Development of a Fatigue Resistant Alloy for High Performance Automotive Applications

Steve Brown - Cookson Electronics

Introduction

- The vast majority of solder alloy developments in the last 10 years have focused on ***process performance improvements*** and ***economic advantages***
- These developments were driven by the high volume, low cost products which were covered by the EU RoHS legislation
- Automotive electronics operating temperatures are increasing
- The need for high reliability in the harsh environment of the vehicle engine bay is not delivered by the standard tin-silver-copper (SAC) alloys.

Project Background

- Future requirements for automotive electronic modules to be located closer to the point of use
  - Harsh environment conditions
    - Higher temperatures / vibration levels
    - Pb-Free
- Available Materials in 2000

Materials		Issues
SnPb37, SnPb36Ag2	→	Limited HT resistance Contains Pb
SnAg3.5, SnCu0.7	→	High Processing Temperatures Limited rel in High T Conditions
SAC (Ag3-4, Cu0.5-0.9)	→	Limited rel in High T Conditions

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Definitions

Fatigue is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading. The maximum stress values are less than the ultimate tensile stress limit, and may be below the yield stress limit of the material

Creep is the tendency of a solid material to slowly move or deform permanently under the influence of stresses. It occurs as a result of long term exposure to levels of stress that are below the yield strength or ultimate strength of the material. Creep is more severe in materials that are subjected to heat for long periods, and near the melting point. Creep always increases with temperature.

Key Alloy Requirements

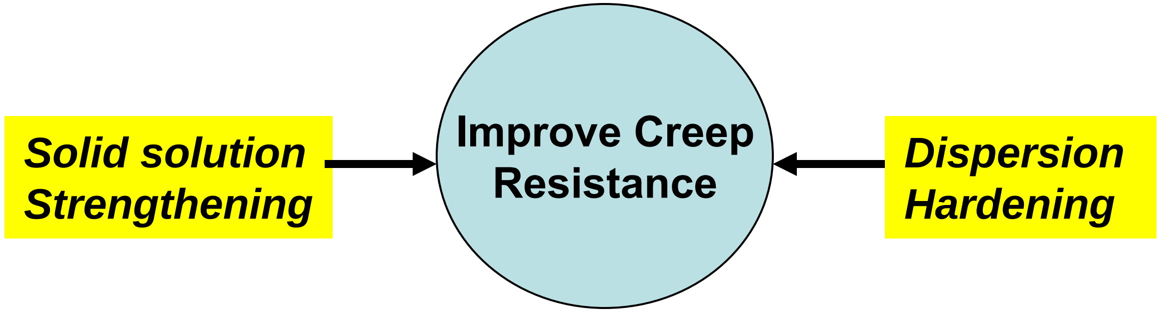
- A high reliability Pb-free alloy developed for the Automotive Industry
- Designed for up to 150°C operating temperature
- To survive 2000 cycles -40°C to 150°C
- Optimal reflow peak less than standard SAC387 (230°C)

Project Definition

- Improve Creep Performance at 150°C operating temperature

- Improve Fatigue performance in thermal cycling performance from -40 to +150°C

- SAC387 used as a baseline to develop from



Alloying Element Selection

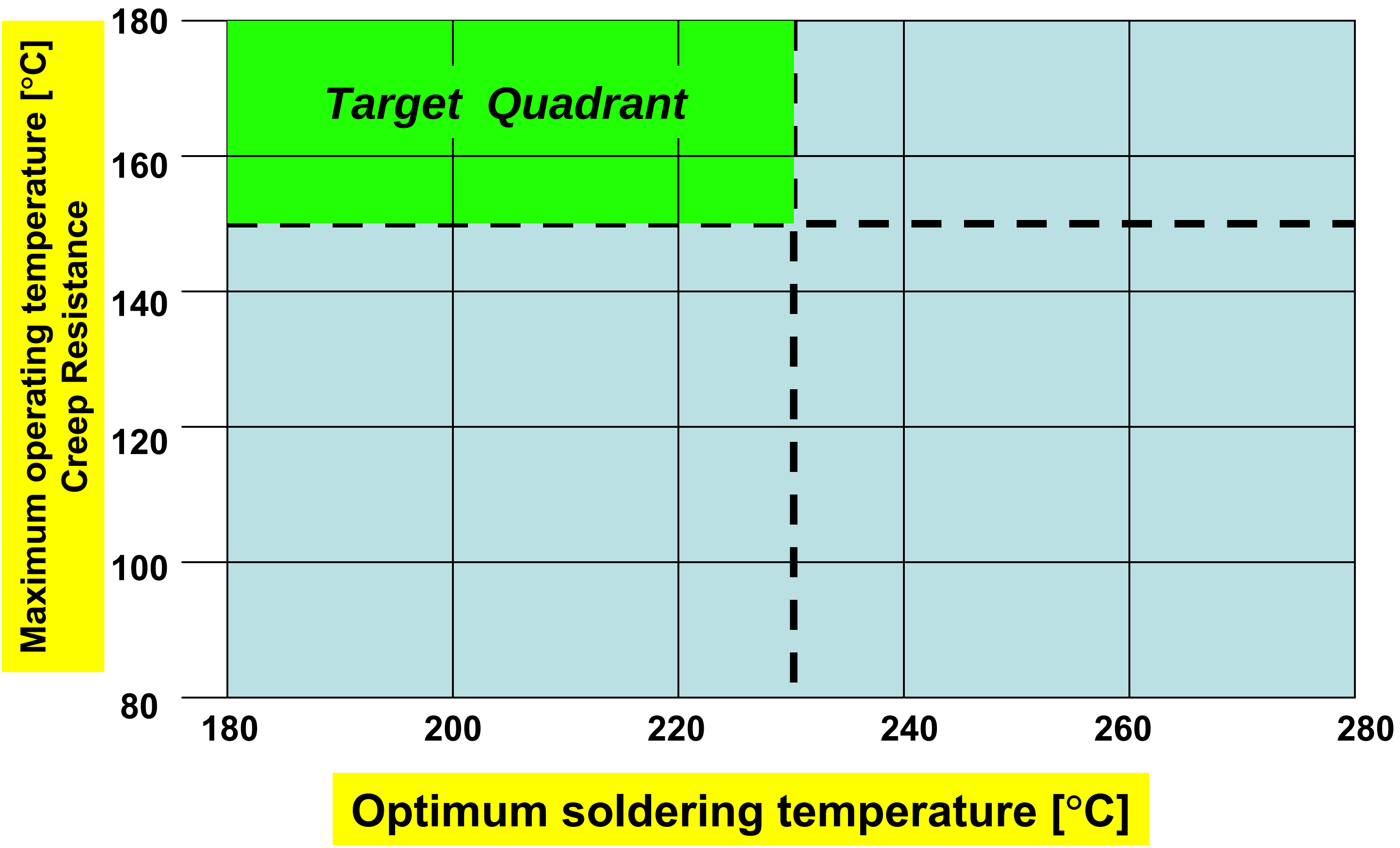
Health And Safety	
Lead	Most problem
Nickel	↑
Antimony	
Copper	
Indium	
Silver	
Tin	
Bismuth	Least problem

