Interface structural analysis of similar and dissimilar magnetic pulse welded joints

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Project MSIM (2010-2012):

Funded by Région Picardie

Workshop Impulse forming & joining

IBS Belgium, 7-8 may 2013

utc Université de Technologie Compiègne

PICARDIE

Projet cofinancé par l'Union Européenne. L'Europe s'engage avec le Fonds européen de développement régional.

Current challenge :

Development of multi-material assembly for lightweight structures → MPW : joining solution

Optimization of the MPW → improvement of durability and reliability of dissimilar-material assemblies

Project MSIM :

Driving the MPW toward its optimal ability for an efficient welding of dissimilar-material assemblies

- Analysis of the interaction process parameters/joint quality
- Analysis of the effect of metal dissymetry on the joint quality
- Modeling and computational simulation of the MPW
- Feasibility study and development of tooling

present results : weld quality depending on the process parameters

Experimental approach :

- characterization and classification of the different joints encountered
- relation between weld quality and process parameters
- weldability study of Al/Al and Al/Cu assemblies

Material and method

Comparison between two cases of assembly :

Similar materials : Al6060T6/Al6060T6

Dissimilar materials : Al6060T6/Cu

} Welding test investigated with identical parameter sets

Material chemical composition (% weight)

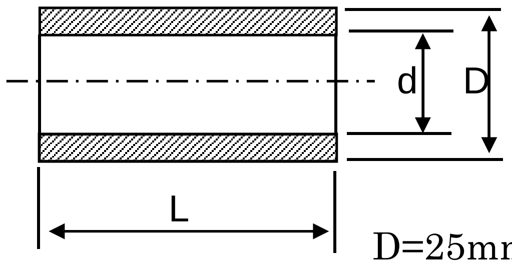
	Mg	Si	Fe	Mn	Cr	Zn	Ti	Cu	Al
Al6060T6	0,8-1,2	0,4-0,8	0,7	0,15	0,04-0,35	0,25	0,15	0,15-0,4	Balance
Cu	-	-	-	-	-	-	-	99,9	-

Material properties

	$\sigma_{él}(\Omega m)^{-1}$	Tf(°C)	ρ(kg/m³)	E(GPa)	G(GPa)	Rm(MPa)	$Rp_{0,2}$(MPa)	Ar(%)	Hv
Al6060T6	$2,5.10^7$	650	$2,7.10^3$	70	26,6	290	240	10	80
Cu	$5,8.10^7$	1065	$8,9.10^3$	124	46,6	250	200	14	80

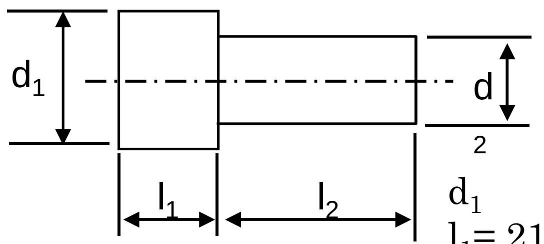
Geometrical characteristic of the samples

Flyer :

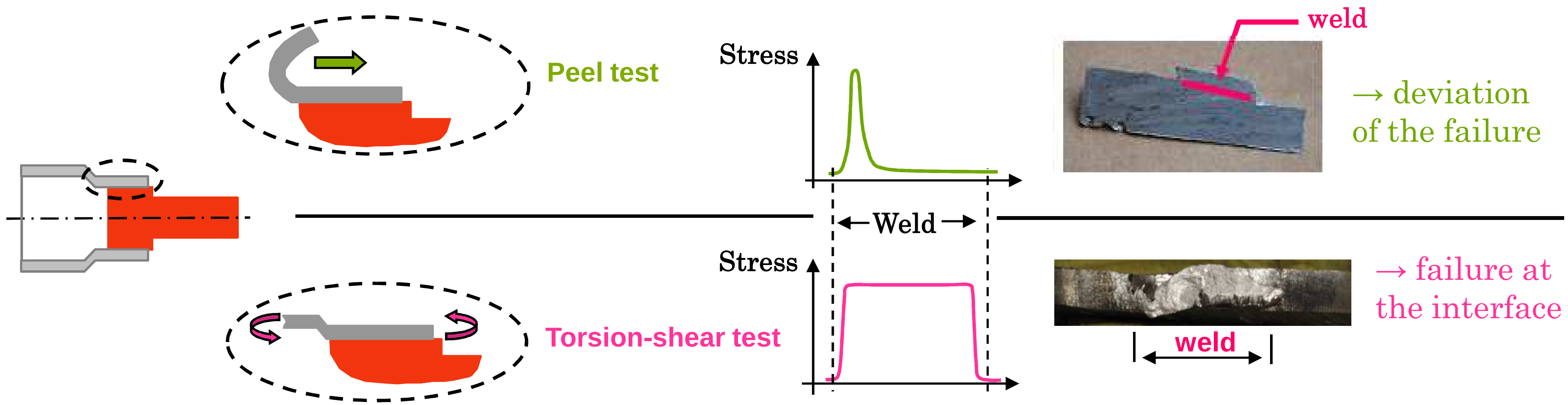


D=25mm
d=22mm
L= 50mm

Target :

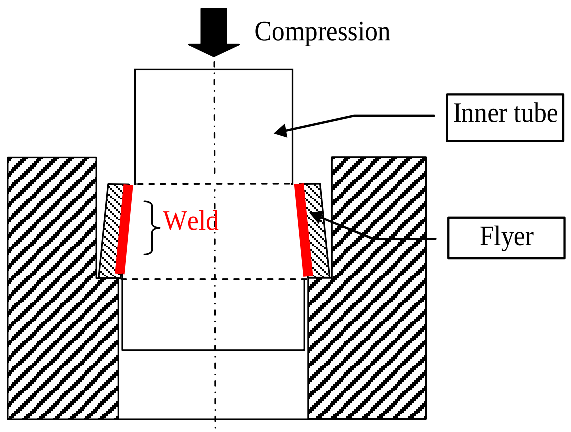


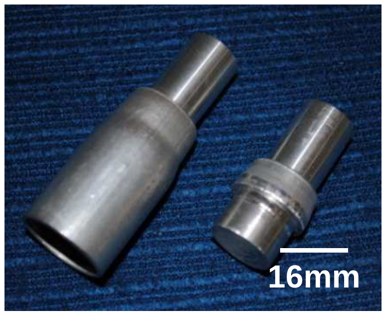
d_1
l_1= 21mm
d_2
l_2= 23mm

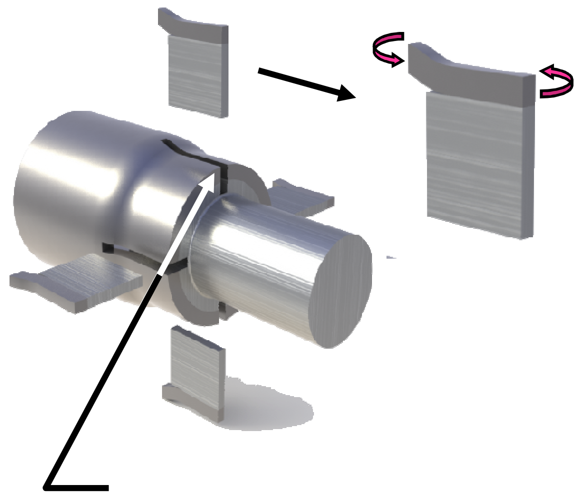


→ dimensional characterization

Push-out test





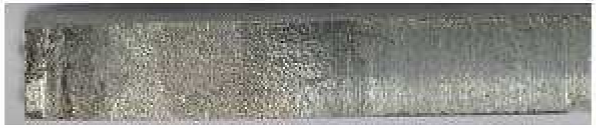


Microstructure examination

→ mechanical characterization

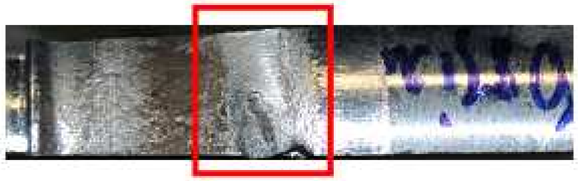
→ structural characterization

Dimensional characterization



Unwelded interface

Beginning of bonding
(trace of residue)



