A Compliant and Creep Resistant SAC-Al(Ni) Alloy

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EXECUTIVE SUMMARY

Addition of Al into SAC alloys reduces the number of hard Ag_3Sn and Cu_6Sn_5 IMC particles, and forms larger, softer non-stoichiometric AlAg and AlCu particles. This results in a significant reduction in yield strength, and also causes some moderate increase in creep rate. For high Ag SAC alloys, adding Al 0.1-0.6% to SAC alloys is most effective in softening, and brings the yield strength down to the level of SAC105 and SAC1505, while the creep rate is still maintained at SAC305 level. Addition of Ni results in formation of large $(Ni, Cu)_3Sn_4$ IMC particles and loss of Cu_6Sn_5 particles. This also causes softening of SAC alloys, although to a less extent than that of Al addition. Addition of Al also drives the microstructure to shift from near-ternary SnAgCu eutectic toward combination of eutectic SnAg and eutectic SnCu. Addition of Ni drives shifting toward eutectic SnAg. For SAC+Al+Ni alloys, the pasty range and liquidus temperature are about 4°C less than that of SAC105 or SAC1505 if the addition quantity is less than about 0.6%. Addition of Al and Ni also results in a slight decrease in modulus and elongation at break, although the tensile strength is not affected.

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Background

- SAC solder with high Ag content needed for thermal fatigue performance & for narrow pasty range. IMC particles of Ag-Sn and Cu-Sn responsible for the fatigue resistance.
- However, for high Ag SAC alloys, a greater ductility is also desired for non-fragility.
- Addition of element which can reduce IMC particles may improve the ductility.

Approaches

- Al reacts with both Ag and Cu, which promises a reduction in the quantity of Ag_3Sn and Cu_6Sn_5, is a very capable candidate.
- Adding Ni is reported to be beneficial, due to its effect in suppressing the growth of IMC scallop size and thickness on Cu.

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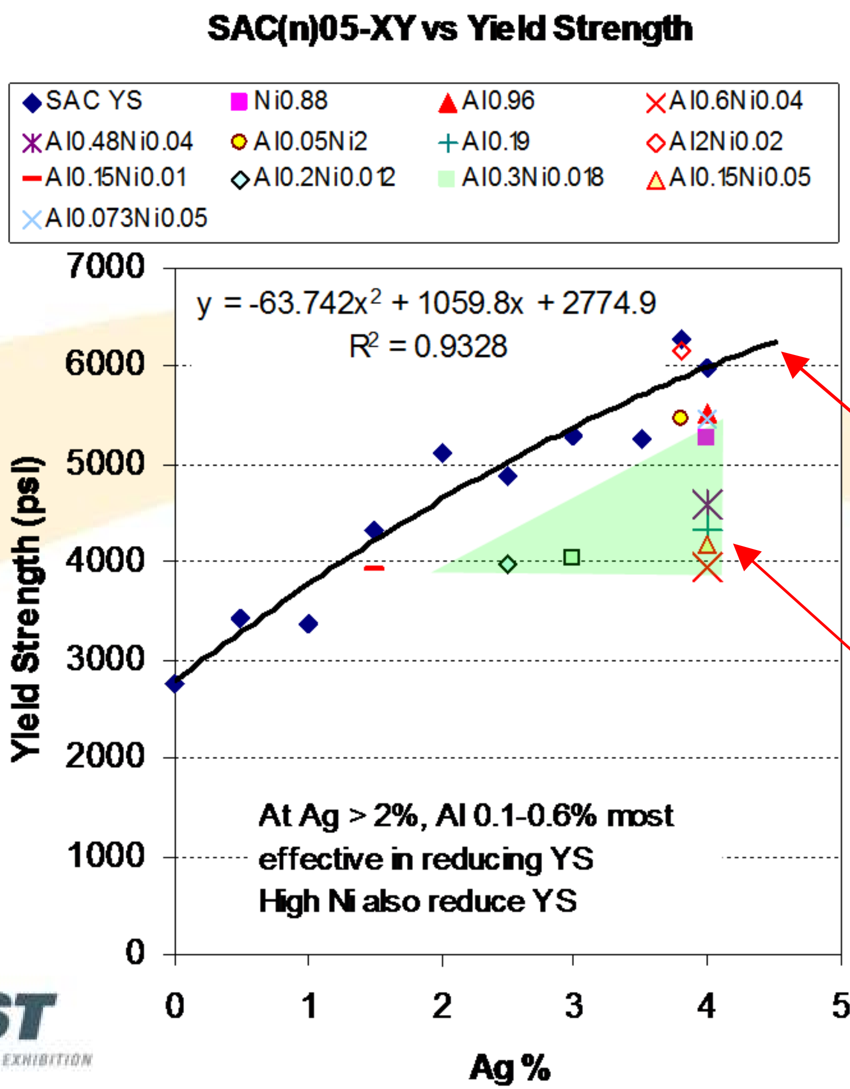
Tests

- Tensile test
  - The diameter and length of the cylinder central testing region is 0.125 inch and 2 inch, respectively.
  - Crosshead speed - 0.2 inch/min.
  - Yield strength, ultimate tensile strength, elongation at break, and modulus determined.
  - 5-15 specimen used for each alloy.
- SEM & EDX for microstructure
- DSC
  - 10°C/min heating & cooling, between -40 & 260 °C
  - 2nd heating run used for comparison
- Creep test
  - Two specimen used for each combination of alloy and stress condition.

Effect of alloy composition on yield strength



Yield strength increases with increasing Ag content

Addition of Al and Ni can result in a significantly reduced yield strength

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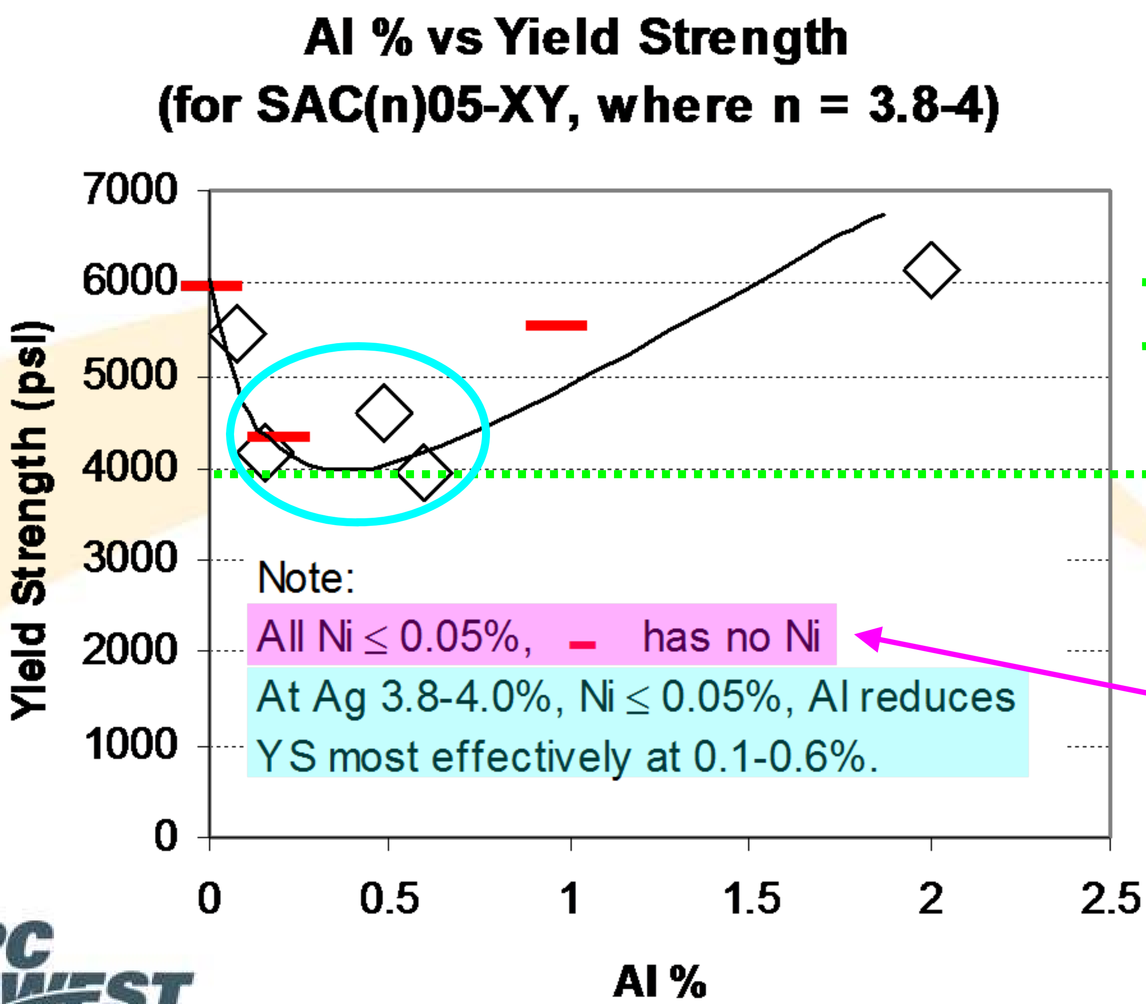
Effect of Al addition on yield strength of SAC(n)05-XY

