# CREEP AND CREEP-FATIGUE STANDARD TESTING FOR SOLDERS - JSMS RECOMMENDATION -

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## ABSTRACT

This paper presents the creep and creep-fatigue standard testing methods for solders recommended by the subcommittee of the Japan Society of Materials Science. The collaborative experiments were carried out for Sn-37Pb and Sn-3.5Ag based on the standard methods. Stable creep and creep-fatigue data were obtained that demonstrated the standard methods generated the reliable creep and creep-fatigue data. Life prediction methods for creep and creep-fatigue were discussed based on the generated data.

## 1 INTRODUCTION

Mechanical testing for solders is one of the key technologies for the quality assurance of solder connections. Conventional mechanical testing that have been used for steels and heat resistant alloys yields a large scatter of the mechanical data of solders. Main causes of the large scatter are considered to be resulted from the difference of microstructure and creep effect. Solder specimens are usually made by casting and the different casting condition results in the different microstructure which leads to the different mechanical properties. Melting temperature of solders is relatively low so that solders exhibit significant creep at even room temperature. This creep effect leads to different mechanical properties if tests are performed at different strain rates.

The Solder Strength Subcommittee was initiated in the Japan Society of Materials Science (JSMS) in 1997 and the committee published Tensile Standard Testing (JSMS [1]) and Low Cycle Fatigue Standard Testing (JSMS [2]) in 2000 and Factual Database on Tensile and Low Cycle Fatigue Properties of Sn-37Pb and Sn-3.5Ag Solders (JSMS [3]) in 2001 as Phase I activity. The committee continued the activity to develop creep and creep-fatigue standard testing methods and their database as Phase Ⅱ activity.

This paper outlines the creep and creep-fatigue standard testing methods proposed by the subcommittee as a fruit of Phase Ⅱ activity. The standards recommend material preparation, testing machine, testing method, life prediction method and the other things necessary for the testing. The creep and creep-fatigue database for Sn-37Pb and Sn-3.5Ag is also published following the standard testing method.

## 2. 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 than the melting point of solders. Inner diameter of the mould should be 20 mm larger than the diameter at the gage section of a specimen, which is designed to exclude the texture developed during casting from the gage portion. Specimens are turned from the cast and should be annealed for an hour at 0.87 T/Tm to stabilize 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 to 5-10 years exposure at room temperature (JSMS [1]).

## 3. CREEP STANSARD TESTING

Round bar specimen shown in Fig.1 is recommended for creep testing. The specimen has two collars where extensometer is attached. Temperature of the specimen has to be controlled because the creep deformation and creep rupture time is very sensitive to testing temperature. The maximum allowance of the temperature variation along the gage length should be within ±5.0 for 263-302K and ±1.5K for

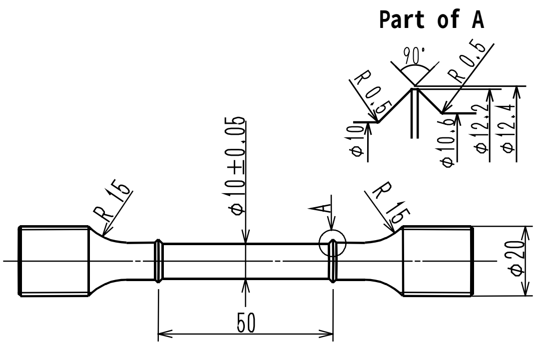
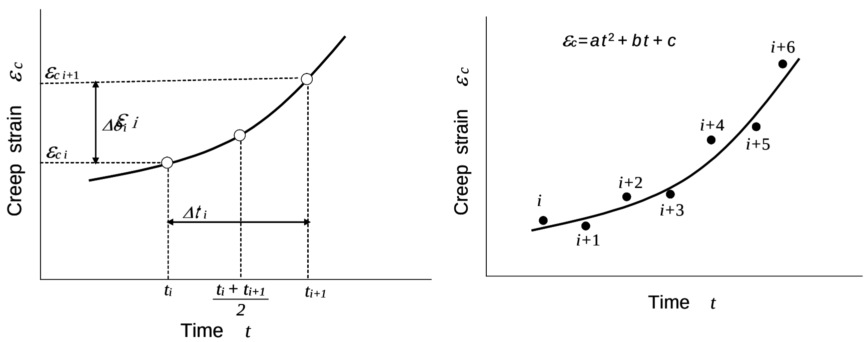



Fig.1 Shape and dimensions of creep specimen.




