METASTABLE STRUCTURES FORMED AT THE INTERFACE IN EXPLOSIVELY WELDED MATERIALS

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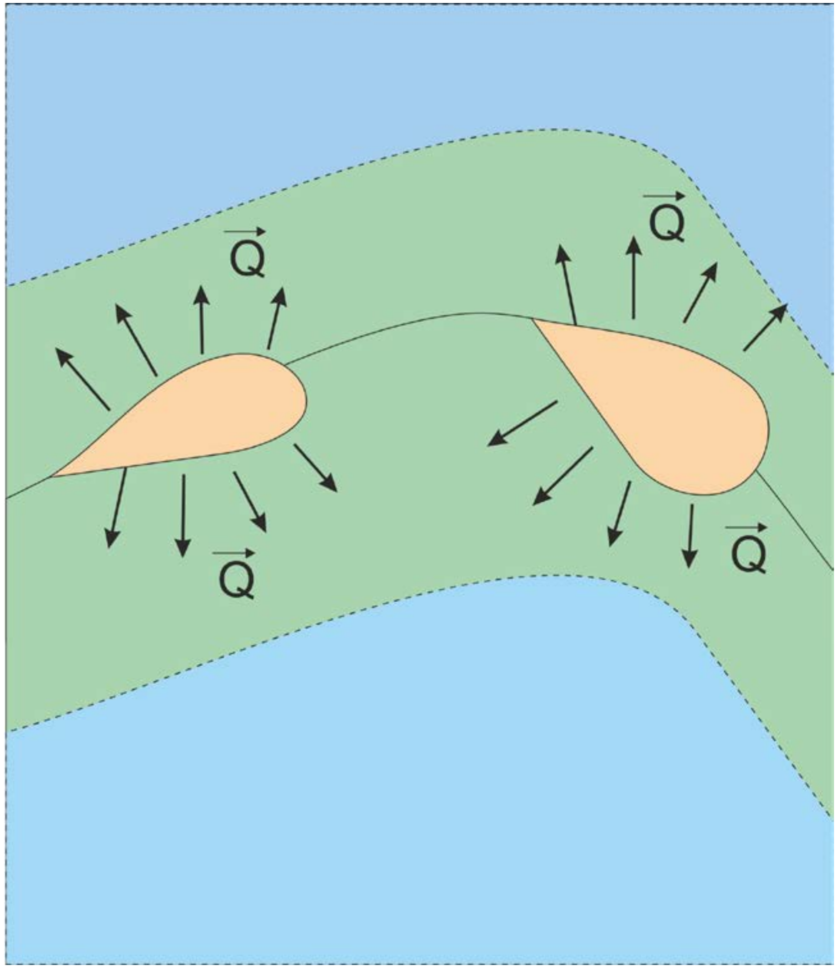
Outline

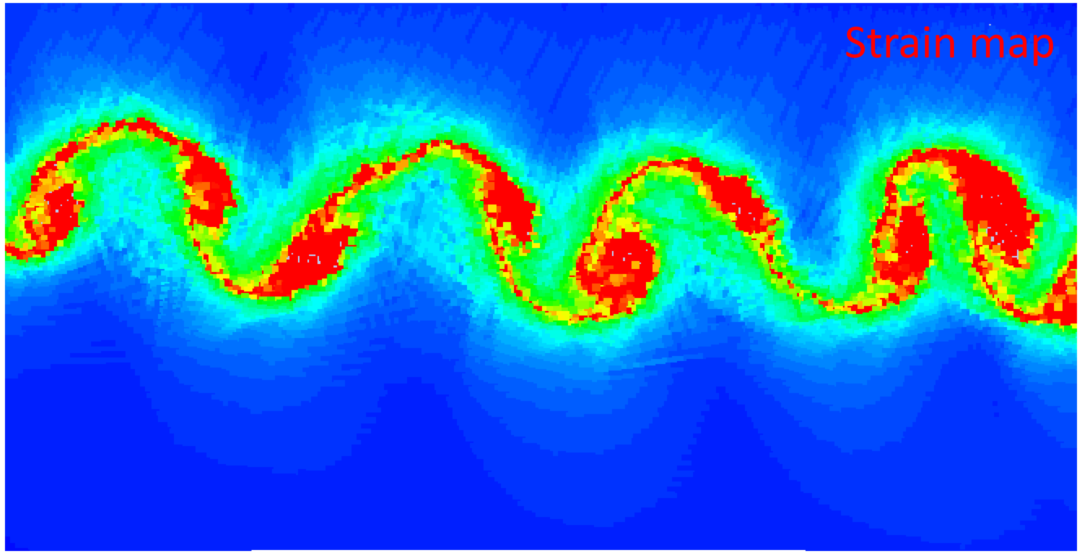
- Numerical simulation
- Welding of identical materials
- Alloys with perfect mutual solubility
- Immiscible alloys (in liquid and/or in solid states)
- Systems with possible formation of intermetallic phases
- Conclusions

Principle scheme of the vortex cooling



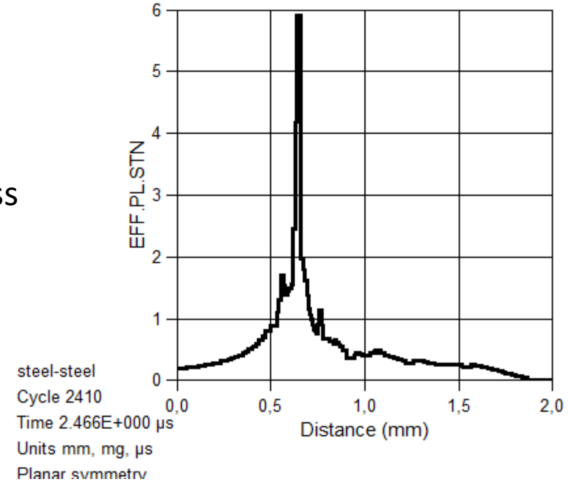
- The exact mechanism of vortexes formation is not fully understood yet
- Due to the severe deformation at the interface of explosively welded materials a localized melting occurs
- Typically, the severe plastic deformation is localized within few hundred micrometers around the interface
- Most part of material stays relatively cold
- High temperature gradient and high coefficient of heat exchange of most of the solids provide exetremely high cooling rate of the vortexes. The cooling rate is comparable with a cooling rate during melt spinning.

