Effect of BGA Reballing and its Influence on Ball Shear Strength

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Abstract

As more components are becoming lead free and not available in the tin lead alloy, there is an industry wide interest when it comes to the reballing and the subsequent effects it has on the strength of those components. This is particularly true for legacy parts needed for military applications some of which use tin lead solder. There is cause for concern due to the potential mixing of alloys and the differences in reflow temperatures of the two different alloys. Additionally, there are unknown characteristics regarding the intermetallics that are formed due to the potential of mixed alloys. This research paper will focus on the effect of various parameters that are used to reball a BGA and their effect on the overall shear strength. Factors that will be looked at include the type of BGA (SAC305 or 63Sn/37Pb), the alloy used to reball (SAC405 or 63Sn/37Pb), the type of flux used (Water Soluble or No Clean), and the environment in which reballing takes place (Nitrogen or Ambient). Being most relevant to industry demands, the focus will be on the effects of reworking a BGA with a base alloy of SAC305 and reballing it with 63Sn/37Pb. After the reballing of the component is complete, samples will be both shear tested and cross sectioned as a method of evaluation. The shear tests will determine the strength of the newly formed solder balls while the cross sections allow for the observation of the solder ball and the bonding characteristics of the new solder alloy to the pad on the BGA. The cross sections will also allow for observation of any defects or abnormalities through the reballing process. When the experimentation is completed, the goal is to determine the optimal factors that should be used in the creation of a robust process for BGA reballing.

Introduction

Tin lead solder alloys have been used in the electronics manufacturing industry for many years. Tin lead solder is known for its good wetting properties, low melting temperature, and high reliability which aid in the soldering process. In the past decade, due to environmental and health concerns, products have been shifting to more lead free applications. When this change occurred, there were many concerns about the reliability of lead free solder alloys. Many engineers believed that lead free solders would not be as compliant as its tin lead counterpart, especially in the aerospace, medical, and military industries[1]. These industries require high standards for electrical components as the products face extreme environmental conditions and can have high consequences if failure were to occur. Lead free solders were known to have tin whiskers, which are hair like structures that grow from lead free solders. Tin whiskers can cause shorts and decrease the strength of a solder joint. The phenomenon of what causes tin whiskers is not exactly known, which leads to more concerns during the transition from tin lead to lead free solder alloys.

With many industries needing to quickly make this transition due to compliance standards, many tin lead parts were put aside as lead free parts replaced them. In order to prevent these parts from becoming scrap and waste, rework is necessary in order to reutilize these components without a large loss[2]. In the case of Ball Grid Array (BGA) components this is done by a reballing process. This involves removing the current solder balls off the pads and reflowing new solder balls on the pads. Typically, this process is done with replacing solder balls of the same alloy, in order to maintain the same properties the component had before. However, with the lead free transition, tin lead components which were shelved could be reballed with lead free solder and still be compliant with the RoHS directive[3]. The benefit of reballing tin lead components to lead free can reduce the amount of components scrapped, save money, and on lead time for lead free components. This process can also be done for reballing lead free components to tin lead solder. This allows for applications in industry such as military and aerospace to be able to use tin lead components when only lead free components are being supplied.

The many benefits of the reballing process also lead to many concerns in the reliability of the reworked components. These concerns include the intermetallic formation, defects through the reballing process, and the primary concern being the mechanical strength of the newly formed solder joint.

Shear testing and cross sectional analysis allow for the newly formed solder joints to be investigated and compared to the original component. The focus of this paper is to compare the shear strength of the reballed BGAs and to analyze the factors which may affect the reliability of a reballed BGA.

Experimental Approach

Test Vehicles

The BGAs used were 27 mm x 27 mm packages each with a 256 ball array along the perimeter of the package (Figure 1). The pitch of the component was 1.27 mm. Both tin lead (63Sn/37Pb) and lead free (SAC305) components were used, with an ENIG finish substrate. The solder balls on the BGAs were each 30 mils in diameter, and both SAC405 and 63Sn/37Pb solder balls from Indium Corporation were used for reballing.

Figure 1: Amkor BGA used for Reballing and Shear Testing

Experiment Procedure

Initial solder balls from the components were sheared off using a Dage KE-2080 shear tester (Figure 2a) for baseline results. Each ball was sheared with a load of 5000 grams at a speed of 500 µm/second. The shear head was set at a height of 0.254 µm and when shear was detected, the machine over traveled 38 µm to ensure that the ball would be clear from any obstructions. The component pads were then cleaned using the hot air nozzle and vacuum cleaning device on a Martin Expert 10.6 HV rework station (Figure 2b). New solder balls were then reflowed onto the bottom of each BGA using a Martin Minioven 04N (Figure 2c) miniature reflow oven and appropriate solder ball stencil. Two reflow profiles were developed for the experiment, one for the SAC405 (Sn95.5/Ag4.0/Cu0.5) and one for 63Sn/37Pb (Figures 3 and 4 respectively). The solder ball stencil was taped in a fashion which allowed solder balls to be placed along the perimeter and centerlines for the least amount of disruption from the Dage KE-2080 shear testing device and to conserve material throughout the testing of these devices (Figure 5). After being reballed, the BGAs were subjected to shear testing in which 30 solder balls were sheared from each component. The data collected was averaged and used in the design of experiment in order to analyze the factors. Samples were then cross sectioned to analyze the intermetallic connection, metallurgical structure, and any defects of the newly placed solder balls.

Figure 2A:
Dage KE-2080 Shear Tester

Figure 2B:
Martin Expert 10.6 HV Rework Station

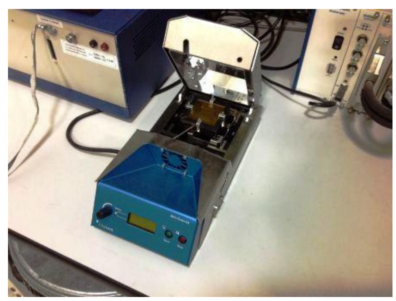

Figure 2C:
Martin Minioven 04N

Figure 2: Equipment Used for Experiment

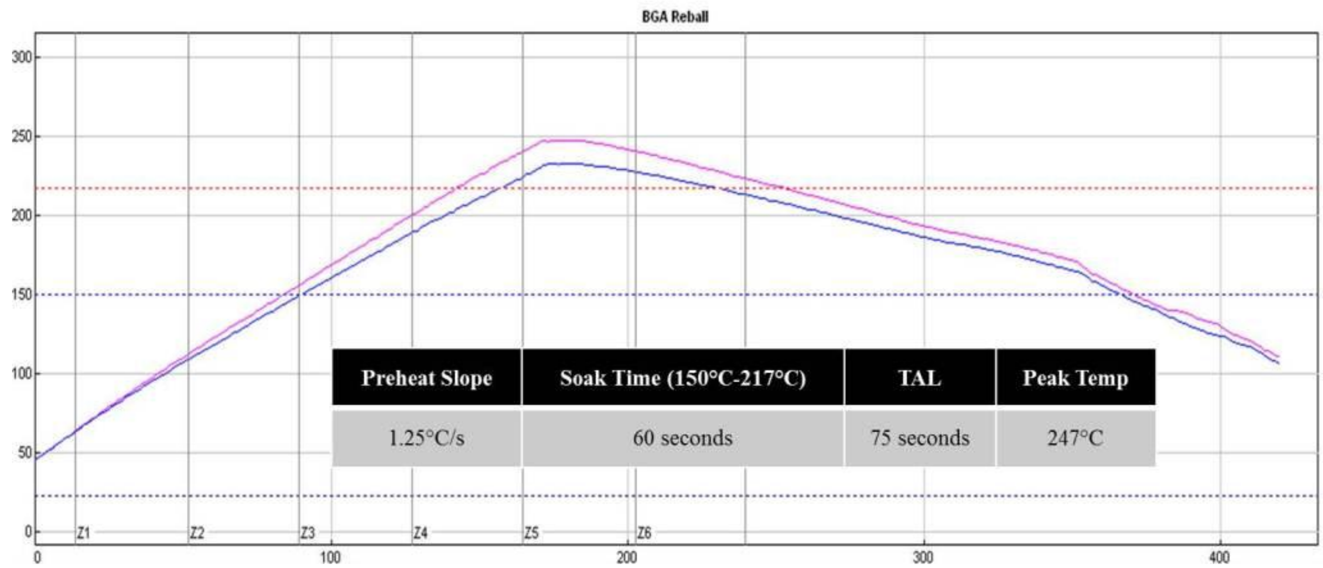

Figure 3: SAC Reballing Profile

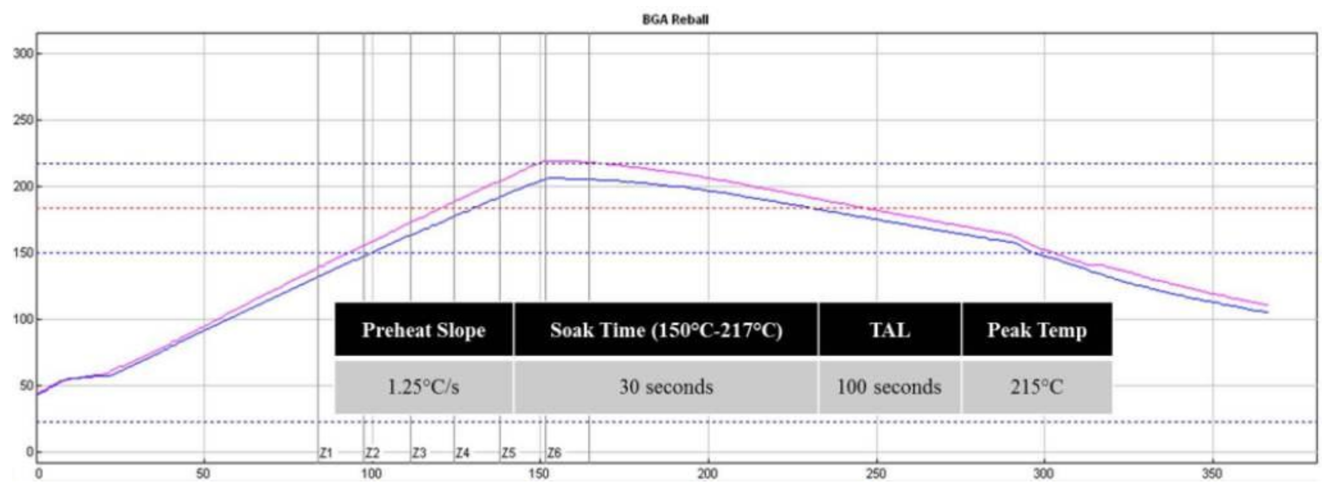

Figure 4: Sn/Pb Reballing Profile

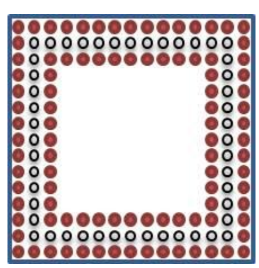

Figure 5: Taped Pattern on BGA Stencil for Reballing
Note: Red indicates where solder balls were placed for shear testing

Design of Experiment

The experiment was carried out using a standard full factorial design of experiment approach. Four factors were chosen at two different levels each (2^4=16). The factors and their respective levels are given below:

Virgin BGA Type:

- Tin/Lead BGA with 63Sn/37Pb solder balls
- Lead free BGA with SAC305 solder balls

Solder Ball Type:

- 63Sn/37Pb solder balls

- SAC405 solder balls

Flux Type:

- Water Soluble Flux (Indium FP-300 Flux Pen)
- No Clean Flux (Indium FP-500 Flux Pen)

Reflow Environmental Conditions:

- Ambient Air Convection
- Inert (N_2) Convection

After completion of the reballing process, 30 random balls from each BGA were sheared on the Dage shear tester. These 30 data points were then averaged to find the mean shear strength (response variable) for each of the treatment combinations of the experiment. The purpose of shearing the large number of balls on each BGA was to minimize the amount of variability between samples and account for unexpected process deficiencies such as uneven reflow between balls on the same BGA. In addition to the mean shear strength, the standard deviation of each treatment combination was also calculated. This allowed for comparison of the actual strength in addition to the inherent variability between treatment combinations.

