

NEXUS

OVERVIEW: Subproject 2

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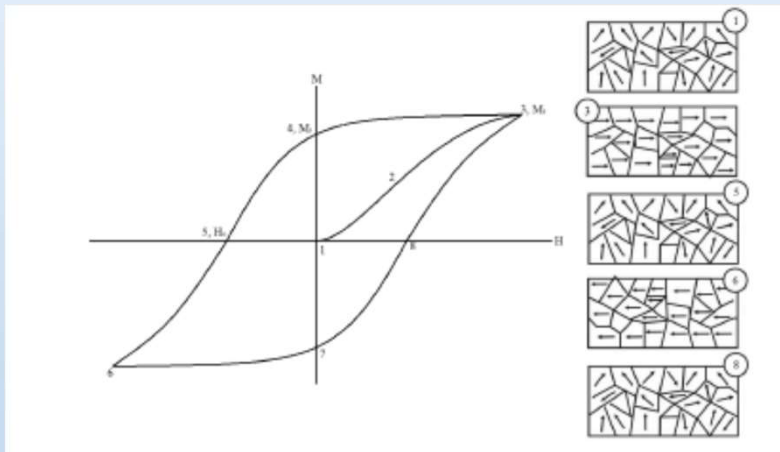
- **Design and synthesis of soft magnetic materials.** Mechanical alloying and rapid solidification are well-established techniques that will be applied by UdG to obtain metastable amorphous and nanocrystalline alloys. Mechanical alloying will allow increasing the solubility limit (extremely important in the study of the Fe-Ni system) whereas melt-spinning will be fundamental to develop amorphous alloys to be combined with Mn-Al. In this latter case, an ulterior controlled annealing will play a double role: the synthesis of the L1₀-MnAl phase and the development of nanostructured soft alloys with an optimized crystalline size and magnetic response.

