MECHANICAL PROPERTIES INVESTIGATIONS OF PB - FREE SOLDER ALLOYS

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In accordance with the requirements and restrictions of the EU concerning the use of toxic materials and substances (RoHS), alternative Pb - free solder alloys have been taken into consideration in the last few years. Solders implemented by means of traditional Sn - Pb eutectic and near - eutectic alloys reveal insufficiency in shear strength, resistance to creep and mechanical fatigue. Pb - free alloys based solders are expected to overcome the above mentioned problems and limitations. An investigation of the mechanical properties of different Pb - based and Pb - free solder alloy types was carried out. The aim was to examine the shear strength, thermal - mechanical fatigue, as well as resonant mechanical properties of different Pb - free and lead - based specimens, i.e. solder joints. Mechanical tests were performed under varying temperature and at given temperature cycles.

Keywords: Restriction of Hazardous Substances (RoHS), Pb - free solder alloys, lead contamination, thermal - mechanical fatigue, temperature cycles.

1. INTRODUCTION

Taking into account the requirements and restrictions of the EU concerning the use of toxic materials and substances (RoHS), as well as aiming at performance and reliability enhancement in electronics, alternative Pb - free solder alloys have been taken into consideration in the last few years [1], [2]. Besides toxicity of lead, there are other problems and phenomena concerning the mechanical properties of tin - lead (Sn - Pb) and Pb - based solder alloys. Solders implemented by means of traditional Sn - Pb eutectic and near - eutectic alloys reveal insufficiency in shear strength, resistance to creep and mechanical fatigue. Pb - free alloys based solders are expected to overcome the above mentioned problems and limitations. Moreover, solder joints should preserve solderability [3]. This would be an advantage and could serve as a prerequisite for applications such as nuclear and automotive electronics, avionics and process control, many of them associated with severe mechanical and thermal influences and overloads. Possible solder joint failures in such applications where reliability is crucial, could be fatal.

Besides improved mechanical properties, new lead - free solder alloys suitable for technological applications should have similar processing characteristics to Sn - Pb solders.

An investigation of the mechanical properties of different Pb - based and Pb - free solder alloy types was carried out. The aim was to examine the shear strength, thermal - mechanical fatigue, as well as resonant mechanical properties of different

Pb - free and lead - based specimens, i.e. solder joints. Mechanical tests were performed under varying temperature and at given temperature cycles.

Printed circuit board prototypes were designed especially for test purposes. The test vehicles are intentionally fabricated with different bearing surface finishes. They comprise traditional SMT packages for passive components, transistors and ICs, as well as classical through - hole technology components.

Investigation results are focused mainly on new Pb - free solder alloys. Pb contamination both on solder alloys and PCB bearing surface finishes has been analyzed.

The results of the overall investigation provide an adequate basis for the selection of a solder alloy with optimal mechanical and electrical characteristics.

Upon selecting a new solder alloy type, it is essential to examine the shear strength of the corresponding solder joint. A commonly used method for measuring the shear strength of solder joint specimens is the ring and plug test [4]. Normally, it provides reliable and consistent results. In accordance with the corresponding specimens, adequate modifications of the method are possible. Results from the ring and plug test could serve as a prerequisite for further examinations.

2. EXPERIMENTAL PROCEDURE

For experimental needs, two types of printed circuit board configurations with different topologies were selected. The first type, further named "T1", consists of a variety of pads and tracks with a regular structure. The second type, further "T2", comprises pads for mounting the most common SMT footprints: FLAT – 1206, 0805 and 0603; MELF; SOT 23 and SOT 89; SO; PLCC and TOFP. Hence all commonly used standard surface mounting devices are being used in our experiment – resistors, capacitors, transistors and integrated circuits.

An essential part of the experiments was the ring and plug test configuration, chosen in accordance with the experience of leading solder alloy manufactrurers, as well as research laboratories [5]. Rings and plugs, used in our experiment had the dimensions, depicted in Figure 1. The test configurations with the shown geometry were cleaned with an acid etch, rinsed with DI water and finally with alcohol.

Two types of solder alloys were used in our examinations. The first one is a classical Sn60Pb40 (ПОК 60) lead - based alloy with a melting temperature range 183 - 190 °C, whereas the second is a lead - free one - Sn95.5Ag3.8Cu0.7 with a melting temperature range 183 - 190 °C. Thermal cycle parameters were chosen as follows: upper temperature limit: +85 °C, duration: 25 minutes; lower temperature limit: -25 °C, duration: 25 minutes; 5 minutes holds at ambient temperature.

Shear strength was measured by means of a strain gauge transducer and a four - channel manual bridge compensator type MK from "HOTTINGER - BALDWIN - MEßTECHNIK". Measurements were performed at ambient temperature and at given temperature cycles.