Environmental Impact	
Copper	Most problem
Silver	↑
Lead	
Antimony	
Nickel	
Tin	
Indium	
Bismuth	Least problem

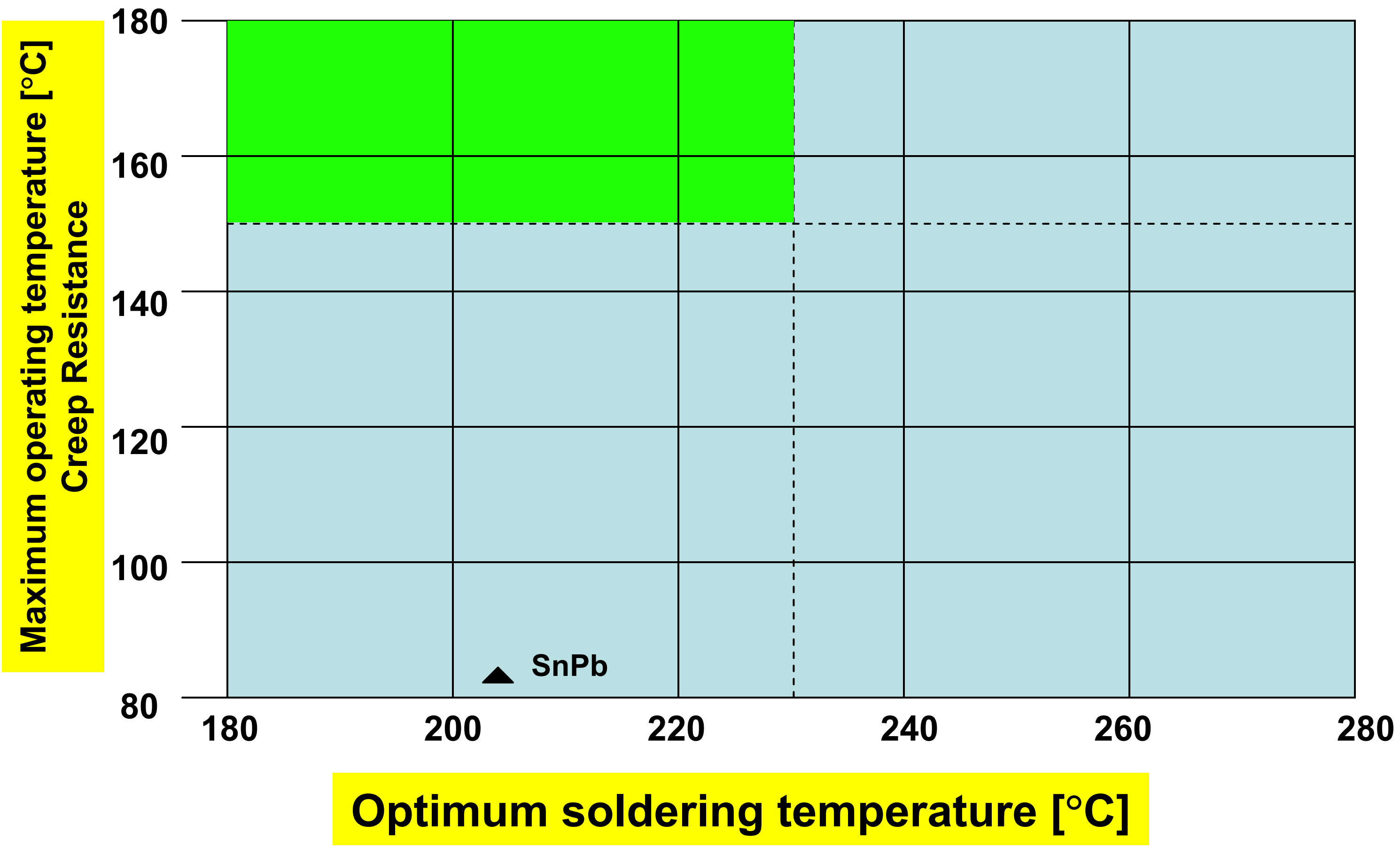
Choice of Suitable Alloying Elements

Bi	☺ Solid solution hardening ☺ Lowers Melting Temperature
Ni	☺ Dispersion hardening by intermetallic phase formation
Sb	☺ Solid solution hardening 👎 Raises melting temperature