Results and Analysis

Design of Experiment Results

The data was analyzed in response to the mean and the standard deviation to find factors with significant effects. The half normal plot for the mean shear strength (Figure 6) shows the interaction between BGA type and the solder alloy used in reballing as significant. When analyzing the standard deviation, the half normal plot (Figure 7) shows the solder alloy used in reballing as a significant factor. This analysis is based on a 95% confidence level. If the confidence level was lowered to 90%, flux type becomes a significant factor, showing it may have had a slight effect on the shear strength. The residual plots for the mean and standard deviation show the data was normally distributed and the variance was constant for this experiment. The main effects plot (Figure 10) shows higher shear strength when the 63Sn/37Pb alloy was used in combination with water soluble flux. The type of environment for reflow did not show a significant increase in shear strength between ambient and nitrogen. When looking at the interaction plot (Figure 11), the interaction between BGA type and reballing alloy used, showed the most significant interaction effect. The plot also shows potential effects between the solder alloy/flux used and BGA type/flux used.

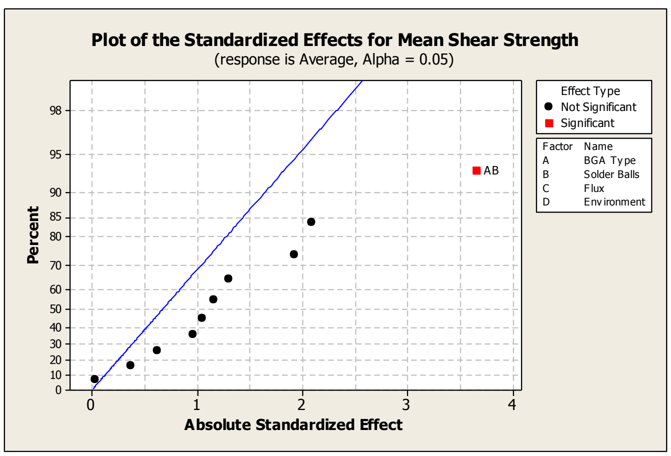

Figure 6: Effects plot in response to the mean of shear strength

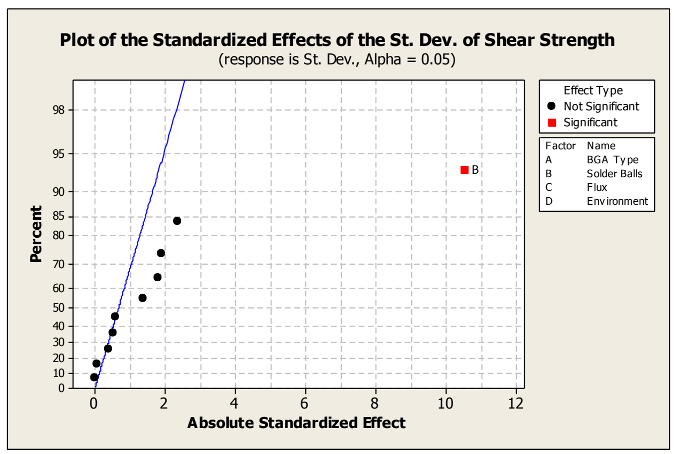

Figure 7: Effects plot in response to the standard deviation of the shear strength

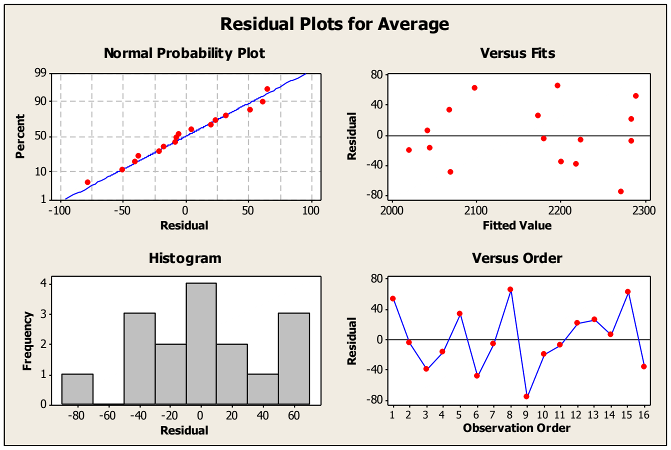

Figure 8: Residual Plots for the Mean

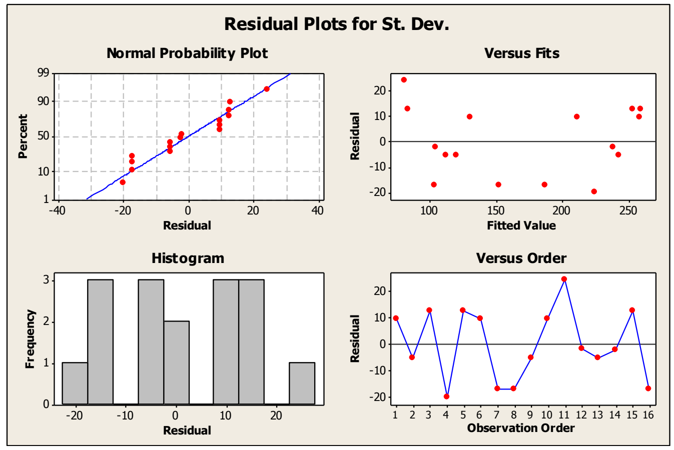

Figure 9: Residual Plots for the Standard Deviation

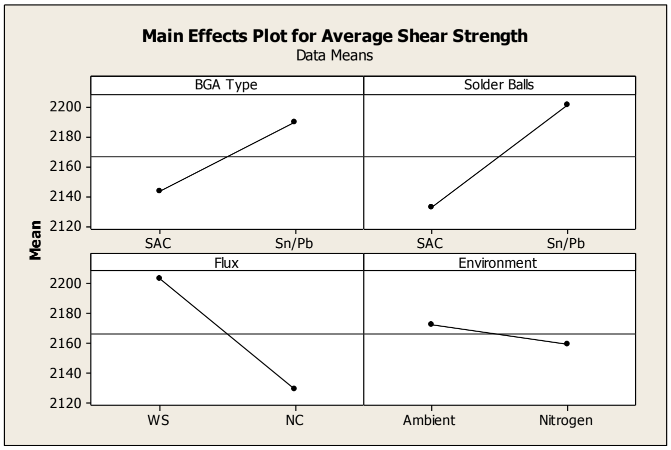

Figure 10: Main Effects Plot for average shear strength

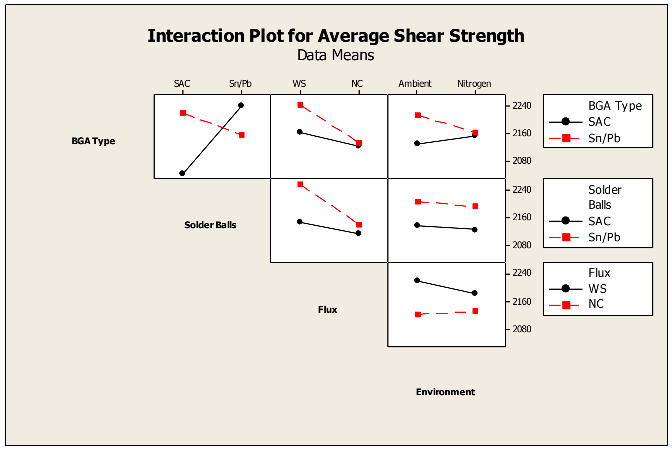

Figure 11: Interaction Plot for average shear strength

Shear Strength Comparison

From the averages of the data, the reballed components showed an overall increase in shear strength. This was unexpected due to the research done leading up to this experiment, which indicated that the baseline shear strength should have been greater than the reballed strength. From the cross sectional analysis it was shown that the solder balls were being sheared at the ball level and not at the intermetallic due to the slow shear speed testing. A sheared solder ball can be seen in Figure 12, which shows the relative location of the failure.

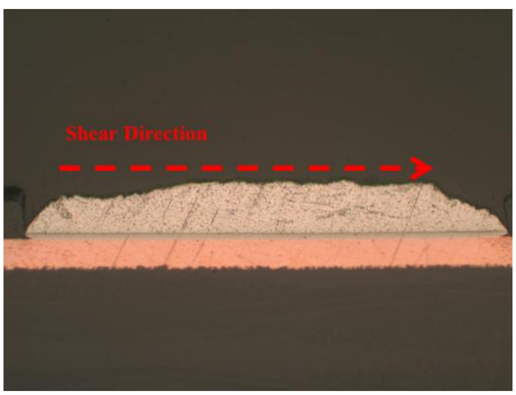

Figure 12: Sheared Solder Ball

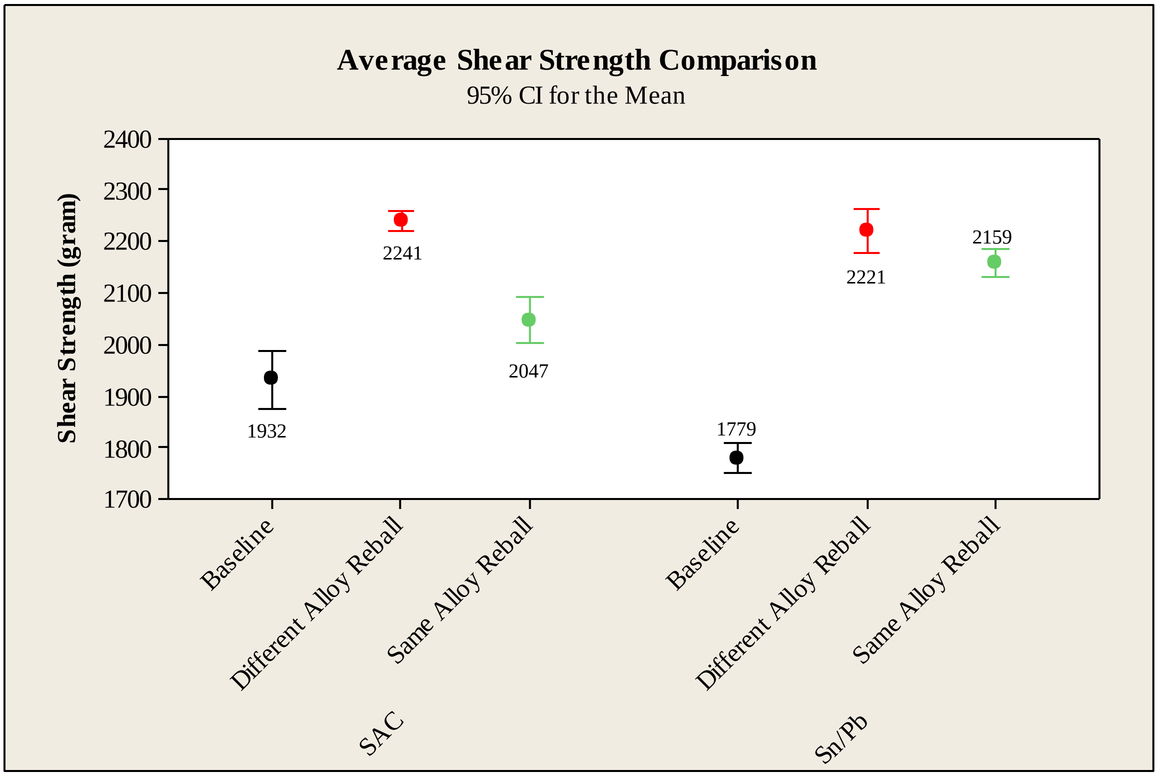

Figure 13: Shear Strength Comparison (all factors considered)

