Structural, morphological and magnetic characteristics of Aluminium Supermalloy new magnetic material obtained by mechanical alloying

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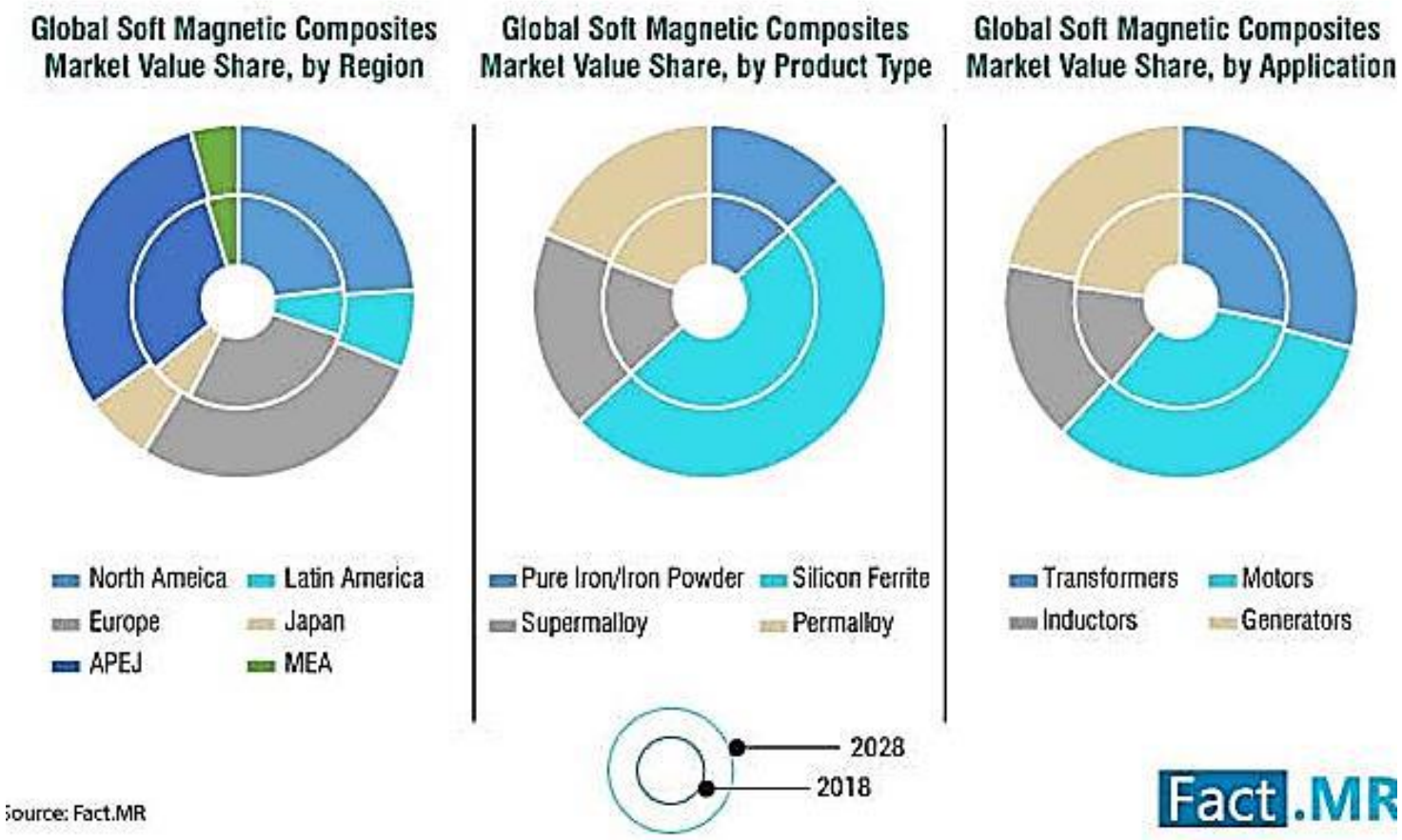
Why Supermalloy based materials?

Supermalloy - Ni75Fe20Mo5

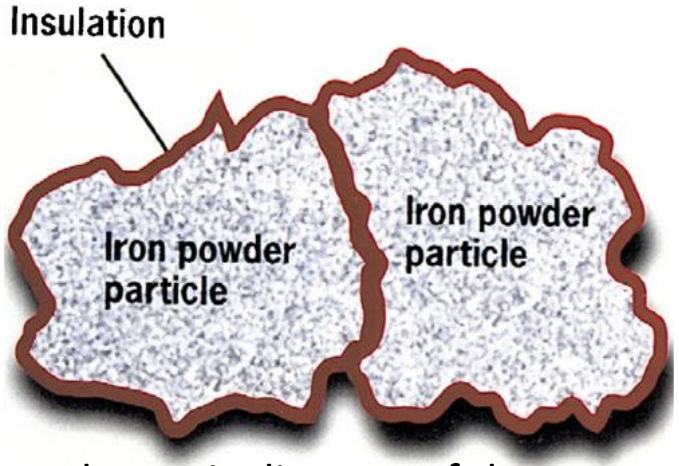
- Good magnetic induction, extremely high magnetic permeability (1000000), and a low coercivity

- Supermalloy is very useful in ultra-sensitive transformers, especially pulse transformers, and ultra-sensitive magnetic amplifiers where low loss is mandatory.

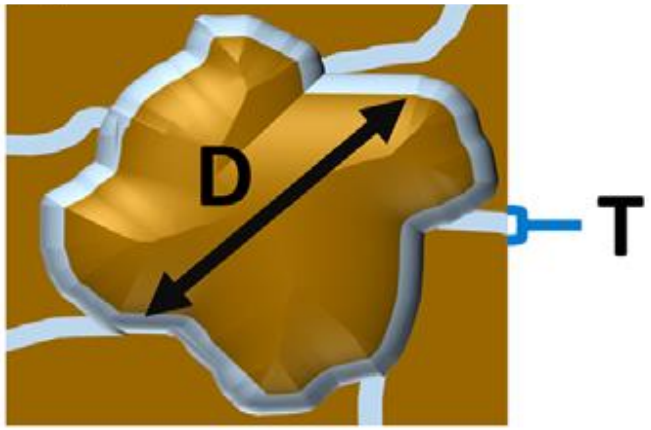


Soft magnetic composite (SMC) market value share analysis

Why soft magnetic composite material

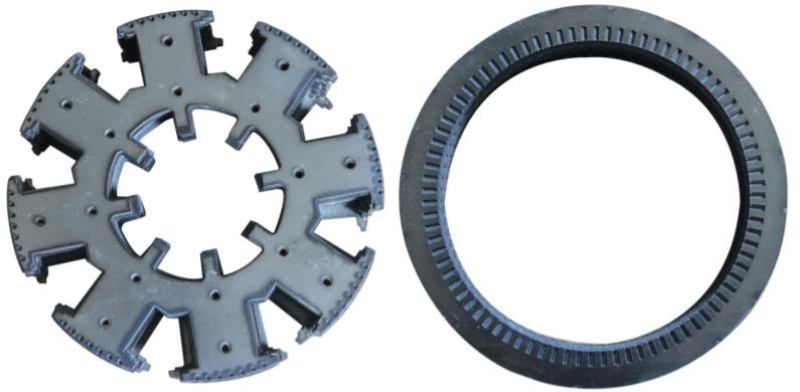


A schematic diagram of the component elements of a powder core.



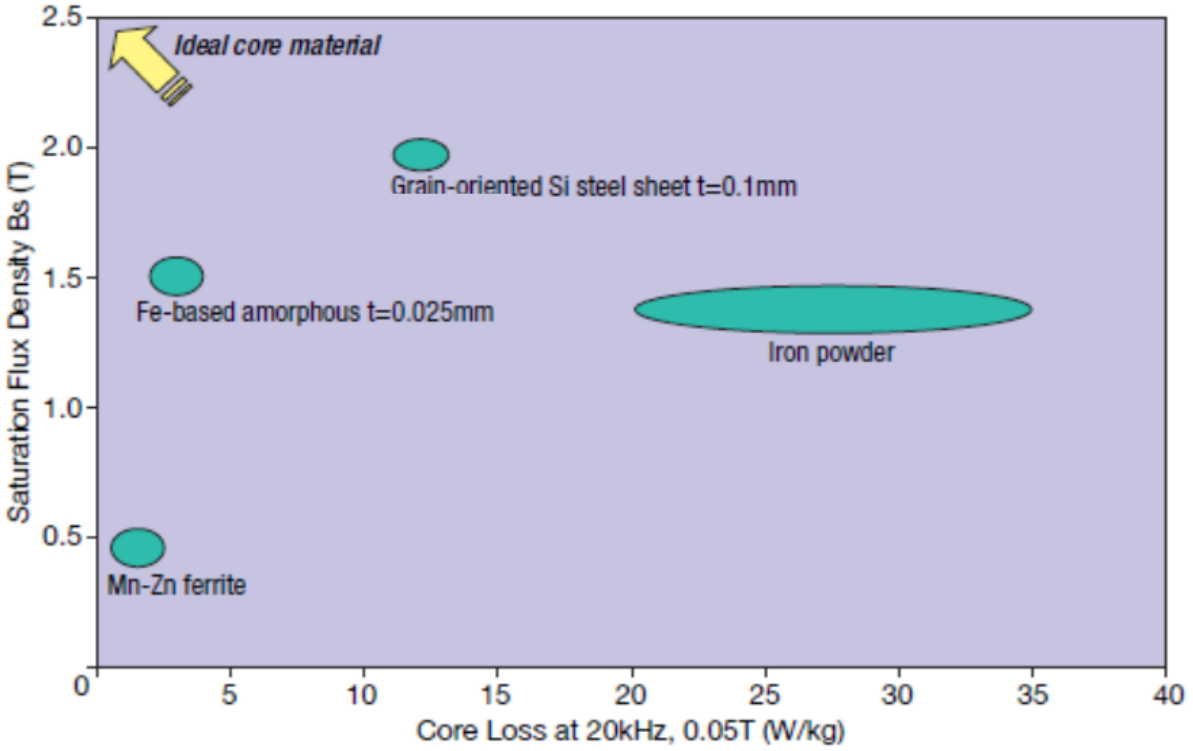
Composite after pressing illustrating the ferromagntic part and the insulating layer.

