# Flange-to-ringframe adhesion enhancement on Air Cavity Package (ACP) via mechanical surface preparation

**Mark Andrew T. Tabucanon[1]**
**Julius Albert C. Patalen[2]**
**Jocy P. Castillo[3]**

Materials Engineering Department[1,2,3]
Binary Street, LISP 1, Brgy. Diezmo, Cabuyao City, Laguna, Philippines 4025
markandrew.tabucanon@ampleon.com[1], julius.patalen@ampleon.com[2], jocy.castillo@ampleon.com[3],

***ABSTRACT***

The adhesion performance of epoxy on Air Cavity Plastic (ACP) package does not only depend on the material selection but also on the surface preparation of the substrate as well. In this study, two types of mechanical surface treatments were investigated: abrasive blasting and dimple stamping. Effects of the treatments were assessed based on the roughness measurement, wettability, ringframe shear performance of the package at zero-hour and reliability conditions. Both methods resulted in a significant increase in Ra and Rq measurement. However, only the abrasive blasting provided a percent wettability improvement of 6.56% at room temperature and 23.25% at 200°C.

Moreover, it is determined that under unbiased Highly Accelerated Stress Test (uHAST) condition, samples subjected to abrasive blasting were able to withstand the effect of humidity/moisture and temperature as 100% yield on leak test was obtained in contrast with the control sample and dimple stamped that experienced ~20% and 40% leak test yield, respectively. Therefore, using the existing process parameters and bill of materials, it can be concluded that the microindentation caused by abrasive blasting with larger abrasive particle size resulted in more effective adhesion than the cavity produced by dimple stamping.

## 1. 0 INTRODUCTION

Ampleon, being amplified with more than 50 years of RF Power experience, has been manufacturing RF power transistors in the form of air cavity packages since founded. Established with the traditional Air Cavity Ceramics (ACC) expertise, Ampleon has progressed and started to adopt a new family package type known as Air Cavity Plastics.

### *1.1 Air Cavity Package*

Having a similar structure to ACC, ACP is made of metal substrate, ringframe and lid but ACP uses polymer lid, polymer ringframe and epoxy adhesive instead of ceramic lid, ceramic ringframe and brazing as jointing method. In Figure 1, package difference between ACC and ACP was shown. This change in material and jointing method allows ACP package to be more suitable for Ampleon's existing die technology since it enables flexibility in package design and it avoids the thermomechanical stresses on the flange due to brazing. However, due to the pursuit of using more advanced die type, ACP package was placed into more stringent workability and reliability conditions. These harsher processing and reliability conditions put unwanted stresses between the flange-to-ringframe section and compromise the joint integrity that leads to leakage and even more a delamination.

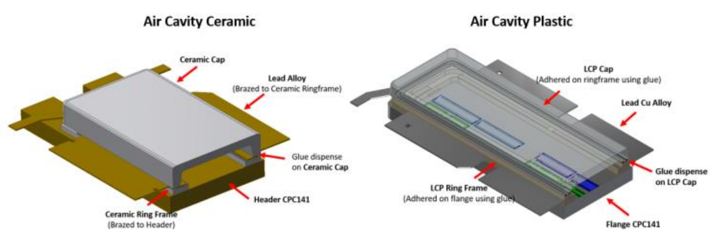



*Figure 1. Air cavity packages*

### *1.2 Air Cavity Package potential risks*

Package assembly processes including testing and even reliability operation produce detrimental stressors. Stressors such as thermal, mechanical, environmental (humid), electrical and chemical loading or combination of any of these are extremely harmful to bi-material interfaces such as ringframe-to-flange joints. Epoxy weakening due to the processing, reliability and even staging condition is inevitable due to the various thermomechanical stresses that the package experiences. Furthermore, owing to the inherent mechanical property mismatch and geometrical discontinuities, the susceptibility of ringframe-to-flange connection is aggravated towards encountering delamination and other failure mechanisms [1].