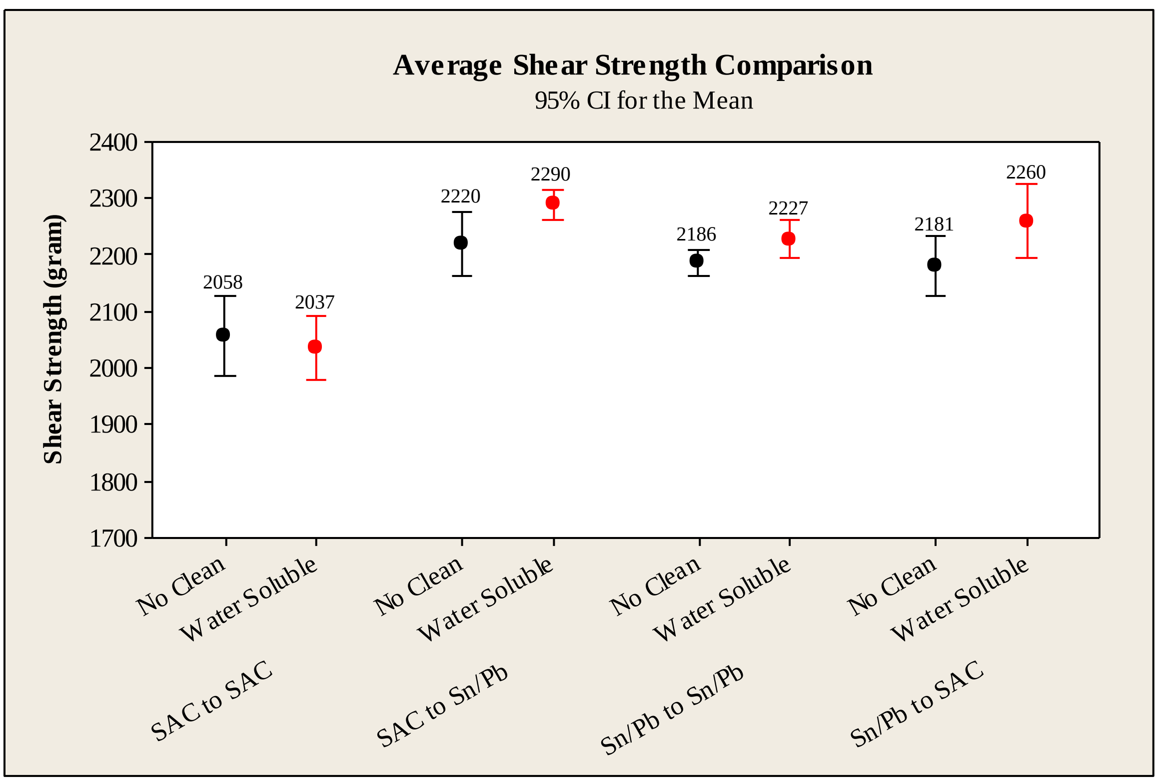

Figure 14: Shear Strength Comparison (broken down by flux type)

Figures 13 and 14 show a comparison of shear strength in response to different factors based on their levels. Each comparison shows the mean shear strength and the range of data collected throughout the trials. Figure 13 shows the strength in terms of the alloy used. This included both the baseline and reballed shear strength for both SAC405 and 63Sn/37Pb. From the interval plot, it is shown that there is a significant difference in shear strength when the BGAs were reballed with the same alloy. For the focus of this research, the case in which SAC405 was reballed with 63Sn/37Pb showed the largest increase in shear strength from the baseline value. Figure 14 shows the interval of shear strength in response to the type of flux used. The plot shows a significant increase in shear strength when using water soluble flux with 63Sn/37Pb alloys. In both cases where 63Sn/37Pb alloy was reballed, the water soluble flux showed a considerable increase in shear strength over that of no clean flux.

Intermetallic Connection Analysis

After shear testing was completed, the cross sections were imaged to take measurements of the newly formed intermetallic connection from the reballing process. The intermetallic connection is typically the weakest point of the solder joint, as it contains alloy mixes from the pad plating and the solder ball. Theoretically, the thicker the intermetallic layer, the weaker the joint strength. In order to take measurements, two solder balls were imaged and ten measurements were taken. An average was taken to account for the variation in the thickness of the intermetallic layer. In all treatment combinations in this experiment, the intermetallic thickness increased from the baseline average. One trend noticed was that 63Sn/37Pb showed a more consistent intermetallic thickness (Figure 15). For each treatment combination measured, it had the least variation from the average of the baseline. The intermetallic layer for SAC405 was inconsistent and had a large variation in thickness at different points on the solder ball (Figure 15). Figure 16 below shows the comparison of the average intermetallic between the different trials. Even though a direct correlation could not be derived between the intermetallic thickness and shear strength, it can possibly be established using high speed shear or drop testing of reballed BGA assemblies.

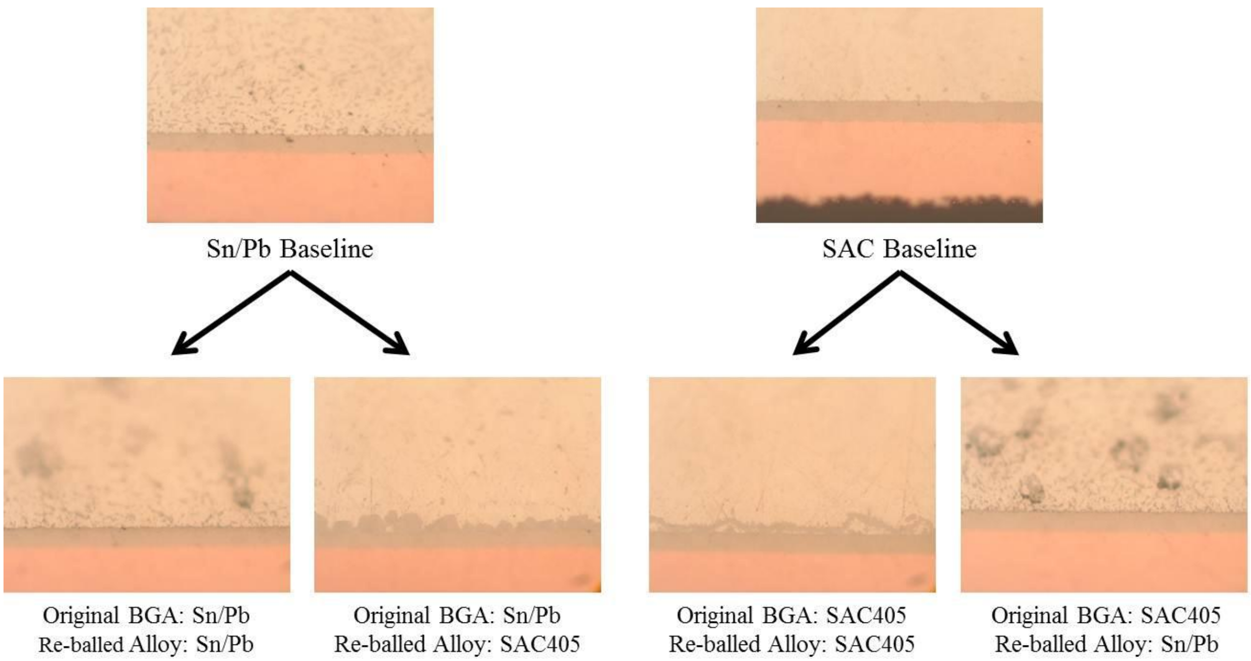

Figure 15: Intermetallic Connection for each Treatment

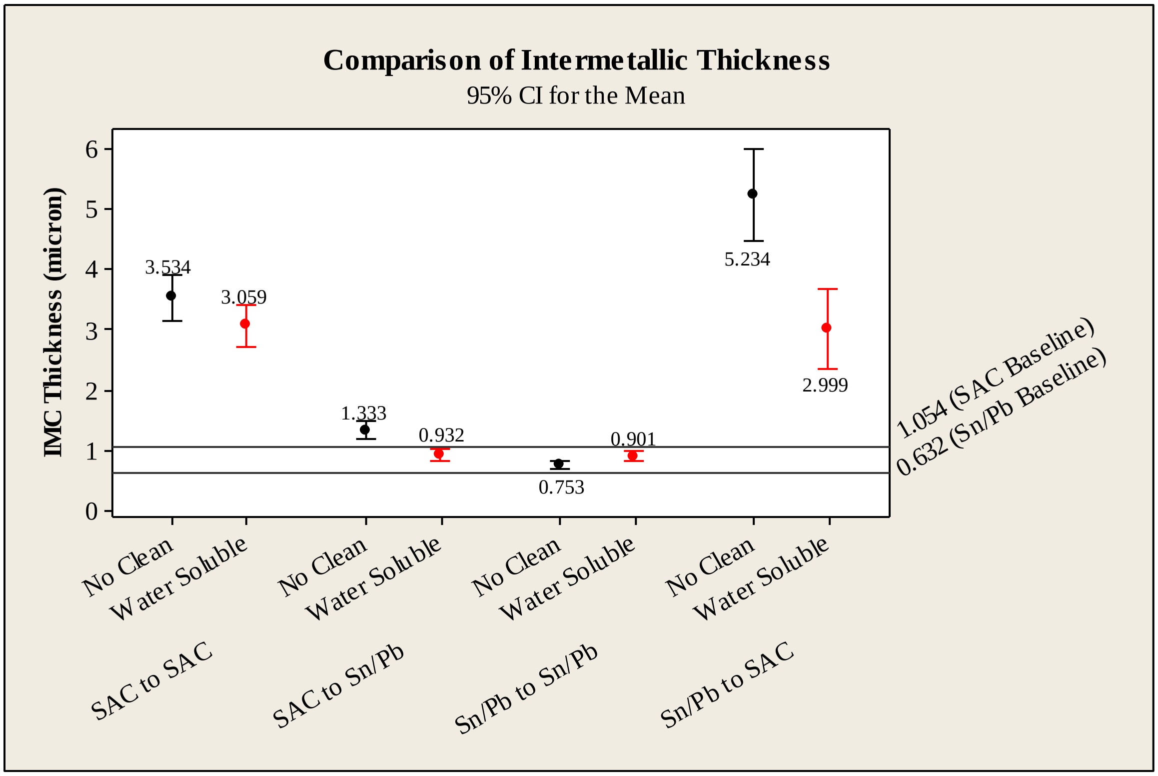

Figure 16: Comparison of Intermetallic Thickness

Potential Defects

Throughout the cross sectional analysis, some defects were found while reballing the new solder balls onto the BGA. These defects were not process induced rather they were inherent to the solder ball itself prior to reworking. The two main defects found were voiding and incomplete solder balls. The voiding defect is not as much of an issue, as voiding is known to happen in the reflow process if there is excess out gassing. Having a defect of an incomplete solder ball is more of an issue, as this will affect the reliability of the component. Figure 17 below shows examples of defects found while completing cross sectional analysis.

Voiding Examples **Incomplete Solder Ball Examples**

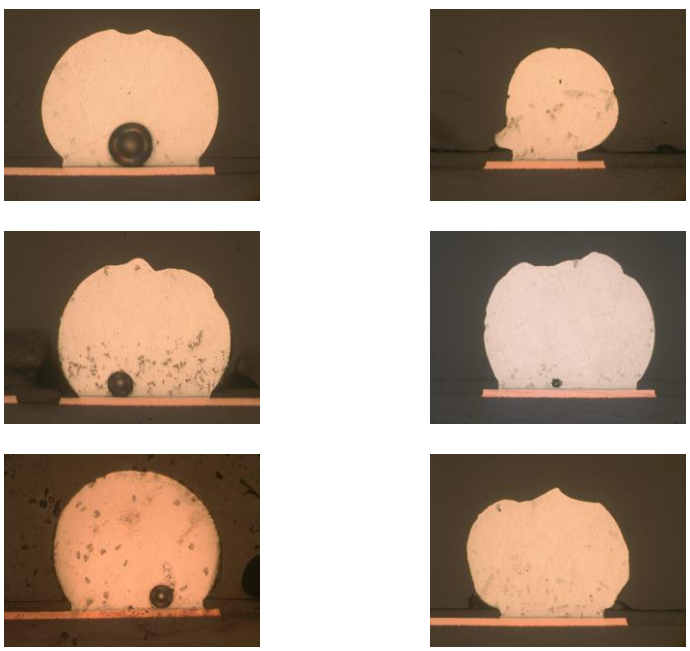

Figure 17: Defects found in Reballing

Summary/Conclusion

1. The overall experiment was successful in reballing SAC components with 63Sn/37Pb and vice versa which show similar shear strengths from the baseline values. Reballing a BGA may take more time for operators, but can save in scrap and shelved inventory. The ability to rework components which maintain their original characteristics is a huge advantage for this industry.