MA, MS, MA +, MS +
Soft-Hard composites

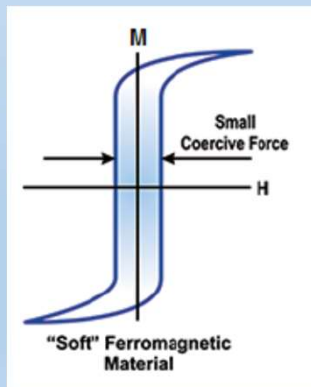


INTRODUCTION

SOFT FERROMAGNETIC Amorphous - Nanocrystalline



Magnetic domains



Area

Energy/Volum

Small Coercivity, H_c

High magnetic susceptibility, χ

High permeability, μ

High Saturation magnetization, M_s

High Polarization, J_s

High Curie temperature, T_c

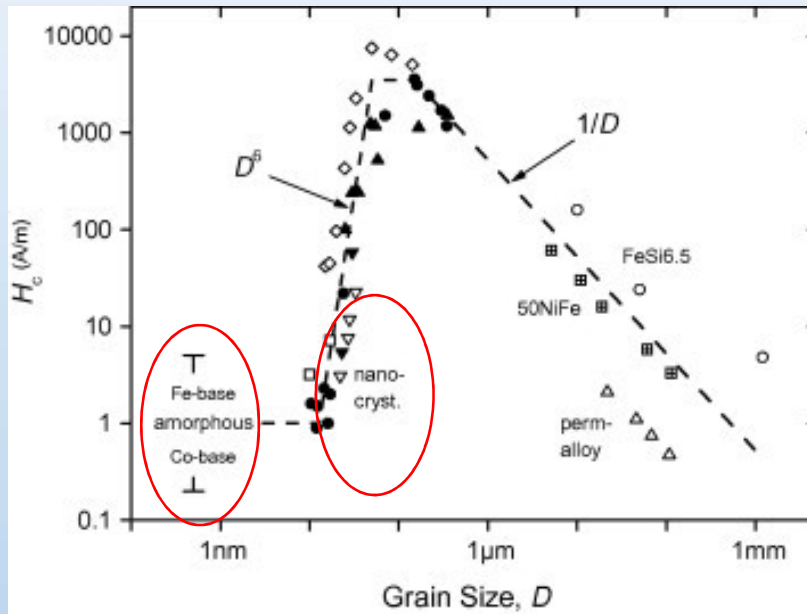
High Electrical resistivity, ρ

High Remanence; M_r

SOFT-HARD: the squareness ratio (M_r/M_s) should be as close to 1



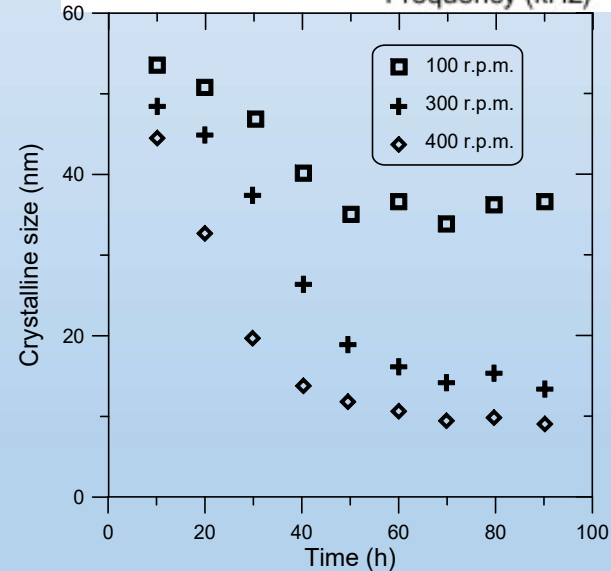
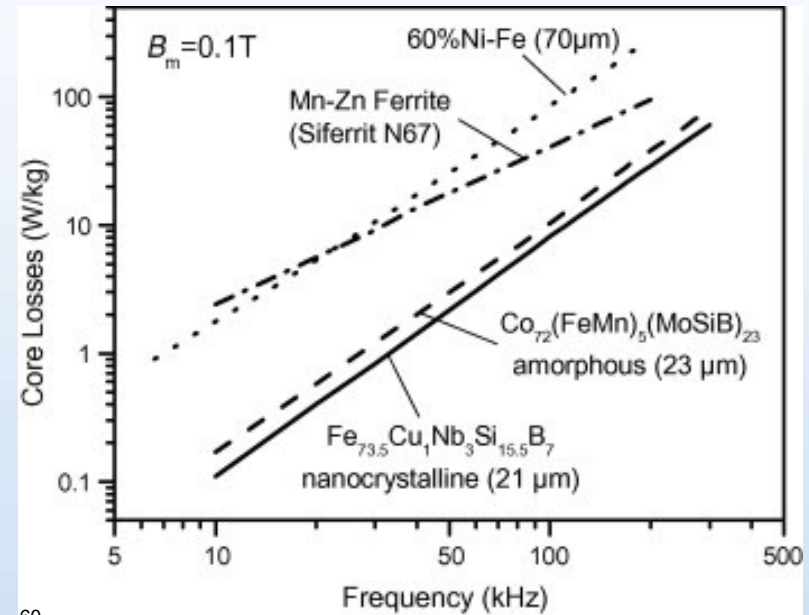
Nanocrystalline or amorphous



G. Herzer, 2013, Acta Materialia

Soft-Hard:

The remanence decreases, sometimes logarithmically, with the average grain size and increase (approximately linearly) with the volume phase of the soft magnetic phase. Nevertheless, an excess of the percentage of the soft phase causes a loss of magnetic properties. The coercive field first increase at small grain sizes whereas decreases at high values of soft phase volume fraction [34].



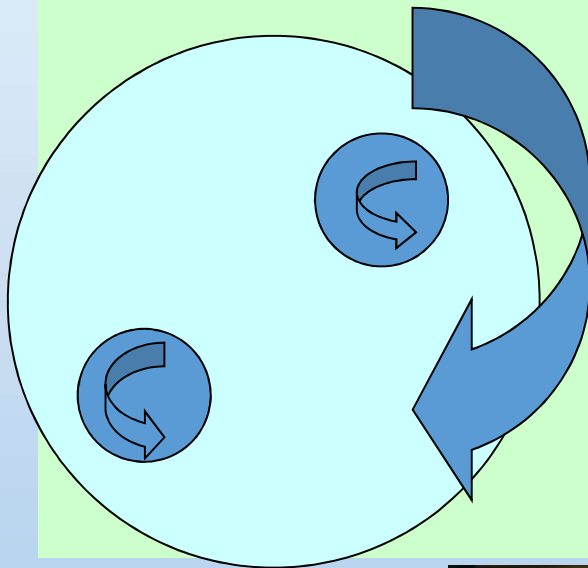
PRODUCTION

Mechanical alloying: POWDER

Arc Melting: Bulk

Consolidation, Composites

Melt spinning: Ribbons (UPC)



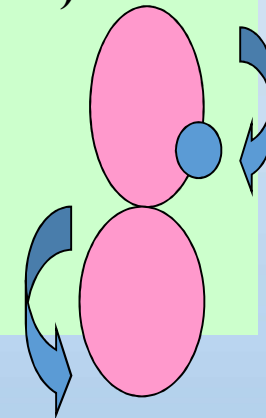
P7, Fritsch

PM400, Retsch

PLANETARY



SPEX 8000
SHAKER



NEXUS: OBJECTIVES

- Synthesis of soft magnetic alloys (with special emphasis on amorphous materials) to be used in the synthesis of $L1_0$ -MnAlC/soft nanocomposites.
- Establishment of correlation between morphological, microstructural and magnetic properties required to achieve an efficient exchange coupling in MnAlC/soft composites.
- Synthesis of the $L1_0$ -FeNi phase by two non-equilibrium processing techniques: mechanical alloying and melt-spinning.

