Study on Establishing Creep Testing Method using Miniature Specimen of Lead Free Solders

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Abstract. To evaluate a size effect on creep properties of solders, we establish a creep testing method including machining method for miniature size lead free solder specimen. Creep tests ware carried out at 313 K under several stress level. Major findings in this study are as follows;

(1) By means of numerical controlled desktop type precision lathe, the method for machining the miniature specimen having various shape & dimensions of the solder was established.

(2) Creep testing method using the miniature specimen was established.

(3) It was found that the creep lives of miniature size specimen always had larger scatter and shorter lives than that of large size specimen.

(4) It was also found that the creep strain rate of miniature size specimen always varied wider than that of large size specimen.

(5) Plenty of defects – small voids which size were obeyed double exponential distribution – cause the scatter of creep properties of miniature size specimen.

Introduction

The solder has low-melting temperature and easy creep deformation at room temperature. So, creep characteristic for thermal stress has influence on reliability of connection part. Former study about creep characteristic of solders have been carried out using bulk specimen that cross section diameter of 7~10 mm. Although, dimensions of actual solder connection part size of high-density packaging board are hundreds of micro meter. Therefore, it is very doubtful whether applicability of bulk specimen creep data to miniature connection part of solders is valid or not. On the other hand, for the protection of human health and the environmentally, the toxicity of lead becomes a topic. As a matter of fact, by a "RoHS" ordinance put into effect on 1st July 2006, have been prohibited a manufactured goods containing a toxic substance such as lead, mercury, cadmium and so on.

The objective of this study is establishing the creep testing method using miniature specimen. For this purpose, miniature specimens with 0.5 mm of cross section diameter were machined and creep tests were carried out by using a lead-free solders.

2. Experimental procedure

2.1 Materials

The solder used in this study was lead free solder 'Sn-3.0Ag-0.5Cu' made by 'Senju Metal Industry Co.'.[1] Table 1 and Table 2 show chemical compositions and several properties of solders, respectively.

Table 1. Chemical compositions of lead free solder

Materials	Chemical composition , wt %					
	Sn	Ag	Pb	Sb	Cu	Bi
Sn-3.0Ag-0.5Cu	Bal.	3.01	–	0.027	0.50	0.0016

Table 2. Several properties of lead free solder

Materials	Melting point T_m	Tensile strength σ_B	Elongation ϕ	Young's modulus E
Sn-3.0Ag-0.5Cu	493 K	53.5 MPa	46 %	41.6 GPa

2.2 Specimen

Figure 1 shows shapes and dimensions of miniature creep specimen. Two types specimen were produced in this study. One is a specimen with collars to observed creep strain, and the other is a specimen without collars. Fig. 2 shows photographs of miniature creep specimen that produced in this study. The desktop type precision lathe

