Creep of Pb-free Solders

Fay Hua, C. Michael Garner

Materials Technology Operation, Intel Corporation

Santa Clara, CA

H. G. Song and J. W. Morris

Center for Advanced Materials, University of California, Berkeley, CA

Introduction

- Proposed EU legislation would ban lead in electronics in 2006 = >*Leading Pb-free solder research*
- Electronics infrastructure is built around Pb-Sn solders
- Pb-Sn solders have been well characterized
- Pb-free solder mechanical properties are in early stage of characterization.
- New failure modes may occur due to the difference in mechanical properties of Pb-free solders vs. Pb-Sn solder.
- Eutectic Sn-Ag-Cu solder generally chosen general use solder for SMT
- Most lead free solders have higher melting point and require higher process temperatures & times
- Creep is critical to solder joint reliability ($T/T_{melt}>0.5$)
  - Is creep impacted by cooling rate?

Testing Matrix

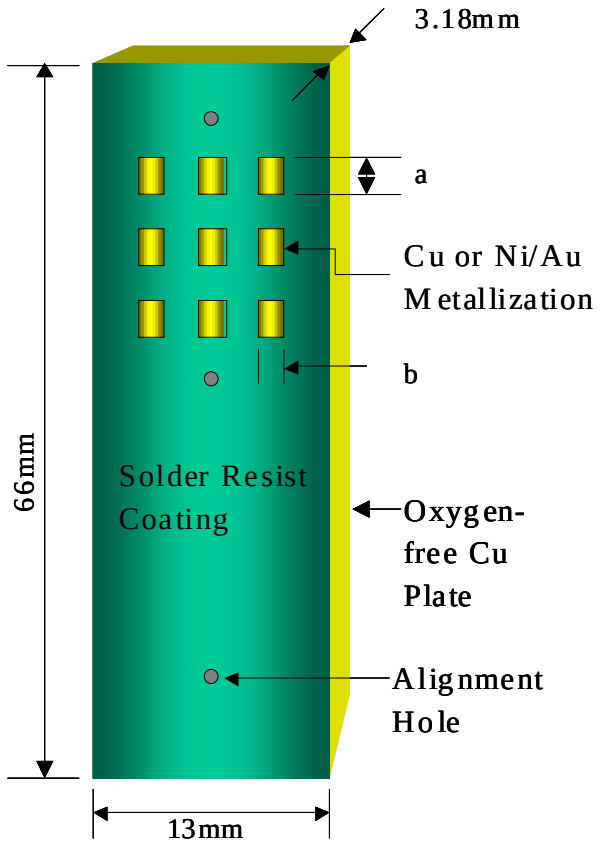
- Alloys studied:Sn-3.5Ag, Sn-0.7Cu, Sn-3.0Ag-0.5Cu, Sn-10In-3.1Ag
- Soldering surface: Cu/immersion Au on electro-less plated Ni
- All solder joints reflowed in N_2 atomsphere with peak temperature 30 degrees above liquidus and aged at 160 °C for 4 hours after reflow
- Two cooling rates: 3.5°C/min. and 2.7 °C/s.
- Creep testing conducted at 60 °C, 95 °C and 130 °C

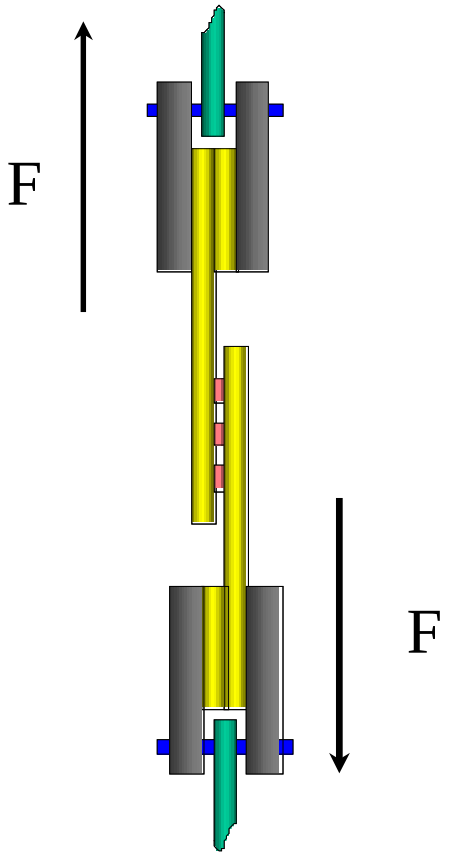
Homologous Temp. for Testing

$T(K)/T_{melt}(K)$

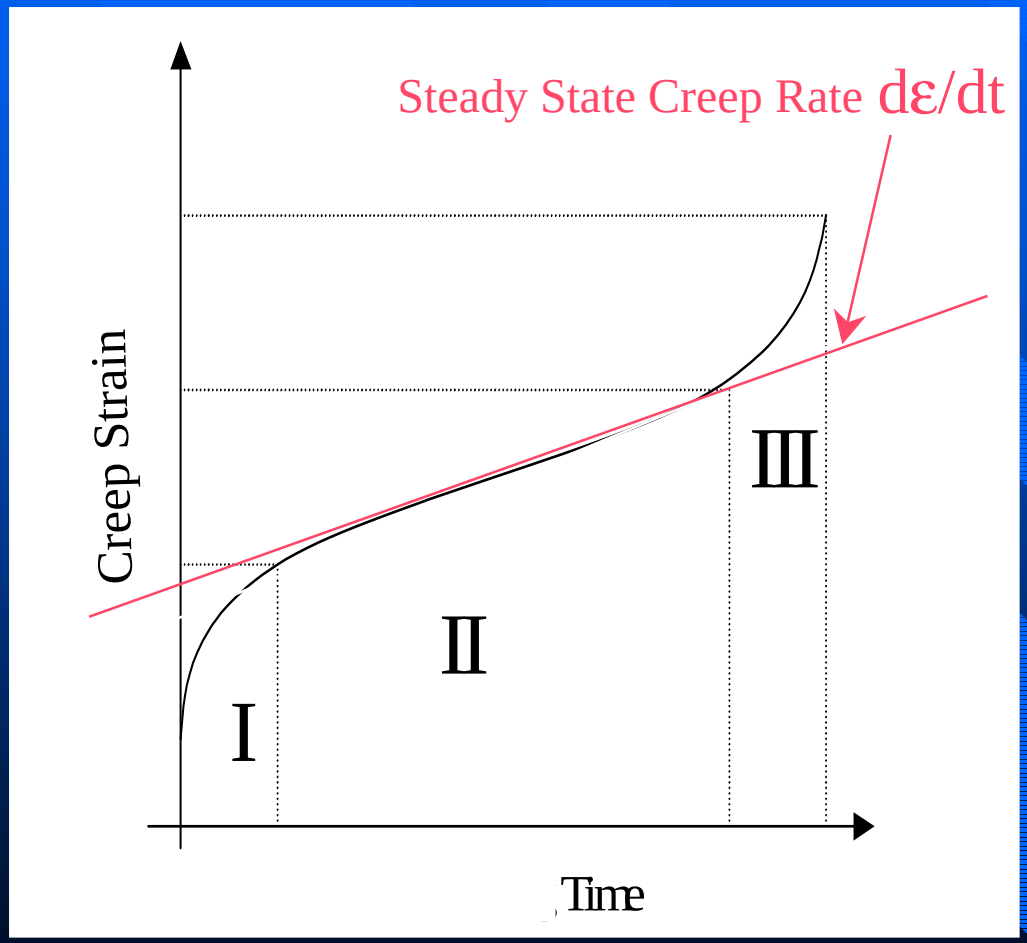
Solders	M.P.(C)	130C	95C	60C
Sn-37Pb	183	0.884	0.807	0.730
Sn-3.5Ag	221	0.816	0.745	0.674
Sn-0.7Cu	227	0.806	0.736	0.666
Sn-3.0Ag-0.5Cu	217	0.822	0.751	0.680
Sn-10In-3.1Ag	201-204	0.845	0.771	0.698

Samples and Creep Measurements





Creep Curve

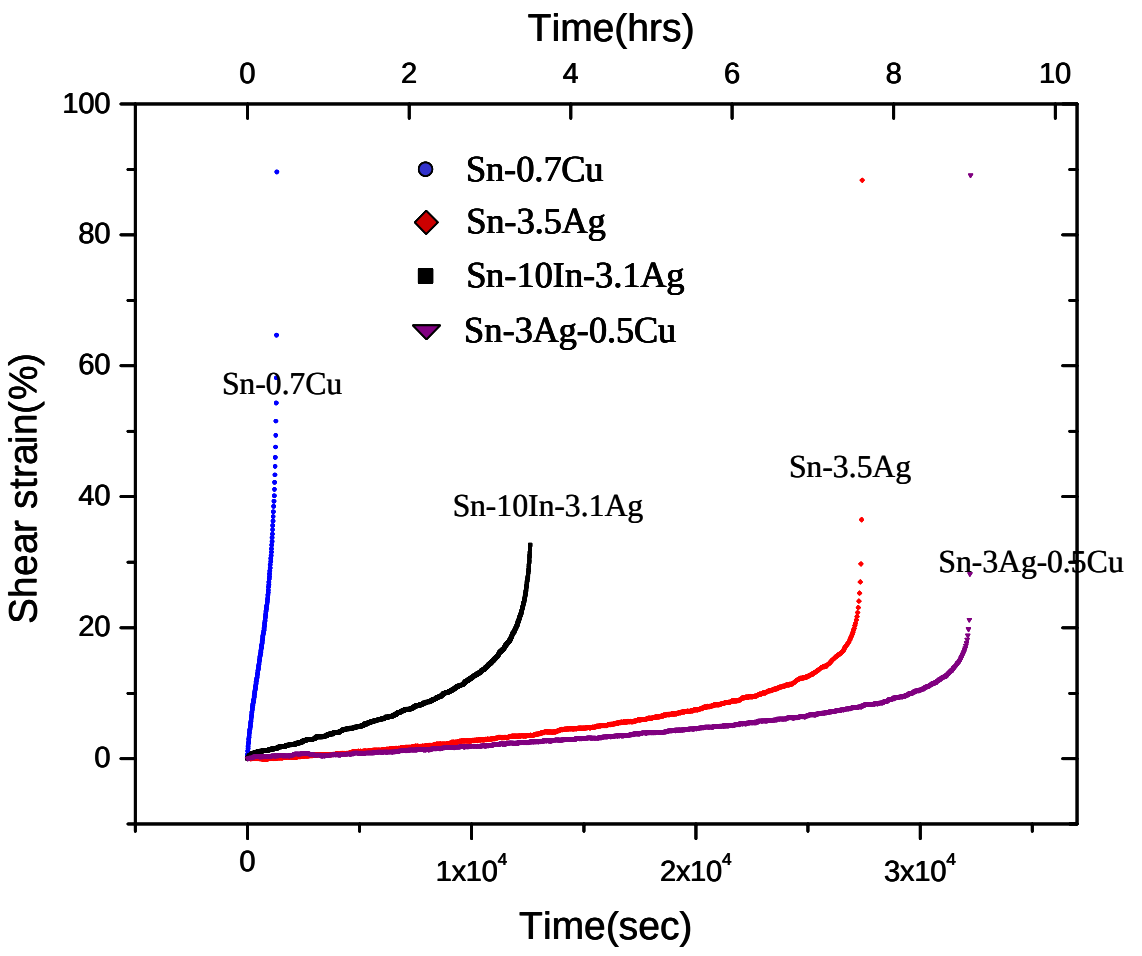


I-Primary creep:
Sub-grain formation – creep rate slows down;