Numerical simulation (SPH) and experiment of steel-steel explosive welding

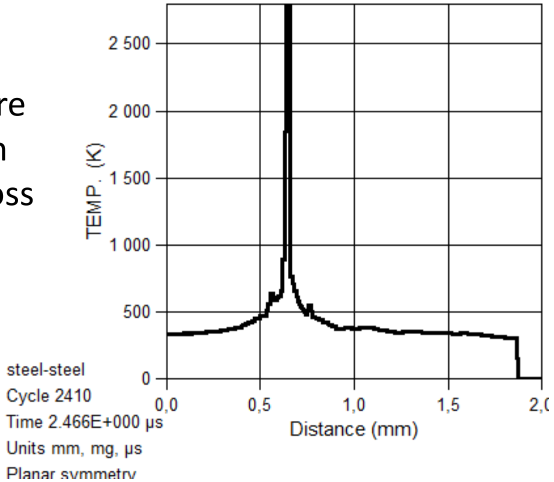


Low carbon steel – low carbon steel joint

Strain distribution profile across the clad

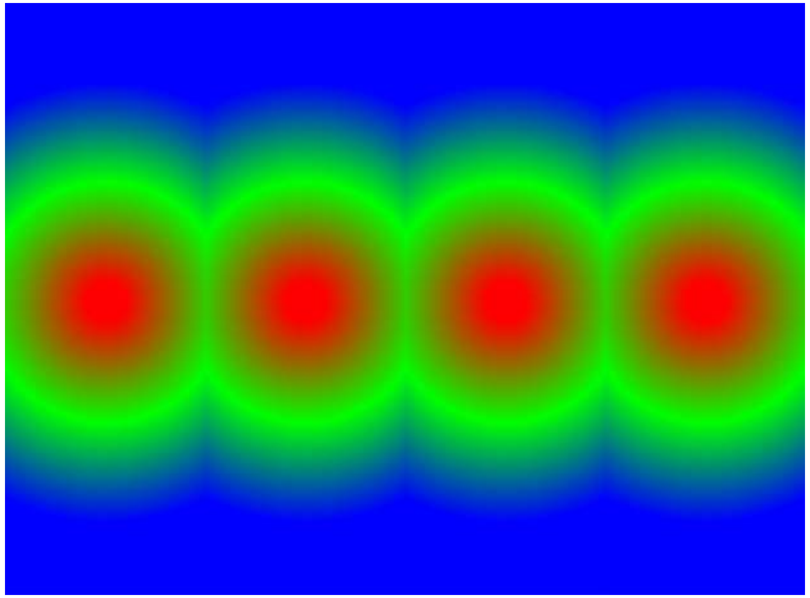


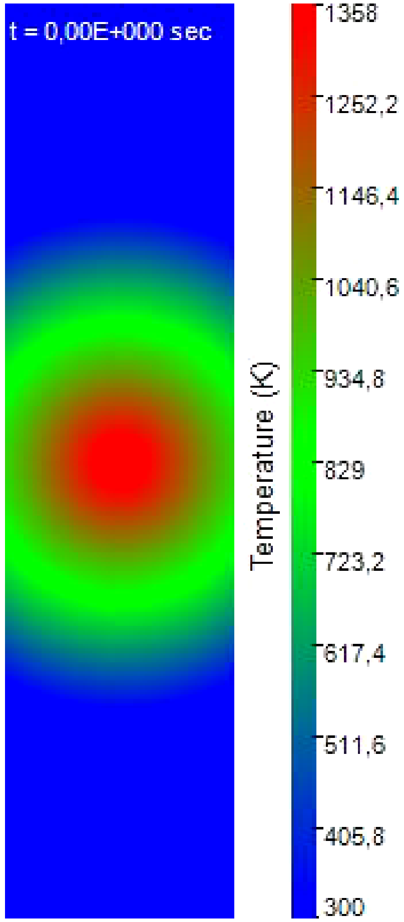
Temperature distribution profile across the clad



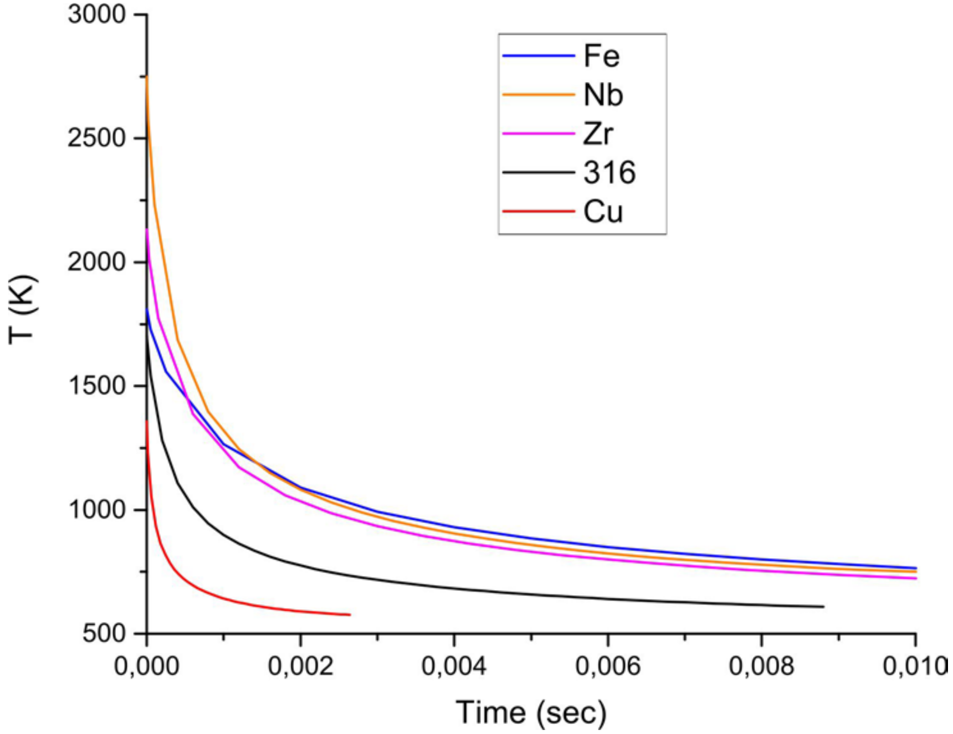
Cooling of explosively welded materials: FDM numerical simulation