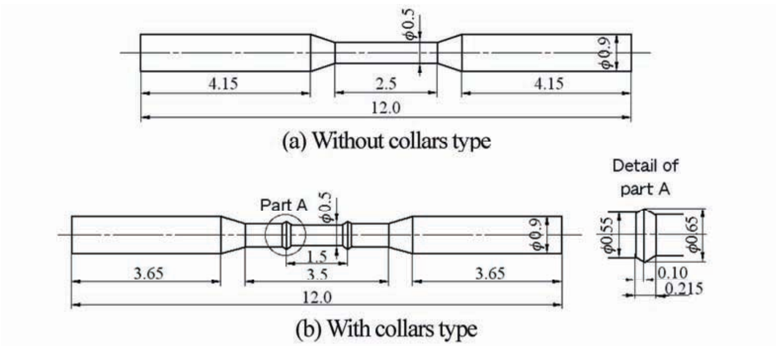


Fig. 1. Shapes and dimensions of miniature creep specimen

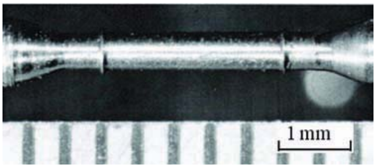


Fig. 2. Photograph of miniature creep specimen

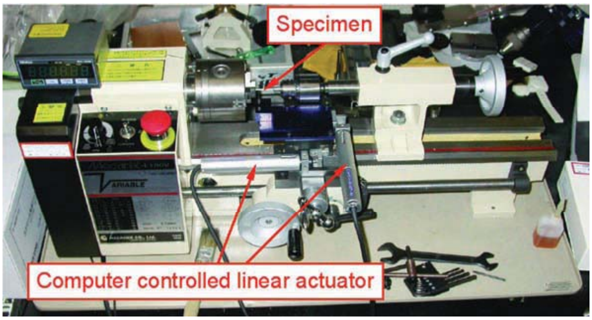


Fig. 3. Computer controlled desktop type precision lathe

made by 'Kotobuki Boeki Co.' was used in machining the miniature specimen. The lathe was improved to numerical control type that use personal computer as shown in Fig. 3. After machining, specimens were heat-treated at 87±1% of the melting points in absolute temperature (= 429 K) for one hour to stabilize the microstructures.[2]

2.3 Testing equipments

In this study, miniature creep testing machine that loading capacity of 10 N was newly developed. Fig. 4 shows assembly drawing of creep testing machine. This machine is a direct loading type. Testing machine has hour meter to detect creep rupture time. As shown in Fig. 5, for keeping constant temperature during creep tests, testing machines were set in an environmental test chamber made by 'Espec Co.'. Creep deformation can be observed by using a long working distance type stereoscopic microscope with high resolution CCD camera. The deformed specimen's images during creep tests were saved to a personal computer at constant interval.

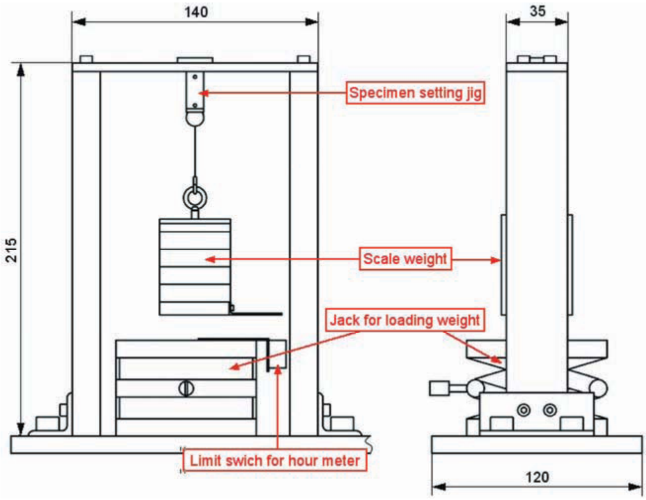


Fig. 4. Assembly drawing of miniature creep testing equipment

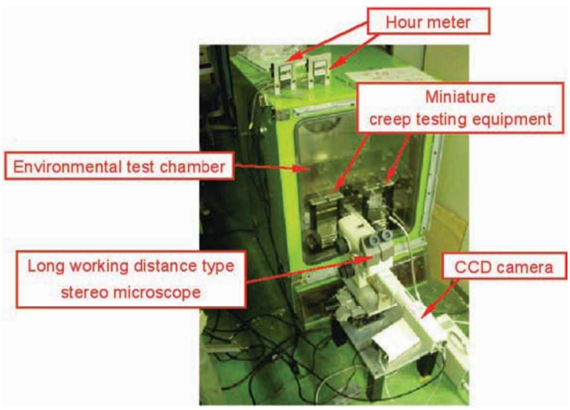


Fig. 5. Whole view of creep testing system

3. Results and discussion

3.1 Creep rupture properties

Creep tests were carried out under applied stress of 13 MPa, 15 MPa and 17 MPa. Testing temperature was 313K in all cases. Fig. 6. shows test results. The open circle symbols indicate the test results of present study. The symbols with an arrow mean truncated data. The open- and solid star symbols show reference data obtained by using large size and miniature size specimen, respectively [3], [4]. To evaluate the scatter of rupture time, we used 9~10 specimens at s = 13 MPa and 15MPa. The scatter distribution were approximated by using the 3-parameter Weibull distribution function (Fig. 7(a) and (b)).