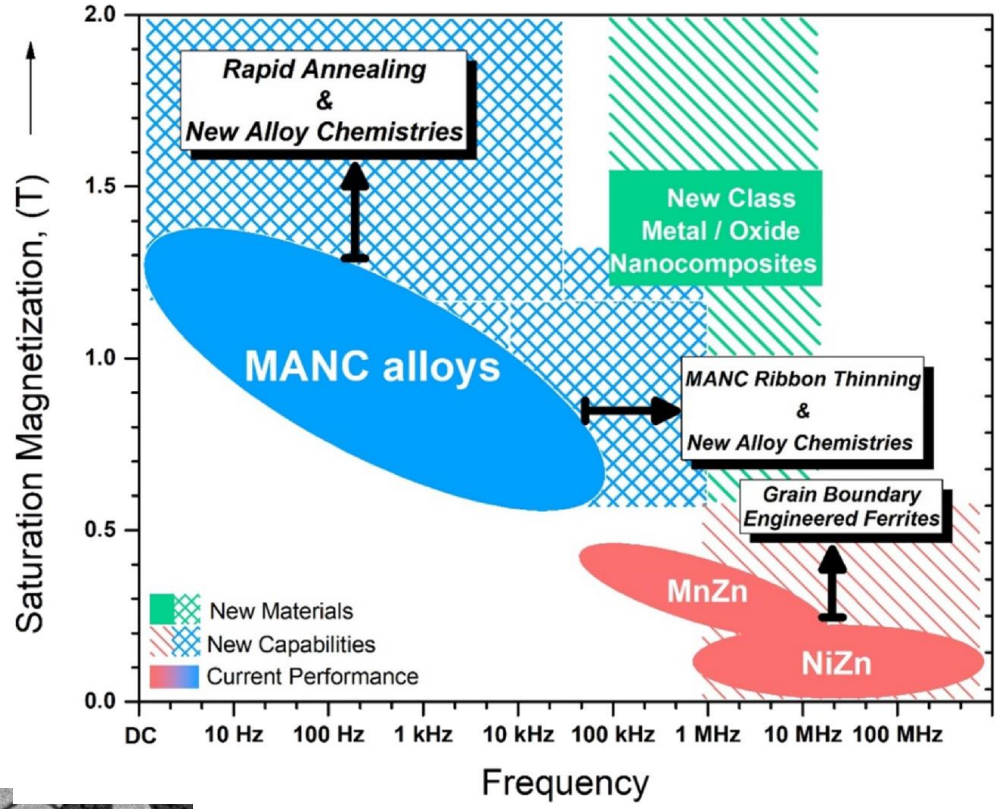
Examples of toroidal inductors on printed circuit board – PCB

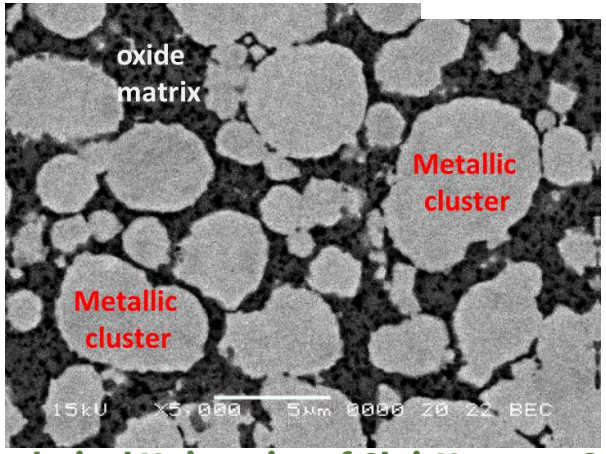


Parts made from supermalloy for motors and generators

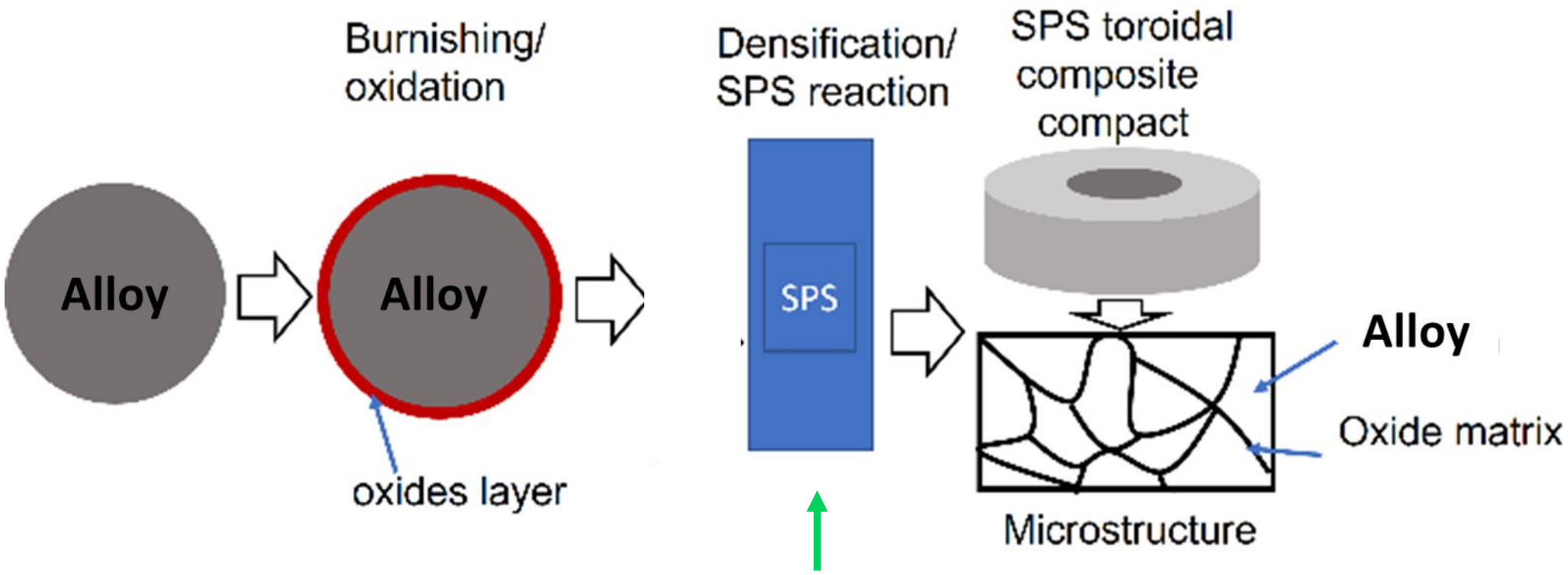
Why composite Supermalloy based@oxide







Why Aluminium Supermalloy?



During SPS reaction between alloy core and oxide shell

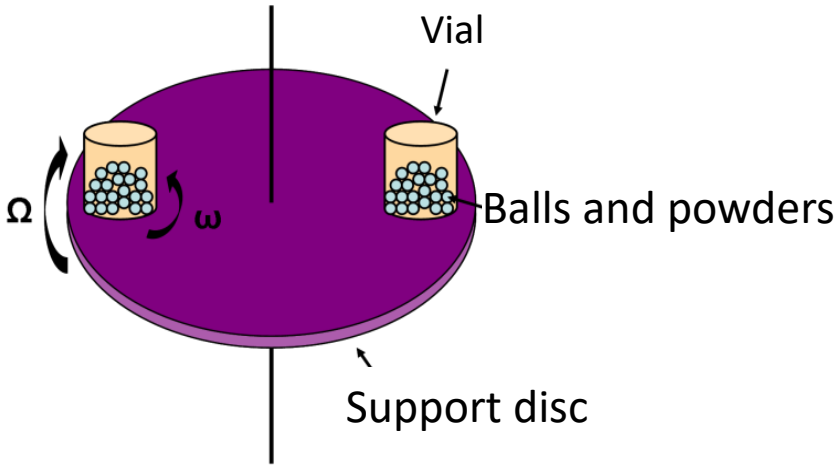
Experimental

Ni70.5Fe18.8Mo4.7Al6 = [Supermalloy (Ni75Fe20Mo5)]94+ Al6 (%wt.)

Ni71,25Fe19Mo4.75Al5 = [Supermalloy (Ni75Fe20Mo5)]95+ Al5 (%wt.)

Ni71.25Fe23.75Al5

- Starting powders: **Ni, Fe, Mo, and Al elemental powder**
- Milling time: up to 20 hours
- Milling atmosphere: argon
- Sampling at: 0,5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15 and 20 h
- Tempered steel vials and balls: 70 balls (ϕ 14)
- Ball to powder ration (BPR): 4:1, 8:1 and 17:1
- Annealing at 450 °C for 4 h in Ar



- **Surface oxidation**: superficial powder oxidations in hydrochloric acid, in air+Ar and industrial burnishing kit

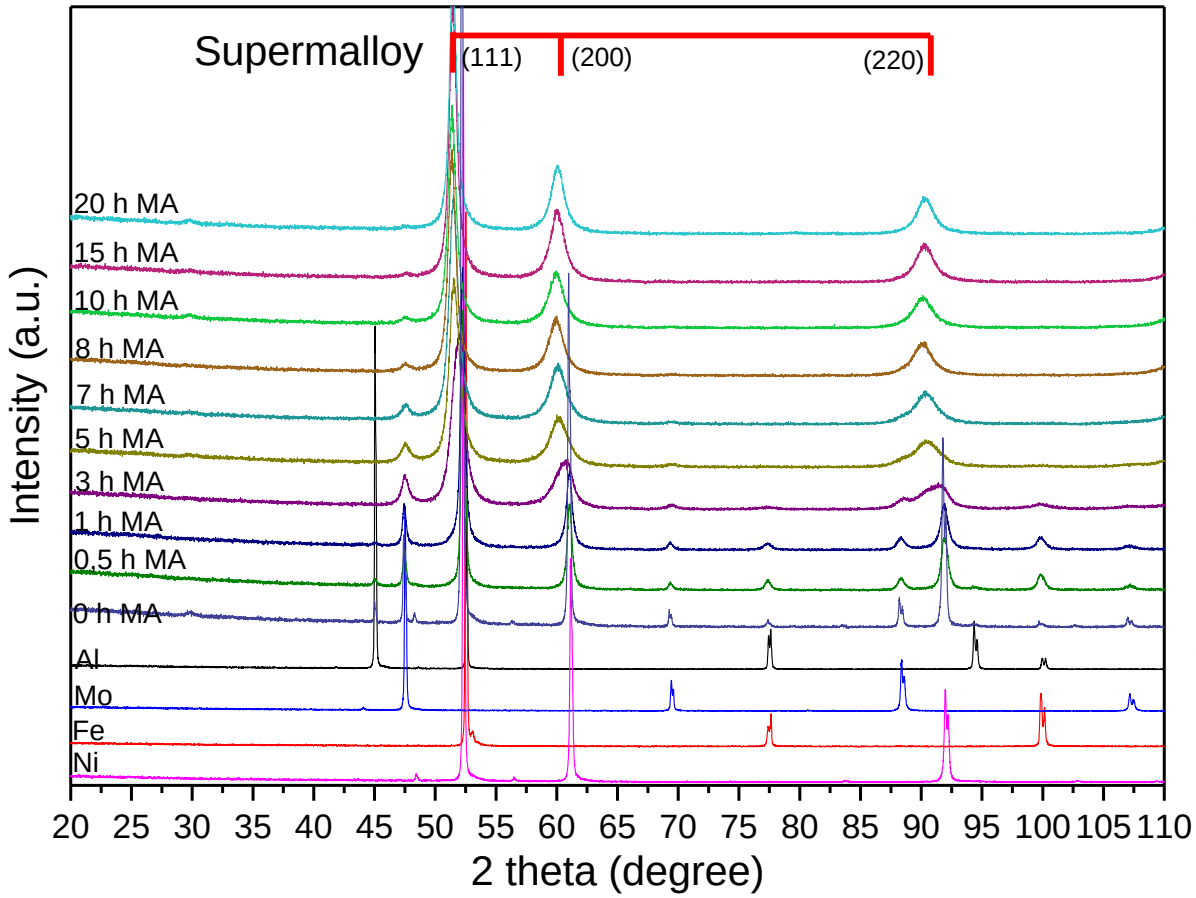
Materials characterisation

- **X-ray diffraction – XRD –** Inel EQUINOX 3000 diffractometer
- **In-situ high temperature X-ray diffraction -** Anton Paar HTK1200N heating furnace + Inel EQUINOX 3000 diffractometer
- **Scanning Electron Microscopy – SEM:** JSM 5600 LV – Jeol
- **Energy dispersive X-ray analysis - EDX:** EDX - Oxford Instruments, model ULTIMMAX65, Aztec software
- **Differential Scanning Calorimetry - DSC:** Setaram Labsys apparatus
- **Fourier Infrared Spectroscopy - FTIR:** Bruker Tensor 27 Spectrometer
- **VSM magnetic measurements**

