Nano-particle enhanced Transient Liquid Phase bonding process

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Why dissimilar joints?

Function

Quality

Mechanical Requirements

Machinability

Component

Energy Saving

Environmental Safety

Weight

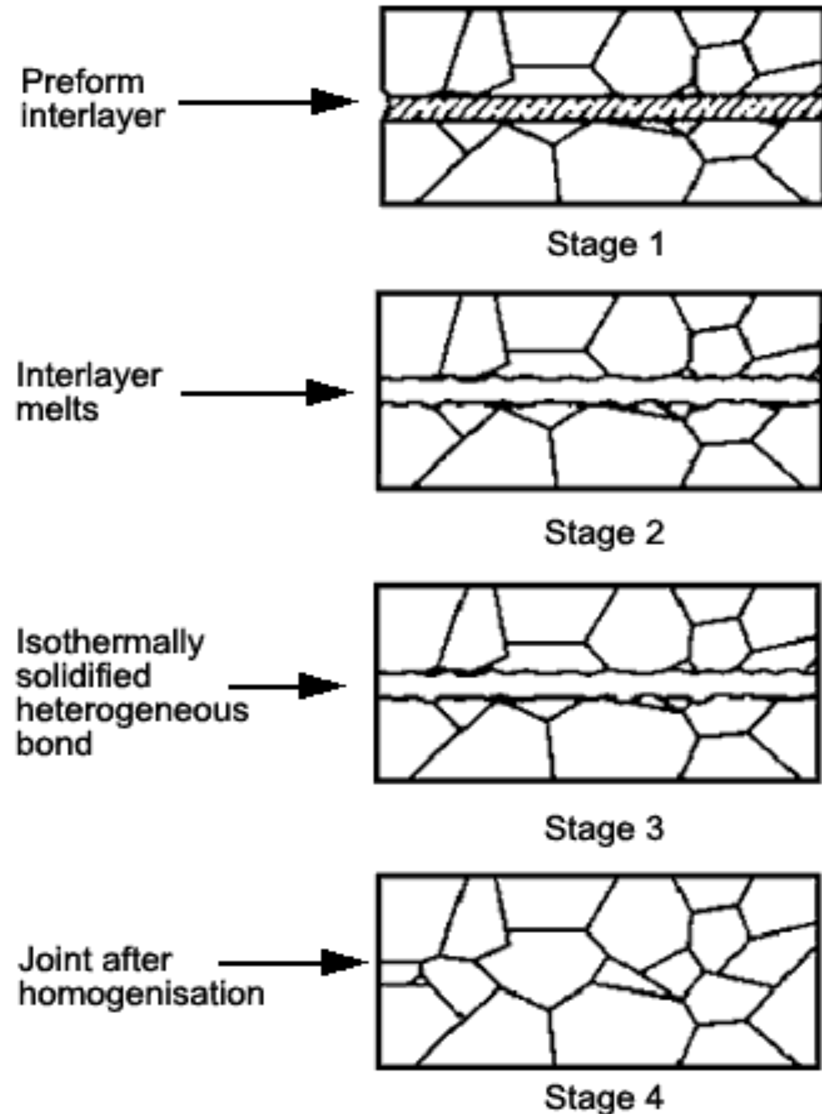
User Safety

Diffusion bonding apparatus

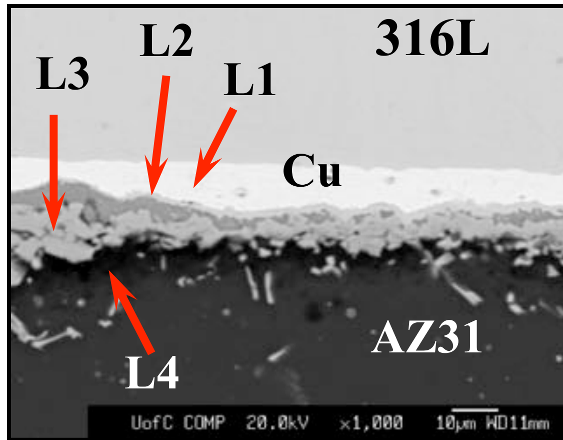
TLP bonding Process

Steps in the process:

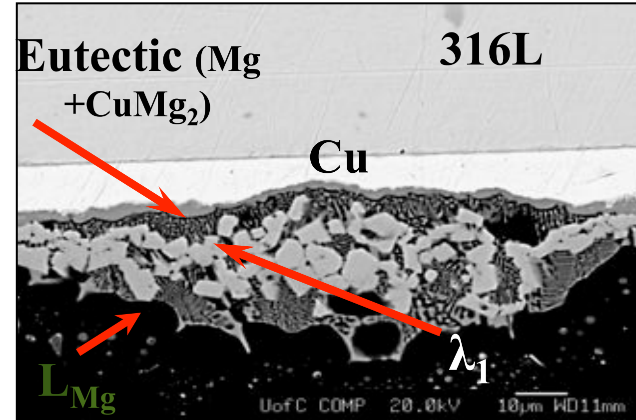
- ➢Solid interlayer
- ➢Interlayer melts
- ➢Isothermal solidification
- ➢Homogenisation



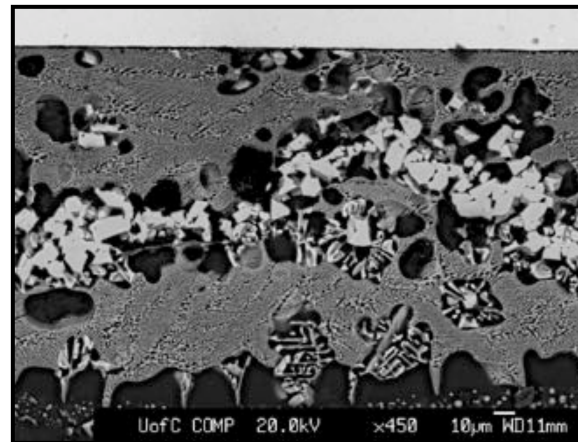
Bonding Mechanism (Cu interlayer)

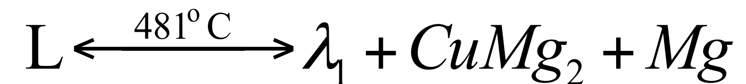


Solid State Diffusion
530°C for 3 min



Eutectic Formation
530°C for 5 min

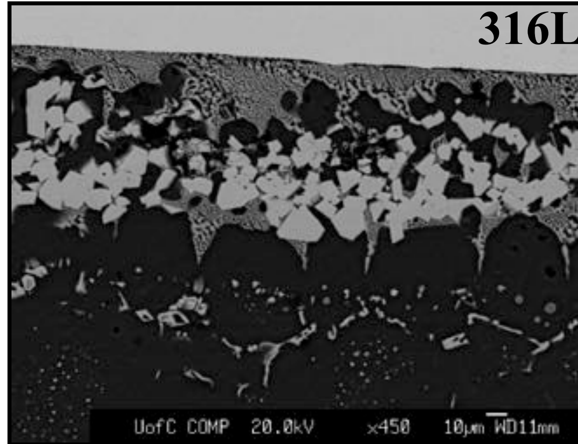




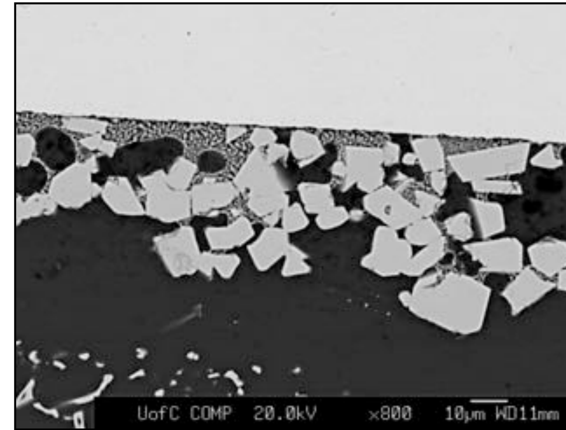
$$L \xleftrightarrow{481^{o}C} \lambda_1 + CuMg_2 + Mg$$

Dissolution and widening
530°C for 10 min

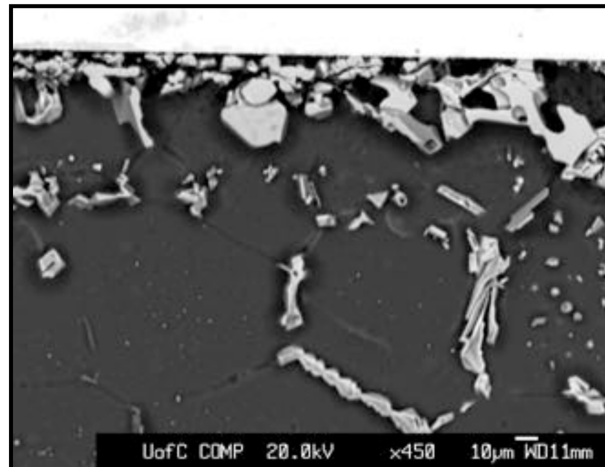
Isothermal solidification at 530°C (Cu interlayer)



