Effect of Starting Powder Premixing on the Interphase Exchange Coupling in $Nd_2Fe_{14}B$+10wt%Fe Nanocomposites Obtained Trough Mechanical Milling

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Outline:

- Introduction
- Synthesis
- Results and Discussion
- Conclusions

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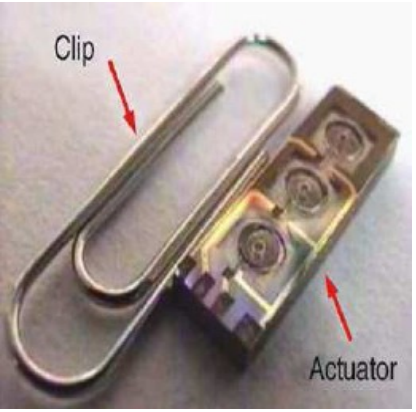
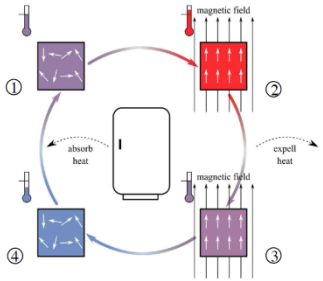
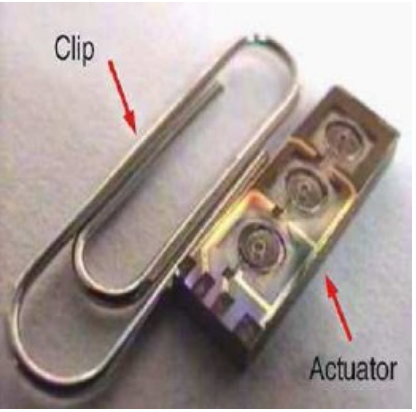
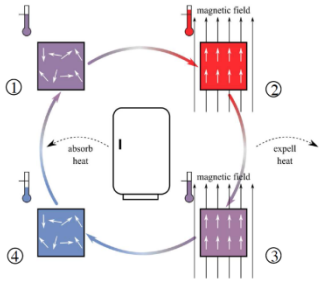


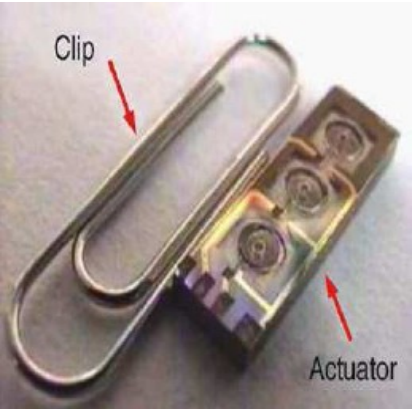


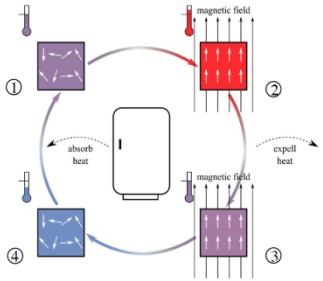
- magnetic materials are ***critical*** components in many devices and for advanced technologies.





- magnetic materials are ***critical*** components in many devices and for advanced technologies.
- high performance magnet (HPM)/wind generator 1000-1600 kg/MW.
- motors and generators: **2 kg** HPM/hybrid electric vehicle-**20 million** vehicles by 2018.
- Magnetocaloric applications 4 kg HPM/kW cooling power.





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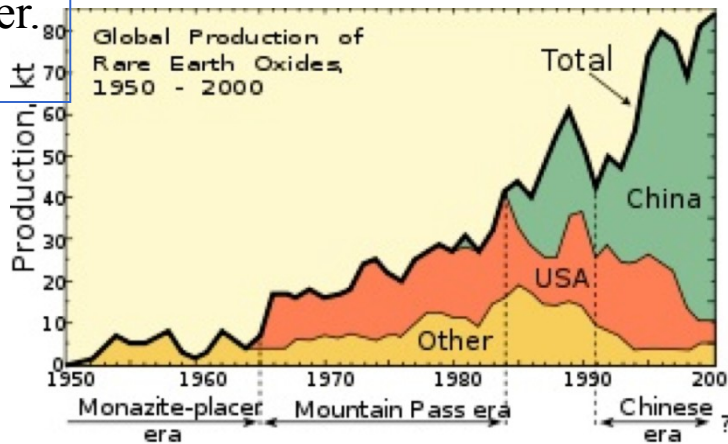
- motors and generators: **2 kg** HPM/hybrid electric vehicle-**20 million** vehicles by 2018.
- Magnetocaloric applications 4 kg HPM/kW cooling power.

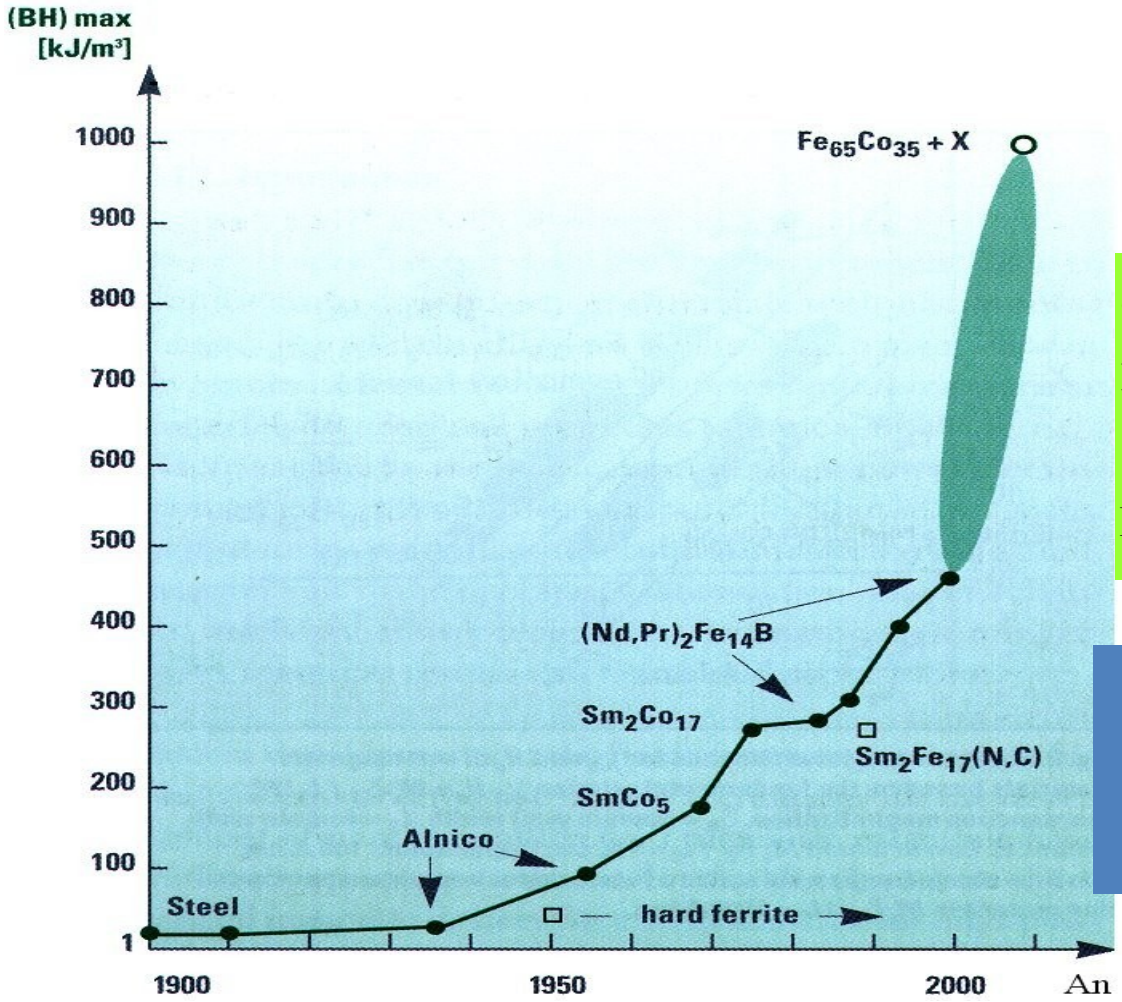
HPM= **rare-earth** based magnets

China manages about 96 % of rare-earth resources in 2011

!!!



