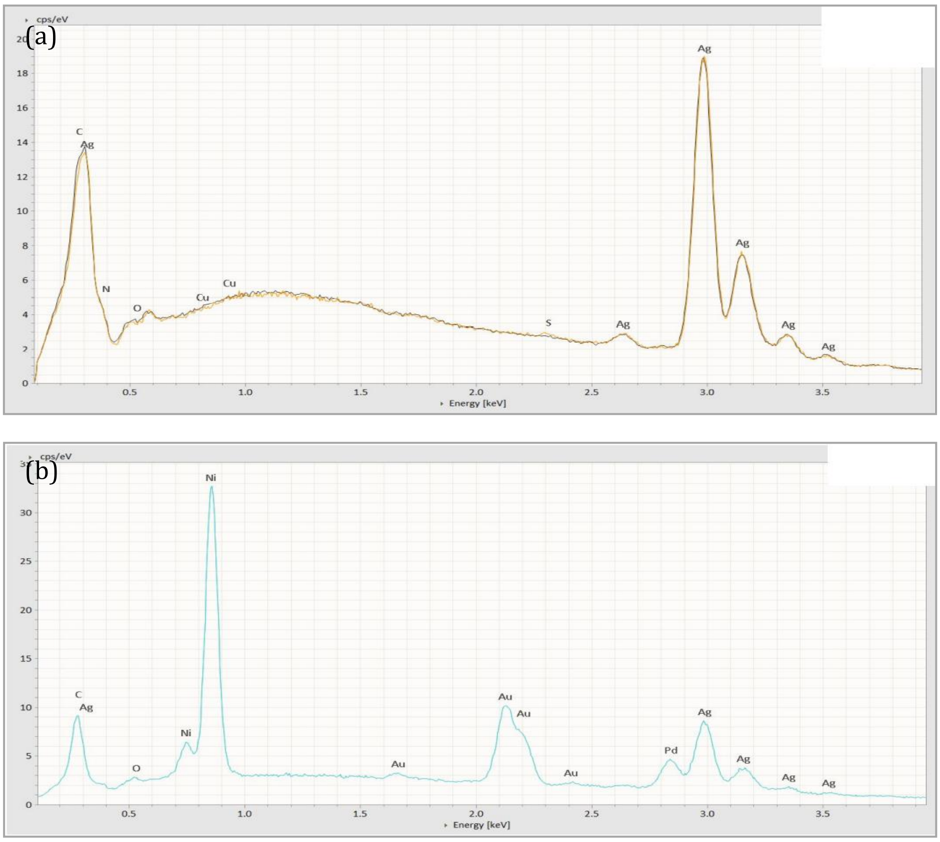


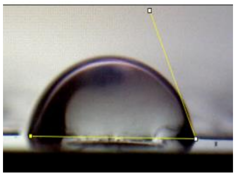
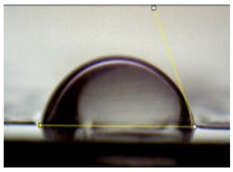
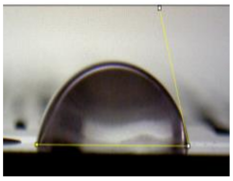
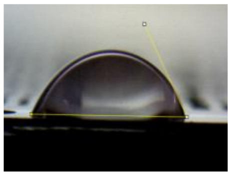
Figure 5. EDS spectra of; (a) standard Cu LF; (b) textured PPF.

The EDS spectra in Figure 5 exhibit the elemental composition of standard Cu LF and textured PPF surface, respectively. Cu and Ag were the main elements in standard Cu LF (Figure 5(a)) due to the base substrate (Cu) and lead plating of the package (Ag). Meanwhile, four main elements were observed for textured PPF (Ag, Ni, Au and Pd) which reflected to the surface texturing procedure (Figure 5(b)).

3.2 Contact Angle Measurement

Table 1 shows the wetting result (average contact angle, θ) and wetting images in comparison with average surface roughness (R_a) for both standard Cu LF and textured PPF. In this wettability test, samples were exposed to two different temperature conditions (room temperature and 175˚C, 120s). For standard Cu LF, low contact angle value was obtained at room temperature (θ = 58°) condition compared with at 175˚C setting (θ = 66°). Meanwhile, contrary result was observed for textured PPF. Low contact angle value was detected at 175˚C setting (θ = 55°) and high contact angle value obtained at room temperature condition (θ = 71°).