15 min



30 min



Eutectic dissolution/grain boundary segregation for 60 min

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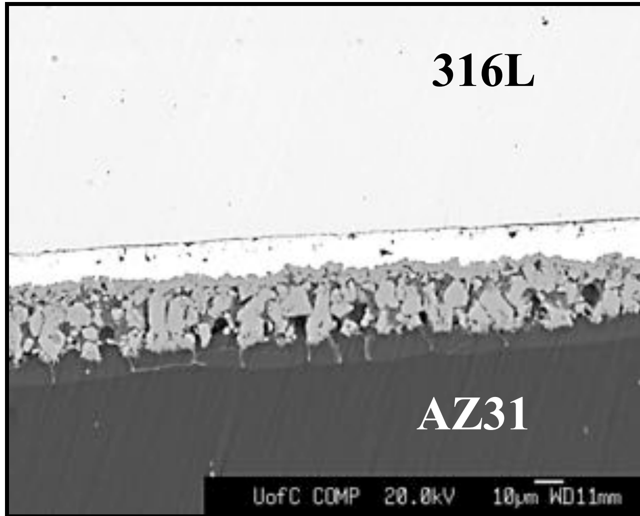
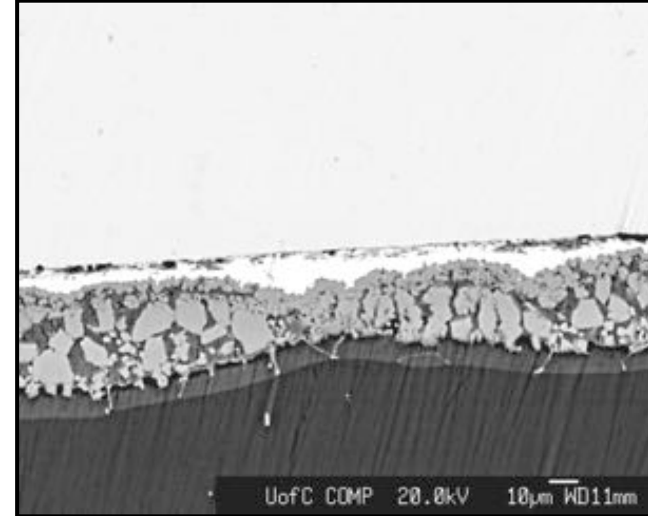
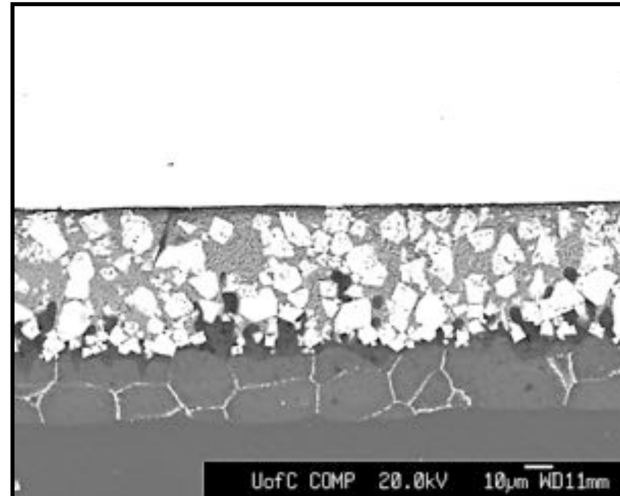
Bonding Mechanism (Ni interlayer)



510°C for 3 min



510°C for 5 min



510°C for 10 min

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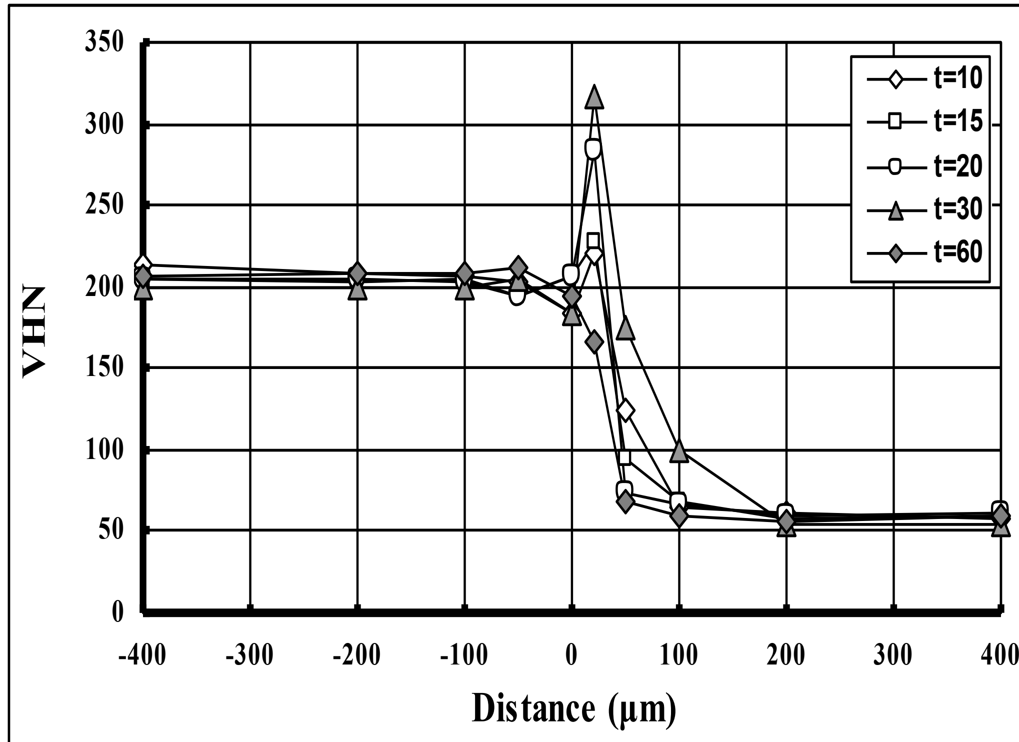
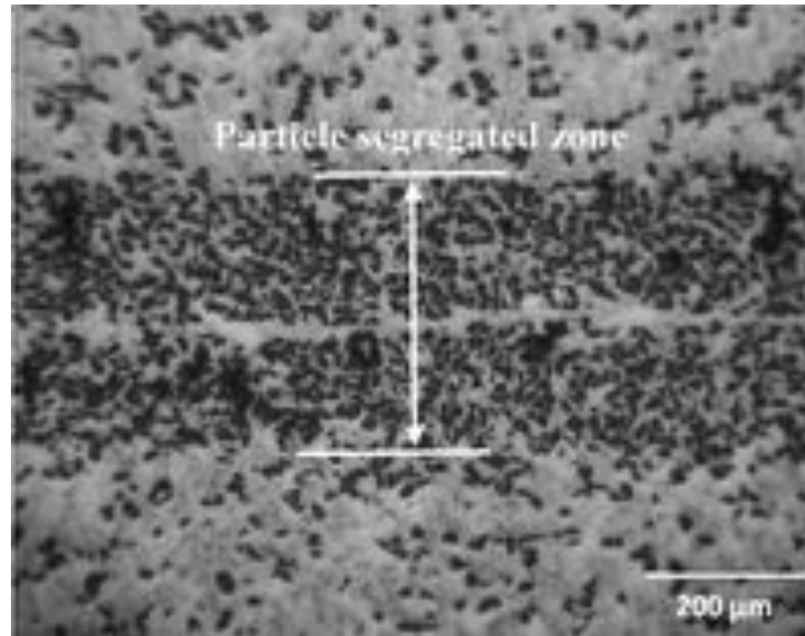
Effect of bonding time on hardness across joint



AZ31/Cu/316L joint at 530°C

Al 6061-15% Al_2O_3



Microstructure of bond made at 600°C for 10 mins using 15 µm Ni coating.

Problems with TLP bonding

- Dissolution of parent metal;
- Dissolution results in rearrangment of strengthening particles at the joint;
- Bonding time controls isothermal solidification but results in intermetallic compound formation;
- Homogenization time causes grain growth at the joint.

Potential solutions

- Reduce interlayer thickness;
- Reduce bonding time;
- Select appropriate interlayer composition;
- Use a nanostructured interlayer.

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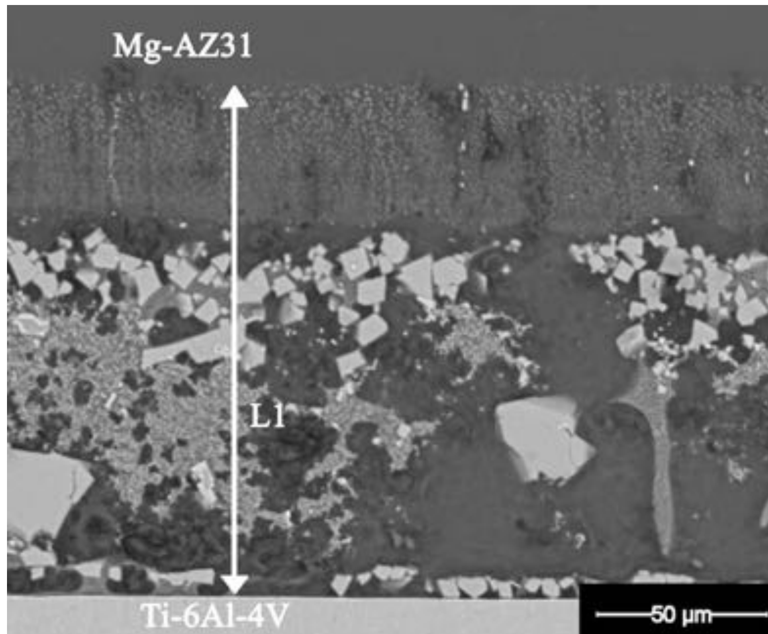
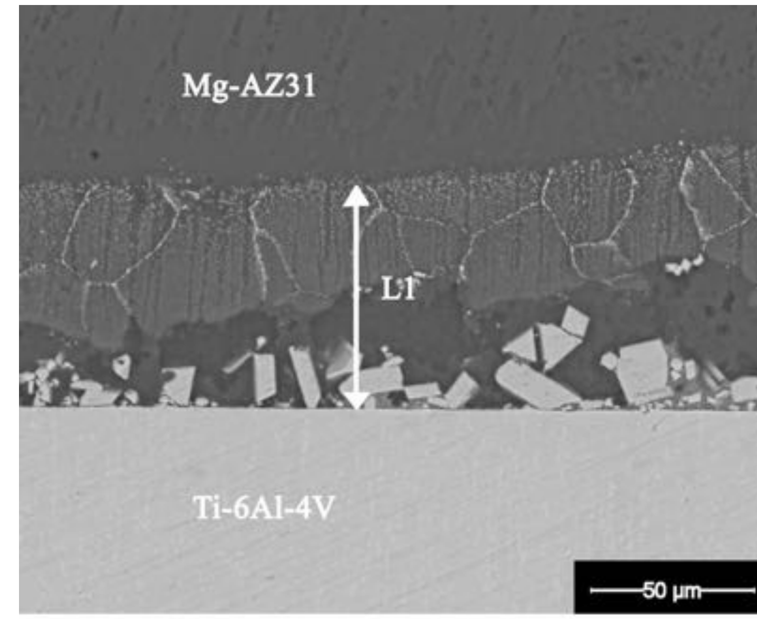
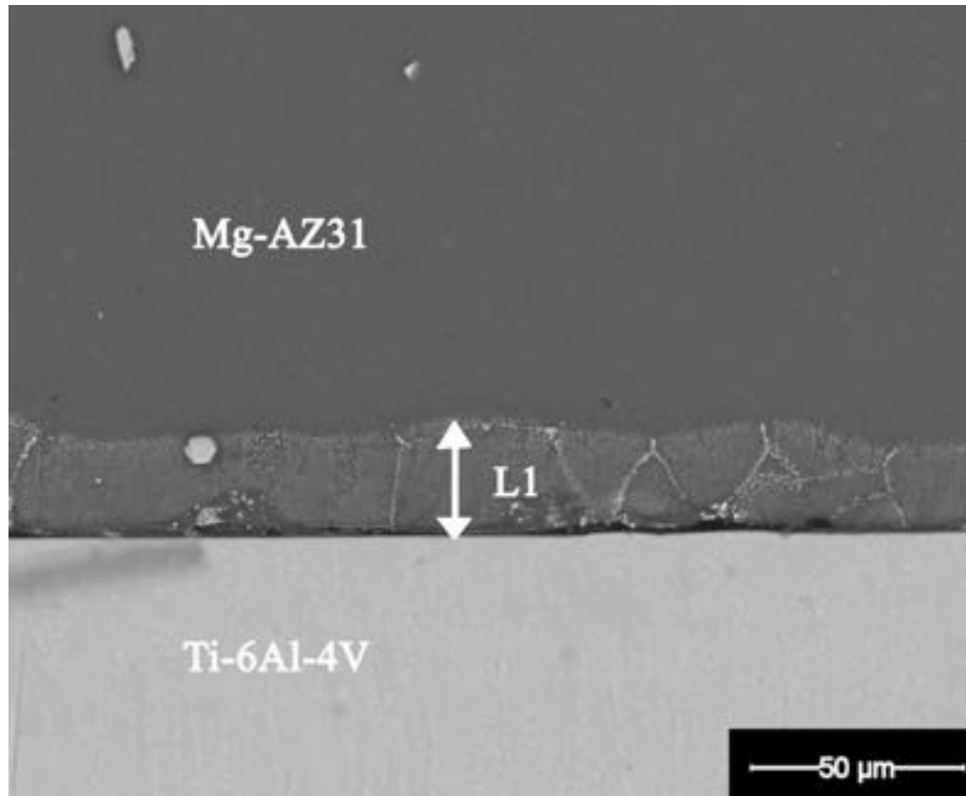
TLP bonds between Ti-alloy and Mg-alloy using Ni coatings [540°C, 20 mins]