Initial conditions



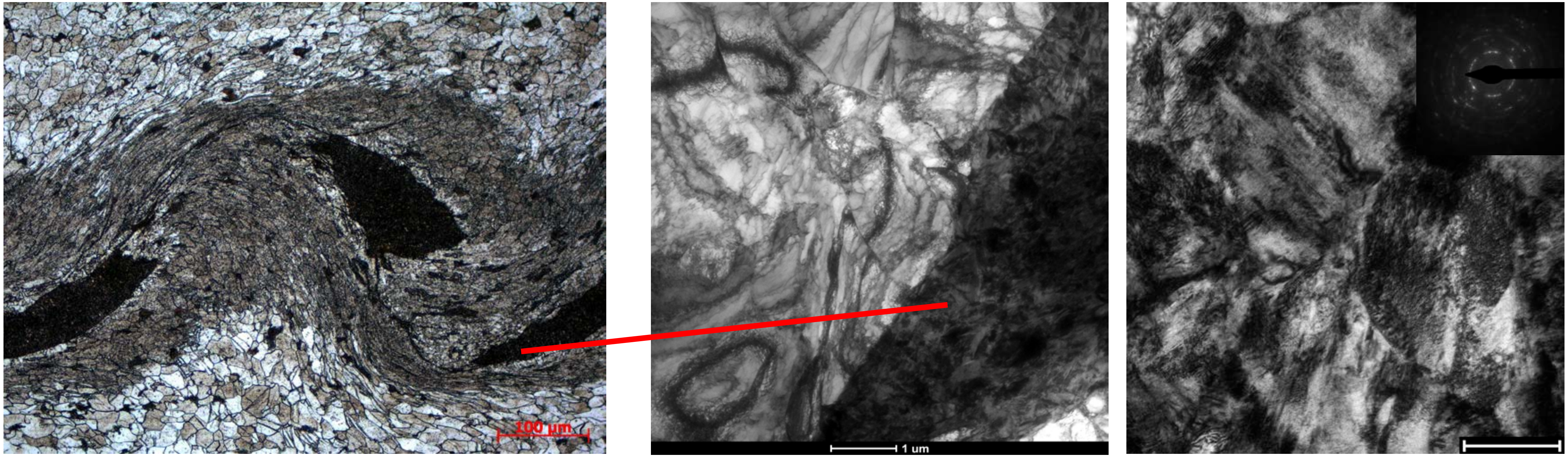


Temperature histories for the middle of the vortex for some materials

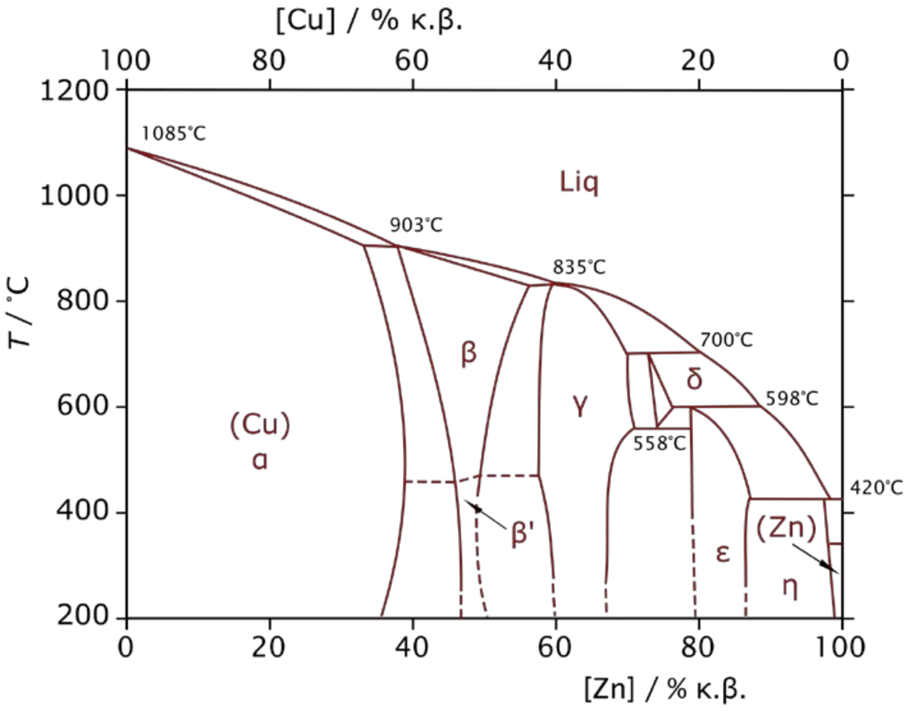


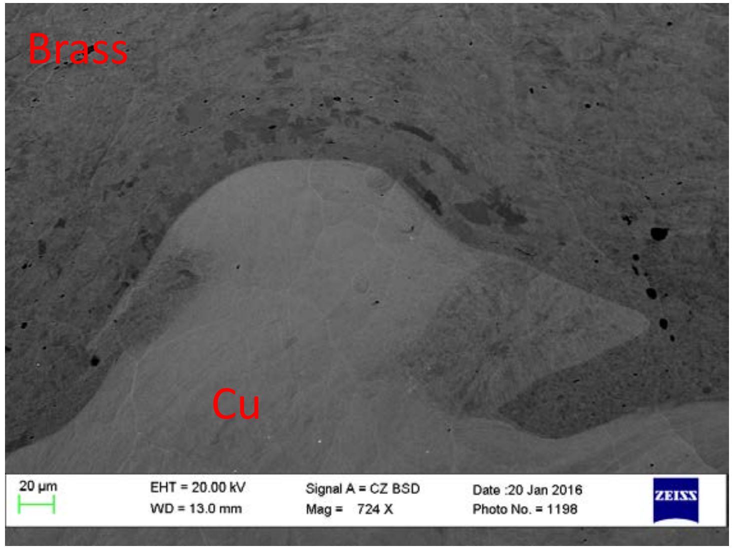
Cooling rates varies from 10^4 to 10^7 K/s

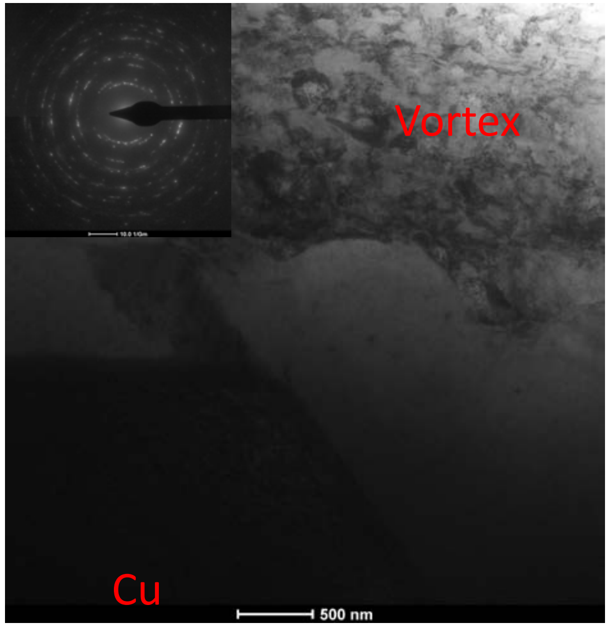
Welding of identical materials
(Low carbon steel welded to low carbon steel)



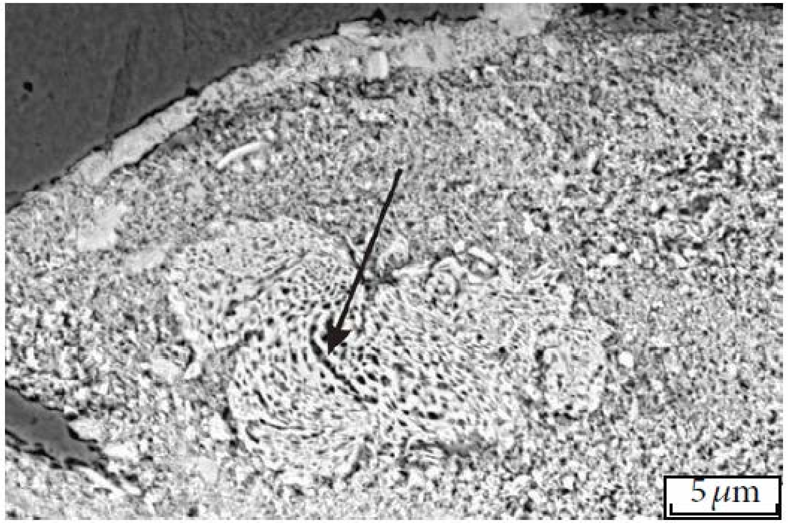
Welding of alloys with perfect mutual solubility (welding of copper to α-brass)