II-Steady state creep:
Stable substructure – dynamic balance of strain harding and softening

III-Tertiary creep:
Softening dominated by micro-voiding, necking…. mechanisms

Load controlled creep testing @ 130C

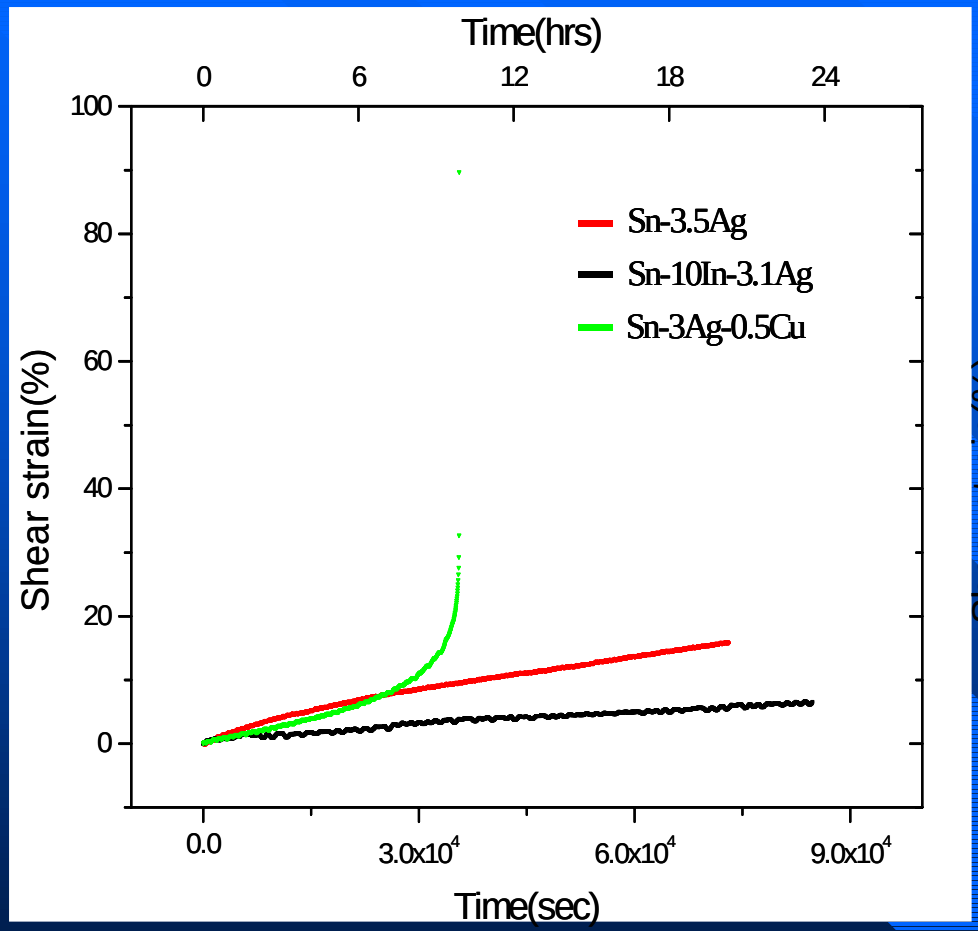


Stress: 5.44MPa @130C, cooled at 2.7C/s

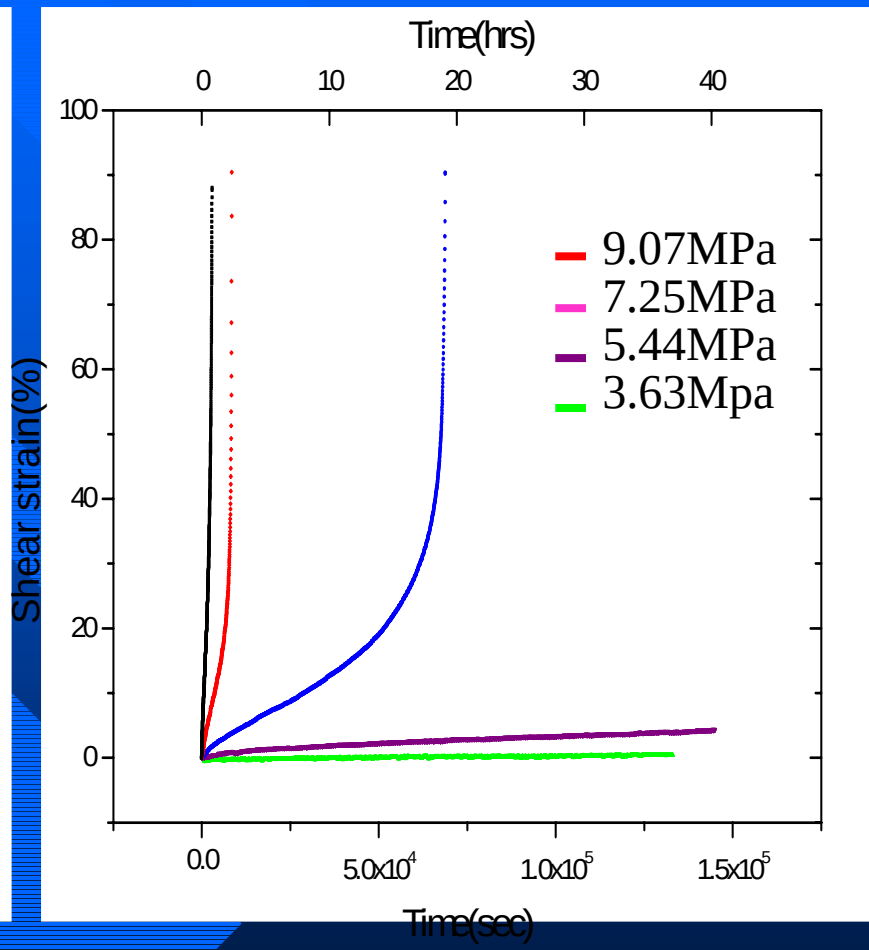
Sn-0.7Cu has shortest rupture time; and Sn-3Ag-0.5Cu has longest rupture time

Do not observe primary creep range!

Load controlled creep testing @60C



12.7MPa



Sn-0.7Cu, stress<9.97MPa

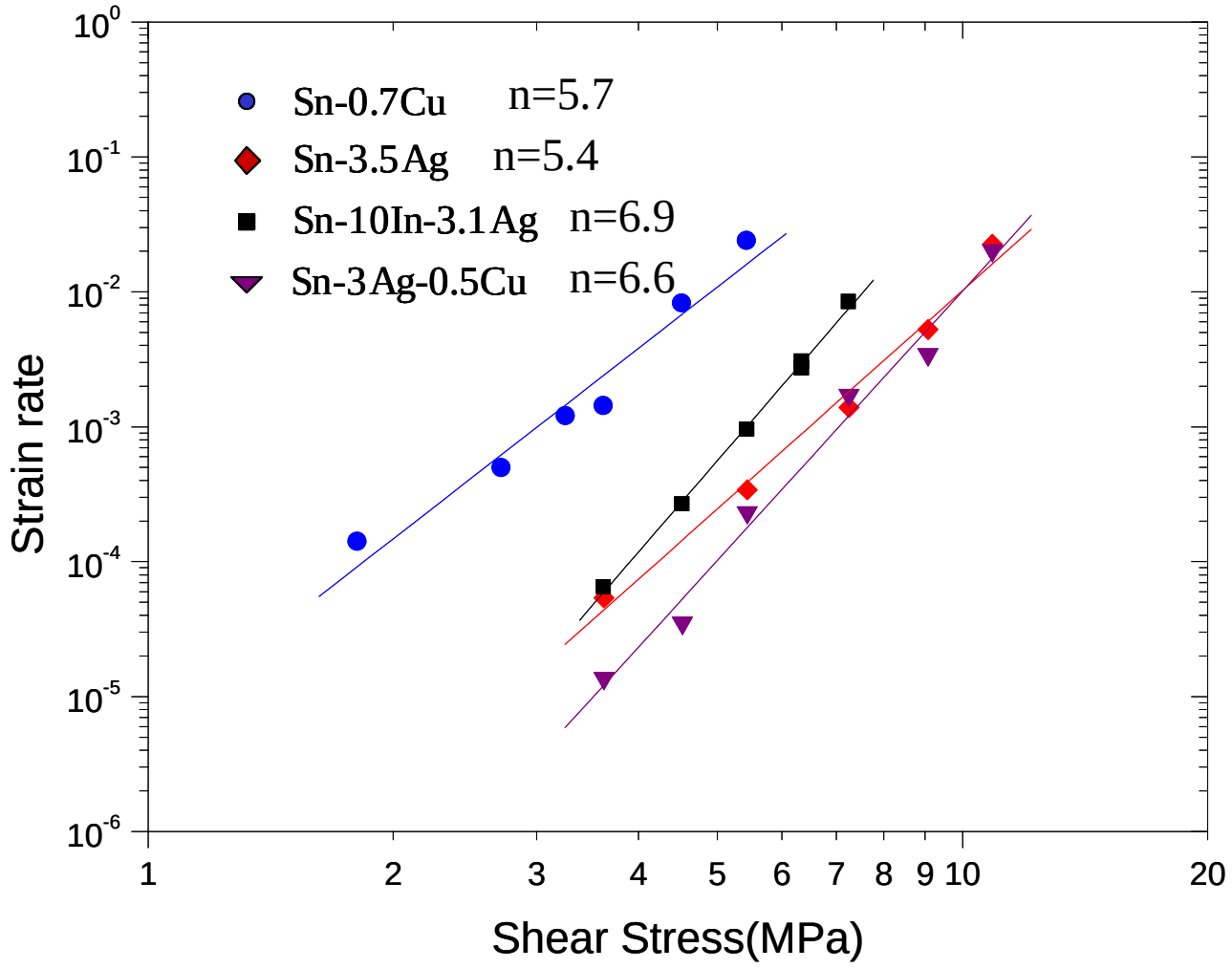
Rupture time:

Sn-Cu<Sn-Ag-Cu<Sn-Ag<Sn-In-Ag

Cooled at 2.7C/s

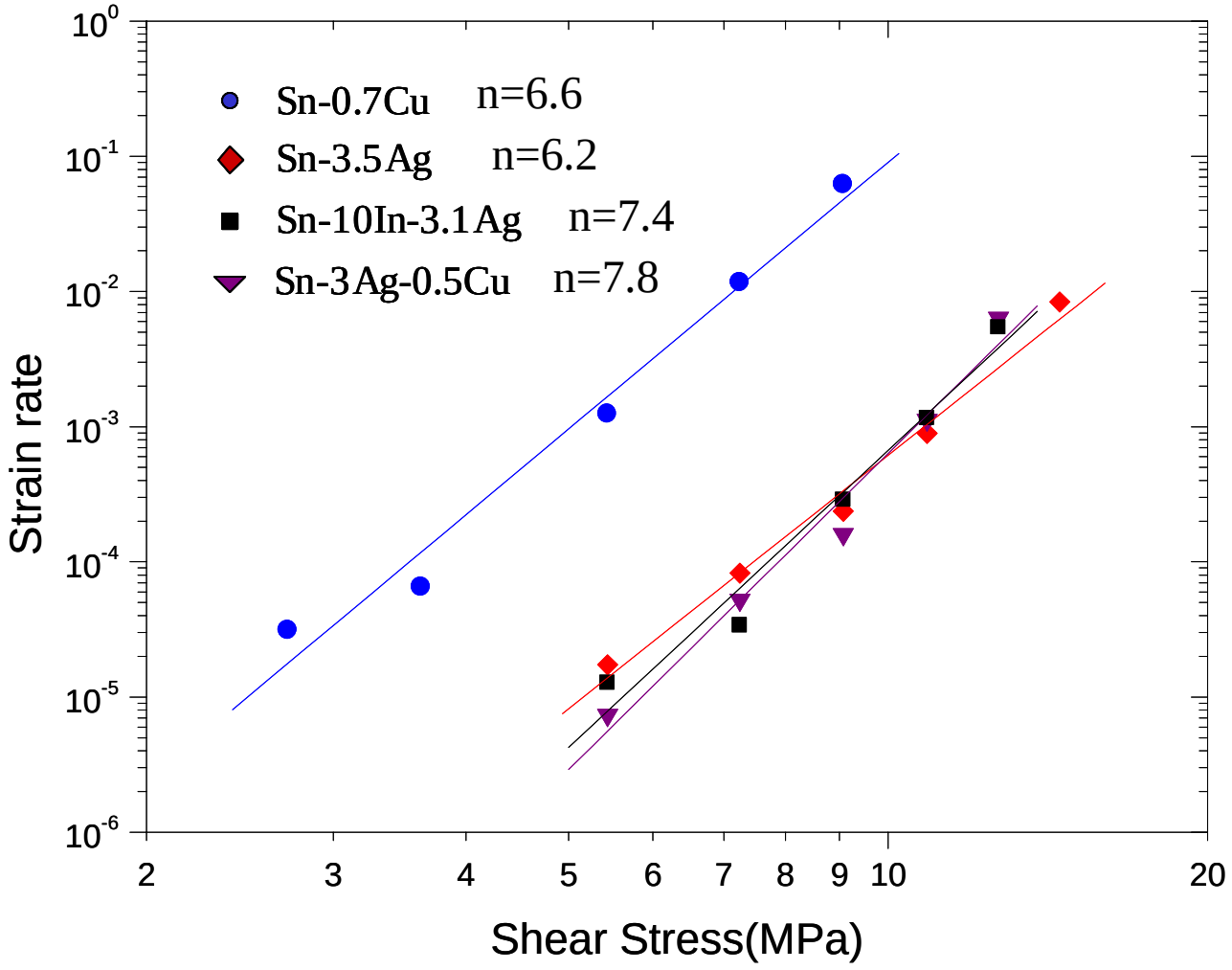
Creep Stress vs. Strain rate @130C

Joints cooled at 2.7C/s



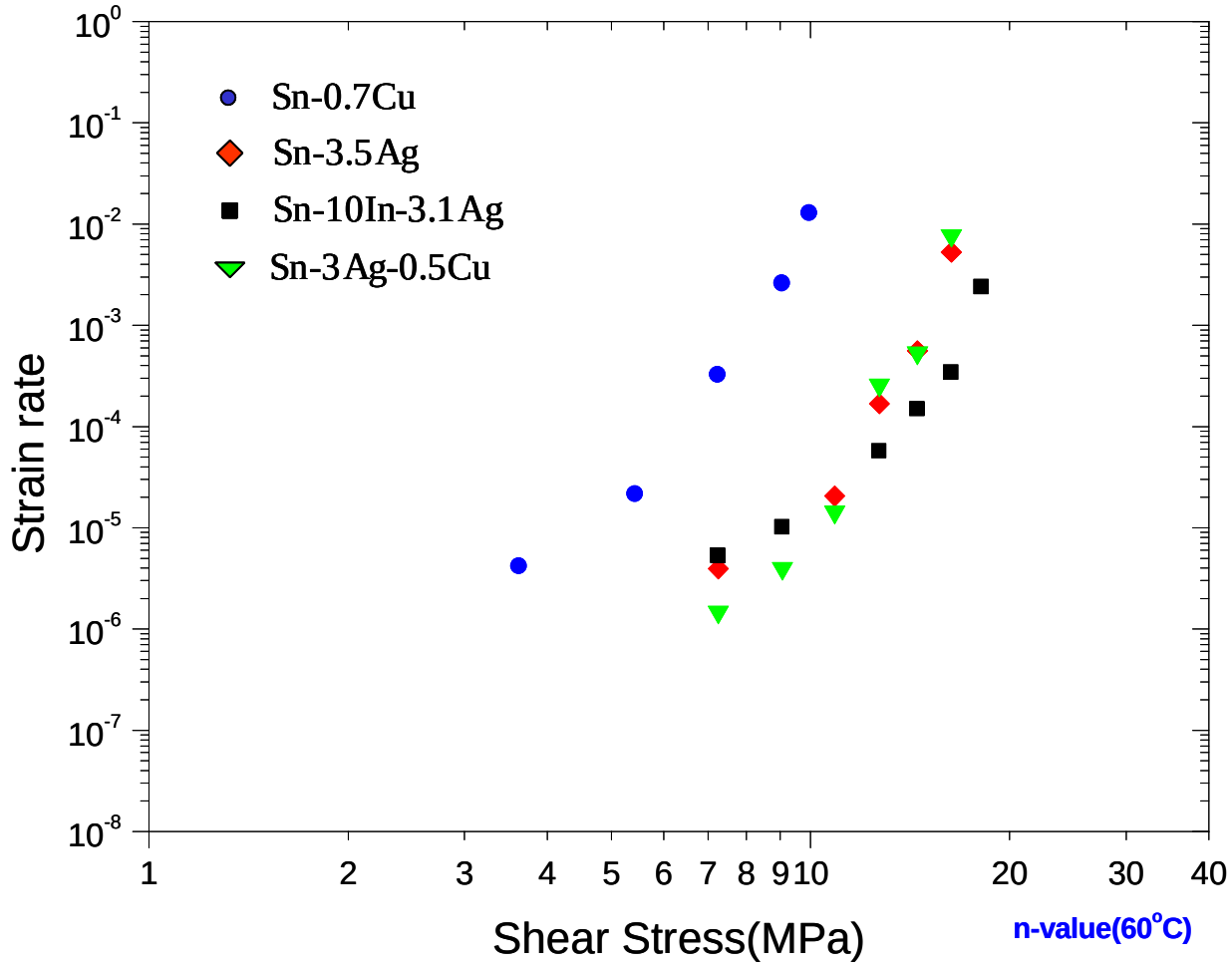
Creep rate vs. Stress @ 95C

Joints cooled at 2.7C/s



Creep Rate vs. Stress @ 60C

Joints cooled at 2.7C/s



Creep activation energy

Alloys	Q(KJ/mol)
Sn-0.7Cu	106
Sn-3.5Ag	105
Sn-3.0Ag-0.5Cu	115
Sn-10In-3.0Ag	117

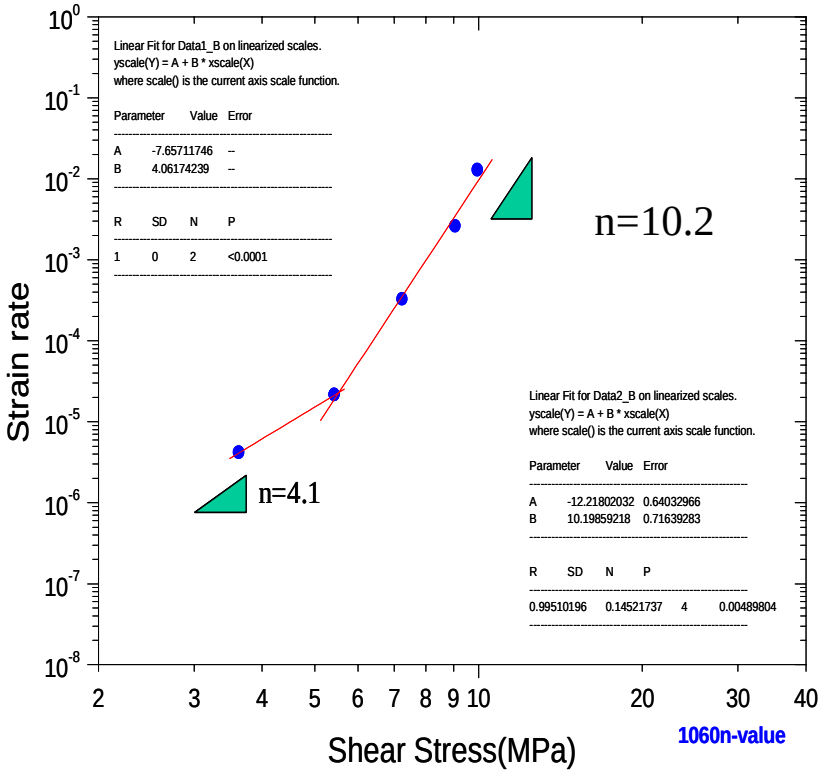
Dorn's equation:

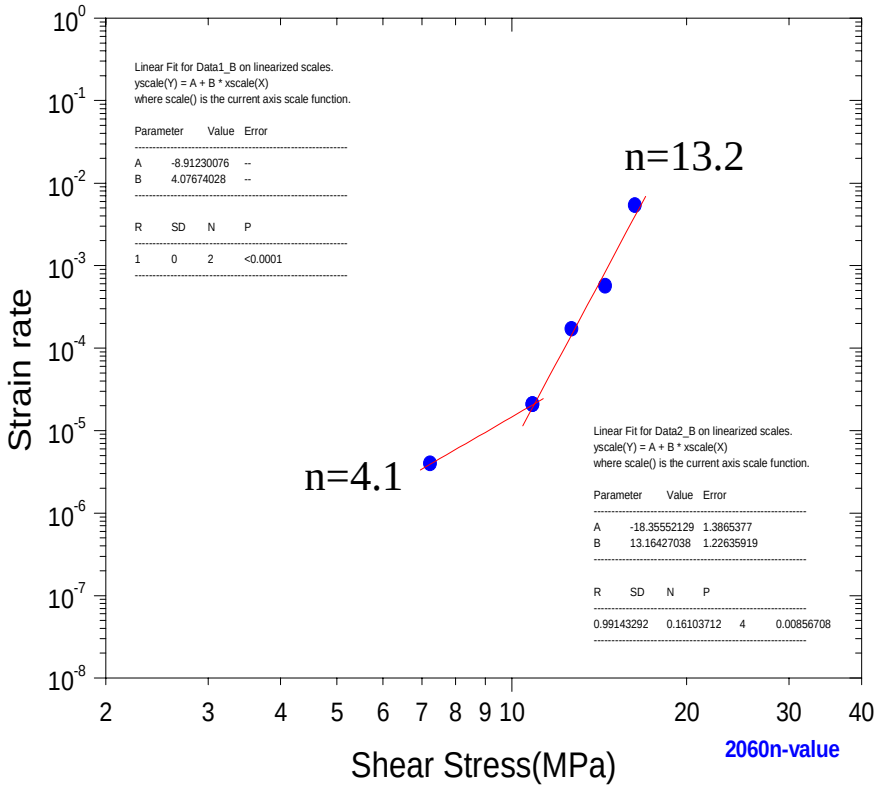
$$\dot{\gamma} = A\tau^n \exp[-Q/RT]$$

- The data fits Dorn's equation.
  - Tin self diffusion (Q is about 107KJ/mol) dominates these alloys
- If n is from 3-6, the creep is matrix creep dominated
  - Self diffusion limited
- For n is smaller than 2, the creep is grain boundary controlled
- 60C data shows clear two different creep mechanisms.