Table 1: Summary of Results

BGA Type	Reball Alloy	Flux	Shear Strength Ranking (1=Best)
SAC	Sn/Pb	Water Soluble	1
SAC	Sn/Pb	No Clean	3
Sn/Pb	SAC	Water Soluble	2
Sn/Pb	SAC	No Clean	4

2. There was an overall increase in shear strength from the baseline for both BGA components reballed with SAC405 and 63Sn/37Pb alloys.
3. 63Sn/37Pb showed higher shear strength than SAC405 on average.
4. The intermetallic thickness for both alloys increased. For SAC the increase in the IMC was greater than that of the 63Sn/37Pb.
5. From the experiment setup and observations in cross sectional analysis, it was observed that the shear failure occurred on the ball, and not at the intermetallic.
6. The DOE showed that the interaction between BGA type and solder alloy to be reballed had a significant effect on the overall shear strength.
7. Flux may have an effect with the solder alloy used. Overall water soluble flux showed higher shear strength over no clean flux.

Future Work/Recommendations

Future research will include the continuation of this study in the reliability of reballing components. More trials will be done to try to optimize the reballing process with other SAC alloys. Drop and Thermal Shock tests will be done to research the effect on reballed components.

Acknowledgements

The authors would like to acknowledge and extend their sincerest gratitude to Scott Rushia and everyone at Martin who donated equipment and materials to make this research possible. The authors would also like to thank Jeff Lonneville and Chris Villareale, lab technician and graduate student, respectively, at the Center for Electronics Manufacturing and Assembly, for their help in running the experiment.

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Agenda

- Objective of the Study
- Experimental Plan
- Design of Experiment
- DOE Results
- Experimental Findings
- Intermetallic Analysis
- Potential Defects
- Conclusions
- Future Research
- Acknowledgements
- Question & Answer

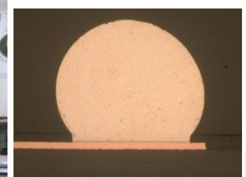
Objective of the Study

- To successfully reball a BGA from a Lead to Lead Free Alloy
- To observe the various effects on the ball shear strength
- Observe factors resulting from reballing with both mixed and same alloys
  - **Lead Free to Lead**
  - **Lead to Lead Free**
  - **Lead Free to Lead Free**
  - **Lead to Lead**

RIT CEMA Lab

SMT Laboratory

Focus Areas:
- Electronics Packaging
- Optoelectronics Packaging
- Microsystems Packaging
- Solar Power/Fuel Cell Packaging



X-ray
Ultrasonic Imaging
Shear Testing
Cross-sections
Thermal Shock
Temp. & Humidity

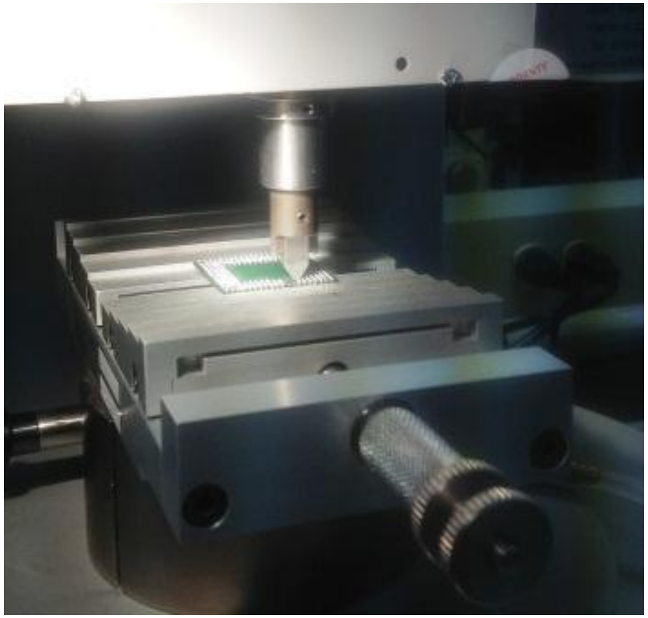
Failure Analysis Laboratory

Factors in BGA Reballing and Shear Strength

- Initial BGA Alloy Type
- Reball Alloy Type
- Flux Type
- Reflow Environment
- Shear Speed
- Substrate Finish
- Reball Times
- Solder Mask Defined Pads?
- Reballing Process

Experimental Plan

- Original Solder Balls from both SAC305 and 63Sn/37Pb BGA's were sheared off for baseline shear strength.



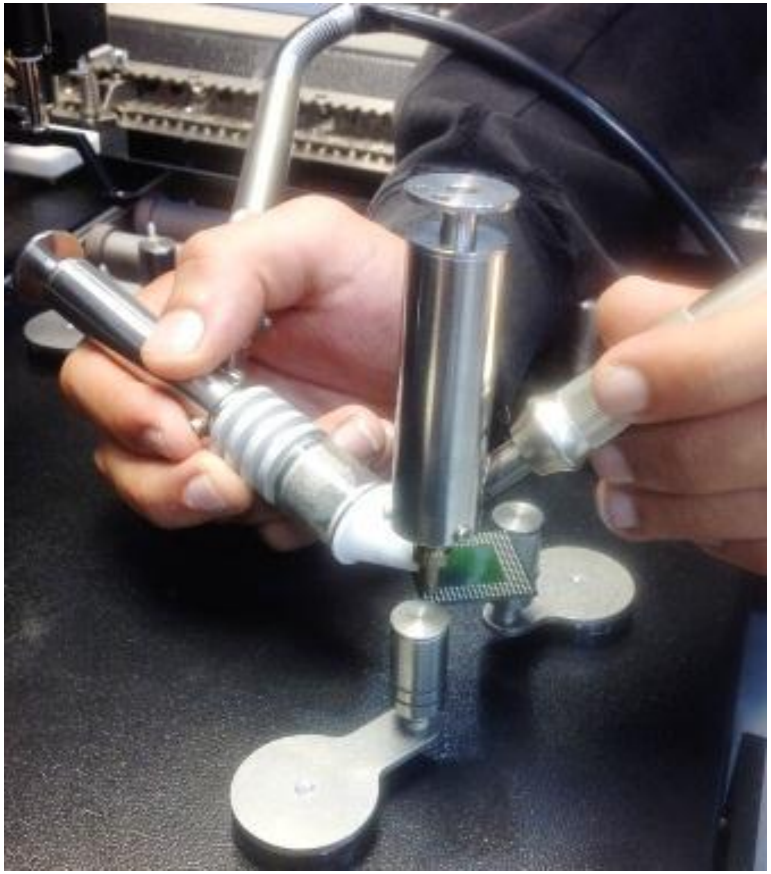
BGA Parameters
Size: 27 mm x 27 mm
Pitch: 1.27 mm
Solder Ball Diameter: 0.75 mm
ENIG Finish

Shear Testing Parameters
Load: 5000 Grams
Speed: 500 µm/second
Shear Height: 0.254 µm
Over-travel: 38 µm

Experimental Plan

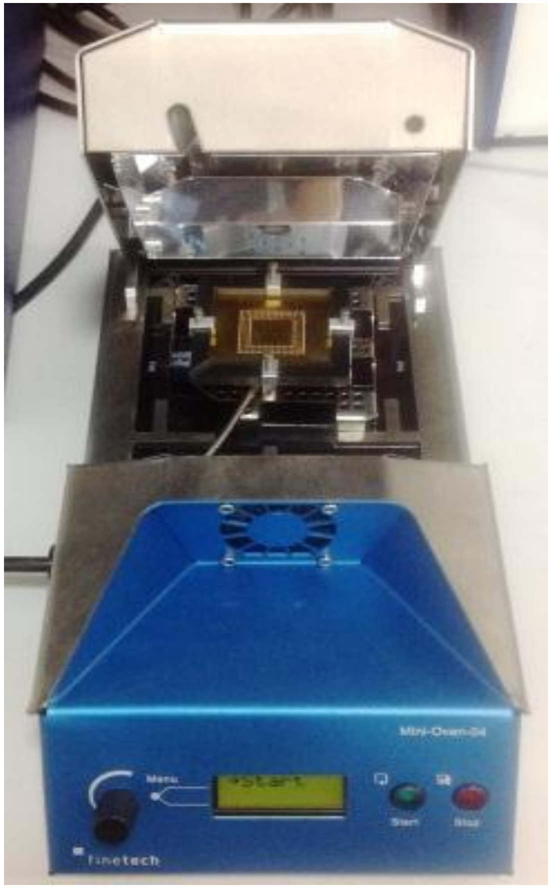
- Solder balls were cleaned off the pads with hot air and vacuum

Cleaning off the BGA pads

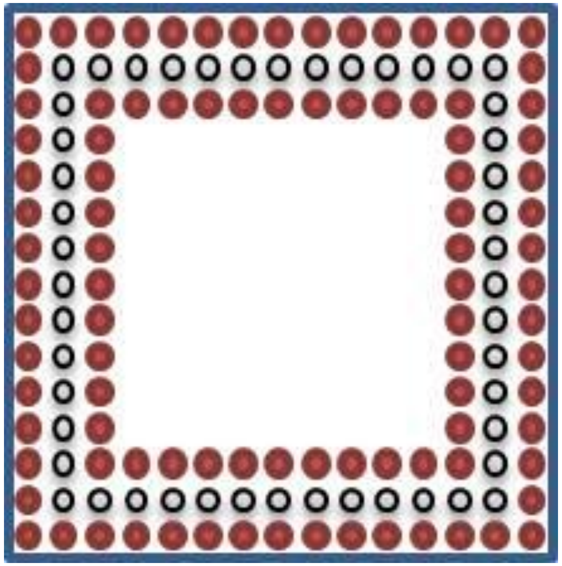


Experimental Plan

- New solder balls were reflowed onto the BGA in a pattern to repeat shear testing