$$F_t(t_r) = 1 - \exp\left\{-\left(\frac{t_r - c}{b}\right)^a\right\}$$

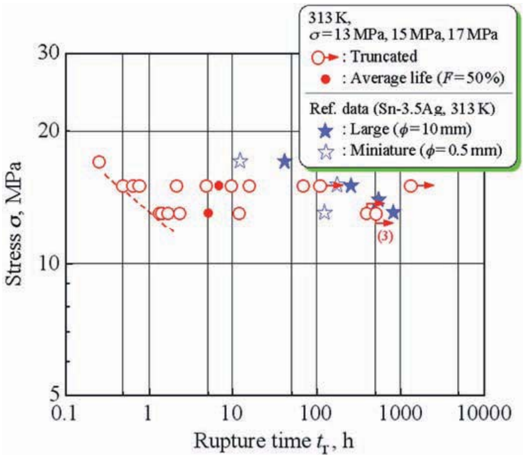


Fig. 6. Relationship between creep stress and rupture time

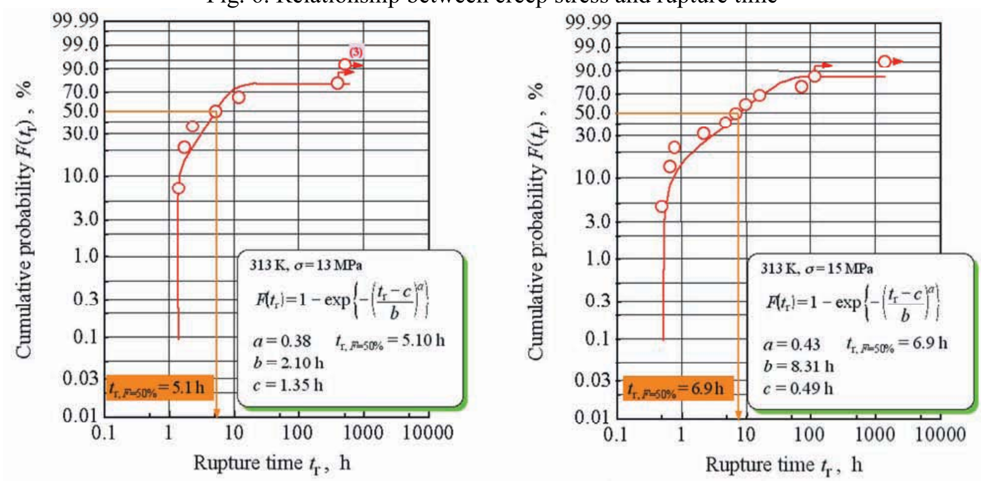


Fig. 7. Probability distributions of creep rupture time (Weibull probability graph)

where, a, b and c is shape-, scale- and location parameter, respectively. Average rupture time at cumulative probability of 50 % and minimum rupture time are indicated in Fig. 6 with small solid circle and broken line, respectively. By comparing these results, it is noticed that rupture time obtained by miniature specimen are always shorter than that of bulk specimen, and there are large scattering over “factor of 100”.

3.2 Creep deformation

Figs. 8(a)-(d) show example of series photographs for creep deformation. Necking started at early stage of creep life, and finally, specimen broken with chisel edge type rupture.

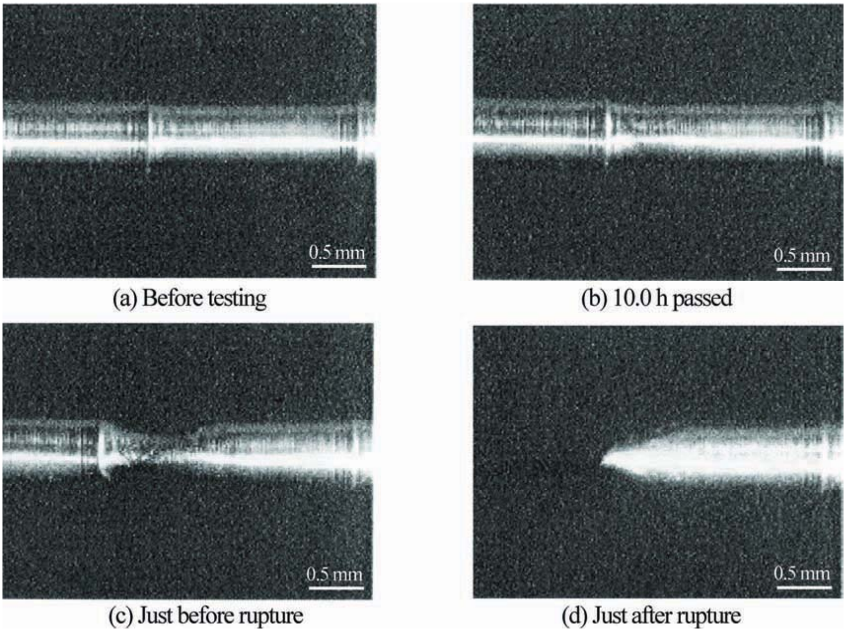
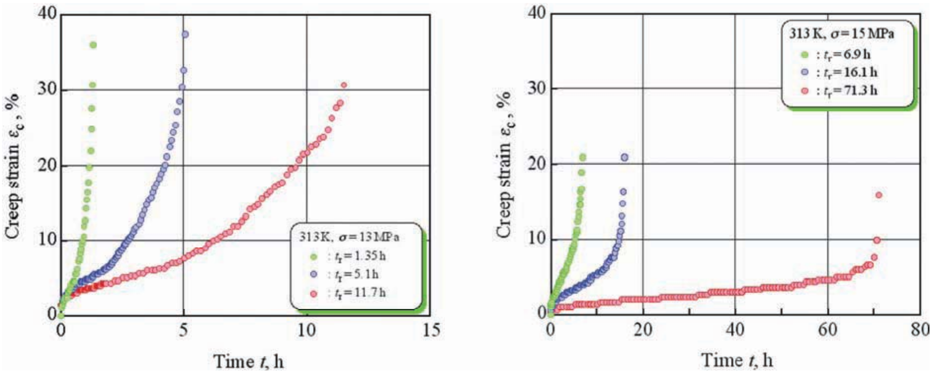


