Supplementary Material for: "**The role of lengthscale in the creep of Sn-3Ag-0.5Cu solder microstructures**"

Tianhong Gu*, Christopher M. Gourlay, and T. Ben Britton

Department of Materials, Imperial College London, SW7 2AZ. UK

*Corresponding author: t.gu15@imperial.ac.uk

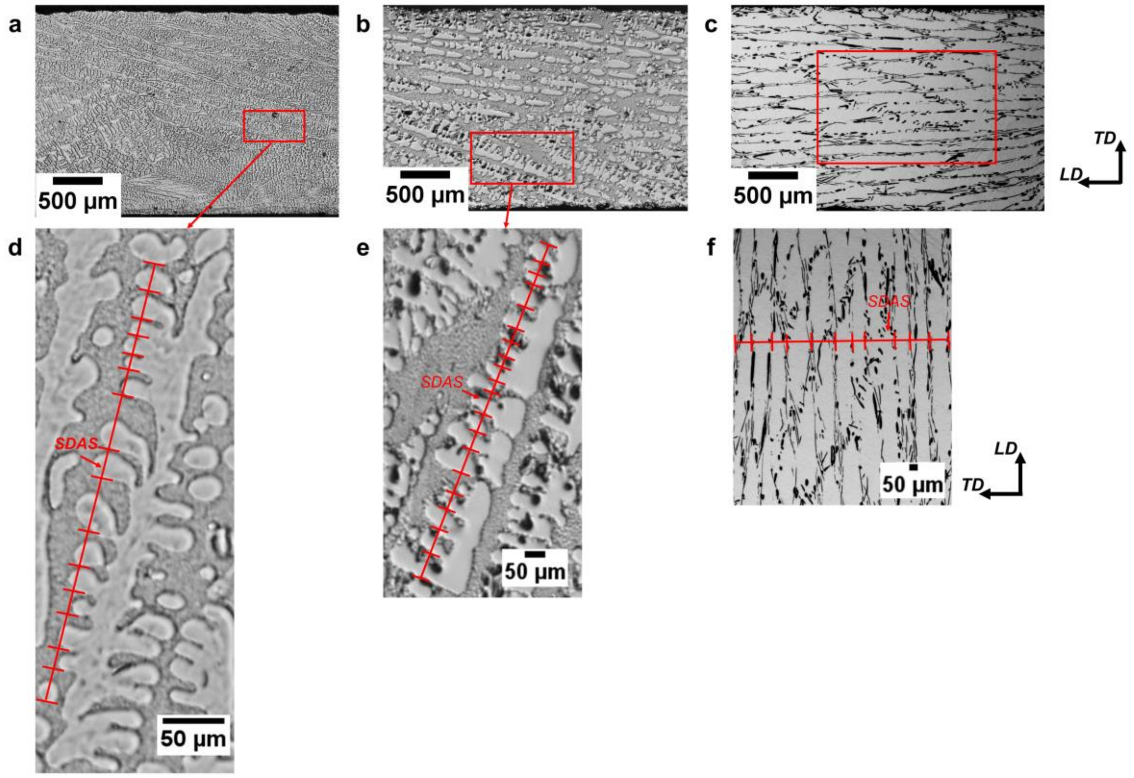

Figure S1. *Optical images of polished DS SAC305 samples in longitudinal direction. (a, d) The fine-structured sample at growth velocity of 200 µm/s, (b, e) the medium-structured sample at growth velocity of 20 µm/s, (c, f) the coarse-structured sample at growth velocity of 2 µm/s. (d, e, f) The higher magnification images of the red-squared region in (a – c) show the dendrite arms with the secondary dendrite arm spacing (SDAS, λ_2) measured. The SDAS is determined by $\lambda_2 = \frac{L}{N}$ where L is the length of the intersection line and N is the number of intersections of the line. The SDAS was calculated as a mean value by measuring four micrographs and the standard deviation (STD) of the value is given in Table I below.*

Growth velocity, v (μm/s)	Length, L (μm)	Number, N	SDAS, $\lambda_2 = \frac{L}{N}$ (μm)		
				Average	STD
20	848	17	49.9	49.9	2.9
	683	13	52.5		
	857	19	45.1		
	883	17	51.9		
200	335	15	22.3	20.4	3.2
	226	12	18.8		
	96	6	16.0		
	340	14	24.3		

Table I. *Summary of SDAS (λ_2) of the DS samples.*

The spacing of rod eutectic morphology can be measured according to Flood and Hunt [1] as

$$0.5\lambda_e = S^r = 0.4\left(\frac{A}{N}\right)^{0.5}$$

Where λ_e is the eutectic spacing in μm and $\frac{N}{A}$ is the number of IMC rods per unit area. A fixed area, A is selected and measured by Image J [2]. The number of particles, N are counted manually from Figure 1 in the manuscript.