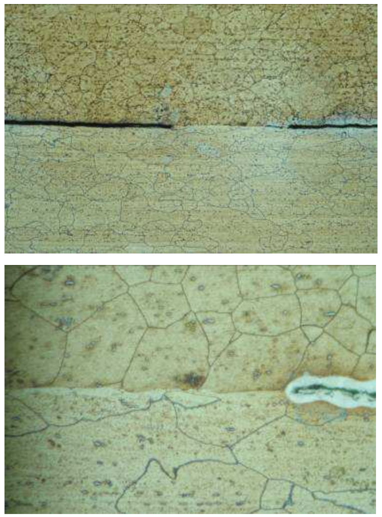
Beginning of good welding
(thin weld)

Large weld

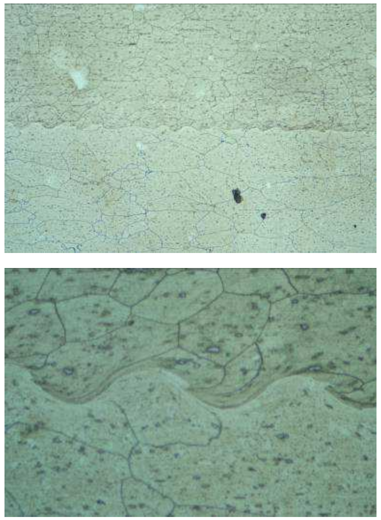
Striation : circular path due to interfacial deformation → ductile and potentially permanent weld

Structural characterization

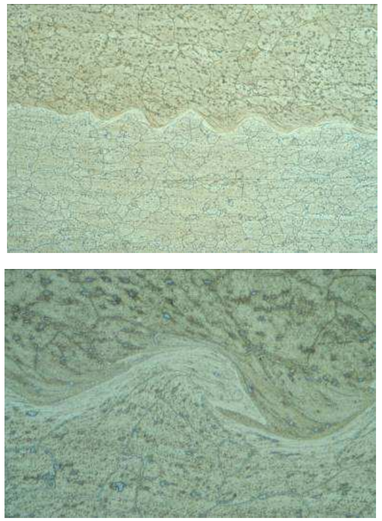
Beginning of bonding



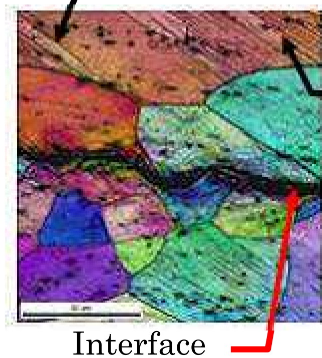
Beginning of good welding



Potentially permanent weld

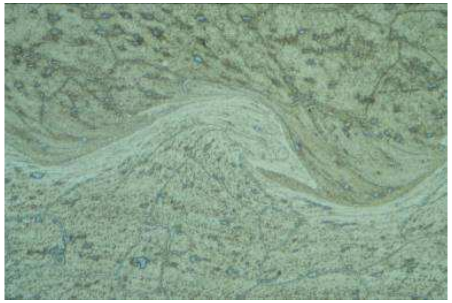


EBSD analysis



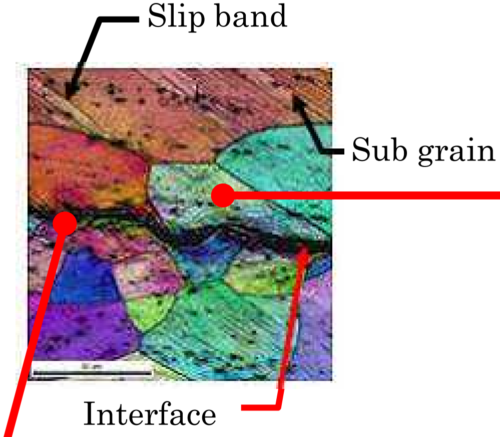
Multiscale characterization of the Al/Al joint

Interface features

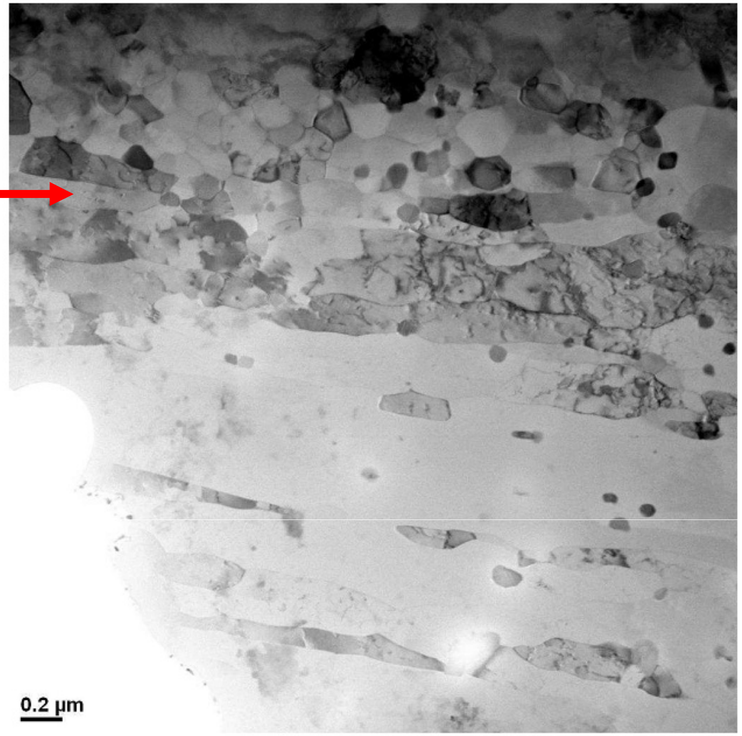


→ grain deformation (strong)

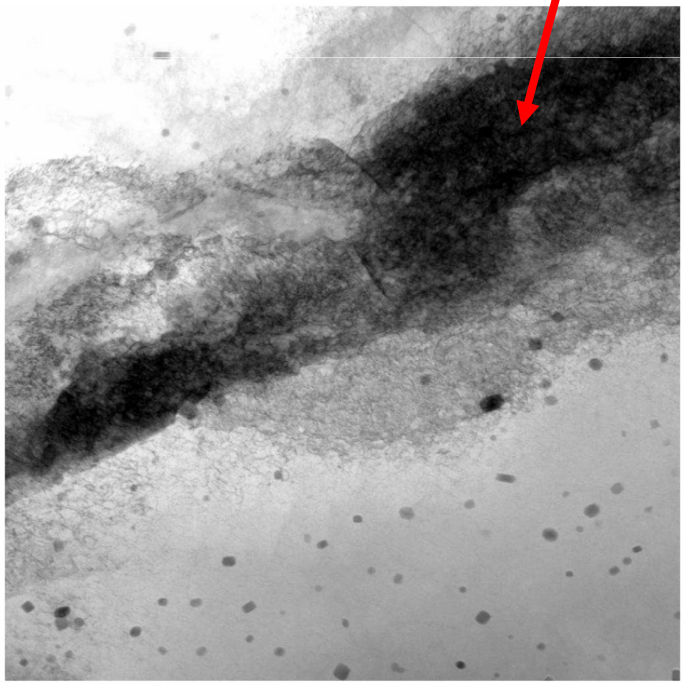
EBSD analysis



TEM analysis



TEM analysis



TEM analysis of the interface :

- high density of dislocation
- grain size (< 500nm) → modification of the mecanichal properties