20 μm coating

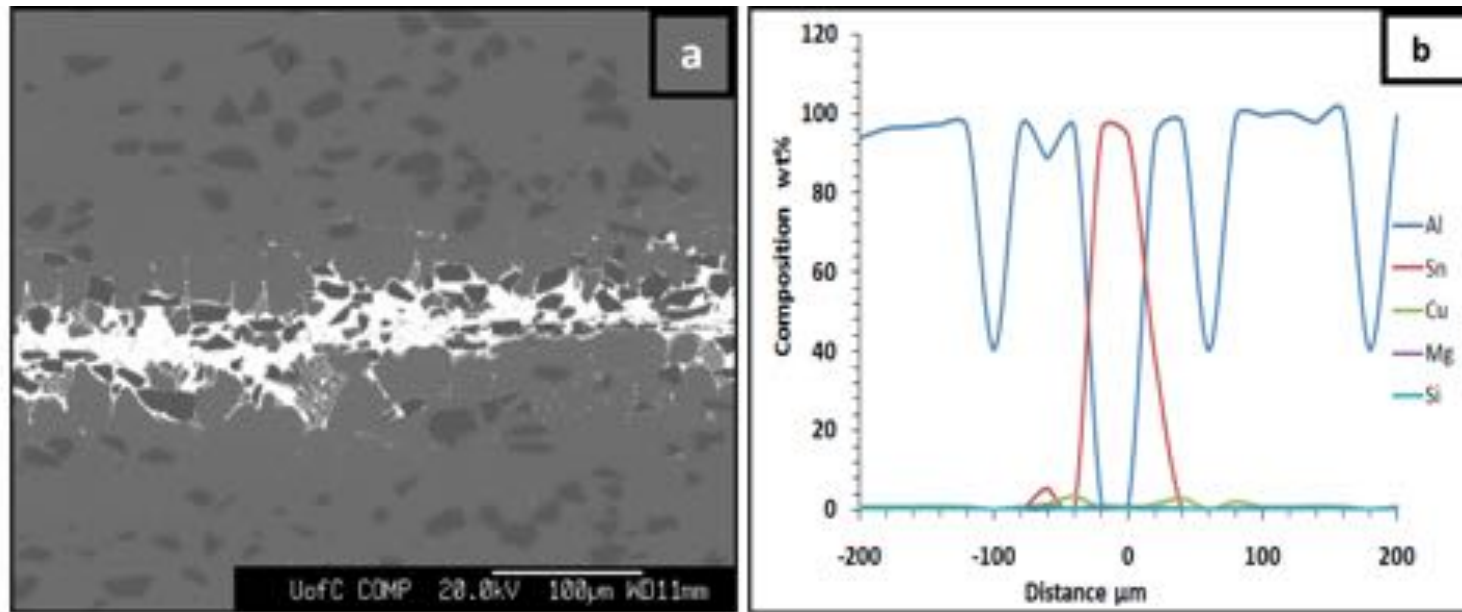


10 μm coating



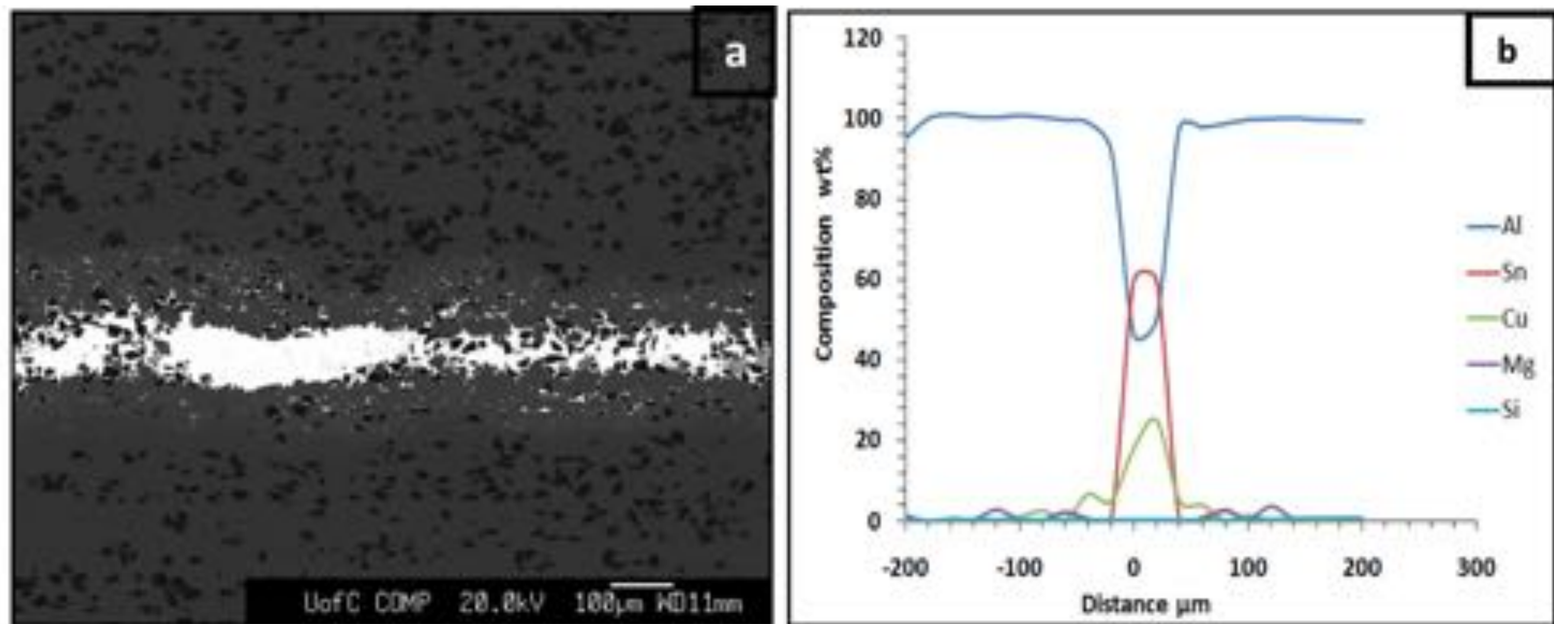
2 µm coating

Preventing parent metal melt-back



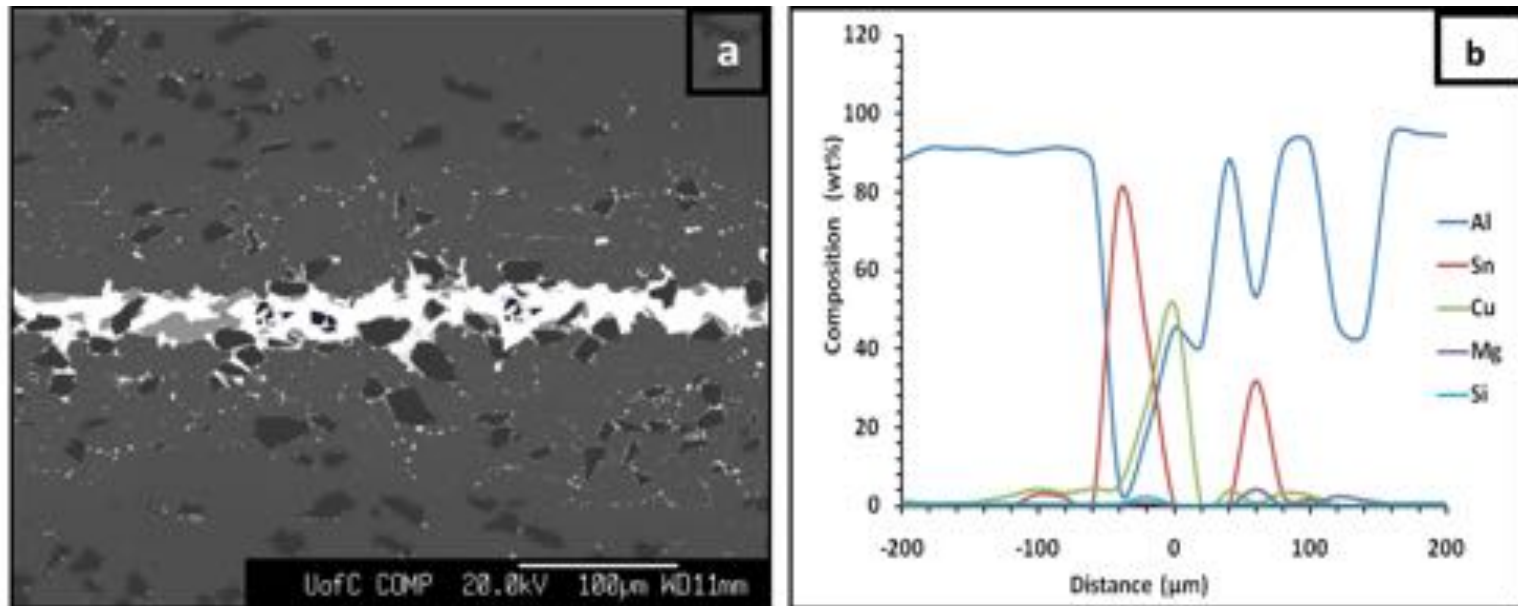
Bond made at 500°C for 2 mins using 5 μm Cu coating on Al-6061 surface and a 50μm Sn interlayer