### *1.3 Surface Mechanical Treatment*

Due to the practicality of adhesive bonding, this method has been widely applied in various fields such as automotive, microelectronic industries, aircraft, etc. to replace brazing, welding and riveting [2]. However, the effectiveness of adhesive bonding much relies on the response between the adhesive and adherent which necessitates appropriate material selection and requires thorough characterization. Thus, changing components to mitigate unwanted package risks and preserve the robustness of flange-to-ringframe adhesion is not an ideal direction since it requires intensive package evaluation. Hence, as an alternative, surface mechanical treatment was investigated as an option.

Several studies have shown the importance of surface treatment to enhance the adhesion between adherent and adhesive material. As one of the most important factors regulating adhesive joint strength, surface treatments are accessible in numerous methods (i.e. mechanical, chemical and electrochemical) [2]. Due to the accessibility and availability of the roughness measurement and wettability as a test response, mechanical treatment is preferred over the other methods. In addition, adsorption and mechanical interlock being the most dominant mechanism allows ringframe shear test to be a good adhesion qualifier.

Thus, in this study, abrasive blasting and dimple stamping was investigated on the feasibility to provide an improvement in the adhesion between ringframe epoxy and flange to reduce undesired package risks and maintain the rigidity of flange-to-ringframe adhesion both at zero-hour and reliability condition.

## 2. 0 REVIEW OF RELATED WORK

There are different methods to improve the interfacial adhesion between two surfaces such as mechanical, chemical and energetic treatments. However, many of these surface preparations present setbacks. In chemical treatments, the best methods are usually detrimental on the product, human and environment. Meanwhile, energetic treatment is not optimal and cost effective when applied in an industrial context [3]. Thus, this study work focuses solely on mechanical treatments.

Surface mechanical treatment mostly relies on the abrasive techniques that removes weak surface layers or roughen the surface layer to create crevices that lead to increase in contact area with adhesive [4]. The effectiveness of the adhesion caused by mechanical treatments is governed by adhesion theory associated with mechanical interlocking [5]. Increased roughness and higher contact area results in higher molecular interaction between the adhesive and adherent.

Spaggiar A. & Dragoni E. (2013) have studied the effect of mechanical surface treatment on the static strength of adhesive lap joints using maximum force in the elastic range, the energy absorbed by the joint, the average failure shear stress, and the structural peel and shear stresses as the response variable. It was determined that mechanical treatment is the only variable that affected all test responses. Also, it was assessed that sandpapering and sandblasting granted the best adhesion performance forcing a cohesive failure.

In another study conducted by Wang et al (2017), surface mechanical treatment via abrasive blasting on steel surface revealed a 25% increase in adhesive bonding with respect to the untreated samples. Moreover, adhesion strength improved upon adjustments of parameters and incorporation of coating method.

In line with the findings above, abrasive blasting and dimple stamping will be utilized in this study to assess the effect of surface mechanical treatment on adhesion performance between epoxy and gold-plated substrate.

## 3.0 METHODOLOGY

In this paper, as-received metal substrates were submitted to various third parties for mechanical surface treatment. Two types of mechanical surface treatment were investigated in this study: (1) abrasive blasting and (2) dimple stamping. The effects of the treatments were assessed based on the roughness measurement, wettability, ringframe shear performance. The adhesive used was held as a control variable by using a single type to standardize the response on the gold-plated substrate.

Control units were processed through abrasive blasting using the standard parameters while evaluation samples were abrasive blasted using the altered pressure and different abrasive particle size. Table 1 shows the parameters that were modified on abrasive blasting. On the other hand, dimple stamping was processed only using a single setting. Figure 2 displays samples image of a substrate processed via dimple stamping.

*Table 1. Abrasive blasting experimental settings*

| Trial | Pressure | Abrasive Particle Size |
|---|---|---|
| Control Sample | O | O |
| Setting 1 | + | O |
| Setting 2 | - | O |
| Setting 3 | O | + |