Shear strength measurements results both for leaded and lead - free solder alloys, obtained from the test vehicles (i.e. test PCBs) are represented in Table 3and Table 4.

Tables 1 and 2 summarize measurement results, obtained from the ring and plug specimens.

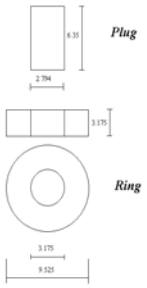


Figure 1

Table 1: Shear Strength measurements for Ring and Plug Test Specimens, Sn60Pb40 Solder Alloy

# Cycles	Shear Strength, [g]	Standard Deviation
0	16000	
2	15048	673.1657
3	14104	948.0028
4	11040	2149.535
5	8440	3123.349
6	9920	3051.336
7	11000	2837.094
8	12540	2629.048
9	10680	2515.117
10	9344	2524.813
15	15880	2691.083
20	11100	2584.769
25	9468	2579.468
30	9840	2538.086

Table 2: Shear Strength measurements for Ring and Plug Test Specimens, Sn95.5Ag3.8Cu0.7 Solder Alloy

# Cycles	Shear Strength, [g]	Standard Deviation
0	14376	
2	11932	1728.169
3	12408	1295.681
4	14760	1406.819
5	14800	1376.193
6	11400	1537.134
7	13944	1425.516
8	11948	1412.828
9	11280	1467.810
10	13780	1406.622
15	12748	1337.810
20	12216	1297.235
25	10664	1396.501
30	13112	1344.490

Table 3: Shear Strength measurements for PCB Test Specimens, Sn60Pb40 Solder Alloy

# Cycles	Shear Strength, [g]	Standard Deviation
0	16000	
2	9480	4610.336
3	13200	3270.800
4	13820	2710.492
5	13220	2347.739
6	9820	2500.200
7	11784	2302.601
8	13720	2176.774
9	13192	2044.770
10	11024	1998.759
15	14440	1982.062
20	13804	1916.506
25	9692	2026.362
30	13760	1973.386

Table 4: Shear Strength measurements for PCB Test Specimens, Sn95.5Ag3.8Cu0.7 Solder Alloy

# Cycles	Shear Strength, [g]	Standard Deviation
0	14376	
2	9528	3428.054
3	14176	2743.082
4	10040	2603.148
5	11280	2279.207
6	12280	2045.115
7	12480	1877.777
8	13868	1856.851
9	13020	1755.616
10	12580	1656.969
15	13700	1622.821
20	11280	1585.878
25	13180	1534.328
30	14320	1556.961

Figures 2 through 5 represent the absolute shear strength as a function of temperature cycles. The standard deviation of the shear strength versus the number of cycles is illustrated on figures 4 through 9.

3. DISCUSSIONS

Results from the PCB tests are very similar to those, obtained from the ring and plug test specimens. Both of them are consistent and dependable. Many research institutions have reportedly used copper or nichrome wires. In our experiments two types of wires were used. Prototype (PCB) boards were examinated by means of Ti - Cu - based wire, with good solderability, whereas ring and plug specimens were

tested with a copper wire. It should be noted, that a possible non - concentricity of the joints was not of a crucial importance for the experiments.

