TENSILE AND LOW CYCLE FATIGUE STANDARD TESTING FOR SOLDERS
- JSMS Recommendation -

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ABSTRACT

This paper proposes the tensile and low cycle fatigue standard testing for lead and lead-free solders. There is no standard method for solder testing, which causes a large scatter in material data of solders. The solder strength working group in the committee on high temperature strength of materials, Japan Society of Material Strength, issued the tensile and low cycle fatigue standards for solder testing. The standards recommend the casting method, specimen shape and heat treatment, strain rate and other testing methods needed for tensile and low cycle fatigue testing of solders. Benchmark testing using Sn-37Pb and Sn-3.5Ag solders, based on the standard methods, demonstrated that these standards generate the reliable data with a small scatter. The tensile and low cycle fatigue database was built based on the standards for the two solders.

KEY WORDS

Solder, Standard testing, Tensile test, Low cycle fatigue test, High temperature

INTRODUCTION

Solders have been used as a connection material for electric and electronic devices. Recent compact mounting technology raises the temperature of the devices which induces more severe damage into solder connections.

Material testing was carried out to obtain mechanical properties of solders but a large scatter in test results was reported due to the difference of testing method. A standard testing method has been needed for generating the stable and reliable material data. The solder strength working group in the committee on high temperature strength of materials, Japan Society of Materials Science, was organized in 1997 and published the two standards in 2000 based on the extensive experiments and discussion. This paper presents the outline of the tensile and low cycle fatigue (LCF) standard testing methods. The standards are applicable to lead and lead free solders in the temperature range of 233K-398K.

TEST SPECIMEN

Specimens have to be cast using a round hollow mould of type 304 stainless steel, cast iron or carbon with 15 mm wall thickness at 100 K higher temperature above the melting point of solders. Inner diameter of the mould should be 20 mm larger than the diameter at the gage section of specimens, which is to exclude the texture developed during casting from the gage section. Specimens are turned from the cast and should be annealed for an hour at 0.87 T/Tm for stabilizing the microstructure of solders ; T is the absolute annealing temperature and Tm the absolute melting temperature. This heat treatment was determined from the extensive aging experiments and corresponds with 5-10 years exposure at room temperature.

TENSILE TEST

Round bar specimen shown in Fig.1 was recommended for tensile testing. Temperature of specimens must be controlled during tensile testing because mechanical properties of solders are sensitive to testing temperature. The allowable variation of temperature along gage length is ±5.0K for the temperature range of 233K-302K and ±1.5K for 303K-398K. Temperature must be raised in more than 30 min and must be stabilized for 15 min before starting tensile test.

Extensometer is attached to the two pyramid collars of the specimen in Fig.1. The specimen with no collars was also recommended to tensile testing. In this case, careful extensometry is necessary not to make any scratch and flaw on the specimen surface when attaching an extensometer.

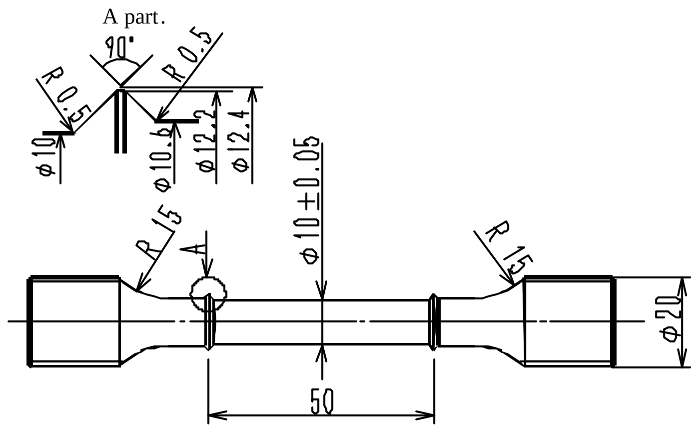


Figure 1: Shape and dimensions of the tensile standard specimen.

Strain rate in tensile test must be 2.0%/s to exclude creep deformation from tensile data. Figure 2 shows the effect of strain rate on the stress-strain relationship of Sn-37Pb used for deciding the tensile strain rate. Flow stresses at 0.5%/s and 1.0%/s are smaller than those at 2.0%/s and 10.0%/s and the flow stress at 2.0%/s is almost same as that at 10.0%. The experimental results indicate that the flow stress saturates at the strain rate of 2.0%/s and that the strain rate faster than 2.0%/s is necessary to exclude the creep deformation from the stress-strain relationship. Almost the similar experimental results were also obtained for Sn-3.5Ag at 398K. Based on the experimental results, the strain rate of 2.0%/s was employed as a strain rate for tensile testing in the standard.