Nanoidentation → gradient of hardness

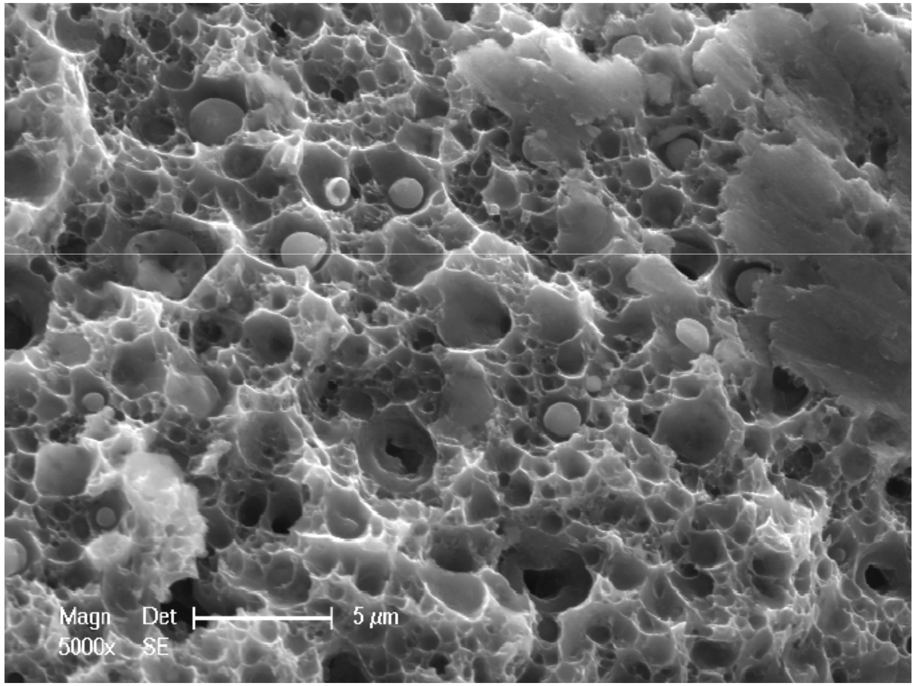
(Hv interface ≈1.5*Hv base metal)

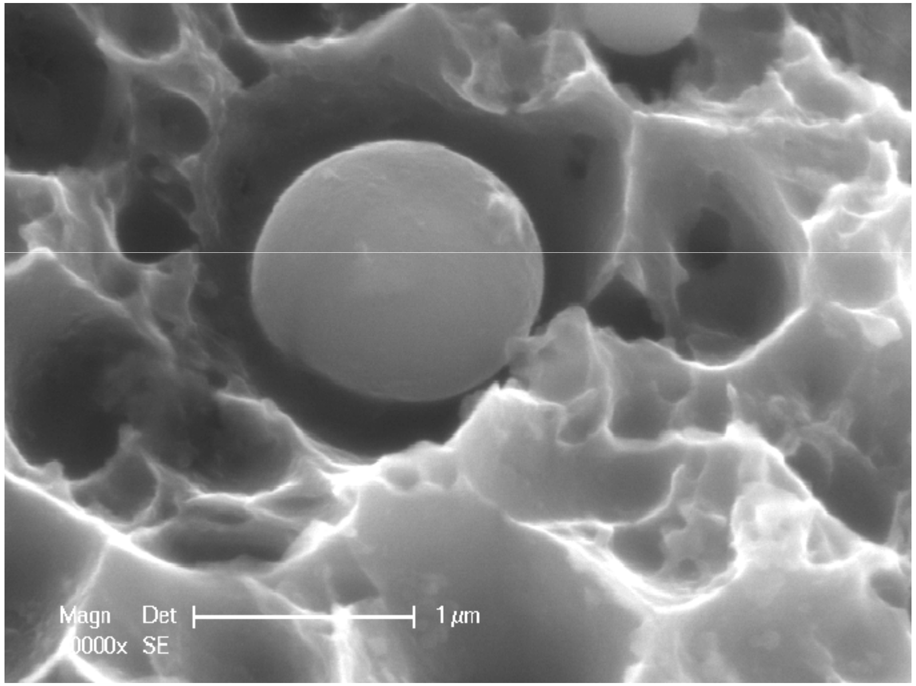
Further SEM analysis

Formation of the dimple :

- creation of cavities (heterogeneous material structure) : decohesion at the phases interface
- création of cavities from inclusion : matrice/inclusion decohesion (e.g. due to precipitates)

Al6060T6 material : with Al_x-Mg_y-Si_z precipitates

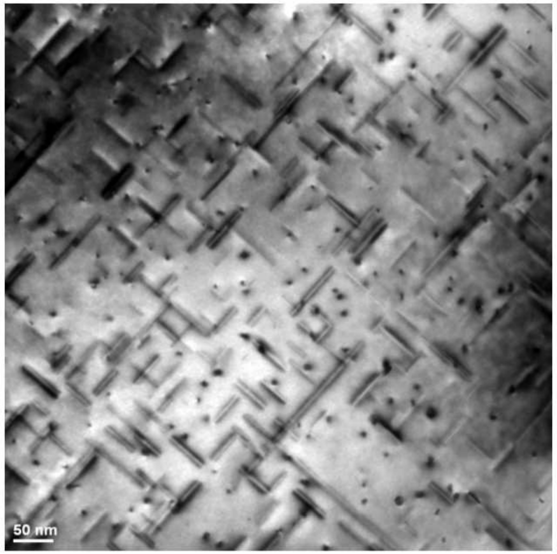




- observation of spheroïdal inclusion inside ome dimples -
EDX analysis of the inclusion : diffraction of Al and Mg

→ development of dimple: potentialydue to precipitates

Structural analysis of the precipitates



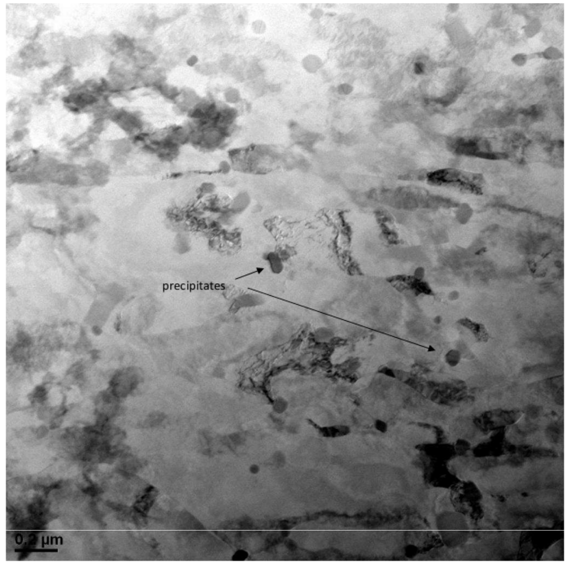
Base metal :

→ matrix of Al
→ needle shape precipitate

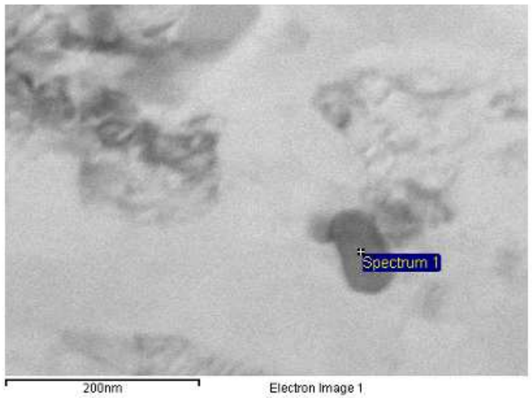
Element	Weight%	Atomic%
Mg K	6.18	6.82
Al K	90.42	89.93
Si K	3.40	3.25
Totals	100.00	

Interface :

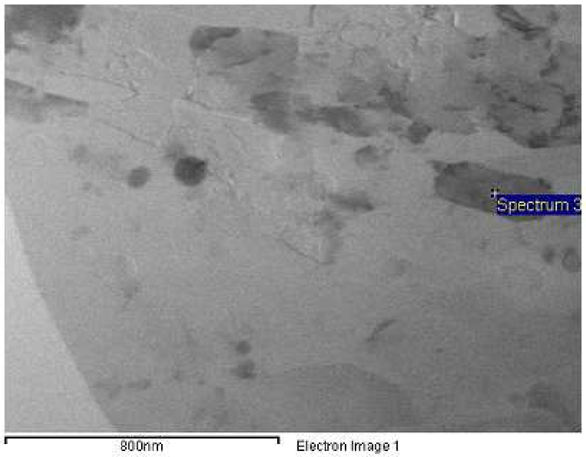
→ needle shape p/tes dissapear
→ spheric p/tes appear