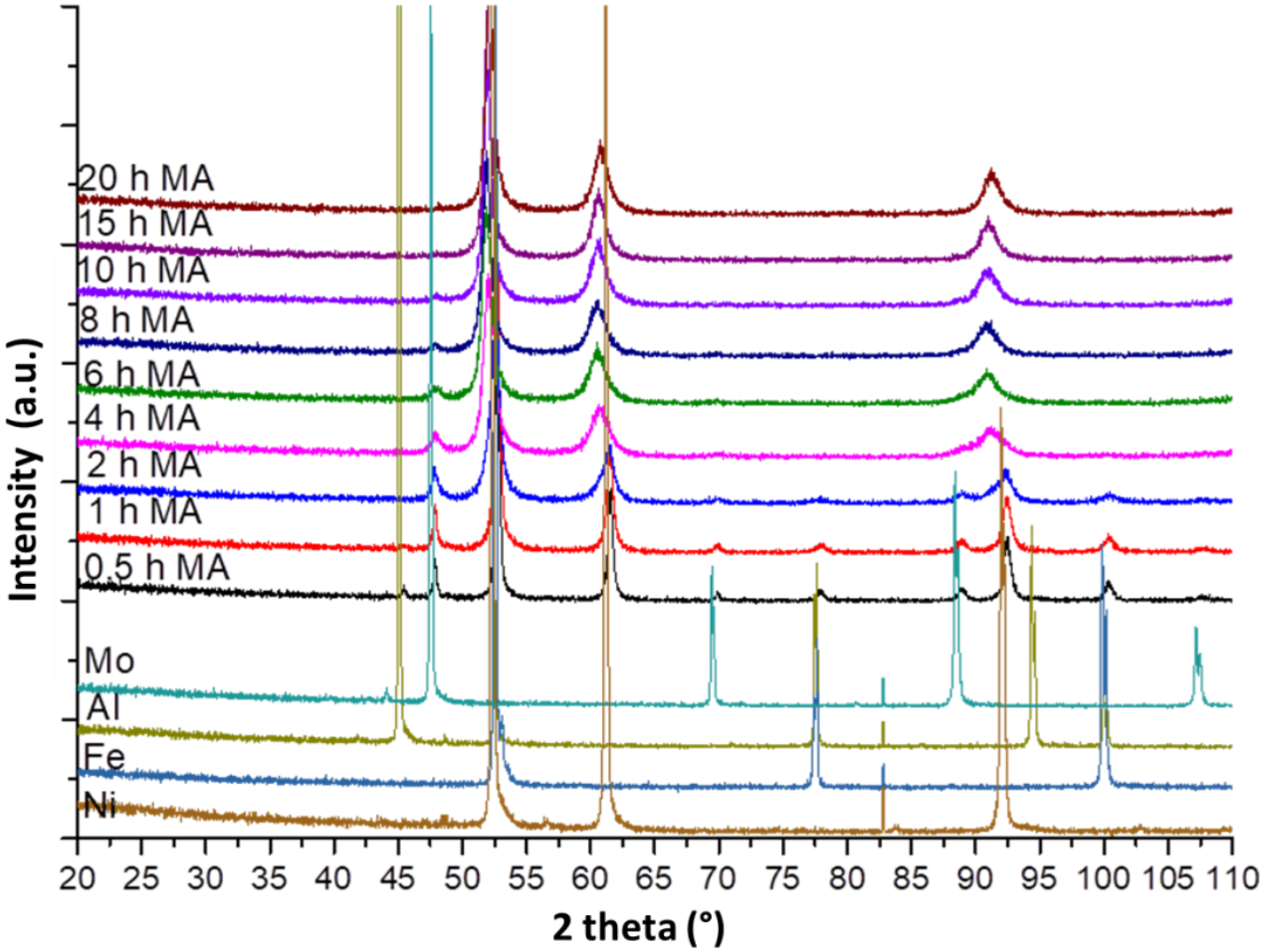
RESULTS

Formation of alloys

XRD



Ni70.5Fe18.8Mo4.7Al6



Ni71.25Fe19Mo4.75Al5

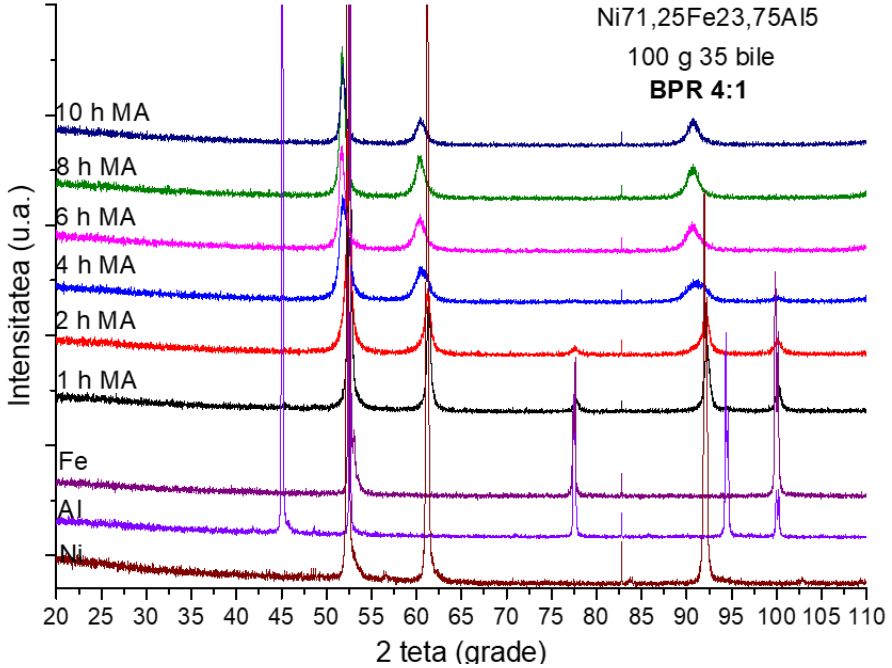
RESULTS

Formation of alloys

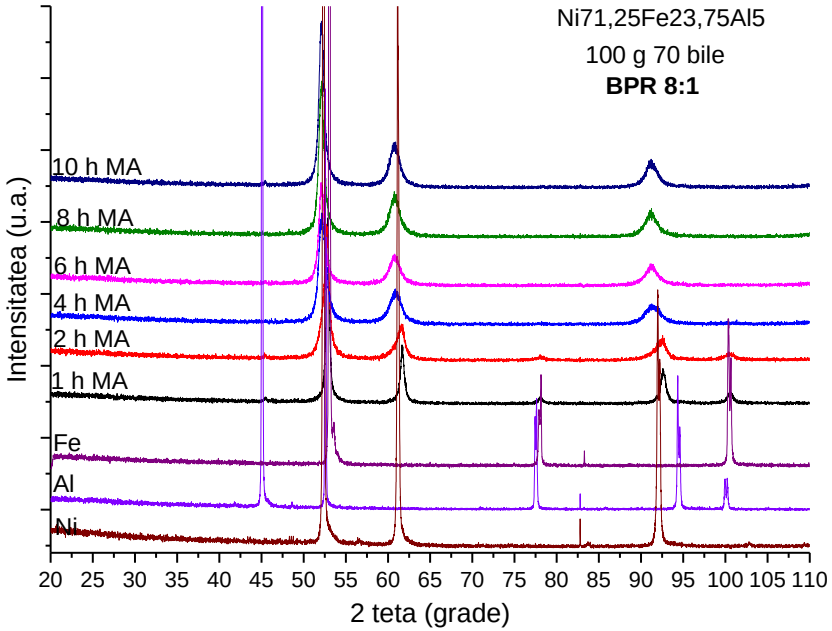
XRD

Influence of milling/alloying parameters

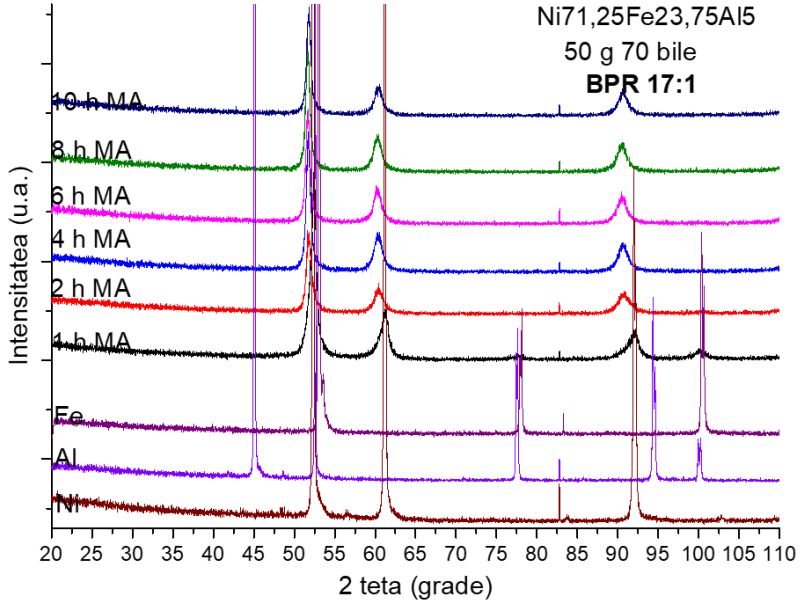
$Ni_{71.25}Fe_{23.75}Al_5$



Alloy obtained after 4 h