Al 6061-15% Al_2O_3



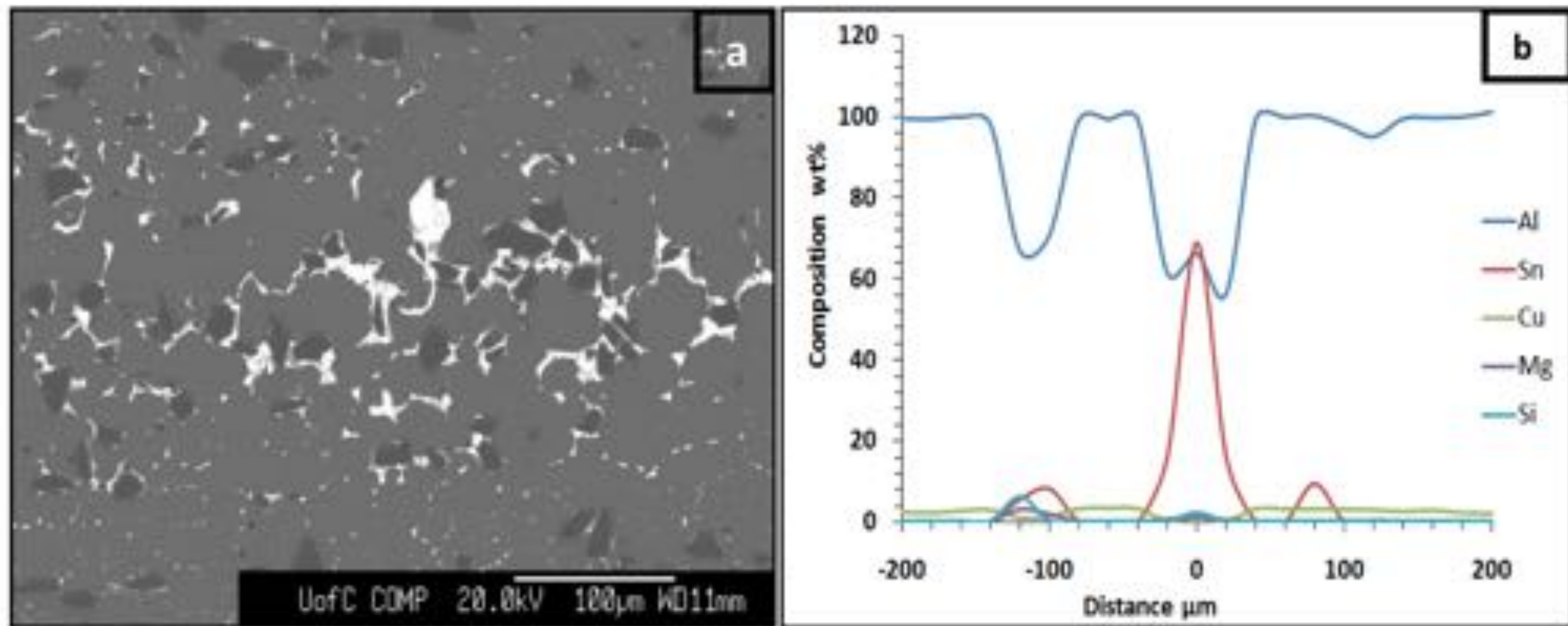
Bond made at 500°C for 30 mins

Al 6061-15% Al_2O_3



Bond made at 500°C for 60 mins

Al 6061-15% Al_2O_3



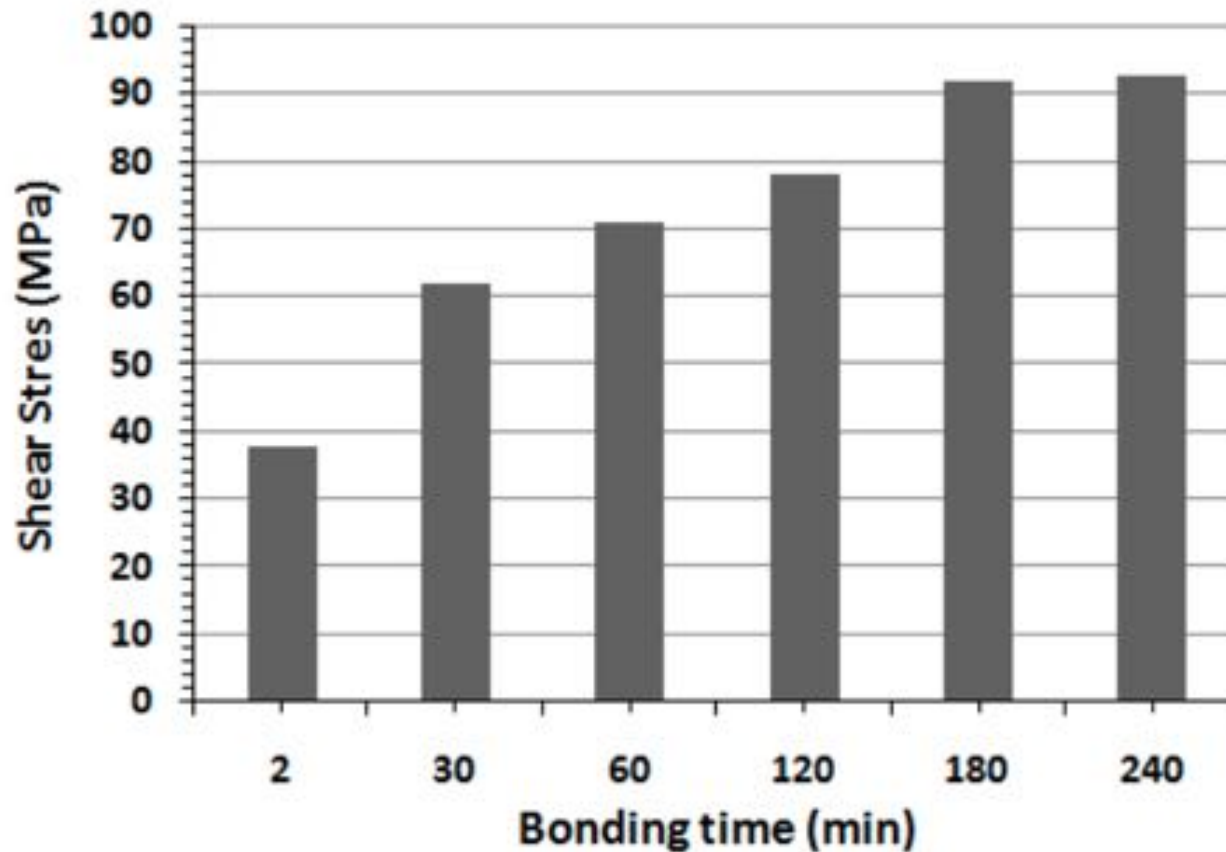
Bond made at 500°C for 180 mins

Diffusivity values at 500°C for the Al-Cu-Sn system

Diffusion type	Diffusivity (D) at 500 °C m^2/s
Sn in Al	8.22×10^{-16}
Sn in Cu	1.29×10^{-13}
Cu in Al	2.58×10^{-9}
Al in Cu	2.81×10^{-14}
Cu in Sn	1.58×10^{-8}
Al in Sn	8.29×10^{-5}
Mg in Al	1.54×10^{-9}

Changes in hardness across joint made with the Cu-Sn system

Al-6061 bonds made using Cu-Sn system



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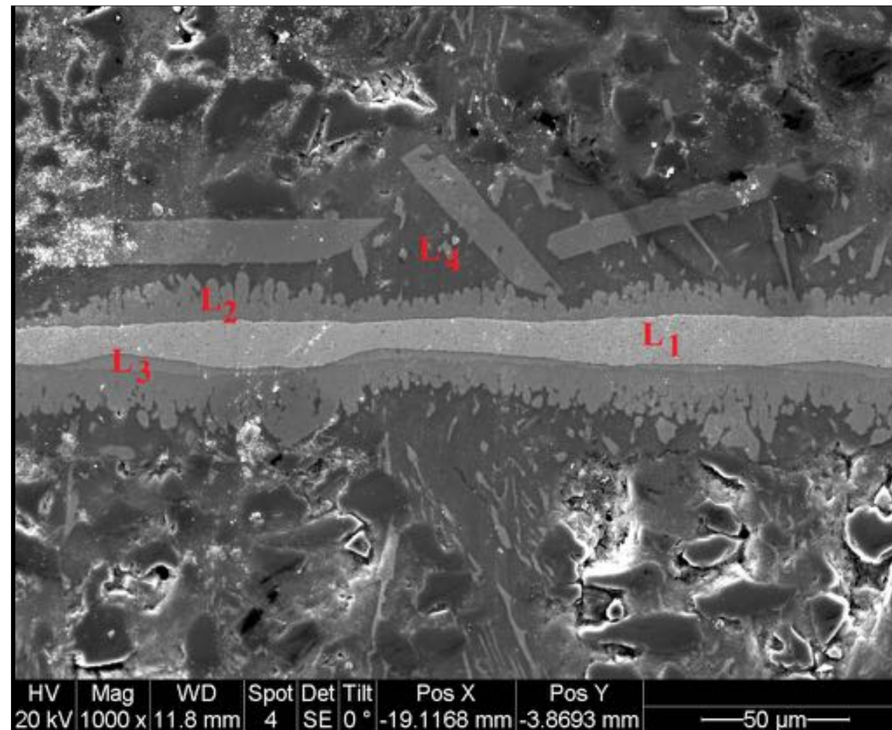
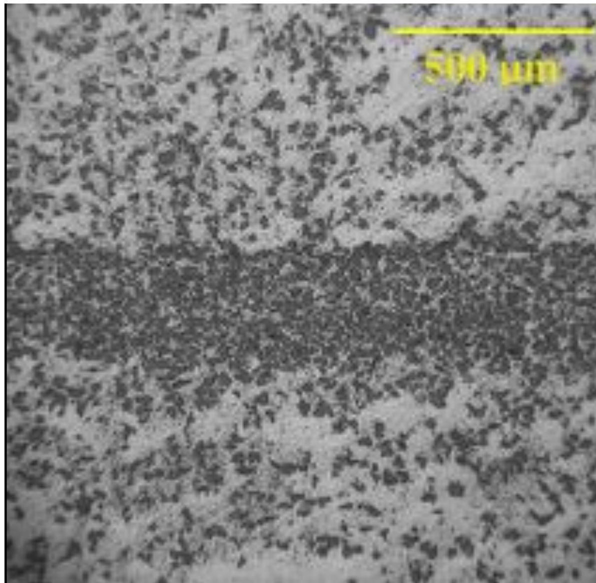
TLP bond in 6061-15% Al_2O_3 at 600°C using different Ni coating thickness