Creep at 60C

Joints cooled at 2.7C/s



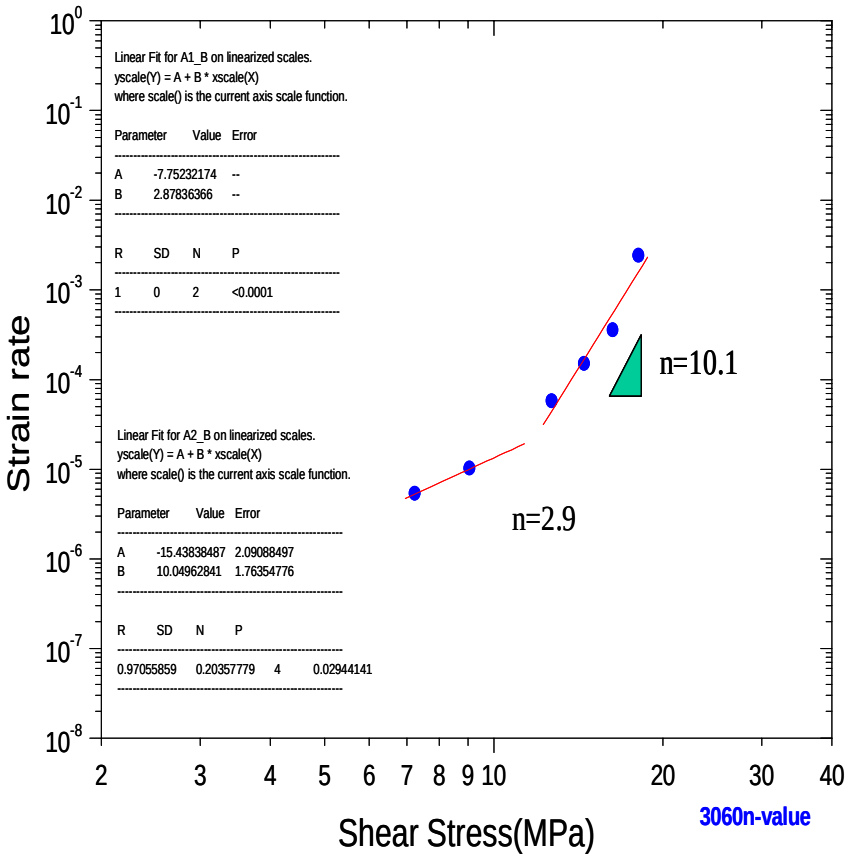


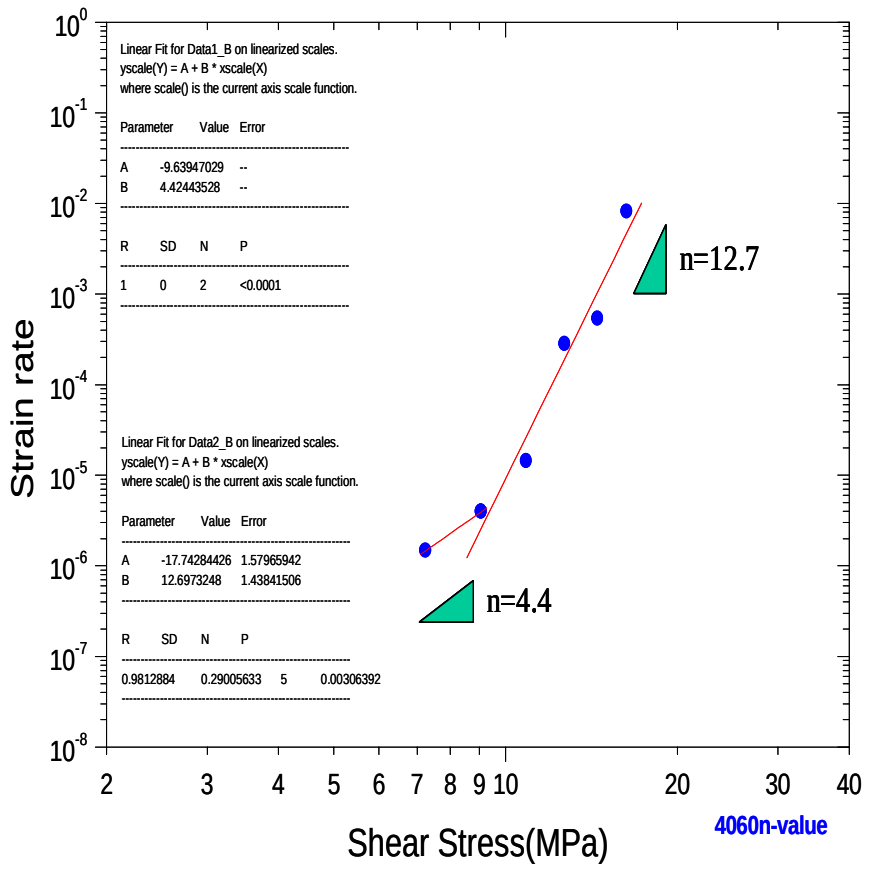
Sn-Cu

Sn-Ag

Creep at 60C

Joints cooled at 2.7C/s

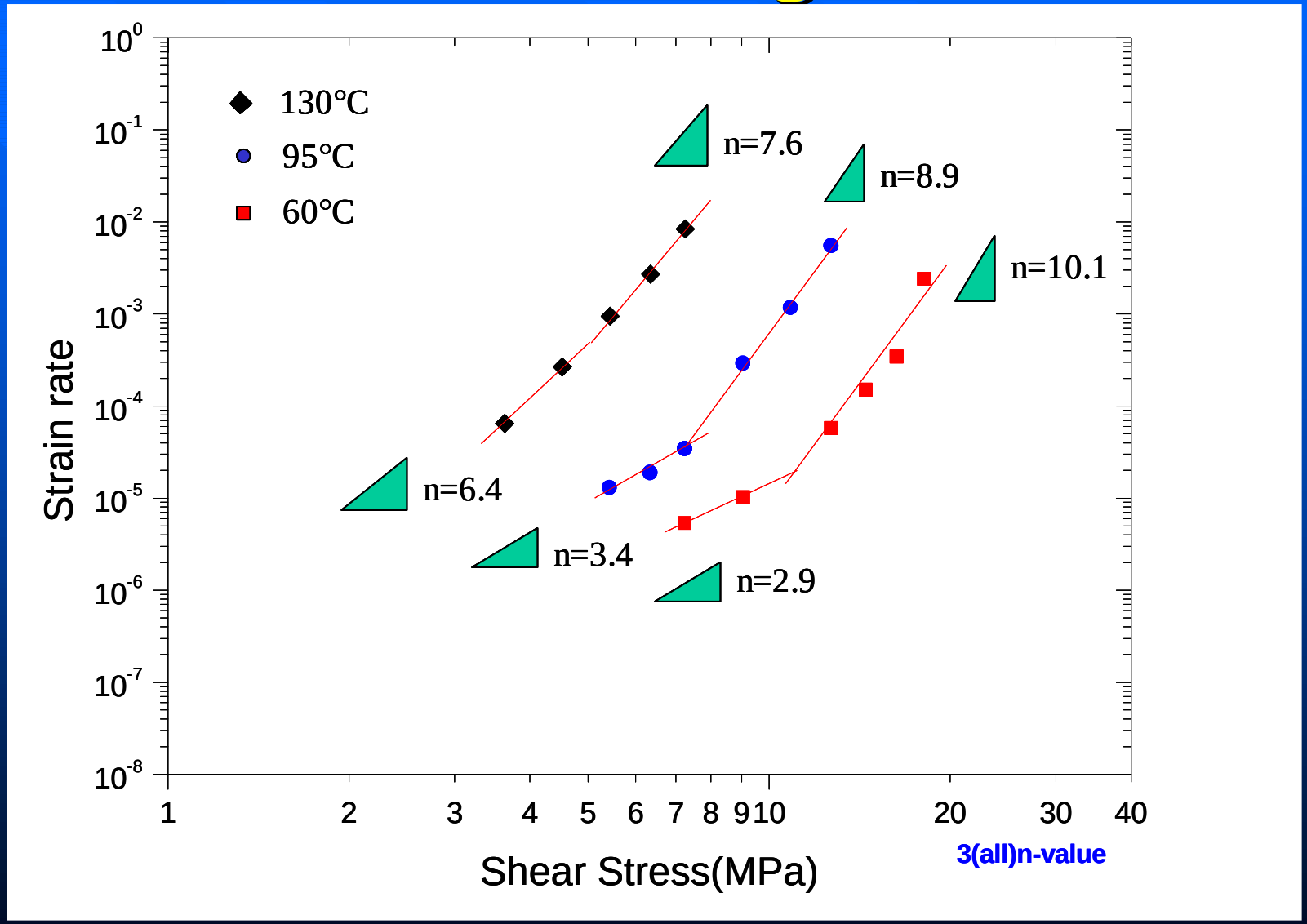




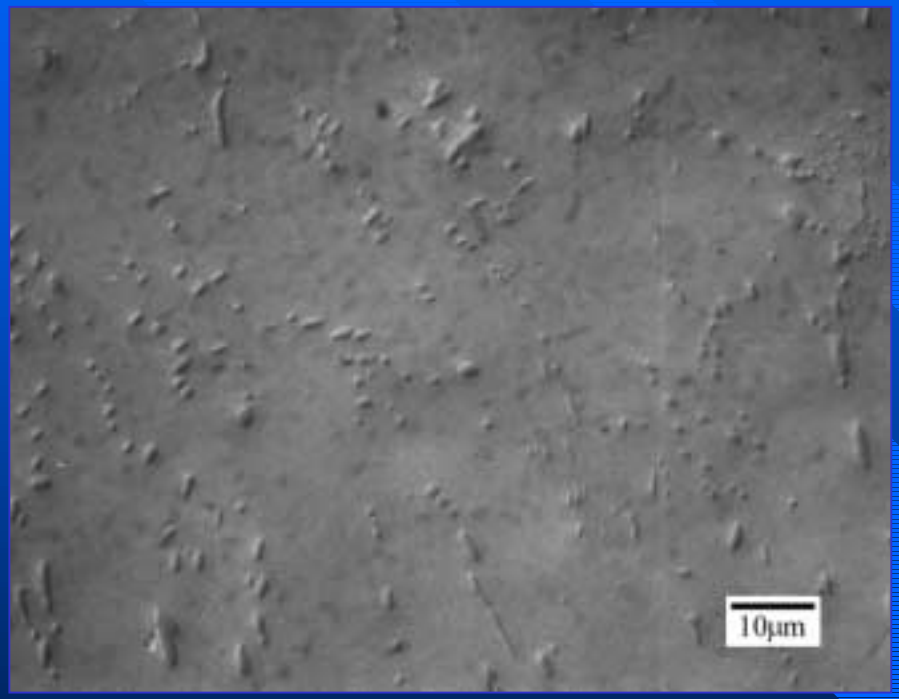
Sn-In-Ag

Sn-Ag-Cu

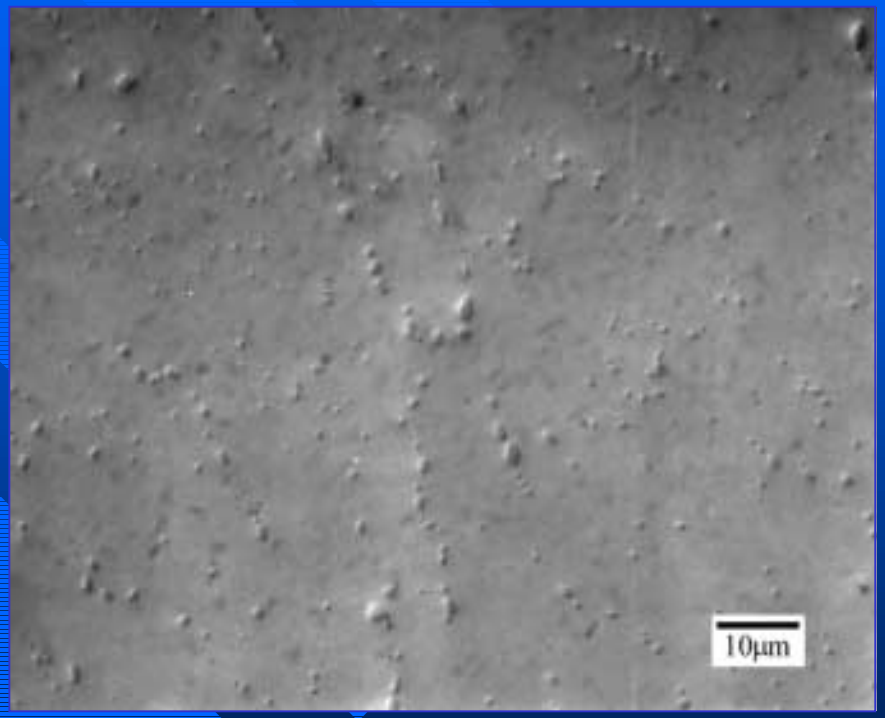
Sn-In-Ag


130°C
95°C
60°C
n=7.6
n=8.9
n=10.1
n=6.4
n=3.4
n=2.9
Strain rate
Shear Stress(MPa)
3(all)n-value

Optical Images of Sn-Cu Joints



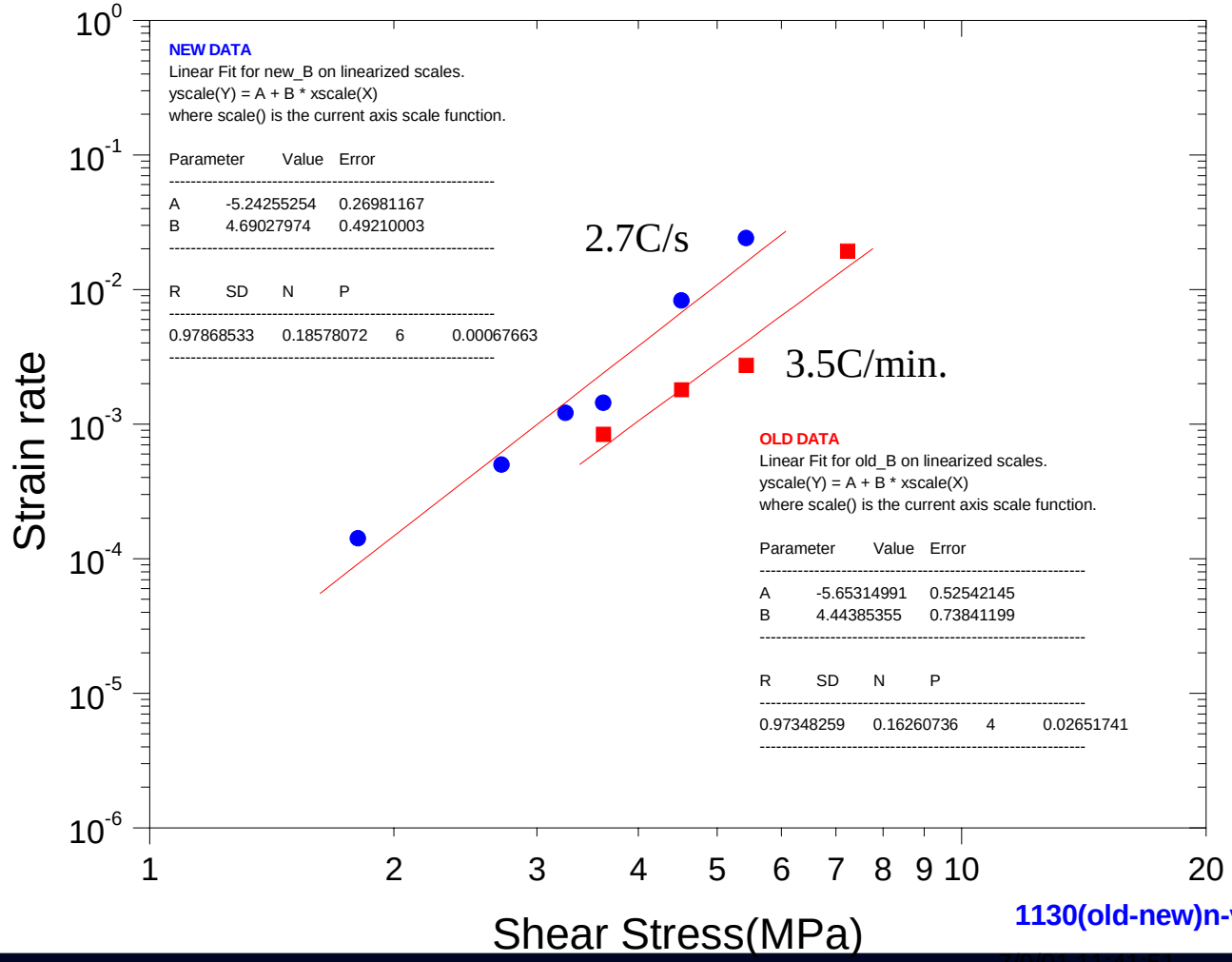
2.7C/s



3.5C/min.

* Smaller Sn grain for faster cooled joints

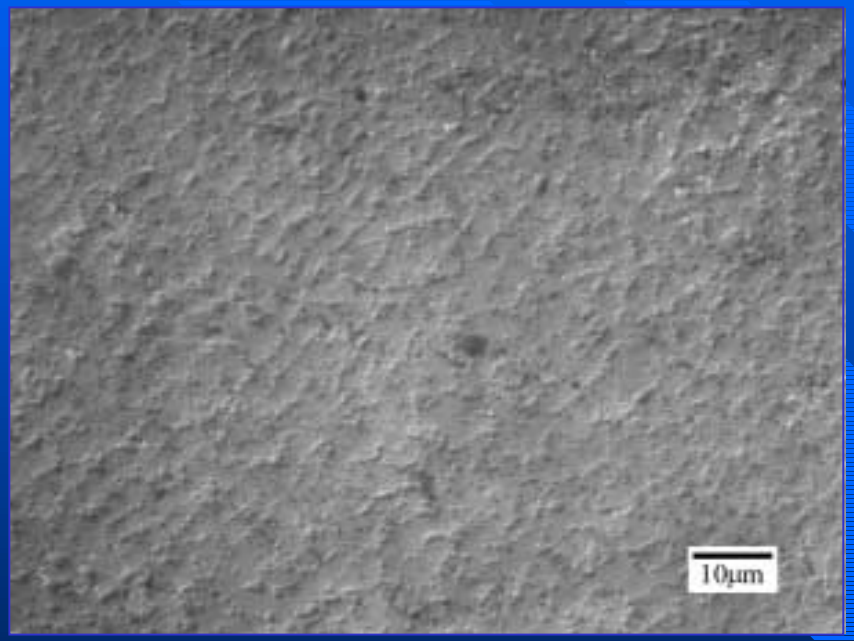
Creep of Sn-Cu at different cooling rates tested at 130C