Tensile test results be reported are Young's modulus, proportional limit, 0.02% and 0.2% proof stresses, maximum tensile strength and elongation. The 0.02% proof stress is newly defined be reported because solders have relatively small proportional limits and large strain hardening. The 0.2% proof stress is too high compared with the proportional limit in the case of solders.

LOW CYCLE FATIGUE TEST

Material preparation for LCF tests is exactly the same as that for tensile tests. Button head specimen with straight gage part shown in Fig.3 was recommended for LCF testing in the standard. An extensometry making no flaws on the specimen surface is essential in LCF testing to avoid crack nucleation from the flaws. To achieve this, two small pyramids of epoxy resin are put on the specimen surface and extensometer rods are pressed on the pyramids, Fig.4. Besides the LCF specimen shows in Fig.3, an hourglass shaped specimen was also recommended in the standard for high strain range test to avoid buckling of the gage part. Radial strain is controlled for the case of the hourglass specimen.

Strain controlled LCF test was recommended in the standard with a fully reversed triangular strain wave at a strain rate of 0.1%/s. Since solders significantly creep even at room temperature, creep damage is included into the LCF test results at this strain rate. However, LCF lives in symmetrical triangular strain waves are not reduced by lowering the strain rate so that the strain rate of 0.1%/s was recommended in the standard, considering that much faster strain rates have a difficulty in experiments. Temperature of specimens should be monitored and controlled during LCF tests. The allowable variation of the temperature along the gage length is ±5K. Temperature must be stabilized for 30mm before LCF testing.

The number of cycles to failure is defined as the cycle of 25% tensile stress drop from that at a half life, Fig.5. This method requires iteration in a couple of times but has an advantage to produce the same failure cycle for given data independent of researcher. The numbers in circles in the figure show the sequence of determining the failure cycle.

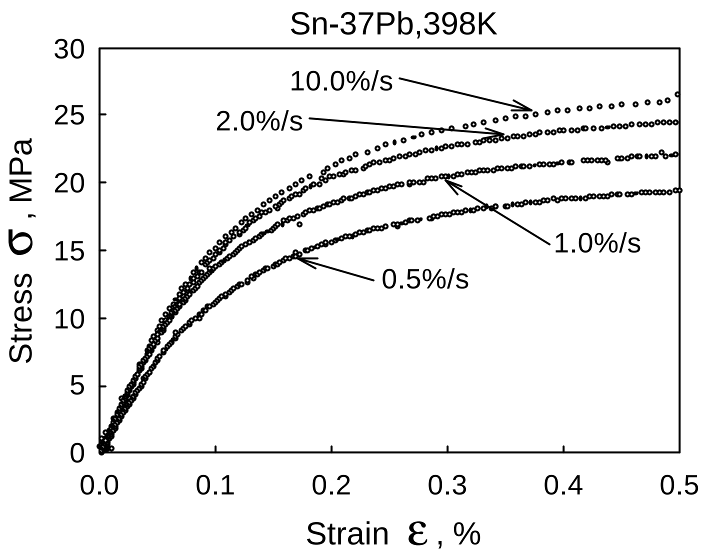
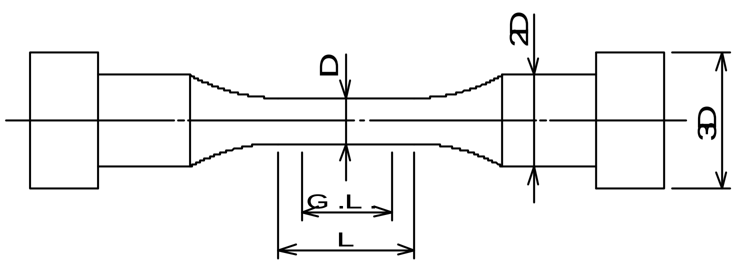


Figure 2:Stress-strain relationship up to 0.5% for Sn-37Pb at the four strain rates at 398K.