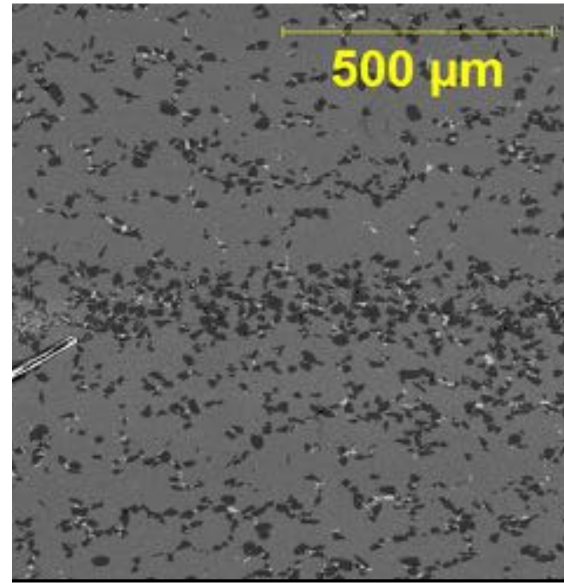


SEM micrograph showing bond made using 15 μm Ni coating for 1 min

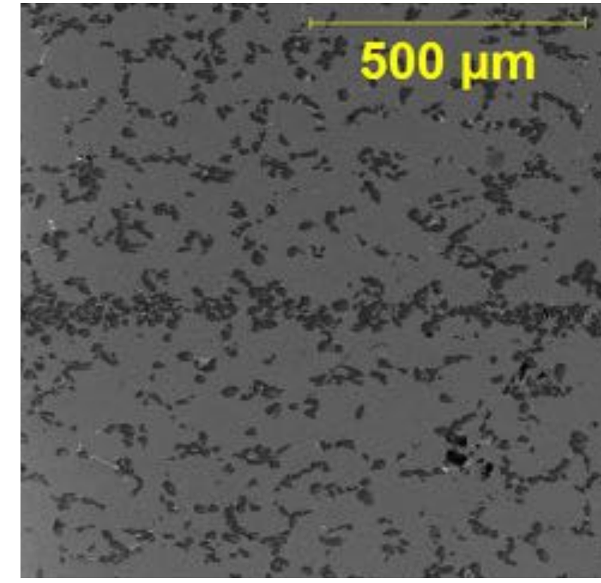
Effect of Ni-coating thickness on Al-6061-15% Al_2O_3 at 600°C



15 µm

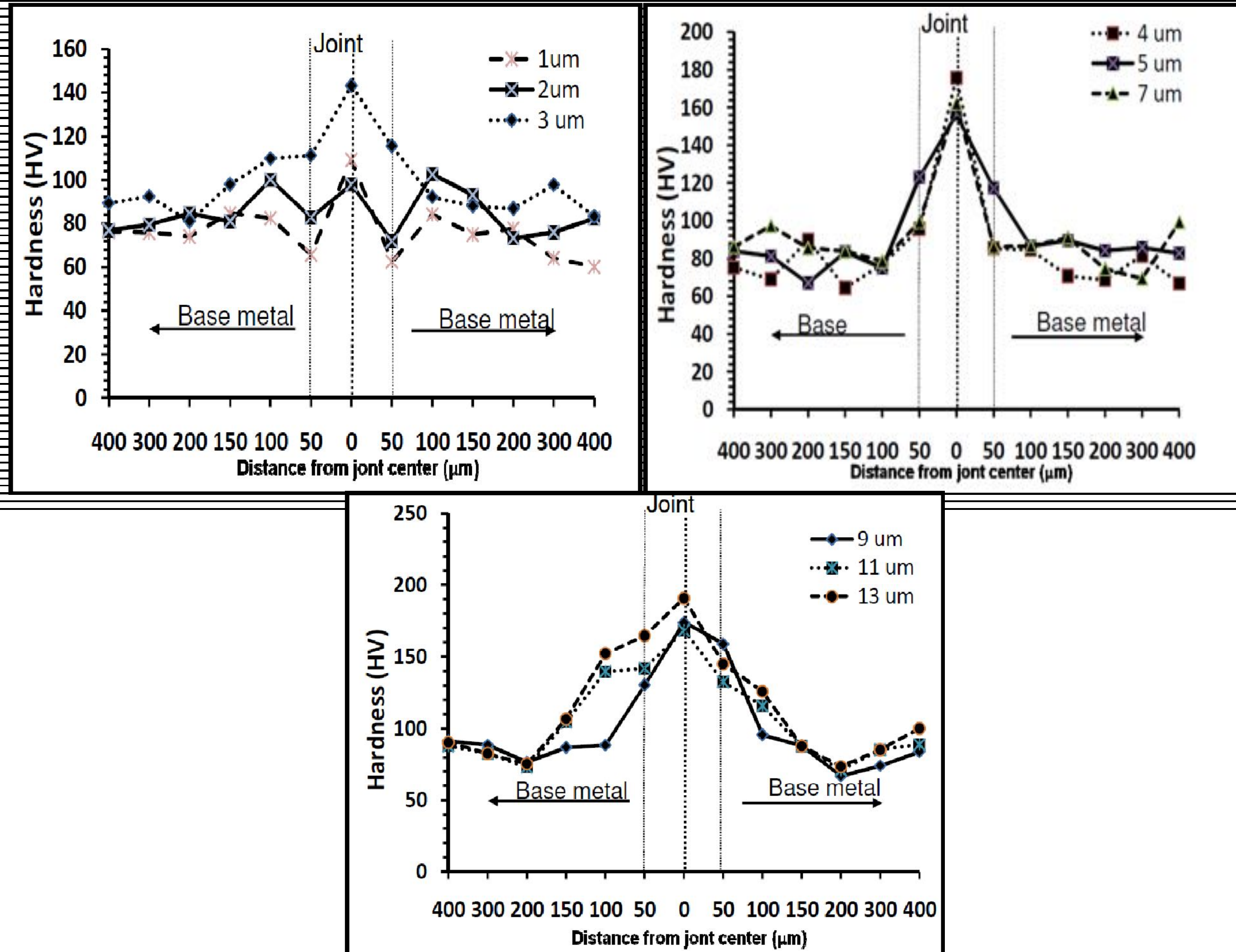


5 µm

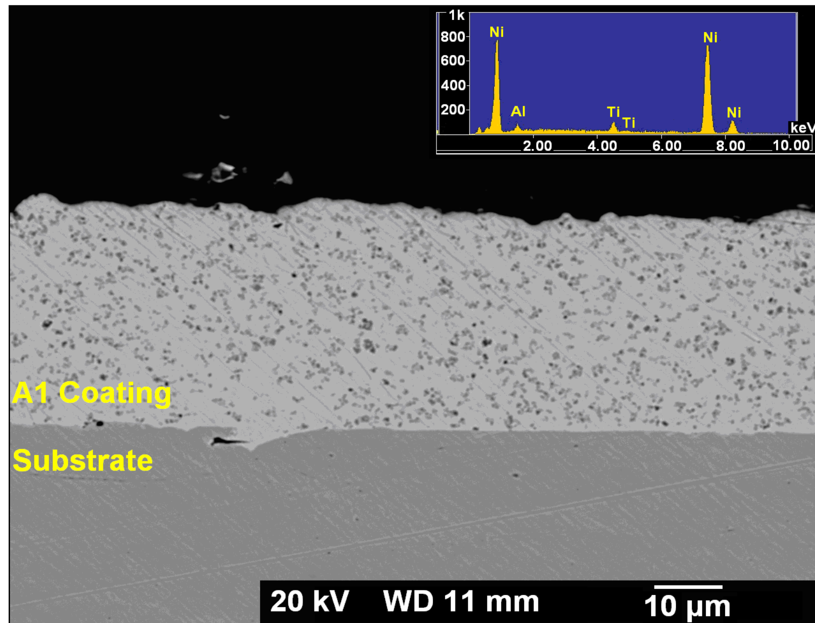


2 µm

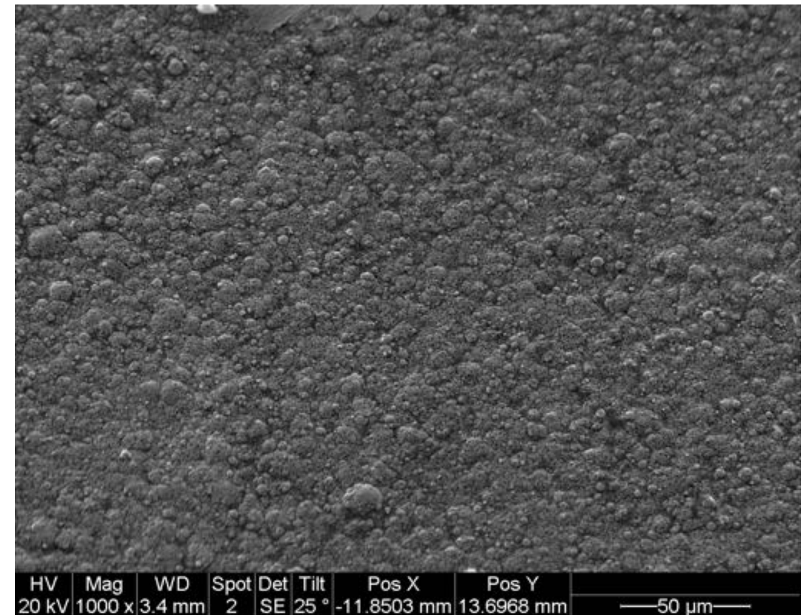
Changes in hardness at the join as a function of coating thickness