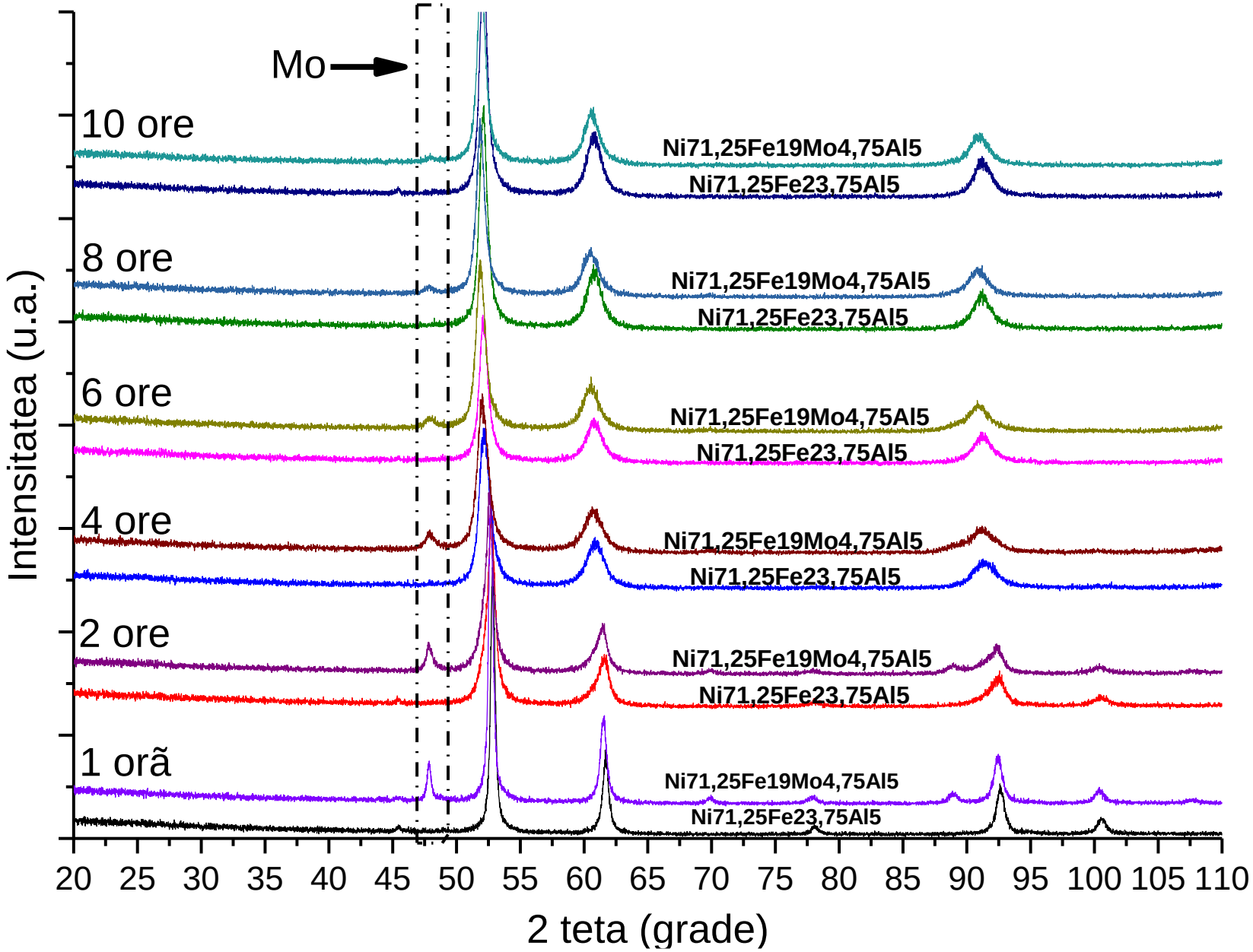
Alloy obtained after 6 h



Alloy obtained after 8 h

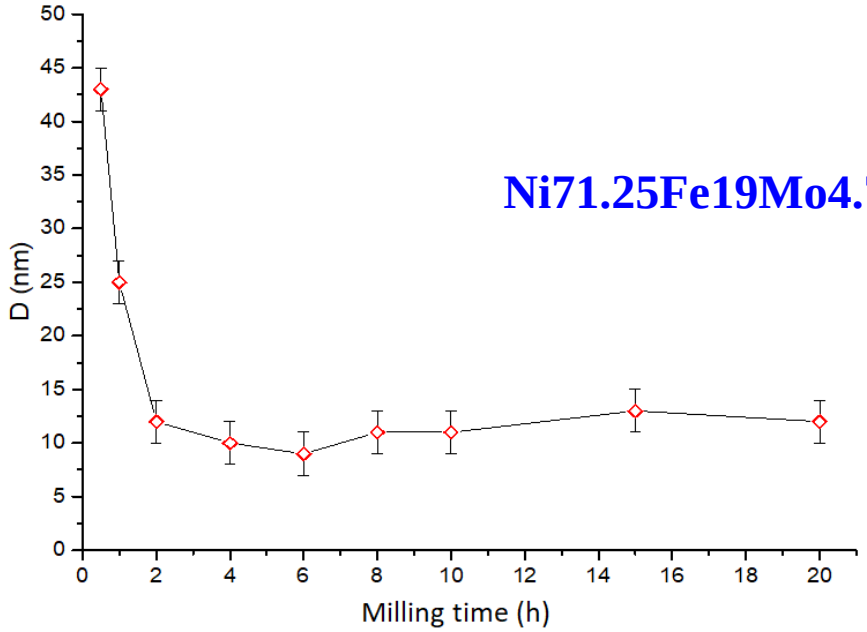
RESULTS

Ni71,25Fe23,75Al5 and Ni71,25Fe19Mo4,75Al5



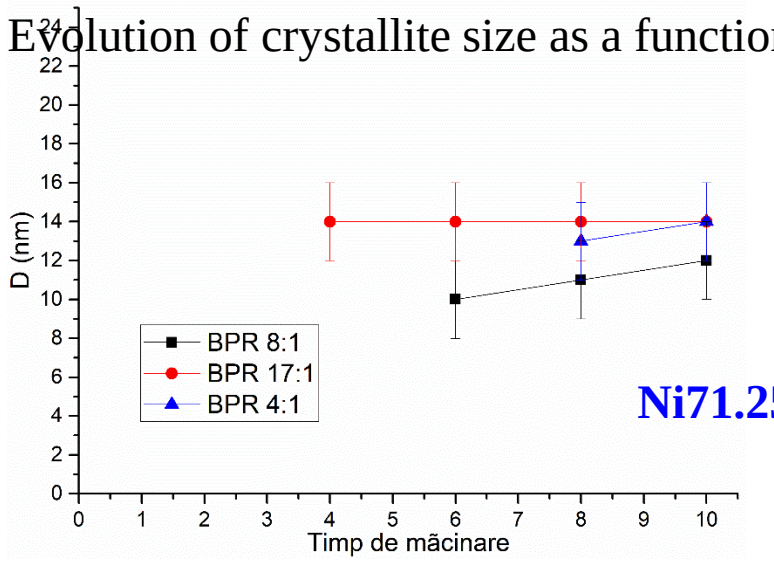
RESULTS

Crystallite size

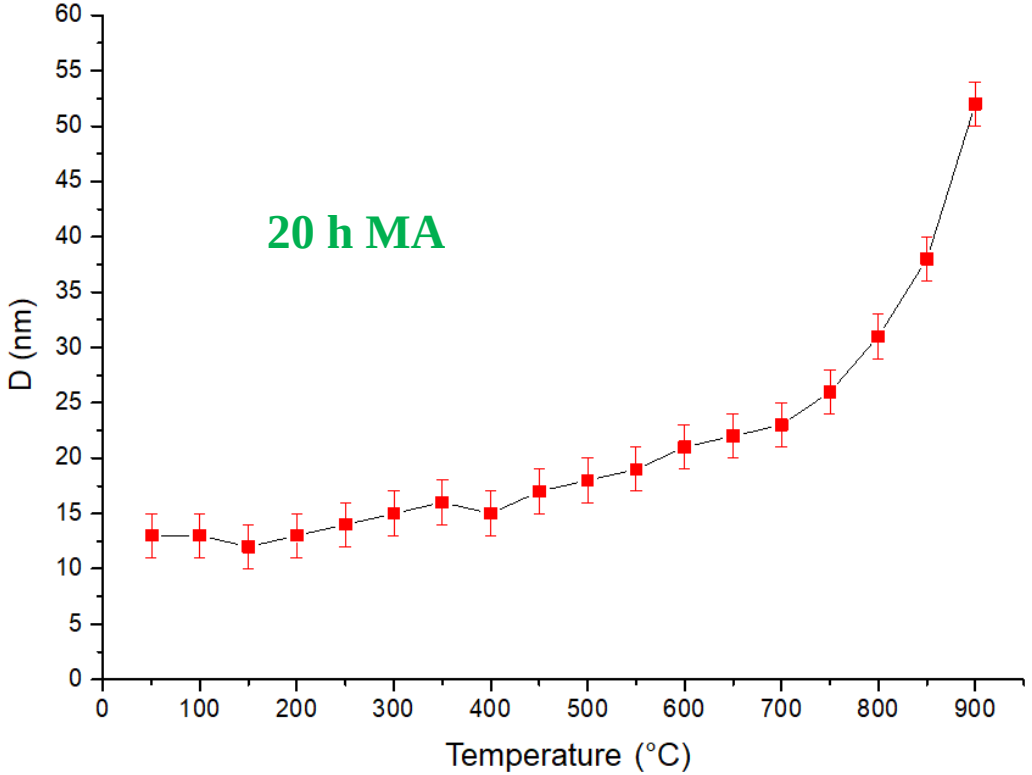


Ni71.25Fe19Mo4.75Al5

Evolution of crystallite size as a function of milling time



