Novel Co 20 Cr 15 Fe 26 Mn 17 Ni 22 ultra-fine grained high-entropy alloy

Michal Mroz, Anna Fraczkiewicz, András Borbély

Novel $Co_{20}Cr_{15}Fe_{26}Mn_{17}Ni_{22}$ ultra-fine grained high-entropy alloy

Michal MROZ, Anna FRACZKIEWICZ, Andras BORBELY

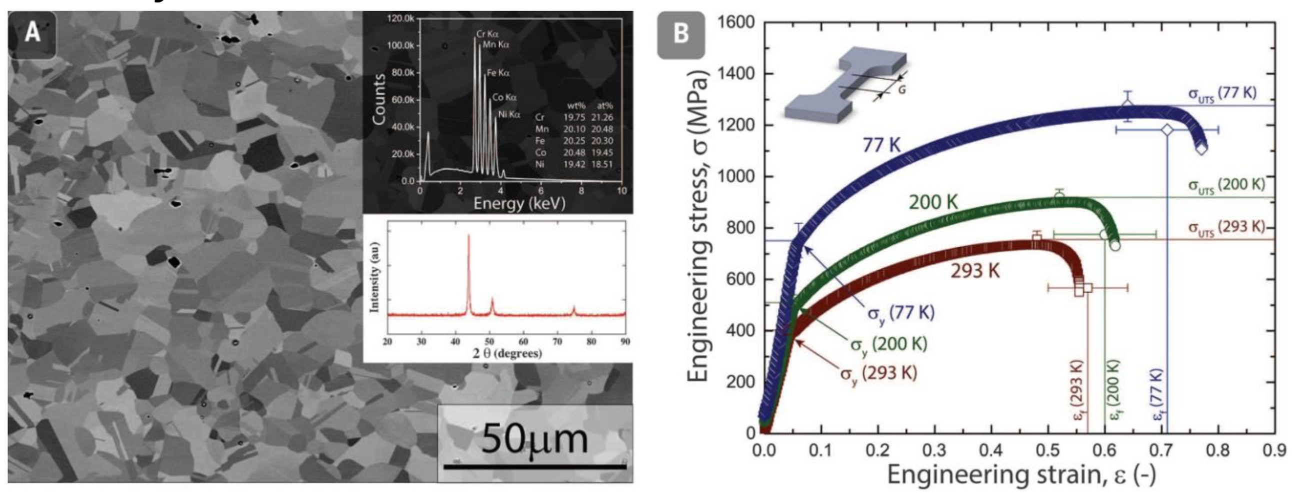
MINES St-Etienne, LGF-UMR 5307, FR-42000 St-Etienne

michal.mroz@emse.fr

Origins of the alloy

NOVEL COMPOSITION: based on equiatomic CoCrFeMnNi

- Reference alloy (Yeh, Cantor, 2004)
- Face-Centered Cubic structure (lattice parameter *a = 3.6Å)*
- Yield strength of ~240MPa (recrystallized) and ~760MPa (cold-rolled)
- High ductility: >60%