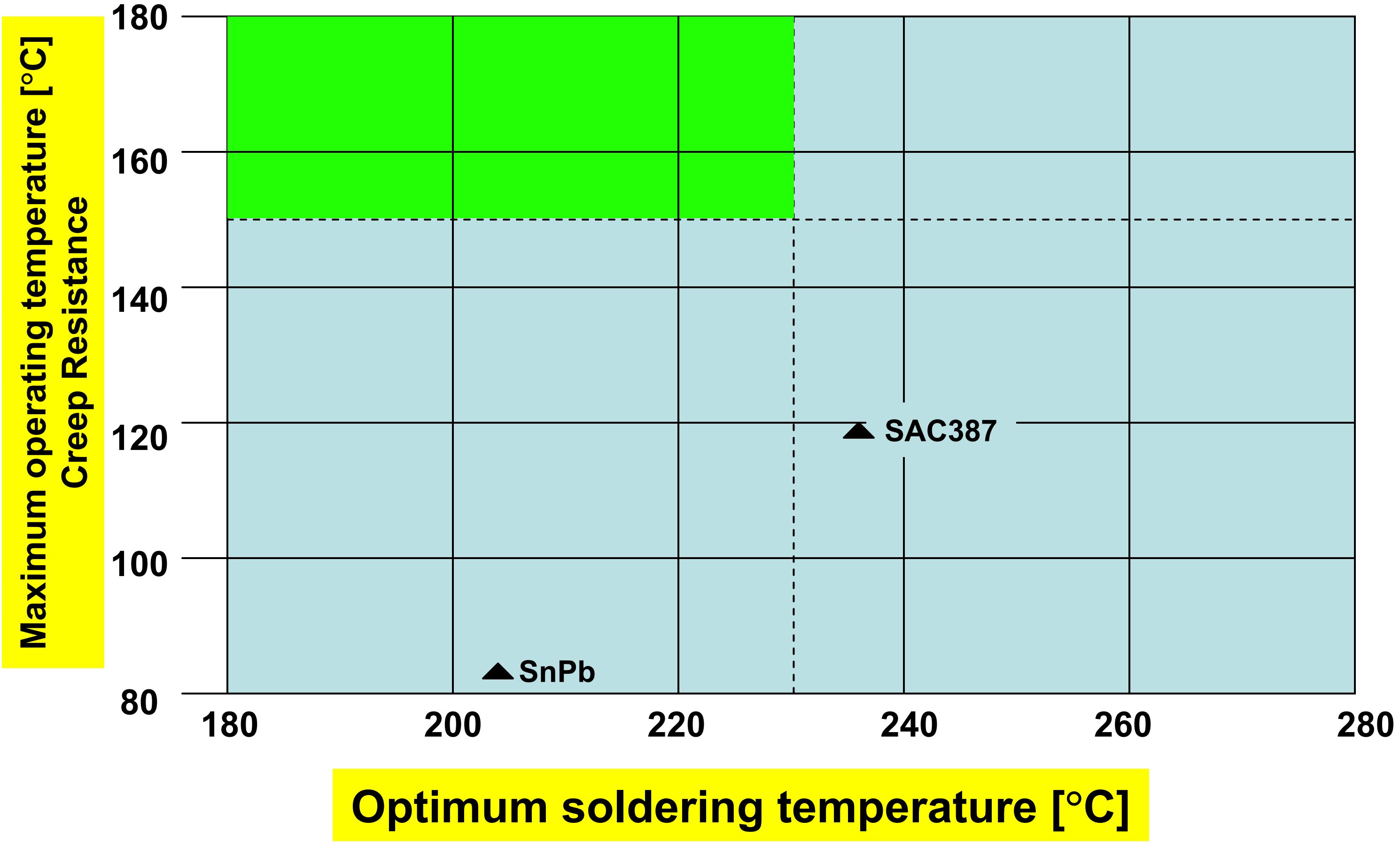
Alloy Optimisation



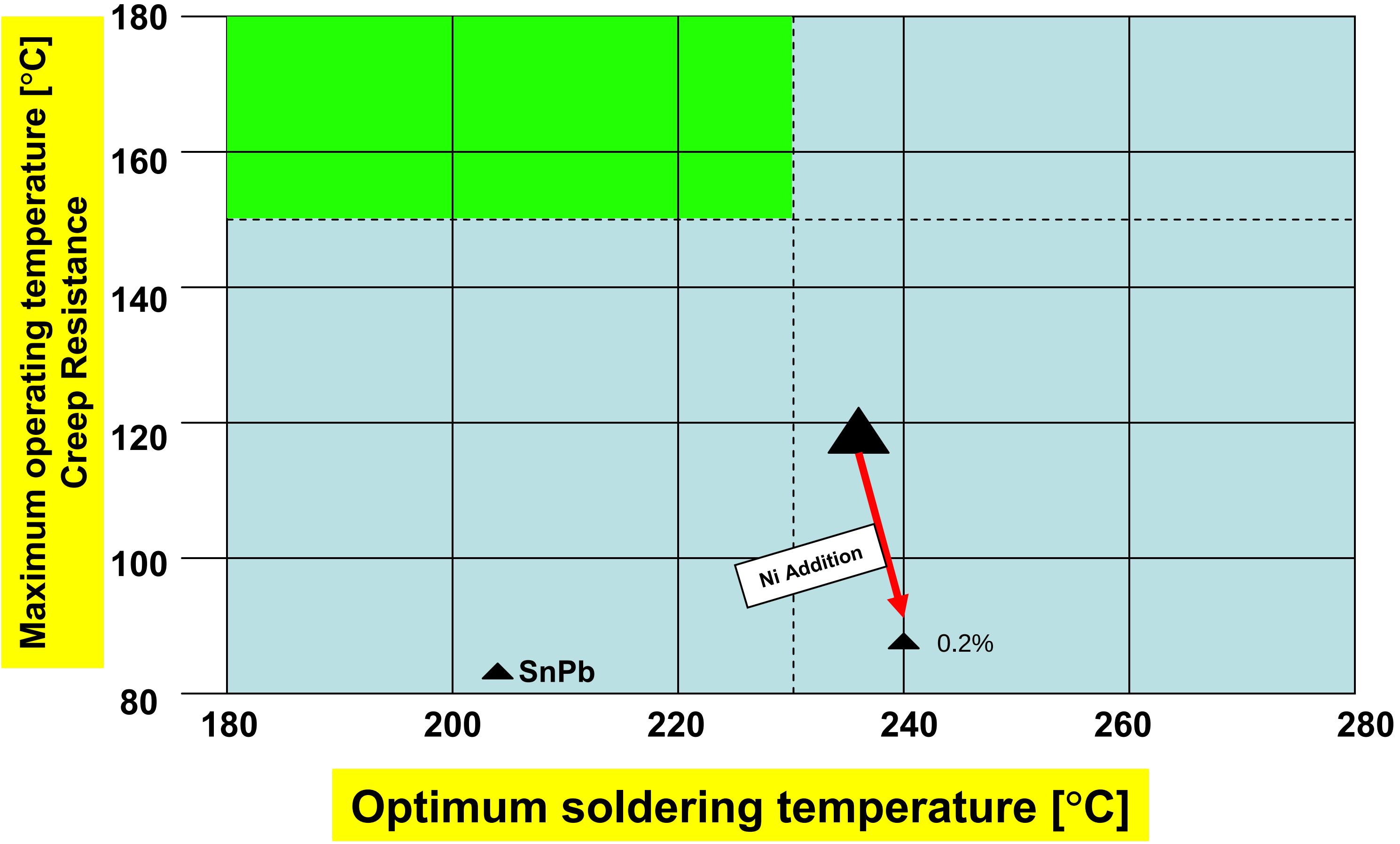
Current State - SnPb



Current State – SnPb & SAC



SAC387 + Single Element Additions



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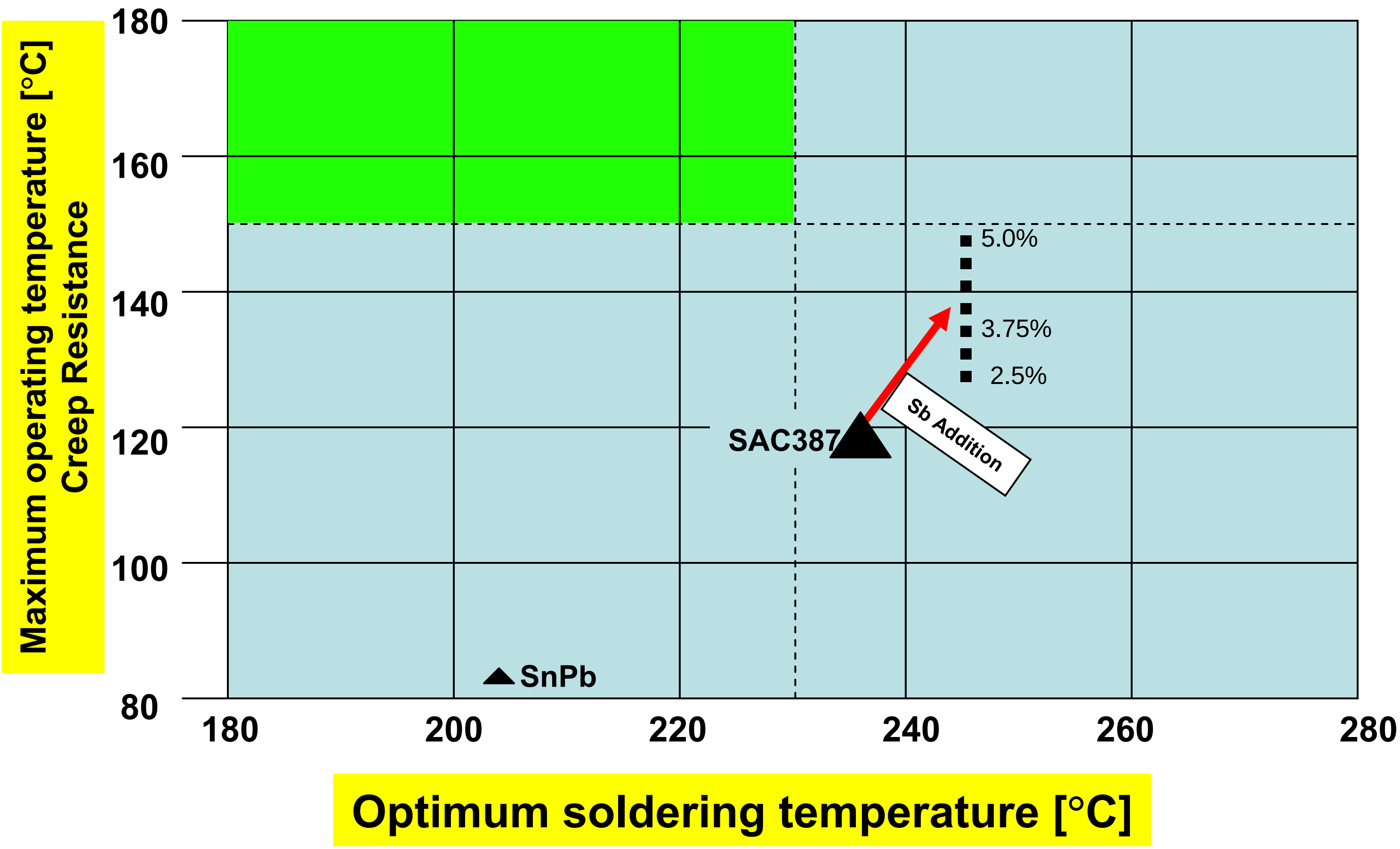