(a) Secant method

(b) Quadric method

Fig.2 Method for calculating creep strain rate.

303-398K. Temperature must be stabilized for 4-24hrs before starting creep test.

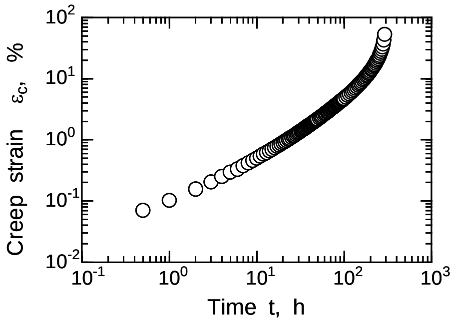
Extensometer is attached to the two pyramid collars of the specimen in Fig.1. The specimen with no collars is also recommended for creep testing. In this case, careful extensometry is necessary without making any flaw on the specimen surface when attaching the extensometer.

Creep strain data must be measured more than 500 points to draw a creep curve. Two methods were recommended to obtain the minimum creep strain rate. One is the secant method where the gradient of two neighbored data is used as shown by the following equation, Fig.2 (a)

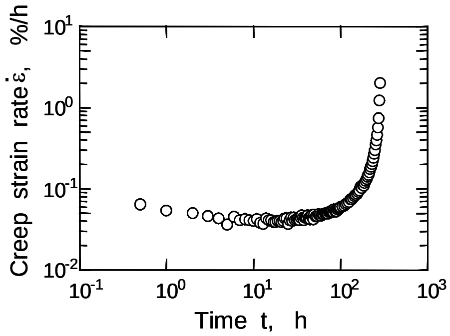
$$\dot{\varepsilon}_{\frac{t_1+t_{1i+1}}{2}} = \frac{\Delta\varepsilon_i}{\Delta t_i} \qquad (1)$$

The other method is to approximate a creep curve with a quadric using a least square method. The secant method is firstly recommended to apply because this method has an advantage that the method accurately represents the actual creep deformation behavior and the method is simple. However, the method sometimes yields a large scatter of strain rate in the cases that the two-neighbored data are too close or have a scatter. To obtain a stable creep strain rate insensitive to the scatter of neighbored data, the standard recommended to use a quadric curve with a least square method as illustrated in Fig.2 (b). The number of data recommended for the least square method is 7. This method is used for the case that the secant method gives a large scatter of creep strain rate.

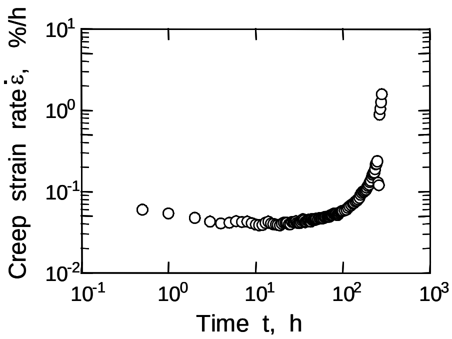
Figure 3 depicts the creep strain rate for the creep curve Fig.3 (a) by the secant method Fig.3 (b) and by the quadric method Fig.3(c). There is no large difference in this case whereas somewhat smaller scatter is found in the secant method, Fig.3 (a). However, the quadric method gives creep strain rate with a smaller scatter if the number of the creep strain data is small. The minimum creep strain rate is defined as the




(a) Time t, h

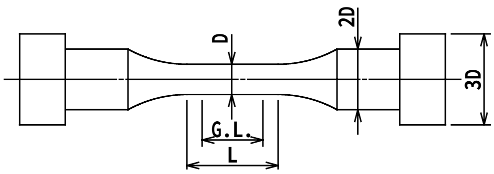



(b) Secant method




(c) Quadric method

Fig.3 Creep strain rate.




| D, mm | G.L. | L |
|---|---|---|
| 8~10 | 2D±D | G.L.+D/2~D |

Fig.4 Shape of creep-fatigue specimen

minimum value of the strain rates shown in Figs.3 (a) and (b).

4. CREEP-FATIGUE STANDARD TESTING

Figure 4 illustrates the shape of creep-fatigue specimen. The specimen shape is the same as recommended in the low cycle fatigue standard (JSMS [2]) but the specimen is allowed to have a relatively short parallel length down to G.L.+D/2 because a specimen that has a long parallel part sometimes showed barreling or buckling caused by severe deformation of the gage part.