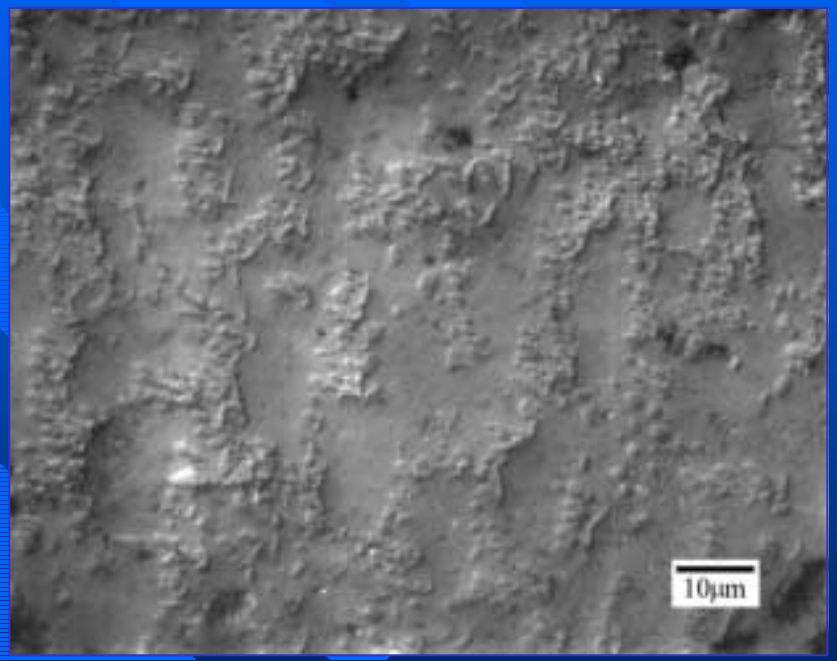
1130(old-new)n-value

7/9/01 11:41:51

Optical Images of Sn-Ag-Cu Joints



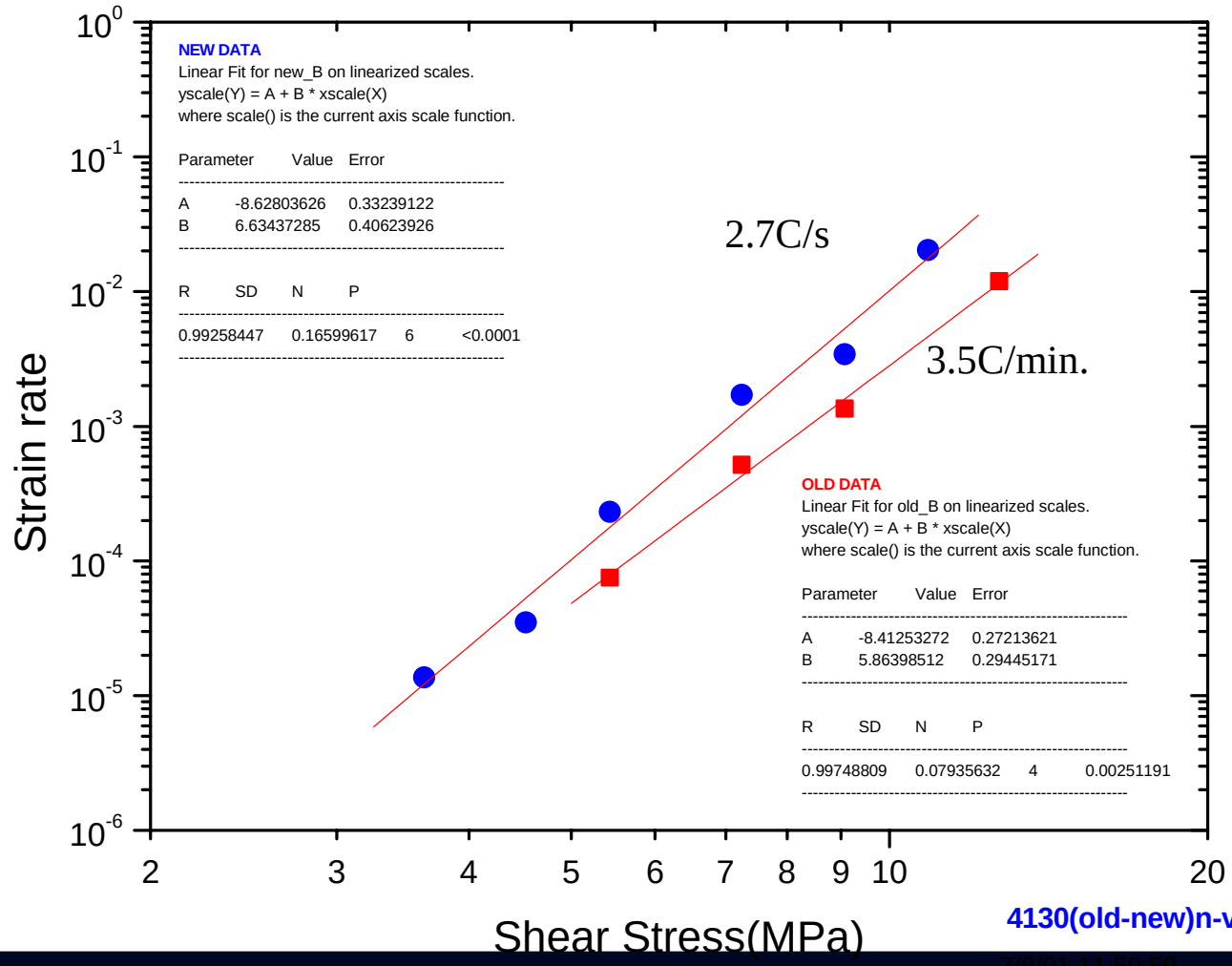
2.7C/s



3.5C/min.

* Smaller Sn grain and finer precipitations for faster cooled joints

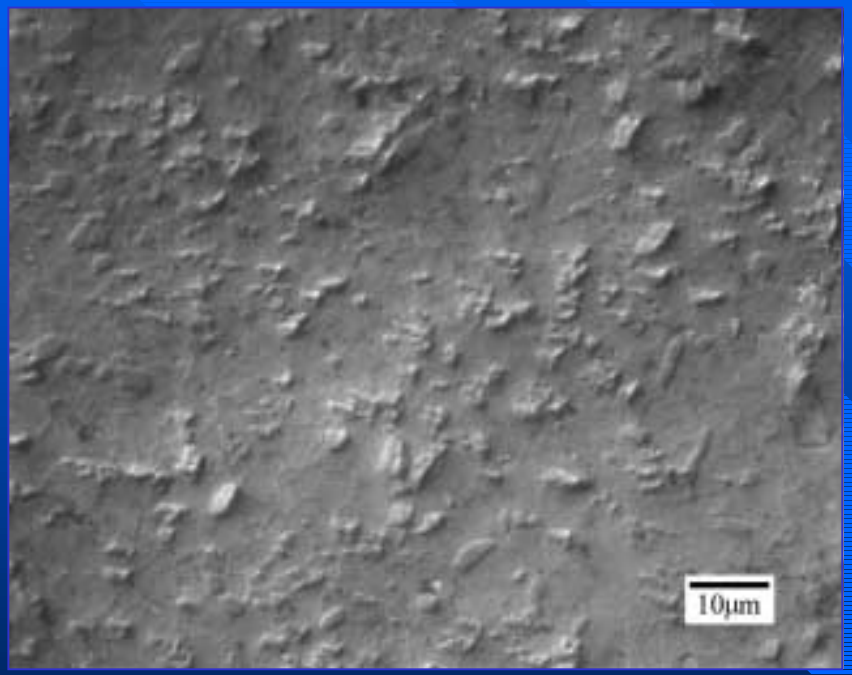
Creep of Sn-Ag-Cu at different cooling rates tested at 130C