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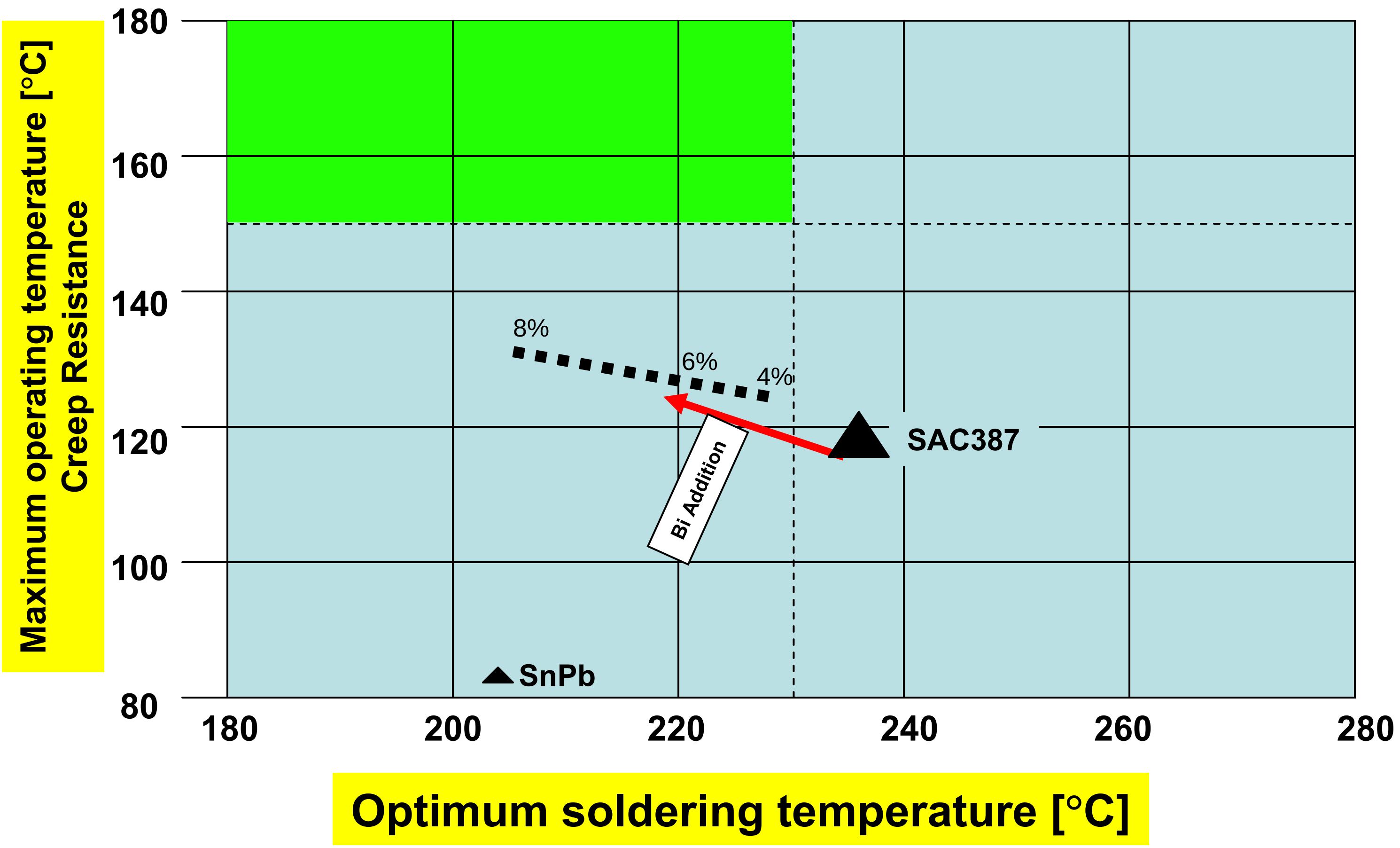
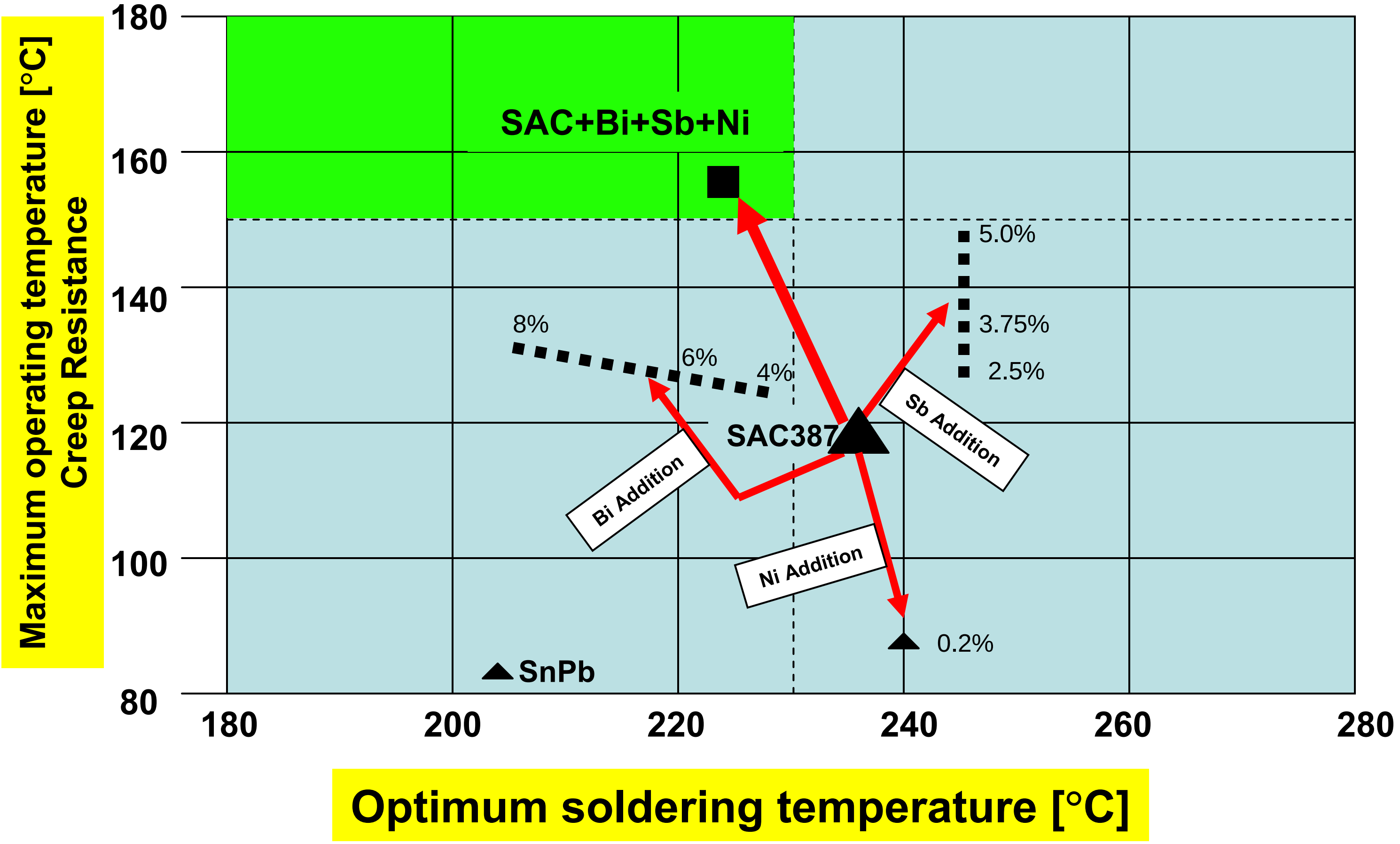
SAC387 + Single Element Additions