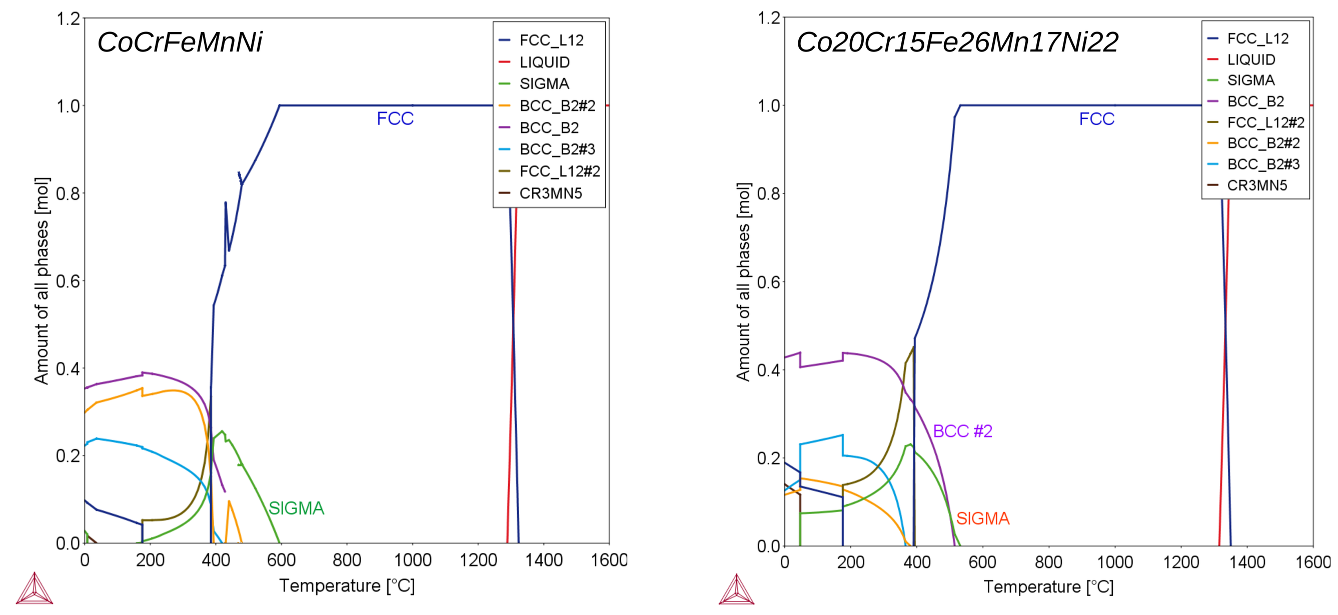


Recrystallized structure and stress-strain curves of CoCrFeMnNi, Gludovatz et al., 2014

- This composition was taken as a reference and optimized with Thermo-Calc software

THERMO-CALC : optimization of 'reference' equiatomic alloy

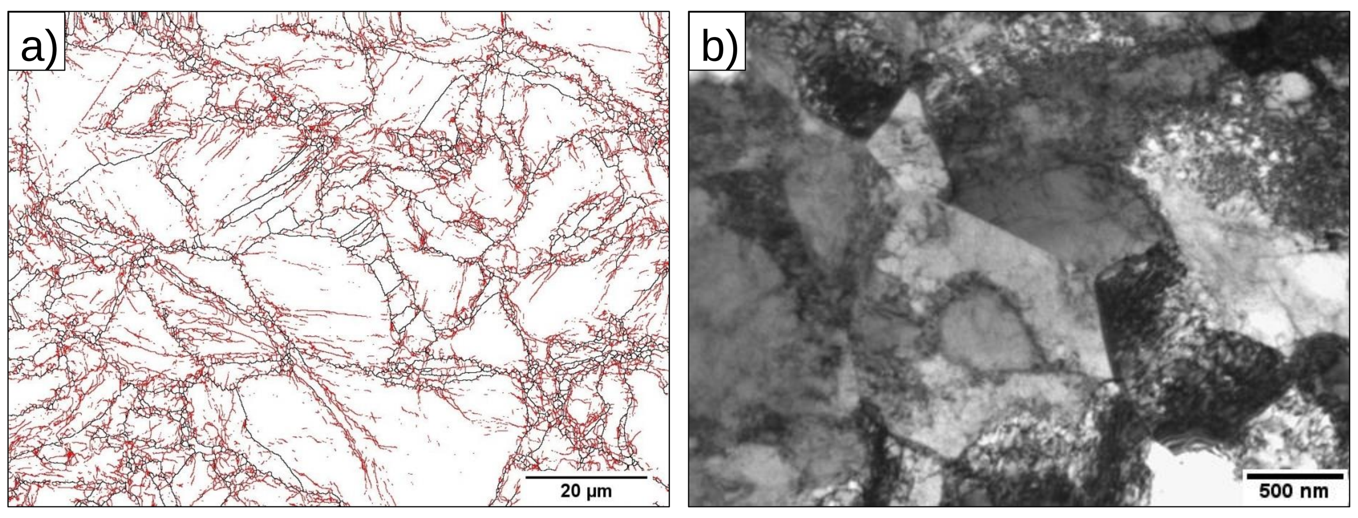
- FCC area increased to assure phase stability
- Intermetallics (especially σ phase) were avoided
- Amount of Cr decreased to lower temperature of phase transformations
- Amount of Ni increased (FCC stabilizing element)
- **Novel alloy called A3S® : austenitic super stainless steel**