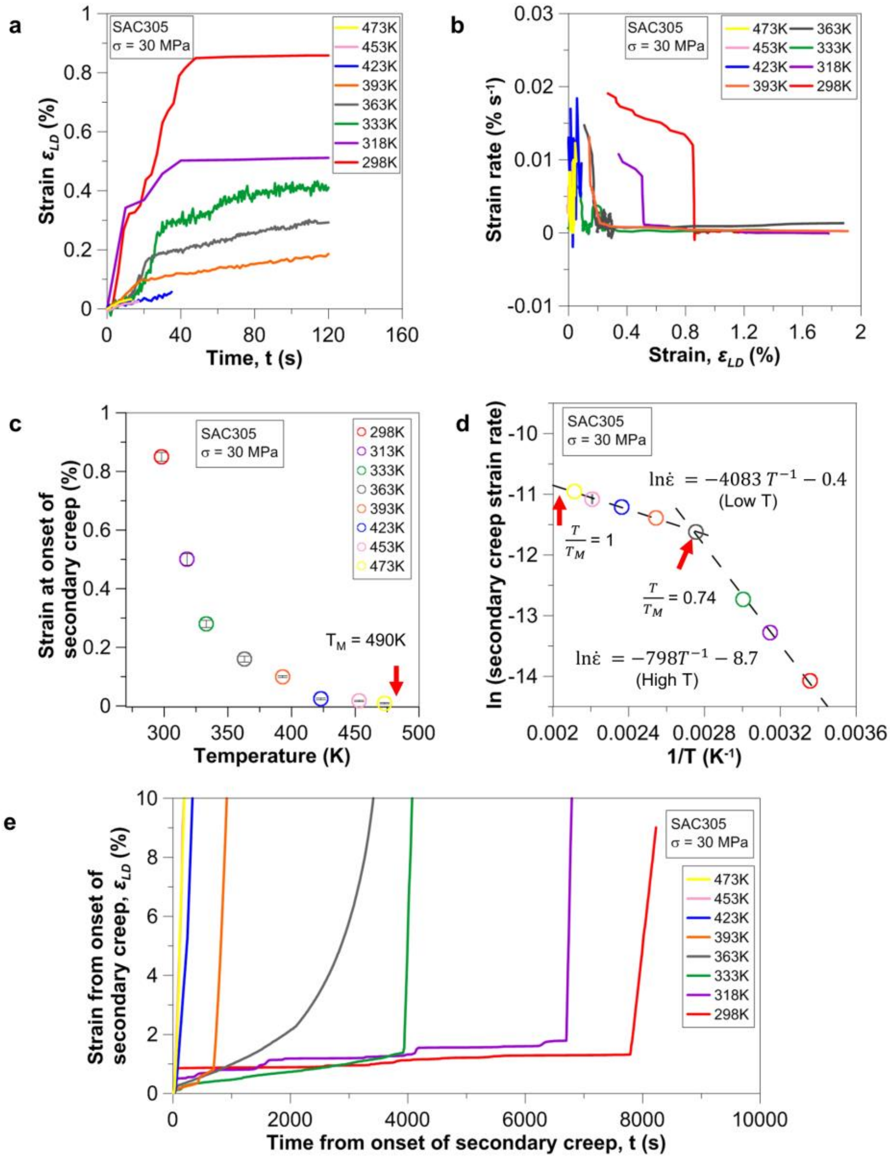

Figure S2. *Fixed load (30 MPa) mechanical creep data from 298 to 473 K of fine-structured SAC305 samples grown at v=200 µm/s. (a) Creep curves from 298 to 473 K from primary to early secondary creep. (b) Creep strain rate vs. creep strain curves showing a gradient of 0 after the secondary stage creep is reached. (c) Variation of the onset of secondary creep with respect to temperature. (d) Creep model analysis of ln (secondary creep strain rate) vs. reciprocal temperature with two creep domains (high temperature and low temperature). (e) Creep curves from the onset of secondary to tertiary stage creep (maximum strain = 10%). (The orientation information is given in* ***Table II****).*

T [K]	Strain at onset of secondary creep (%)	Secondary creep strain rate (s^{-1})	Failure creep strain (%)	Number of β-Sn grains	β-Sn Orientation measured by EBSD
298	0.85	7.71×10^{-7}	9.0	1	[110]
318	0.50	1.71×10^{-6}	26.2	2	[110] [100]
333	0.28	2.96×10^{-6}	38.5	2	[110] [110]
363	0.16	8.98×10^{-6}	22.7	3	[110][110][100]
393	0.10	1.13×10^{-5}	25.8	3	[110] [110] [110]
423	0.03	1.35×10^{-5}	29.8	2	[110] [100]
453	0.02	1.54×10^{-5}	21.6	2	[110] [110]
473	0.01	1.74×10^{-5}	21.2 (not fractured)	3	[110] [110] [100]

Table II. *Summary of fine-structured SAC305 mechanical creep samples under fixed load of ~30 MPa testing from 298 to 473K showing the values of secondary creep strain rate, strain at the onset of secondary creep, failure creep strain and grain orientation of the samples.*

