Effects of Lead-Free Solders on Flex Performance

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Abstract

Ceramic capacitors have proven themselves very reliable with extremely low failure rates. As processes continue to improve, reliability of the dielectric also continues to increase. This increase in the reliability of the dielectric has caused other categories to emerge as the main contributors to the overall failure rate. A recent review of field failure analysis of surface mount MLCCs, has shown Flex Cracks account for as much as 40% of ceramic capacitors failures. Flex Cracks are created when a physical displacement of the board mounted MLCC generates sufficient stress within the ceramic body to fracture the ceramic material. As the industry moves to lead free soldering systems, which are less ductile, there is a concern about the effects on flex performance.

This paper was written in response to customer concerns of flex performance as they switch from lead based to lead free soldering processes. In this paper we present the results of flex testing, comparing standard lead based solders to lead free solders.

Preparation of samples

The objective of this study is to determine the effects of lead free solders and solder process on the flex failure rate. To get an accurate picture of the effects across a variety of sizes, the following case sizes were selected for this study: 0603, 0805, 1206, and 1812. The lead based solder used as a control for this study was a 63-37 Tin Lead (SnPb) solder, and the Lead Free solder (Pb-Free) was a SAC 305 (SN 96.5%, Ag 3% Cu .5%). The solder was dispensed with a metering pump to ensure constant solder amounts. The amount of solder dispensed for each case size was validated before during and after the parts were mounted. The soldering profiles followed the solder paste manufactures recommendation.

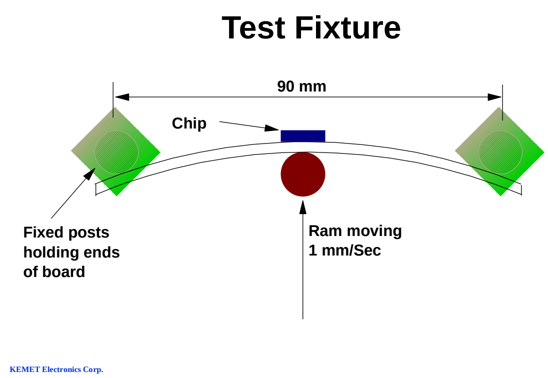


Figure 1. Flex Testing Fixture [1]

Testing

400 pieces from each part number were mounted on test boards. 200 using Pb-Free solder, 200 using standard SnPb solder. The boards were then flexed at a rate of 1 mm/Second, to a maximum of 10 mm. Continuous capacitance measurements were made and recorded while the part was under test. The test continued until a crack was detected, defined as a 2% capacitance change. [1]

Limits

Figure 2 shows the Weibull plot of cumulative failures for an 1812 capacitor mounted with a Pb-Free solder. The calculated failure rate line is generated using the lower end of the Weibull distribution. This line is used to predict the expected failure rate at a given displacement.

1812C474K5RAB – Pb-Free Solder

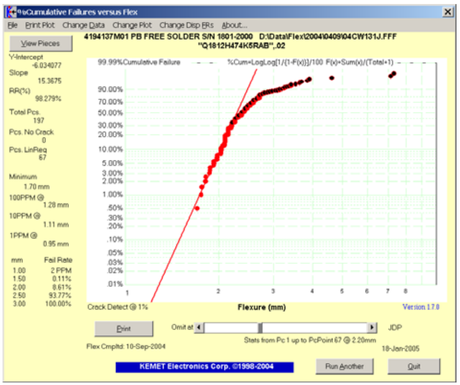


Figure 2. Weibull plot of 1812, .47 uF, X7R

The calculated failure rate line is also used to calculate the amount of flex required for 1 PPM, 10 PPM, and 100 PPM failure rates.

Because continuous data for each part is stored, there is the ability to review post test data to investigate different crack detection limits. Figure 3 shows the Weibull distribution of a single test. The analysis was performed at several different detection levels. There is little difference between 2.0% and 1.0% levels, but when .1% and .2% levels are analyzed, random noise in the measurement gives a false indication that a crack has occurred. Selecting the appropriate crack detection limit is important. If a chip with 10 layers is flexed and a crack occurs across a single layer will result in a capacitance loss of 10%. Likewise, a crack across a single layer of a capacitor with 100 layers will result in 1% loss in capacitance. And a capacitor with 500 layers or more, a crack through a single layer will result in less then .2% loss in capacitance. It is important to evaluate the design and data to determine the appropriate detection limit. After reviewing all the data, it was determined that a 1% detection limit was acceptable for all but 0603 case size for this study.