Ni71.25Fe23.75Al5

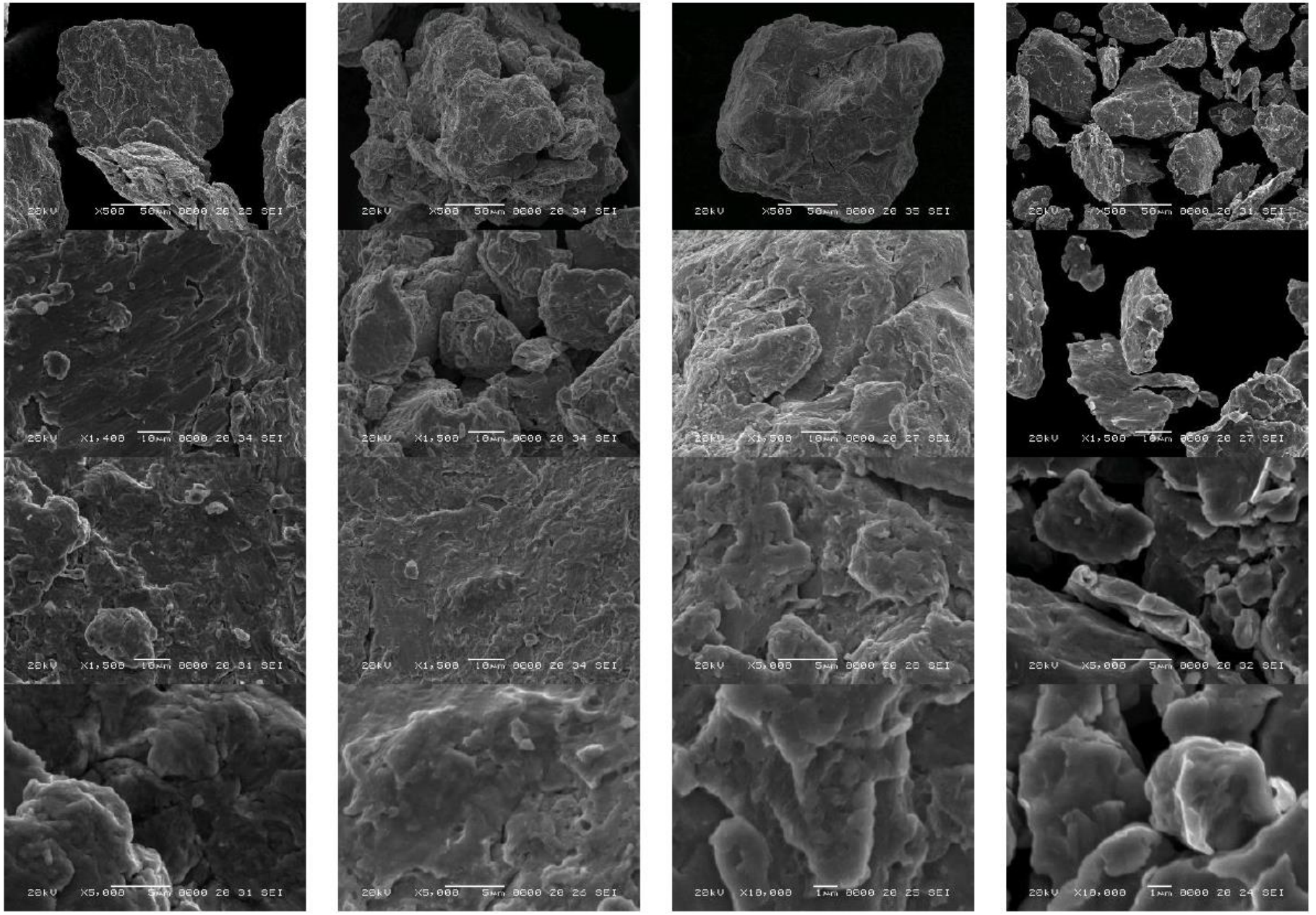


20 h MA

Evolution of crystallite size in temperature

SEM

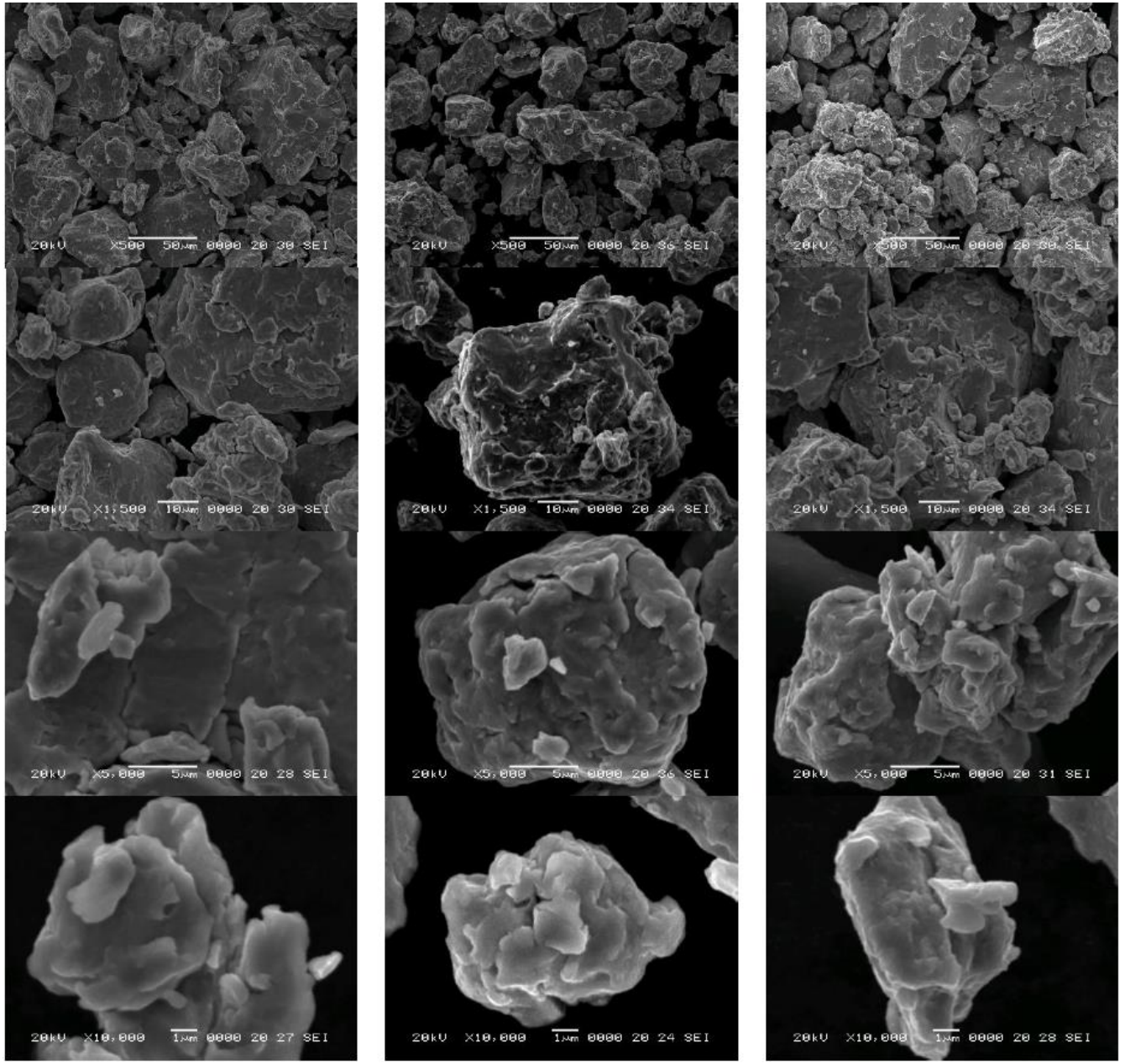
Ni70.5Fe18.8Mo4.7Al6



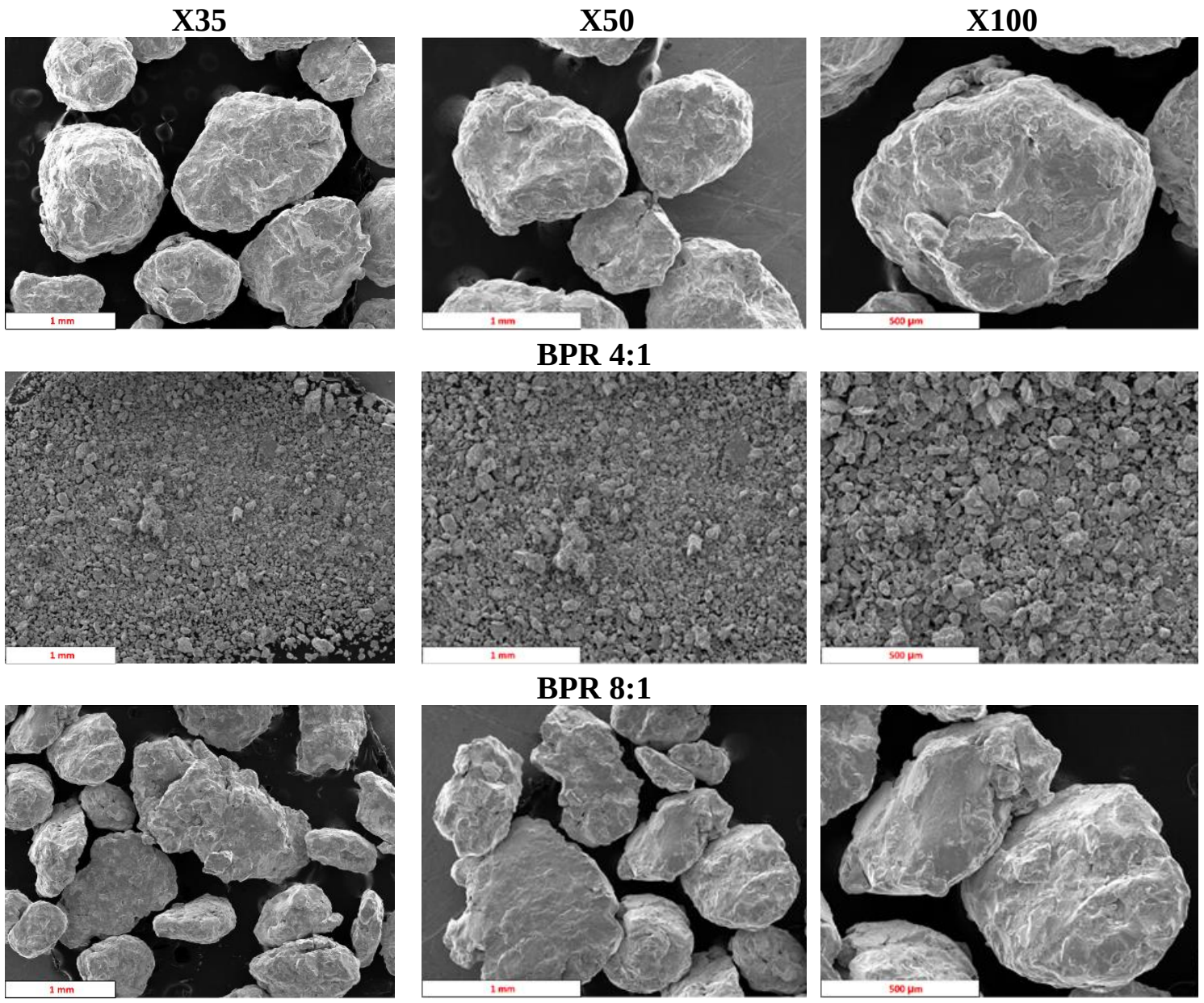
0,5 h | 2 h | 6 h | 8 h

SEM

Ni70.5Fe18.8Mo4.7Al6

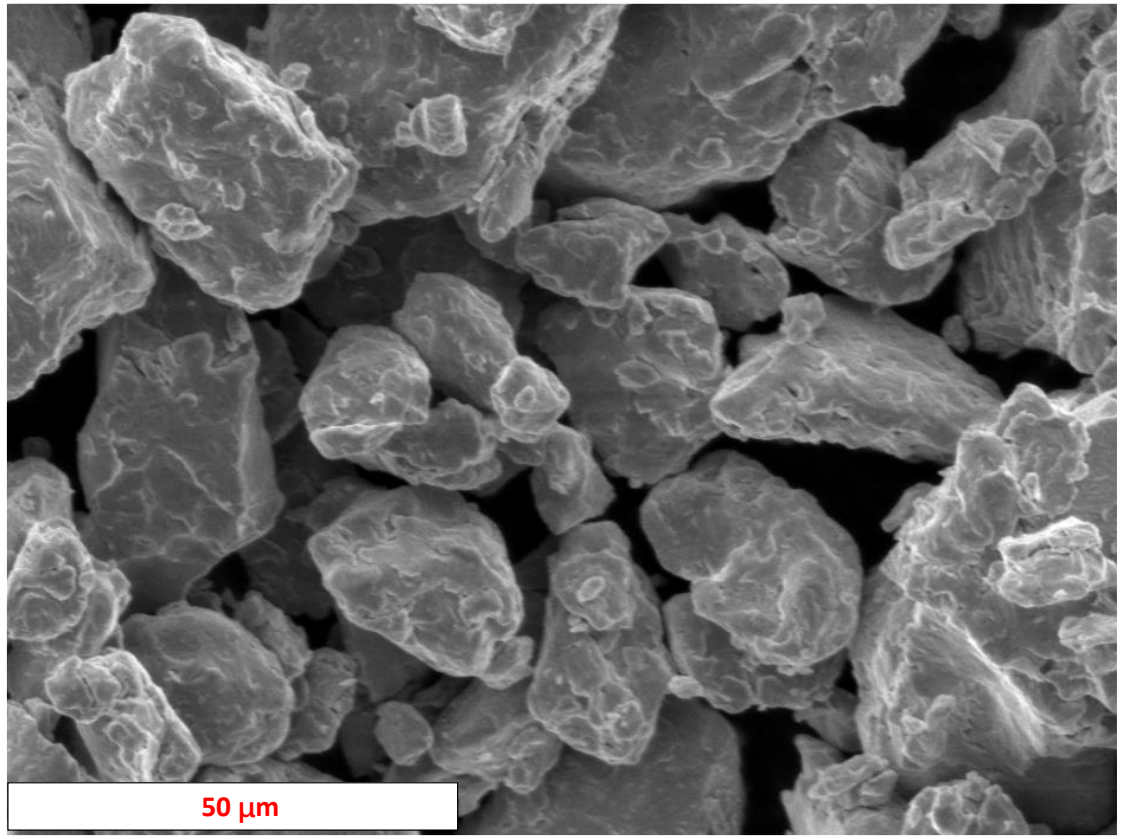


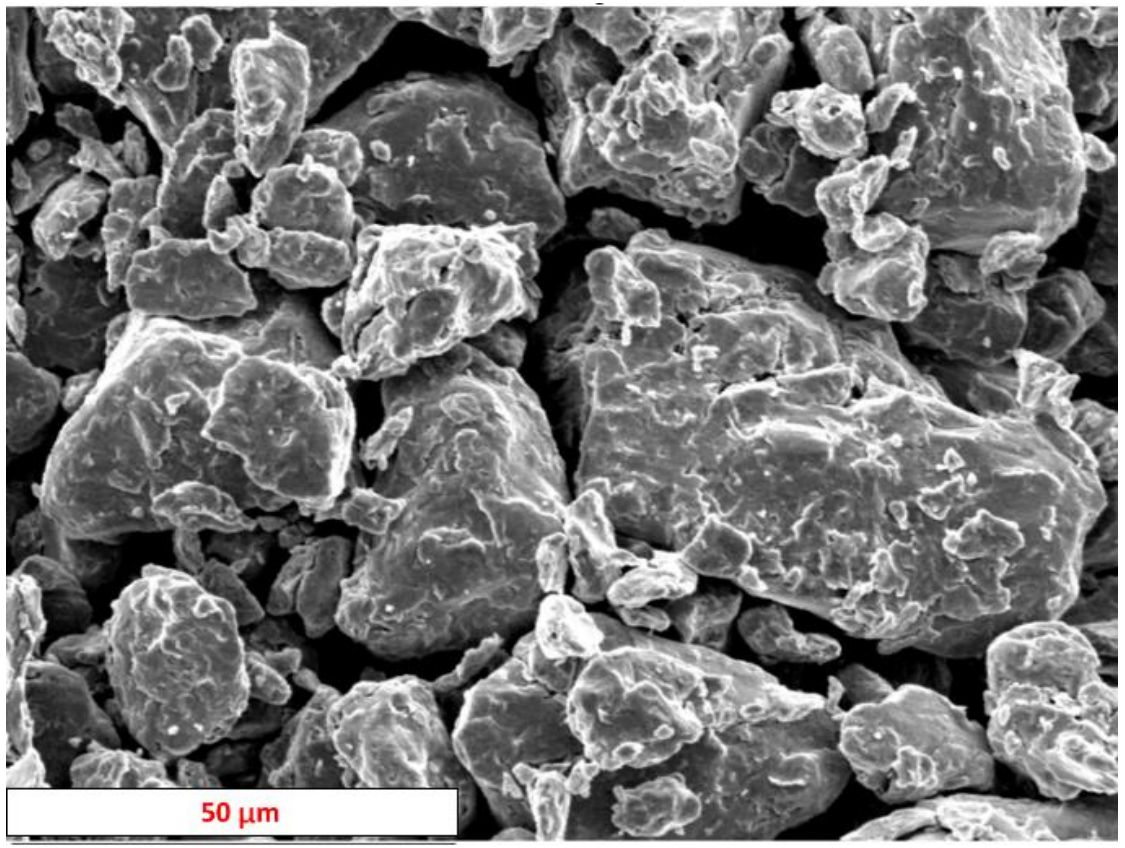
