Experimental analysis of creep behaviour of solder alloys at near eutectic point by using indentation test

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Abstract: *Eutectic solder alloys are widely used in the microelectronics industry. The phenomenon of creep and its mechanisms are important aspects that influence the performance of solder alloys. During the last two decades, a Pb - solder alloys is fast becoming a reality in lead free electronic products due to harmful caused as toxic material to environment and health, international legislative pressure and marketing. The replacement of Sn - Pb alloys with Sn-Ag-Cu (SAC) alloys needs reliable results for assuring the usage of this solder joints material in electronic industry. In this paper has been studied the creep behaviour of a group of alloy in the system Sn-Ag-Cu (SAC) near the eutectic point. In this research work we have used three different alloy samples which are 95, 5Sn-3, 8Ag-0,7Cu, 96, 5Sn-3, 0Ag-0,5Cu and 95, 46Sn-3, 58Ag-0,96Cu. Indentation technique has been conducted to study the creep behaviour of these three SAC alloys by determining the creep parameters at different temperatures. The temperature used was at room temperature 30^{o}C until 100^{o}C and the stress used was 64MPa-178MPa for the indentation diameter 1 mm and 0.5 mm. The experimental method and results of the creep parameters like activation enthalpy Q, the stress exponent n of the power law model and the parameter of the material A were briefly described in this paper. From the creep curves, constructed for alloys and considered loads, the values of creep stress exponent n were determined for the studied alloys.*

Keywords*:* CREEP MECHANISMS, SN-AG-CU ALLOYS, CREEP STRESS EXPONENT *n*, INDENTATION TECHNIQUE.

1. Introduction

The purpose of this research work has been focused on the experimental study of the creep behaviour of a solder alloys at near eutectic point and in particular the determination of the reinforcement exponent *n* which is depending on the SAC microstructure.[1,2]

Indentation technique has been applied to study the creep behavior of this SAC alloys by determining the creep parameters at different temperatures. Based on it, the experimental study of the creep behavior through indentation instrument has become a useful technique to explore the dependence on time on the mechanical properties of materials and structures. Furthermore, the usage of the indentation technique is driven by the fact that this method requires minimal amount of study material as well as minimum sample preparation in comparison of the conventional method such as tensile test.

Three different samples such as 95,5 Sn-3,8Ag-0,7Cu, 96,5Sn-3,0Ag-0,5Cu and 95,46Sn-3,58Ag-0,96Cu have been used for determination of the creep behavior of SAC solder alloys at near eutectic point by using indentation test. The temperature used was at room temperature 30^{o}C until 100^{o}C and the stress used was at 64MPa until 178MPa for 1mm and 0.5 mm diameter. A constant load has been applied to the sample surface with a suitable penetrator for a period of time which largely exceeds the duration of the standard hardness test. The experimental method and results of the creep parameters like activation enthalpy Q, the stress exponent n of the power law model and the parameter of the material A were are estimated in this paper.

The goal of our experiments was to determine the creep behavior near room temperature depending on the microstructure of solder alloy Sn-Ag-Cu. The experimental method used was the indentation creep test. Indentation creep has become a useful technique for exploring the time-dependent mechanical properties of materials and structures and its recent advance is driven by the potential applications to small material structures, since the indentation creep experiment is inherently simple, accurate, and require minimum sample preparation (compared with the conventional methods such as the tensile test) [1,3,4].

2. Metallographic preparation of samples and experimental procedures

2.1 Metallographic preparation of samples

The materials were used in this study are Sn based solder alloys: 95,5Sn-3,8Ag-0,7Cu, 96,5Sn-3,0Ag-0,5Cu and 95,46Sn-3,58Ag-0,96Cu. The samples were produce in *Felder GmbH* company in Germany. The samples are prepared accordign to the standart ASTM 26 [5,6].

In figure 1 are presented the diagram for binary composition and the SAC ternary phase diagrame, that we have pointed the chemical positon for our samples and on the table 1 are presented the phase content of SAC ternary phase diagram[7,8].