Ni-coating containing nano-particles



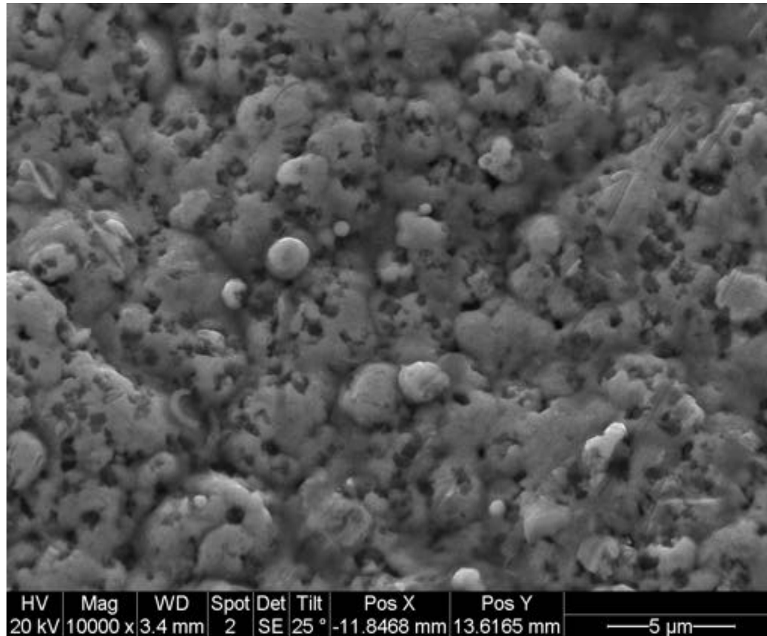
(a)

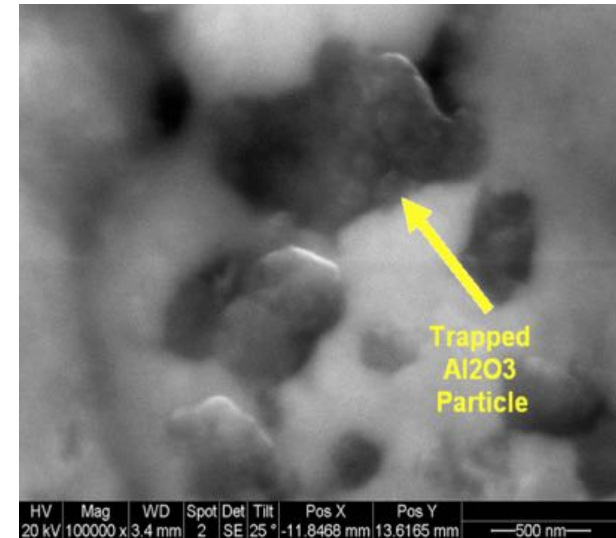


(b)

SEM micrographs showing:
(a) cross-section through Ni coating; (b) surface morphology

Dispersion of Al_2O_3 nano-particles in the Ni coating





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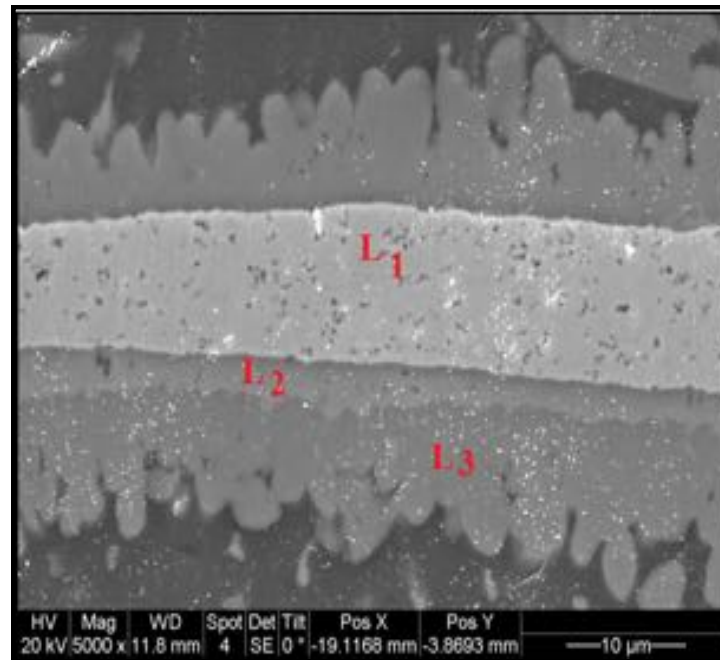
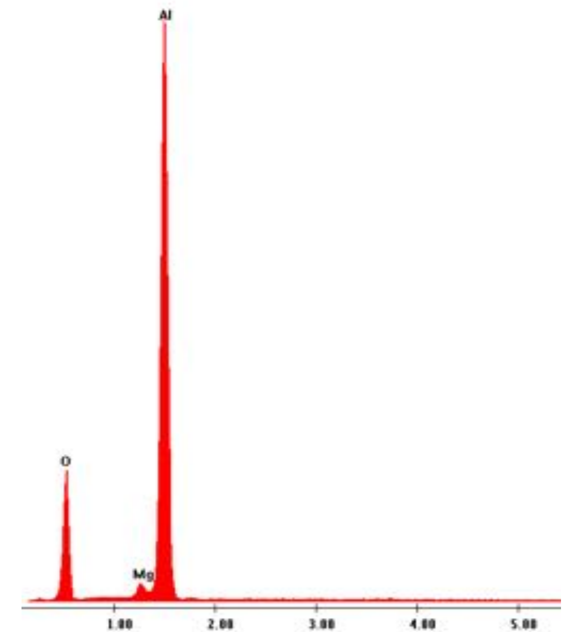
TLP bonds in 6061-15% Al_2O_3 at 600°C using nano-particles



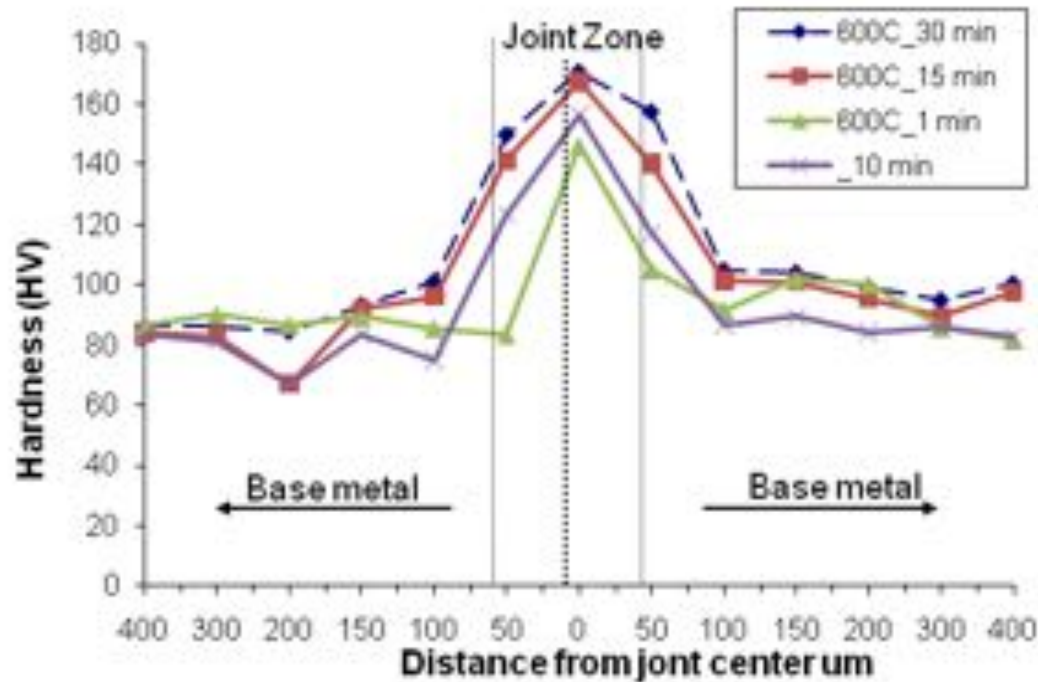


SEM micrograph of joint bonded using a 15 µm Ni-Al_2O_3 coating for 1 min

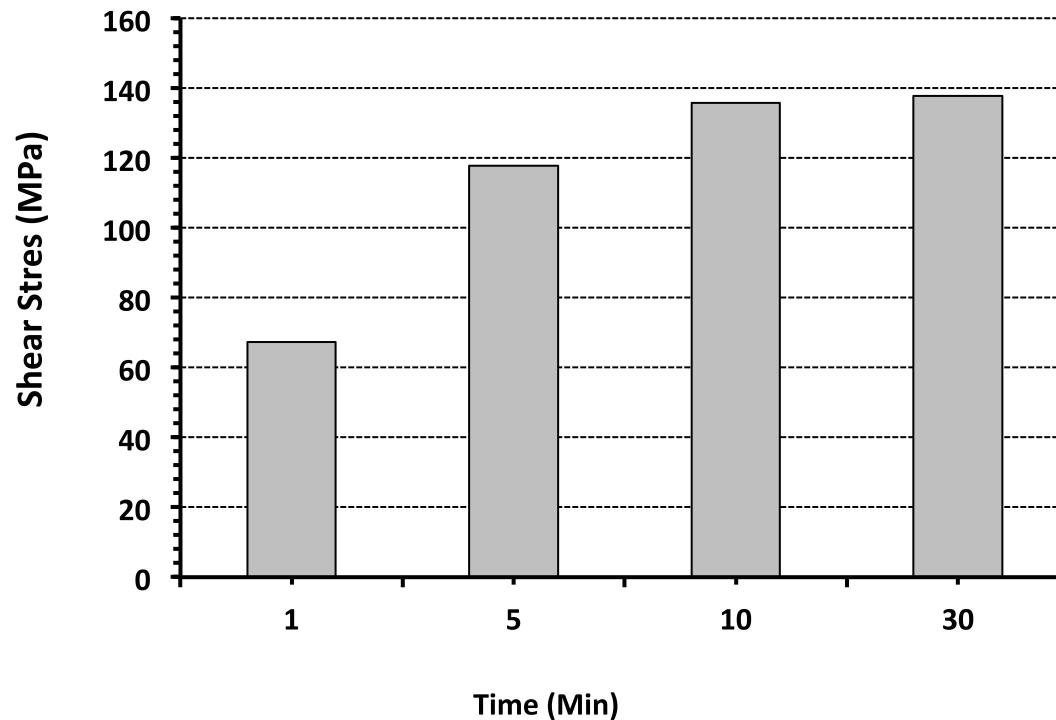
EDS quantitative analysis of reaction layers