Mini Reflow oven to reball BGAs

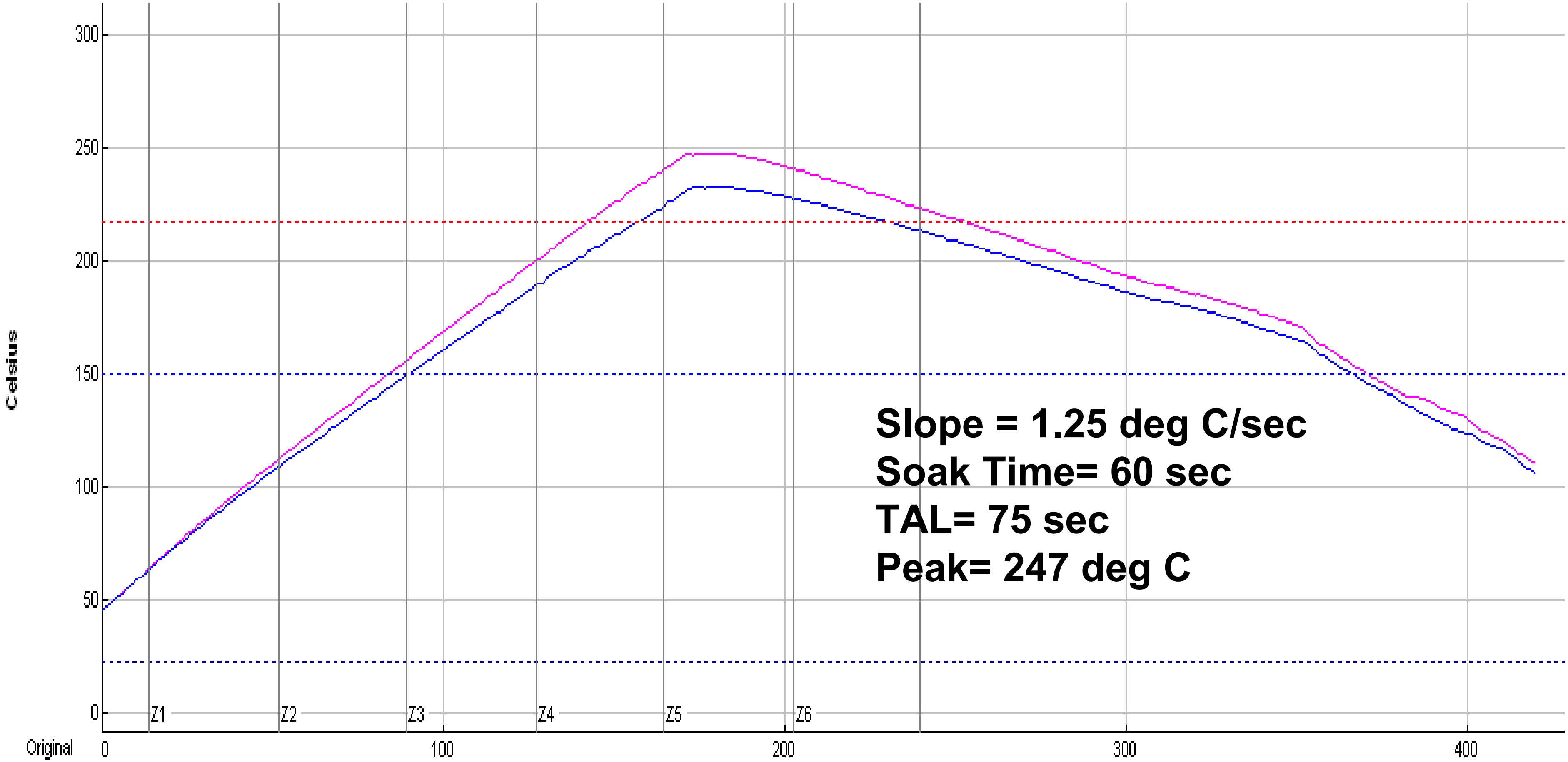


= Solder Ball Placement

Reflow Profiles

Graph Legend
Bottom Side BGA
Top Side BGA

- SAC405



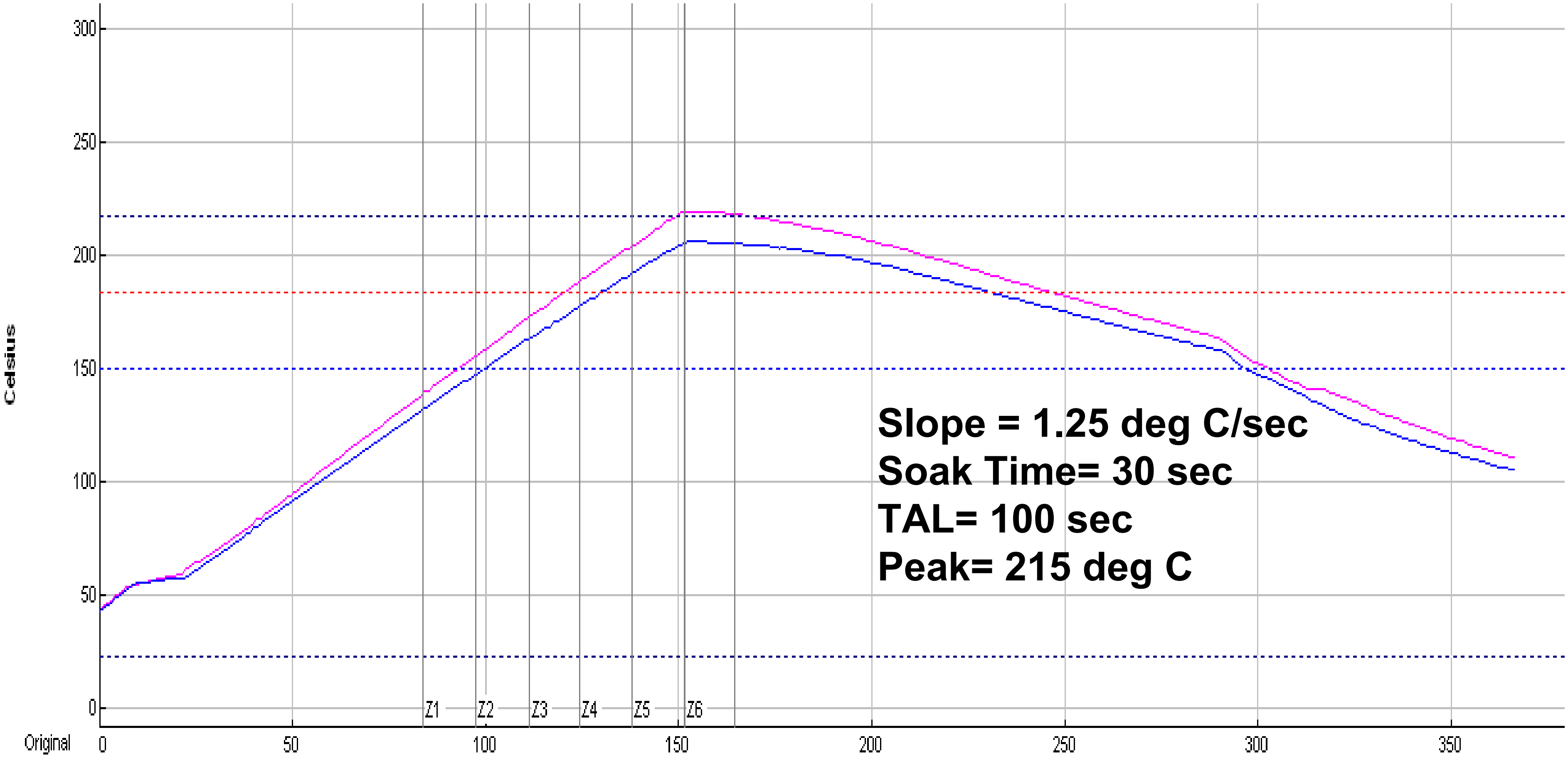
Reflow Profiles

- 63Sn/37Pb

Graph Legend

Bottom Side BGA

Top Side BGA



Design of Experiment

- A full factorial DOE was conducted to determine significant effects on shear strength of re-balled BGAs
- The DOE consisted of 4 factors at 2 levels
- 30 Solder Balls were sheared for each trial
- Response Variable:
  - Mean Shear Strength
  - Standard Deviation of Shear Strength

Experimental Factors

BGA Alloy

(2 Levels)

SAC305 **63Sn/37Pb**

Reball Alloy

(2 Levels)

SAC405 **63Sn/37Pb**

Flux Type

(2 Levels)

No Clean **Water Soluble**

Reflow Environment

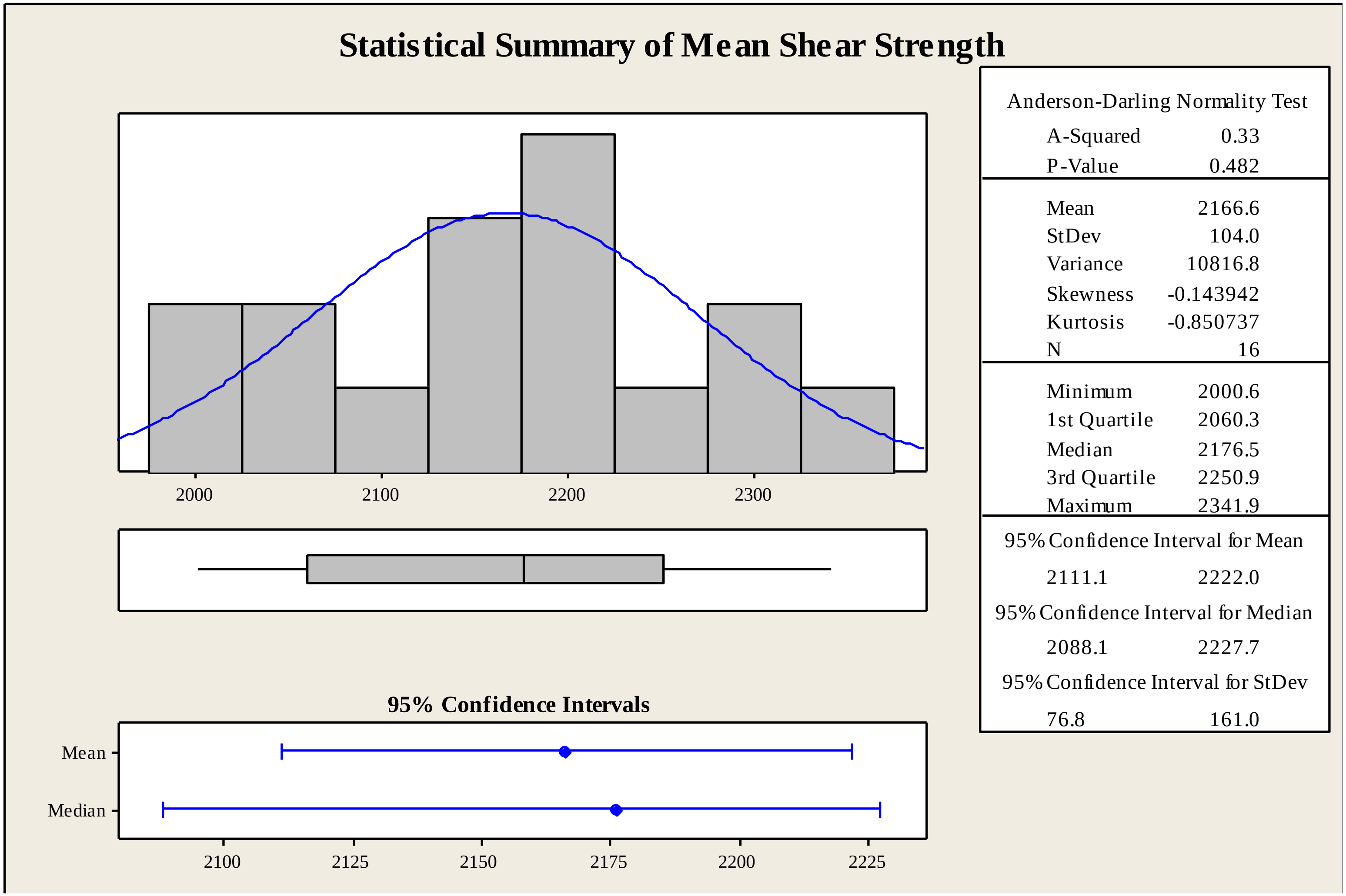
(2 Levels)

Ambient **Nitrogen**

Experimental Run Order

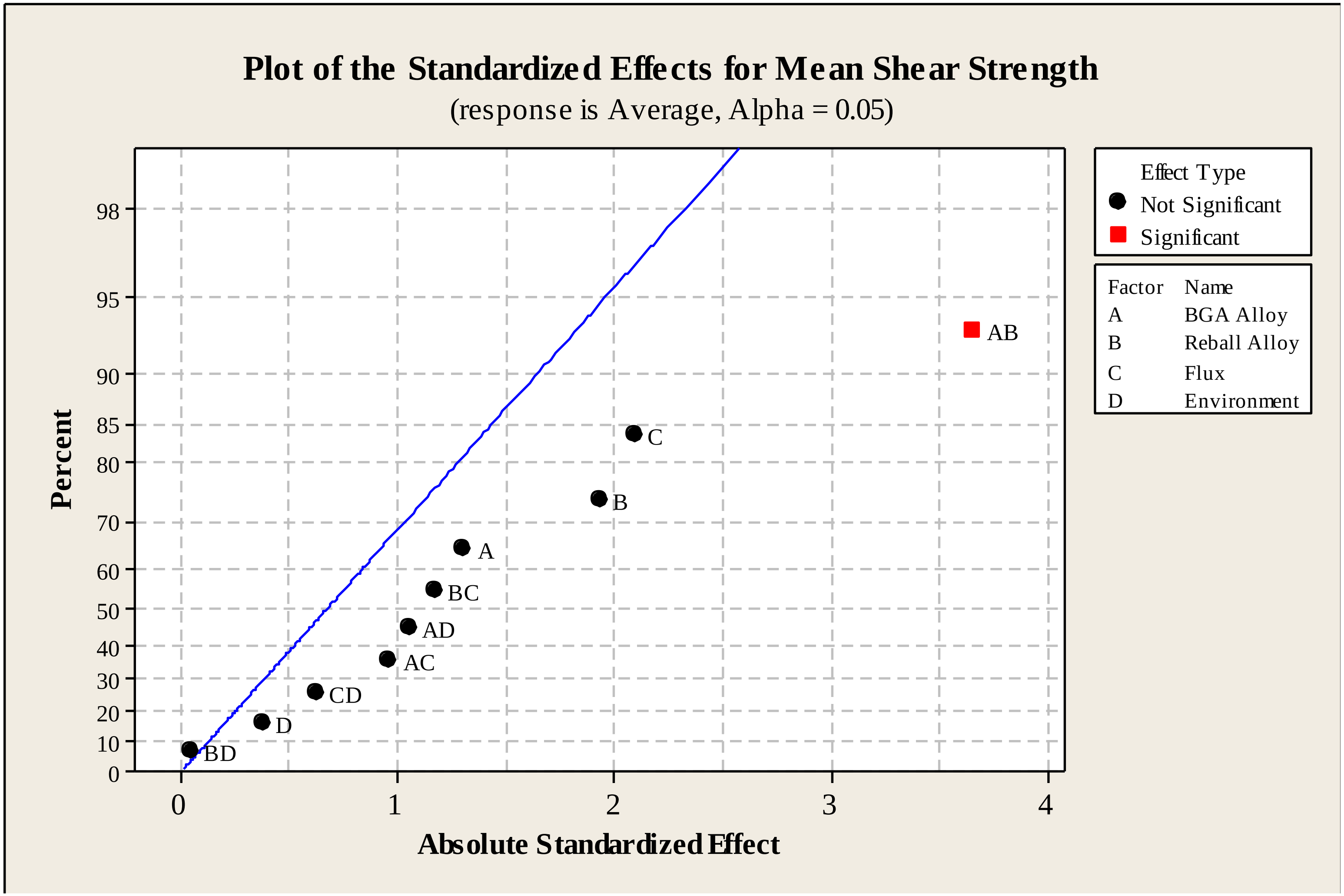
Run Order	BGA Alloy	Reball Alloy	Flux	Environment
1	Sn/Pb	SAC	WS	Ambient
2	SAC	Sn/Pb	NC	Ambient
3	Sn/Pb	SAC	WS	Nitrogen
4	SAC	SAC	WS	Nitrogen
5	SAC	SAC	NC	Nitrogen
6	Sn/Pb	Sn/Pb	NC	Nitrogen
7	SAC	Sn/Pb	NC	Nitrogen
8	Sn/Pb	Sn/Pb	WS	Nitrogen
9	Sn/Pb	Sn/Pb	WS	Ambient
10	SAC	SAC	NC	Ambient
11	SAC	Sn/Pb	WS	Nitrogen
12	SAC	Sn/Pb	WS	Ambient
13	Sn/Pb	SAC	NC	Nitrogen
14	SAC	SAC	WS	Ambient
15	Sn/Pb	Sn/Pb	NC	Ambient
16	Sn/Pb	SAC	NC	Ambient