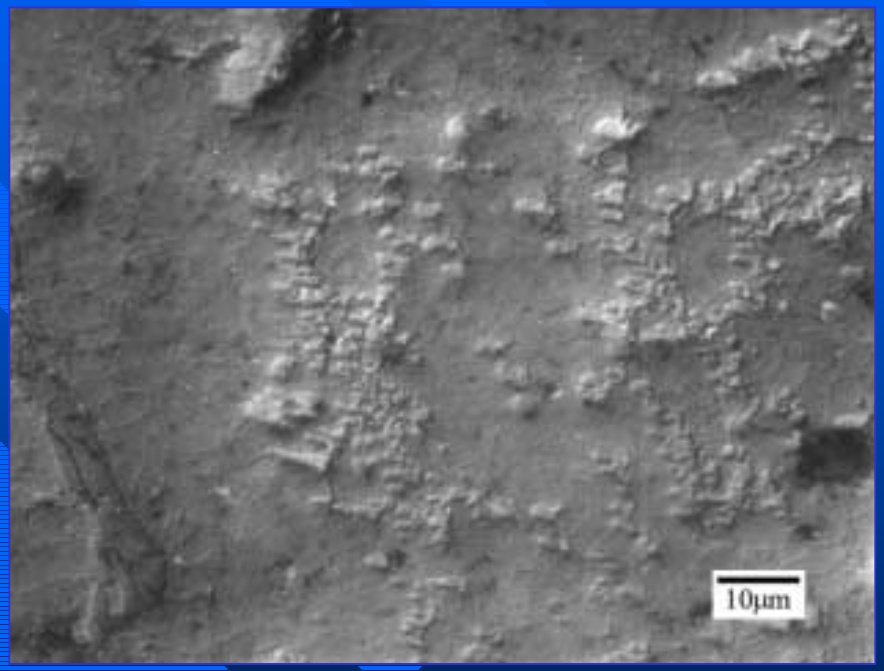
4130(old-new)n-value

7/9/01 11:50:59

Optical Images of Sn-In-Ag Joints



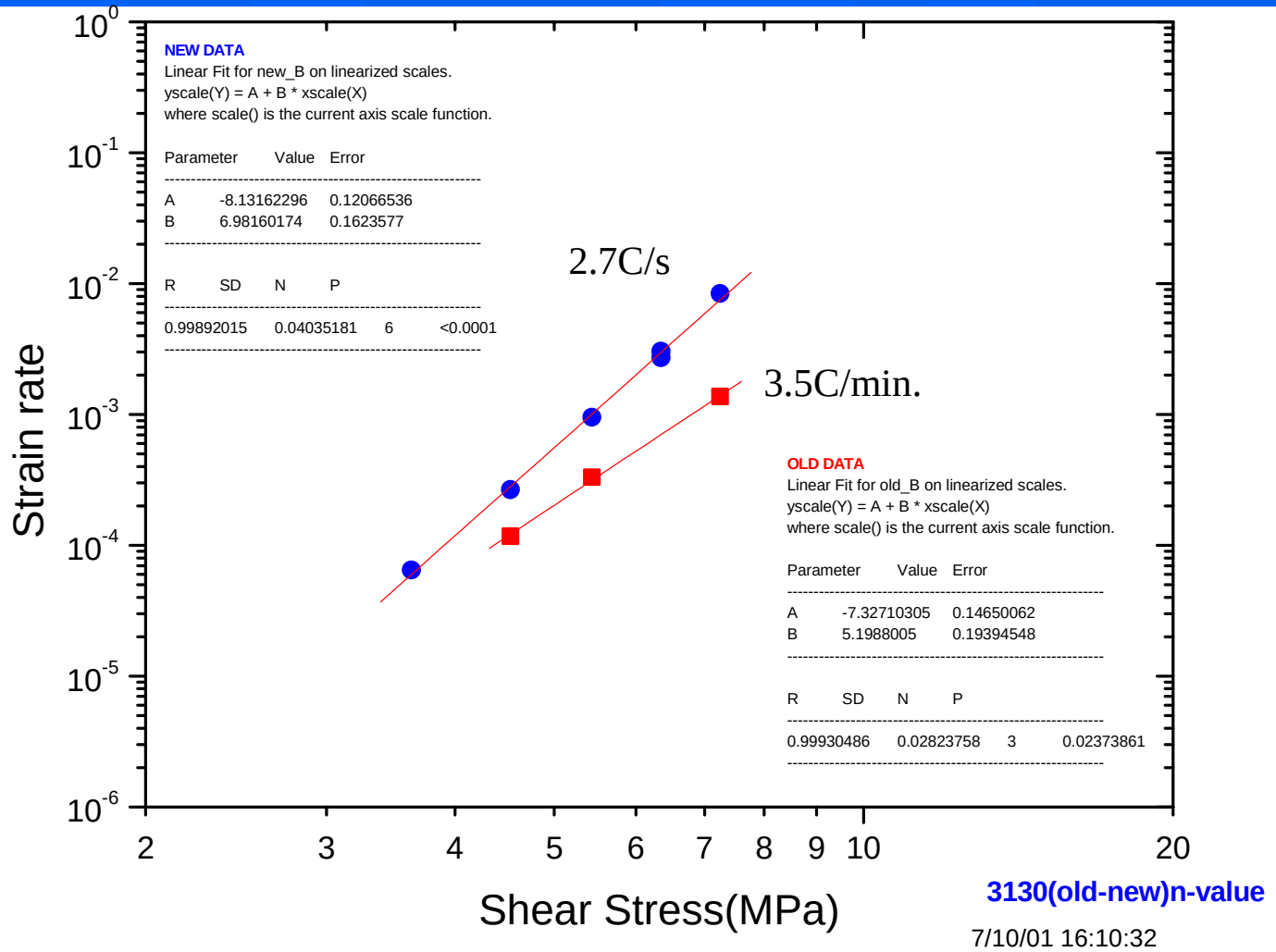
2.7C/s



3.5C/min.

* Smaller Sn grain and finer precipitations for faster cooled joints

Creep of Sn-In-Ag at different cooling rates tested at 130C

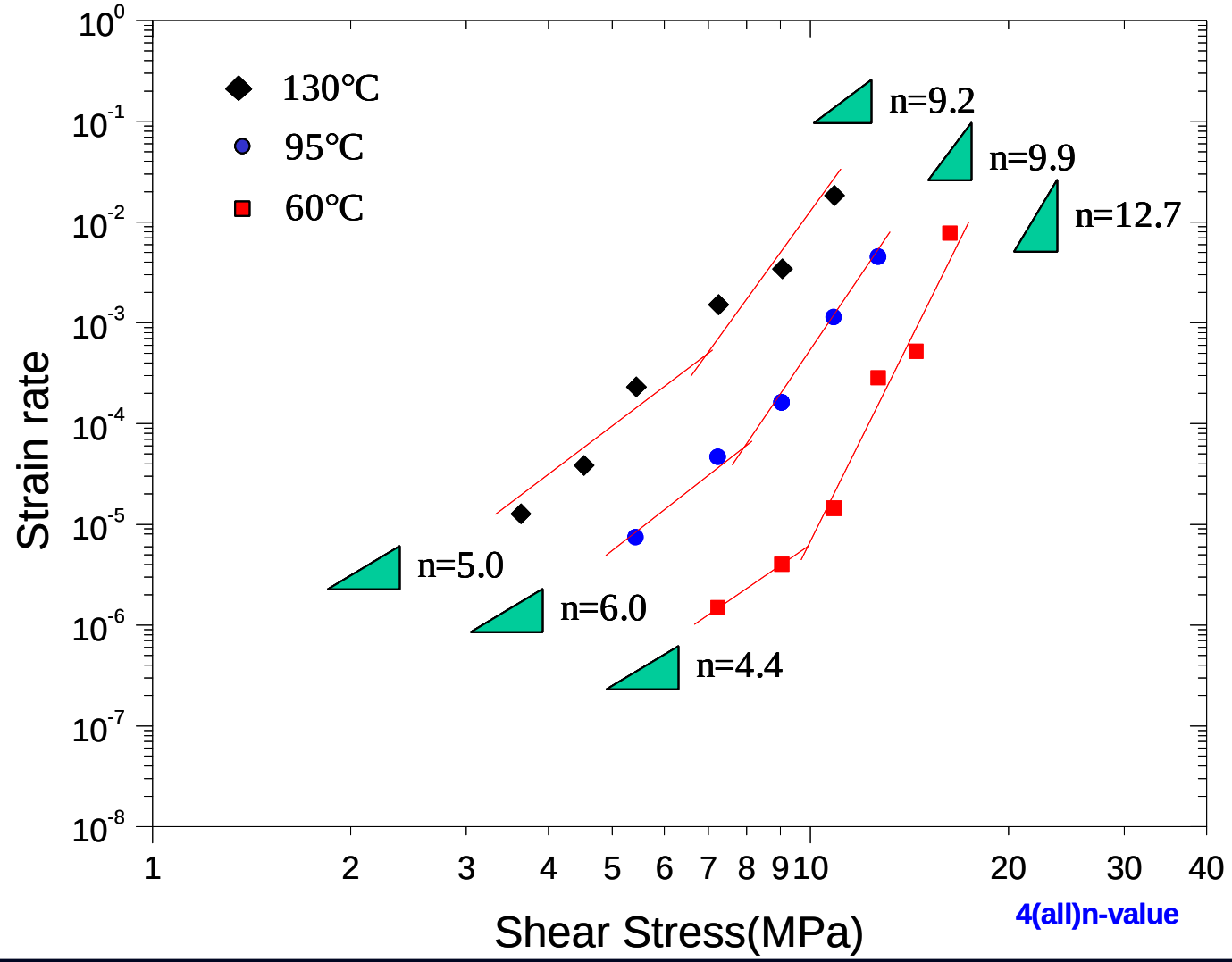


Summary

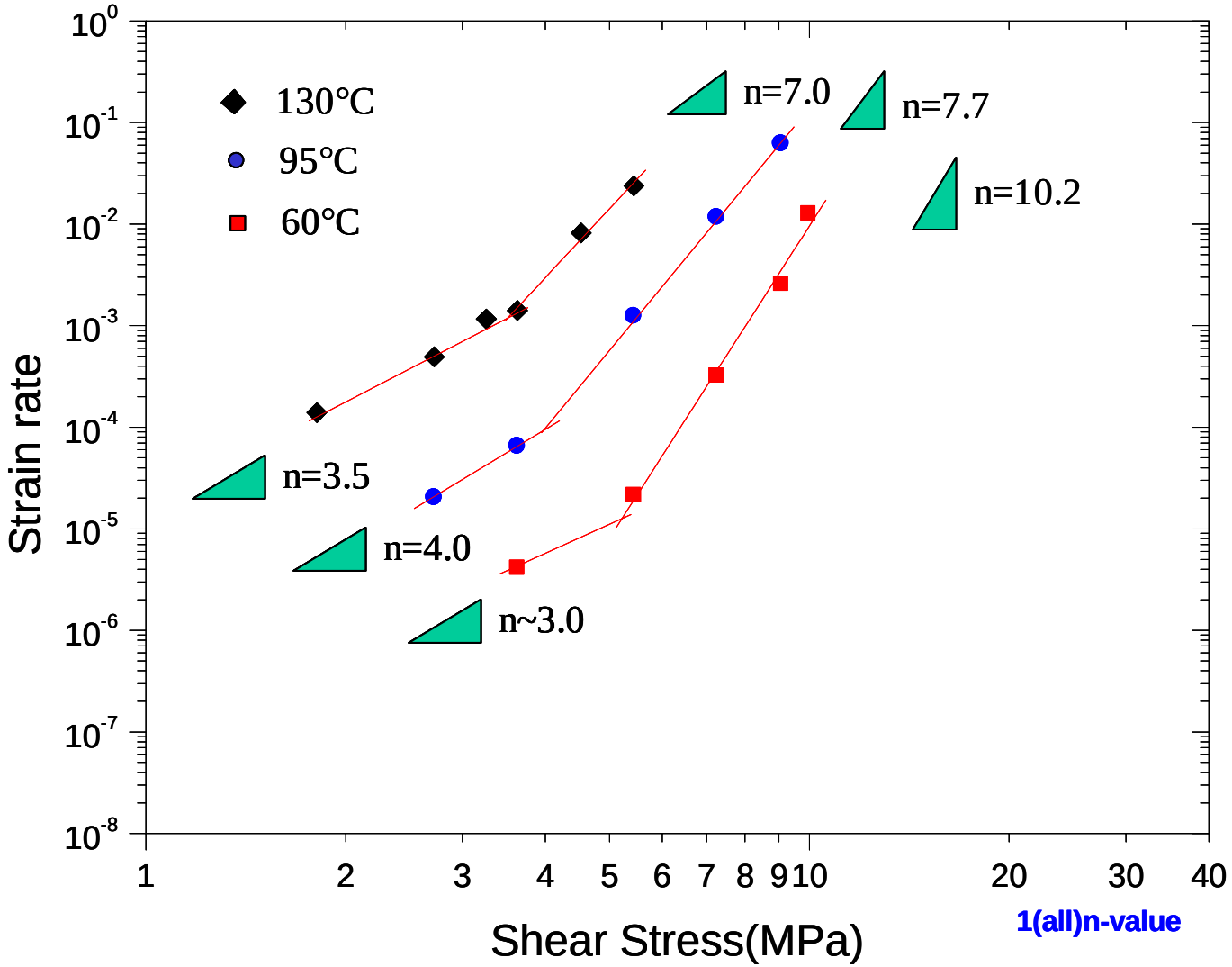
- Sn-0.7Cu has the lowest creep resistance
- The average activation energy for creep agrees well with Sn self-diffusion activation energy
  - Matrix creep dominated creep mechanism in the stress range tested for all the solders.
- All the Pb-free solders show clear two creep mechanisms at low temperature, 60C
  - More study required
- Faster cooling rate decreased creep resistance
  - Finer and uniformly distributed precipitates
  - Smaller grain in Sn matrix