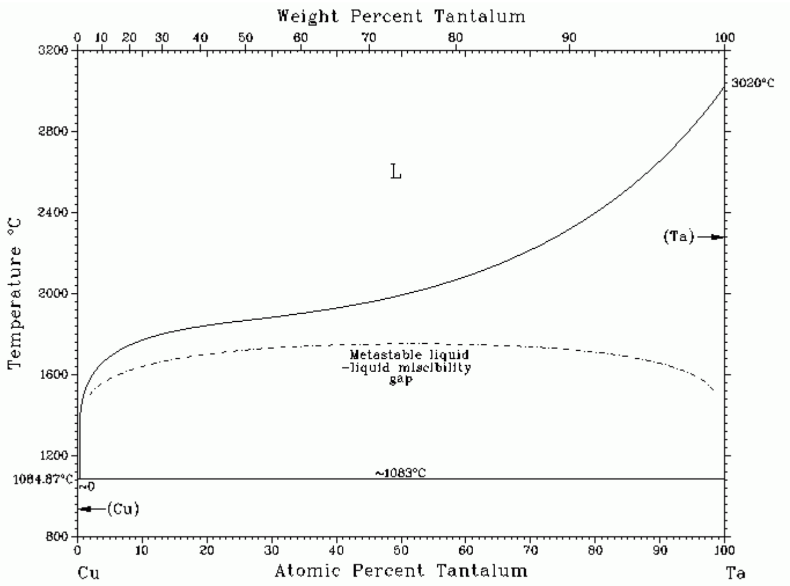


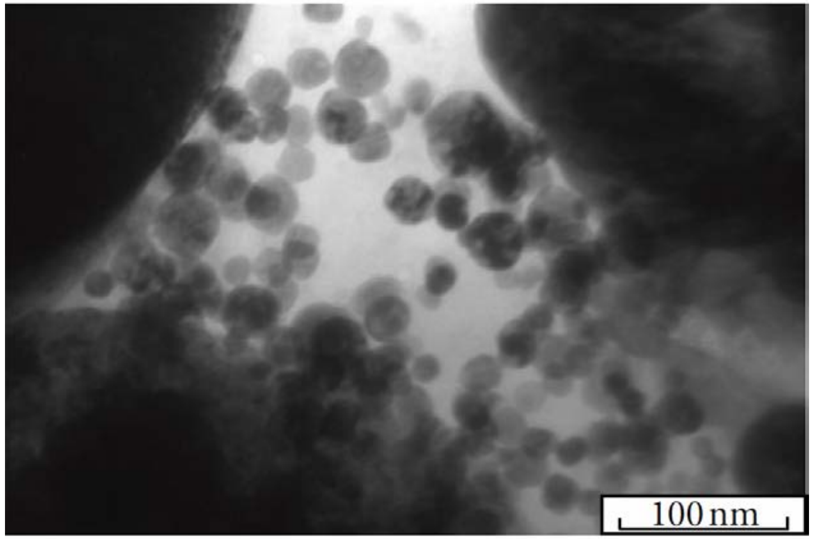


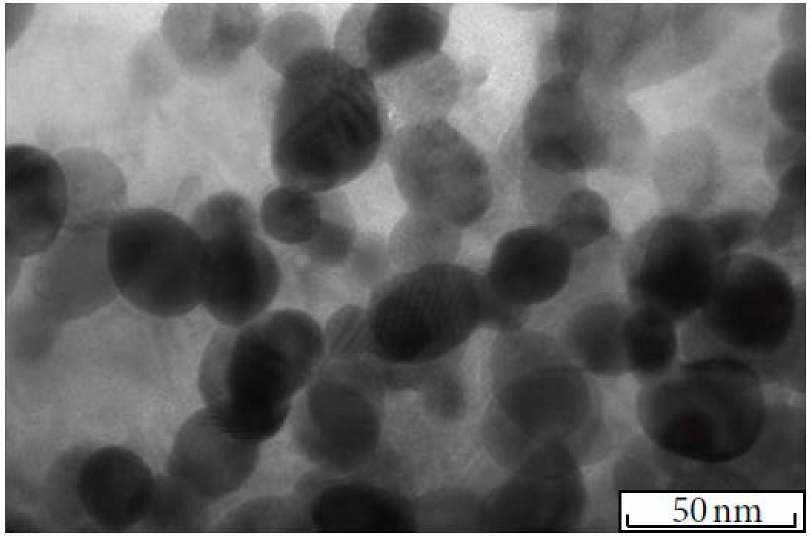


Example of welding of immiscible alloys (Ta-Cu)









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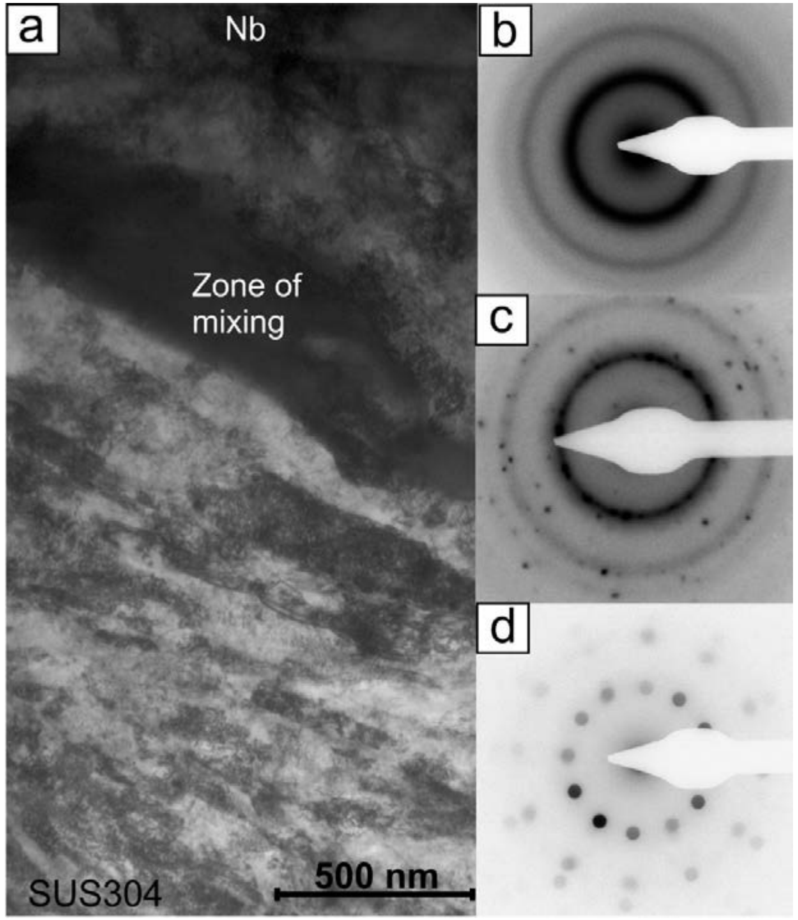
Alloys which tend to from intermetallic compounds upon mixing



Nb-stainless steel welding

The ratio of the atomic radii				
	Fe	Ni	Cr	Nb
Fe	-	1.004	1.006	1.15
Ni	-	-	1.003	1.15
Cr	-	-	-	1.14
Nb	-	-	-	-
Enthalpy of mixing				
	Fe	Ni	Cr	Nb
Fe	-	-1.6	-1.5	-15.7
Ni	-	-	-6.7	-29.9
Cr	-	-	-	-7.2
Nb	-	-	-	-

