The Mechanical Analysis of Sn-Base Bump

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Abstract. In this paper, the mechanical properties of multiple Sn-based bump are compared. In the experiment, the bumps with different contents of lead, such as 90Pb10Sn of high lead, 60Pb40Sn of medium lead, 37Pb63Sn of low lead and Sn 1.8 Ag of lead-free were selected to investigate the influence of lead-tin content ratio on mechanical behavior. After the preparation of whole bumps, high-temperature storage tests were carried out for different bump, and then the shearing stress test through pushing ball was carried out for the all bump at different timeline, and the morphology of the shearing end face was observed.

1. Introduction
Tin-lead solder as electronic packaging interconnection material has been used for decades, because of its good surface quality, good weldability, and good mechanical, seismic, thermal cycle ability and electrical performance, can ensure the reliability of electronic products, widely used in national defense, high-tech and military production. As the most important connection material in flip chip, bump is conducive to supporting device structure and transmitting interconnection signal, and plays a decisive role in the welding effect of flip chip. However, the welding performance of convex point is affected by many factors. Lin Pengrong [1] found that the volume of bump had significant effect on the its mechanical performance. With decrease of bump volume, shear strength which bump could withstand would increase. Gu Bo [2] believed that after high temperature storage, the shear strength of bump was related to the thickness of interfacial metallic compounds. However, Shih [3] finished shear strength tests on the bump under multiple remelting and high temperature storage conditions and found that the shear strength of the bump did not change significantly under multiple remelting and aging conditions, because the shear fracture of the bump occurred near the interface of the solder matrix instead of at the interface. The material properties of the bump have great influence on the mechanical behavior of the bump. Therefore, this paper selects the bump with different tin content for experiment and studies the difference of mechanical properties.

2. The material and method of experiment
In this paper, four kinds of bump, including 90Pb10Sn of high lead, 60Pb40Sn of medium lead, 37Pb63Sn of low lead and Sn1.8Ag of lead-free, were selected for the test. The diameter of the bump was 120 μm. The size of chips used was 22*20mm and 725 μm in thickness. On the chip, and the diameter of UBM was 105μm. The structure of UBM was composed of Ti-Cu-Ni (0.1μm-5 μm-2 μm).

After the bump preparation test, the chips with bumps were used for high-temperature storage test. Five time nodes of 100h, 400h, 900h, 1600h and 2500h were prepared. The Conditions of high temperature storage test is 150℃. After high temperature storage, shear strength tests were carried out.
on bump with different time nodes of each component for shear strength data. The method of shear strength test is shown in figure 1(b). The height for shear strength test was set at 17 μm. The shear end face was observed by Scanning electron microscopy.

Figure 1. Bump morphology and shear test

3. Organization of the Text

3.1. Comparison of shear mechanical behavior of high lead, medium lead, low lead and lead-free bump

Figure 2 shows the trend of the shear strength of four types of bump with different Pb content after Reflow soldering. It can be seen that the shear strength decreases with the increase of lead content in bump. This is because the shear strength of Sn is 23MPa and the shear strength of Pb is 17MPa. Therefore, if the bump contains more Sn, the shear strength of the whole bump will be greater.

Figure 2. Schematic diagram of shear force as a function of lead content

3.2. Shear mechanical properties of bump under conditions of high temperature storage

As the results from figure 3, the shear strength always decreases with the increase of lead content in every period. In addition, as can be seen from the line diagram in FIG. 3, after reflow soldering, the shear strength decreases at the fastest rate in the early stage. From 100h to 1600h in high temperature storage, the rate of shear strength decreases most rapidly in the middle stage with the decrease of lead...
content. In the 2500h stage of high temperature storage, the shear strength decreases most rapidly with the increase of lead content in the later stage.

![Figure 3](image1.png)

**Figure 3.** Trend of shear force with lead content under different high temperature storage times

![Figure 4](image2.png)

**Figure 4.** Trend diagram of shear force after high-temperature storage of bumps with different compositions

FIG. 4 shows the trend of shear strength about four types of bumps after high temperature storage. Compared with shear strength for bumps, Sn1.8Ag has the largest shear strength, followed by 37Pb63Sn, 60Pb40Sn, and 90Pb10Sn has the smallest shear strength. It can be found that with the increase of Pb content and the decrease of Sn content, the shear strength at the bump presents a gradually decreasing trend.

For the SnAg bump, the shearing strength is monotonically decreasing with the increase of the high temperature storage time from 0h to 2500h. After reflow soldering, the shearing strength is 57.37g at the SnAg bump. After 2500h high temperature storage, the shearing strength is 50.52g, decrease by
11.94%. For the bump of 37Pb63Sn, 60Pb40Sn and 90Pb10Sn which containing lead, the shear strength first increases and then decreases in the early 900h of high-temperature storage. Such shear strength trends may be related to the thickness of intermetallic compounds. At the initial stage of high temperature storage, IMC with a certain thickness is conducive to improving the shear strength of bump. With the increase of high temperature storage time, IMC becomes thicker, and when the thickness is excessively larger, IMC will make the interface more brittle, thus reducing the shear strength. However, for the bump of 37Pb63Sn and 60Pb40Sn, the shear strength increases obviously in the later period of high temperature storage. This may be related to the interconversion between different nickel-tin compounds in the later stage of the reaction.

