

Wire Bond Comparison of Different Aluminum Alloys and Thicknesses

Barry Njoes
Dr. David W. M. Williams
Technical Materials Inc.
5 Wellington Road
Lincoln, RI 02865
401-333-1700
fax 401-333-2848
Barry_Njoes@beminc.com
David_Williams@beminc.com

Michael McKeown
Orthodyne Electronics
16700 Red Hill Avenue
Irvine, CA 92606
516-739-2690
Mike.McKeown@orthodyne.com

Jason Hibbert
Alex Marralaw
Farmingdale State College
2350 Broadhollow Road
Farmingdale, NY 11735

Abstract

As manufacturing of electronic components for the automotive industry becomes increasingly global, variations in material selection on different continents raise questions regarding compatibility to meet performance requirements.

This paper compares wire bondability of two aluminum alloys commonly used in leadframe material systems for hybrid applications. The two aluminum alloys used are A91145 and AlSi1 which are the standard materials, used for years as the bonding pads for automotive leadframes, for the US and European markets, respectively. These two alloys are similar in chemistry containing 99.0% minimum aluminum, with the main difference being impurity levels which can affect hardness. These alloys will be studied using different inlay thicknesses and also different leadframe base metal variations. These alloys will then be wire bonded using standard machine settings and a range of typical wire diameters. Wire bonds will be subjected to standard pull testing, shear testing and visual inspection to determine if differences in aluminum alloy, hardness or thickness and leadframe base metal selection effect wire bond quality.

All the samples used in this study are from production products and are being used in a variety of sensors and power modules. The metal combinations being evaluated are aluminum alloy A91145 inlaid into C19400 (U.S. standard) and aluminum AlSi1 inlaid into C51900 (European standard). The material properties for these four alloys will be shown and discussed in detail.

AlSi1 thickness to be evaluated is 10 – 30um (0.0004" - .0012"). A91145 aluminum will be evaluated in three thicknesses, 0.0004 – 0.0012", 0.002" and 0.005" minimum. The wire used in all the tests will be grade 99.99% aluminum supplied by SPM. The three wire diameters used for bonding will be .006", .010" and .015" and wire bonding will be done using an Orthodyne Electronics Model 3600Plus Wire Bonder utilizing standard default settings. Orthodyne Electronics will do the pull and shear testing and characterize the initial bond nugget quality and grade the bonds. Technical Materials, Inc. (TMI) will do the metallurgical examinations of the wire bonds to better understand any differences that may exist within the tested material systems.

Key Words: wire bonding, comparison, aluminum alloy, wire size

Introduction

For over twenty years the automotive industry has been using heavy aluminum wire bonding as a means of producing strong, reproducible interconnects for electronic hybrids. These modules have been designed to withstand major shock, vibration and temperature cycling during normal operation (-40° to 150° C) and have passed with superior results. This work has been well documented and will not be part of this paper [1,3]. The design of these modules incorporates a wire bondable leadframe which facilitates the wire bonding process. These copper alloy leadframes are designed with an aluminum inlay metallurgically bonded to the copper, in the area where the wire bonding takes place and thus gives a bondable surface to these output terminals. These clad terminals are then insert molded into the plastic housing of the various electronic components. As this technology started to grow in the United States a standard material system was designed. This product incorporated a copper alloy C19400 (ASTM B465) as the base material and this alloy was chosen because of its well documented history of use in the semiconductor industry namely the TO – 92 leadframe. The aluminum alloy used as the wire bondable material for the inlay was the grade 1145 and was .002" thick. This alloy was chosen because of its wire bond history as the cladding used for Cerdip leadframe materials. The more consistent chemistry of the 1145 (99.45% Al) alloy over the standard 1100 grade aluminum made for more reproducible wire bondability and the hardness more closely match the wire being used[2]. The aluminum inlay thickness of .002" thick was based on manufacturability of the skive inlay process and an early undocumented study showing that going thinner or thicker had little effect on pull strength results when tested with 10 mil wire.

About the same time the US was developing a wire bondable material system for automotive electronics the same procedure was taking place in Europe. However, different materials were being chosen. The European material system was being designed around their major terminal base material C51900 (ASTM B103). The aluminum alloy chosen was AlSi1 (99.0%Al,1%Si), which is a standard alloy used in the manufacturing of fine aluminum bonding wire both in the US and Europe. The aluminum cladding for this system is much thinner .0004"-.0012" and because of the Si content, up to 1%, it is harder and has less elongation for the same amount of cold work as shown in Tables 1 and 2.