SAC387+Bi+Sb+Cu = InnoLot



InnoLot Alloy Composition

Sn	**Bal**
Ag	**3.8**
Cu	**0.7**
Bi	**3.0**
Sb	**1.4**
Ni	**0.15**

Alloy Performance

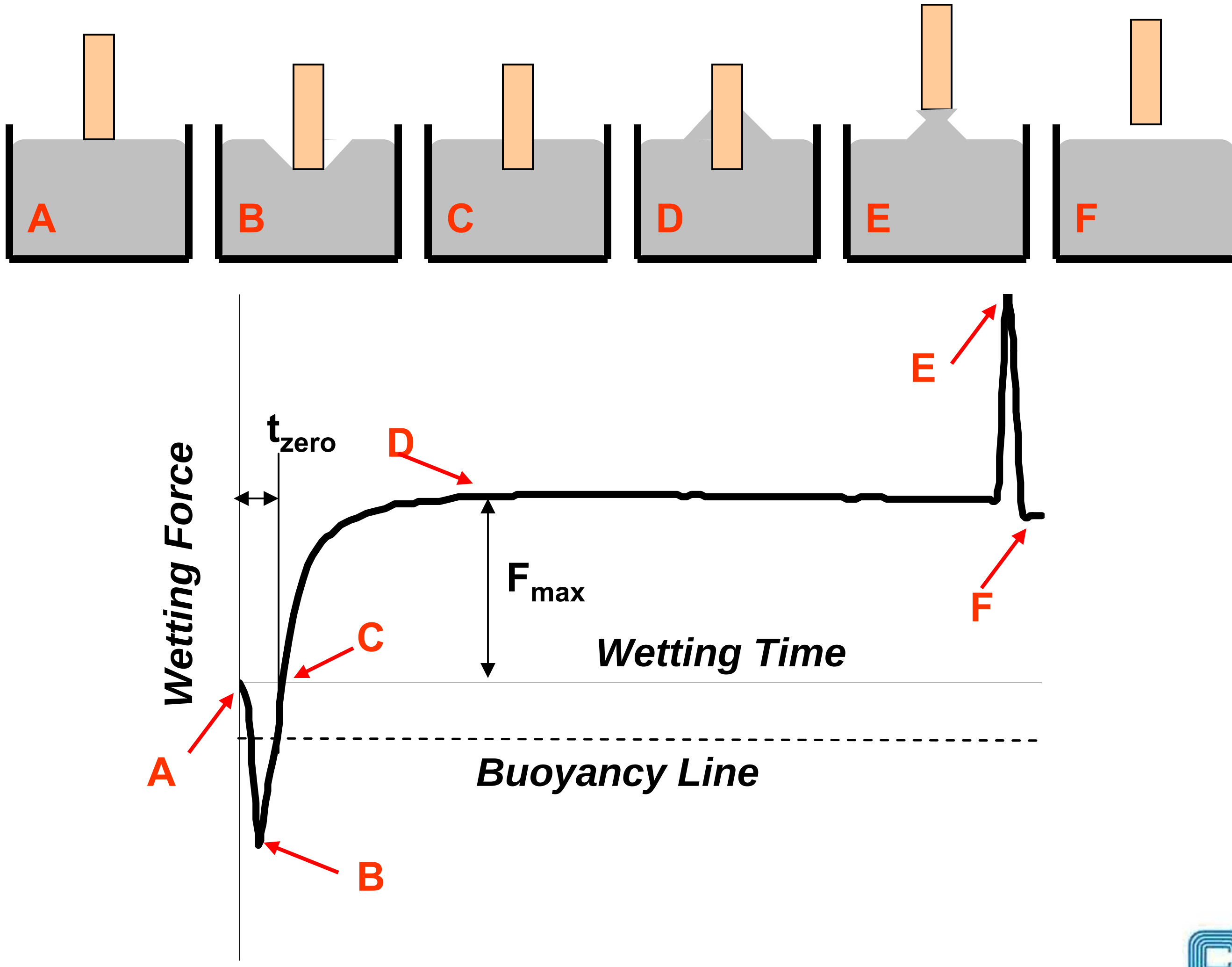
Wetting

In General…

- Bismuth enhances wetting
- Antimony can reduce wetting

- Wetting balance testing on Cu OSP PCB's
  – New OSP Coupons
  – Aged OSP Coupons

Defining Wetting Curve



Wetting Tests

Cu OSP PCB		Alloy Temperature					
Alloy	Atmosphere	225		235		260	
		T0	Fmax	*T0*	Fmax	*T0*	Fmax
InnoLot	Air	5.42	37	1.56	64	1.33	76
Innolot	N2	3.21	48	1.31	77	0.99	87
SAC387	Air	7.85	20	1.44	62	1.12	65
SAC387	N2	5.77	34	1.21	75	0.82	81

Cu OSP 4Hrs/155°		Alloy Temperature					
Alloy	Atmosphere	225		235		260	
		T0	Fmax	*T0*	Fmax	*T0*	Fmax
InnoLot	Air	Abort	/	4.54	21	3.01	46
Innolot	N2	Abort	/	3.21	34	2.29	59