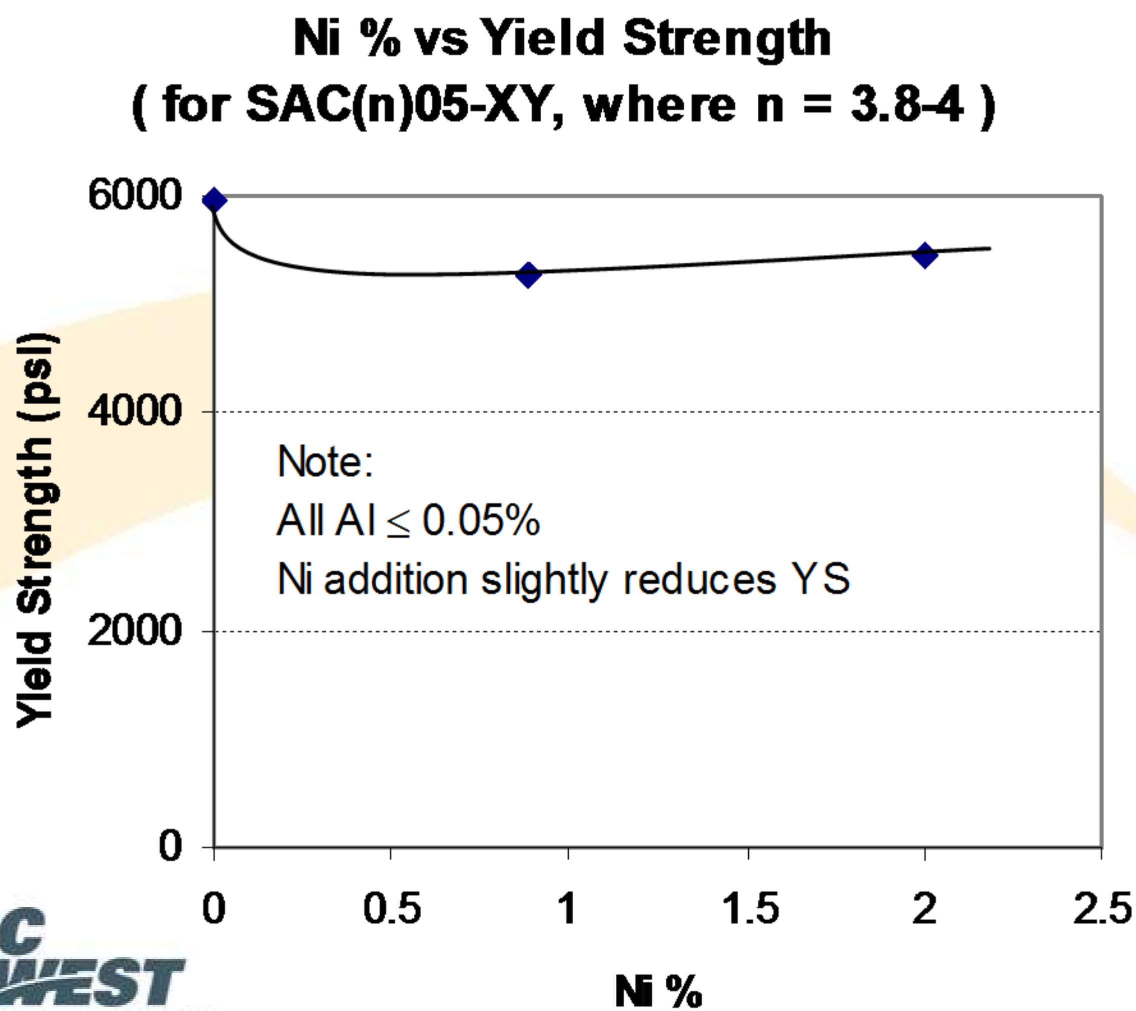


YS of SAC405 & SAC305

YS of SAC105 & 1505

Al dominant in effect on YS (w & w/o Ni, trends comparable)

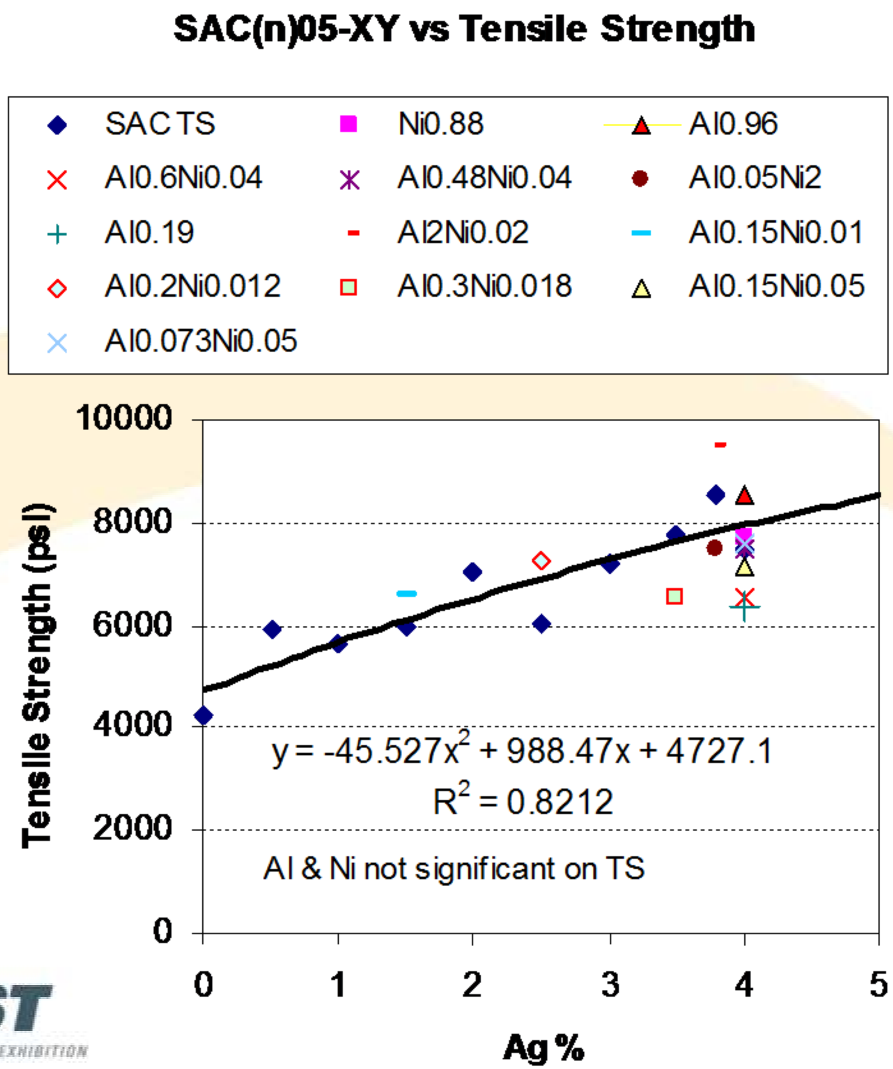
Effect of Ni addition on yield strength of SAC(n)05-XY



Addition of Ni results in a slight decrease in yield strength.

The extent of yield strength drop is about 1/3 of Al addition (6000 →4000)

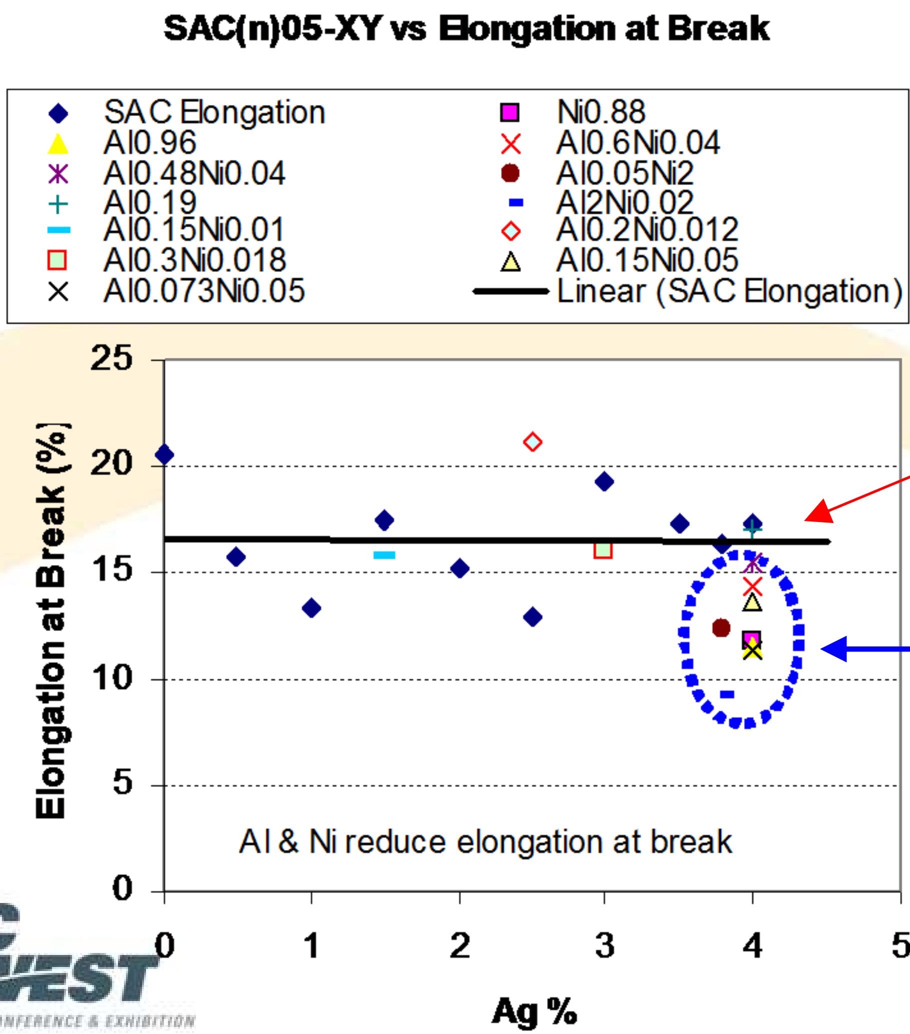
Effect of alloy composition on tensile strength