Theoretical predictions:

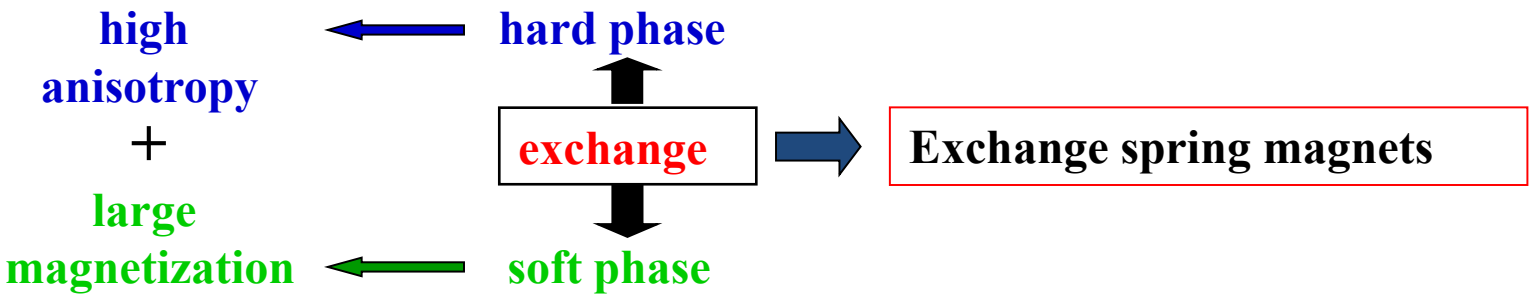


Best magnets on the market:
(BH)max ≈ 500 kJ/m3

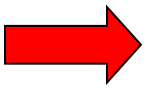
$(BH)_{max}$ = 1090 kJ/m³ for nanostructured multilayers $Sm_2Fe_{17}N_3/Fe_{65}Co_{35}$

R. Skomski, J. Appl. Phys. 76 (1994) 7059

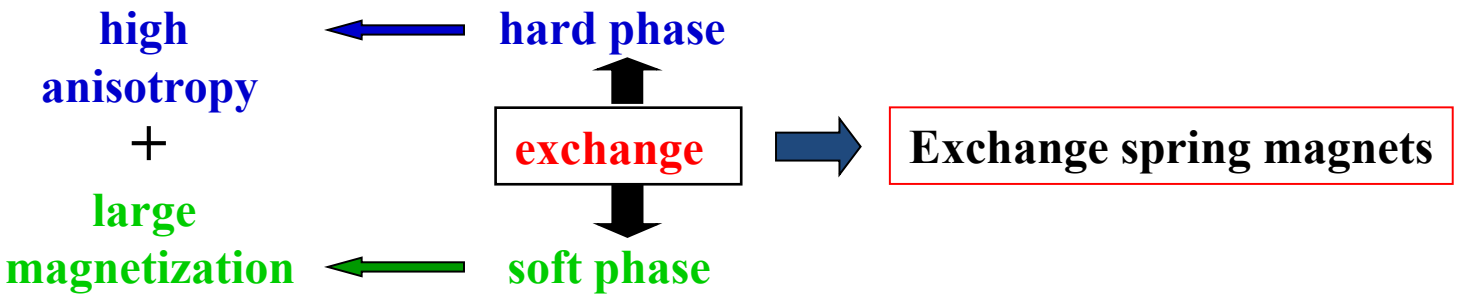
Kronmuller & Coey *Magnetic Materials*, in *European White book on Fundamentel Research in Materials Science* Max Planck Inst. Metallforschung, Stuttgart, 2001, 92-96


high
anisotropy
+
large
magnetization
hard phase
exchange
soft phase
Exchange spring magnets

Structure
Microstructure

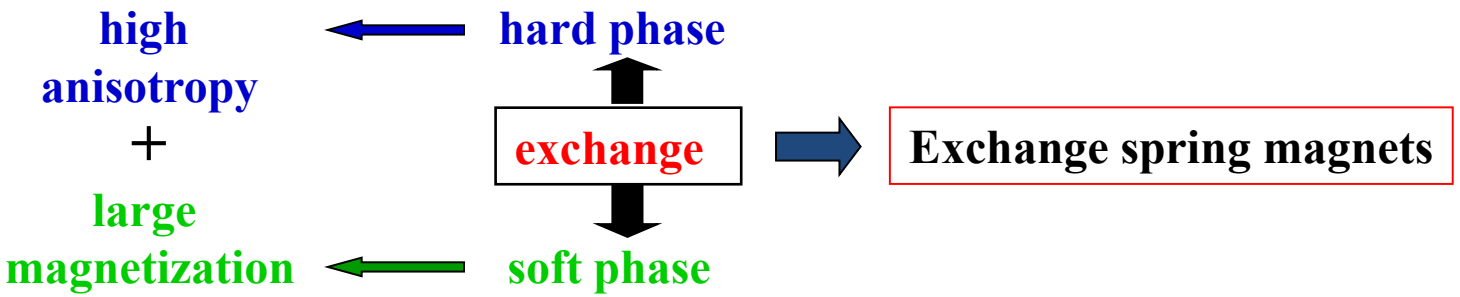


Soft-hard exchange hardness



D_{cr} = **soft phase critical dimension**
δ_h = width of domain wall in the hard phase
A_h and K_h are the exchange and anisotropy constants

Structure
Microstructure → **Soft-hard exchange hardness**



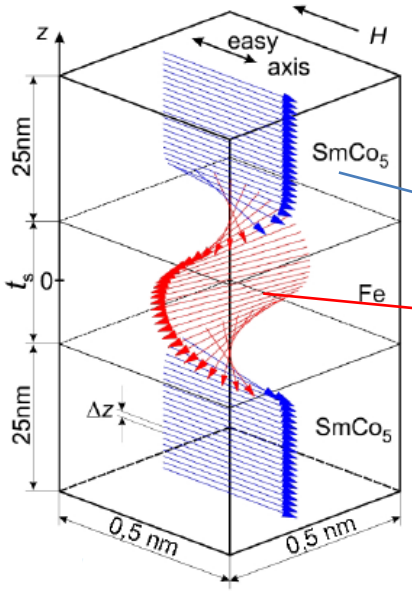
- hard magnetic phases of $SmCo_5$, $SmCo_3Cu_2$, $R_2Fe_{14}B$
- soft magnetic phases of α-Fe, Fe-Co (~20 or 10 wt%)

Structure
Microstructure → **Soft-hard exchange hardness**

high anisotropy + **large ‹tization**

hard phase ↑ **exchange** ↓ **soft phase**

→ **Exchange spring magnets**



- **hard magnetic phases of $SmCo_5$, $SmCo_3Cu_2$, $R_2Fe_{14}B$**
- **soft magnetic phases of α-Fe, Fe-Co (~20 or 10 wt%)**

$SmCo_5$	large anisotropy
$SmCo_3Cu_2$	large coercivity
$R_2Fe_{14}B$	best magnets