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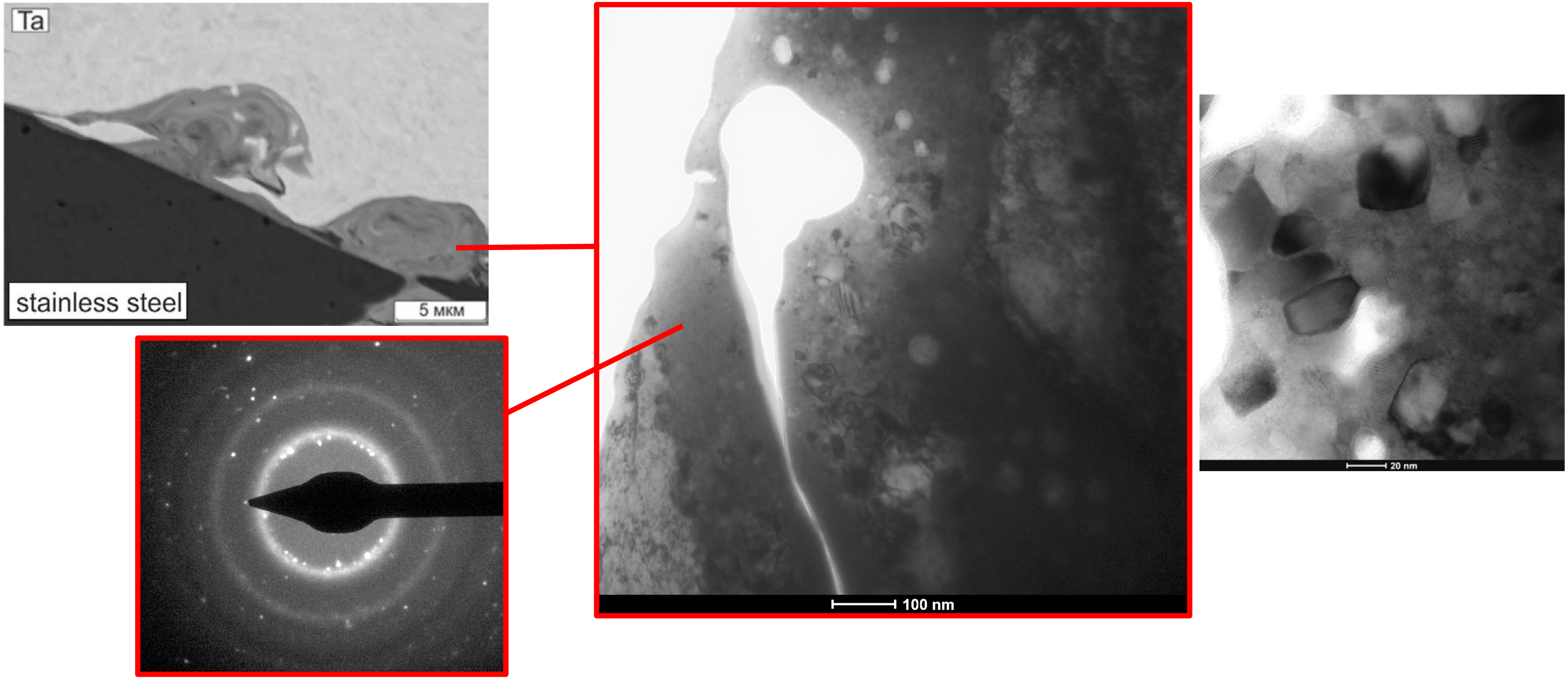
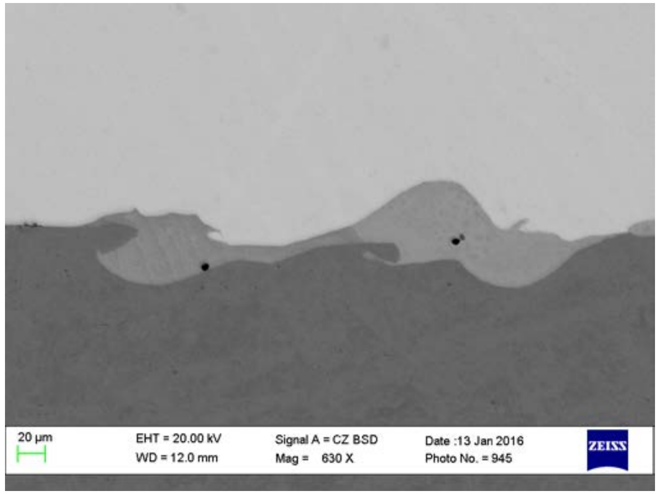
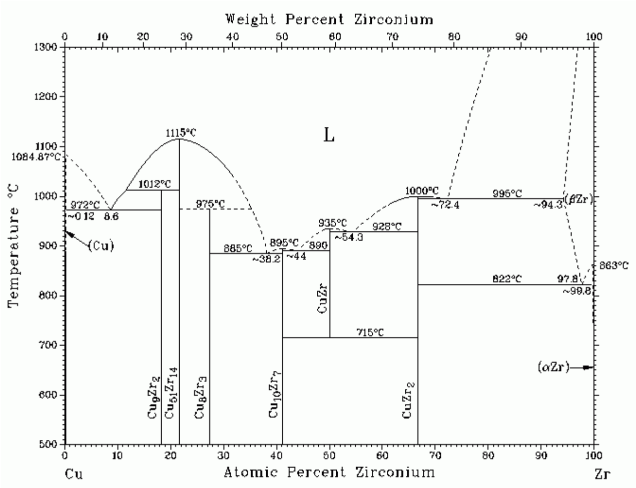
Ta-stainless steel welding

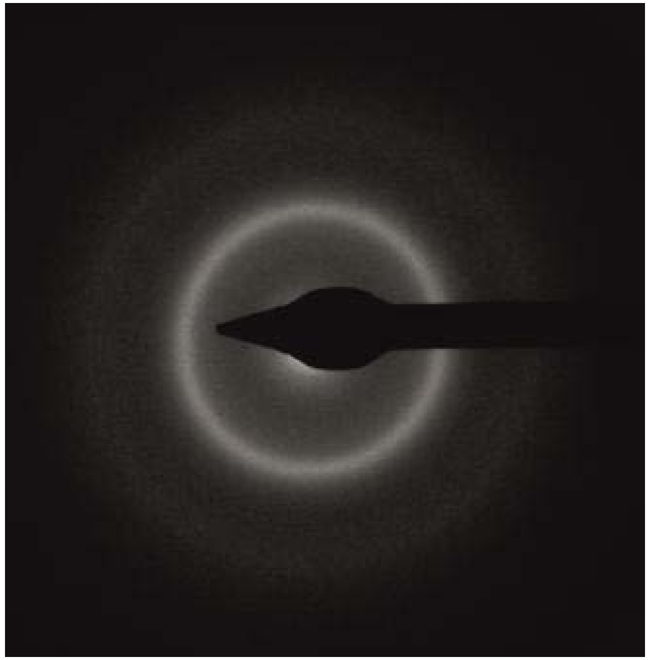


Best binary glass formers, which are know from melt spinning experiments: Zr-Cu, Zr-Ni