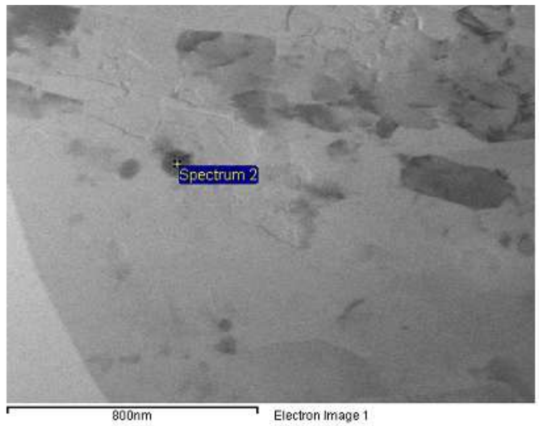
Element	Weight%	Atomic%
O K	4.13	8.17
Al K	62.70	73.50
Si K	0.71	0.80
Mn K	17.70	10.19
Cu K	14.76	7.35
Totals	100.00	

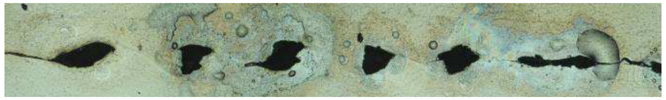


Element	Weight%	Atomic%
O K	6.55	11.14
Al K	84.22	84.91
Cu K	9.24	3.95
Totals	100.00	



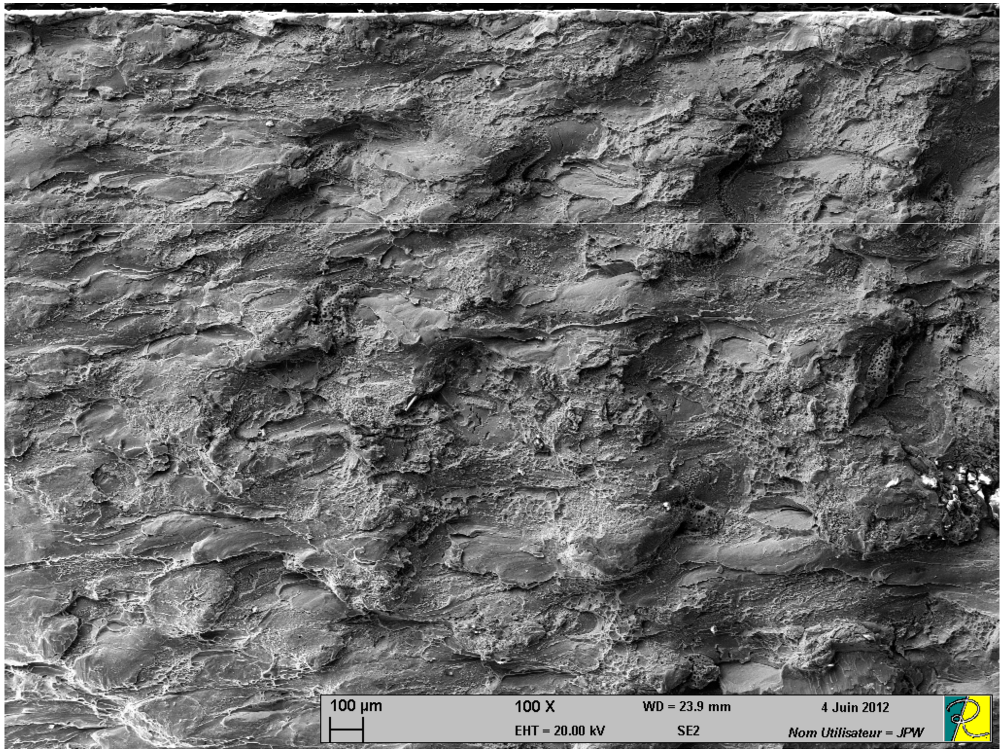
Element	Weight%	Atomic%
O K	37.16	51.43
Al K	25.93	21.28
Si K	32.81	25.87
Cu K	4.09	1.43
Totals	100.00	



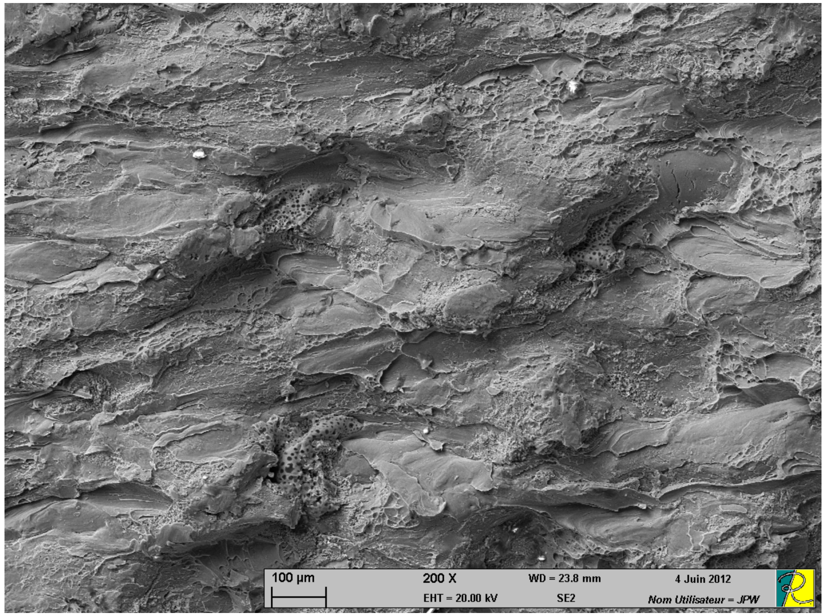


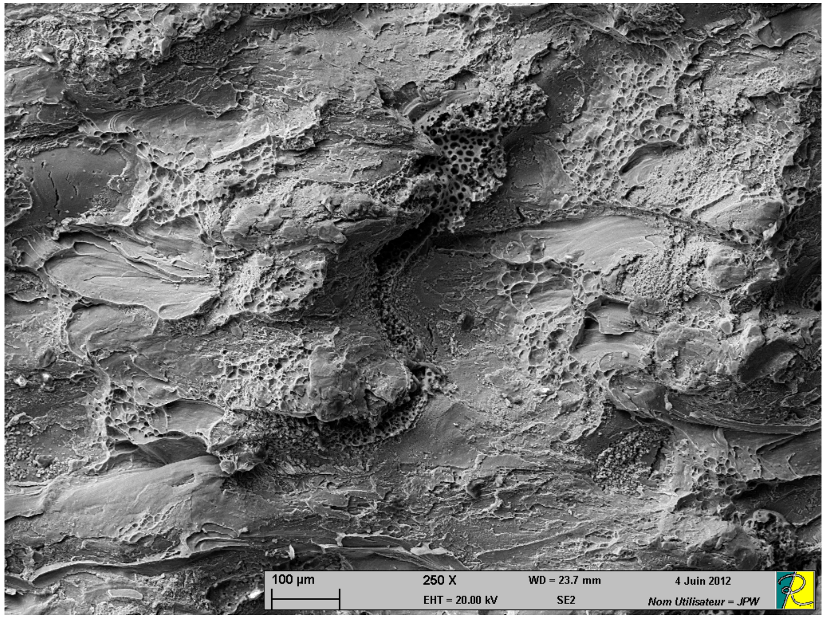
→ creation of macro-cavities (crack initiation sites)