Detection Level Effects

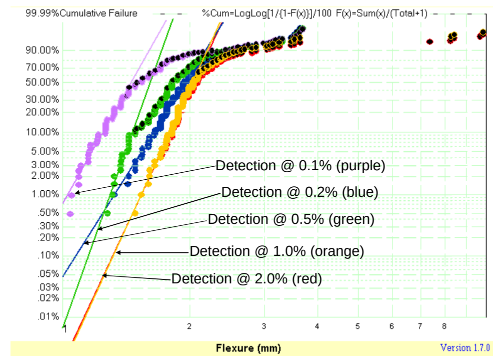


Figure 3. Different detection levels for the same part number

Figure 4 shows the capacitance verses millimeters of flexure for the two lowest readings for the C1812C474K5RAB part number. Because of the piezoelectric effect inherent in high K dielelectrics like X7R, Capacitance will decrease as physical stress is generated across the capacitor. The crack signature for piece #199 (on the right) shows that the capacitance actually increases when the crack occurs. This is the result of the flex crack only occurring in the margin area or in the solder fillet, but not in the active layers of the capacitors. The crack through the margin areas relieves the stress generate by the flexure, and capacitance is regained. It is also interesting to note that the original 2% limit did not detect the correct limit. With this 2% limit the flex crack was detected at somewhere around 2 mm, but on further investigation, the initial crack occurred at 1.75 mm as the mechanical stress is relieved.

Two Lowest Readings

1812C474K5RAB – Pb-Free Solder

Figure 4. Actual data for the two lowest readings.

Results

It is commonly believed that because the Pb-Free solders are less ductile[2] and therefore would be less likely to absorb the forces generated, causing a larger failure rate for a given flex amount. If the two Weibull plots are overlaid the comparison becomes much easier. For the 1812 .47 uF, X5R (Figure 5), it is apparent that the Pb-Free solder had better flex performance. This is contrasts common belief that Pb-Free solders would cause an increased failure rate at a given displacement.

1812C474K5RAB

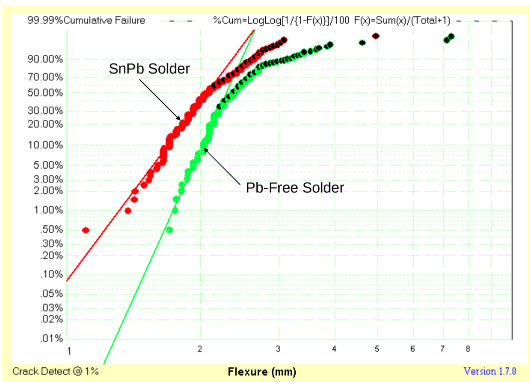


Figure 5. Flex performance 1812, .47 uF X7R, Pb-Free vs. SnPb Solders

When the two Weibull plots for the 0603, .22, X7R plots (Figure 6) are overlaid, shows that there is almost an equal performance between Pb-Free and SnPb solders. Since this is a high capacitance part number with many layers, the crack detection limit was set to .5%.

0603C224K4RAC

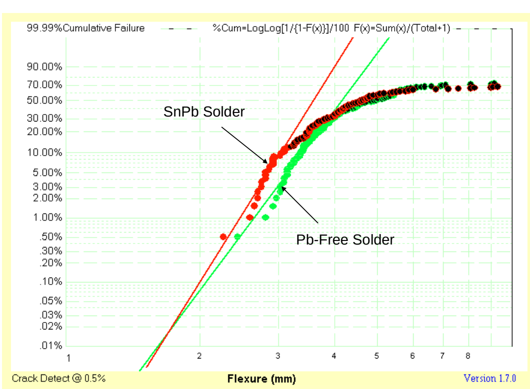


Figure 6. Flex performance 0603, .22 uF X7R, Pb-Free vs. SnPb Solders

Figure 7 shows the performance of an 0805, .22 uF X7R part. Although the Pb-Free parts performed better, the difference between the two plots at the calculated 100 ppm failure rate is less then .3 mm of flexure.

0805C224J3RAB

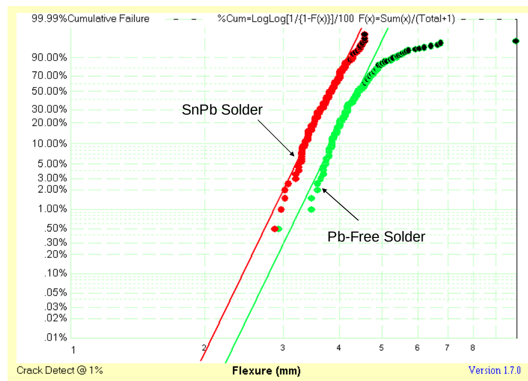


Figure 7. Flex performance 0805, .22 uF X7R, Pb-Free vs. SnPb Solders

The low capacitance 1206, 8.2 nF, X7R in Figure 8 shows an interesting result that for lower stress levels, the SnPb solders performed better. Because of the lower shallower slope of the Pb-Free line, above 2.6 mm of flexure stress, the Pb-Free soldered parts performed better.

1206C822K1RAC

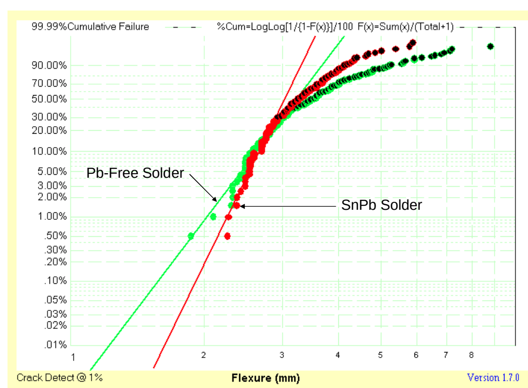


Figure 8. Flex performance 1206, 8.2 nF X7R, Pb-Free vs. SnPb Solders

The high capacitance 1206, .1 uF, X7R (Figure 9) showed that both performed equally well, with no discernable difference in flex performance.