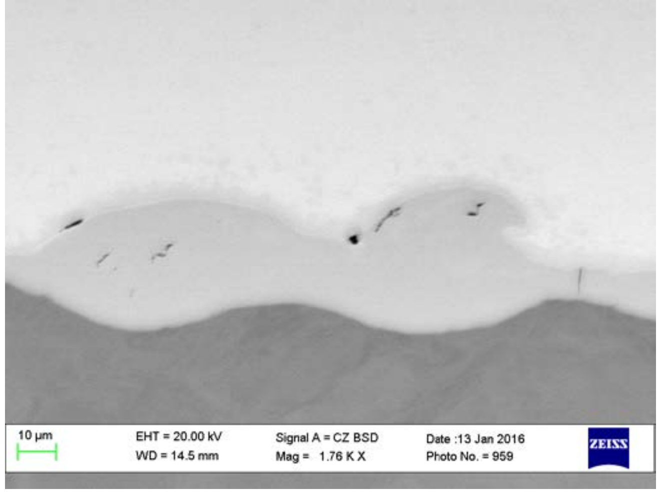
Zr-Cu

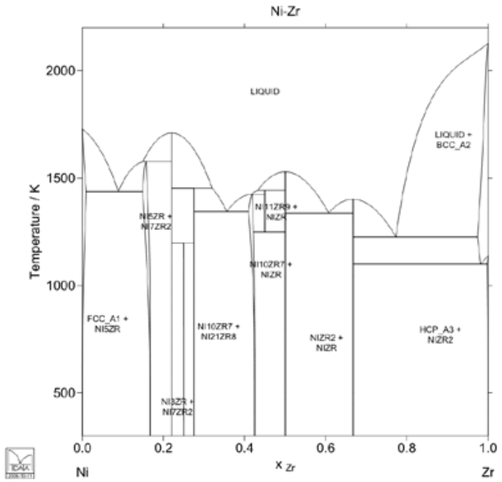




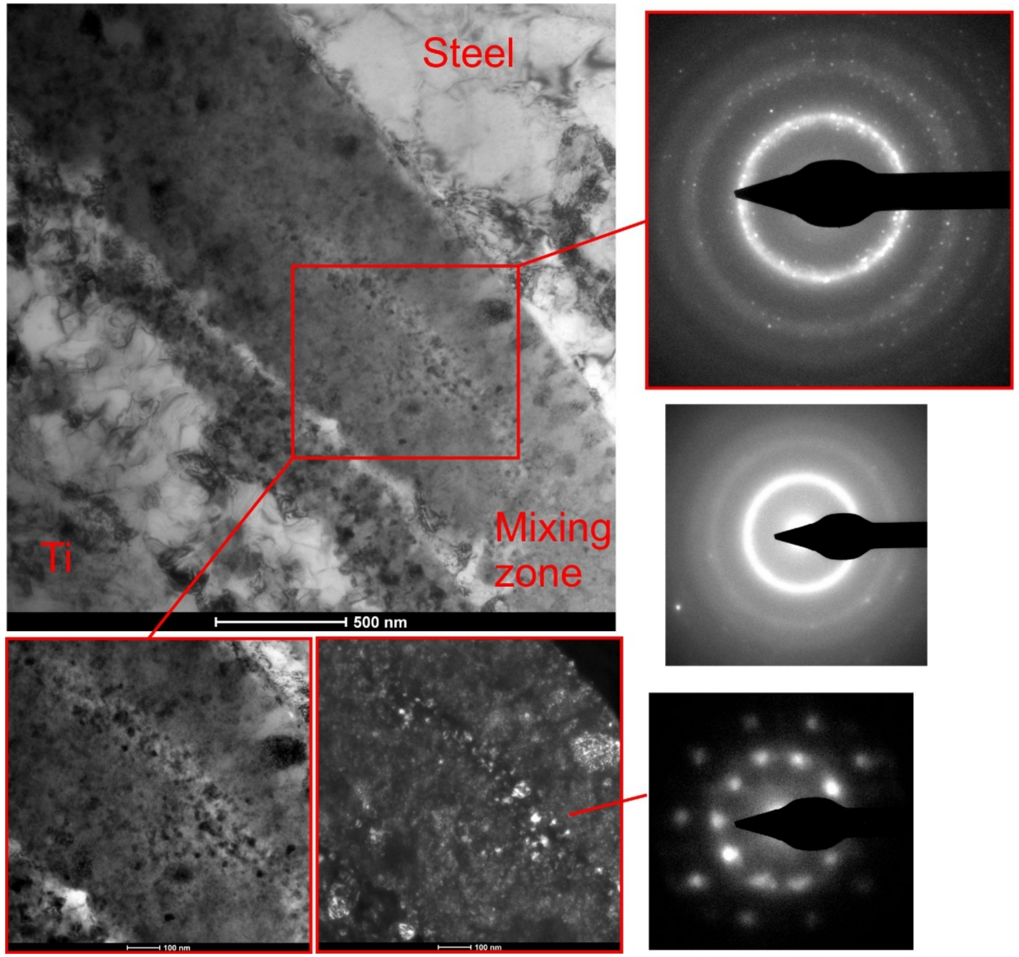


Zr-Ni



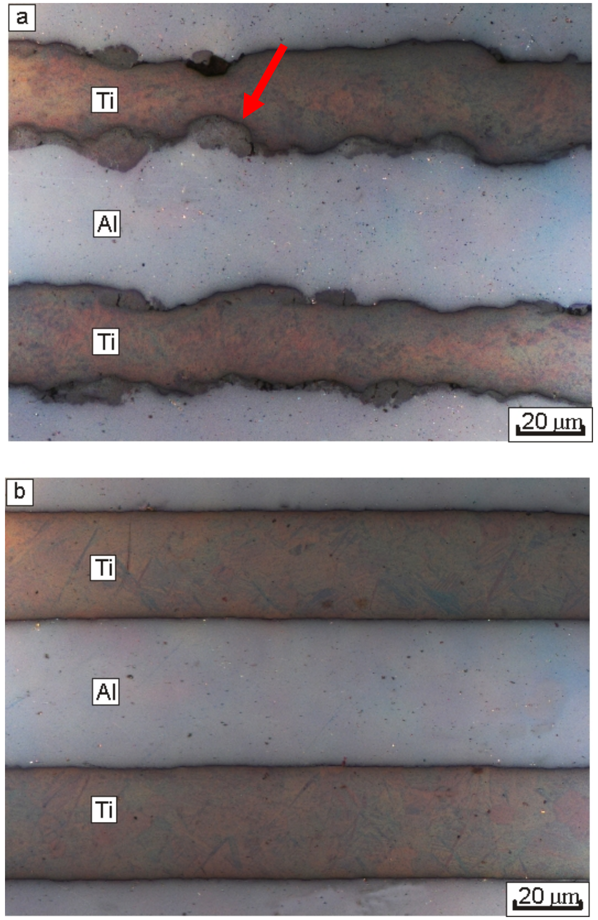


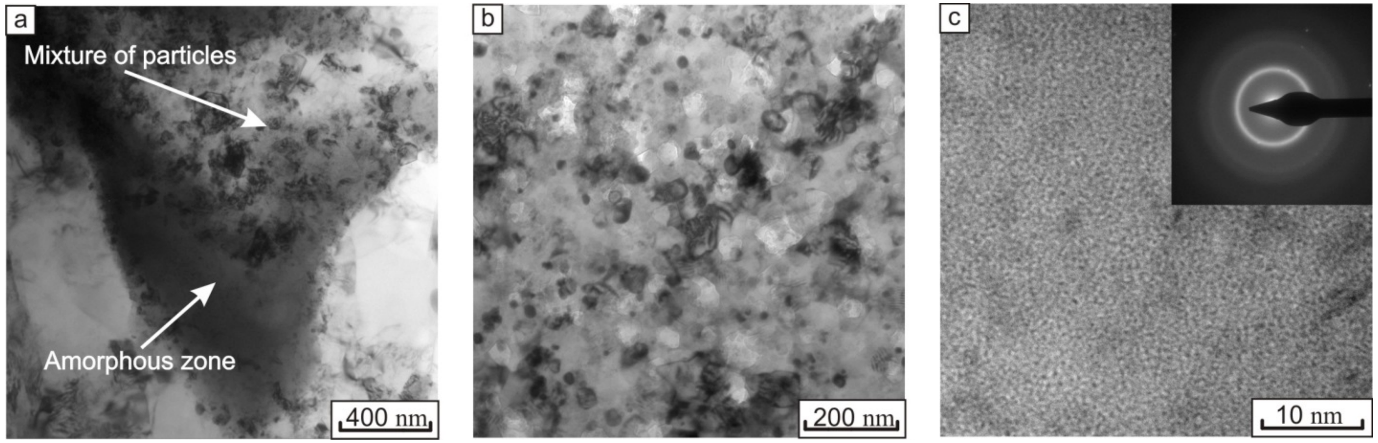
Metallic glass and quasicrystals formation at the interface of explosively welded titanium alloy and low carbon steel



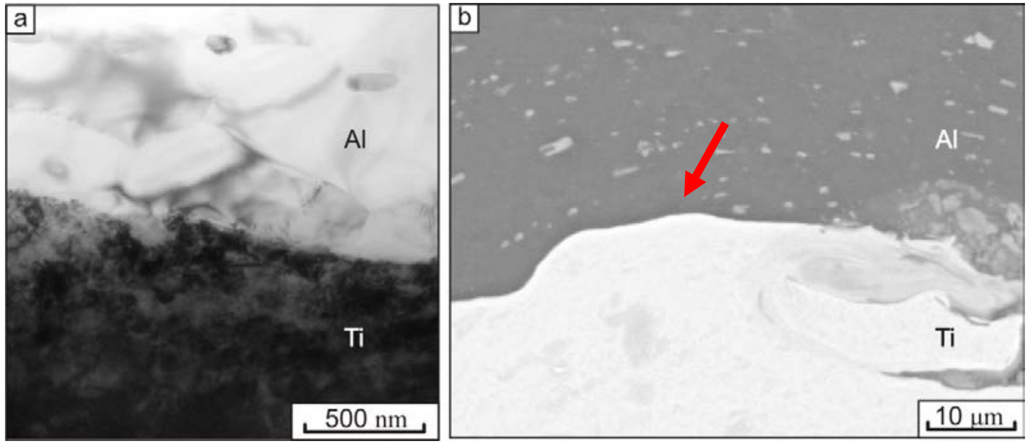
- Low carbon steel (0.2) and titanium alloy (Ti-4Al-3.4V-1.2Mo-0.5Cr-0.3Zr) were explosively welded
- The mixing zone consisted of glassy matrix and nanoscale precipitations of quasicrystalline phase and some stable Ti-Fe phases
- Amorphous phase was also observed in Ti-steel welds by Nishida et al (ISIJ International. 1995;35:217-9.) but qc formation was not reported

Metallic glasses and some metastable phases at the interface of explosively welded Ti and Al: the regions with and without mixing





The mixing regions consisted of amorphous and crystalline zones



Some part of the interface didn't contain the mixing zones.