O = standard, + = high setting, - = low setting

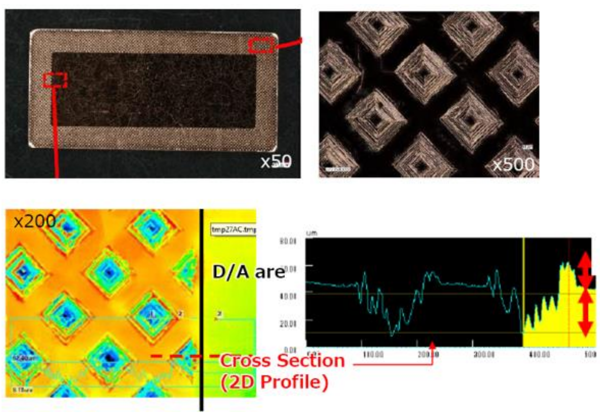



*Figure 2: Dimple stamped sample image.*

The roughness of the samples was measured using Contour Bruker-GT optical profiler while wettability surface characterization was done at three sites on the longside of the flange using the water sessile drop test method at 25°C and 200°C. Contact angle formed was then captured using a high-resolution camera. In addition, Tukey-pairwise, paired t-test and Analysis of Variance (ANOVA) were used to verify any significant change in the performance.

As for the zero-hour and reliability condition, samples were processed in the assembly line using Ampleon's in-house operating parameters and conditions wherein adhesion performance was tested via ringframe shear and Bubble Leak Test (BLT). The reliability of the package was evaluated using uHAST at 130°C, 85% Relative Humidity (RH) and 2 atmospheric pressure (atm) with Moisture Sensitivity Level 3 (MSL3) as soaking precondition. uHAST was used as reliability condition to challenge further the ringframe-to-flange interface since moisture penetration is one of the major reliability concerns in electronic packaging and presents detrimental effects to epoxy bi-material interface [7]

## 4.0 RESULTS AND DISCUSSION

### 4.1 Roughness measurement, Ra & Rq

To examine the effectiveness of the mechanical treatments on the surface of the substrate, roughness Ra and Rq were examined. It can be observed in Figure 3, that the pristine samples had the lowest roughness reading while the dimple stamped substrates obtained the highest roughness measurement. The high roughness measurement and variation seen on dimple stamped samples are mainly attributed to the geometry of the cavities and the profound depth introduced by stamping (Figure 2). To determine the significance of the effectiveness of the treatments, ANOVA and Tukey Pairwise were used.

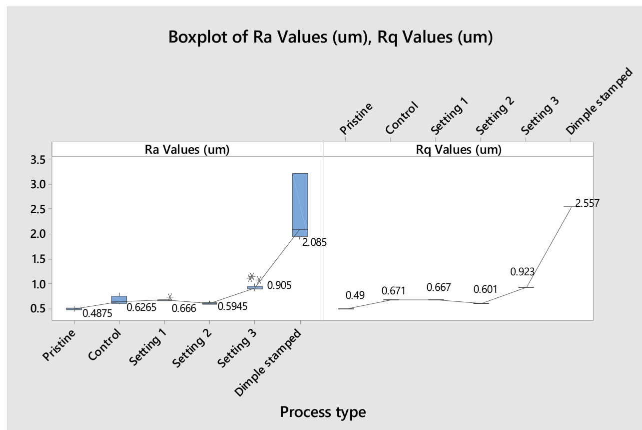



*Figure 3: Boxplot of Ra and Rq*

Using Tukey pairwise tool, it was observed that pristine sample was effectively roughened by most of the mechanical treatments except for Setting 2 (pointed by blue arrow). This implies that lowering the existing pressure of abrasive blasting does not result in any significant roughening improvement on unprocessed samples. This could mean that lowering the force during abrasive blasting leads to ineffective surface roughening. Furthermore, in comparison with the control settings, it was determined that both Setting 1 and Setting 2 did not contribute to roughening as zero mean differences for Ra values were observed as shown in Figure 4 (pointed by red arrows). On the other hand, dimple stamped and Setting 3 samples are on the right side of the plot which asserts the roughening effectiveness of these two preparation methods.