Tensile strength increases with increasing Ag content

The effect of Al and Ni addition not significant

Effect of alloy composition on elongation at break



Elongation at break is insensitive to Ag content

Adding Al or Ni does cause a decrease in elongation at break

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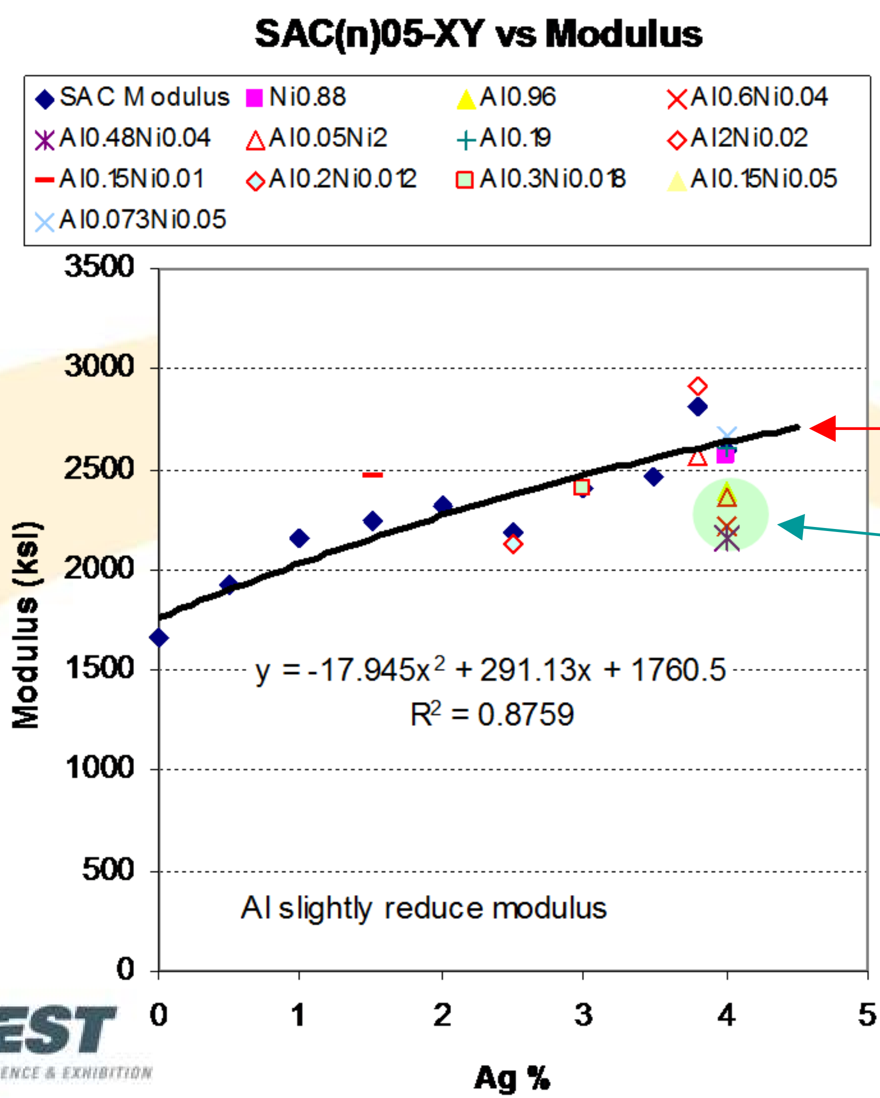
Effect of alloy composition on modulus



Modulus increases with increasing Ag content

Addition of Al and Ni results in a slight decrease in modulus

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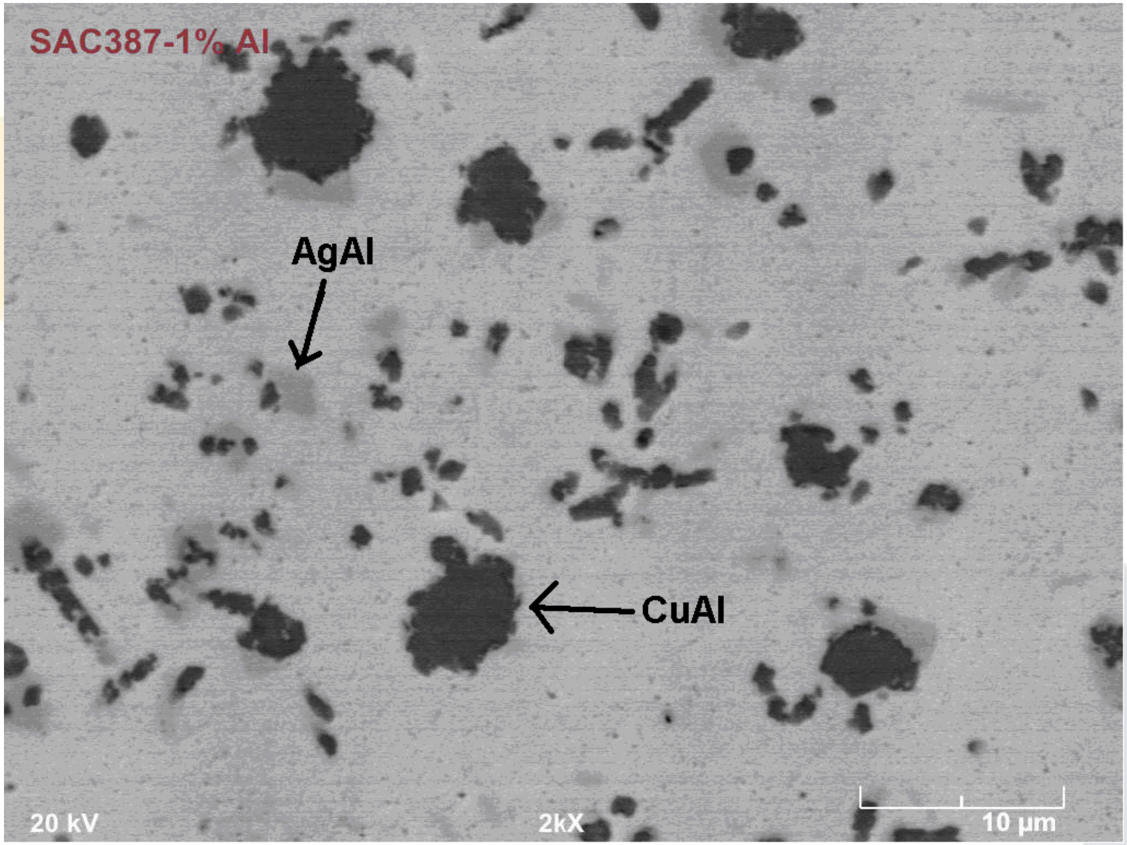
SEM micrograph of Sn94.43Ag3.97Cu0.64Al0.96 (2000X)