3.3. Comparison of shear mechanical behavior of high lead, medium lead, low lead and lead-free bump

FIG. 5 shows the shear fracture morphology after reflow soldering and high temperature storage about bumps with different components. First, SnAg bumps after reflow soldering, in early stage about shear failure, a large area of the viscoelastic flow can be seen. This same phenomenon was observed in shear face about 37Pb63Sn bumps. The bump of 60Pb40Sn and 90Pb10Sn, besides the viscoelastic flow area, also show a certain slip zone at the early stage of shear failure, which is a significantly plastic deformation behavior. This is determined by the properties of the material and environmental conditions. The melting point of Sn-base bump is very low (T/Tm > 0.6). Therefore, at normal temperature, it exhibits the characteristics of high-temperature state. Under a special strain rate, it tends to show some more obvious viscosity. This is a high temperature mechanical property for Sn-based bump.

On the other hand, in the late stage for shear failure, the bumps for SnAg, 37Pb63Sn and 60Pb40Sn have some pits in the shape of a tear. In addition, it can be seen that with the decrease of Sn content and the increase of Pb content, these tearing pits become larger and larger and occupy more and more area. This is the result of reduced ductility and increased brittleness of the solder with bump, and it is the reduction of the Sn component that results in reduced mechanical behavior of the solder at high temperatures. At the same time, in the early stage of high temperature storage after reflow soldering, Ni-Sn compound and Ag-Sn compound are easier to be generated with sufficient Sn content. Such intermetallic compounds have smaller particles in the initial stage and are prone to tear during the shear process.

With the increase of high temperature storage time, the shear failure behavior of different bumps of different components also changed. In the shear failure behavior of 2500h high temperature storage, different conditions also occur at the end of failure. The SnAg bump and 90Pb10 bump, macroscopically, at the end of shear fractures are characterized by elongated torn pits which belongs to the microporous aggregate fracture, and it is caused by the nucleation, growth and polymerization of the micropores. In the process of shearing, the bumps will form micropores, which will grow and connect with each other and eventually lead to fracture. The core of microporous initiation is usually impurity or second phase particle. Presumably, the SnAg pump, will not only produce nickel-tin compounds at the interfaces, and may also scattered with more Ag3Sn particles, these particles will form the core of the formation material, thus in particle shear dislocation, these dislocations are clustered around each other to produce a dislocation plug group, the top of which is located at the beginning of the interface transition. Due to the continuous accumulation of stress in the shear process, when it reaches a certain critical value, the interface will be pulled apart, and the initiation of microcracks or cavities, etc., will gradually converge with the occurrence of the shear process, and finally form fracture.
4. Conclusion

In this paper, the mechanical properties of bumps with different Sn contents are compared and investigated after high-temperature storage test by means of shearing and pushing the bump, and it is found that:

1. The content of Sn in the bump has a certain influence on the mechanical properties of bump. When the Sn content decreases, the shear strength at the bump presents a gradually decreasing trend.

2. As a whole, the shear strength at bumps increases firstly and then decreases with the increase of high-temperature storage time, and generally reaches the maximum value of shear strength at 100 hours of high-temperature storage.

3. Failure analysis of shear faces shows that the increase of high temperature storage time will lead to stronger brittleness of bumps. The opening in the shape of tear is the epitome of the microporous aggregate fracture, which is usually due to the second phase particles generated from the interface between the bumps.

References

[1] Lin Pengrong. Mechanical behavior of tiny lead-free solder joints with finite grain [D]. Harbin Institute of Technology, 2008.

[2] Gu Bo, Wang Wei, Tang Xingyong, et al. Analysis of Solder Joint Shear Strength of Sn-Ag-Cu and Sn-Ag-Bi Solder on Ni-P Substrate [J]. Journal of Fudan University (Natural Science), 2006, 45 (4): 501-505.

[3] Po-Cheng Shih, Kwang-Lung Lin. Correlation between interfacial microstructure and shear behavior of Sn-Ag-Cu solder ball joined with Sn-Zn-Bi paste. J Mater Sci. 2007 (42): 2574-2581.

[4] Wang Bo, Chen Shijie, Zhu Jinzhuan, et al. Study on shear mechanical properties of Sn single grain micro-bumps [J]. Electronics & Packaging, 2015 (6): 32-34.

[5] Yin Limeng, Michael Pecht, Wei Song, et al. Effect of solder joint height on mechanical behavior of micro-scale solder joints [J]. Transactions of the China Welding Society, 2013, 34 (8): 27-30.