Fig. 8. Example of series photographs of deformed miniature specimen (σ= 15 MPa, t_r = 16.1 h)

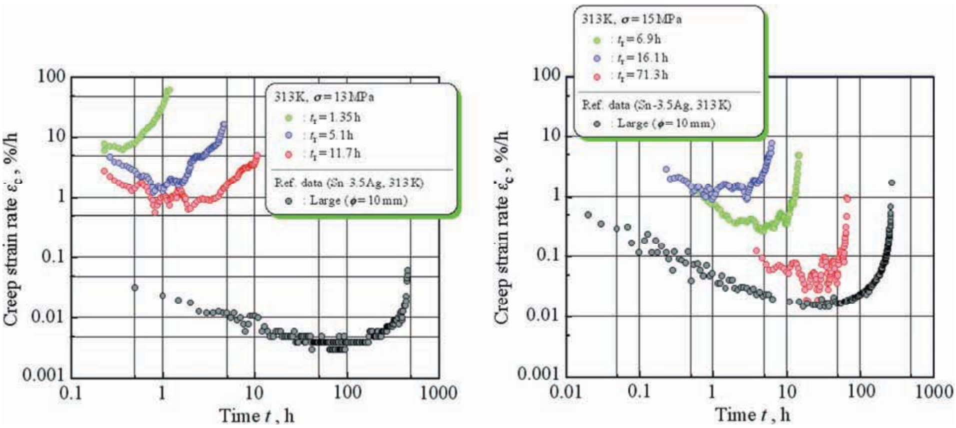
3.3 Creep strain and creep strain rate

Figs. 9(a) and (b) show relationship between creep strain and time of σ= 13 MPa and 15 MPa, respectively. As same as a rupture time, in cases of miniature specimen, there are large scatter in the creep strain. Figs. 10(a) and (b) show relationship between creep strain rate and time of σ= 13 MPa and 15 MPa, respectively. Creep strain rate were calculated by using Least square method – which was recommended method on the JSMS standard [2] – using thirteen point data for approximating a creep curve. Small black circle symbols in Fig. 10(a) and (b) indicated creep strain rate of lead free solder’s large size specimens in Ref. [4]. It is obvious that creep strain rate obtained by miniature size specimens are always much faster than that obtained by large size specimens. Fig. 11 shows relationship between minimum creep strain rate and rupture time. In case of miniature size specimen, it is characteristic that creep strain rate is different, even if the applied stress is same. However, as shown in Fig. 11, in the case of miniature size specimens, the minimum creep strain rate were dependent on the creep rupture time. In this study, we obtained a convenient relational expression; $\dot{\varepsilon} \times t_r^{1.43} = 11.9$.