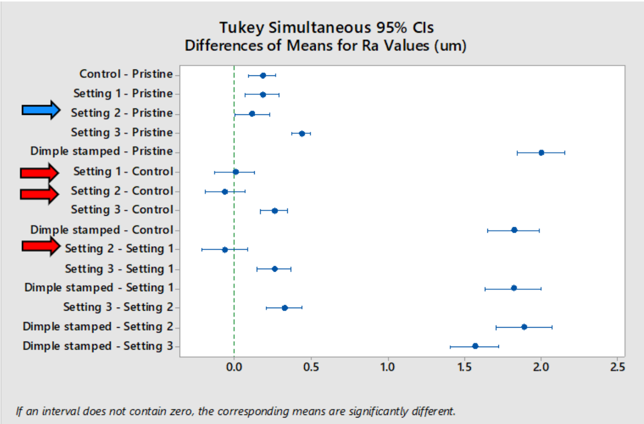



*Figure 4: Tukey Pairwise Plot*

## 4.1 Wettability characterization

In terms of wettability, the contact angle measured at room temperature of mechanically treated specimens obtained median values ranging between 53.3°–56.8°, having Setting 3 with the lowest contact angle (Figure 5). ANOVA was used to assess which treatment deviated from the group; however, it was determined that among the treatments, no mechanical preparation caused significant change as p-value = 0.079 is obtained.

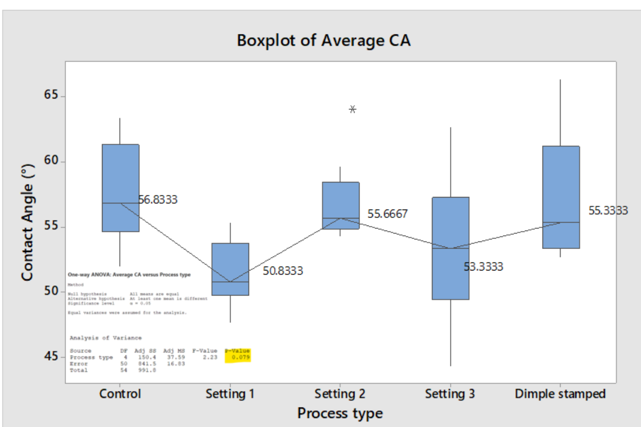



*Figure 5: Boxplot contact angle at room temp*

To investigate further the wettability of the treatments, Setting 3 and dimple stamped samples that had caused significant increase in roughness were subjected to another contact angle test by using heated samples. The samples processed using Setting 3 and dimple stamping were heated up to 200°C to replicate assembly processing conditions.

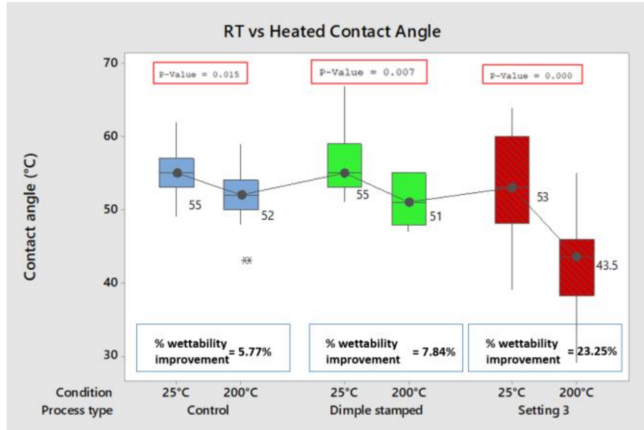



*Figure 6: Boxplot contact angle at 25°C and 200°C*

As shown in Figure 6, heat treatment significantly improved the wettability for both control and two evaluation treatments which were likely due to the volatilization of adsorbed gases on the surface of the flanges. Deep crevices and cavities of the mechanically treated samples could be perfect sites for adsorbed gases which were eliminated during the heating process. Between the two mechanical treatments, Setting 3 provided the highest wettability improvement with 23.25% increase. The significant difference in Ra and Rq implies that Setting 3 has more defined surface peaks and valleys than control settings. By blasting larger abrasive particle size on the metal substrate, the surface could be effectively roughened which leads to improved wettability performance.

## 4.3 Zero-hour and reliabity condition performance

To assess the device level performance of the mechanical treatments, the samples were processed in assembly line and were subjected to BLT and ringframe shear to check the robustness of ringframe-to-flange joint at the typical processing condition.