1206C104J5RAB

Figure 9. Flex performance 1206, .1 uF X7R, Pb-Free vs. SnPb Solders

Summarizing the calculated flex to achieve the levels of PPM (Figure 10) shows that in one case the Sn-Pb solders performed better, and two other case sizes, the Pb Free solders performed better. The remaining test did not show a discernable difference. The red arrows notes where one solder had a clear advantage over the other.

Pb vs. Pb-Free (Low PPM)

PN	Solder	Pcs	Level	Minimum Detected (mm)	100-PPM FR (mm)	10-PPM FR (mm)	1-PPM FR (mm)
0603C224K4RAC	SnPb	193	0.5%	2.25	1.62	1.32	1.07
	PbFree	194		2.42	1.61	1.26	0.98
0805C224J3RAB	SnPb	200	1.0%	2.86	2.07	1.76	1.50
	PbFree	199		2.92	→ 2.37	→ 2.01	→ 1.71
1206C822K1RAC	SnPb	198	1.0%	→ 2.25	→ 1.63	→ 1.38	→ 1.17
	PbFree	197		1.86	1.22	0.95	0.73
1206C104J5RAB	SnPb	200	1.0%	1.48	1.13	0.97	0.83
	PbFree	200		1.43	1.08	0.90	0.76
1812C474K5RAB	SnPb	200	1.0%	1.10	0.80	0.62	0.48
	PbFree	197		→ 1.70	→ 1.28	→ 1.11	→ 0.95

Figure 10. Calculated PPM Failure Rates

Another way to look at the data is to calculate the failure rate at 1mm, 2 mm, and 3 mm of flexure. Using this method, only at lower stress levels and even then only half the trials we see an improvement of one soldering system over another. There is no clear cut winner.

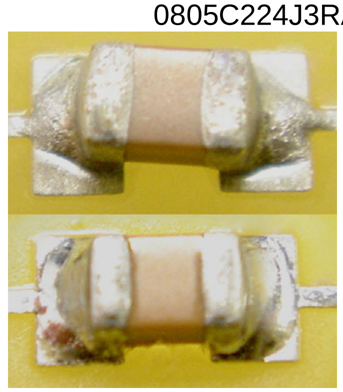
Pb vs. Pb-Free (Flex)

PN	Solder	Pcs	Level	RR (%)	Flex @ 1mm FR	Flex @ 2mm FR	Flex @ 3mm FR
0603C224K5RAC	SnPb	193	0.5%	94.05	<1 PPM	0.1%	8.9%
	PbFree	194		97.11	1 PPM	755 PPM	3.6%
0805C224J3RAB	SnPb	200	1.0%	98.33	<1 PPM	61 PPM	2.0%
	PbFree	199		96.40	<1 PPM	→ 9 PPM	→ 0.3%
1206C822K1RAC	SnPb	198	1.0%	96.39	→ <1 PPM	→ 0.19%	82%
	PbFree	197		97.13	16 PPM	0.90%	31%
1206C104J4RAB	SnPb	200	1.0%	98.56	→ 16 PPM	43.6%	→ 90%
	PbFree	200		97.89	37 PPM	→ 28.2%	92%
1812C474K5RAB	SnPb	200	1.0%	98.00	806 PPM	40.0%	93%
	PbFree	197		98.28	→ 2 PPM	→ 8.6%	93%

Figure 11. Calculated Failure Rates for Given Displacement

Upon investigating the solder joints, it was noted that the SnPb solder had a better wetting over the whole pad area when compared to the Pb Free solder (Figure 12). The reduced wetting with the Pb Free solders effectively reduces the pad width. Pad width is known to have an impact on flex performance [4]. A pad that is smaller then the termination width will have a better flex performance then a pad that is larger then the width of the termination. This effect of wetting may explain the improved performance Pb Free solder over the SnPb solder in some of the experiments.

0805C224J3RAB



Pb-Free Solder

SnPb Solder

Figure 12. Solder Fillets

Conclusions

There have been concerns that moving away from lead based solders to Pb-Free solders will increase the flex failure rate. In this paper we showed the results are mixed, and that there is no clear cut winner a majority of the time. With some cases sizes, the Pb-Free solders performed better and other parts the Sn-Pb parts performed better. And in one instance, the Sn-Pb solder parts perform better at low flex and at a higher level, the Pb-Free based solders perform better. There may be other factors that may affect flex performance, including wetting of the solder, and pad layouts, that may have an interaction and affect the flex performance.

References

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3. J. Berganthal, "Ceramic Chip Capacitors "Flex Cracks": Understanding Solution," KEMET Engineering Bulletin F2111. January, 1998

4. MuRata Manufacturing Co., Ltd, "Chip Type Monolithic Ceramic Capacitor Bending Strength Technical Data," issued 1994.