Lead-Free Microstructure Evolution Studies

Lead Free: Constitutive Equations

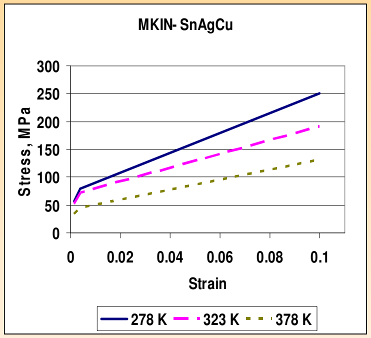
Time-Dependent Creep

Model	Reference	Equation	Composition	Constants			
Power Law Creep	Wiese	$\dot{\varepsilon} = C_1\left[(C_3\sigma)\right]^{C2}\exp\left(\frac{-C_4}{T(K)}\right)$		C1 [s^{-1}]	C2	C3 [MPa^{-1}]	C4 [K]
			SnAg4.0Cu0.5	$2x10^{-21}$	18	1	9995
			SnAg3.5	$5x10^{-6}$	11	1	9028
	Darveaux Garofalo Creep fitted by Krishna		SnAg3.5	$9.64x10^{-6}$	6.5	1	6557
	Amagai	$\dot{\varepsilon} = A(\sigma)^n e^{-\left(\frac{Q}{R_g T}\right)}$	SnAg3.5Cu0.75	Q/R	N		A
				13180	15.795		$4.77x10^{12}$
Garofalo Creep. Sinh		$\frac{d\gamma_s}{dt} = C_1\left[\sinh(C_2\sigma)\right]^{C_3}\exp\left(\frac{-C_4}{T}\right)$		C1 [s^{-1}]	C2 (1/MPa)	C3	C4
	Darveaux		SnAg3.5	18(553-T)/T	1/(6386-11.55T) psi	5.5	5802 K
	Hong		SnAg3.5	96437	0.103	6.65	9562 K
	Lau		SnAgCu	441000	$5x10^{-9}$ Pa	4.2	5412 K
Anand's model	Amagai	$\dot{\varepsilon}_p = Ae^{(-Q/RT)}\left[\sinh\left(\varsigma\frac{\sigma}{s}\right)\right]^{1/m}$ $\dot{s} = \left\{h_o\left\|1-\frac{s}{s^*}\right\|^a .sign\left(1-\frac{s}{s^*}\right)\right\}.\dot{\varepsilon}_p$ $s^* = \bar{s}\left[\frac{\dot{\varepsilon}_p}{A}e^{(Q/RT)}\right]^n$	*For SnAg3.5Cu0.75*				
			Q/R (1/K)	8400			
			A (1/sec)	4.61×10^6			
			ς	0.038			
			m	0.162			
			$\bar{s}$ (MPa)	1.04			
			n	4.60×10^{-3}			
			a	1.56			
			h_o (MPa)	3090			

- It is very difficult to find consistent data among literature, or one source for all the properties needed.

Time-Independent Plasticity

Solder	Elastic Modulus (GPa)	CTE (ppm/K)
63Sn37Pb	30	24
SnAgCu	50	20
SnAg	48	21



Lead Free: Fatigue Life Prediction

- Most fatigue tests in literature are based on tests of bulk solder samples, not testing of actual packages.

Power-law

$$N_f = \left(\frac{D}{C}\right)^{\frac{1}{n}}$$

OR

Crack Growth Rate

$$\frac{da}{dN} = C(D)^n$$

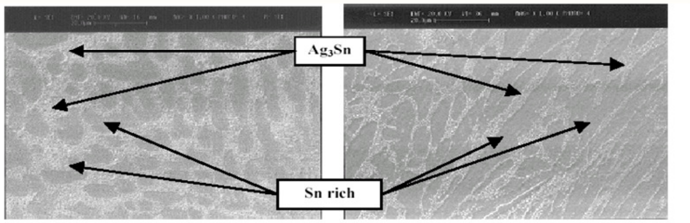
Solder	D	C	n	source
63Sn37Pb	$\Delta\varepsilon_{in}$	.46	-.42	Dasgupta
Sn3.9Ag0.6Cu	$\Delta\varepsilon_{in}$	2.75	-.45	Dasgupta
63Sn37Pb	W	28.6	-.45	Dasgupta
Sn3.9Ag0.6Cu	W	227	-.58	Dasgupta
Sn3.9Ag0.6Cu	$\Delta\varepsilon_{plastic}$	3.7	-1.37	Kanchanomai

Solder	D	C	n	source
63Sn37Pb	ε_{accin}	2E-6	1	Wiese
Sn3.9Ag0.6Cu	ε_{accin}	5E-6	2	Wiese
63Sn37Pb	W	8E-7	1	Wiese
Sn3.9Ag0.6Cu	W	2.5E-8	1.8	Wiese

All tests were isothermal low cycle fatigue

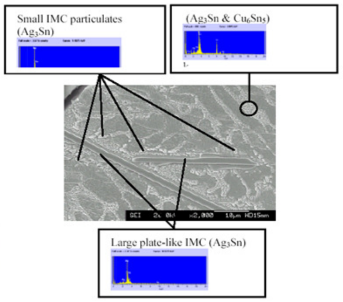
Microstructure Evolution

- Constitutive and predictive models do not take the microstructure information into consideration
- Current efforts are directed towards determining evolution of microstructure during field-use and during accelerated thermal cycling for SnAgCu alloy systems
- Microstructure consists of Ag_3Sn and Cu_6Sn_5 Inter Metallic Compounds (IMC) dispersed in β-Sn matrix



- As soldered specimen does not have any preferred orientation
- Shear loading (at 125°C) leads to coarsening of the Ag_3Sn IMC and the Sn rich structure and Ag_3Sn particulates have preferred orientation

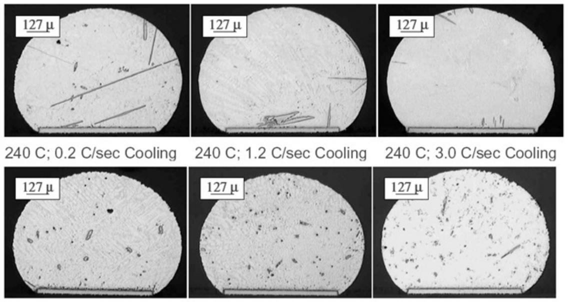
Effect of Ag Composition and Cooling Rate



- Ag_3Sn particulates can grow in form of plates during reflow
- Slow cooling rates assist in formation of Ag_3Sn plates
- SAC405 Alloy exhibits plate formation at slow cooling rates. SAC305 Alloy does not exhibit plate formation

SAC405

SAC305



240 C; 0.2 C/sec Cooling 240 C; 1.2 C/sec Cooling 240 C; 3.0 C/sec Cooling

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Henderson, *Ag_3Sn Plate Formation in the Solidification of Near Ternary Eutectic SnAgCu Alloys*, 2004