Amount of phase vs temperature (HEA1 database)

Facility of nanostructuration

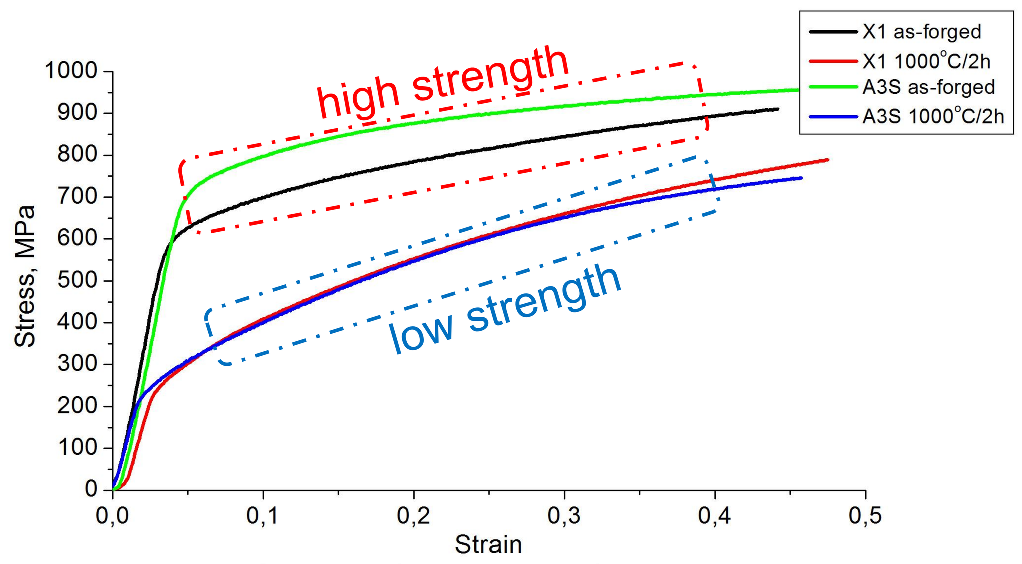
- After **hot forging**, nanostructure/UFG structure is formed in both alloys
- Many low-angle grain boundaries in grains, nanometric size of cells
- High density of dislocations



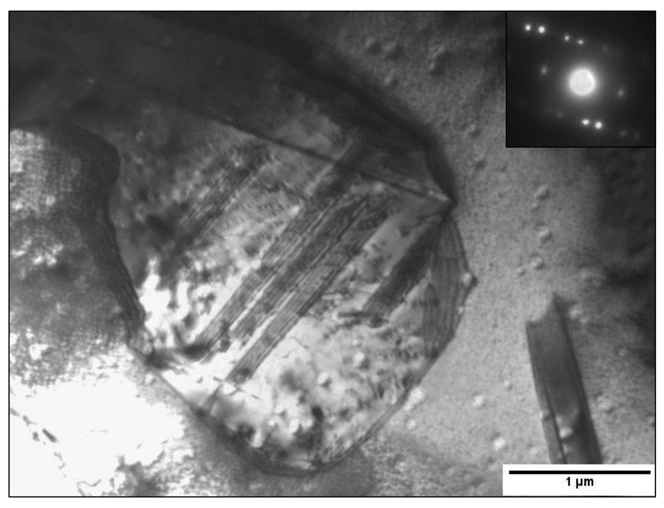
a) EBSD and b) TEM imaged of as-forged A3S