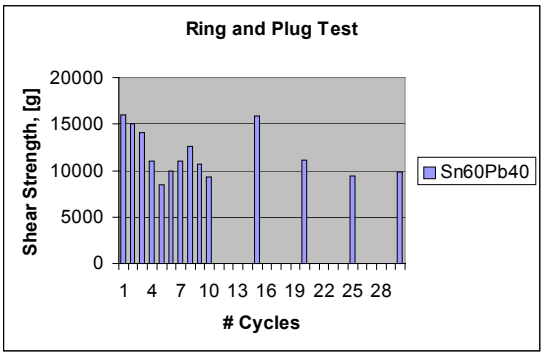


Figure 2

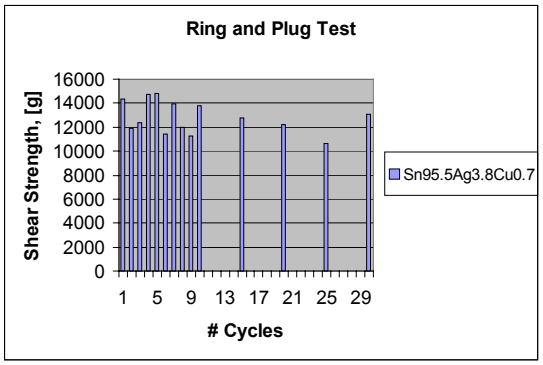


Figure 3

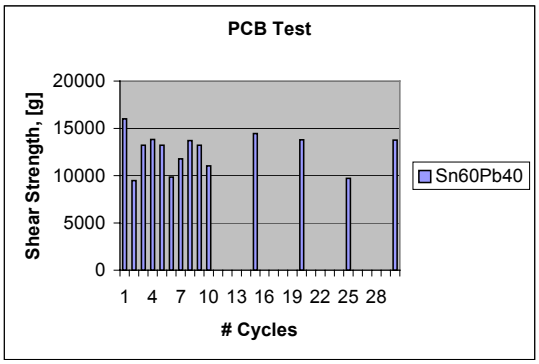


Figure 4

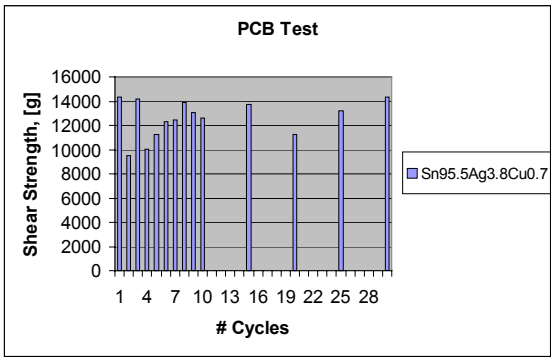


Figure 5

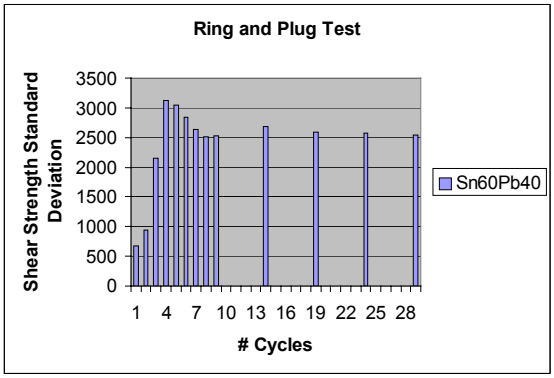


Figure 6

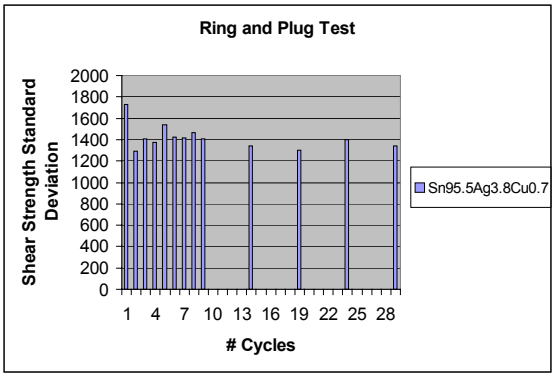
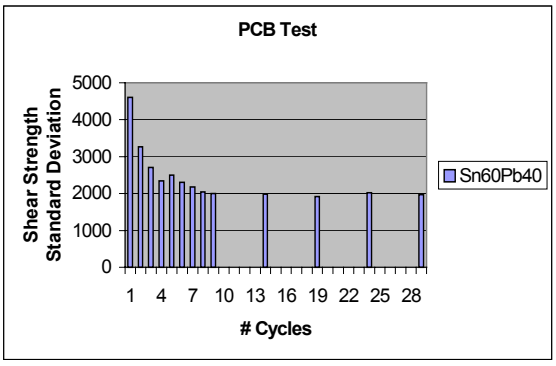
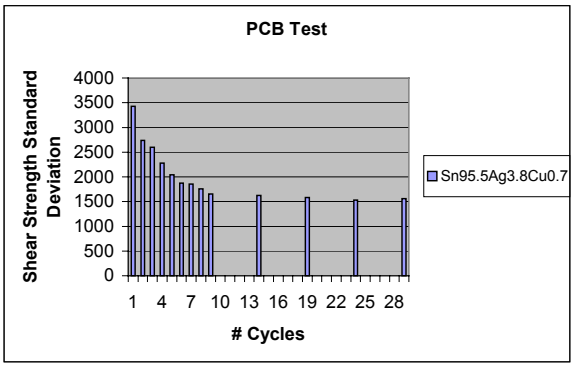


Figure 7





4. CONCLUSIONS

The shear sterngth of a classical leaded (Sn60Pb40) and a relatively new one lead - free solder alloy (Sn95.5Ag3.8Cu0.7**)** were examined. Tests were performed at ambient temperature and over a given temperature range and number of cycles. Results from both prototype boards and ring and plug specimens are very similar, which is an indication of a high reliability and consistency. Both specimen groups exhibit a decrease in shear strength after thermal cycling. The latter is more obvious for the classical leaded alloy. It could be expected, that newer lead - free solder alloys demonstrate better mechanical properties, such as shear and pull strengths. Further investigations are required to verify this hypothesis. Part of them, which are perfomed now, will be discussed in a future work.

5. REFERENCES

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