Table 1 – Mechanical Comparison

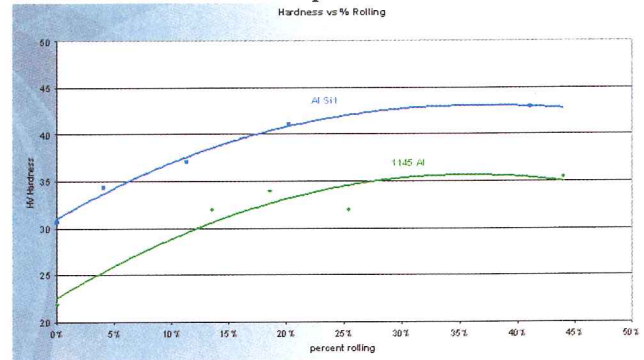
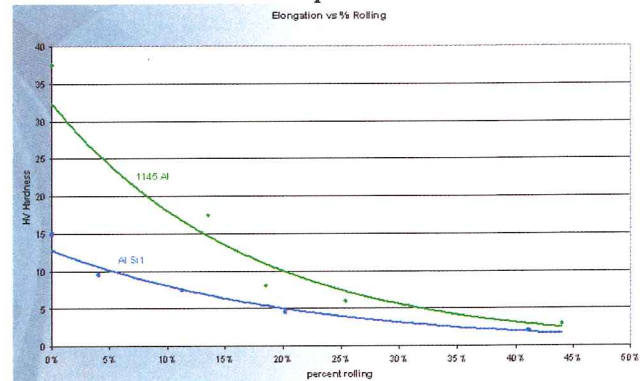


Table 2 – Mechanical Comparison



It is this difference in material selection and design, and the lack of any formal global specification, that has driven us to prepare this study. Our intent is to answer a number of questions, 1. is there a difference in what aluminum alloy to use for the inlay process, 2. does the inlay thickness play a role, and 3. does the base metal of the leadframe have any effect?

Test Matrix

Coupons were taken from production run material and represented the differences in leadframe base metals, aluminum inlay thicknesses and alloys. These variables are shown in Table 3A. These materials were then bonded at Farmingdale State College, using an Orthodyne 3600Plus Large Diameter Wire Bonder. The bonding was done with standard machine default settings for each of the three wire sizes used in the study, as well as the appropriate standard bonding tools, cutter blades and wire guides.

The wire used in the study was supplied by SPM of Armonk, NY, with the individual wire specifications are shown in Table 3B. The three wire sizes are a good representation of what is used in production.

Table 3A – Material Matrix

Leadframe Base Metal	Inlay Type	Inlay Thickness
C519	AlSi1	.0004 - .0012"
C194	A91145	.0004 - .0012"
C194	A91145	.002"
C194	A91145	.005"

Table 3B – Wire Matrix

Diameter mils	Purity (Al)	Tensile grams	Elongation %
6	99.99	125	6-12
10	99.99	400 – 450	9 – 13
15	99.99	900	15 – 25

The pull and shear testing was done at Orthodyne Electronics in Irvine, CA using a Dage Series 4000 Bondtester. All the reported results are from a testing size of twenty bonds per coupon. The visual analysis and grading of the pull and shear testing was also done at Orthodyne Electronics. A confirmation run was done at Farmingdale State College and those wires were tested on an XYZTEC Condor 70 Bond Tester.

Results

Pull Strengths

Achieving acceptable bonds with the standard machine settings for the three wire sizes was easily done on all coupons. The mean pull strength data by wire size, inlay type, inlay thickness along with the base metal variations are shown in the Tables 4A, 4B, and 4C. These tables do show subtle differences in pull strengths values but all the results would be considered acceptable in a production environment. All breaks were either heel or mid-span breaks and no lifts were reported. This test did not provide any discrimination between aluminum grades or thicknesses and all results were well within acceptable wire bond criteria.

Table 4A - Mean Pull data for .006" wire

All inlay thickness

Base Metal	Al Type	Al Thickness	Pull grams
C519	AlSi1	.0004 - .0012"	184.4
C194	1145	.0004 - .0012"	154.7
C194	1145	.002"	150.3
C194	1145	.005"	164.8

Table 4B - Mean Pull data for .010" wire

All inlay thickness

Base Metal	Al Type	Al Thickness	Pull grams
C519	AlSi1	.0004 - .0012"	524.7
C194	1145	.0004 - .0012"	491.0
C194	1145	.002"	499.0
C194	1145	.005"	504.9

Table 4C - Mean Pull data for .015" wire

All inlay thickness

Base Metal	Al Type	Al Thickness	Pull grams
C519	AlSi1	.0004 - .0012"	1198.0
C194	1145	.0004 - .0012"	1291.8
C194	1145	.002"	1247.9
C194	1145	.005"	1272.4

Shear Strengths

Based on the minor differences in the pull strength results, shear testing was performed as a more stringent evaluation of wire bond quality and performance. Once again all test results for all inlay thicknesses were well within acceptable wire bond criteria, irrespective of aluminum chemistry. However, greater variations in wire bond strengths were obtained which may be related to the mechanical differences of the material systems. Tables 5A, 5B, and 5C show the shear results for 0.006", 0.010" and 0.015" wire size, respectively.