- After annealing (1000ºC/2h) : only high-angle grain boundaries, high density of twins

- Due to two different types of microstructure, two modes of deformation can be distinguished:
  - high strength: high (~750MPa for A3S and ~600MPa for X1) yield strength, low work hardening coefficient
  - low strength: low (~250MPa) yield strength, high work hardening coefficient
- A3S has higher strength than equiatomic alloy; in X1 - nanotwins



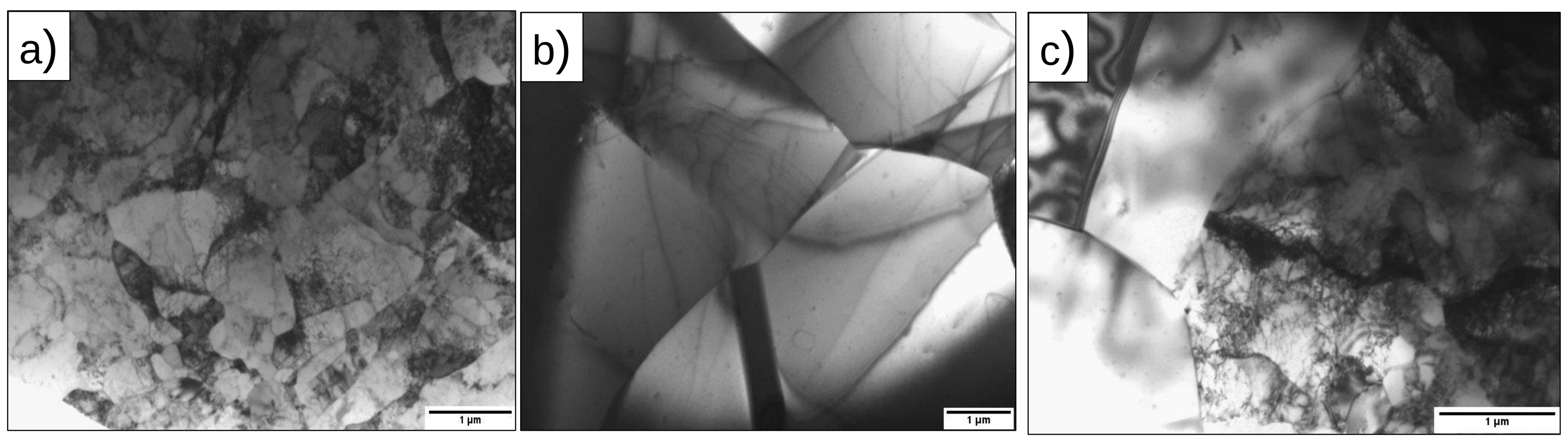
Compression stress-strain curves



TEM bright field images of as-forged X1