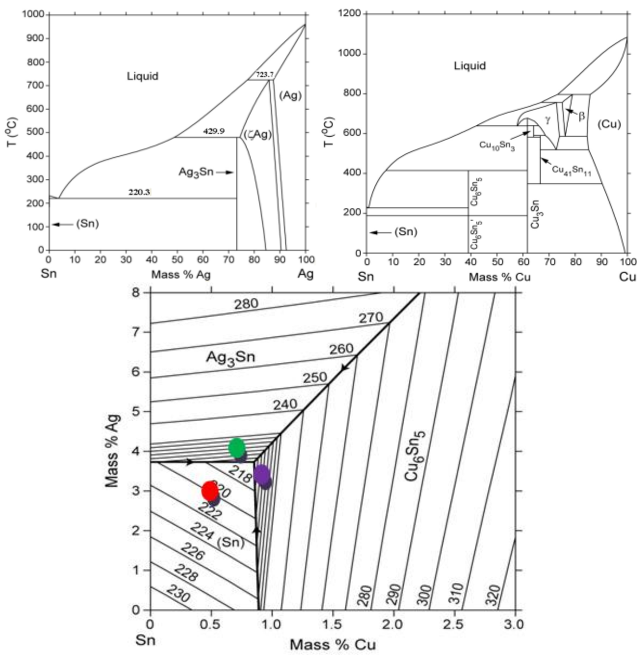


Fig.1 a)*Sn-Cu binary phase diagram ; b)Sn-Ag binary phase diagram ; c) Sn-Ag-Cu ternary phase diagram (Sn-rich corner); d) Sn-Ag-Cu ternary phase diagram [NIST]*

Table 1: *Phase contentof SAC ternary phase diagram*

Phase	*Density*	*Content of elements in phase%*			*Content of phases% mass*	*Content of phases% volume*
		Sn	*Ag*	*Cu*		
β-Sn	*7,31*	*100,00*	*0,00*	*0,00*	*92,65*	*94,14*
Ag3Sn	*9,93*	*26,83*	*73,17*	*0,00*	*4,89*	*3,66*
Cu6Sn5	*8,28*	*60,89*	*0,00*	*39,11*	*2,45*	*2,20*

2.2 Experimental procedures

The main objective in a creep test is to measure how a given metal or an alloy will perform under constant load, at constant temperatures. The indentation creep test (impression test) is schematically illustrated in Fig.2. A flat bottomed cylindrical punch of diameter is pushed into the creep test specimen under an applied pressure F load. The punch diameter used was 1mm, 0.75mm and 0.5 mm with a chemical composition of stainless steel and was used for creep test for temperature in the range 30^{0}C until 100^{0}C. The depth of indentation h of the punch is monitored as a function of time. The impression creep curve is derived by plotting the indentation versus time [9, 10,11,12].

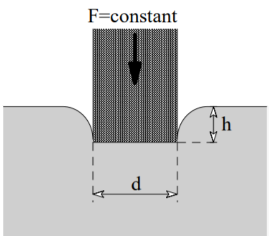
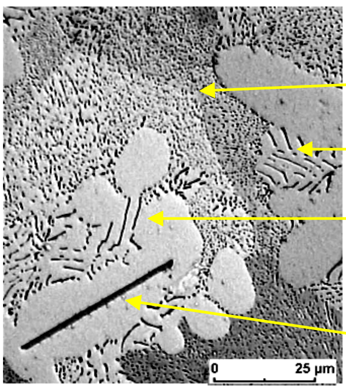


Fig.2 *Schematic of the indentation creep test [NIST].*

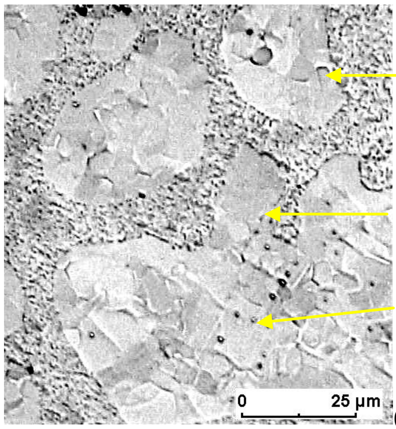
3. Experimental results

In SAC alloyes the formation of intermetallic compounds between the primary elements Sn, Ag and Cu in properties of alloys (Ag_3Sn,Cu_6Sn_5,Cu_3Sn). Precipitated particles of intermetallic compounds have a higher strength than the bulk of the material and also improve the fatigue resistance of solder alloys [13,14,15].

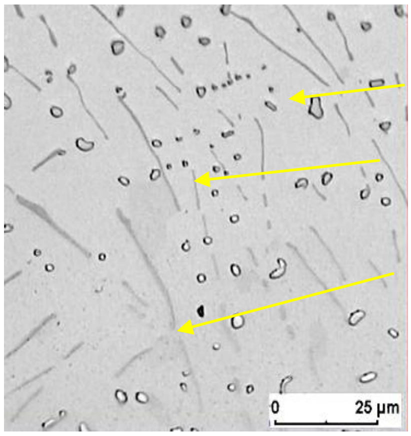
The metallographic examinations were carried out with the Neophot 30 light microscope (Carl Zeiss Jena) with a built-in digital color camera (JVC TK-C1381) carried out. The pictures were taken with the standard magnifications 25, 125, 250 and 500 times (figure 3). The microstructure of 95.5Sn-3.8Ag-0.7Cu contains the following ingredients: Base-Sn (1); Ag_3Sn lamellae which were even before thermal treatment near Sn dendrites (2); fine Ag3Sn particles which have been constituents of binary and tertiary eutectic and partially coagulated (3) and thicker Cu_6Sn_5 particles as constituents of ternary and coagulated eutectic (4).