Table 1 Contact angle measurement result

Test conditions	Average contact angle, θ (°)		Average surface roughness, R_a (nm)
	Room temperature	175˚C	
Standard Cu LF	58 	66 	174
Textured PPF	71 	55 	284

From the contact angle measurement, higher contact angle value was observed for textured PPF compared with standard Cu LF at room temperature setting. Besides, this PPF sample possesses higher average surface roughness (284nm) compared with R_a for standard Cu LF (174nm). Similar observation was reported by Vivet *et al.* They reported that the apparent contact angle value increases when the surface roughness increases. Such roughness will form deep valleys on the solid surface. These deep valleys are accountable to trap the air between the solid surface and spreading liquid. As a result, the spreading liquid does not wet the deep valleys of the solid surface and form bridges over the valleys. Hence, higher contact angle is observed for rough surface at room temperature which reflected to incomplete or poor wetting [5,12]. However, when both samples were exposed to 175˚C in order to simulate the inline manufacturing condition, lower contact angle was observed for textured PPF compared with standard Cu LF which lead to good wetting. Good wettability is attributes by low contact angle value and vice versa [2,13]. The low contact angle value indicates that the liquid disperses and sticks onto the solid surface. This happens when the surface tension of solid-air (δ_s) is larger than the sum of surface tensions for liquid-air (δ_L) and solid-liquid (δ_{sL}) as shown in equation 1 [2,4]. As a result, the surface energy of the solid increases hence increases the adhesion force to a solid. Therefore, this study shows that the applied temperature (175˚C) helps to improve the wettability attribute for textured PPF even though this sample holds higher surface roughness.

$$\text{Good liquid spreading onto solid surface} = \delta_s > \delta_L + \delta_{sL} \quad (1)$$

3.3 Mold Shear Strength Test

Mold shear strength test is commonly used to measure the interfacial bond strength between mold compound – leadframe and mold compound – chip surface. Roughened and well wetted surface will provide better adhesion as a result from this shear strength test [14]. This disclosure is vividly observed for the textured PPF in this study. Figure 6 exhibits the mold shear strength test for both standard Cu LF and textured PPF samples. Higher adhesion strength was observed for textured PPF compared with standard Cu LF. This observation (good adhesion) is consistent with the contact angle result in which textured PPF exhibits the lowest wetting result at 175˚C. In addition, high adhesion strength result that contributed by rougher surface has also been reported previously. This rough surface provides an anchor effect between mold compound and leadframe hence improves the adhesion between these interfacial layers [15].