Layers	Al	Ni	Si	Mg	Compound
L_1	12.5	87.5	0	0	$Ni + Al_2O_3$
L_2	46.71	50.67	0.27	0	NiAl
L_3	72.84	24.31	0	0.55	$NiAl_3$
L_4	72.84	24.31	0	0.55	NiAl3

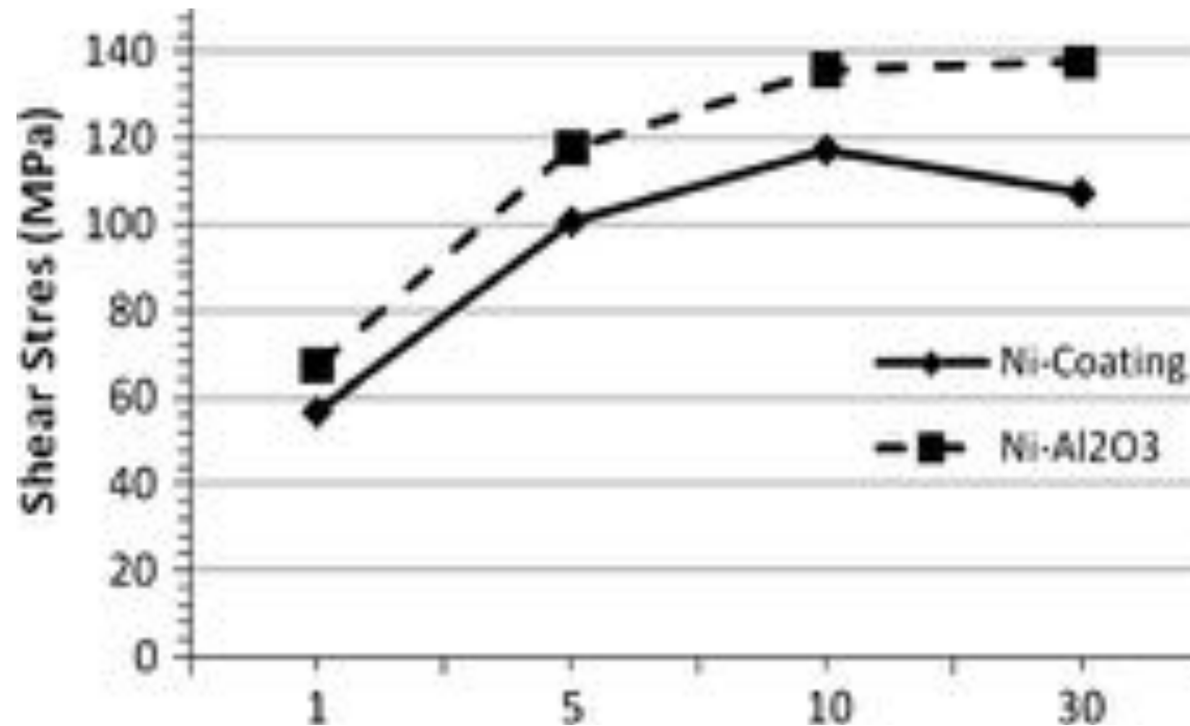
TLP bonds in 6061-15% Al_2O_3 at 600°C



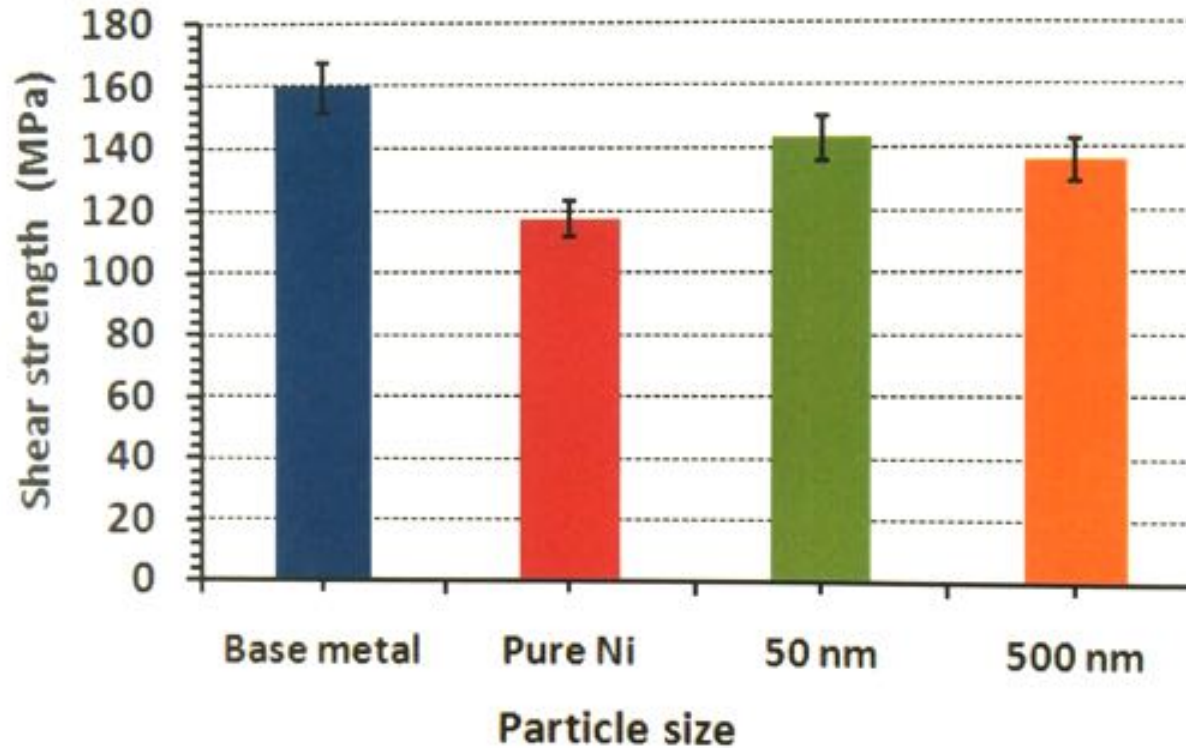
TLP bond strengths using 5µm thick Ni-Al_2O_3 coating made at 600°C



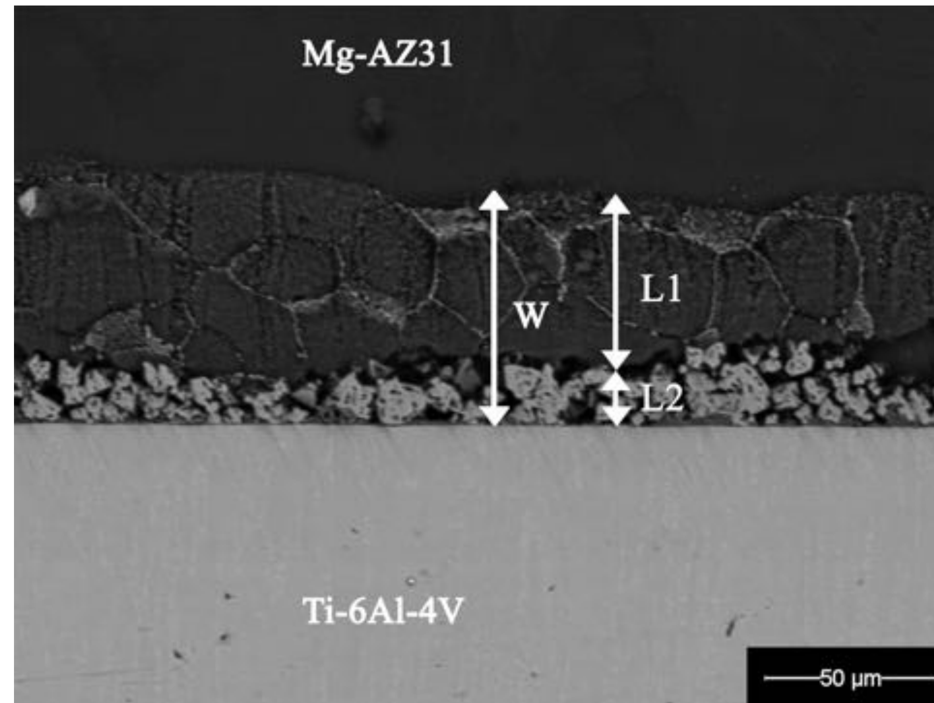
Effect of nano-particles on joint strength