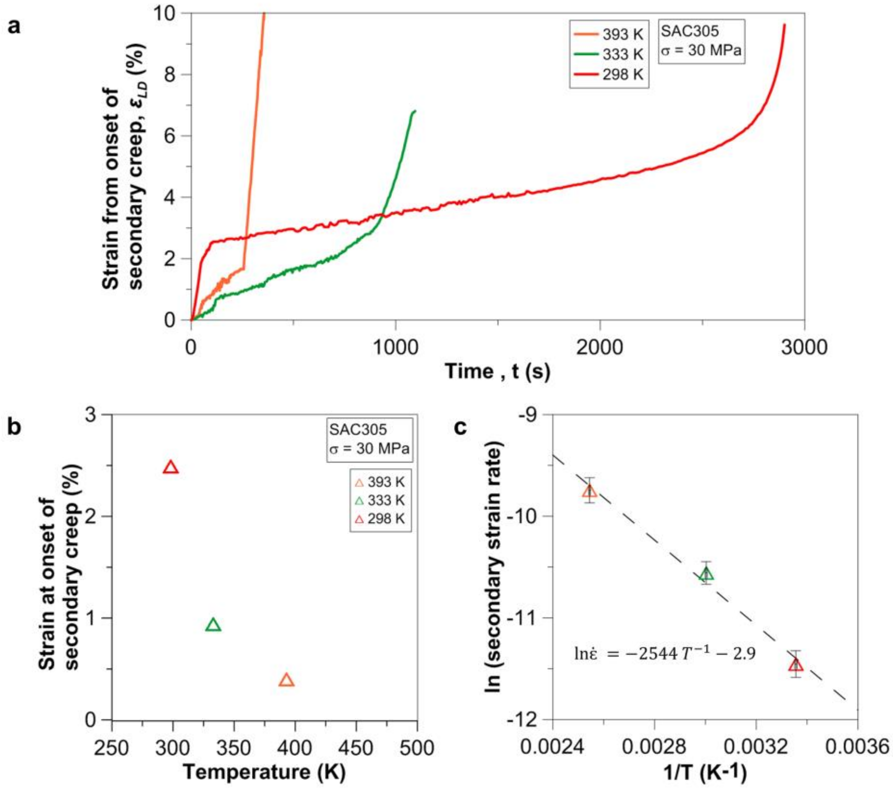

Figure S3. *Fixed load (30 MPa) mechanical creep data from 298 to 473 K of coarse-structured SAC305 samples grown at v=2 μm/s. (a) Creep curves from 298 to 393 K (maximum strain = 10%). (b) Variation of the onset of secondary creep with respect to temperature. (c) Creep model analysis of ln (secondary creep strain rate) vs. reciprocal temperature. (The orientation information is given in* ***Table III****).*

T [K]	Strain at onset of secondary creep (%)	Secondary creep strain rate (s^{-1})	Failure creep strain (%)	Number of β-Sn grains	β-Sn Orientation measured by EBSD
298	2.42	1.06×10^{-5}	9.6	1	[110]
333	0.94	2.60×10^{-5}	6.8	4	[100] [110] [110][110]
393	0.40	5.86×10^{-5}	14.8	3	[100] [110] [110]

Table III. *Summary of coarse-scaled SAC305 mechanical creep samples under fixed load of ~30 MPa testing from 298 to 393 K showing the values of secondary creep strain rate, strain at the onset of secondary creep, failure creep strain and grain orientation of the samples.*

Slip system		CRSS ratio	weighted Schmid factor m_w [110]
3	(110)[001]	1	0.28
5	(100)[010]	1.05	0.49
6	(010)[100]	1.05	0.44
13	(010)[101]	1.25	0.40
15	(100)[011]	1.25	0.40

Table IV. *The common Sn slip systems [3] with the highest five weighted Schmid factors. The values of m_w are calculated The values of CRSS (critical resolved shear stress) ratio are estimated from by Zamiri et al. [4] The values of weighted Schmid factor (m_W) are calculated using equation $m_{W^i} = \frac{\tau_{CRSS^i}}{\tau_{CRSS^{Min}}}$ for [110]) orientation along [100] loading direction.*

1. S.C. Flood and J.D. Hunt, *Modification of Al-Si eutectic alloys with Na.* Metal science, 1981. **15**(7): p. 287-294.
2. C.T. Rueden, J. Schindelin, M.C. Hiner, B.E. DeZonia, A.E. Walter, E.T. Arena and K.W. Eliceiri, *ImageJ2: ImageJ for the next generation of scientific image data.* BMC bioinformatics, 2017. **18**(1): p. 529.
3. M. Fujiwara and T. Hirokawa, *The strength of Main obstacles to dislocation motion in white tin crystals.* J. Jpn. Inst. Met., 1987. **51**(9): p. 830-838.
4. A. Zamiri, T.R. Bieler and F. Pourboghrat, *Anisotropic crystal plasticity finite element modeling of the effect of crystal orientation and solder joint geometry on deformation after temperature change.* Journal of electronic materials, 2009. **38**(2): p. 231-240.