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- **Synthesis**
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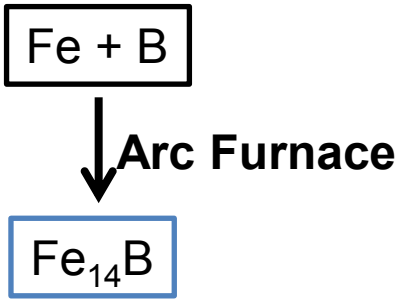
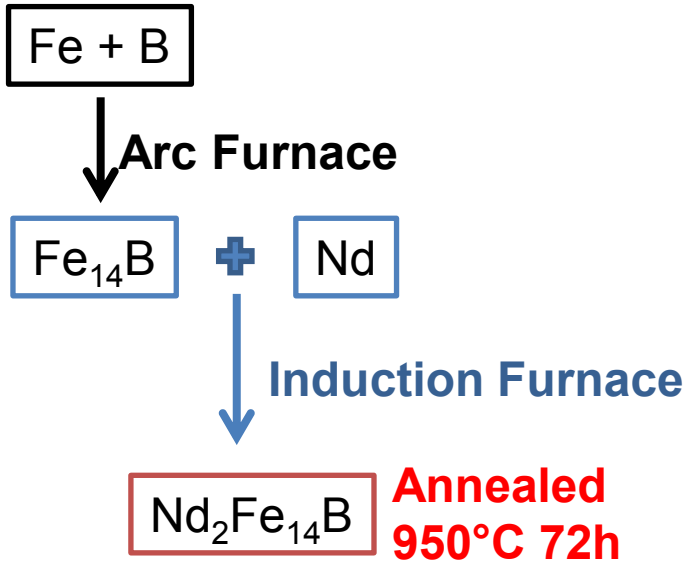
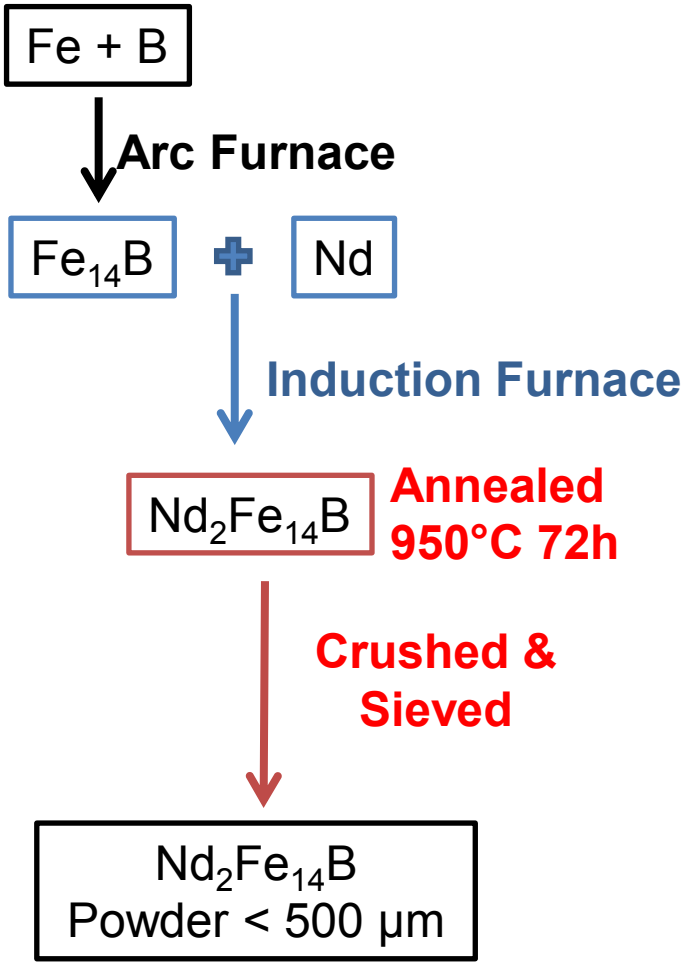
Synthesis :



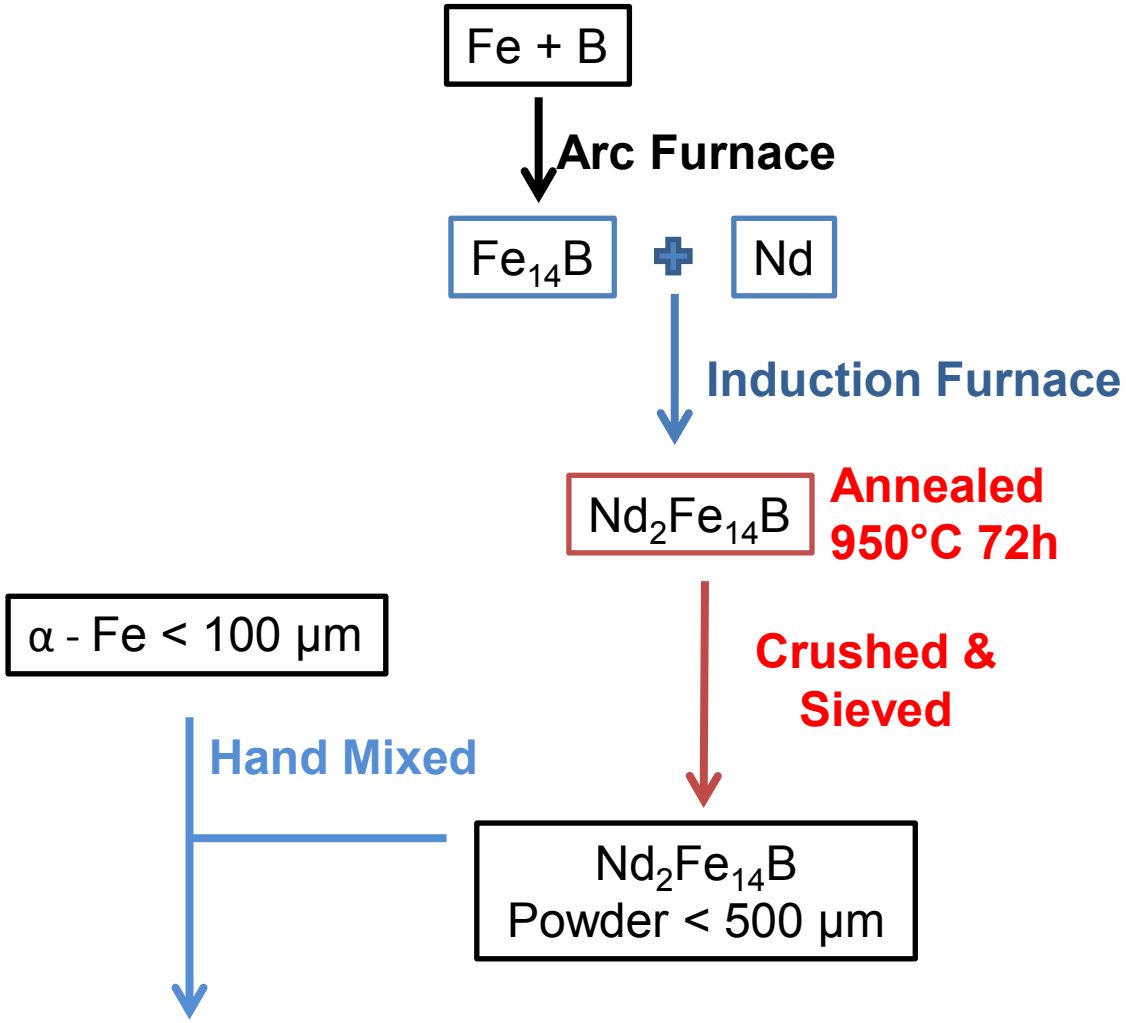
Synthesis :


Fe + B
Arc Furnace
$Fe_{14}B$
Nd
Induction Furnace
$Nd_2Fe_{14}B$
Annealed
950°C 72h

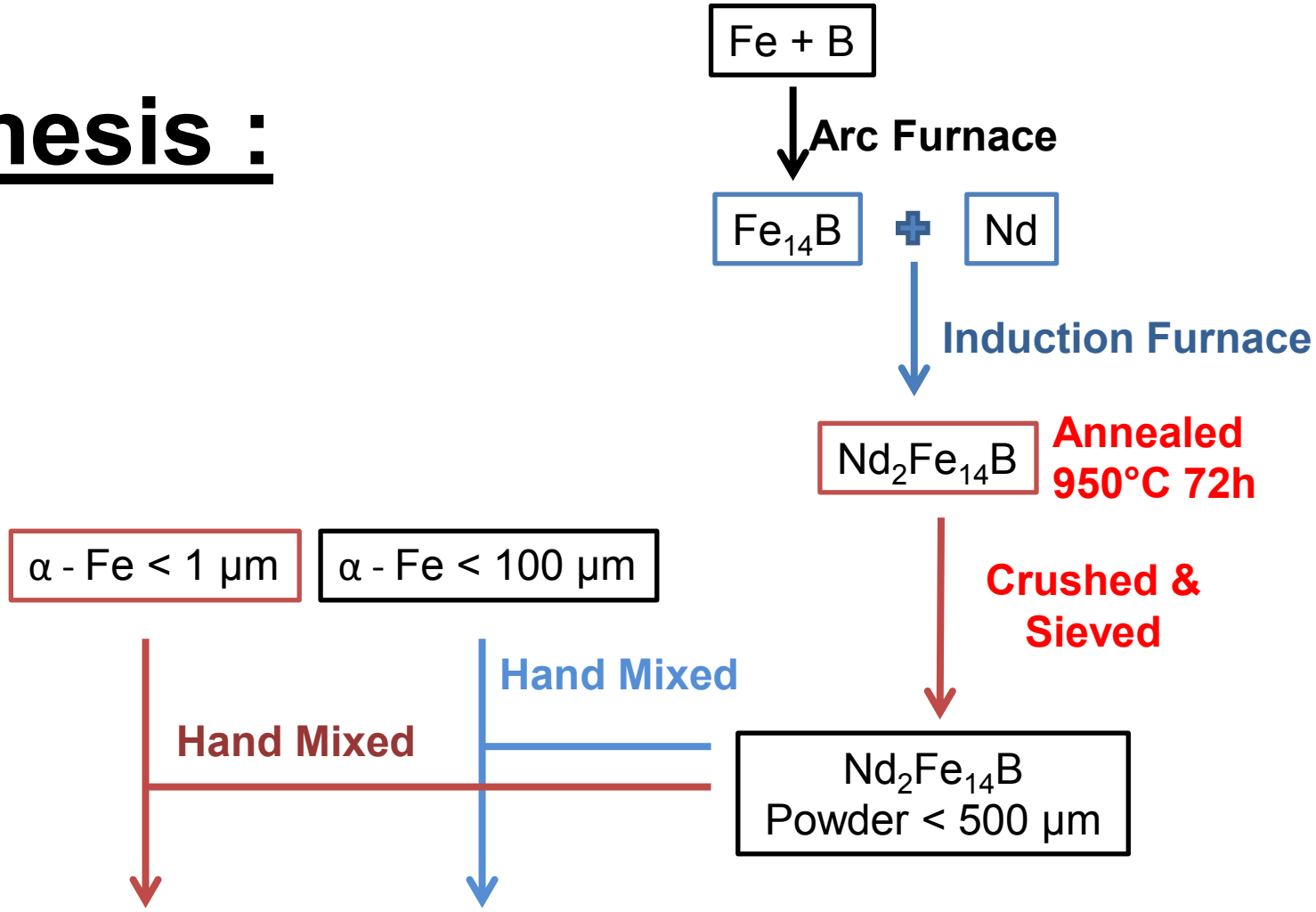
Synthesis :