Back-up

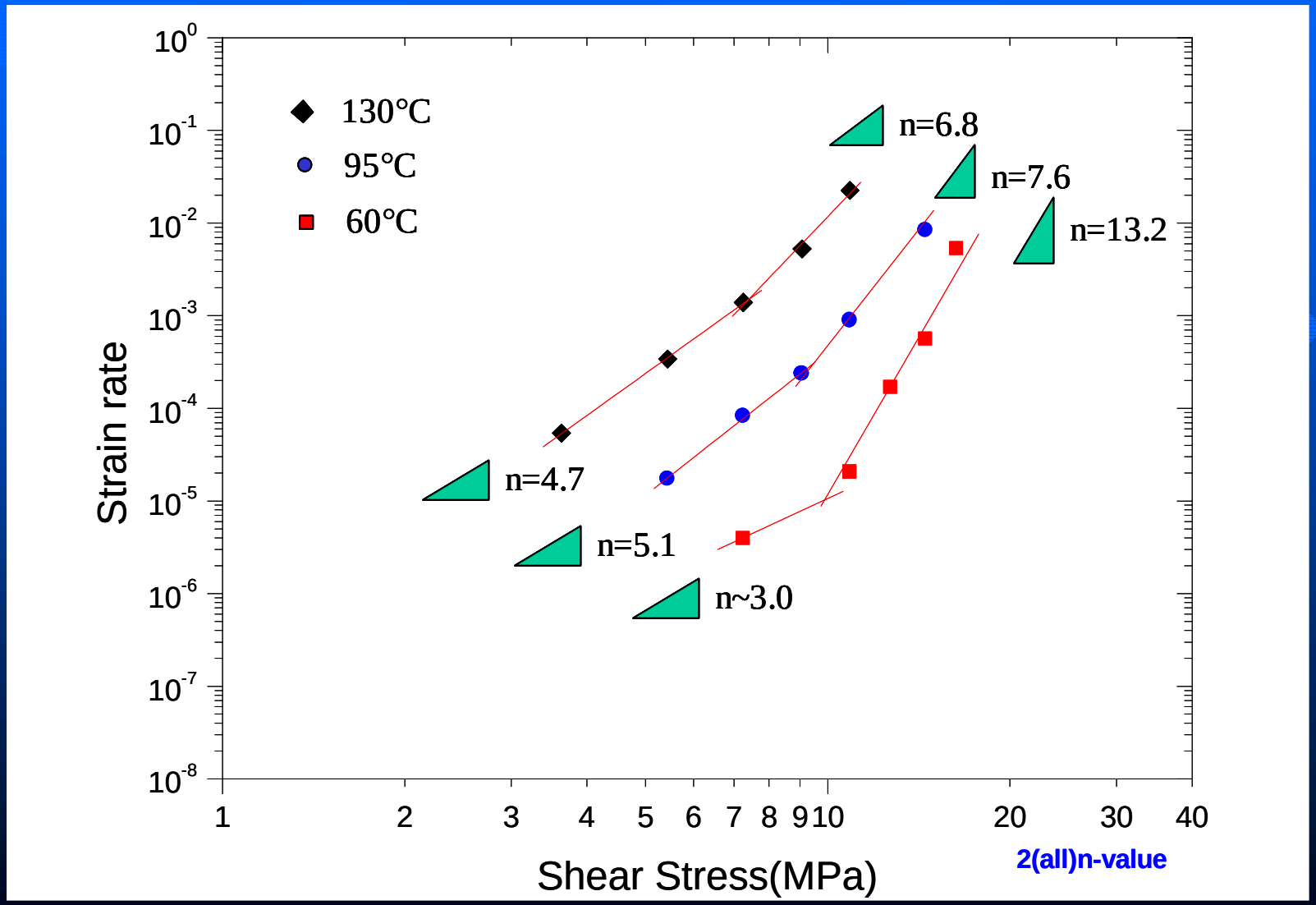
Sn-Ag-Cu


130°C
95°C
60°C
n=9.2
n=9.9
n=12.7
n=5.0
n=6.0
n=4.4
Strain rate
Shear Stress(MPa)
4(all)n-value

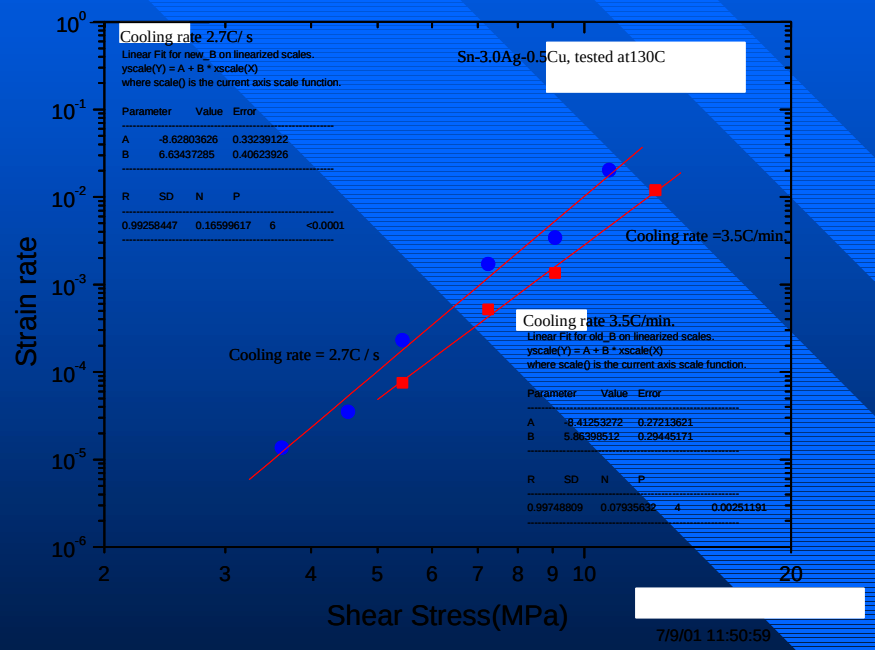
Sn-Cu

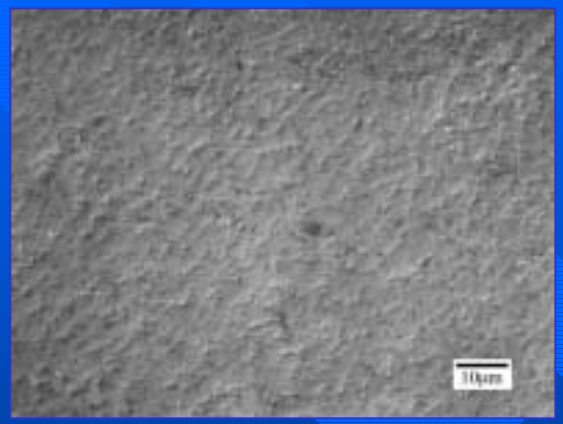

130°C
95°C
60°C
n=7.0
n=7.7
n=10.2
n=3.5
n=4.0
n~3.0
Strain rate
Shear Stress(MPa)
1(all)n-value

Sn-Ag

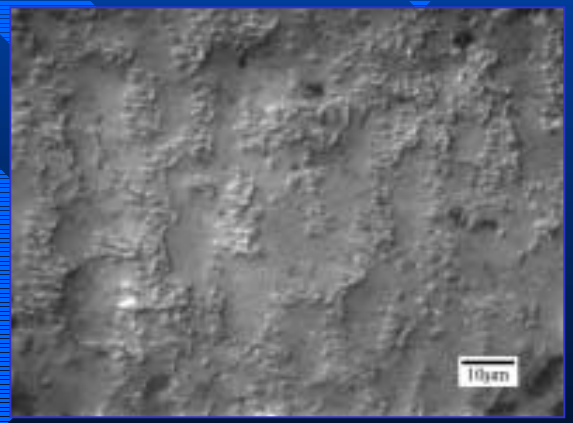

130°C
95°C
60°C
n=6.8
n=7.6
n=13.2
n=4.7
n=5.1
n~3.0
Strain rate
Shear Stress(MPa)
2(all)n-value

Sn-Ag-Cu



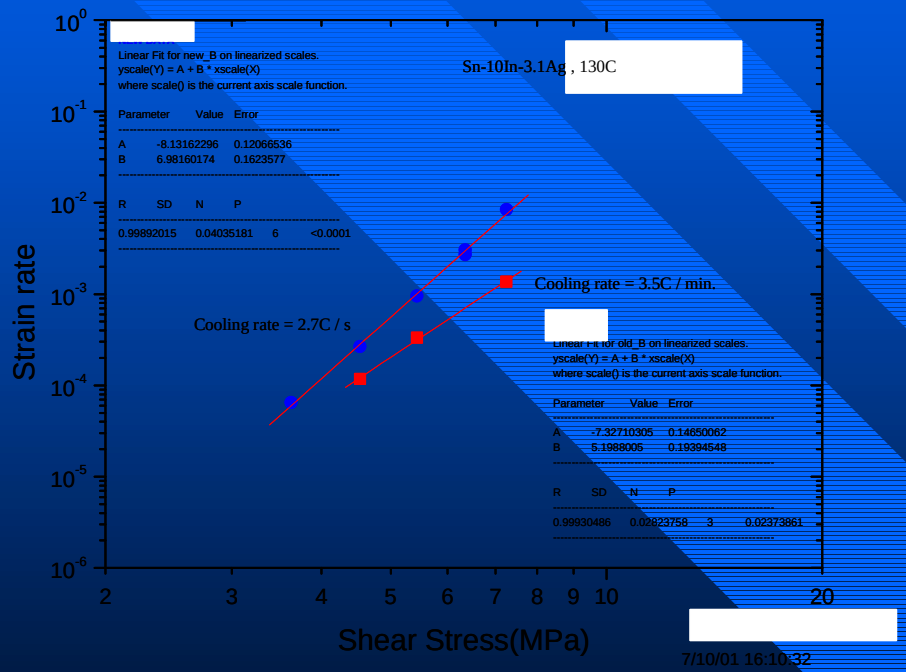


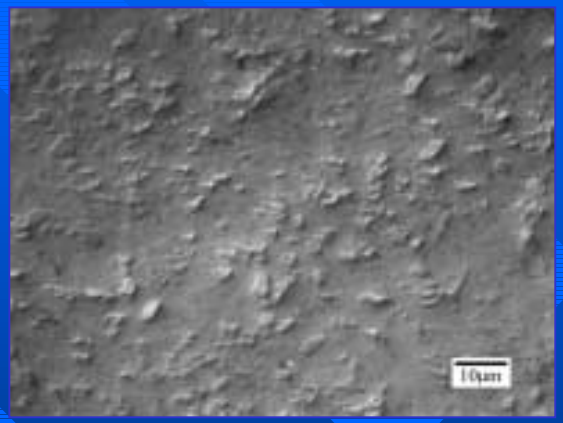
2.7C/s



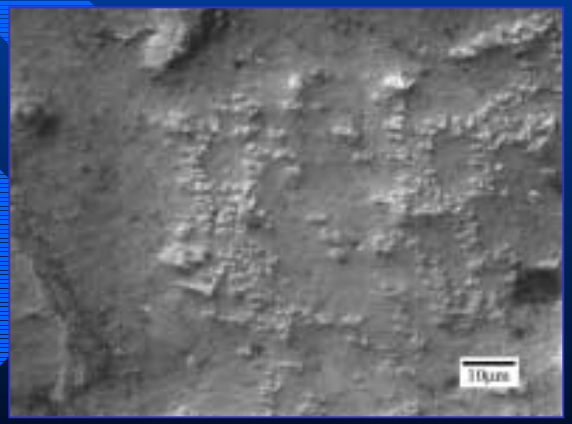
3.5C/min.

Sn-In-Ag





2.7C/s



3.5C/min.