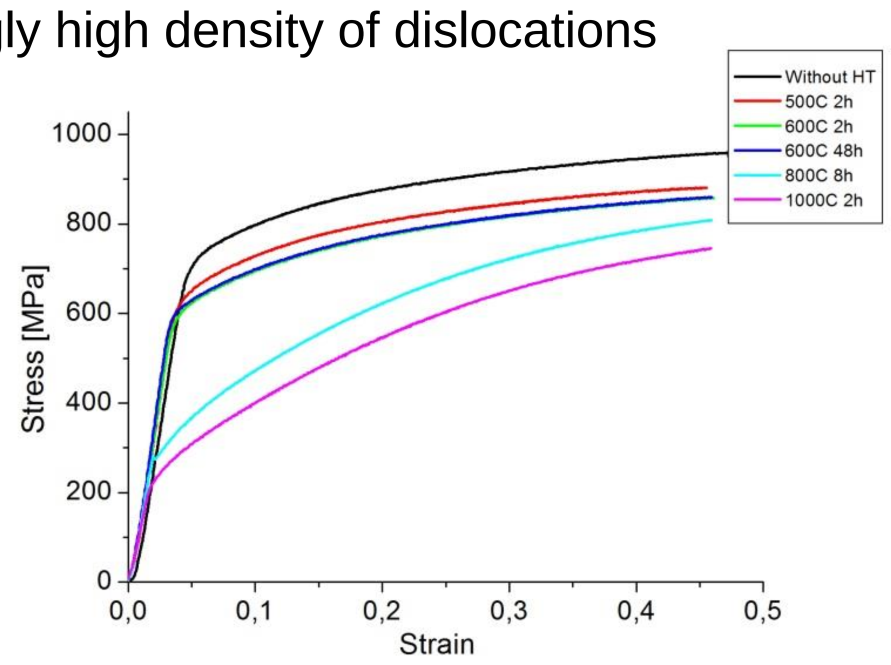
Recovery and recrystallization phenomena

- Nanostructure is stable until ~700ºC , when the alloy loses its high strength properties
- Even after long heat treatment at 600ºC (1 month), grains with dislocations cells are still present



TEM bright field images of A3S annealed at: a) 600ºC/48h, b-c) 600ºC/1 month

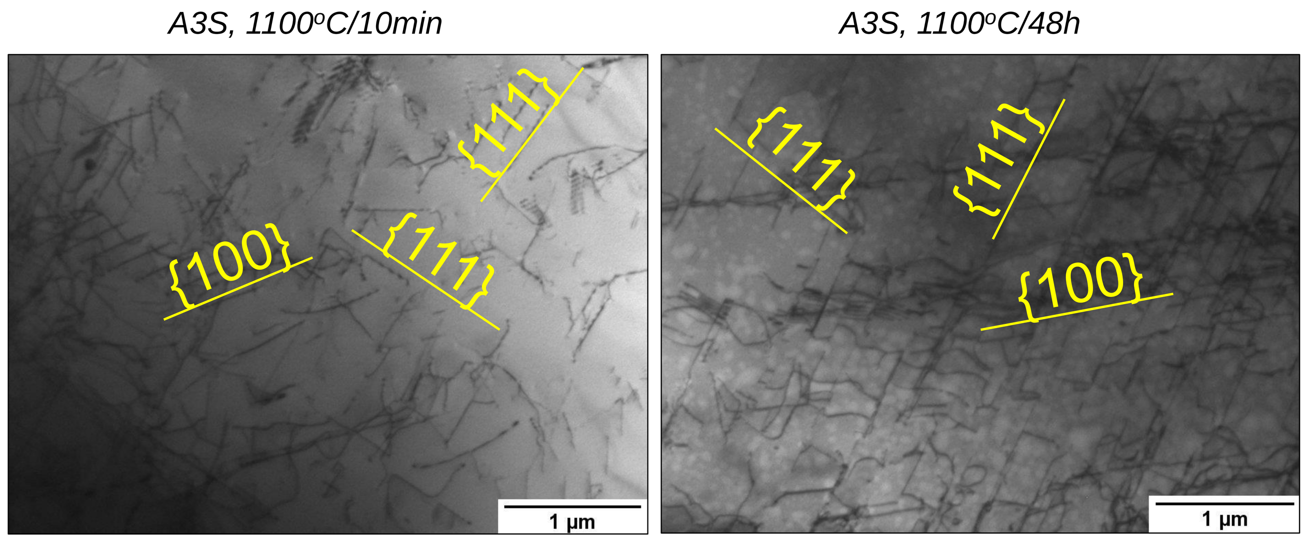
- After 800ºC/8h annealing there are no substructures, grains with HAGB of few µmeters
- Surprisingly high density of dislocations