IMC particles are primarily IMC of AlAg and AlCu partially mixed with Sn



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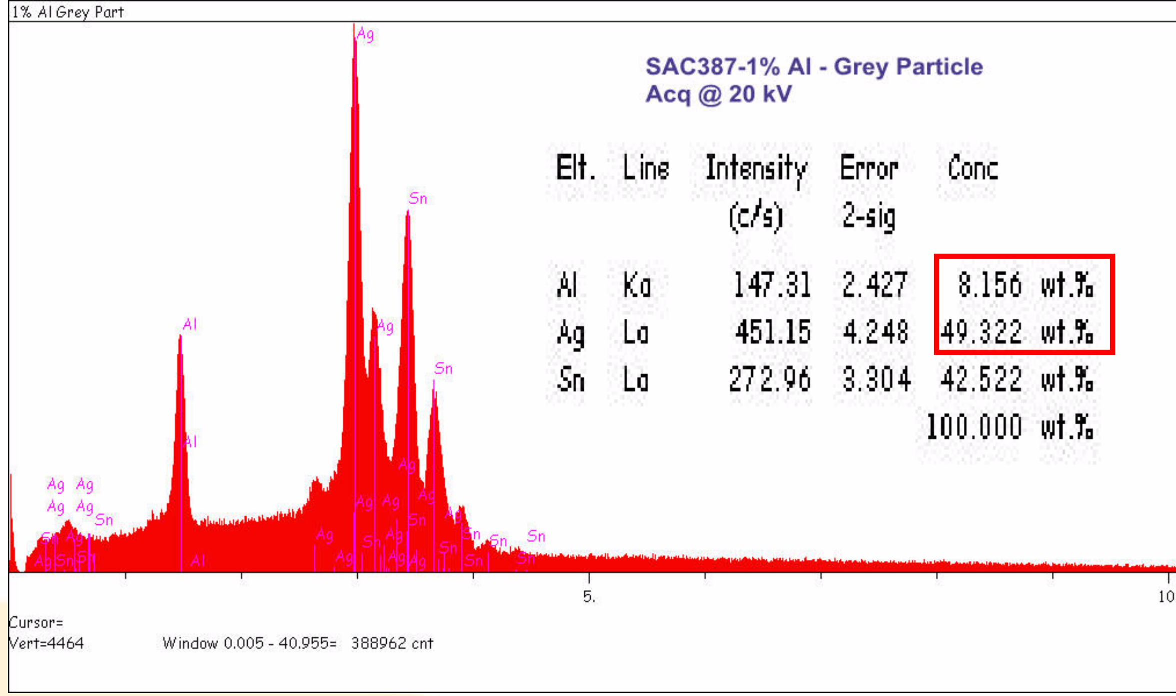
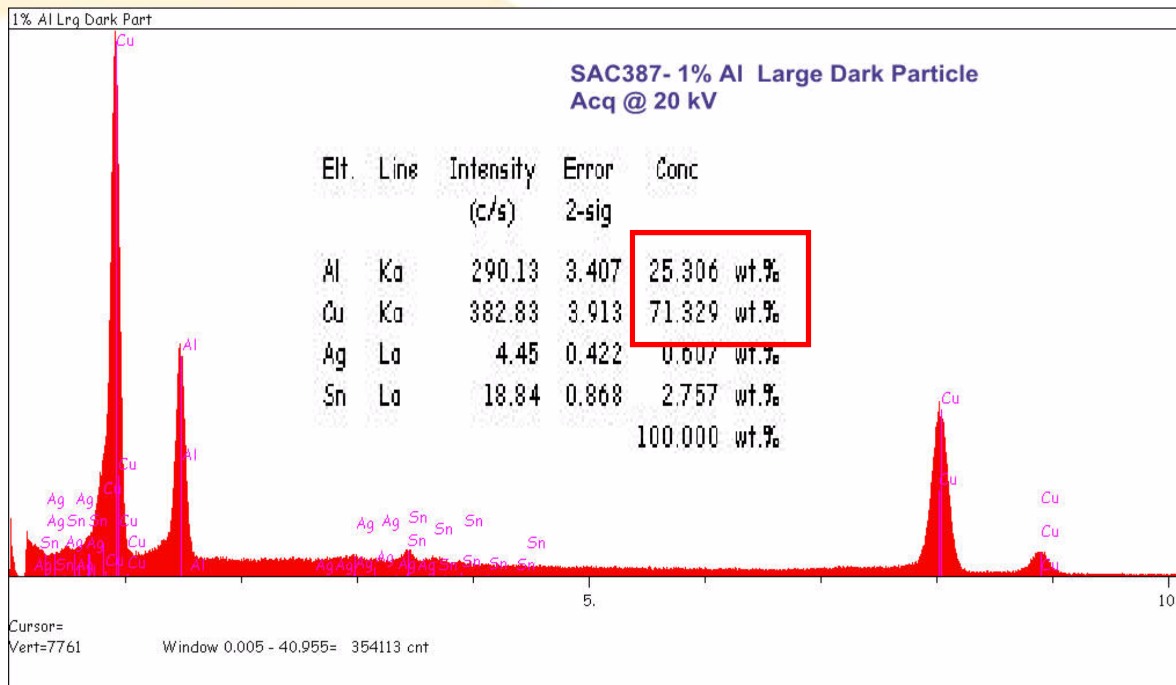
EDX graph on gray (top) and dark (bottom) IMC particles of Sn94.43Ag3.97Cu0.64Al0.96



The weight ratio of Ag to Al is about 6:1, and the weight ratio of Cu to Al is about 3:1 here.

Therefore, at Al content of 0.96%, most of the Ag and Cu in this alloy Sn94.43Ag3.97Cu0.64Al0.96 will be drained from the solder matrix and be associated with Al.



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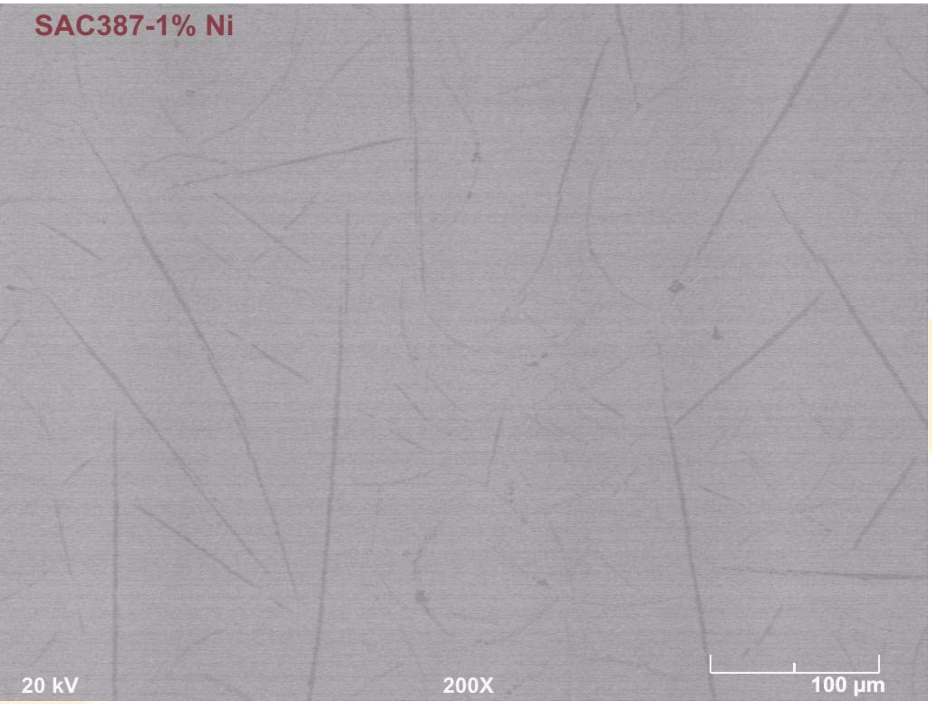
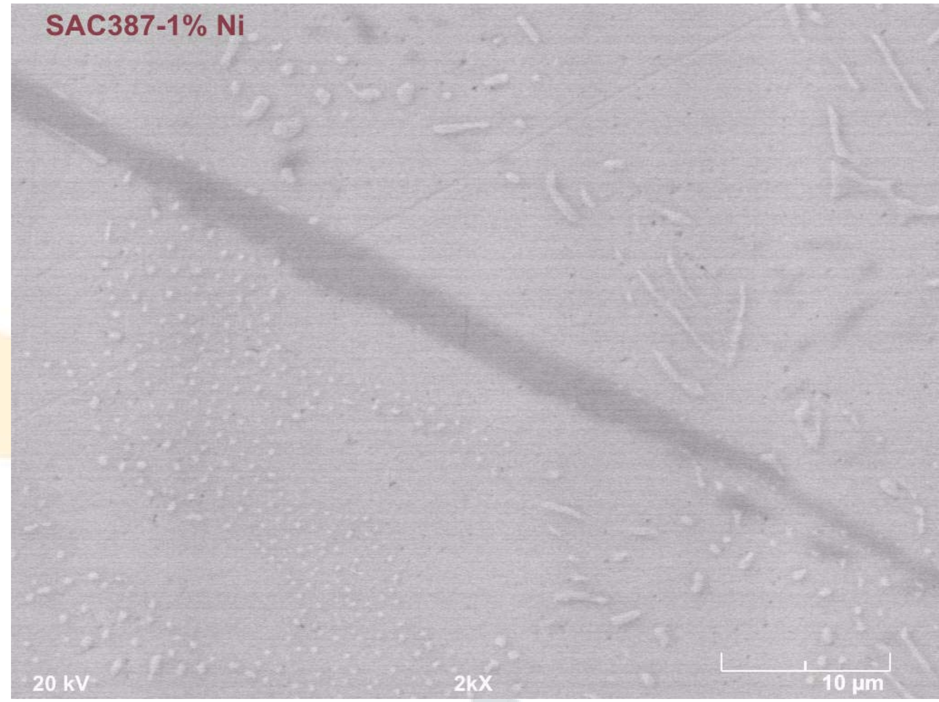
SEM micrograph of Sn94.49Ag3.99Cu0.64Ni0.88



200X

The gray needle was identified as $(Ni,Cu)_3Sn_4$



2000X

Many bright Ag_3Sn IMC particles in the form of micron-sized round particles or short rods