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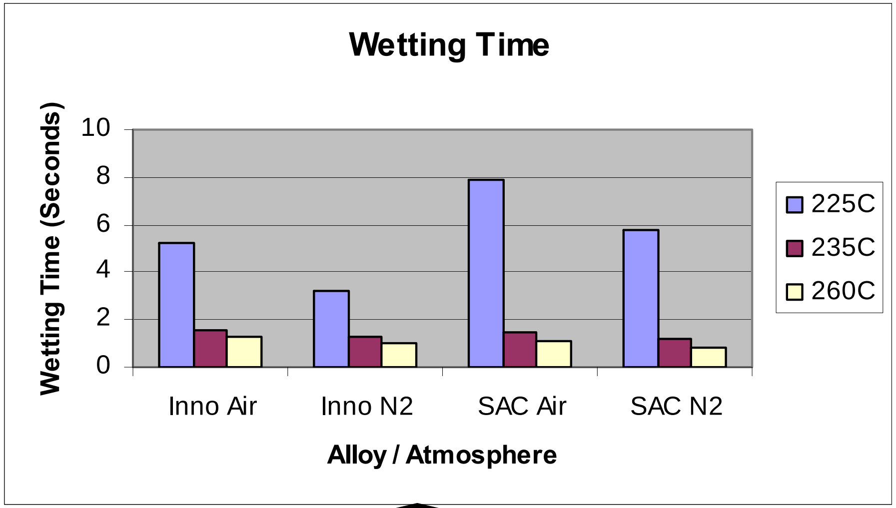
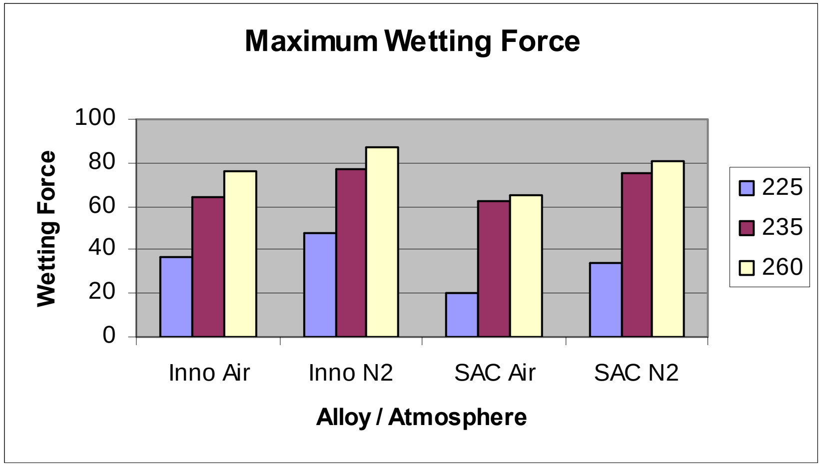
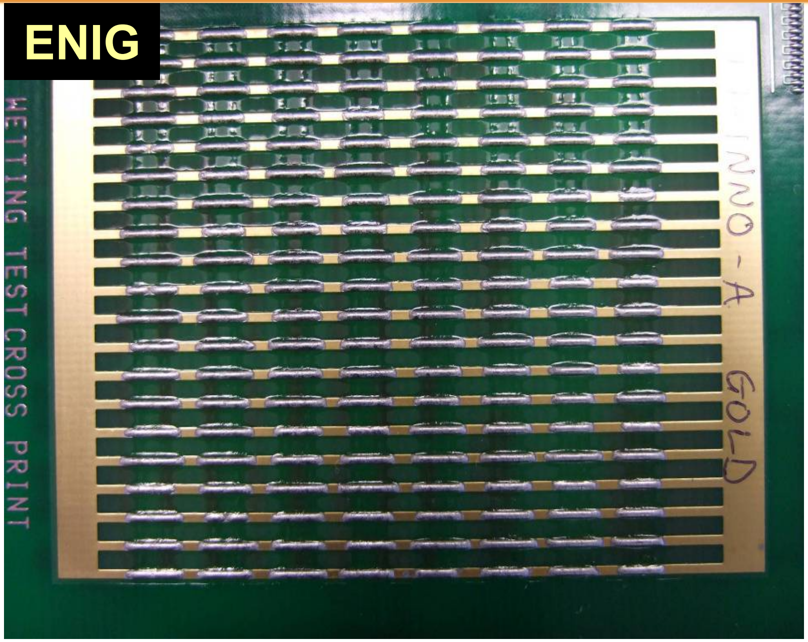
Wetting Comparison

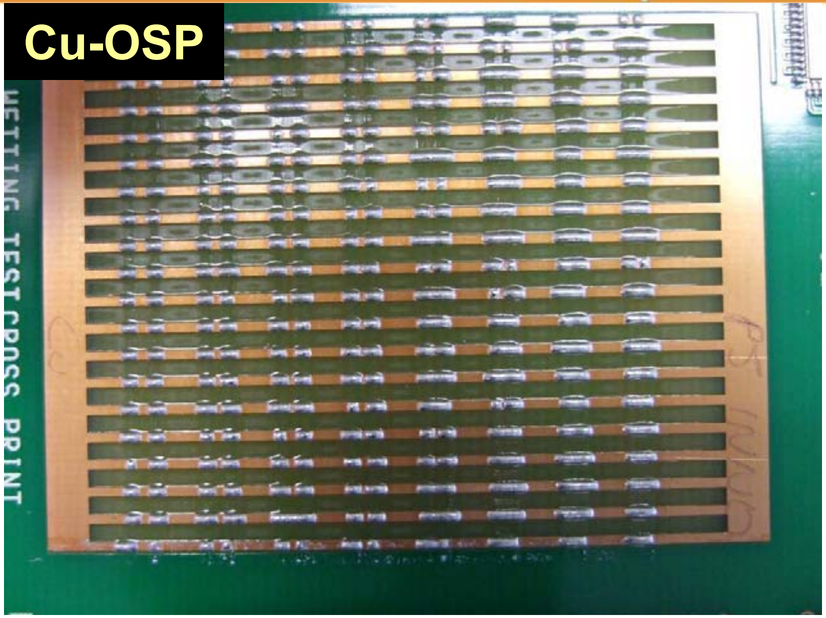


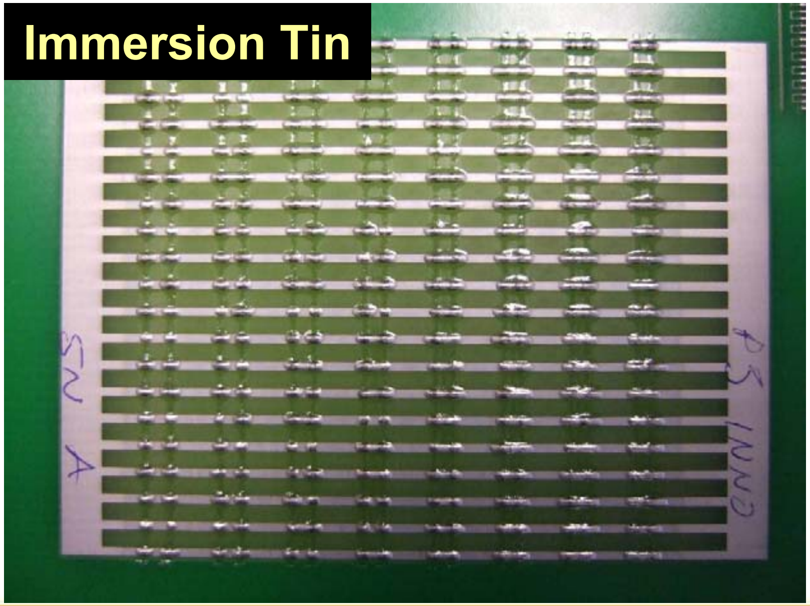
- InnoLot exhibits faster wetting at 225°C
- Comparable performance at 235°C