In the collaborative creep-fatigue tests, five strain waves shown in Fig.5 was used, where (a) is the fast-fast (PP), (b) fast-slow (PC), (c) slow-fast (CP), (d) slow-slow (CC) and (e) tension-hold (TH) strain waves. In the strain waves, the strain rate in the fast parts was 0.1%/s and that in the slow strain parts was 0.005%/s. Figure 6 shows the creep-fatigue lives of Sn-37Pb and Sn-3.5Ag at 313K in the five strain waves. The figures clearly show that the CC and TH waves give a little reduction of fatigue life compared with the PP wave. Small reductions were found in these strain waves but the fatigue lives remained within a factor of two band from the PP data for the two solders. The PC and CP strain waves give a large reduction of fatigue lives from the PP data. The PC data locate around a factor of 6 band and the CP data around a factor of 30 band from the PP data for Sn-37Pb. The same trend is found for Sn-3.5Ag whereas the reduction is somewhat smaller than Sn-37Pb. The smaller creep-fatigue lives in the CP wave than the PC lives means that the tensile creep damage is more detrimental than the compressive creep damage.

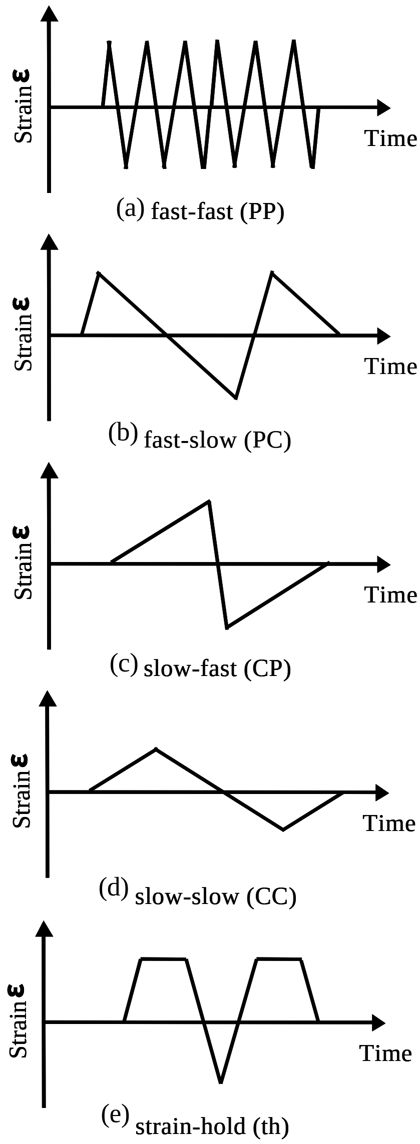



Fig. 5 Five strain waves for creep -fatigue tests.

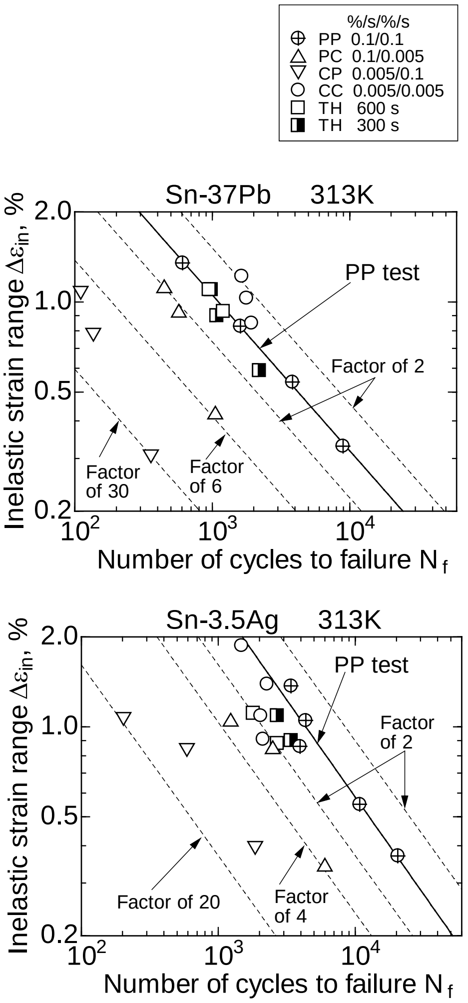



Fig. 6 Correlation of creep-fatigue lives in the five strain waves with inelastic strain range.