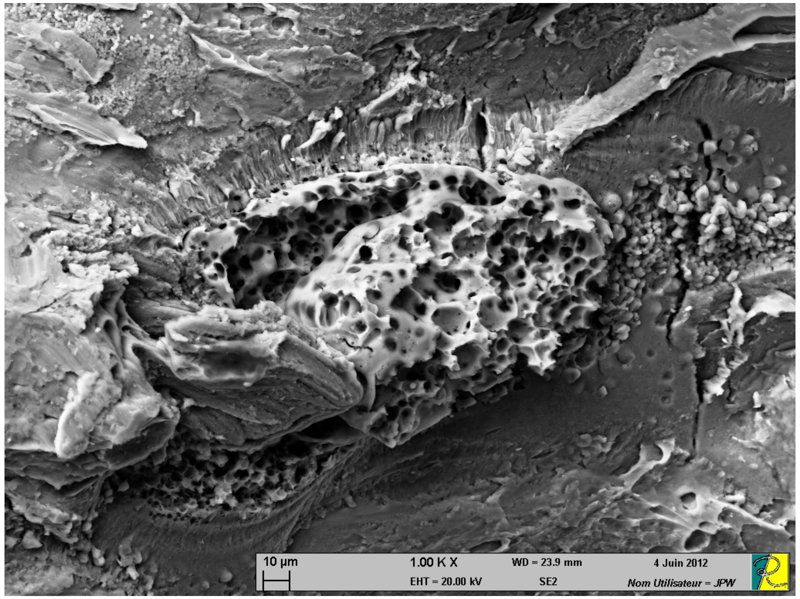
Fractal analysis

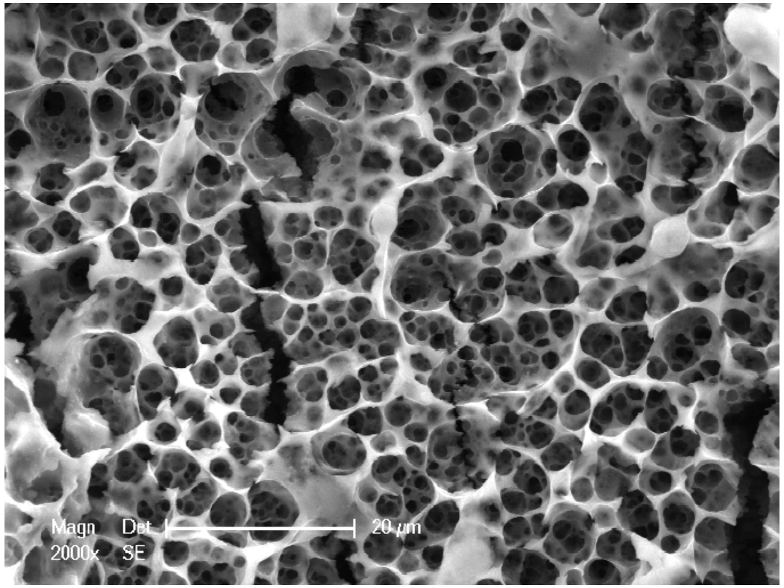


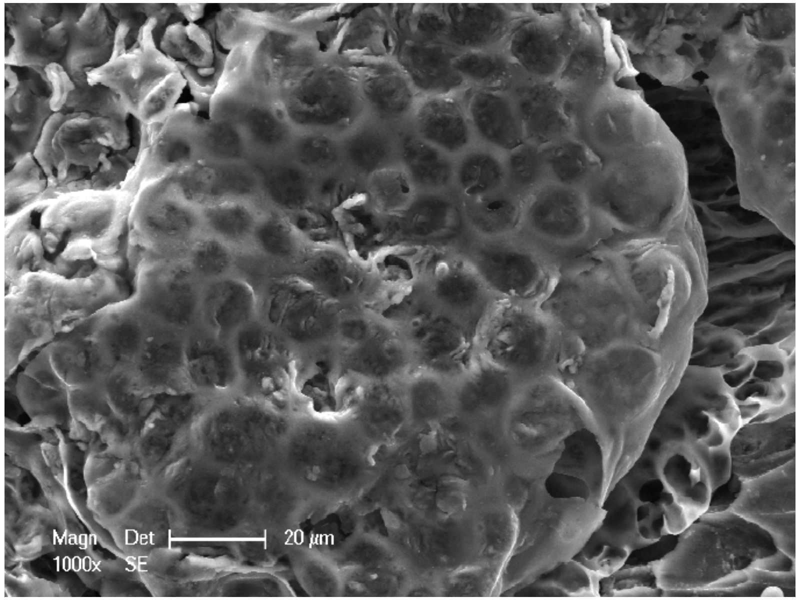
→ regular distribution of humps
→ porous zone within the hump



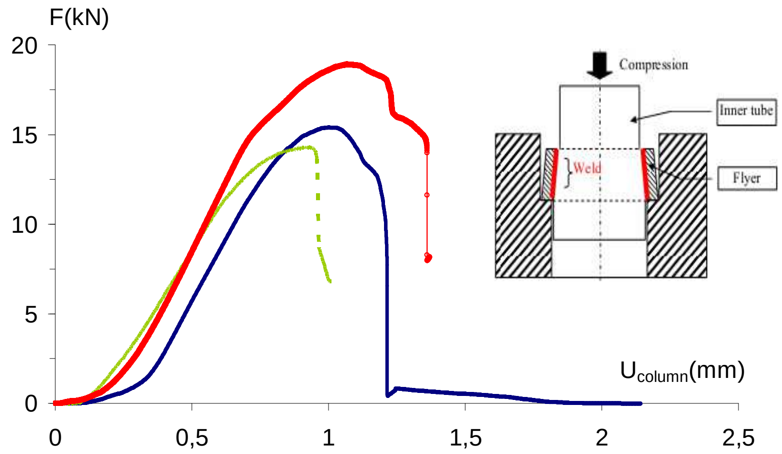








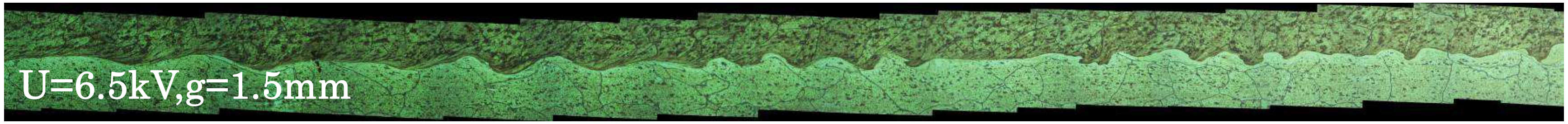
Effect on the mechanical behaviour



Local analysis of the porous zones → porosity with high density (attributable to cavitation)

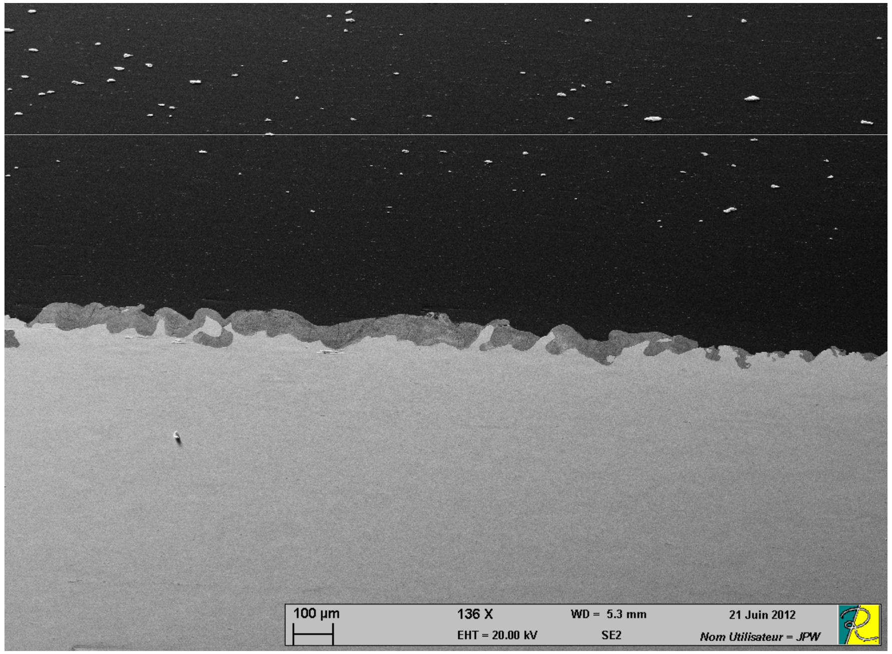
Effect of material dissymetry : effect on the weld features