Table 5A - Mean Shear data for .006" wire
All inlay thickness

Al Type	Al Thickness	Shear grams	Grade
AlSi1	.0004 - .0012"	391.1	4.0
1145	.0004 - .0012"	344.5	4.0
1145	.002"	324.4	4.0
1145	.005"	293.4	4.0

Table 5B - Mean Shear data for .010" wire
All inlay thickness

Al Type	Al Thickness	Shear grams	Grade
AlSi1	.0004 - .0012"	1064.5	4.0
1145	.0004 - .0012"	1278.7	4.0
1145	.002"	1268.0	4.0
1145	.005"	1205.6	4.0

Table 5C - Mean Shear data for .015" wire
All inlay thickness

Al Type	Al Thickness	Shear grams	Grade
AlSi1	.0004 - .0012"	1746.4	2.7
1145	.0004 - .0012"	2477.6	3.7
1145	.002"	2452.6	3.7
1145	.005"	2411.2	3.9

With 6-mil wire, the AlSi1 yielded the highest shear strengths with values of the 1145 aluminum inlays gradually decreasing as substrate inlay thickness increased. It is believed that the higher shear strength with AlSi1 may be due to the "anvil effect" of a harder substrate resulting in slightly larger wire bond footprint.

This trend was reversed with 10 mil wire as shown in Table 5B. Using the larger wire diameter the anvil effect results in the percentage difference in the size of the wire bond footprint between hard and soft inlays being essentially eliminated with the 1145 inlay having higher shear strengths than the AlSi1 inlay.

The trend of shear strength of softer 1145 aluminum being higher than the harder AlSi1 continues with the 15 mil wire, see Table 5C.

Wire Bond Nugget

Table 6 shows the criteria, in this study, for grading shear strength nuggets. The column labeled Grade in Tables 5A, 5B and 5C shows a comparison of nugget Grade using different wire diameters and inlay thicknesses. Although there were shear strength differences between 6 mil and 10 mil wire, they all had the same visual nugget grade of 4. However, using 15 mil wire the harder inlay of AlSi1 had a lower average grade of 2.7 while all the softer 1145 inlays were graded significantly better at 3.7 and 3.9, this corresponds well with the shear strength data.

Table 6 – Visual Grading System

Grade	
1	0 – 25% Nugget
2	25 – 50% Nugget
3	50 – 75% Nugget
4	75 – 100% Nugget

Conclusions

The purpose of this work was to investigate the influence, if any, of different chemistries of aluminum used for US and European leadframes in automotive hybrid packages upon wire bond strengths.

The first, and possibly the most important conclusion, is that all materials exhibited acceptable wire bond strength requirements. The different base materials tested had little or no affect on wire bond results.

The harder AlSi1 alloy did exhibit higher pull strengths than 1145 aluminum with the thinner diameter wires but results were reversed with the 15 mil wire. There was very little variation in pull strengths of the 1145 alloy irrespective of inlay thickness or wire size.

Shear testing resulted in more differences than pull testing. Again, the thin AlSi1 inlay had slightly better shear strengths with .006" wire, however this trend reversed itself quickly, showing lower strengths with 10 mil and even greater differences with 15 mil wire.

Further work is necessary to quantify the relationship between wire bond footprint and shear

strength for different hardness's of aluminum. In addition to hardness or elongation difference, the presence and thickness of intermetallic compound formed between the aluminum and copper alloys may influence wire bond strength. Based upon data obtained for 1145 alloy, both in pull and shear, there appears to be little or no advantage to the thicker aluminum inlay studied in this work.

Acknowledgements

The authors wish to thank Richard Young and Paula Goldstein of Technical Materials Inc., Erich Mueller of Orthodyne Electronics and Dr. Raju Venkitaswamy of Farmingdale State College for their technical expertise and support in producing this paper

References

1. Brouillard, M. and Johnson, W., "Electroplated Phosphorous Nickel For Use in Wire Bonding Applications"
2. Lees, Njoes, and Williams, "The Influence of Surface Defect Size on Wire Bond Pull Strengths for Automotive Lead Frame Materials"
3. Harman, G. "Wire Bonding In Microelectronics" page 151