Fe + B
Arc Furnace
$Fe_{14}B$
Nd
Induction Furnace
$Nd_2Fe_{14}B$
Annealed
950°C 72h
Crushed &
Sieved
$Nd_2Fe_{14}B$
Powder < 500 µm

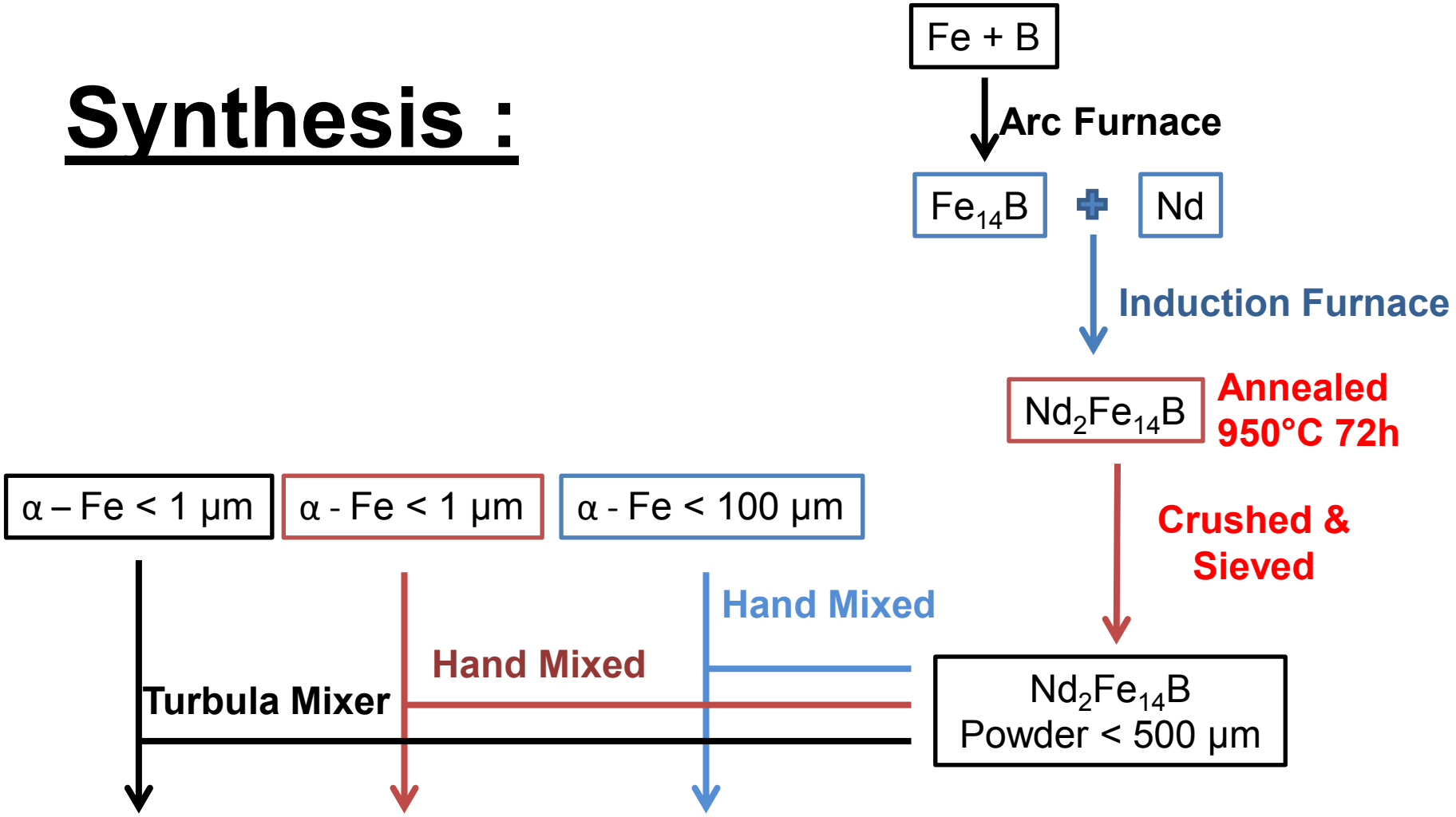
Synthesis :


Fe + B
Arc Furnace
$Fe_{14}B$
Nd
Induction Furnace
$Nd_2Fe_{14}B$
Annealed
950°C 72h
α - Fe < 100 µm
Crushed &
Sieved
Hand Mixed
$Nd_2Fe_{14}B$
Powder < 500 µm

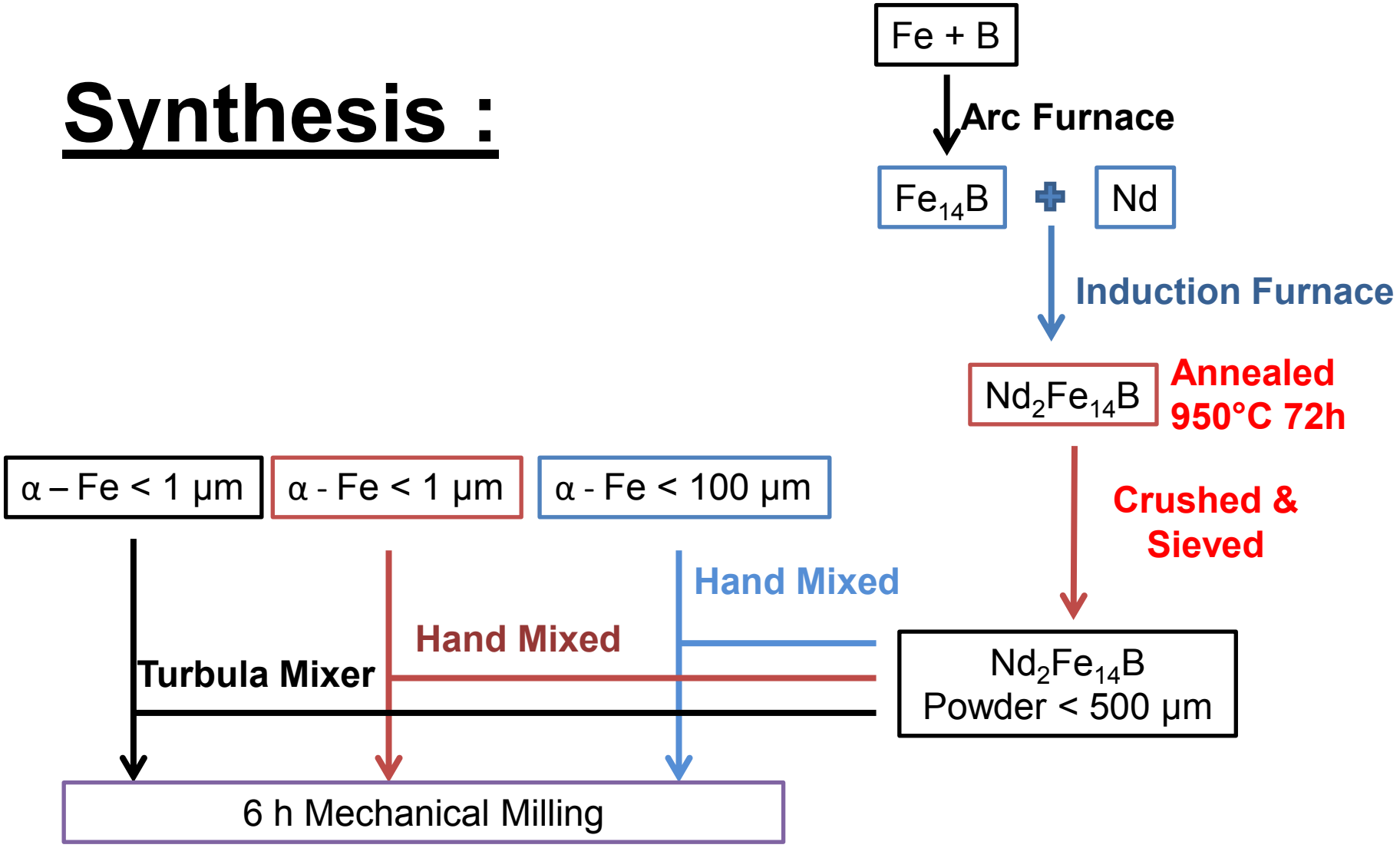
Synthesis :