Production of FeNi alloys and development of $L1_0$ -FeNi phase by mechanical alloying, arc-melting and melt-spinning techniques. [Years 1 and 2]	Formation of the hard magnetic phase in FeNi alloy and stabilization.
Synthesis of FeNi-based alloys doped with elements found in meteorites containing $L1_0$ -FeNi. [Year 2]	Determination of the effect of the different additives on the crystal structure and phase transformation temperature in order to form the $L1_0$ -FeNi phase in a feasible time scale.
Translation of results obtained in model systems to ribbons and milled powders. [Years 2 and 3]	Promotion of the formation of $L1_0$ -FeNi ordered phase.
Production of $L1_0$ -MnAlC by arc-melting, melt-spinning and heat treatments. [Year 1]	Formation of the hard magnetic phase in MnAlC alloy and stabilization.
Design and synthesis of customized soft magnetic materials. [Years 1 and 2]	Establishment of the synthesis routes for fabricating customized soft magnetic materials to be used for the nanocomposite fabrication.
Synthesis of $L1_0$ -MnAlC/soft composites. [Years 2 and 3]	Determination of the optimum soft magnetic material, content and synthesis process to achieve an efficient exchange-coupling between hard and soft phases.



NEXUS TASKS (first year)

S2/1.1 Design and synthesis of customized soft magnetic materials (Responsible: L. Escoda)

[Participants – Research Team: L. Escoda / Work Team: S. Alleg]

Design of customized soft magnetic materials in the shape of bulk, ribbons and powder to achieve an efficient exchange-coupling in MnAlC/soft nanocomposites. Synthesis techniques that will be used: arc melting, melt spinning and mechanical alloying.

Soft magnetic alloys as Mn-B and Fe based will be produced.

It should be noted that some ferromagnetically soft samples and alloys are already available because of previous experience in these alloys.

S2/1.2 Preparation of the Mn-Al and FeNi bulk alloys (Responsible: J.J. Suñol)

[Participants – Research Team: J.J. Suñol / Work Team: A. Wederni]

The preparation of bulk alloys will be carried out in an arc fusion furnace. These shall be the precursor alloys for:

- (i) their subsequent processing in the form of ribbons or powders using ultra-fast cooling (melt spinning) or mechanical grinding techniques;
- (ii) as a reference for their chemical composition, phase evolution and thermomagnetic and magnetic properties with respect to (powdered or ribbon-shape) alloys. In the case of powder alloys, they will also be obtained by mechanical alloying of the precursors.

The effect of processing parameters on the final properties will be studied.

S2/1.3 Design of thermal treatments (Responsible: J. Saurina)

[Participants – Research Team: J. Saurina / Work Team: S. Alleg]

Design of thermal treatments to improve both, magnetic behaviour and thermal stability of the alloys. Analysis of the influence of thermal treatments (including furnace, controlled atmosphere heat treatments and quenching conditions) in the atomic order, the atomic sites of the elements and microstructure by electron microscopy and X-Ray diffraction, with additional information from Transmission Mössbauer spectroscopy.

NEXUS TASKS (first year)

S2/1.4. Preparation of soft-hard composites (Responsible: L. Escoda)

[Participants – Research Team: L. Escoda / Work Team: A. Wederni]

Preparation of the first composites by mechanical alloying from the materials produced (previously, first semester) in the laboratories from IMDEA and UdG.

Analysis of the effects of the soft-hard combination (pathway, percentage of addition) in the microstructure. Furthermore, the analysis of the influence of the processing parameters on the final properties of the nanostructured composites.

S2/1.5 Communication activities to the society (Responsibles: L. Escoda and J.J. Suñol)

[Participants – Research Team: All / Work Team: All]

The dissemination to the society will be performed by generating at least an activity of Open Science, with the active participation in communication activities of the university and the academic center (Science week, International Science day, UdG activities linked to gender equality in research). Likewise, a webpage at university's portal with the main results of the project (including a pathway to facilitate forums and discussions).

Interaction with companies that are memberships of the Spanish Association of Powder Metallurgy.