DOE Results



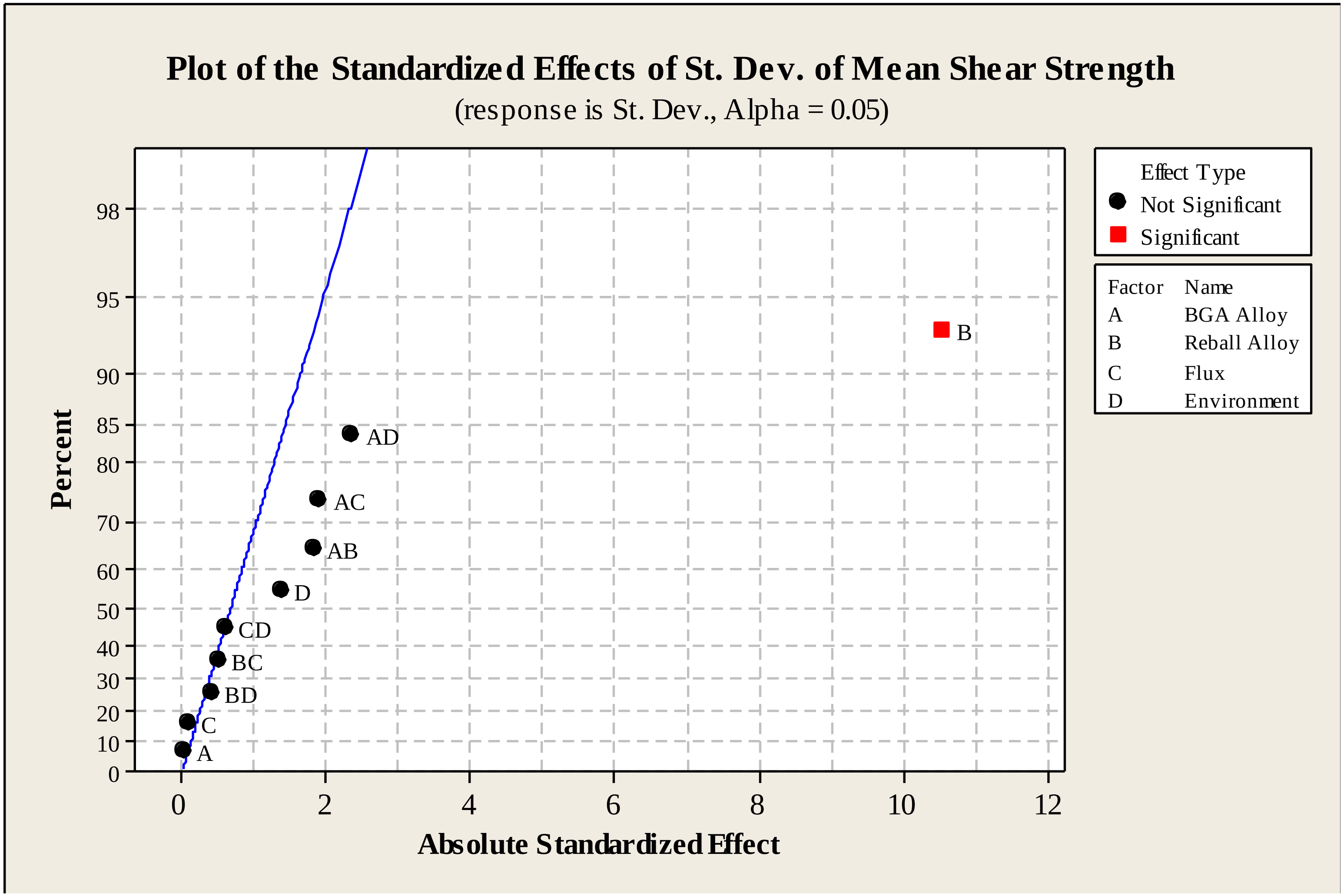
The statistical summary shows that the data collected was normally distributed and was suitable for making statistically significant observations

DOE Results



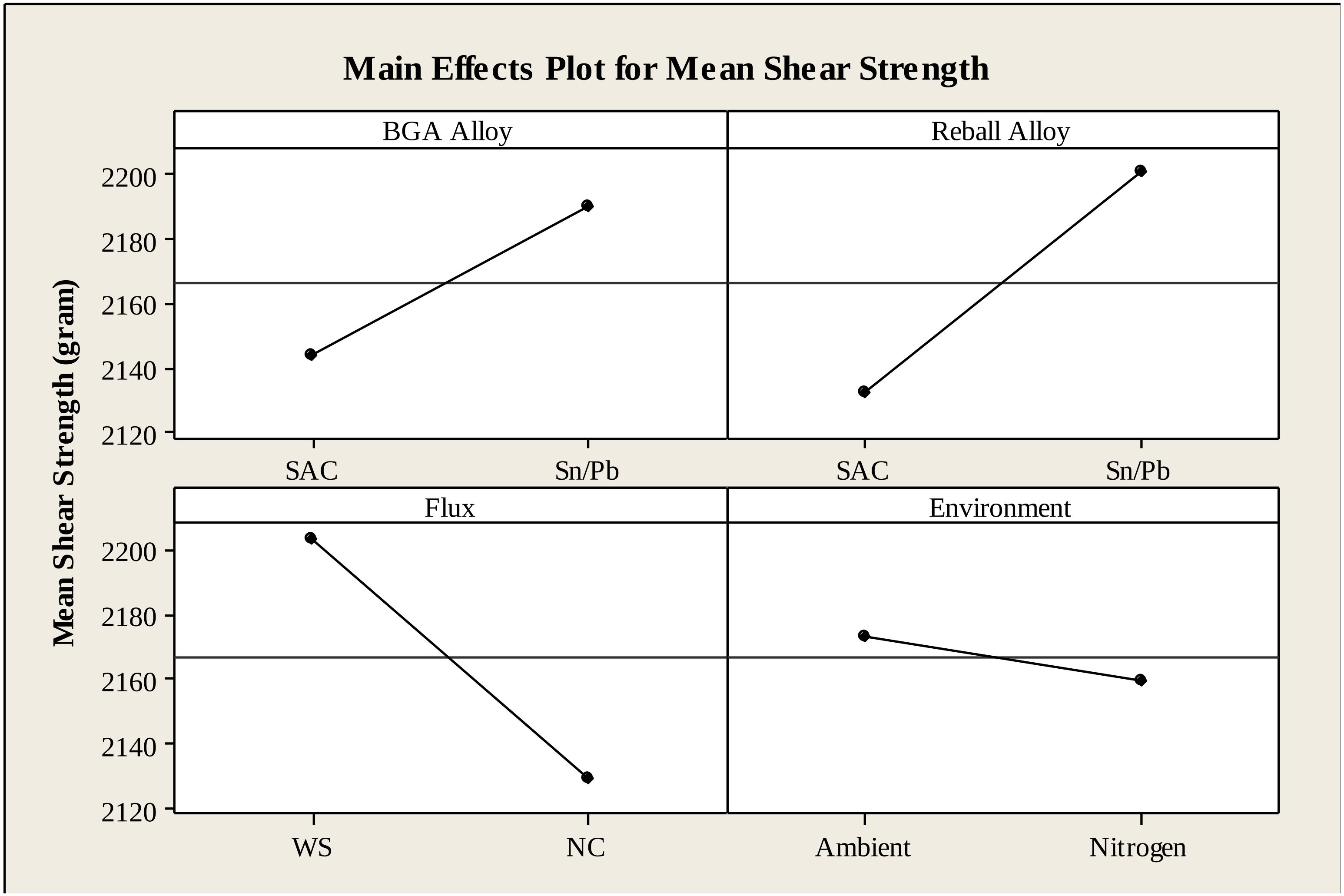
Based upon the average shear strength with 95% confidence level, it was determined that the interaction of BGA alloy and reball alloy were significant

DOE Results



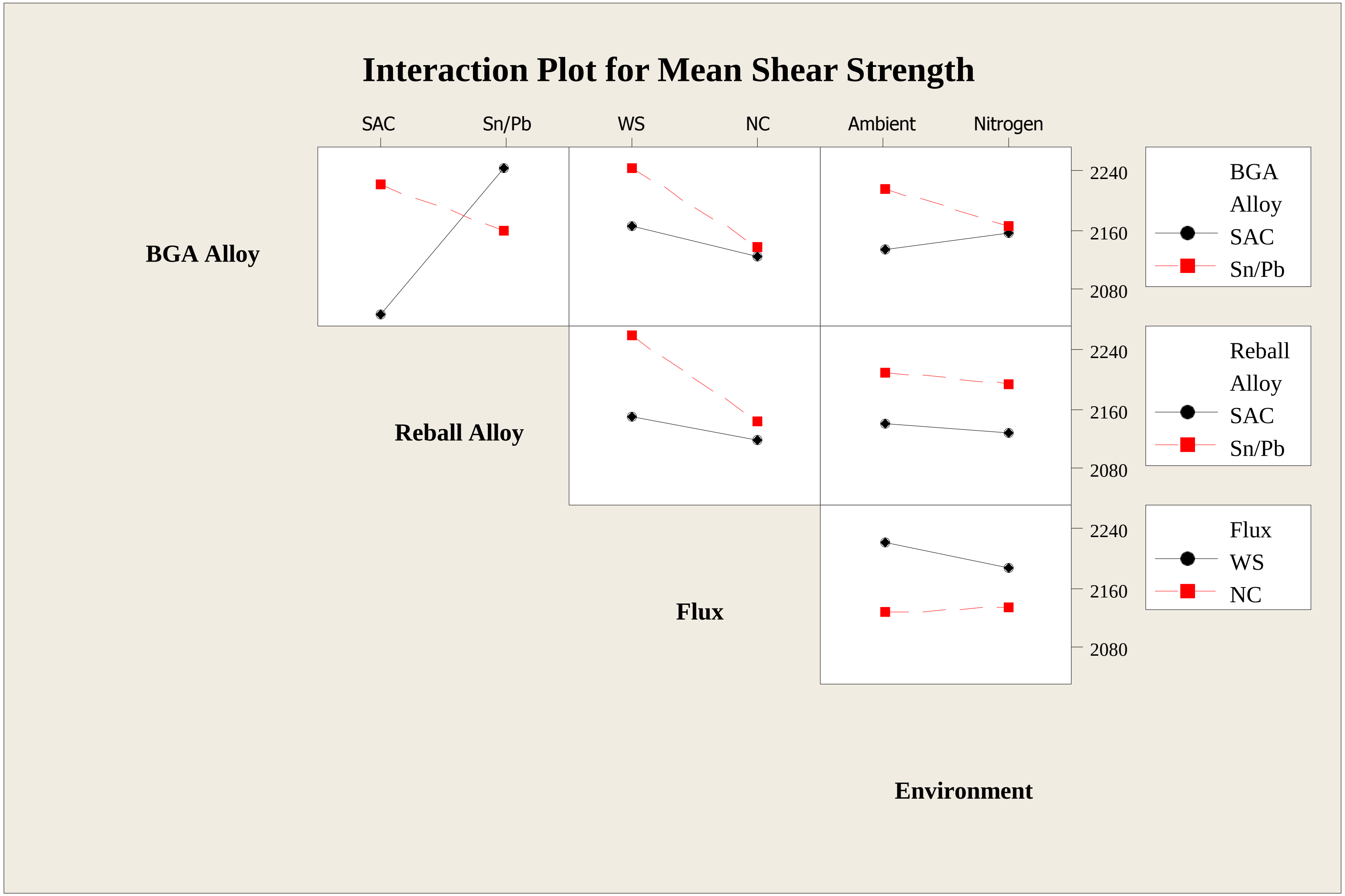
Based upon the standard deviation of shear strength with 95% confidence level, it was determined that the reball alloy factor was significant