Fe + B
Arc Furnace
$Fe_{14}B$
Nd
Induction Furnace
$Nd_2Fe_{14}B$
Annealed
950°C 72h
α - Fe < 1 μm
α - Fe < 100 μm
Crushed &
Sieved
Hand Mixed
Hand Mixed
$Nd_2Fe_{14}B$
Powder < 500 μm

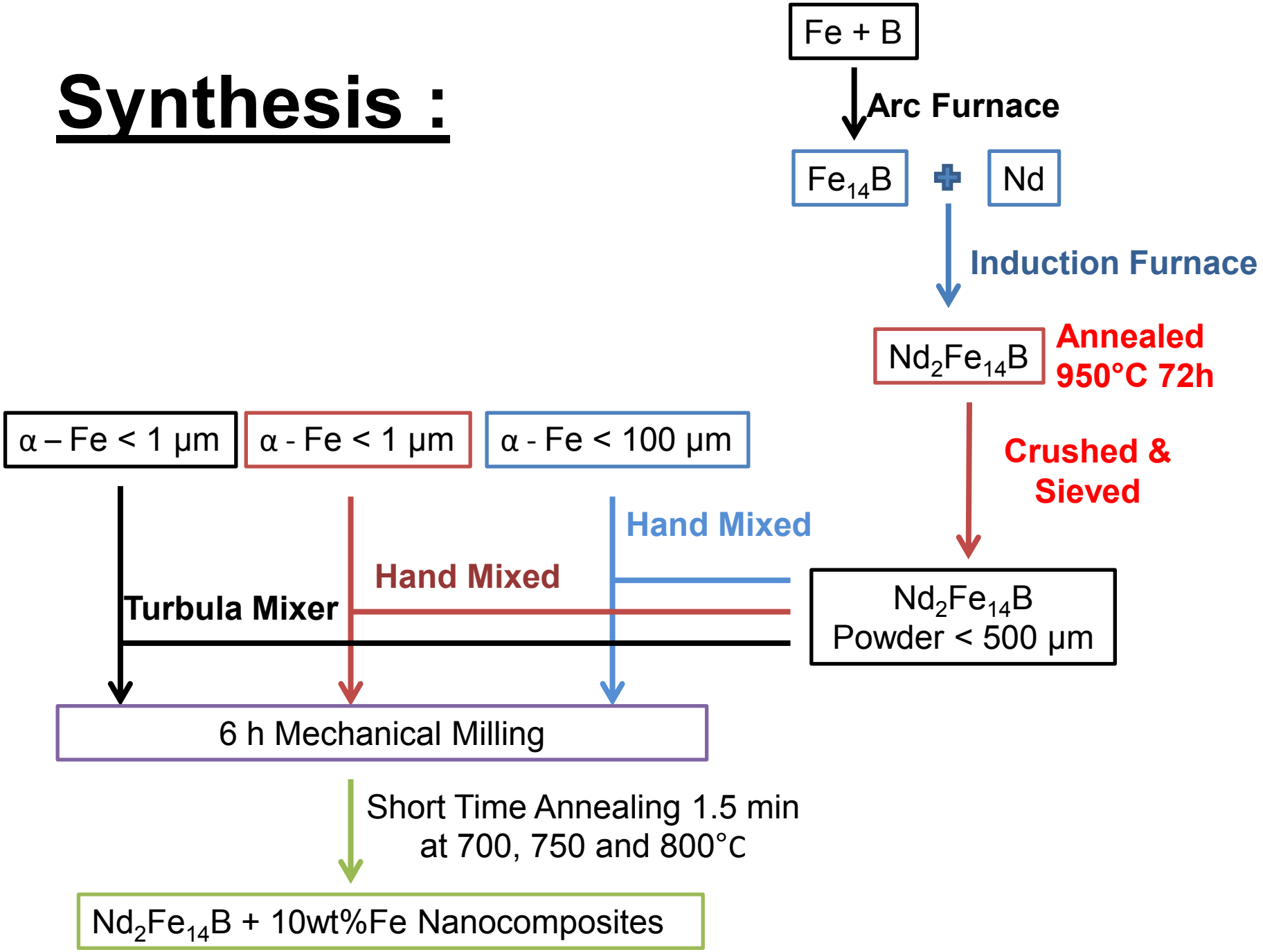
Synthesis :


Fe + B
Arc Furnace
$Fe_{14}B$
Nd
Induction Furnace
$Nd_2Fe_{14}B$
Annealed
950°C 72h
Crushed &
Sieved
α – Fe < 1 μm
α - Fe < 1 μm
α - Fe < 100 μm
Hand Mixed
Hand Mixed
Turbula Mixer
$Nd_2Fe_{14}B$
Powder < 500 μm

Synthesis :


Fe + B
Arc Furnace
$Fe_{14}B$
Nd
Induction Furnace
$Nd_2Fe_{14}B$
Annealed
950°C 72h
Crushed &
Sieved
α – Fe < 1 μm
α - Fe < 1 μm
α - Fe < 100 μm
Hand Mixed
Hand Mixed
Turbula Mixer
$Nd_2Fe_{14}B$
Powder < 500 μm
6 h Mechanical Milling

Synthesis :


Fe + B
Arc Furnace
$Fe_{14}B$
Nd
Induction Furnace
$Nd_2Fe_{14}B$
Annealed
950°C 72h
Crushed &
Sieved
α – Fe < 1 μm
α - Fe < 1 μm
α - Fe < 100 μm
Hand Mixed
Hand Mixed
Turbula Mixer
$Nd_2Fe_{14}B$
Powder < 500 μm
6 h Mechanical Milling
Short Time Annealing 1.5 min
at 700, 750 and 800°C
$Nd_2Fe_{14}B$ + 10wt%Fe Nanocomposites