The conventional creep-fatigue damage laws were applied to the data shown in Fig.6. They were the linear damage rule, the frequency modified fatigue life, the ductility exhaustion model and the strain range partitioning rule. Those rules have been successfully applied to the heat resisting alloys and steels. However no rules did not predict the creep-fatigue lives of the solders within a small scatter. One result is shown in Fig.7, where the lives predicted by the linear damage rule were compared with the experimental lives. The rule is expressed as,

$$\Phi_f = \sum \frac{N}{N_f}, \quad \Phi_c = \sum \frac{t}{t_r} \qquad (2)$$

$N_f$ is the number of failure cycles in PP test, $N$ that in creep-fatigue test, $t_r$ the creep rupture time. The linear damage rule significantly underestimate the creep-fatigue lives for Sn-3.5Ag as seen in Fig.7. The maximum scatter reached to 30 for Sn-3.5Ag. The same trend was observes in Sn-37Pb. The other rules stated above also did not correlate the creep-fatigue lives with a small scatter of which the graphical representation is not made here. Therefore, the standard recommended to use the following method to predict the creep-fatigue lives of solders.

Inelastic strain range can be used for predicting the creep-fatigue lives in CC and TH waves based on the PP data. For predicting the creep-fatigue lives in PC and CP lives, the tensile and compressive strain rates that the actual solder connections experience should be used to generate the creep-fatigue lives for the life prediction. This method is the most reliable from considering the present state of research on creep-fatigue life prediction of solders.

Recently, a new creep-fatigue life prediction method was proposed based on the grain boundary sliding model (Shiratsuchi [4]). The model is expressed by the following equation.

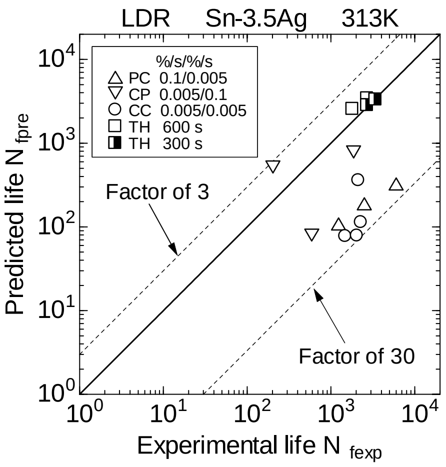



Fig. 7 Correlation of creep-fatigue lives with the linear damage rule.

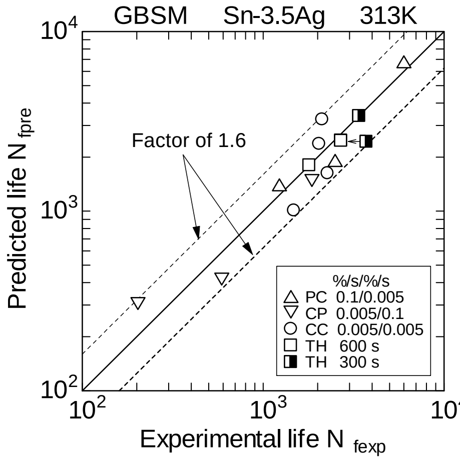



Fig. 8 Correlation of creep-fatigue lives with the grain boundary sliding model.

$$\Delta\varepsilon_{in} = 207\left[N_f\left\{\left(\frac{\dot{\varepsilon}_p}{\dot{\varepsilon}_c}\right)^{0.341} + \left(\frac{\dot{\varepsilon}_p}{\dot{\varepsilon}_c}\right)^{0.832} + 0.697\dot{\varepsilon}_c^{-0.157} + \frac{1}{0.710e^{-8.09t_H} + 0.290}\right\}\right]^{-0.639} \quad (3)$$

In the equations, $\Delta\varepsilon_{in}$ is the inelastic strain range, $\dot{\varepsilon}_p$ the fast strain rate, $\dot{\varepsilon}_c$ the slow strain rate and $t_H$ the length of hold-time. Figure 8 compares the creep-fatigue lives predicted by the grain boundary sliding model. The model predicts the creep-fatigue lives in the four strain waves within a small scatter.

## CONCLUSION

This paper stated the standard testing methods of creep and creep-fatigue for solders. The standards recommended the specimen preparation, creep and creep-fatigue testing methods, creep and creep-fatigue prediction methods and other detailed things relating to creep and creep-fatigue testing. The methods were verified to yield the stable creep and creep-fatigue data from the collaborative experiments.

The authors would like to express their gratitude to the members of the solder strength subcommittee for their intensive efforts for the collaborative activaties.

## REFERENCE

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