DOE Results



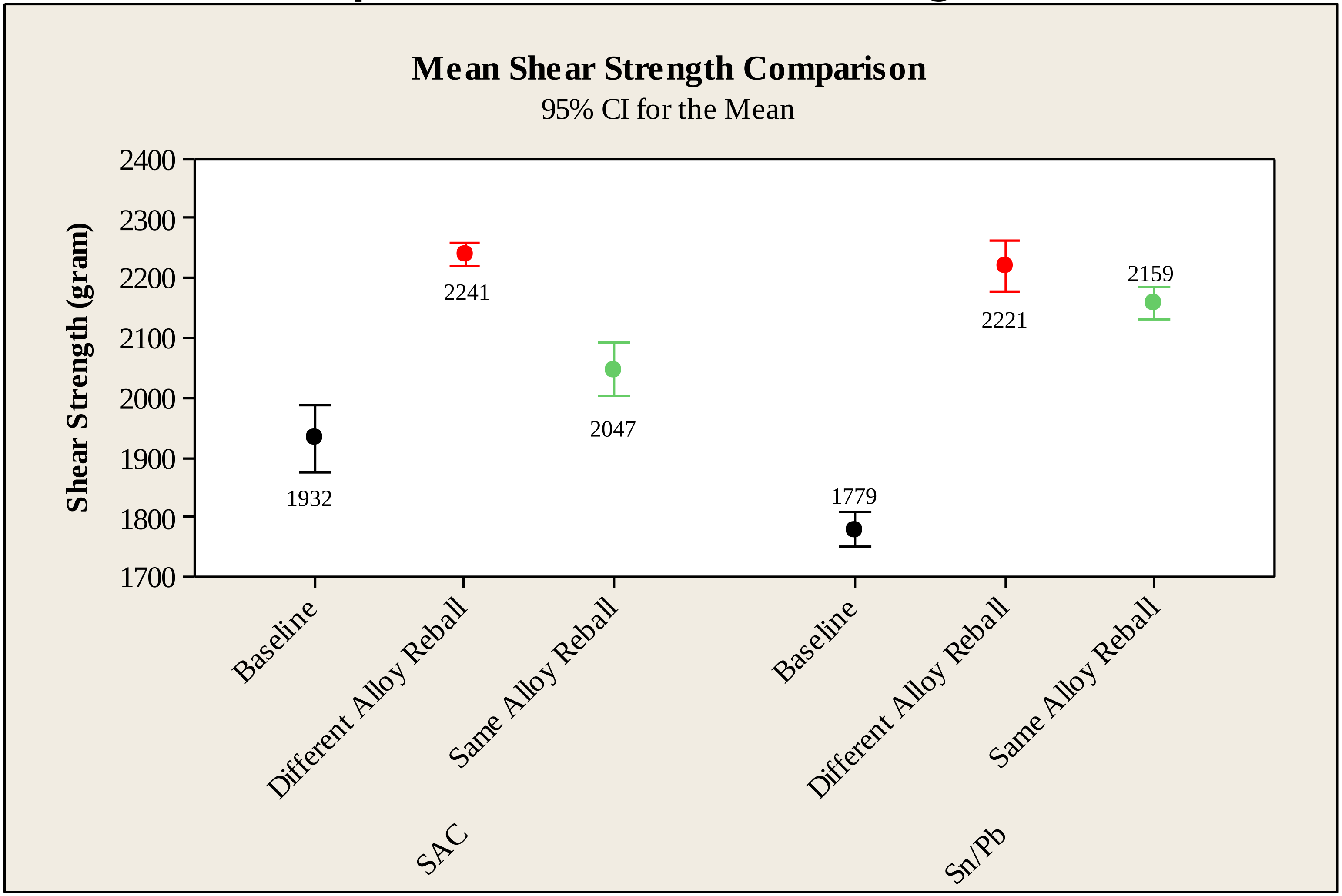
The mean shear strength of reballed BGAs based upon each factor at its respective level