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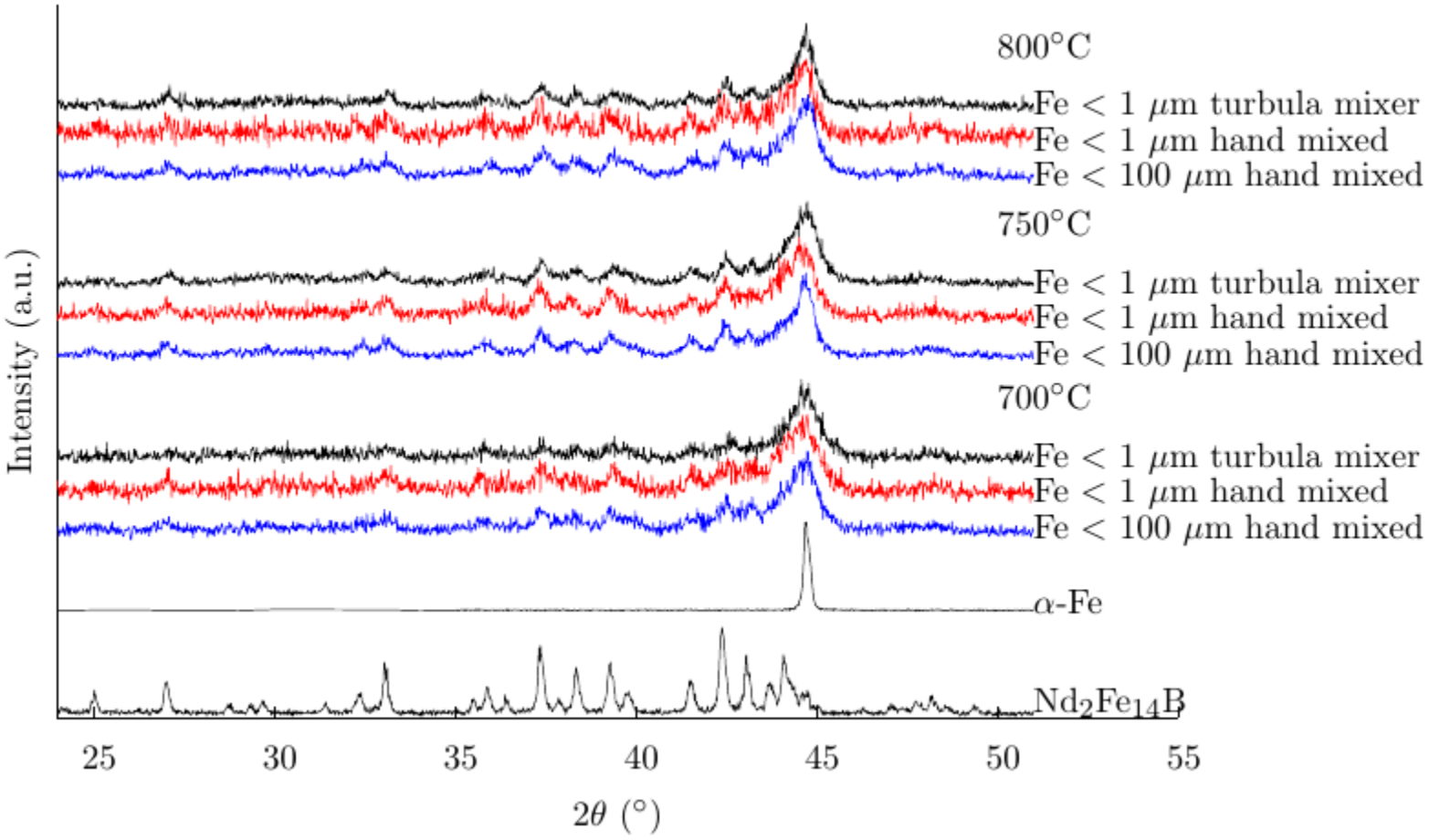
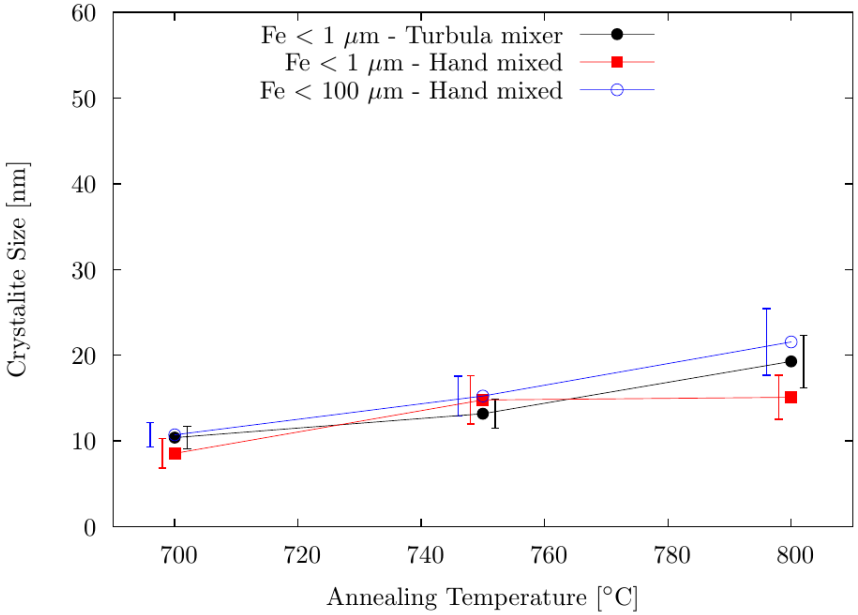
XRD Pattern For 6h MM and Annealed for 1.5 min $Nd_2Fe_{14}B$+10%Fe Nanocomposites

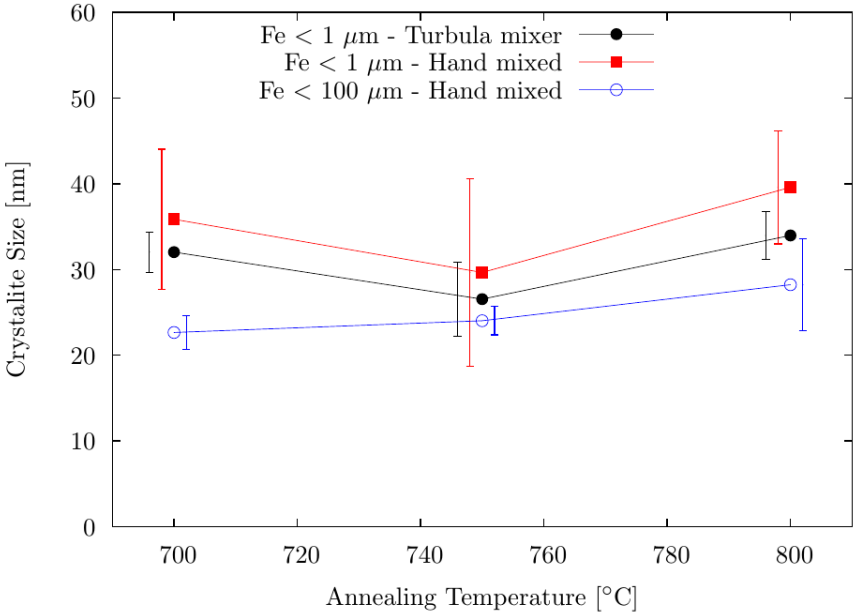


Crystalite Sizes for 6h MM and Annealed for 1.5 min $Nd_2Fe_{14}B$+10%Fe Nanocomposites
Derived from XRD