Compression stress-strain curves after different heat treatments

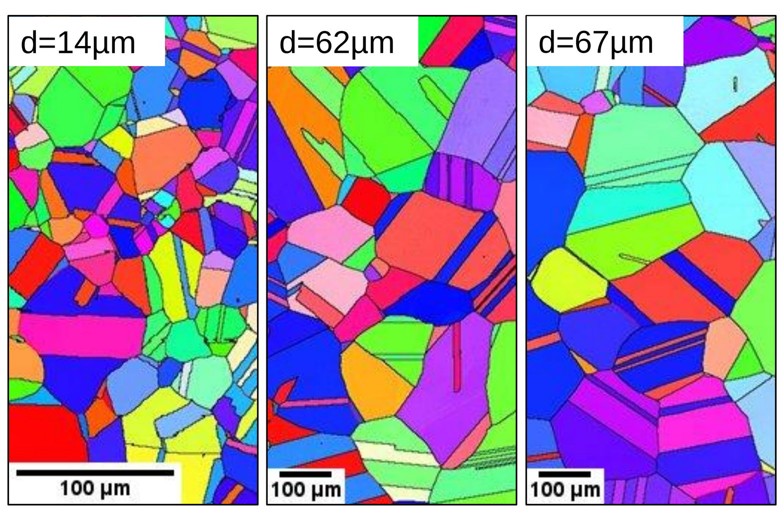
- High density of dislocations even after high T annealing (1000, 1100ºC)
- Dislocations traces in characteristic planes: {111} and {100}

A3S, 1100ºC/10min *A3S, 1100ºC/48h*



ZA=[011], g=[-200] ZA=[011], g=[00-2]

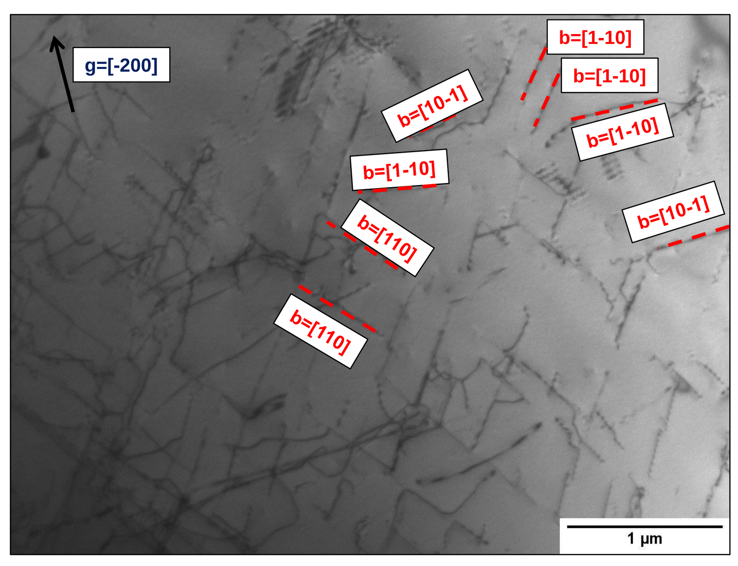
EBSD images of A3S after heat treatment at 1100ºC



10min 5h 14h

EBSD images of A3S after heat treatment at 1100ºC

- Typical Burger vectors of type <110> were observed
- Common for FCC metals



TEM bright field image of A3S/1100ºC/10 min

- Series of heat treatments at 1100ºC revealed no recrystallization phenomena
- Only recovery occurs at high temperatures
- Dislocations locking may be due to nanofluctuations of composition

CONCLUSIONS

- New original composition A3S® was developed starting from equiatomic CoCrFeMnNi high-entropy alloy
- Comparing to reference composition, much higher (+150MPa) yield strength is achieved with similar elongation
- Easy formation of nanostructures after hot forging
- Stable UFG structure until ~700ºC
- Untypical phenomena of recovery/recrystallization:
  - grains free of dislocations after low T annealing
  - high density of dislocations after high T annealing