D , mm	G.L.	L
8 10	2D±D	G.L.+D

Figure 3:Shape and dimensions of the low cycle fatigue standard specimen.

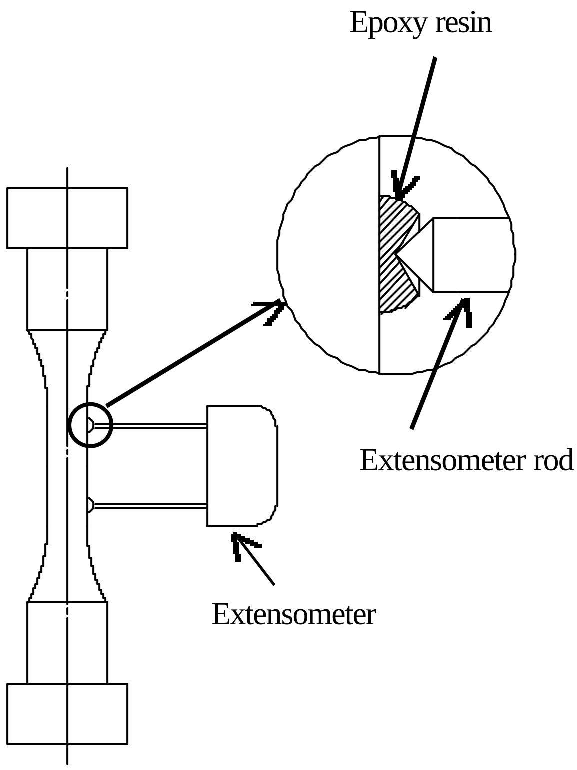


Figure 4: Extensometry using epoxy resin pyramids.

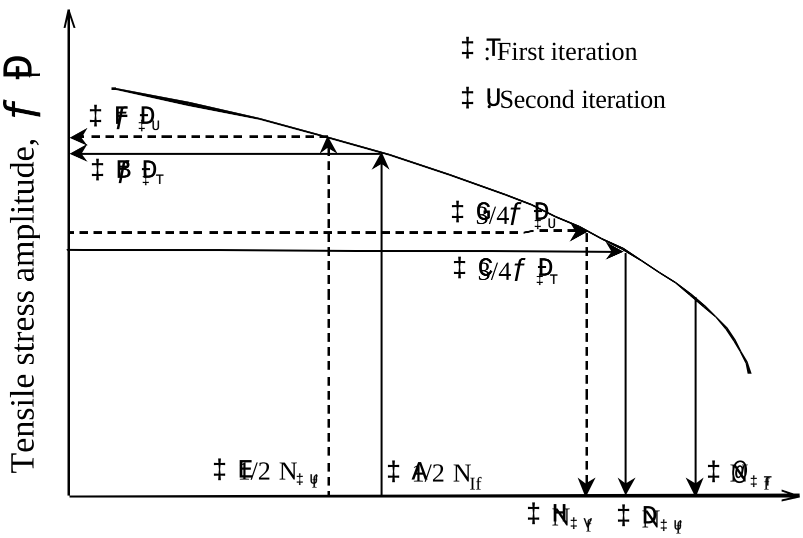


Figure 5: Calculation method of determining the number of cycle to failure.

LCF test results be reported are total strain range-failure cycle relationship, inelastic strain range-faiture cycle relationship, hysteresis loops and cracking site. The strain ranges at half life should be used as a representative value. Photographs of fracture surface is subsidiary recommended to report.

TENSILE AND LOW CYCLE FATIGUE DATABASE

Tensile and LCF database were generated for Sn-37Pb and Sn-3.5Ag solders based on the standards. The database contains, Young's modulus, yield stress, proof stresses, elongation, stress-strain curves at 233K, 253K, 313K and 353K. Low cycle fatigue data were also collected into the database for the two solders at 313K and 353K. The database has not only the failure cycle but also the variation of stress amplitudes and cyclic stress-strain relationships.

CONCLUSION

The outline of the tensile and low cycle fatigue standards for solder testing was presented. The standards recommend the specimen preparation, temperature control, strain rate, definition of failure cycle and so on. The standards were demonstrated to generate the stable tensile and low cycle fatigue data of solders. The database of Sn-37Pb and Sn-3.5Ag in tensile and low cycle fatigue was introduced.

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