(a)



(b)



(c)

Fig.3*Microstructure of solder alloys performed with Light Microscope: a) 95.5Sn-3.8Ag-0.7Cu; b) 96.5Sn-3.0Ag-0.5Cu; c) 95.46Sn-3.58Ag-0.96Cu*

The temperature used was in the range 30^{0}C - 100^{0}C and the stress used was 64MPa-178MPa for 1mm, 0.75 mm and 0.5mm diameters. The following relations were used for all experiments (Table 2):

Table 2: *The relations used for our experiments: X-h-ε-έ*

X – chronometer value	
h – indentation	h=X/10
ε – deformation	ε = h/d
έ – creep rate	έ=Δh/Δt

The following graphs shows the results obtained from the experiments performed for the samples used in this study, depending on the *creep displacement dependence* **(**Table 3):

Table 3: *The creep displacement for three functions: έ-σ-T*

Creep displacement		***σ***	***Temp***
creep rate vs. deformation	*έ= function (σ)*	*102 MPa*	*TR,*
		77 MPa	*50°C ,*
		64 Ma	*80°C,*
		178 Mpa	*100°C*

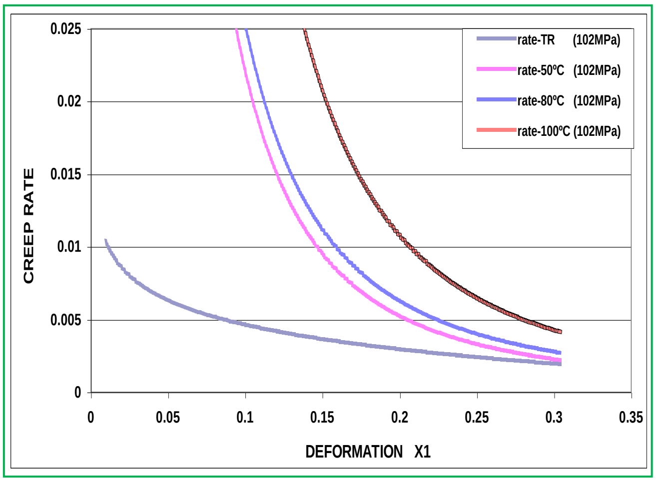


Fig.4 *The graphics show the functions for the dependence of creep rate vs. strain ε=funx(σ) for RT,50,80,100 °C , diameter 1mm and stress 120MPa*

The graph in figure 4 show the dependence of creep rate vs. strain ***ε=f (σ)*** for a load 800gr applied at the different temperature (**RT, 50, 80, 100**), the diameter **d=1mm,** and the stress **σ = 102MPa.**

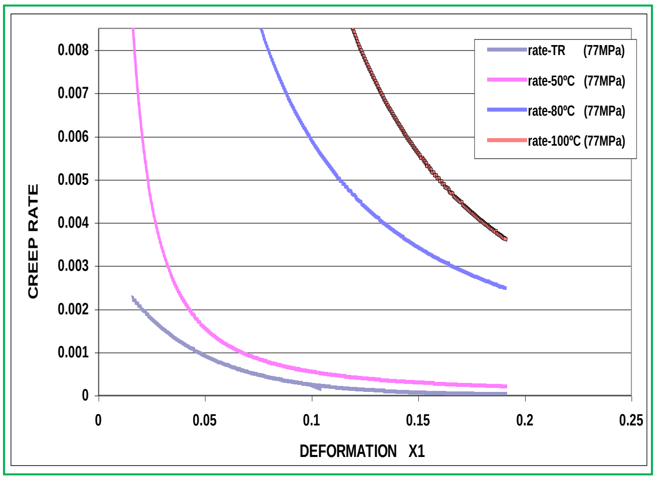


Fig.5 *The graphics show the functions forthe dependence of creep rate vs. strain ε=funx(σ)for RT,50,80,100 °C , diameter 1mm and stress 77 MPa*

The graph in figure 5 show the *dependence* of creep rate vs. strain ***ε=f (σ)*** for a load 800gr applied at the different temperature (**RT, 50, 80, 100**), the diameter **d=1mm,** and the stress **σ = 77 MPa.**