- InnoLot exhibits greater wetting force at 225°C
- Comparable performance at 235°C









Cross Print Wetting Test

Quantitative Wetting Comparison

8 Groups of Tramlines 0.1 – 1mm Gap

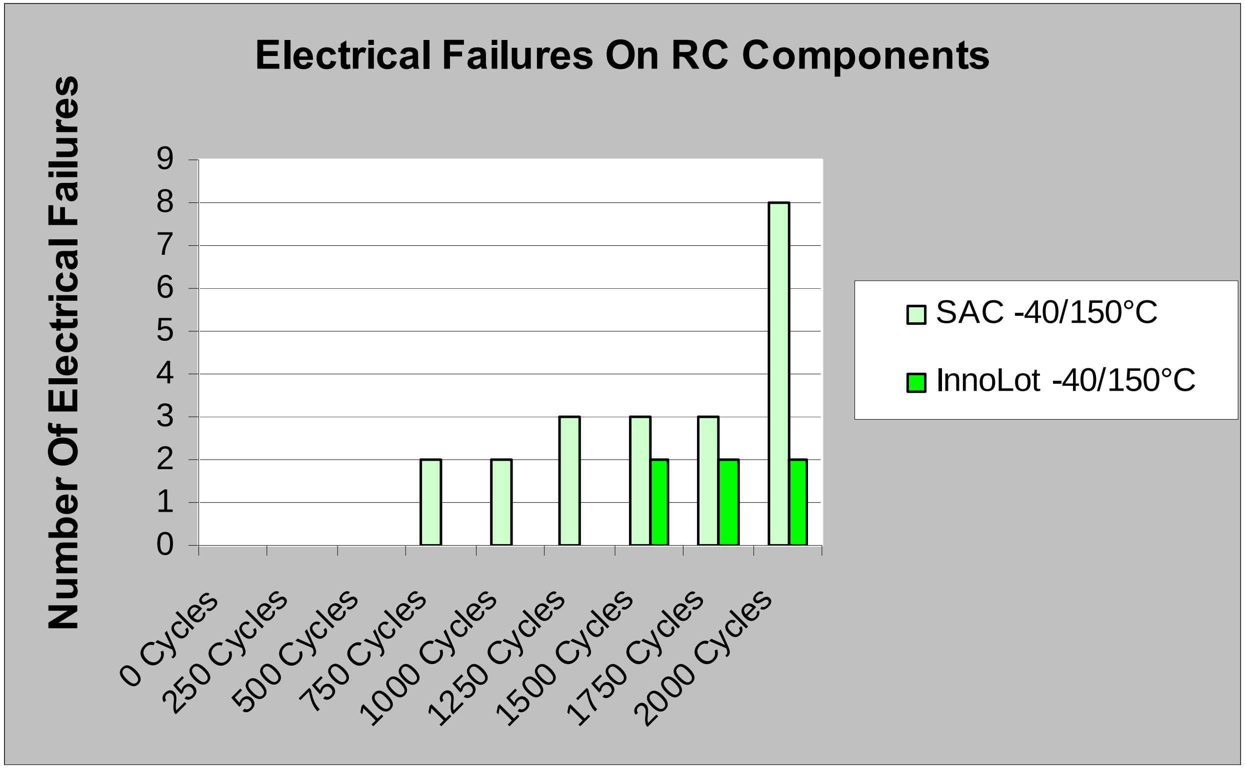
Each with 20 bridging opportunities

ENIG : Best Performance

Imm Sn :Mid performance

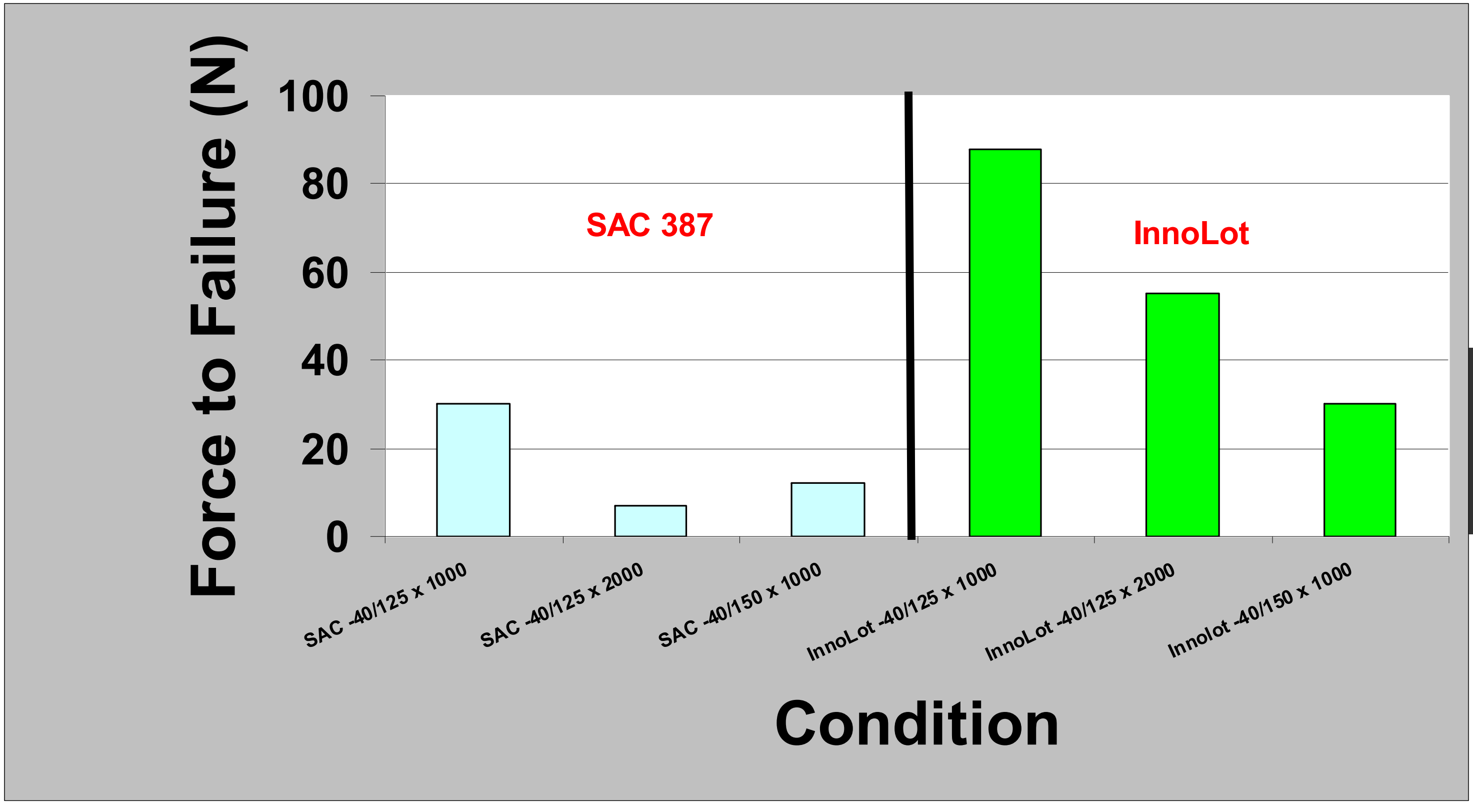
Cu OSP : Worst performance

Thermal Cycling Performance



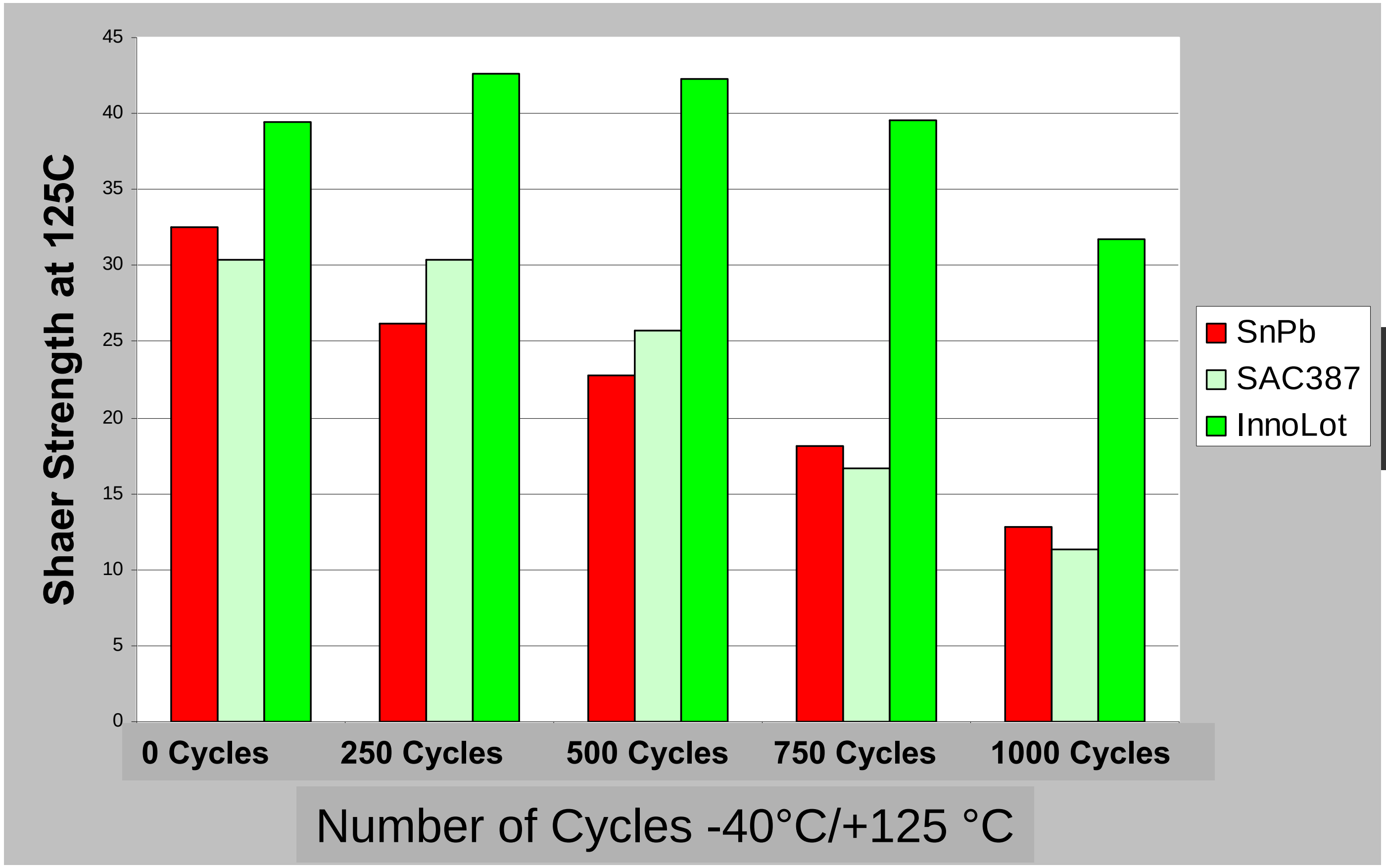
First failures on SAC at 750 cycles.
First failures on InnoLot at 1500 Cycles

Shear Testing Of Capacitors After Thermal Cycling



Shows that Innolot at -40C/+150°C is equivalent to SAC387 at -40/+125°C

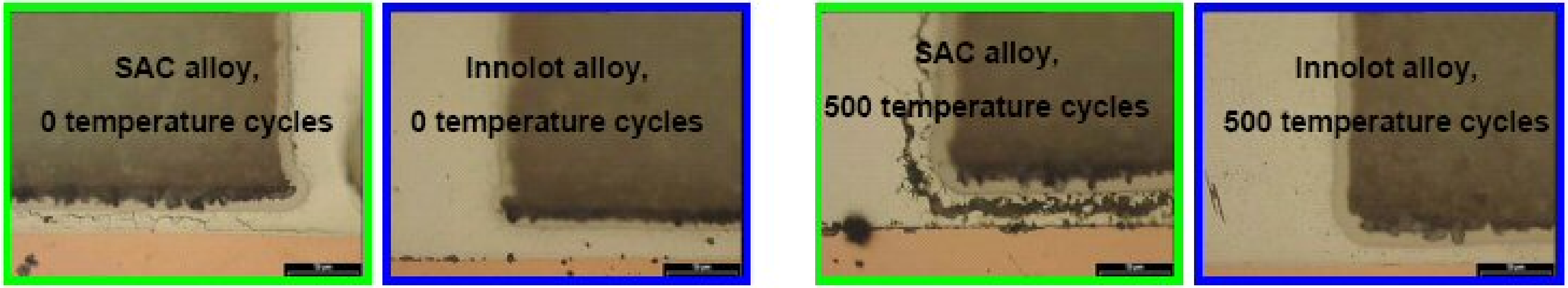
Shear Testing at Elevated Temperature After Thermal Cycling



Shows effects of alloying elements at elevated temperature

Vibration Testing

0603 Failure characteristics under vibration (with and without thermal cycling)



Test	i	ii	iii	iiia	iv	v	vi	vii	viii	ix	x
V.force	2g	5g	10g	15g	15g	15g	15g	15g	20g	20g	30g
Time (min)	3	3	3	3	15	15	45	60	15	60	60

1st SAC387 Failure (Test iii)

1st Innolot Failure (Test v)

Summary

- InnoLot alloy is proven to be mechanically superior to SAC387 in vibration testing after zero and 500 thermal cycles
- Proven evidence of improved reliability in -40/ +150°C thermal cycling
- A good fit for harsh environment vehicle electronics