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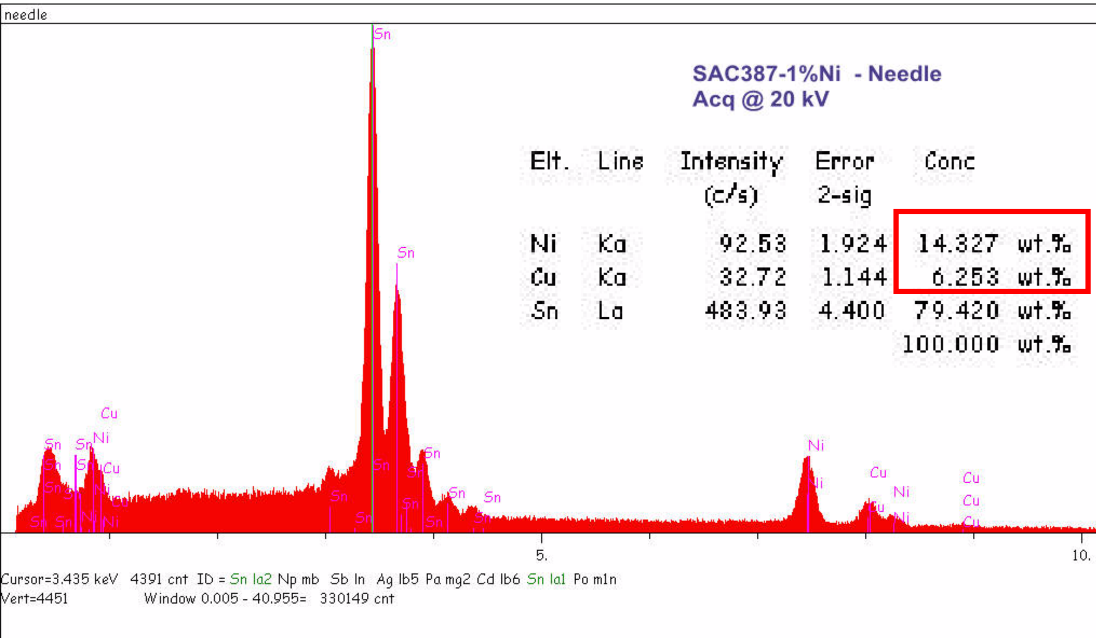
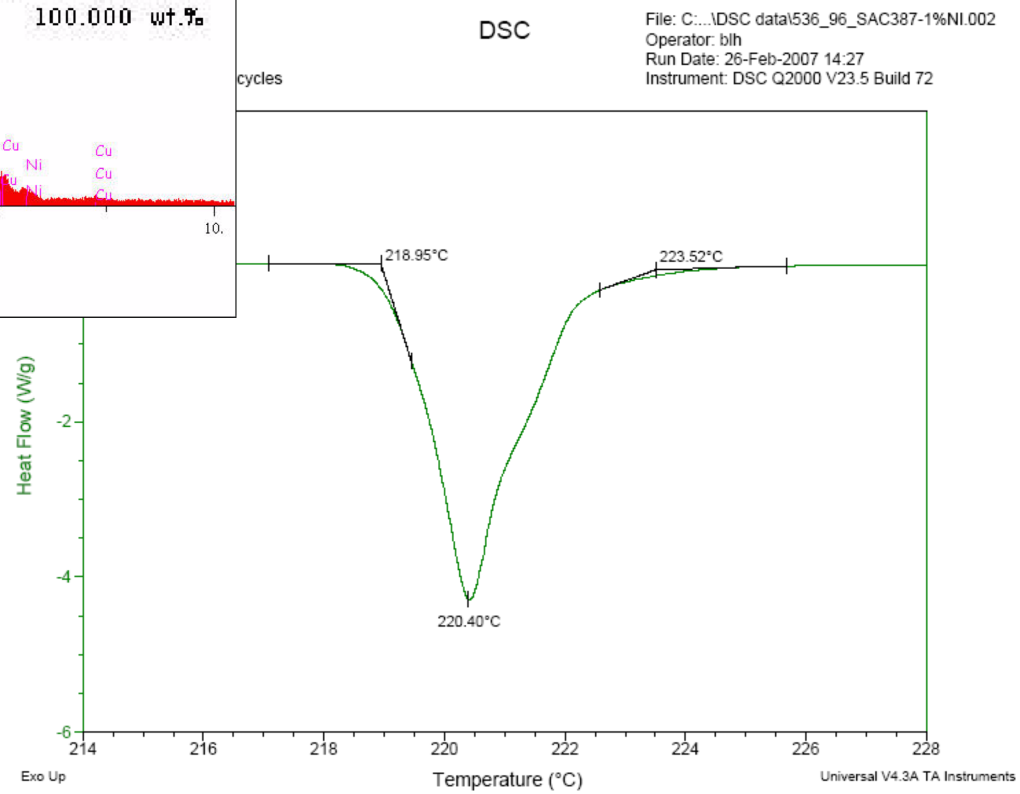
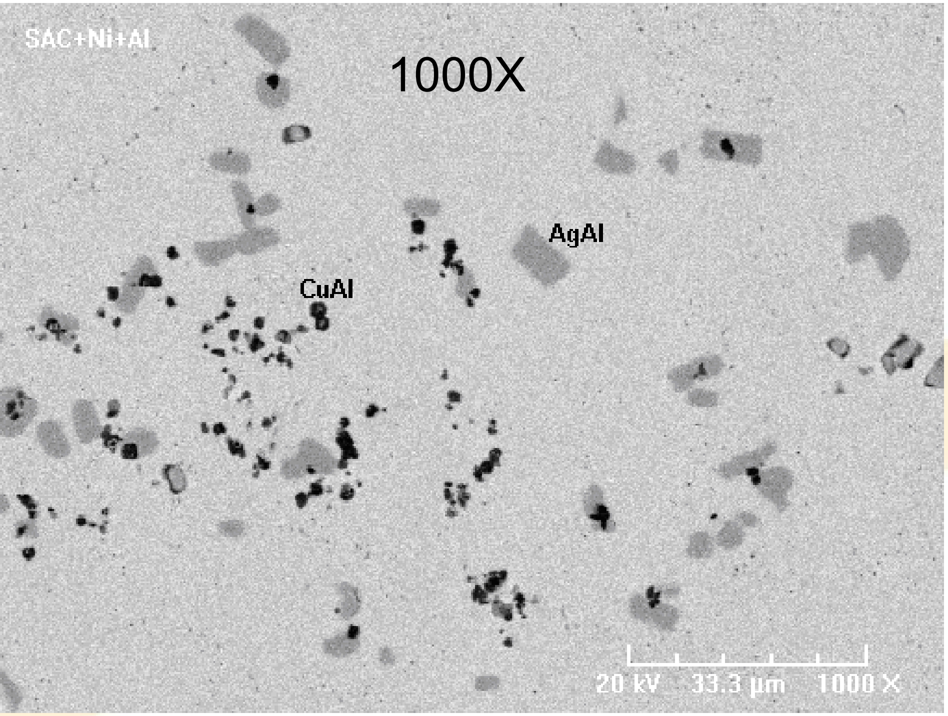
Sn94.49Ag3.99Cu0.64Ni0.88

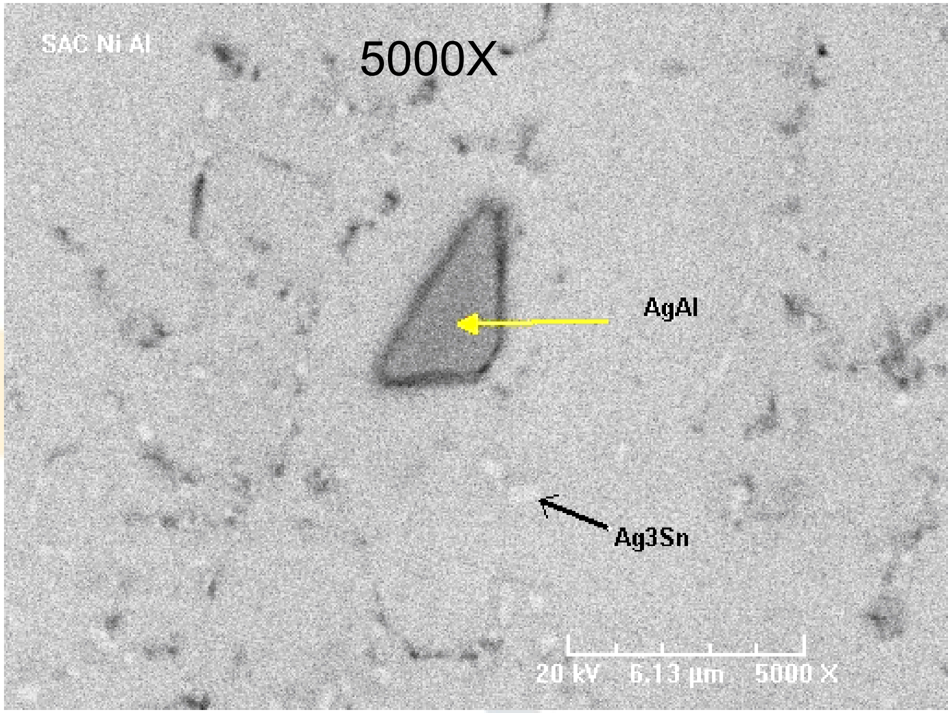


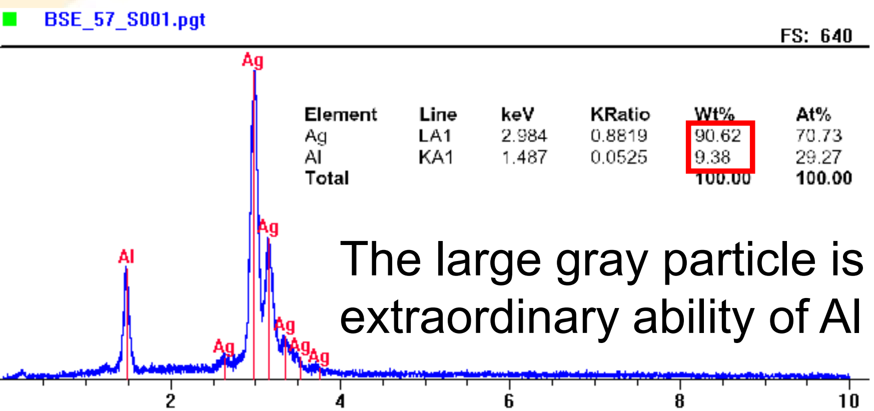


The weight ratio of Ni to Cu is about 2.3:1. With Ni concentration being 0.88%, the Cu entrapped in the (Ni,Cu)3Sn4 is estimated to be about 0.4%. In other words, Cu will be highly depleted by Ni-Cu-Sn IMC formation. As a result, the SAC matrix composition here is expected to be greatly skewed toward near-eutectic Sn-Ag structure.