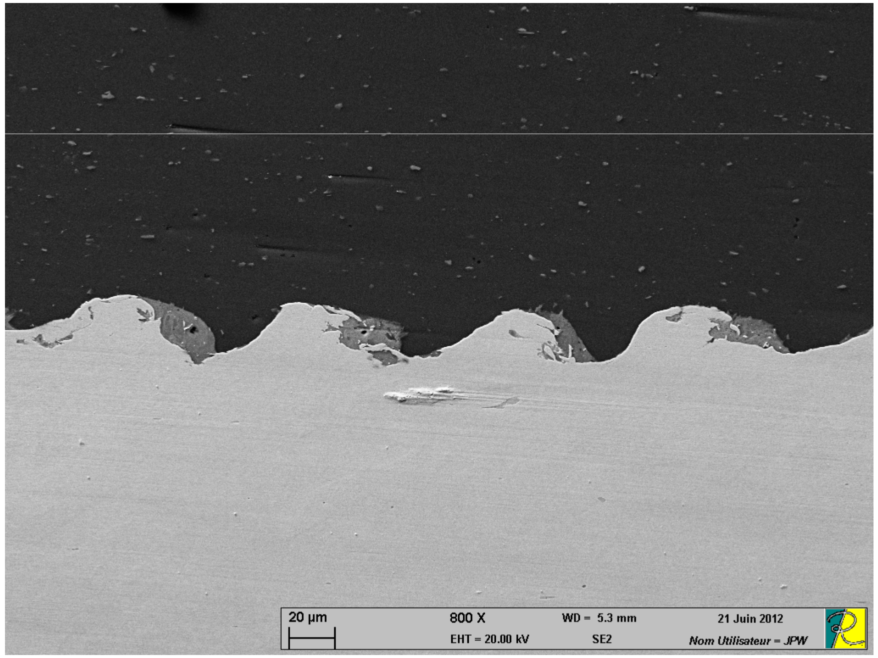
Al/Al



Al/Cu

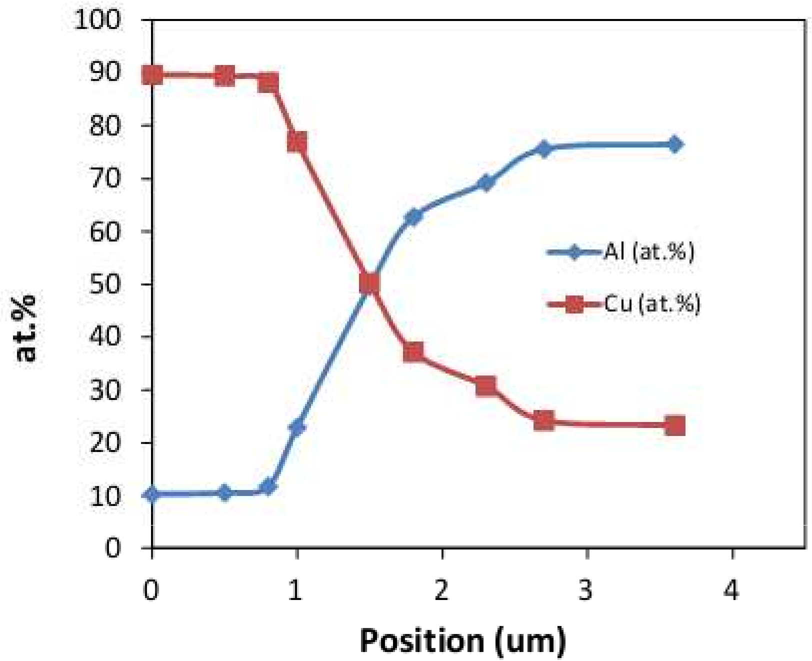
→ Formation of intermetallic phase

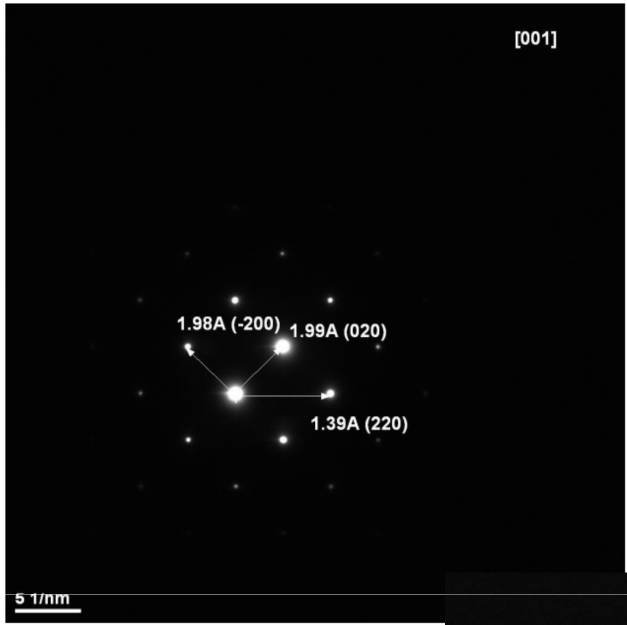




→ continuous layer or discontinous pockets

EDS and TEM analysis



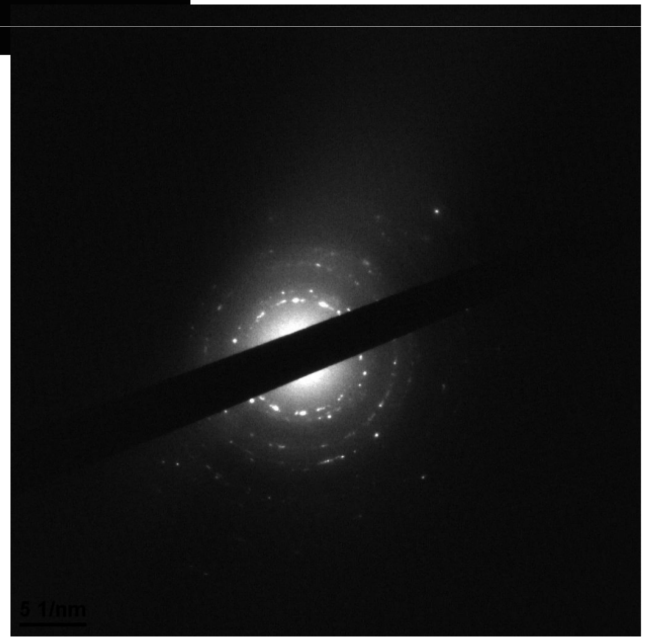


Diffraction in the Al part

→ ordered structured

→ crystal lattice

Diffraction in Al_nCu_m



Intermetalic :