.

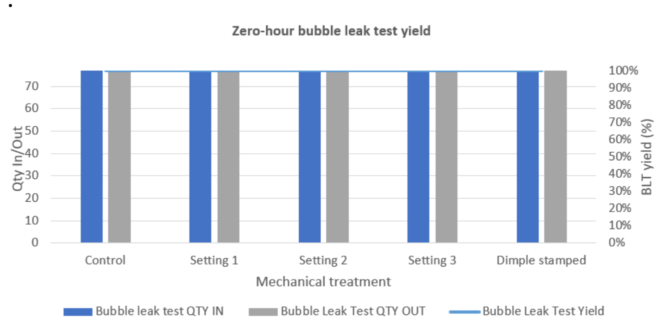



*Figure 7: Zero-hour BLT yield*

It can be seen on the Figure 7 above that control and all evaluation treatments passed the BLT with 100% yield without encountering any anomalies such as leakage or delamination.

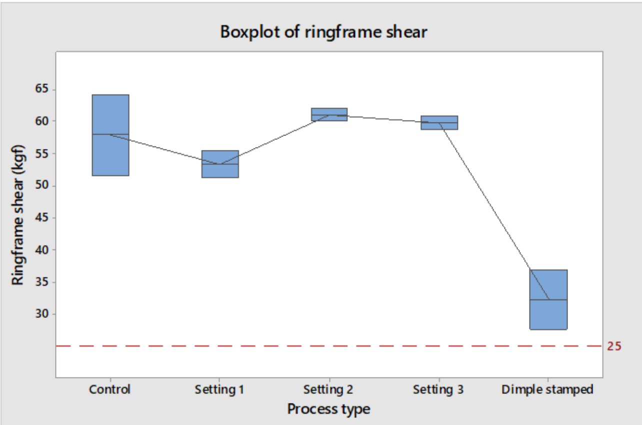



*Figure 8: Zero-hour ringframe shear*

Furthermore, the samples were subjected to ringframe shear test to quantify the adhesion between ringframe and flange. Figure 8 displays the ringframe shear performance of the samples wherein experimental abrasive blasting treatments provided a comparable performance with the control while the dimple stamped samples approximates to the lower limit specification of the ringframe shear test. To stress test the samples further and validate the zero-hour condition performance, units were loaded in 96 hours of uHAST. Prior to uHAST loading, samples were soaked with MSL3 preconditioning. Figure 9 shows the yield obtained on uHAST loading wherein monitoring of yield started in zero-hour followed by preconditioning then uHAST 24 hours and uHAST 96 hours. Setting 1 and Setting 2 encountered gross reject at uHAST 24 hours as units encountered leakage due to delamination. This outcome coincides with the roughness findings as the two settings did not produce significant improvement in roughness measurement. Control settings encountered a few rejects as well after 24 hours of uHAST resulting in 95.5% yield. Despite the comparable roughness readings between the control and the two settings, Setting 1 and Setting 2 poor performance could be attributed to the unstandardized and unreleased process parameter on abrasive blasting. The blasting angle, tip-to-the-flange distance and blasting duration could be optimized to provide better roughness and adhesion improvement.

Control samples managed to survive and reach uHAST 96 hours but with low yield of 21%. This poor yield of Control settings necessitates the need for ringframe-to-flange improvement which can be resolved by Setting 3. Setting 3 exhibited the desired rigidity on the packages as from zero-hour up to uHAST 96 hours, no failure was encountered resulting in 100% yield which can be attributed to the significant increase in roughness and improved wettability.

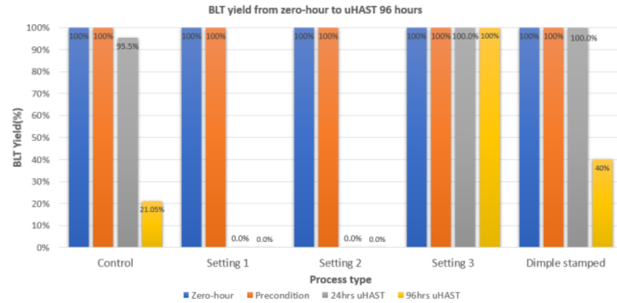



*Figure 9: Zero-hour to uHAST BLT yield*

This outcome asserts that using larger abrasive particle size effectively roughened and enhanced the adhesion of ringframe and flange. On the other hand, dimple stamped samples sustained 24 hours of uHAST condition but failed on 96 hours with 40% yield.