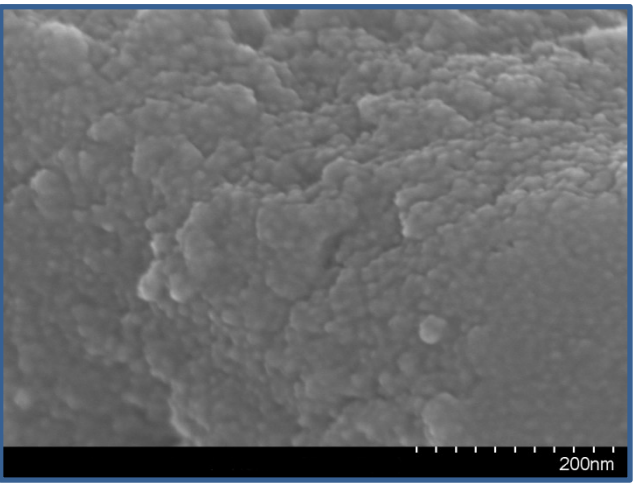
α - Fe

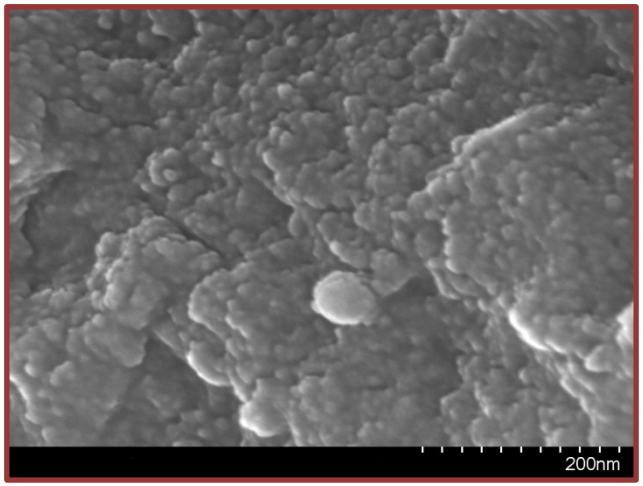


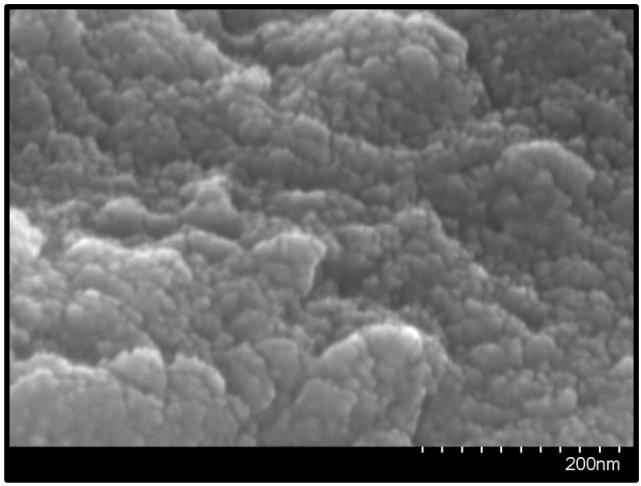
$Nd_2Fe_{14}B$



SEM Images for 6h MM and Annealed for 1.5 min $Nd_2Fe_{14}B$+10%Fe Nanocomposites