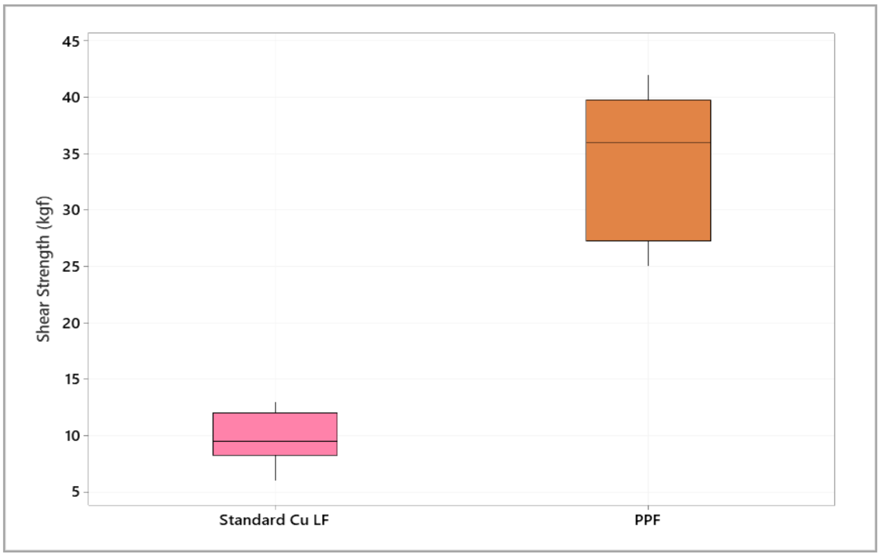


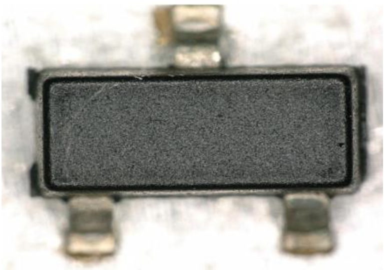
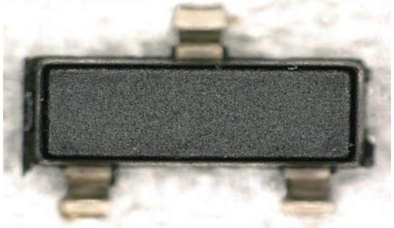
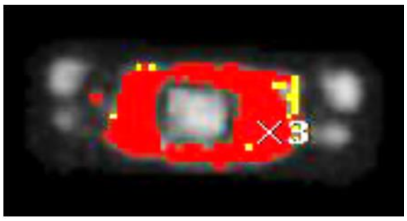
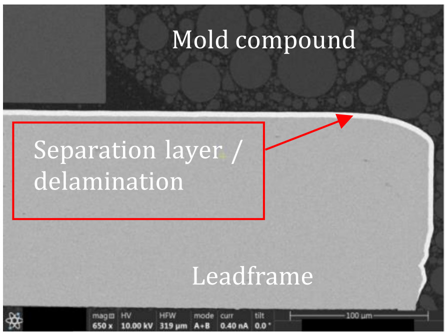
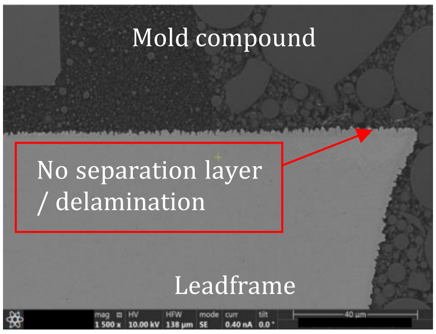
Figure 6. Shear strength test

3.4 Reliability Test

Scanning acoustic tomography (SAT) was used to spot the delamination region on the complete IC package for both standard Cu LF and textured PPF after underwent the reliability test. Table 2 depicts the optical, SAT and FESEM images for both samples. From the optical image of the topside of IC package, no defect or damage was observed for both standard Cu LF and PPF samples. However, delamination occurrence was spotted under SAT analysis for standard Cu LF (marked as red). No delamination was identified for PPF sample. The SAT result was then confirmed by cross-section and close up view using FESEM. FESEM image indicated that there was a separation layer (delamination) between mold compound and leadframe for standard Cu LF sample. As expected, no separation layer or delamination was observed for PPF sample.

The reliability test result is in line with the contact angle measurement and shear strength test. Textured PPF possesses lower contact angle value and high shear strength yields in better adhesion. This attribute (better adhesion) of textured PPF is confirmed by no delamination and separation observed after reliability test. Thus, significant improvement of adhesion between mold compund and leadframe is achieved using texturing (roughening) procedure on the leadframe surface. In addition, rough surface helps to increase the effect of mechanical imterlocking between mold compound and PPF surface thus improve the adhesion between two different interfacial surfaces [3,8]. The improvement in adhesion between these surfaces helps to boost the IC package reliability and quality [9].

Table 2 Reliability test result

	Standard Cu LF	Textured PPF
Optical image		
SAT image		
FESEM image		

4. CONCLUSION

A correlation between surface texturing on pre-plated leadframe and delamination occurrence in IC package for automotive application was studied and evaluated. Standard Cu leadframe without textured surface was used as comparison. This correlation study was conducted based on contact angle measurement (wetting property), mold shear strength test and reliability test of complete IC package. The wetting test showed that textured PPF possessed low contact angle value at 175°C which reflected to good wetting property of the spreading liquid on the solid surface. High shear strength was also observed for textured PPF contributed by better adhesion between mold compound and leadframe for PPF sample compared with standard Cu LF. The reliability test verified that textured PPF exhibited better adhesion attribute compared with standard Cu LF. No delamination phenomenon was observed for PPF sample while delamination occurrence detected for standard Cu LF sample. There is a solid correlation between interfacial bond strength and roughness on the leadframe surface. Enhanced and better adhesion property can be obtained at optimum surface roughness value. This suggests that texturing (roughening) treatment on the leadframe surface increases the shear strength of the sample and improves adhesion between mold compound and leadframe with no delamination occurrence. Consequently, high quality and reliable IC package can be produced.

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