(a) σ= 13 MPa (b) σ= 15 MPa

Fig. 9. Relationship between creep strain and elapsed time



(a) σ= 13 MPa (b) σ= 15 MPa

Fig. 10. Relationship between creep strain rate and elapsed time

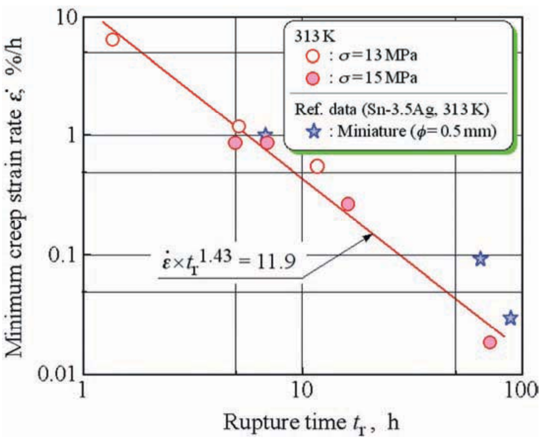


Fig. 11. Relationship between minimum creep strain rate and rupture time

3.2 Effects of defect size on creep rupture time

As shown in Fig. 12, wire solder have a large number of small defects. Fig. 13 shows a relationship between cumulative probability and defects size. The cumulative probability can be approximated by using a double exponential distribution function. By using this distribution function, the Monte-Carlo simulations were carried out for estimating the defects size in a miniature size and/or large size specimen. From the simulation, it was confirmed that a ratio of defect size to a bulk specimen's diameter is less than 6 ~ 7 %. Although, it was found that the ratio of defect size to a miniature specimen's diameter ranged widely from 10 % to 40 %. Therefore, it is considered that the short rupture time and a large scatter observed in a miniature specimen is originated in wide difference of net stress as shown in Fig. 14, schematically.

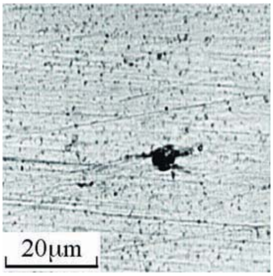


Fig. 12. Example of defect in solder

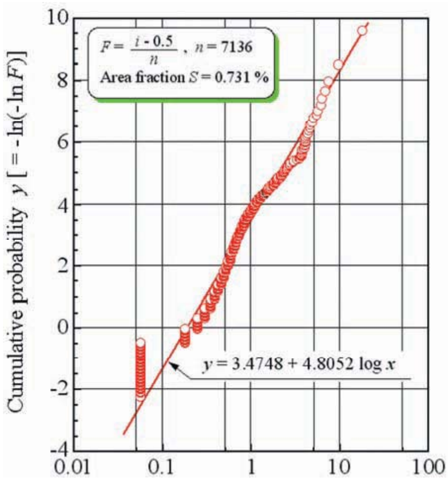


Fig. 13. Defects size distribution
(Double exponential distribution graph)

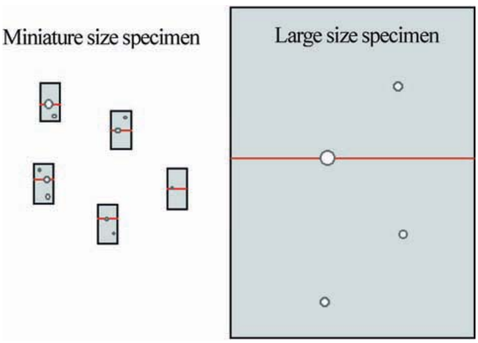


Fig. 14. Schematic illustration for defect size effects on both size specimen

Conclusions

Major findings in this study are as follows;

(1) By means of numerical controlled desktop type precision lathe, the method for machining the miniature specimen having various shape & dimensions of the solder was established.

(2) Creep testing method using the miniature specimen was established.

(3) It was found that the creep lives of miniature size specimen always had larger scatter and shorter lives than that of large size specimen.

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(5) Plenty of defects – small voids which size were obeyed double exponential distribution – cause the scatter of creep properties of miniature size specimen.

Acknowledgment

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References

[1] http://www.senju-m.co.jp/j/product/ecosolder/index.html

[2] "Standard Creep Testing for Solders" , The Society of Materials Science, Japan (2004).

[3] "Miniature creep of Sn-Pb and Sn-Ag solders", Masao Sakane, Akio Takada, Hiroshi Danjyo, Yutaka Tsukada, Hideo Nishimura, Proc. of the 9th International Conference on the Mechanical Behavior of Materials (ICM9), May 25-29, 2003, Geneva, (CD-ROM) (2003).

[4] "Factual Database on Creep and Creep-Fatigue Properties of Sn-37Pb and Sn-3.5Ag Solders", The Society of Materials Science, Japan (2004).