SEM micrograph of Sn94.78Ag4.0Cu0.58Al0.6Ni0.04





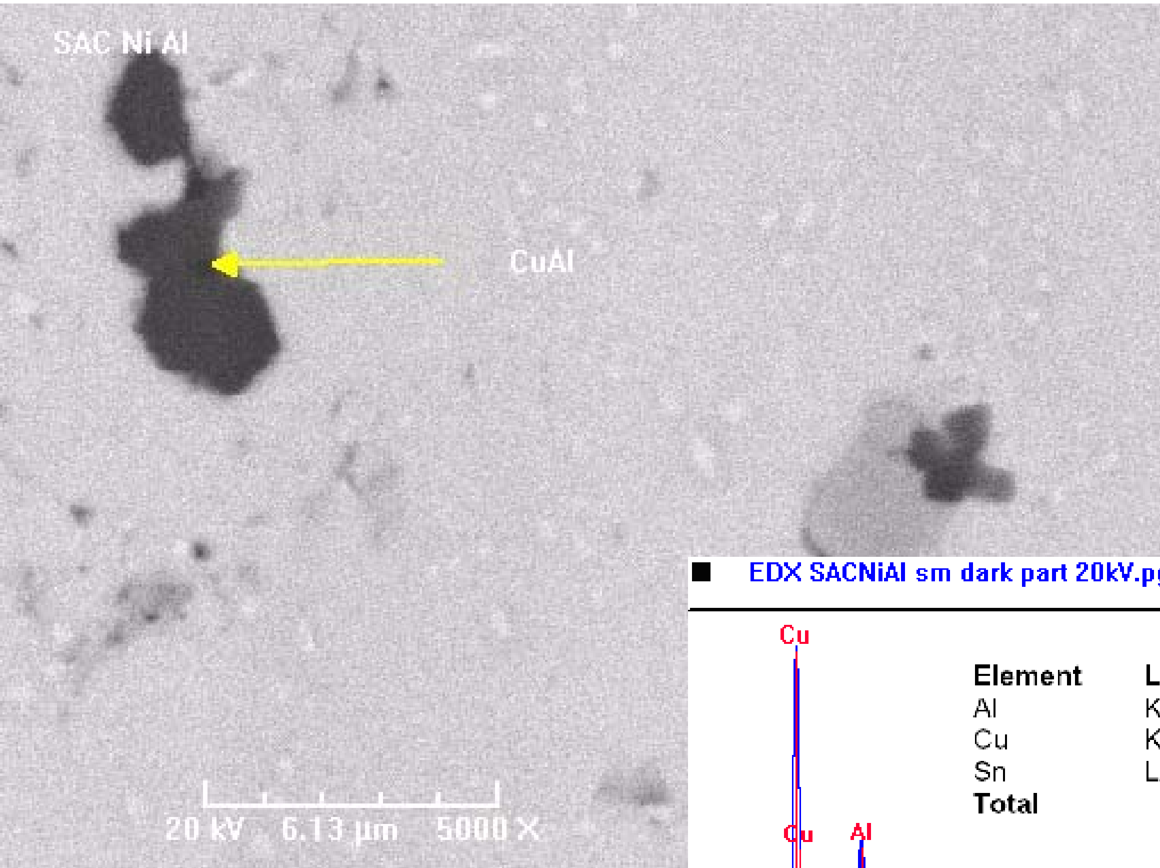


Element	Line	keV	KRatio	Wt%	At%
Ag	LA1	2.984	0.8819	90.62	70.73
Al	KA1	1.487	0.0525	9.38	29.27
Total				100.00	100.00

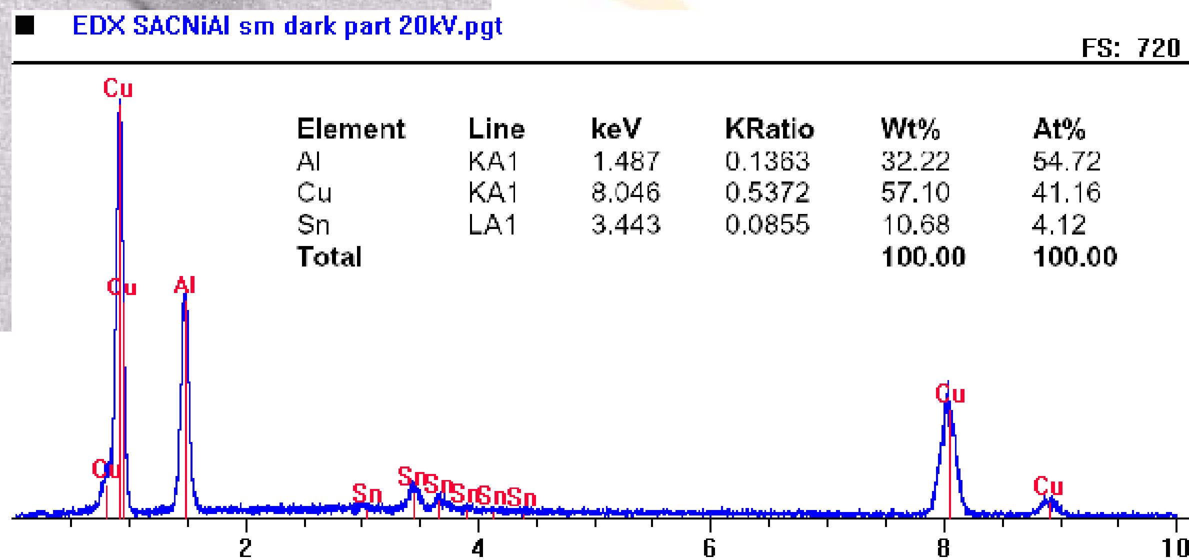
The bright particles are Ag3Sn IMC.

The large gray particle is Al9.4-Ag90.6, indicating the extraordinary ability of Al to drain Ag from SAC matrix.

SEM micrograph of Sn94.78Ag4.0Cu0.58Al0.6Ni0.04 (5000X)



The dark small particle is Al32.2-Cu57.1-Sn10.7



Element	Line	keV	KRatio	Wt%	At%
Al	KA1	1.487	0.1363	32.22	54.72
Cu	KA1	8.046	0.5372	57.10	41.16
Sn	LA1	3.443	0.0855	10.68	4.12
Total				**100.00**	**100.00**