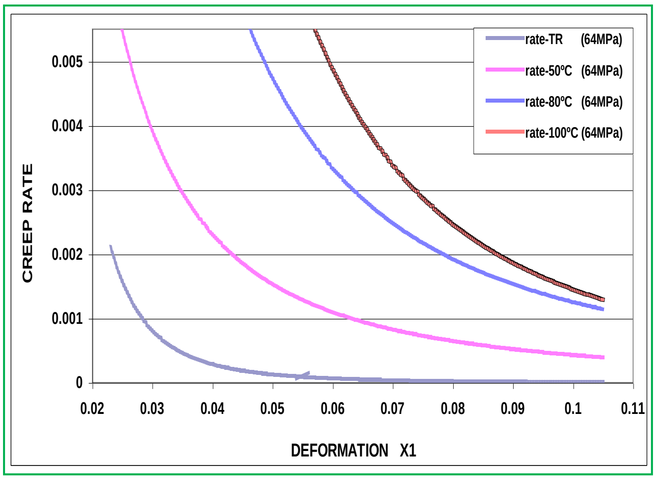


Fig.6 *The graphics show the functions for the dependence of creep rate vs. strain ε=funx(σ)for RT,50,80,100 °C , diameter 1mm and stress 64 MPa*

The graph in figure 6 show the dependence of creep rate vs. strain ***ε=f (σ)*** for a load 800gr applied at the different temperature (**RT, 50, 80, 100**), the diameter **d=1mm,** and the stress **σ = 64 MPa.**

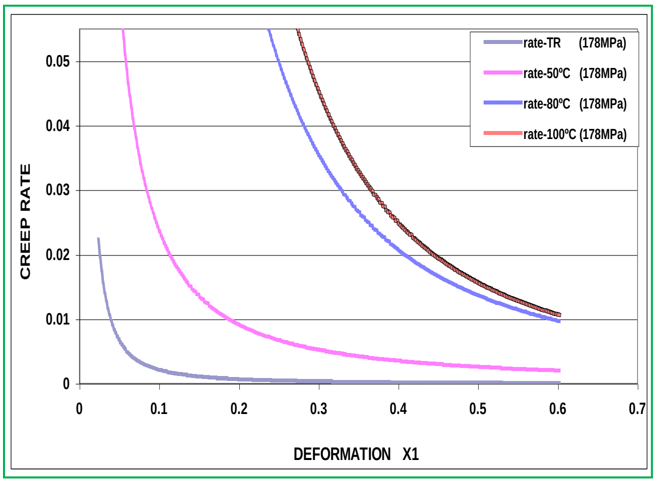


Fig.7 *The graph show the dependence of creep rate vs. strain ε=funx(σ)for RT,50,80,100 °C , diameter 0.5mm and stress 178 MPa*

The graph in figure 7 show the dependence of creep rate vs. strain ***ε=f (σ)*** for a load 800gr applied at the different temperature (**RT, 50, 80, 100**), the diameter **d=0.5mm,** and the stress **σ = 178 MPa.**

4. Discussions and Conclusions

From our experimental study we can draw the following interpretations and conclusions:

1. The realization of the experiments tests of the creep evaluation of the SAC alloys in the laboratory equipment with indentation test. The equipment was initially adjusted for the upper stress limit (with Fe sample) and for the lower stress limit (with Sn sample).

2. For the case of pure Sn sample, the exponent of stress was also evaluated, according to the law of power, which resulted: *n = 2.4*. This value is between the interval which are evaluated from other authors in different study referred to creep behavior SAC (1.8 - 2.8).

3. For the alloy 96,5Sn-3,0Ag-0,5Cu-IIRL we found *n = 6.3* which can be said to show a higher creep resistance compared to the samples with long-term aging, probably due to intermetallic particles in large quantities that can be in the microstructure.

4. For the alloy 95, 5 Sn-3, 8Ag-0,7Cu we find the exponent *n = 5.6* for the aging time at 200 ° C of 170 hours, and *n = 7.5* for the aging times 340 and 510 hours.

5. Even in our study it has been found that with the increase of the applied strain the minimum velocity of creep deformation increases, in the second stage.

6. For a more complete interpretation of the creep behavior of SAC bonds it is necessary that the study proceed with the evaluation of the size of the intermetallic particles as well as the nature of the matrix particleboards.

7. Future work will be focused on the investigation of microstructures of our samples for evaluation of precipitates into the matrix.

10. Acknowledgment

The authors gratefully acknowledge the TU Bergakademie Freiberg, Germany for providing the SAC alloy samples used in this work, part of the project ‘Network of Materials Science and Engineering (NMST)’supported by DAAD and Polytechnic University of Tirana for partial funding of this study.

9. Conflict of interests

The author would like to confirm that there is no conflict of interests associated with this publication and there is no financial fund for this work that can affect the research outcomes.

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