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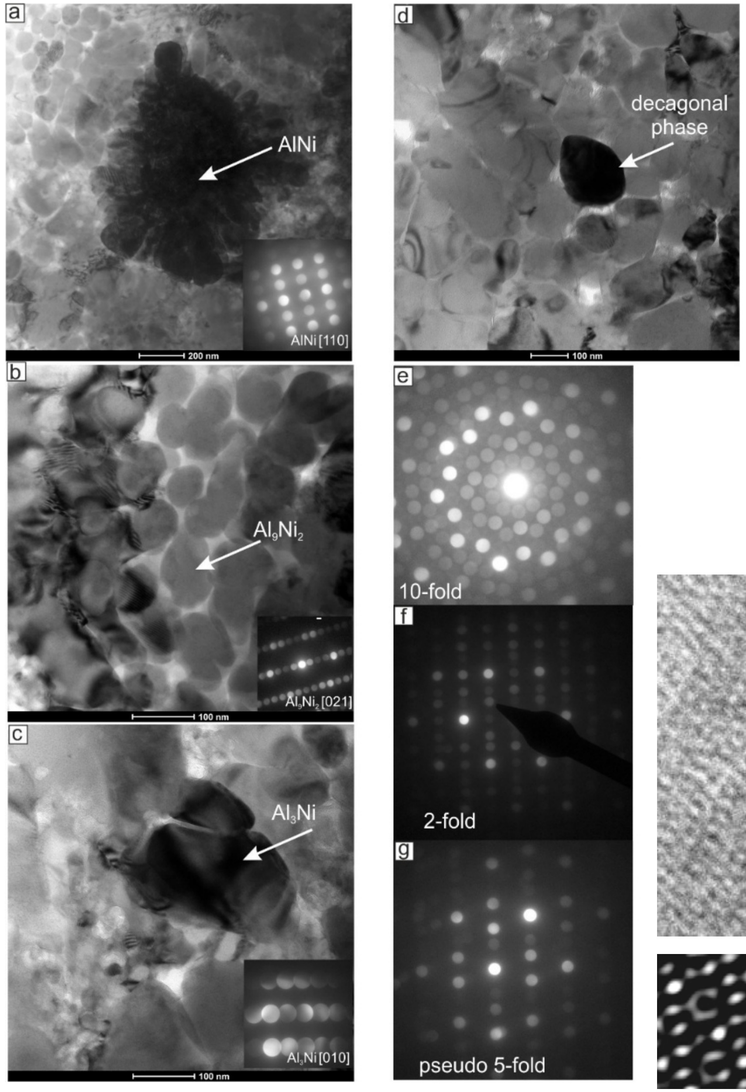
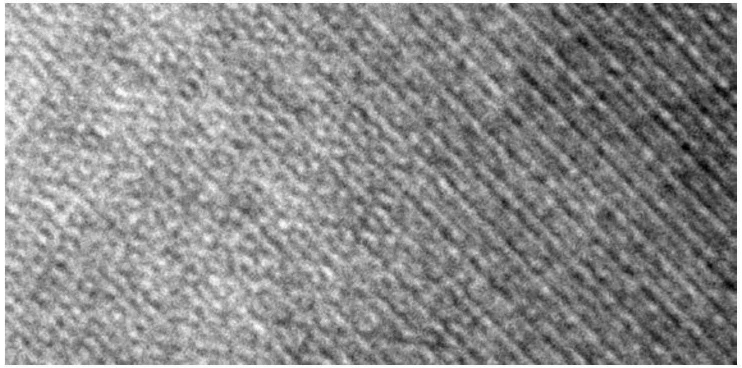
Decagonal quasicrystals at the interface of explosively welded Ni and Al: the structures of the mixing zones

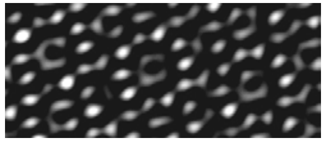


- The interface consists of chaotic mixture of stable phases (AlNi, Al_3Ni) and metastable phases (Al_9Ni_2 and decagonal phase)
- Previously Al_9Ni_2 and decagonal phase were observed in rapidly solidified Al-Ni ribbons

(Pohla C, Ryder PL. Crystalline and quasicrystalline phases in rapidly solidified Al-Ni alloys. Acta Materialia. 1997;45:2155-66.

Li XZ, Kuo KH. Decagonal quasicrystals with different periodicities along the tenfold axis in rapidly solidified Al-Ni alloys. Philosophical Magazine Letters. 1988;58:167-71.)





HRTEM FFT filtered image indicating local atomic arrangements with 10-fold symmetry