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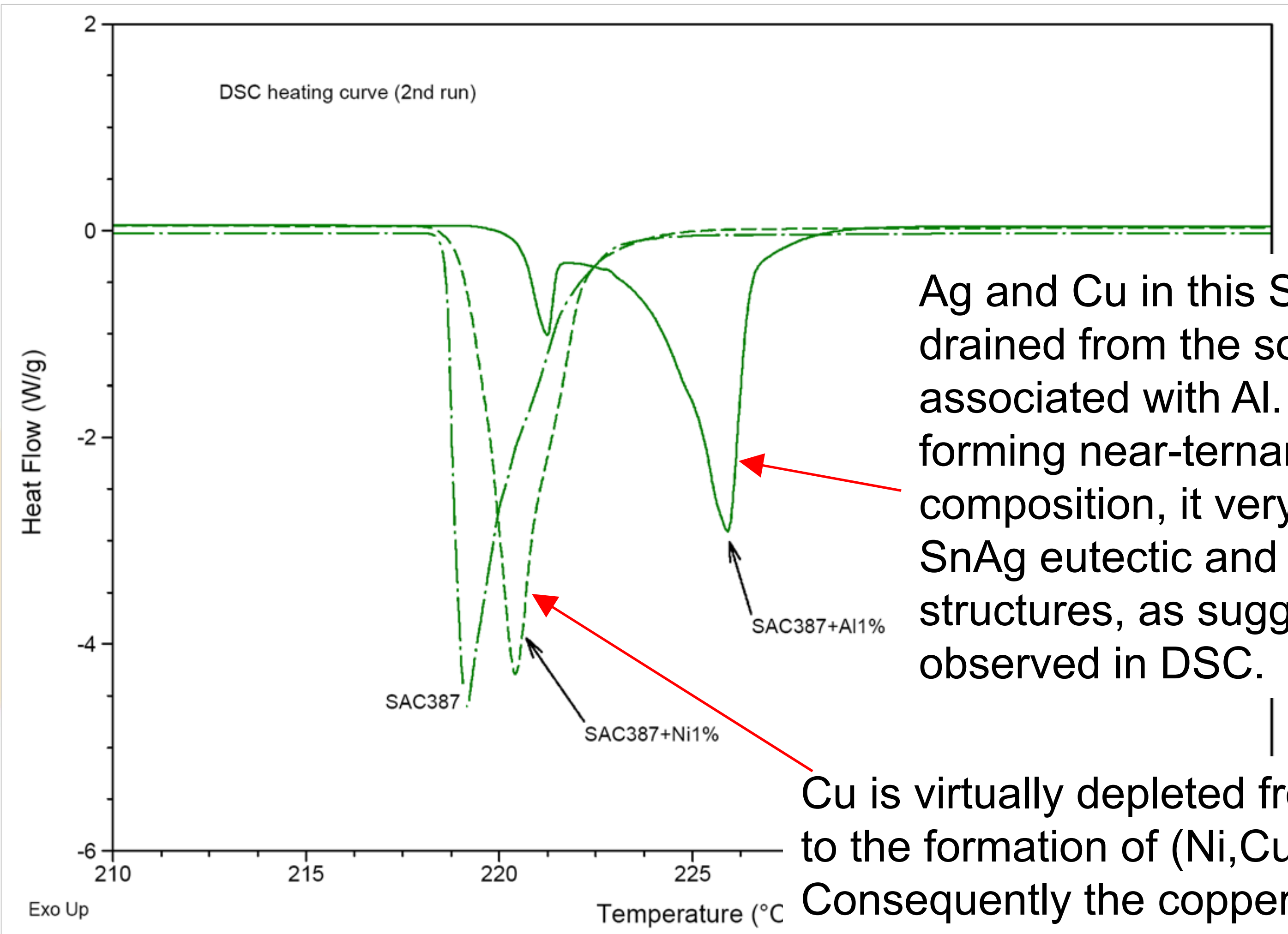
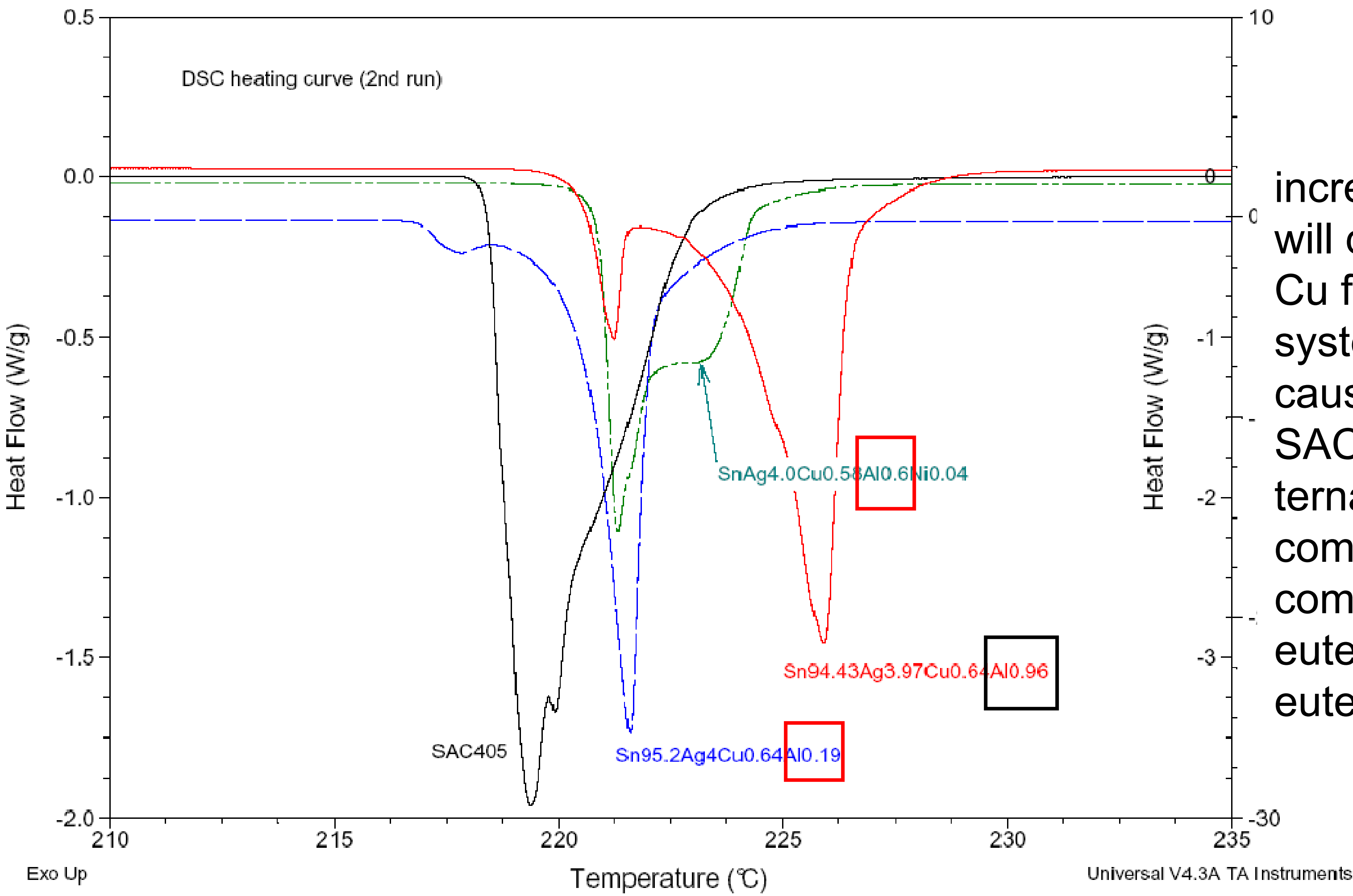
DSC thermographs (second run heating) of SAC387, SAC+Al (Sn94.43Ag3.97Cu0.64Al0.96), and SAC+Ni (Sn94.49Ag3.99Cu0.64Ni0.88)



Ag and Cu in this SAC+Al alloy mostly drained from the solder matrix and be associated with Al. Thus, instead of forming near-ternary-eutectic SAC composition, it very likely forms near-SnAg eutectic and near-Sn-Cu eutectic structures, as suggested by the two peaks observed in DSC.

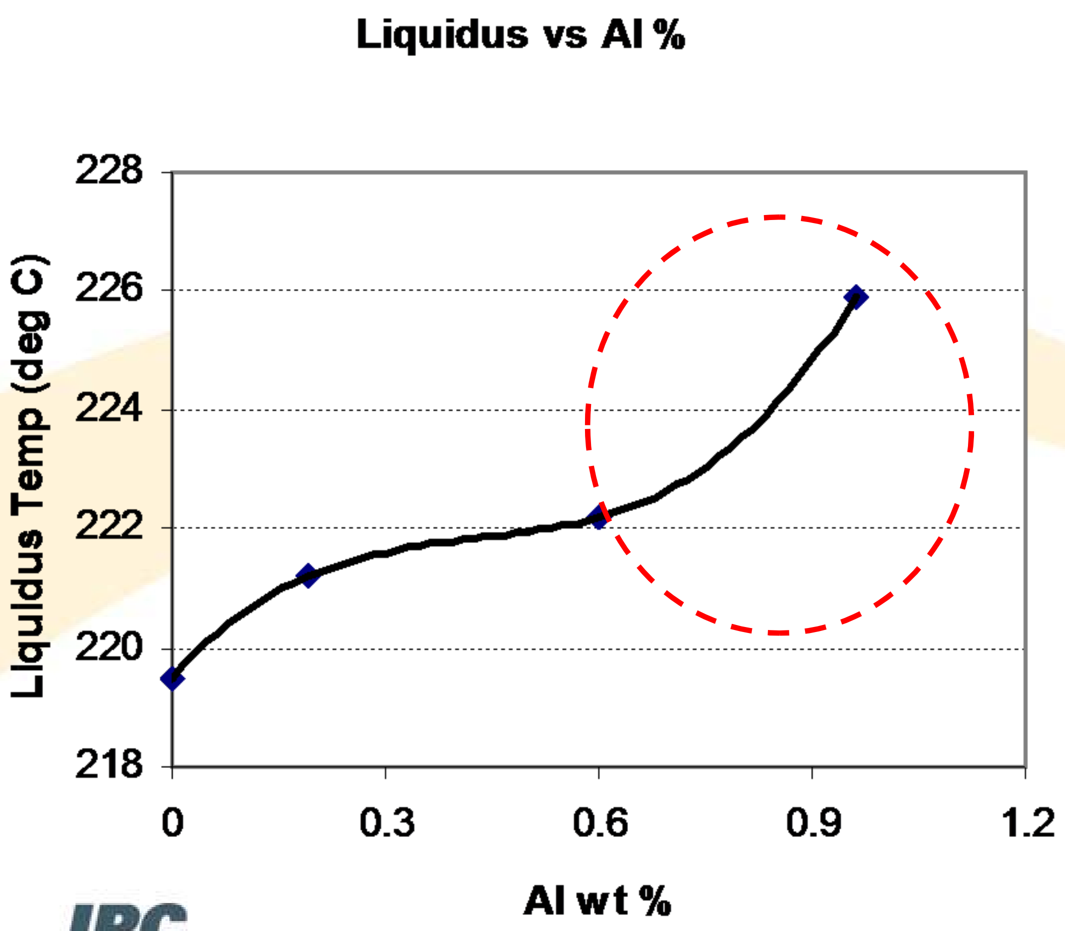
Cu is virtually depleted from SAC+Ni due to the formation of (Ni,Cu)3Sn4. Consequently the copper-striped matrix becomes near-eutectic SnAg structure.