DOE Results

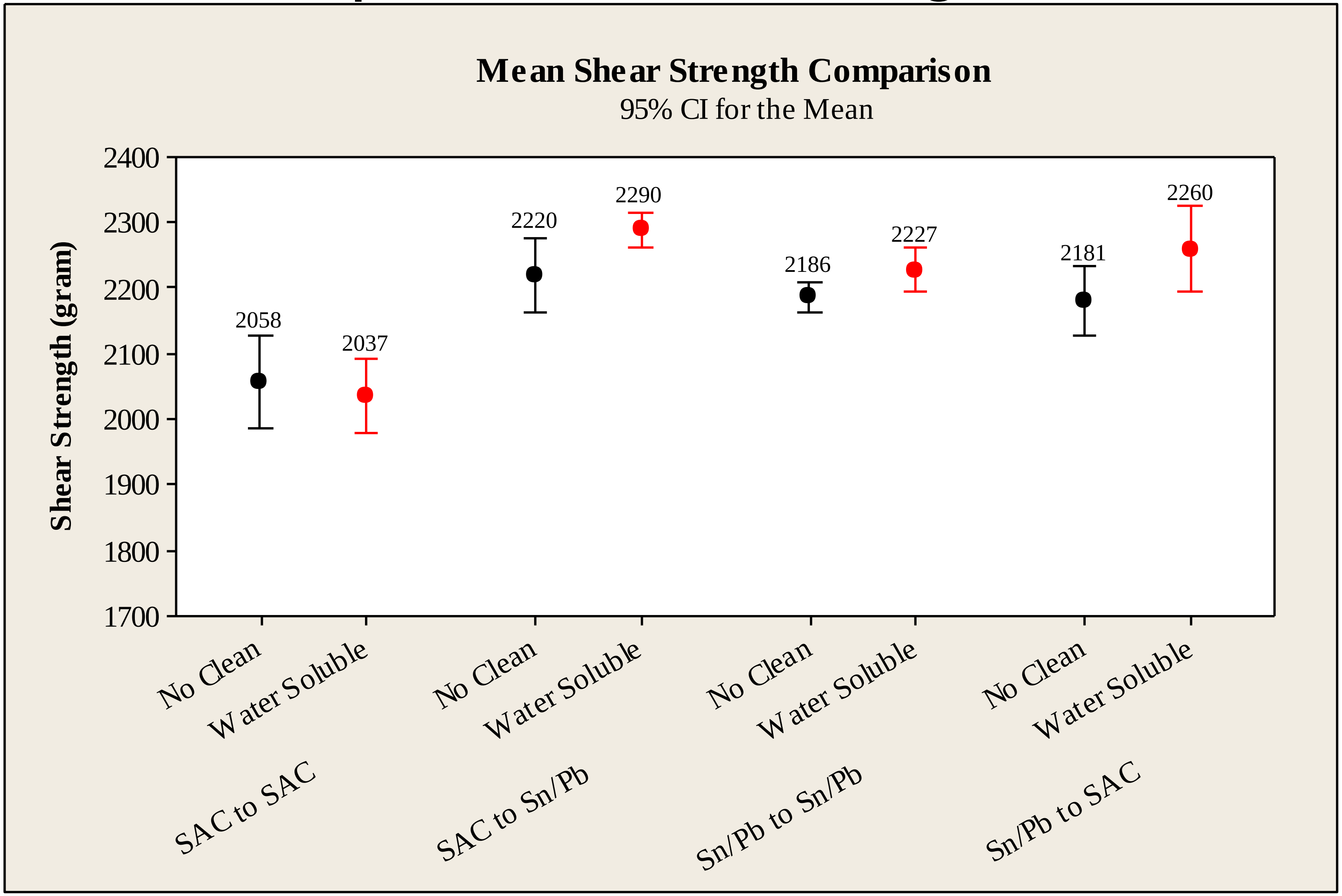


The interaction between factors of the mean shear strength

Experimental Findings

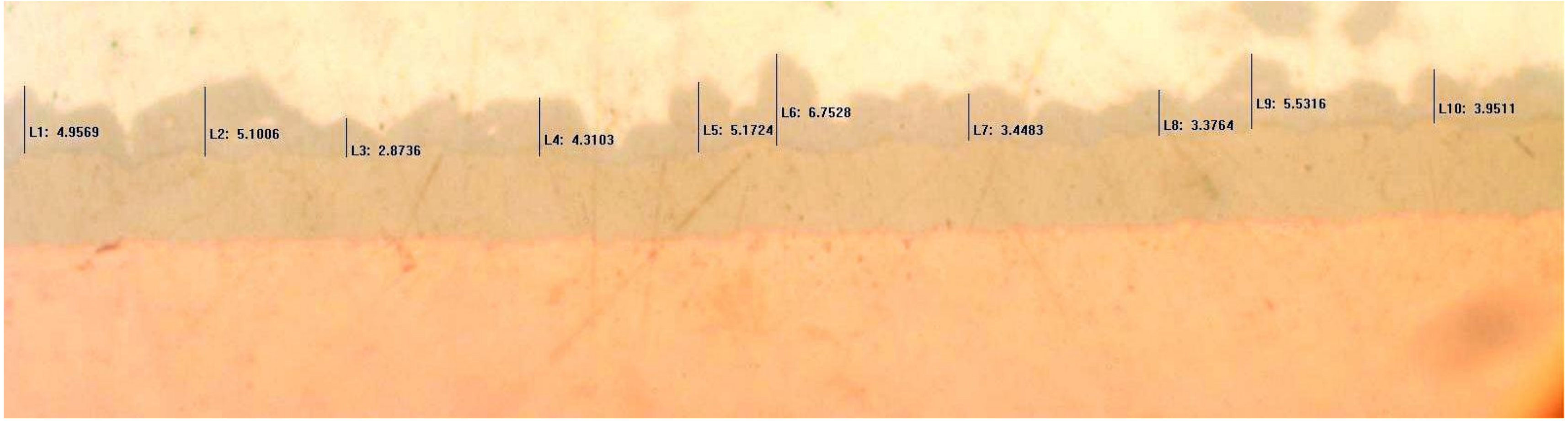


Experimental Findings

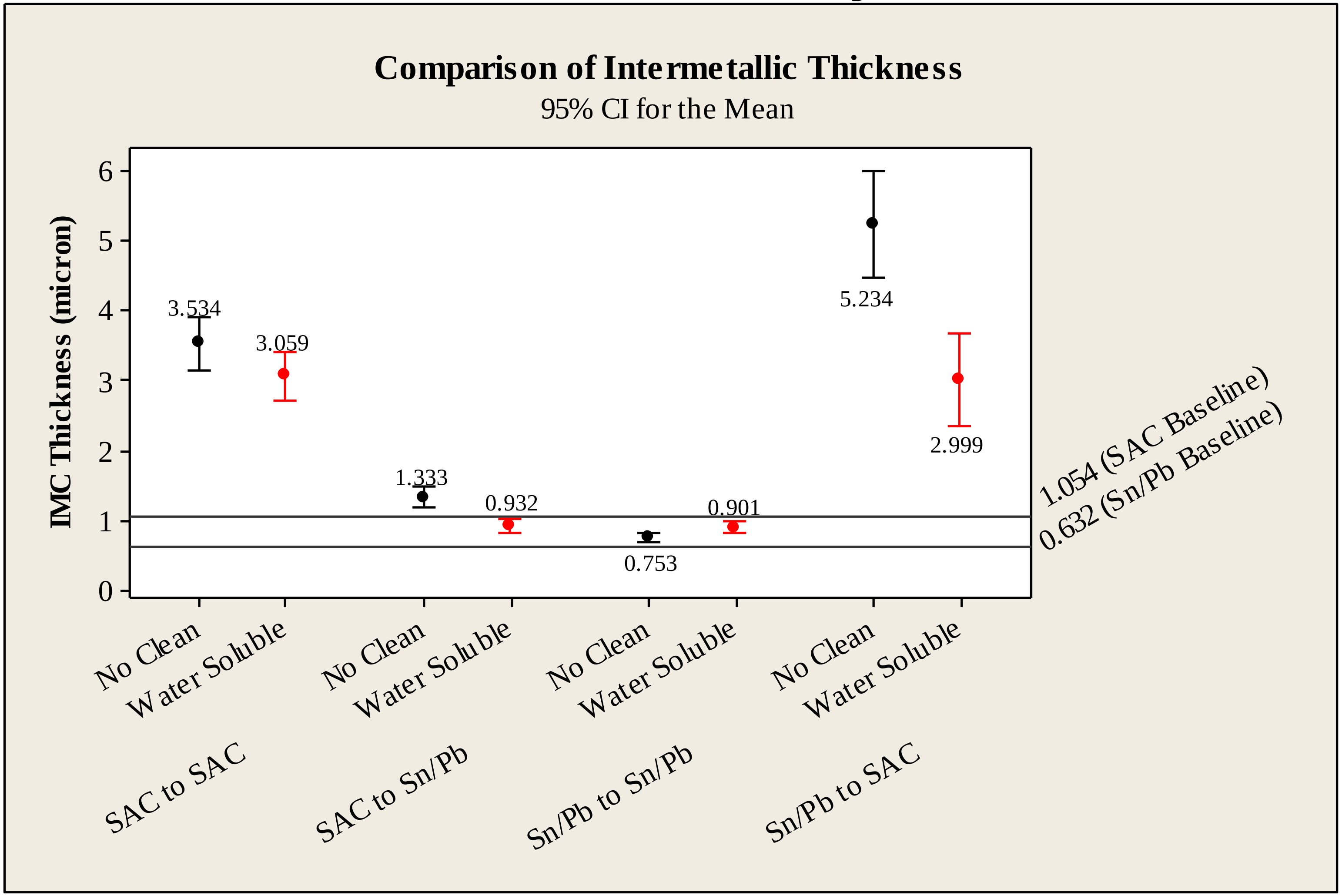


Intermetallic Analysis

- Measurements were taken and averaged from the IMC each BGAs
- 20 total measurements from 2 solder balls were taken (10 from each ball)
  - Accounts for variations along the IMC



Intermetallic Analysis



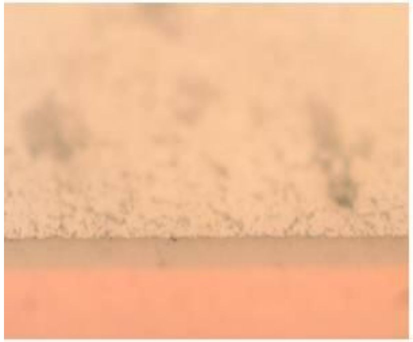
Intermetallic Analysis

- In all treatments, the IMC increased from the baseline average
- 63Sn/37Pb had the most consistent IMC thickness after reballing
- 63Sn/37Pb showed minimal increase in the IMC thickness as compared to the baseline observations
- SAC405 showed the least consistent IMC thickness with large variation along the solder ball interconnection

Intermetallic Analysis

Sn/Pb Baseline

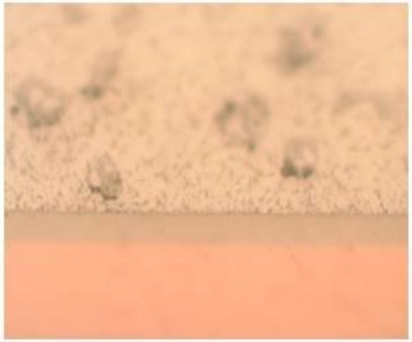
SAC Baseline



Original BGA: Sn/Pb
Re-balled Alloy: Sn/Pb

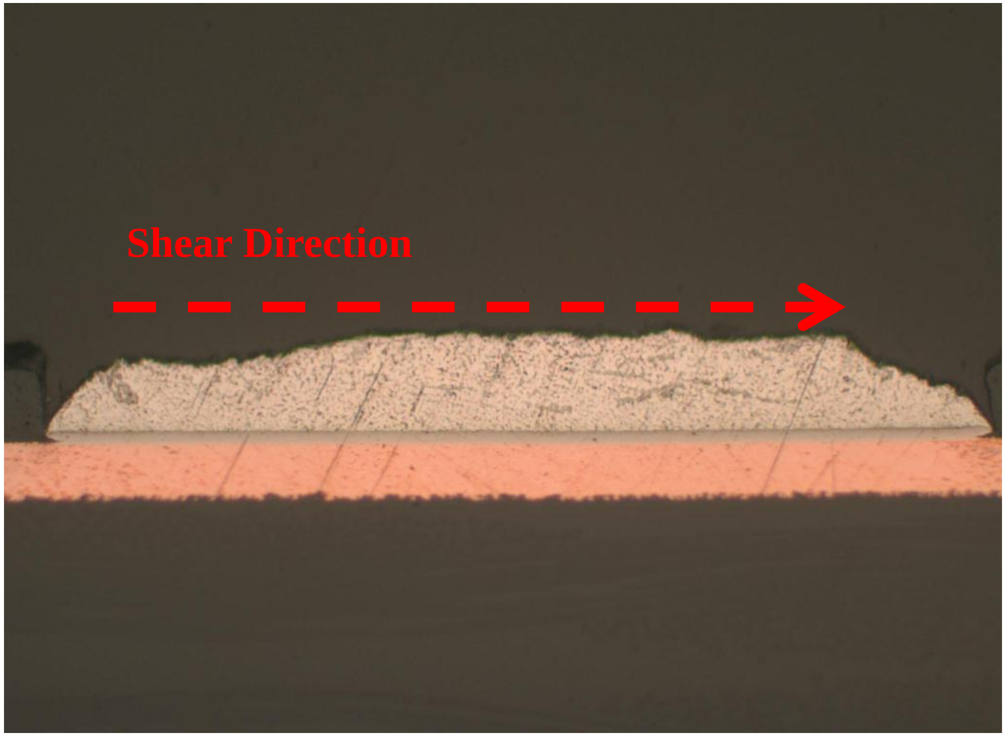
Original BGA: Sn/Pb
Re-balled Alloy: SAC405

Original BGA: SAC405
Re-balled Alloy: SAC405



Original BGA: SAC405
Re-balled Alloy: Sn/Pb

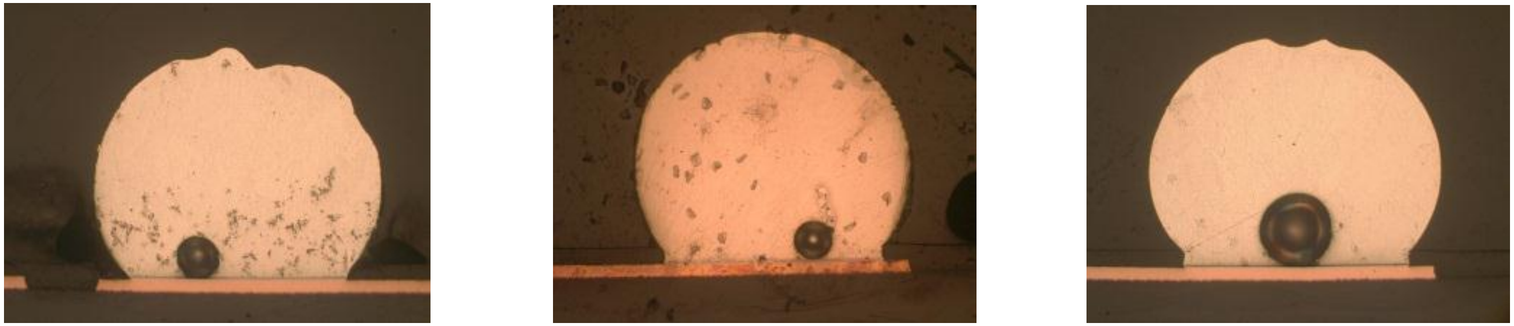
Observations from Shear Testing



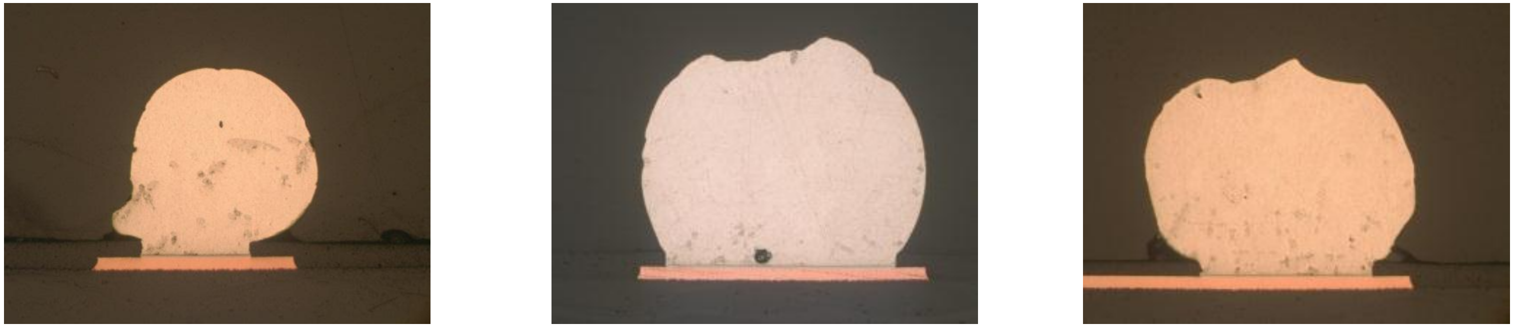
- From the experimental setup and the observations in cross sectional analysis, it was observed that the shear failure occurred on the ball (ductile fracture) and not at the intermetallic (brittle fracture).
- Low speed shear is theorized to be the cause of the failure mode

Potential Defects

- Defects observed while reballing
  - Solder Ball Voiding



  - Incomplete Solder Balls



Conclusions

- Reballing was successful in both SAC components and 63Sn/37Pb.
- There was an overall increase in shear strength from the baseline for reballed BGAs.
- The DOE showed that the interaction between BGA type and solder alloy to be reballed had a significant effect on the overall shear strength.

Conclusions

- Flux may have an effect with the solder alloy used. Overall water soluble flux showed higher shear strength over no clean flux.

- The intermetallic thickness for both alloys increased.

- Reballing a BGA may take more time for operators, but can save in scrap and shelved inventory. The ability to rework components which maintain their original characteristics is a huge advantage for this industry.

Summary of Results

BGA Type	Reball Alloy	Flux	Shear Strength Ranking (1=Best)
SAC	Sn/Pb	Water Soluble	1
SAC	Sn/Pb	No Clean	3
Sn/Pb	SAC	Water Soluble	2
Sn/Pb	SAC	No Clean	4

Future Research

- Future research includes (RIT-CEMA is looking for consortiums):
  - The continuation of this study focusing on the reliability of reballed BGAs assembled on test vehicles.
  - More trials will be done to try and optimize the reballing process with other SAC alloys.
  - Drop and Thermal Shock tests will be done to research the effect on reballed components assembled on test vehicles.

Acknowledgements

- Jeff Lonneville - Lab Manager of RIT CEMA Lab

- Scott Rushia – Representative from Martin

Questions?