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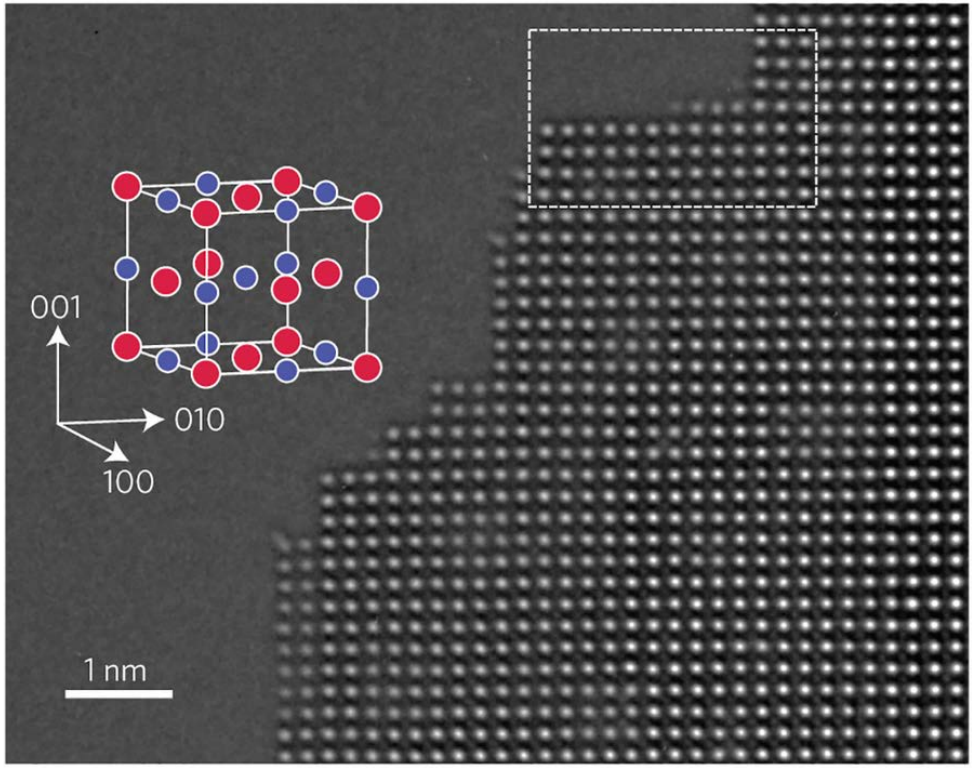
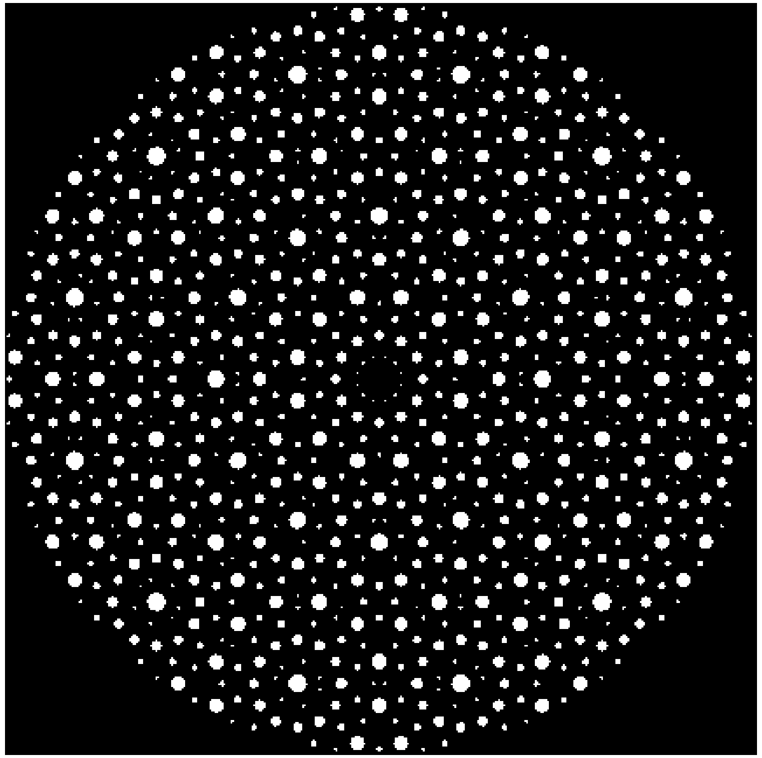
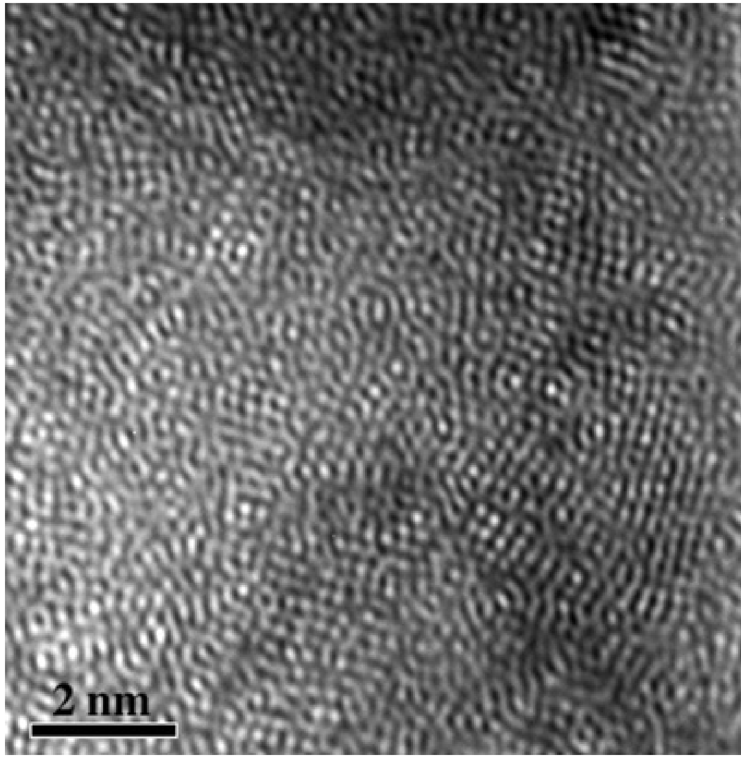
Metallic glasses and quasicrystals: unusual state of metallic solid materials



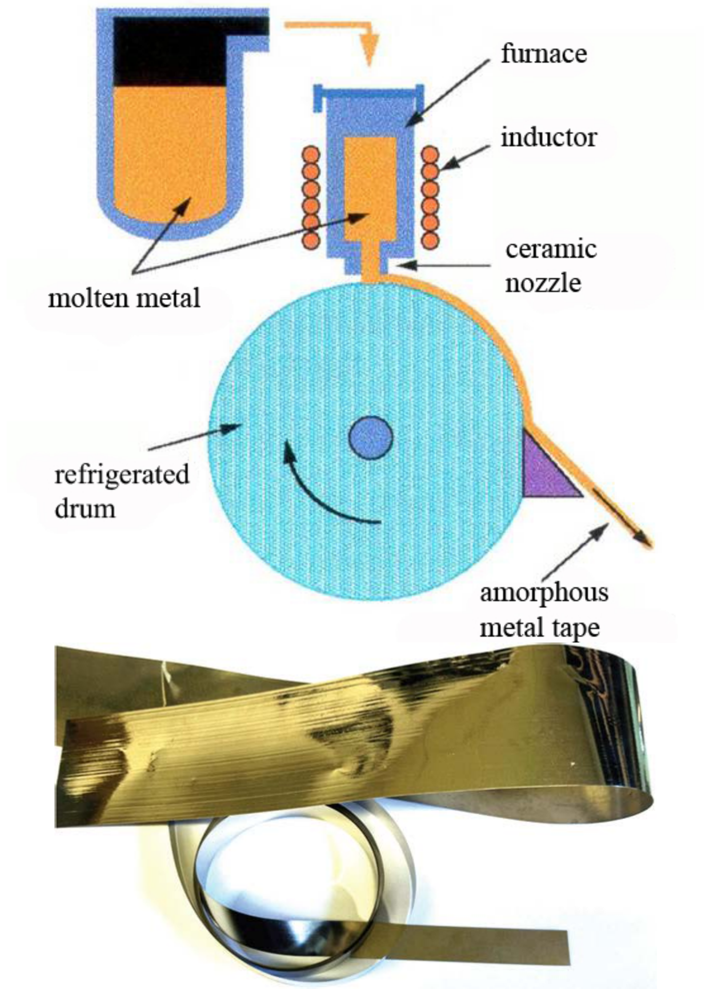




- Crystalline solid (translational and rotational symmetries)
- Quasicrystalline solids (only rotational symmetry)
- Amorphous solids (no long-range symmetry)

Empirical rules of metallic glass formation

- High cooling rate
- Multicomponent systems (typically 3 or more elements) (confusion principle)
- Negative heat of mixing between main components (decrease the Gibbs energy of the disordered glassy phase G=H-TS)
- The difference in atomic radii is above 12% (to achieve best random packing density)
- Near eutectic compositions



Preferable structures of vortexes

The brittle structures at the interface significantly lower mechanical properties of the clad. From this point of view the structures at the interface can be arranged in the following way from the most desirable to the least desirable:

- Solid solutions
- Metallic glasses
- Crystalline intermetallics
- Quasicrystalline intermetallics

Conclusions

- Materials at the interface experience localized melting and subsequent rapid solidification
- The calculated cooling rate during explosive welding in of the order 10^4 -10^7 K/s
- The structure of vortexes is always metastable. Formation of metallic glasses, quasicrystals, metastable intermetallics and supersaturated solid solutions is highly possible

Thank you for your attention

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