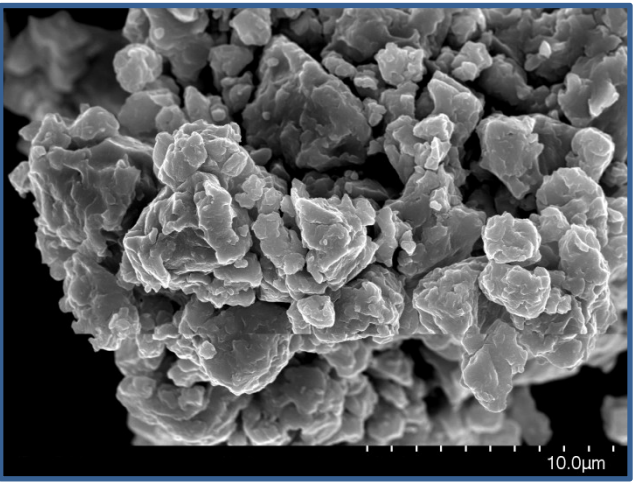


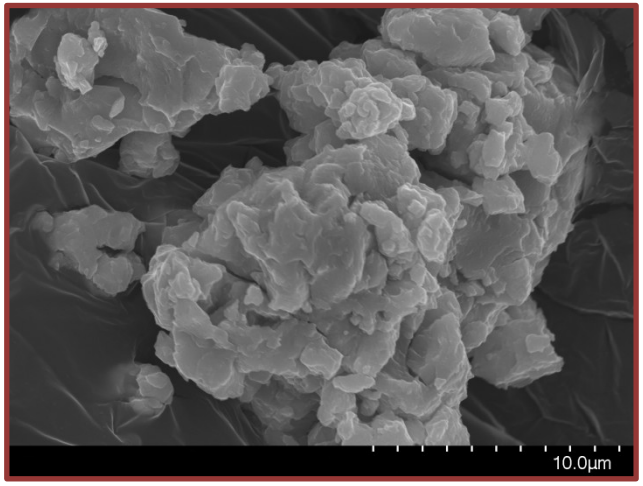


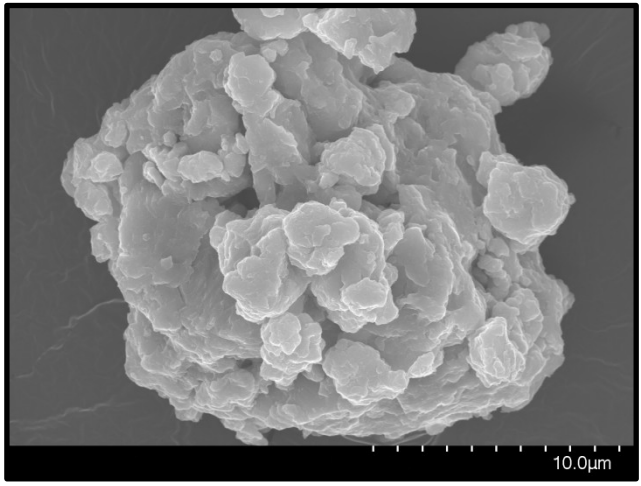
Fe < 100 μm
Mixed by hand

Fe < 1 μm
Mixed by hand

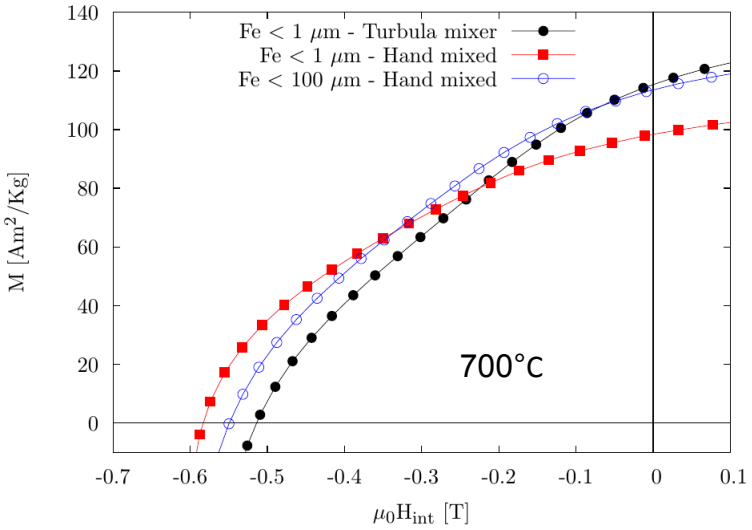
Fe < 1 μm
Mixed using Turbula Mixer

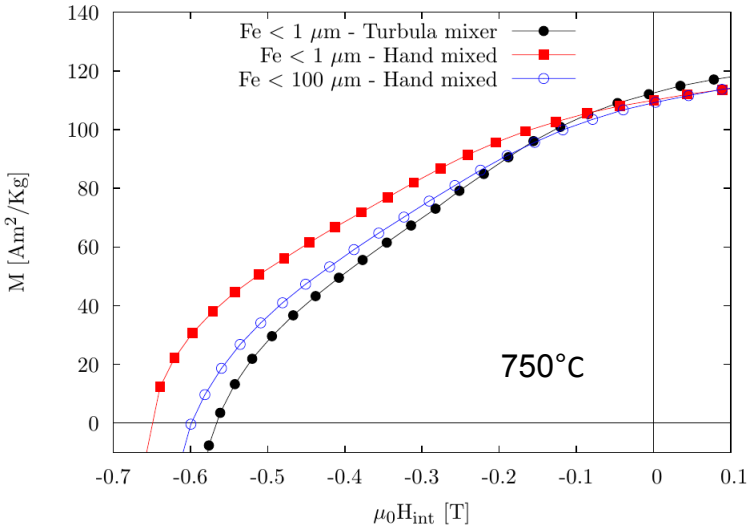


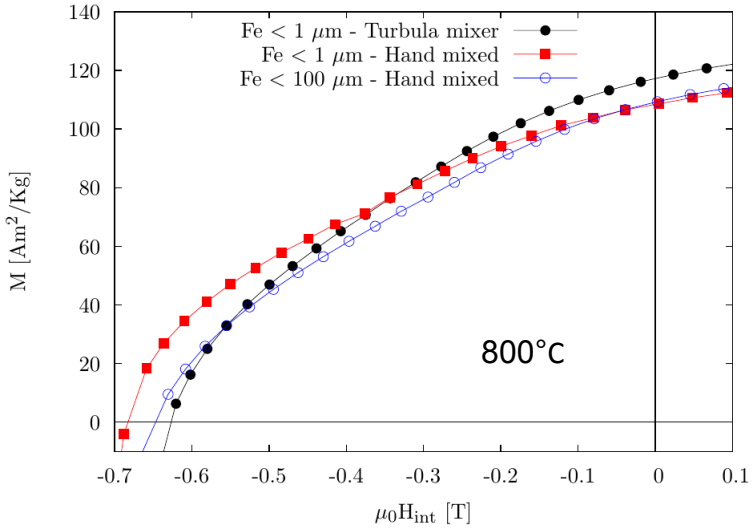




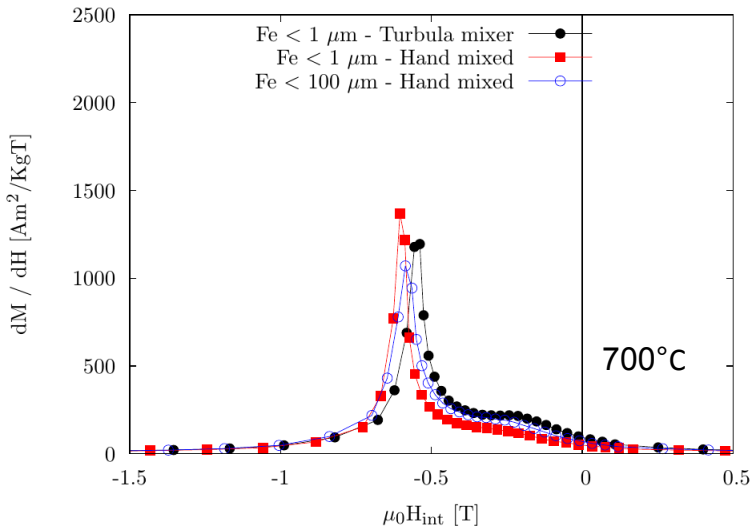
Demagnetization curves at 300 K for 6h MM and Annealed for 1.5 min $Nd_2Fe_{14}B$+10%Fe Nanocomposites

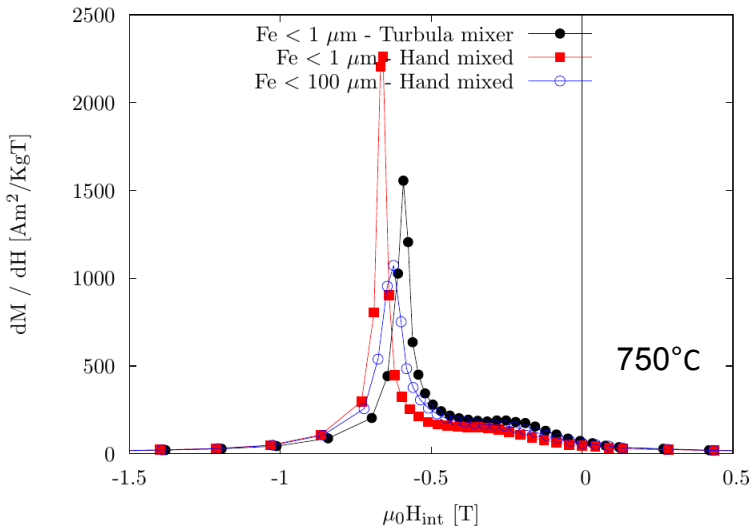


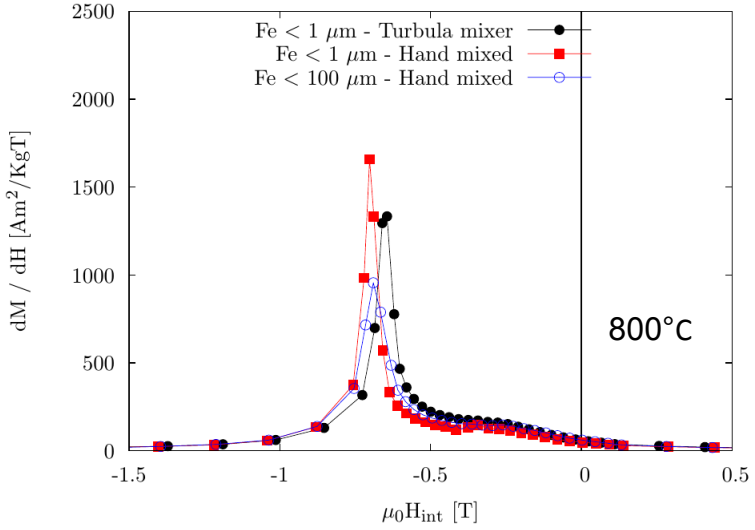




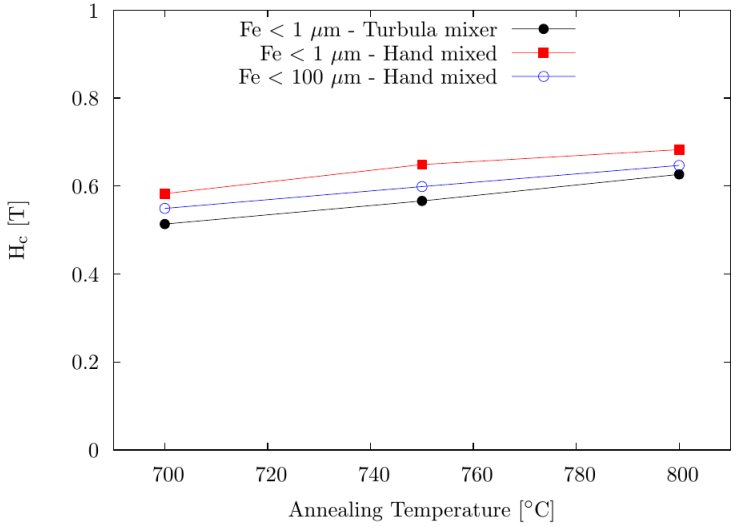
dM/dH vs H plots at 300 K for 6h MM and Annealed for 1.5 min $Nd_2Fe_{14}B$+10%Fe Nanocomposites

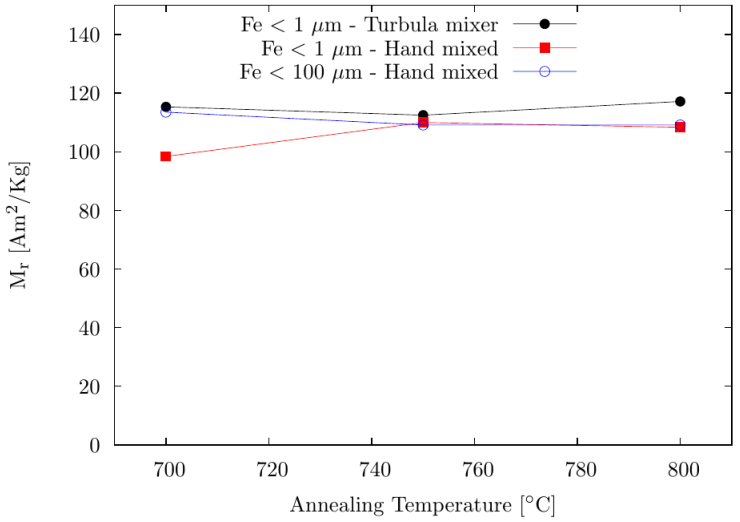


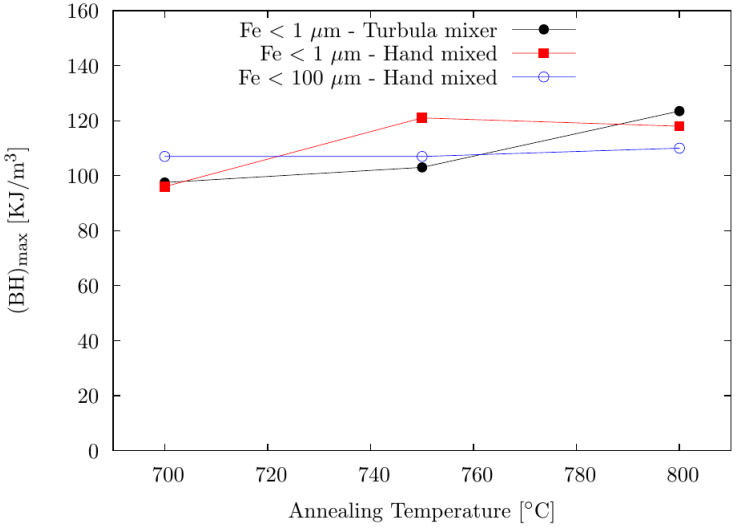




H_c, M_r and $(BH)_{max}$ at 300 K for 6h MM $Nd_2Fe_{14}B$+10%Fe Nanocomposites as a Function of Annealing Temperature







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Conclusions:

- **All starting powders produce similar microstructures**
- **Interphase exchange coupling improves when using the smaller Fe powder in the starting mixture**
- **Premixing with Turbula mixer further improves the intrephase exchange coupling**

Acknowledgements:

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Thank your for your attention !