SEM



$Ni_{71,25}Fe_{23,75}Al_5$ 10 hours MA

SEM



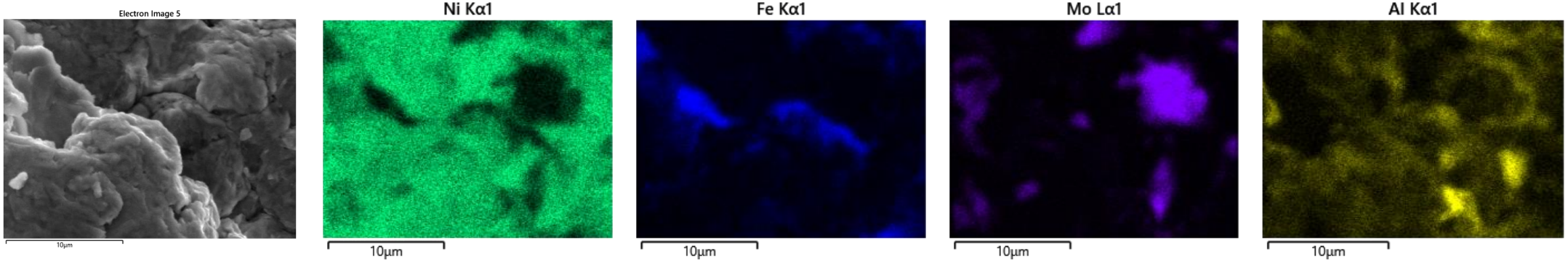


BPR 8:1 **Ni71,25Fe23,75Al5 and Ni71,25Fe19Mo4,75Al5**

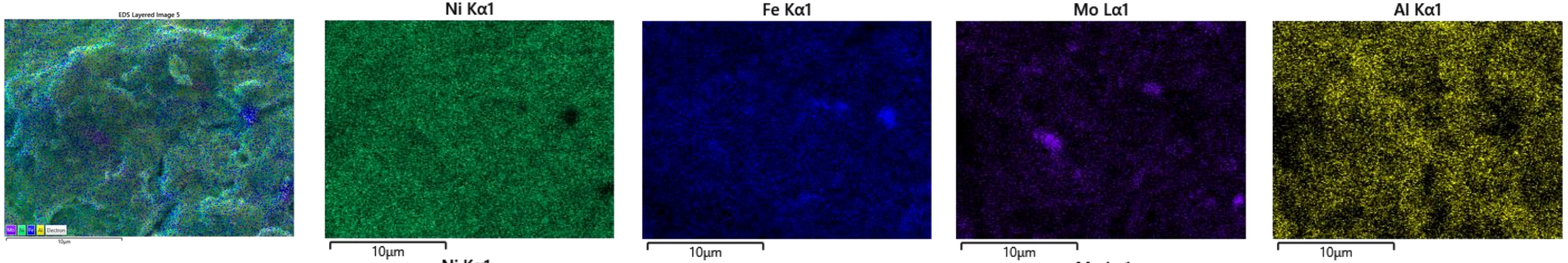
EDX

Ni Fe Mo Al

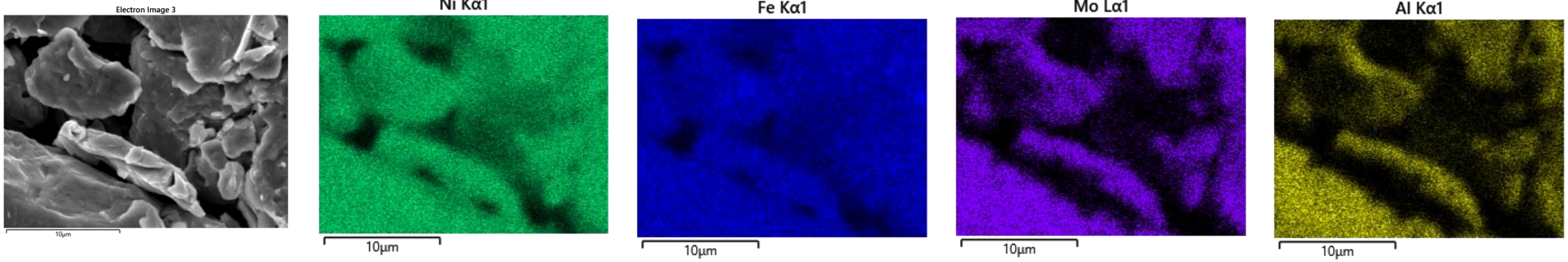
0.5 h MA



2 h MA

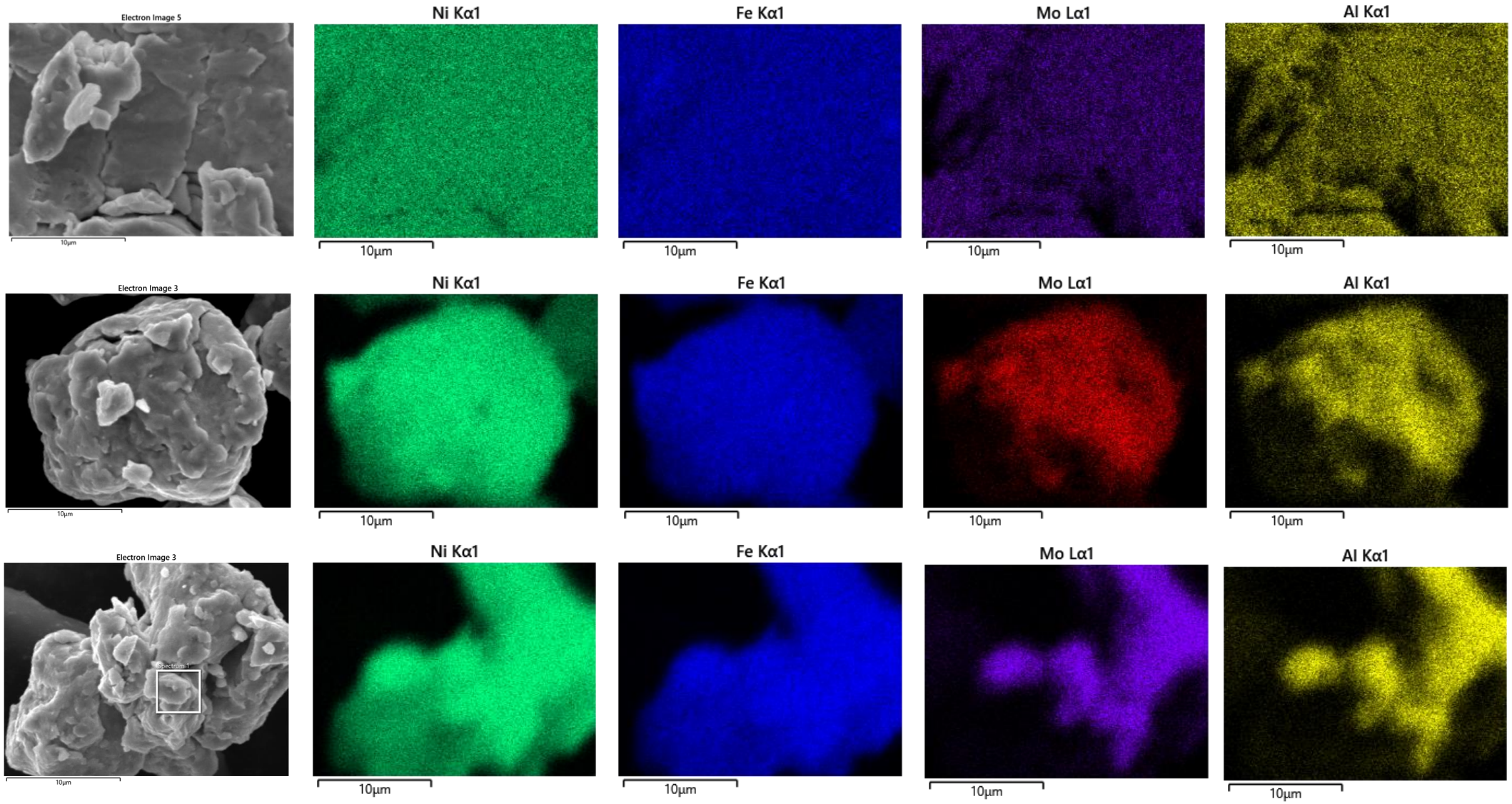


8 h MA



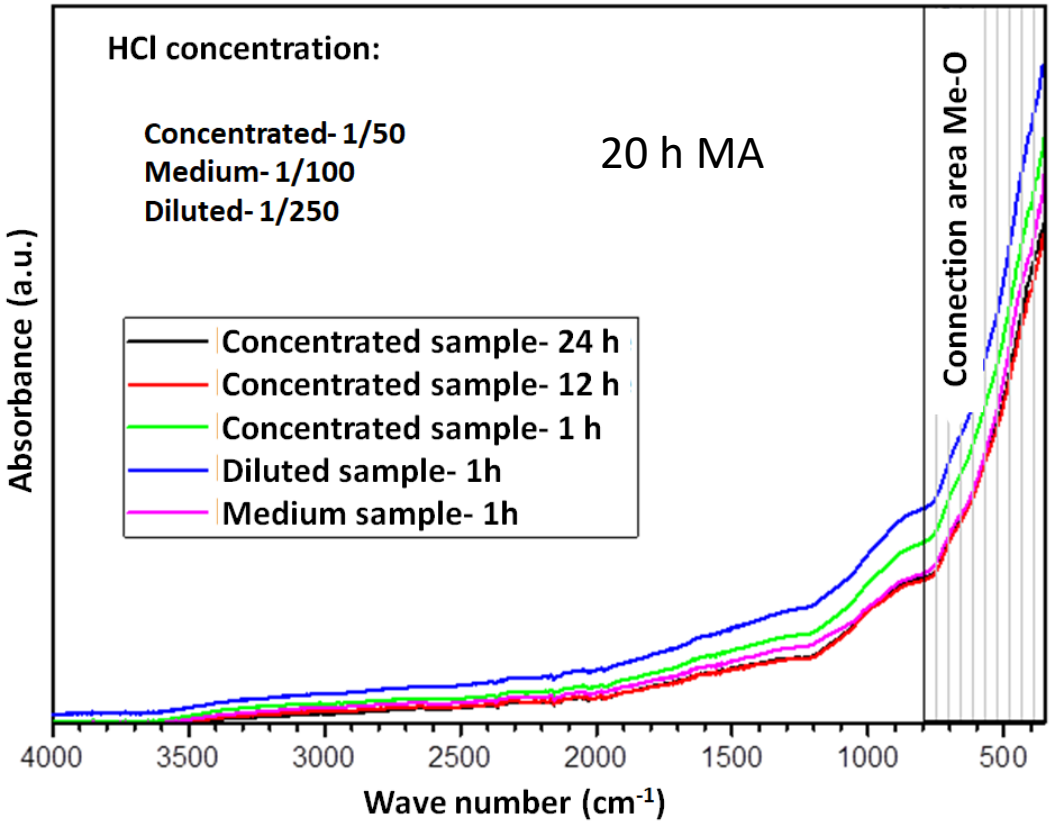