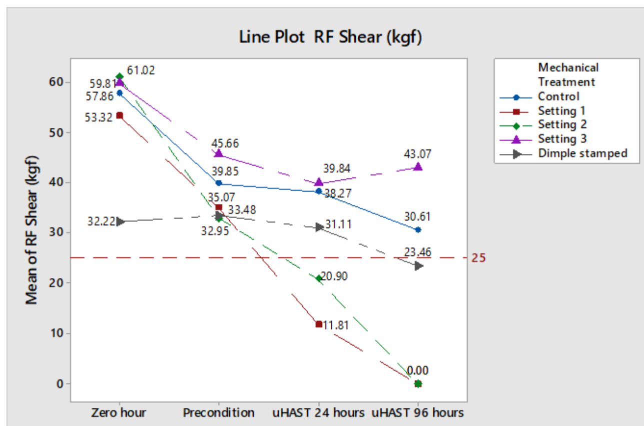
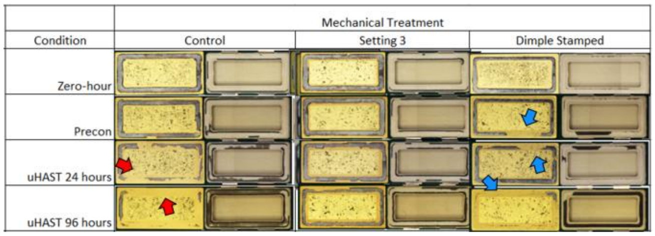



*Figure 10: Zero-hour to uHAST Ringframe shear readings*

To examine these findings further, ringframe shear readings were taken. Figure 10 shows the decreasing trend of ringframe shear values from zero-hour up to uHAST 96 hours. This decrease in value is due to the weakening of ringframe epoxy-flange adhesion caused by the moisture penetration during soaking precondition and uHAST. Setting 1 and Setting 2 failed the ringframe shear requirement even at early condition which coincided with and justified the poor BLT yield performance. On the contrary, Control, Setting 3 and dimple stamped units showed good ringframe shear values up to uHAST 96 hours, thus to elucidate this outcome, the ringframe sheared images were examined.

*Table 2: Ringframe sheared images*




The table above shows the qualitative progression of glue adhesion weakening on both control and dimple stamped samples. As pointed by the arrows, control and dimple stamped samples have portions of detached glue from the flange which became more progressive and defined at 96 hours of uHAST. This adhesive failure was due to the moisture penetration that seeps between the ringframe-flange interface and causes BLT failure with delamination as the failure mode. Meanwhile, Setting 3 displayed good adhesion as glue remains are still intact on the substrate and the failure observed is cohesive as ringframe traces are observable on the epoxy.

In line with this outcome, the good adhesion performance of mechanical surface treatment Setting 3 can be attributed to the microindentation caused by larger abrasive particles. These deeper and more defined crevices (in comparison with the control) could potentially enhance the mechanical interlocking and anchoring between the ringframe epoxy and metal substrate [4]. This adhesion mechanism outweighs the effect of moisture penetration as Setting 3 was able to resist uHAST condition and provide 100% BLT yield.

## 5.0 CONCLUSION

In this study, it was determined that surface mechanical treatment via abrasive blasting on metal substrate provided an improved ringframe-to-flange adhesion. The mechanical treatment Setting 3 improved the BLT yield of control settings from 20% to 100%. The significant increase in roughness and enhancement in wettability obtained from using larger abrasive particles resulted in better epoxy and flange connection. Mechanically treated samples via abrasive blasting that uses larger particle size improved the device level performance at zero-hour and reliability conditions resulting in 100% yield withstanding the assembly line stressors and moisturized condition.