S2/1.6 Elaboration of Report-Year 1 (Responsibles: L. Escoda and J.J. Suñol)

[Participants – Research Team: L. Escoda, J. Saurina, J.J. Suñol]

The report should include the main results, the degree of achievement of the objectives, a protocol of optimization of the materials production, the scientific and technological main problems/questions after the first year of the project and the evaluation and re-evaluation (if necessary) of the following activities.

This report will be analysed together with IMDEA Group.



NEXUS TASKS (second year)

S2/2.1 Synthesis of Fe₅₀Ni₅₀-based alloys by melt-spinning and mechanical alloying

(Responsible: J. Saurina)

[Participants – Research Team: J. Saurina / Work Team: S. Alleg]

S2/2.2 Fabrication of MnAlC/soft composites by ball milling *(Responsible: L. Escoda)*

[Participants – Research Team: L. Escoda / Work Team: A. Wederni]

S2/2.3 Characterization of Fe-Ni system by Mössbauer spectroscopy *(Responsible: J.J. Suñol, through collaboration with J.-M. Greneche from University Le-Mans CNRS, as part of the “Work Team”)*

[Participants – Research Team: J.J. Suñol / Work Team: J.M. Greneche]

S2/2.4 Correlation between magnetism and microstructure *(Responsible: L. Escoda)*

[Participants – Research Team: L. Escoda, J. Saurina, J.J. Suñol]

S2/2.5 Communication activities to the society *(Responsibles: All)*

[Participants – Research Team: All / Work Team: All]

S2/2.6 Elaboration of Report-Year 2 *(Responsible: J.J. Suñol)*

[Participants – Research Team: L. Escoda, J. Saurina, J.J. Suñol]

NEXUS TASKS (third year)

S2/3.1 Determination of the alloys and compositions with the best functional response (*Responsible: J.J. Suñol*)

[Participants – Research Team: L. Escoda, J.J. Suñol / Work Team: S. Alleg]

S2/3.2 Optimization of general production conditions and magnetic response of MnAlC/soft compounds (*Responsible: J. Saurina*)

[Participants – Research Team: J. Saurina, J.J. Suñol / Work Team: S. Alleg]

S2/3.3 Optimization of general production conditions and magnetic response of L1₀-FeNi phase (*Responsible: L. Escoda*)

[Participants – Research Team: L. Escoda, J.J. Suñol]

S2/3.4 Establishment of correlations between microstructural, electronic and magnetic properties (*Responsible: L. Escoda*)

[Participants – Research Team: L. Escoda, J. Saurina, J.J. Suñol]

S2/3.5 Communication activities to the society (*Responsibles: All*)

[Participants – Research Team: All / Work Team: All]

S2/3.6 Elaboration of Report-Year 3 (*Responsible: J.J. Suñol*)

[Participants – Research Team: L. Escoda, J. Saurina, J.J. Suñol]

Milestone	Milestone name	M	Means of verification
MS1	Unveiling the origin of cosmological L1 ₀ -FeNi through model systems: thin films and nanowires	12	Demonstration of successful synthesis of L1 ₀ -FeNi nucleation sites (MFM, MOKE microscopy)
MS2	Synthesis of customized soft magnetic alloys (for their use in the synthesis of nanocomposites)	12	Saturation magnetization: $M_s > 1.8 \text{ T}$
MS3	Successful synthesis of MnAlC/carbides nanostructures	12	Microstructural study showing carbides precipitates in L1 ₀ -matrix
MS4	Establishment of a complete protocol for proper detection and measurement of the target L1 ₀ structures	24	Combination of experimental conclusive results: MOKE, MFM, neutron diffraction and Mössbauer.
MS5	Synthesis of state-of-the-art L1 ₀ MnAl-based magnetic materials	24	L1 ₀ -MnAl(CA): $(BH)_{\max} > 5 \text{ MGOe}$
MS6	Artificial synthesis of the L1 ₀ -FeNi phase above state-of-the-art values	24	Synthesis of L1 ₀ -FeNi with content >15 wt.%
MS7	Correlation between microstructure, electronic and magnetic properties in optimized materials	30	Correlation equations and modelling validated by results and publications.
MS8	Synthesis of state-of-the-art L1 ₀ FeNi-based magnetic materials	30	L1 ₀ -FeNi: $(BH)_{\max} > 15 \text{ MGOe}$
MS9	Development of L1 ₀ magnets by additive manufacturing techniques (FFF and SLA)	36	Demonstration of no-deterioration of the magnetic properties of the L1 ₀ precursors.
MS10	Mechanical and corrosion resistance	36	Demonstration of structural stability under standardized tests done in industrial environment
MS11	Industrial validation of methods and protocols (cost-efficiency and environmental impact)	36	1 patent; 1 contract 1 collaboration agreement