Ni70.5Fe18.8Mo4.7Al6

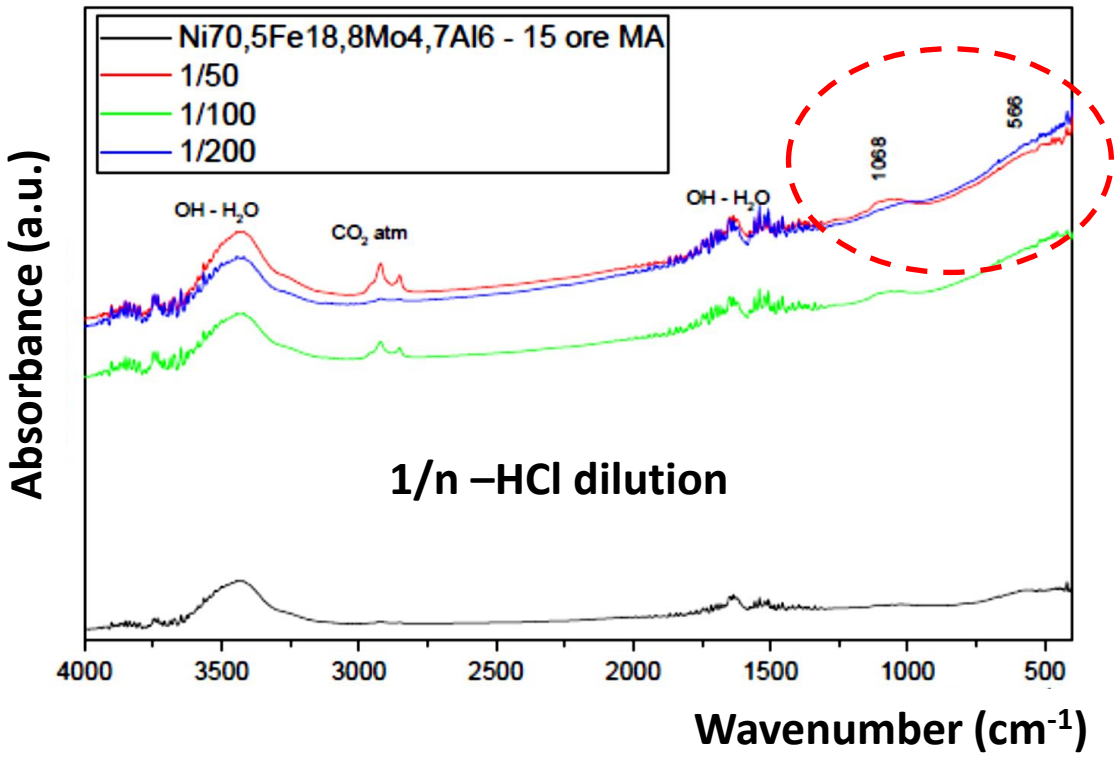
EDX



Ni70.5Fe18.8Mo4.7Al6

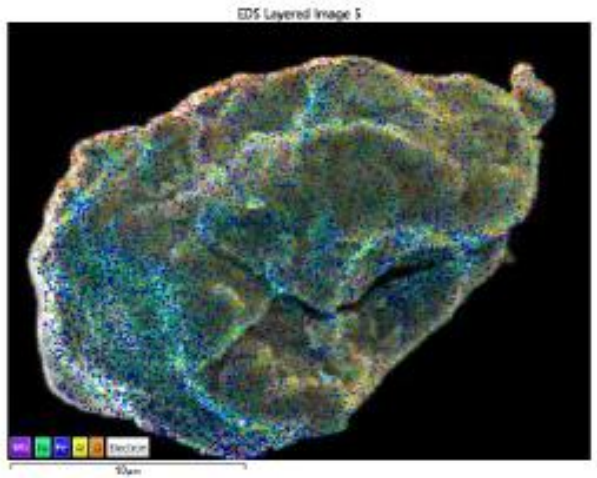
FTIR-

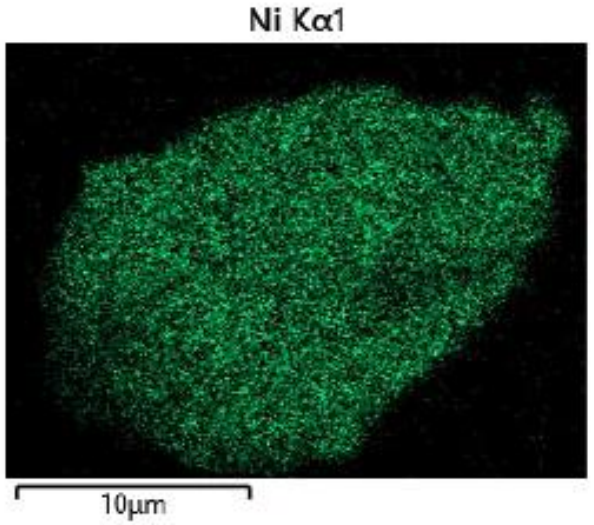


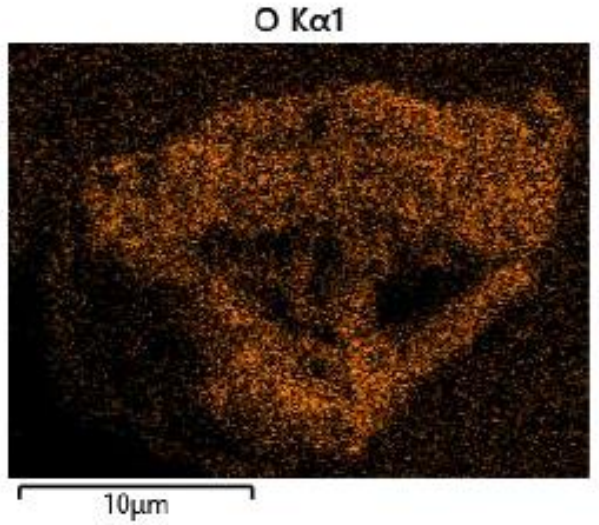


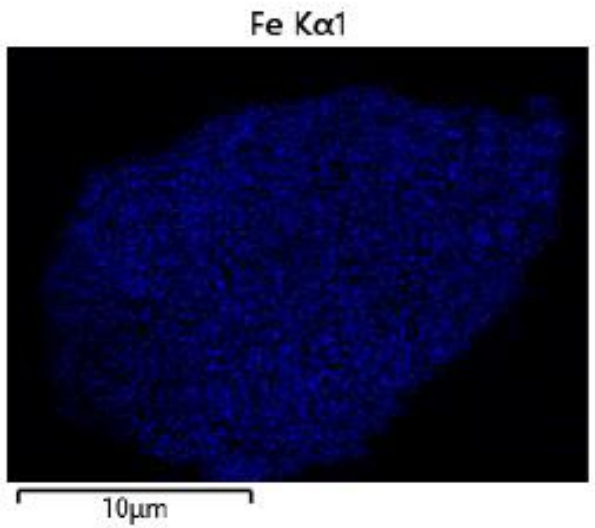
Ni71.25Fe19Mo4.75Al5@oxide and Ni70.5Fe18.8Mo4.7Al6@oxide (superficial oxidation in HCl)