## 6.0 RECOMMENDATIONS

This study focuses on the package-level adhesion performance, hence, to elucidate better the effectiveness of mechanical treatment, an in-depth analysis on the substrate surface could be recommended. Element traces during pre-treatment and post-treatment could also be inspected as well as contour profile of the cross-sectioned sample to verify Ra and Rq results.

In addition, it could also be recommended to have a theoretical or quantitative study regarding adhesion and the effect of moisture.

## 7.0 ACKNOWLEDGMENT

The authors would like to thank the following for their support of this study:

- Romeo Peralta – Sr. Director, Quality & Reliability, Ampleon Phils., Inc.
- Olga Rivera – Director, Materials & Design Engineering/ Sustainability/ NPI-BET Quality, Ampleon Phils., Inc.
- Manolito Maalat – Sr. Manager, Failure Analysis/ Reliability and Calibration, Ampleon Phils., Inc.
- Nenita Ignacio – Senior Engineer, Incoming Quality Control, Ampleon Phils., Inc.
- Rodjie Ortiguerra – Master Technician, Materials and Sustainability Engineering, Ampleon Phils., Inc.

## 8.0 REFERENCES

[1] Lei, Wei-Sheng, and Ajay Kumar. "Delamination and Reliability Issues in Packaged Devices." *Adhesion in Microelectronics*, 2014, 267-312. doi:10.1002/9781118831373.ch7.

[2] Kim, Won-Seock, Il-Han Yun, Jung-Ju Lee, and Hee-Tae Jung. "Evaluation of mechanical interlock effect on adhesion strength of polymer–metal interfaces using micro-patterned surface topography." *International Journal of Adhesion and Adhesives* 30, no. 6 (2010), 408-417. doi:10.1016/j.ijadhadh.2010.05.004.

[3] Spaggiari, A., and E. Dragoni. "Effect of Mechanical Surface Treatment on the Static Strength of Adhesive Lap Joints." *The Journal of Adhesion* 89, no. 9 (2013), 677-696. doi:10.1080/00218464.2012.751526.

[4] Ebnesajjad, Sina. "Material Surface Preparation Techniques." *Surface Treatment of Materials for Adhesive Bonding*, 2014, 95-138. doi:10.1016/b978-0-323-26435-8.00006-x.

[5] Petrie EM. Handbook of adhesives and sealants. 2nd ed. New York, United States: The McGraw-Hill Companies, Inc., 2007.

[6] Wang, Binhua, Xiaozhi Hu, and Pengmin Lu. "Improvement of adhesive bonding of grit-blasted steel substrates by using diluted resin as a primer." *International Journal of Adhesion and Adhesives* 73 (2017), 92-99. doi:10.1016/j.ijadhadh.2016.11.012.

[7] Wang, Jing, Yuling Niu, Shuai Shao, Huayan Wang, Jiefeng Xu, Vanlai Pham, and Seungbae Park. "A comprehensive solution for modeling moisture induced delamination in electronic packaging during solder reflow." *Microelectronics Reliability* 112 (2020), 113791. doi:10.1016/j.microrel.2020.113791.

## 9.0 ABOUT THE AUTHORS

Mark Andrew T. Tabucanon is a University of the Philippines – Diliman alumnus who graduated with a degree of B.S. in Materials Engineering. He has an experience in the research field and worked as a Science Research Specialist in academe settings. Currently, he is employed as a Jr. Materials Engineer at Ampleon Philippines, Inc

Julius Albert C. Patalen is a Materials Engineering Technician in Ampleon. He started his career in NXP Semiconductors Philippines in 2013 as a Test Operator until becoming an Outgoing Quality Inspector. He carried over his role as inspector upon Ampleon's divestment from NXP and joined the Materials Engineering group in 2020. Throughout his experience in the industry, he gained valuable knowledge on product-level testing, product reliability, material-level risk assessment and material characterization.

Jocy P. Castillo is a Materials Engineering Technician in Ampleon. She started her career in Ampleon Philippines as a FA/ Reliability inspector and then as a Specialist inspector for Incoming Quality Inspector. Her expertise are on Material specifications compliance, product reliability, material-level risk assessment and material characterization.