DSC thermographs (second run heating) of SAC405 and SAC405+Al(Ni) alloys, including Sn95.2Ag4Cu0.64Al0.19, Sn94.78Ag4.0Cu0.58Al0.6Ni0.04, and Sn94.43Ag3.97Cu0.64Al0.96



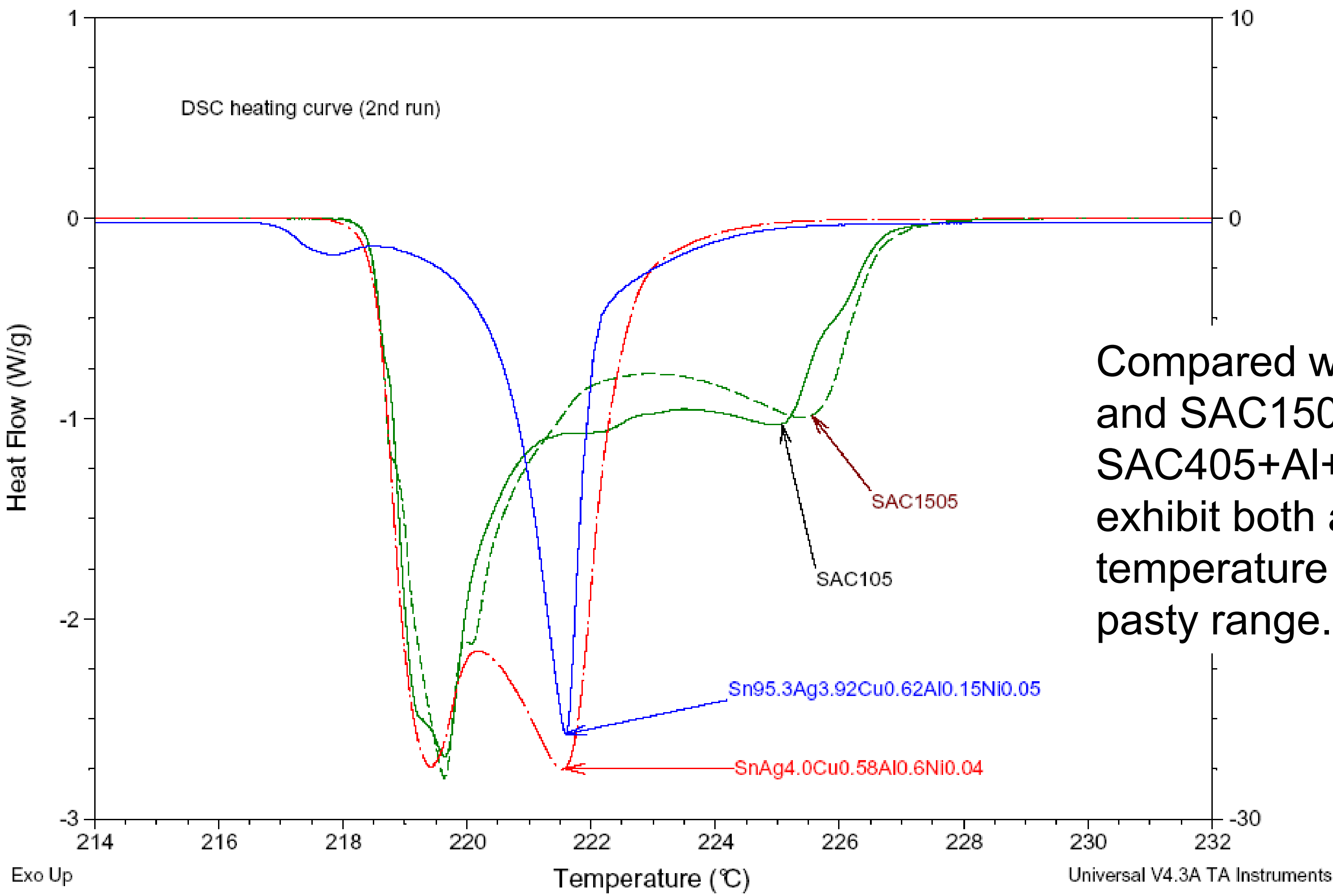
increase in Al content will drain more Ag and Cu from the SAC system. This in turn causes a shift of SAC405 from near ternary eutectic composition towards combination of eutectic SnAg and eutectic SnCu.

Liquidus temperature of SAC+Al(Ni) alloys as a function of Al content



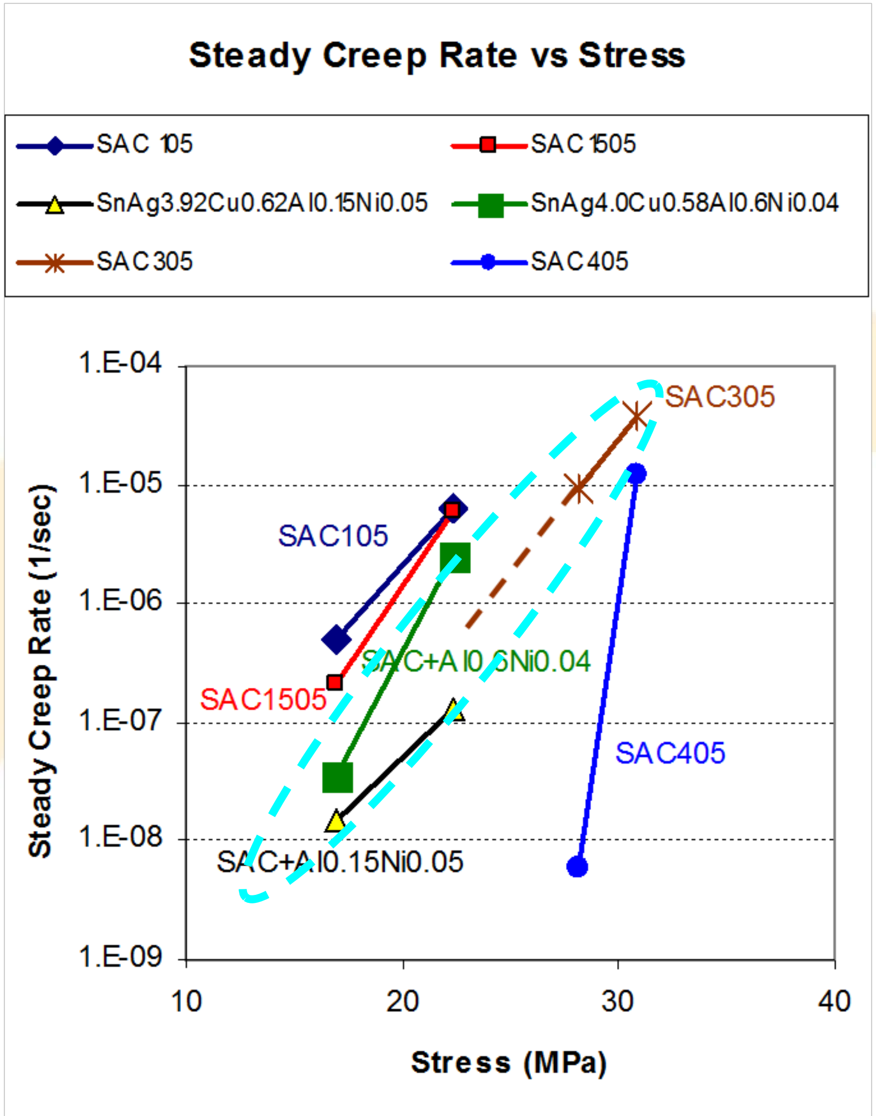
At Al content greater than 0.6%, the liquidus temperature increases more rapidly with continued increase in Al content

DSC thermographs (second run heating) of SAC105, SAC1505, and SAC405+Al+Ni alloys, including Sn95.3Ag3.92Cu0.62Al0.15Ni0.05 and Sn94.78Ag4.0Cu0.58Al0.6Ni0.04



Compared with SAC105 and SAC1505, the SAC405+Al+Ni alloys exhibit both a lower liquidus temperature and a narrower pasty range.

Effect of alloy on steady creep rate



The yield strength of both SAC405+Al+Ni alloys is much lower than SAC405 & 305, and is similar to that of SAC105 and SAC1505

However, both SAC405+Al+Ni alloys exhibit a steady creep rate lower than that of SAC105 and SAC1505, comparable with SAC305, and are higher than SAC405.

Thus, new alloy exhibit SAC305 creep rate but SAC105 softness.

Discussion

- Softening attributed to
  - Large no. of small hard Ag_3Sn converted into small no. of large soft non-stoichiometric Ag-Al IMC particles
  - Reduction in Cu_6Sn_5 particles due to formation of non-stoichiometric Al-Cu and large $(Ni,Cu)_3Sn_4$ IMC particles
- Creep rate
  - Non-stoichiometric IMC particle or large particle, although less effective in increasing yield strength, are considered still harder than Sn, therefore are expected to provide resistance in creep.

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Conclusion

- Addition of **Al** into SAC alloys reduces the number of hard Ag_3Sn and Cu_6Sn_5 IMC particles, and forms larger, softer non-stoichiometric AlAg and AlCu particles. This results in a **significant reduction in yield strength**, and also causes some **moderate increase in creep rate**.
- For high Ag SAC alloys, adding Al 0.1-0.6% to SAC alloys is most effective in softening, and brings the yield strength down to the level of SAC105 and SAC1505, while the creep rate is still maintained at SAC305 level.
- Addition of **Ni** results in formation of large $(Ni,Cu)_3Sn_4$ IMC particles and loss of Cu_6Sn_5 particles. This also **causes softening** of SAC alloys, although to a less extent than that of Al addition.
- For SAC+Al+Ni alloys, the **pasty range and liquidus temperature** are about **4°C less than that of SAC105 or SAC1505** if the added quantity is less than about 0.6%.
- Thus, new alloys exhibit SAC305 creep rate, SAC105 softness, & lower mp than SAC105.