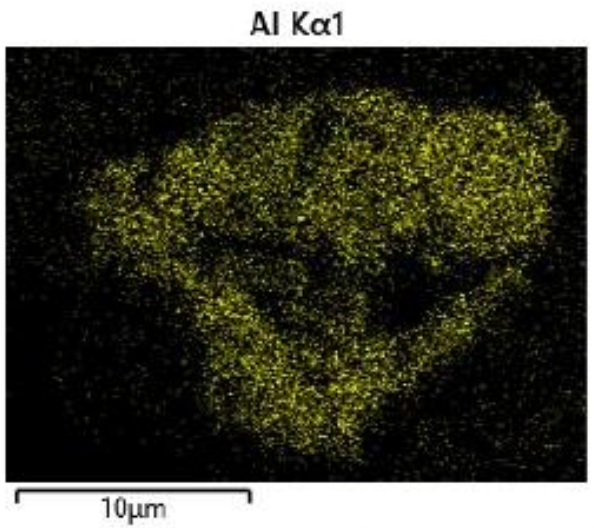
SEM+EDX - Ni70.5Fe18.8Mo4.7Al6@oxide

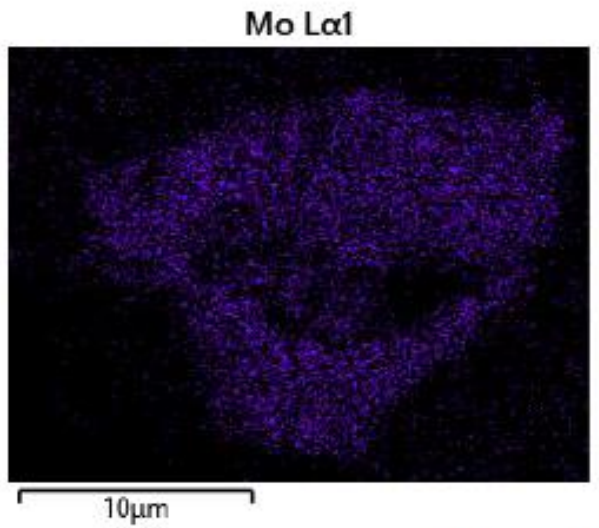






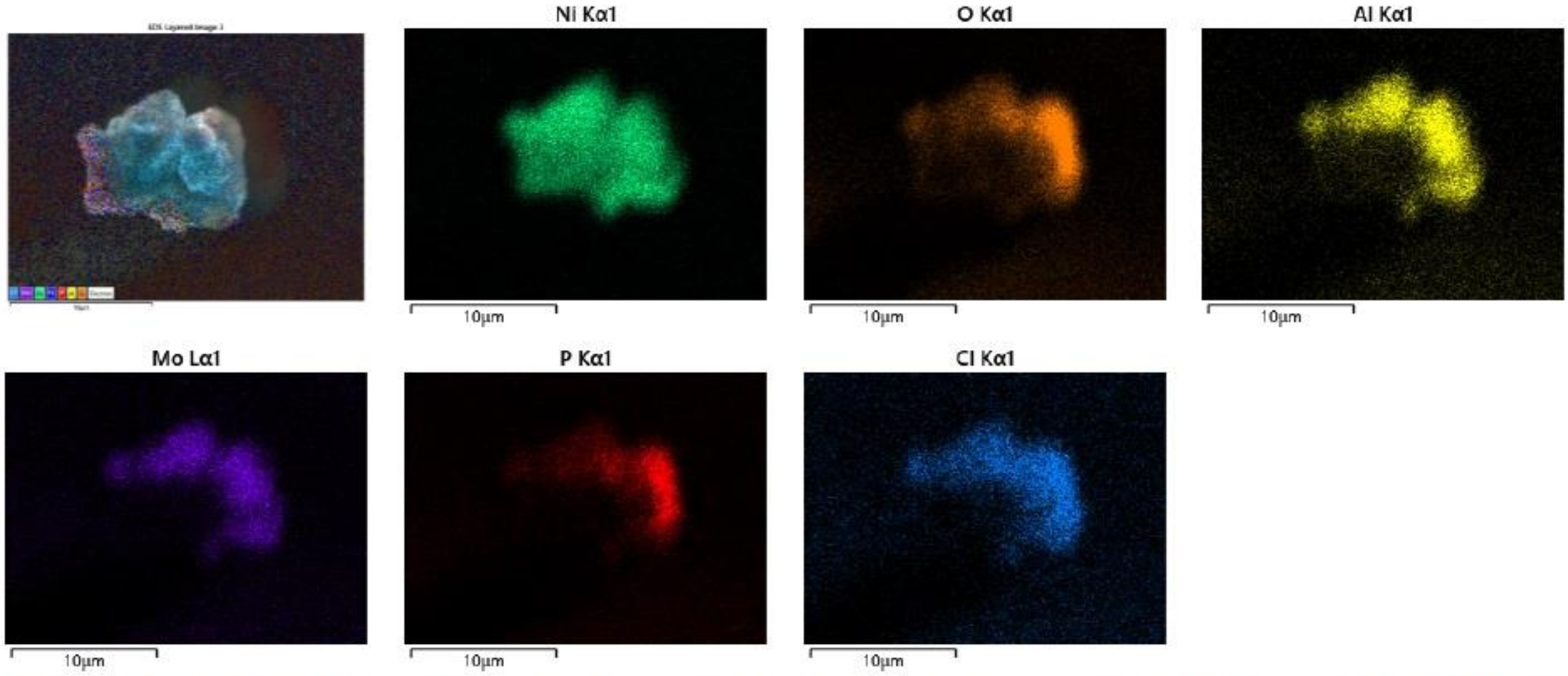






superficial powder oxidations in air+Ar

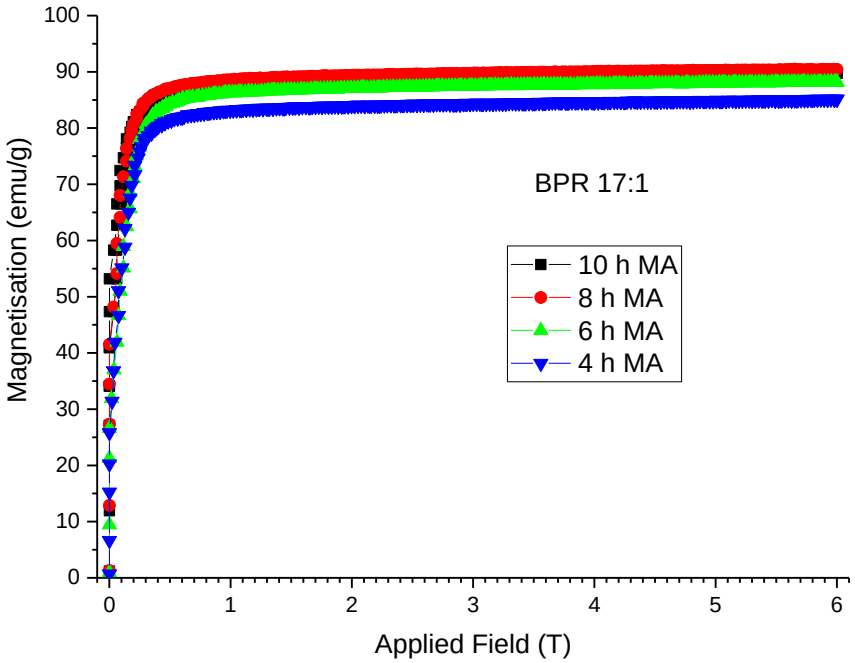
SEM+EDX - Ni70.5Fe18.8Mo4.7Al6@oxide



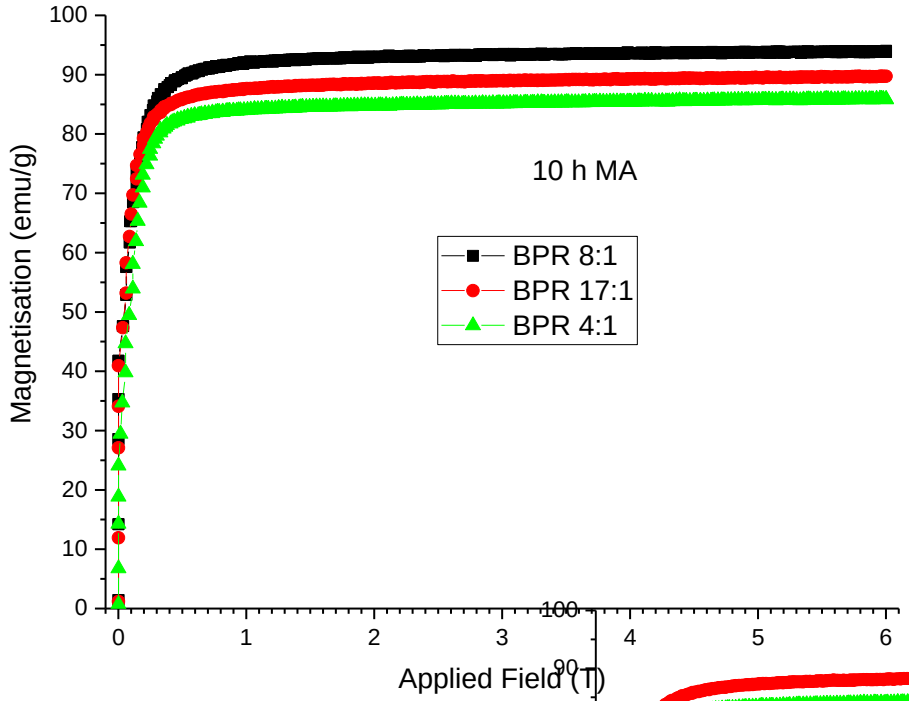
superficial powder oxidations by industrial burnishing kit

Magnetic characteristics

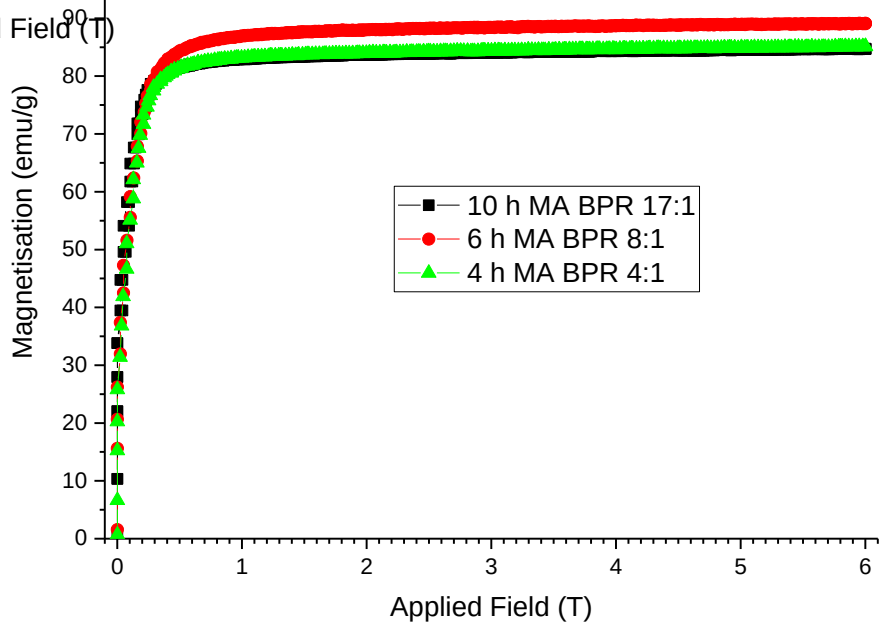
Magnetisation vs milling time



Magnetisation vs BPR



Ni71,25Fe23,75Al5



Conclusions

- By mechanosynthesis up to 20 h and annealing **new alloys Ni70.5Fe18.8Mo4.7Al6, Ni71.25Fe19Mo4.75Al5 and Ni71.25Fe23.75Al5** as single phase was succesfully obtained.

- The alloys are in nanocrystalline state, 15 nm after 15 h of mechanical milling.

- The partucles size can be controlled by optimization of milling/alloying parameters

- The alloys were superfically oxidazed in order obtain **alloy@oxide** composite core-shell particles for sintering

- The addition of 5-6% wt. of Aluminium does not have a significant impact on magnetisation

Thank you for your attention!

Acknowledgement

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