Effect of nano-particle size

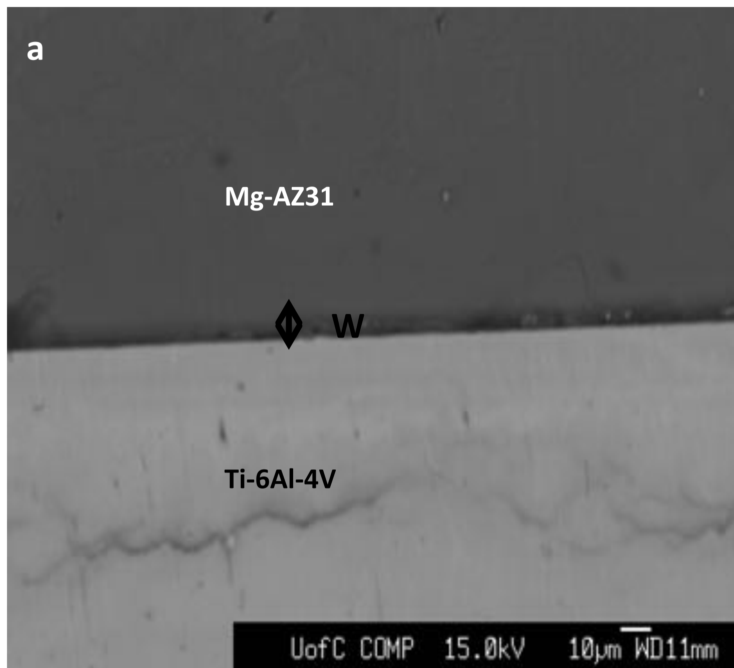


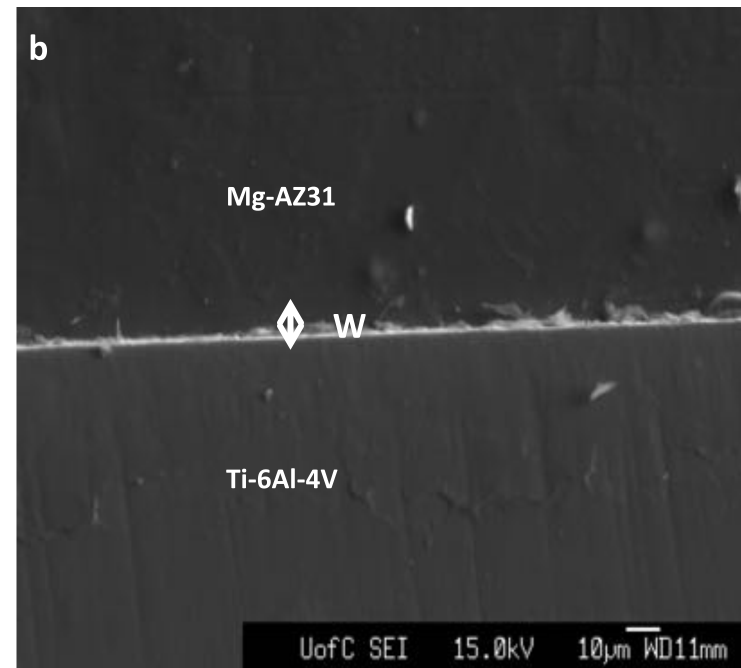
TLP bonds made with Ni coating containing Ni nanoparticles



10 µm coating thickness [520°C, 20 min]

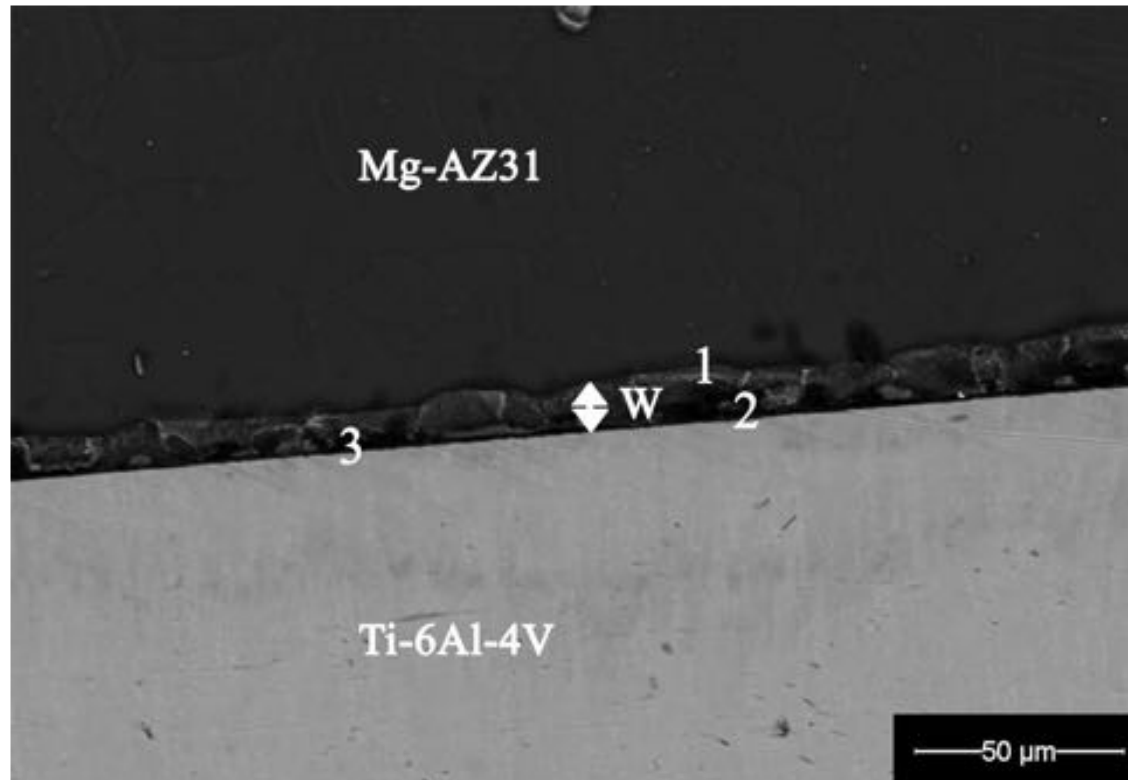
TLP bonds made with Ni coating containing Cu nanoparticles





10 μm coating thickness [520°C, 20 min]

TLP bonds made with Ni coating containing Cu-Ni nanoparticles



10 µm coating thickness [520°C, 20 min]

Effect of nanoparticles on eutectic width

Joint zone width (μm)

90
80
70
60
50
40
30
20
10
0

73
58
5
15

Ni coat
Ni-Nano
Cu-Nano
Ni/Cu Nano Matrix

Nano coat type

Joint shear strengths

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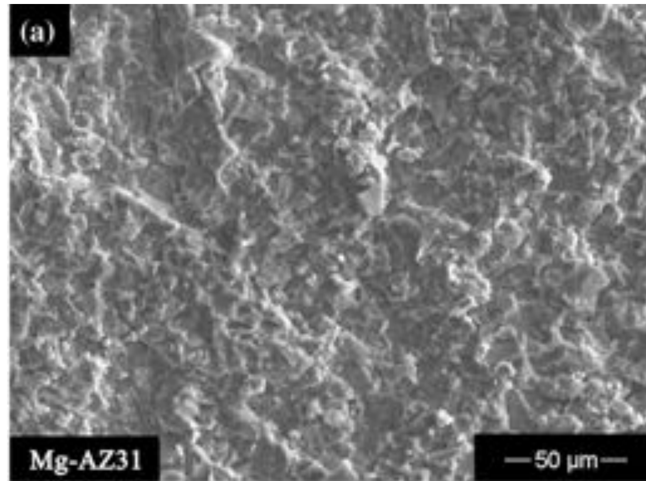
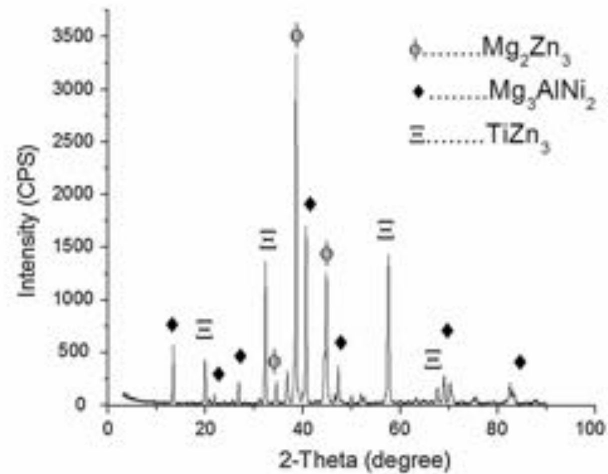
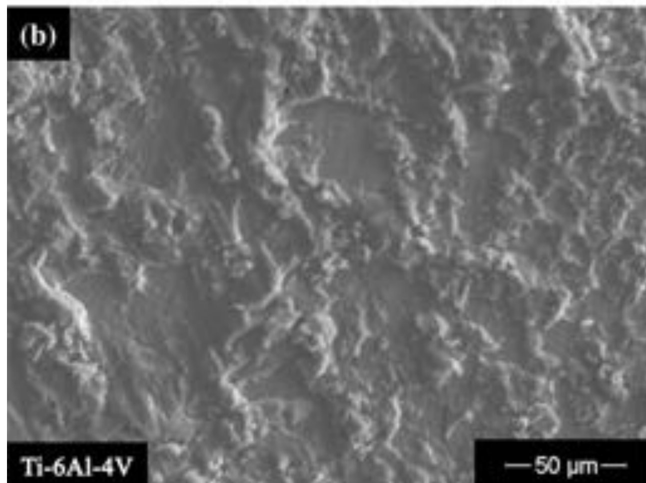
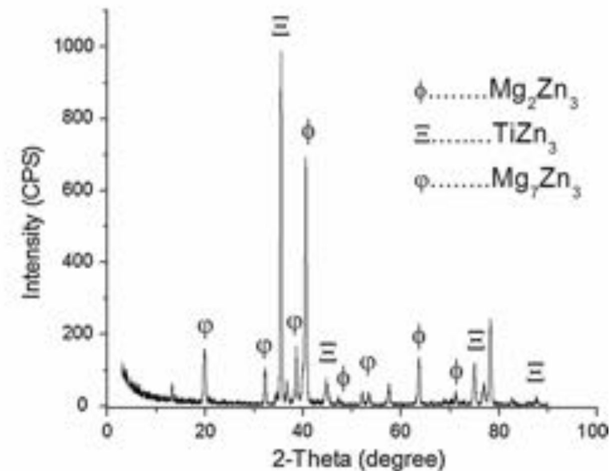
Ti-6Al-4V/Ni nano/Mg-AZ31









Summary

- ❖ Dissolution and melt-back is reduced using thinner interlayers;
- ❖ Nano-particles can be used to reduce the eutectic liquid thickness and increase solidification rate;
- ❖ Nano-particles present in the interlayer can provide greater joint strengths than using pure metal interlayers;
- ❖ The size of the nano-particles used as a dispersion affect the extent of strengthening.

Acknowledgements
Research Team at University of Calgary