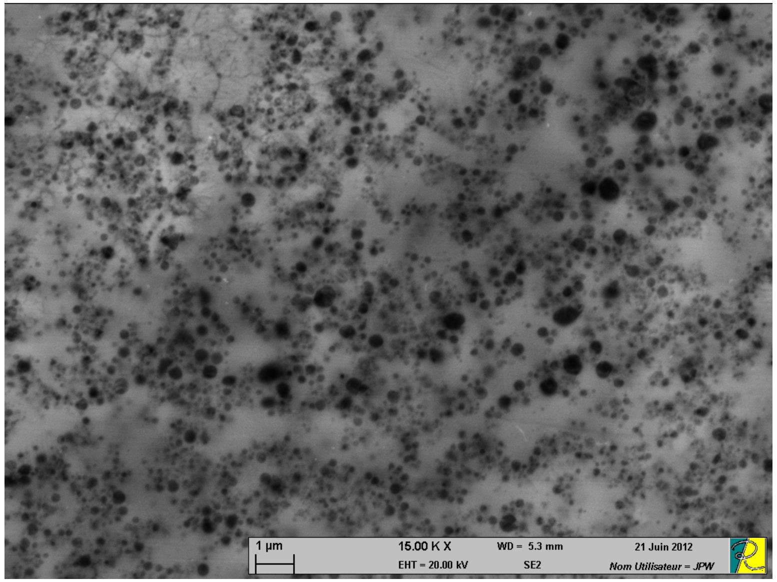
→ complex structure

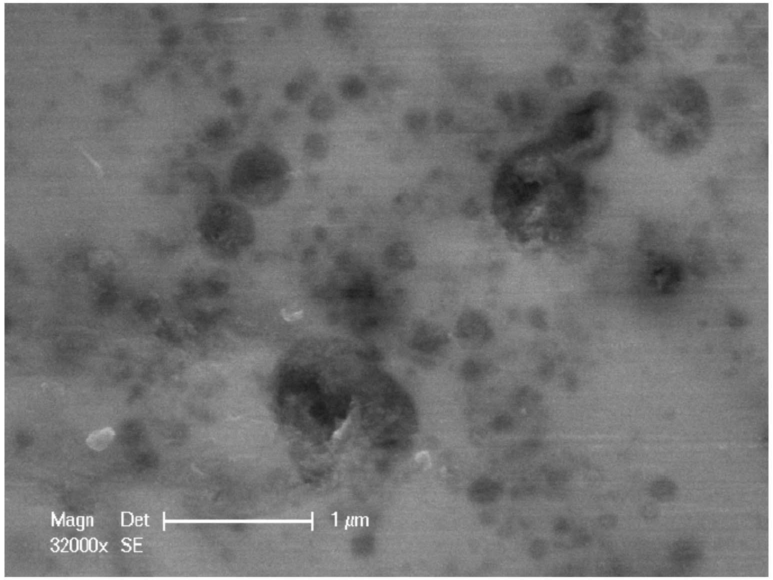
→ random distribution

→ extremely fine grains

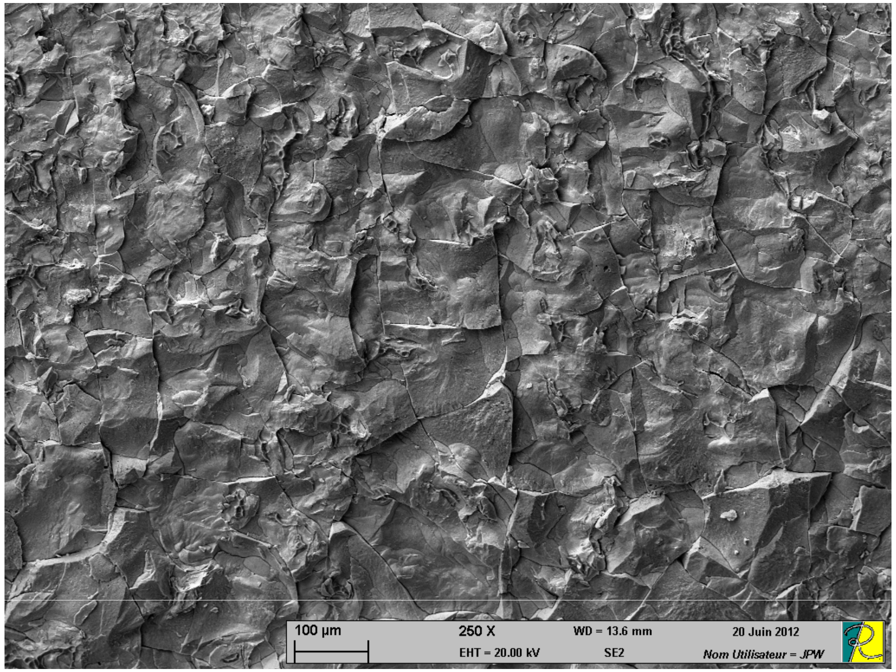
- **amorphous phase**
- **formation by hyperquenching**
  (quick cooling : 10^4-10^6K/s)

Further characterization of the intermetallic phase



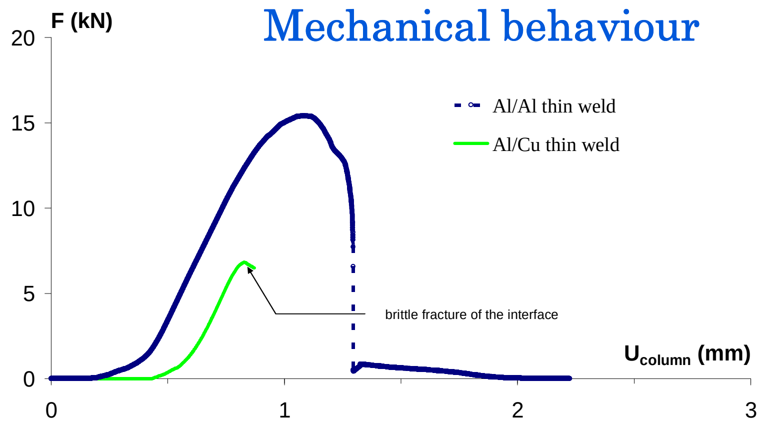


→ porous structure (size of ~ hundreds nm)

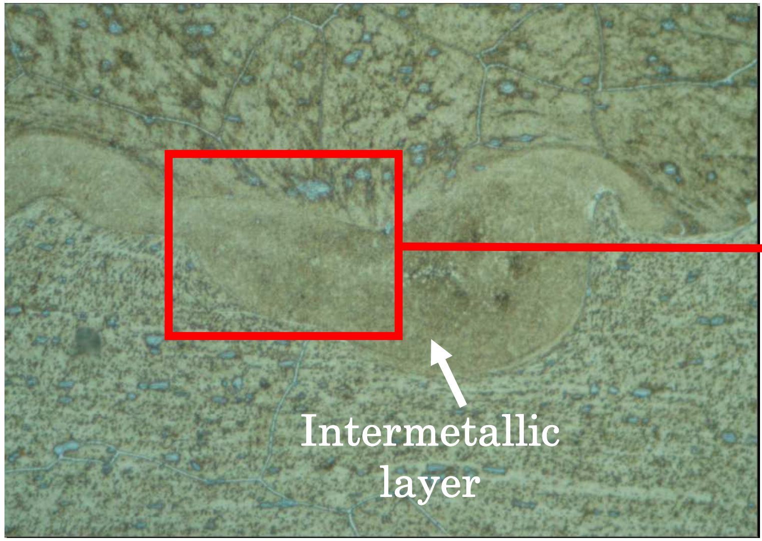


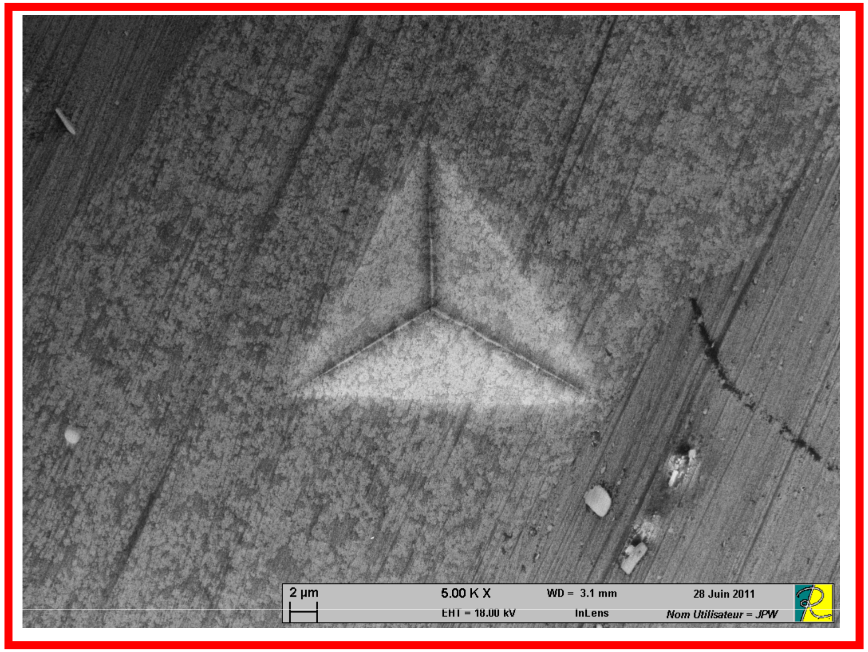
→ fracture surface : rupture by fragmentation

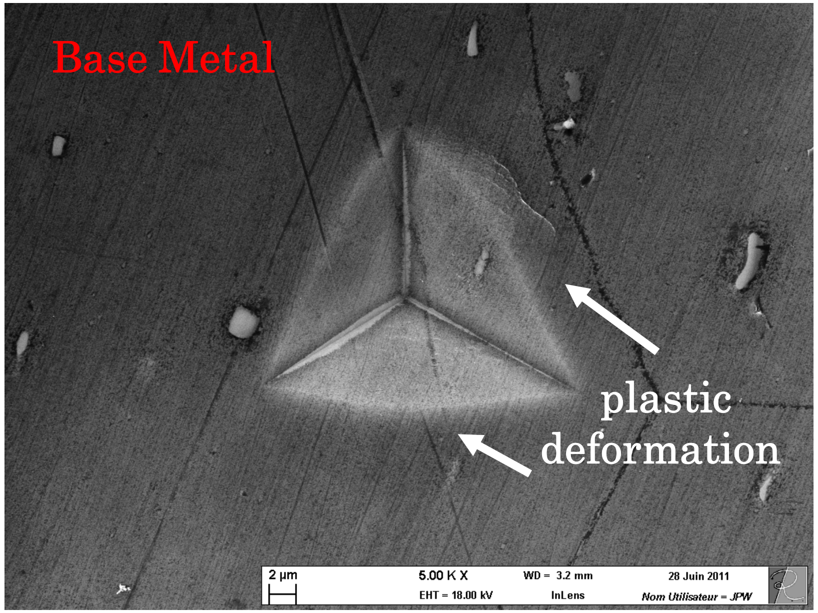
Mechanical behaviour



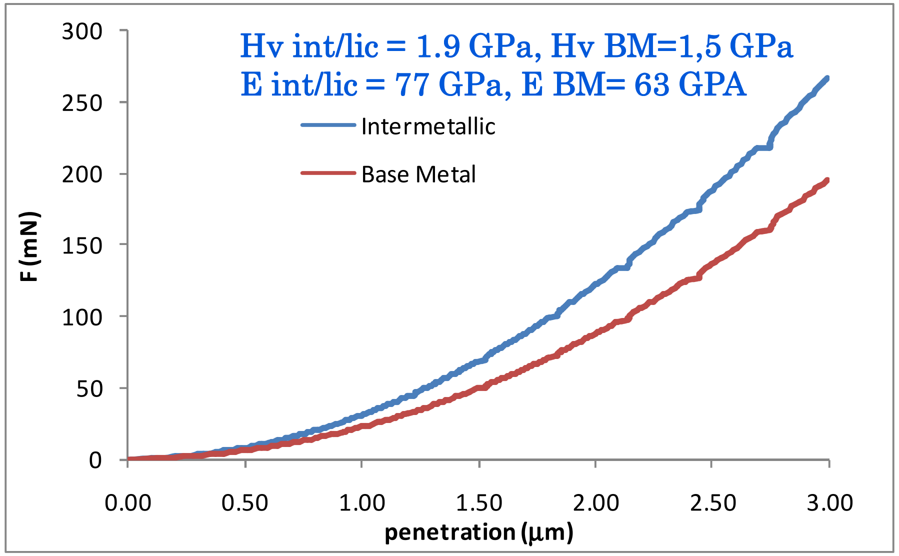
Amorphe phase : britle weld







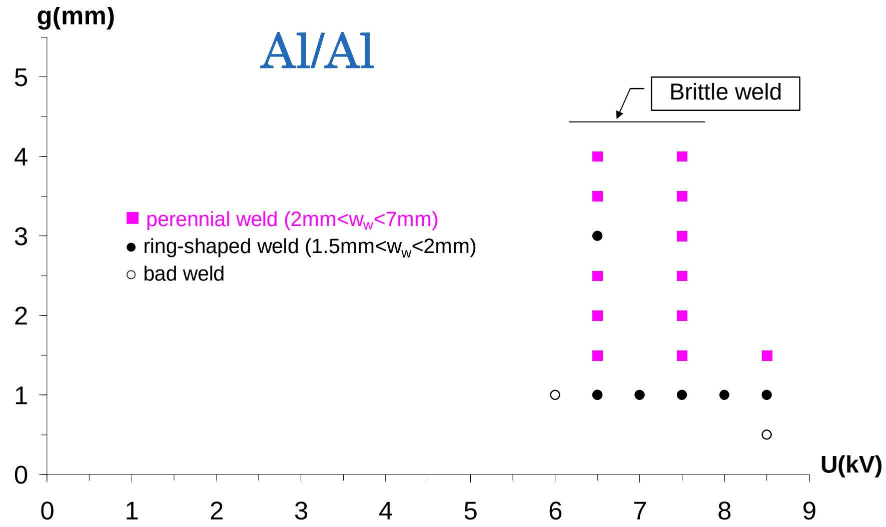
Force / displacement indentation curve

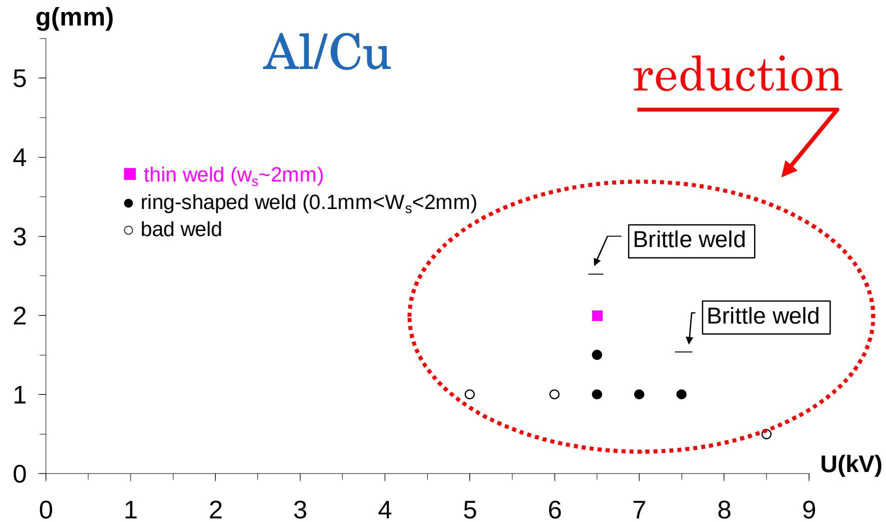


Intermetallic → no plastic deformation surrounding the indent, increase of the hardness

Effect of metal dissymetry

Welding range





Comparison of achieved good weld

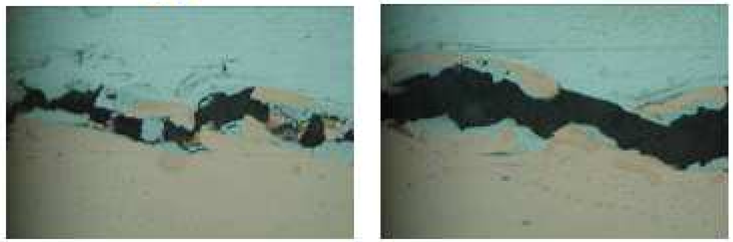
Al/Al

Large residue

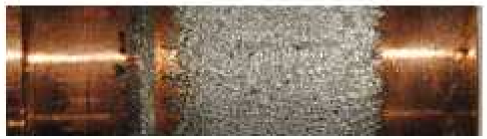
Al/Cu

Short length residue

Illustration of Al/Cu weld above the upper limit (brittle weld)



(case with U=7.5kV, g=4mm)



Conclusions

- interface structural analysis of a similar AA6060T6 weld :

  - weld enable to undergo plastic deformation
  - potentialy permenant weld: ductile with a wavy interface
  - welded interface with high density of dislocations and nanograin
  - heat effected interface : disappearance of needle shape precipitate and formation of new sheroidal ones
  - formation of defective weld with voids and porous zone

- interface structural analysis of a dissimilar AA6060T6/Cu weld :

  - formation of Cu_aAl_b intermetallic phase
  - intermetallic : → discontinous pocket or continous layer
    → amorphous phase and/or with nanograin
    → phase with nanovoids
    → brittle and low resistant weld

→ combination of Al6060T6/Cu : not good for the interface integrity
reduction of the weldability range

Related papers

1. RAOELISON R., BUIRON N., RACHIK M., HAYE D., FRANZ G., HABAK M., 'Study of the elaboration of a practical weldability window in magnetic pulse welding', Journal of Materials Processing Technology (2013) http://dx.doi.org/10.1016/j.jmatprotec.2013.03.004.

2. RAOELISON R., BUIRON N., RACHIK M., HAYE D., FRANZ G., 'Efficient welding conditions in magnetic pulse welding process', Journal of Manufacturing Process, 14(2012), 372-377.

3. RAOELISON R., BUIRON N., RACHIK M, 'Investigation of material dissymetry effect on magnetic pulse welding of Al/Cu assembly: effect of intermetallic on the weld characteristic and the weldability', (to be submitted).

4. RAOELISON R., BUIRON N., RACHIK M., HAYE D., FRANZ G., 'Assessment of Gap and Charging Voltage Influence on Mechanical Behaviour of Joints Obtained by Magnetic Pulse Welding', Proceedings of the 4th International Conference of High Speed Forming, Germany 2012, 207-216.

5. RAOELISON R., BUIRON N., RACHIK M., HAYE D., HABAK M., 'Elastoplastic and Damage Behaviour of Magnetic Pulse Weld Interfaces', Proceedings of the 10th International Conference on Technology of Plasticity, Aachen, Germany, p. 1160-1163, 2011