Fibres-based soft magnetic composites

B.V. Neamţu[1], T.F. Marinca[1], F. Popa[1], I. Chicinaş[1], M. Năsui[2],
M. Pszola[3], H. Vermeşan[4], A. Opriş[1], N. Lupu[5]

[1] *Technical University of Cluj-Napoca, Materials Science and Engineering Department,*

[2] *Center for Superconductivity, Spintronics and Surface Science, Technical University of Cluj-Napoca,*

[3] *Institute of Electrical Machines, RWTH Aachen University, Aachen, D-52062, Germany*

[4] *Technical University of Cluj-Napoca, Department of Environmental Engineering and Sustainable Development Entrepreneurship,*

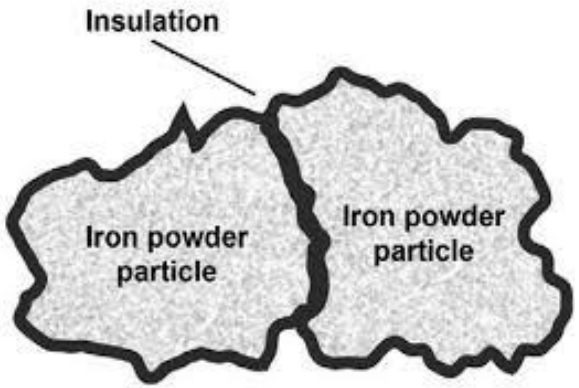
[5] *National Institute of Research & Development for Technical Physics, 700050 Iasi, Romania*

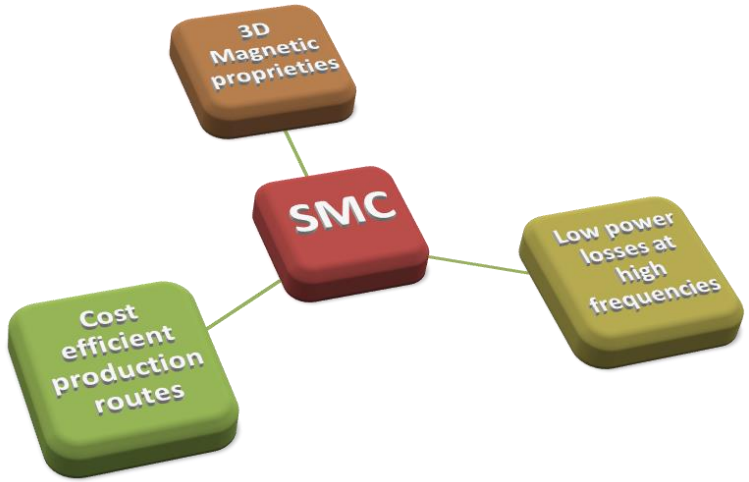
2021 Research Conference of Technical University of Cluj-Napoca,
October 20-22, 2021

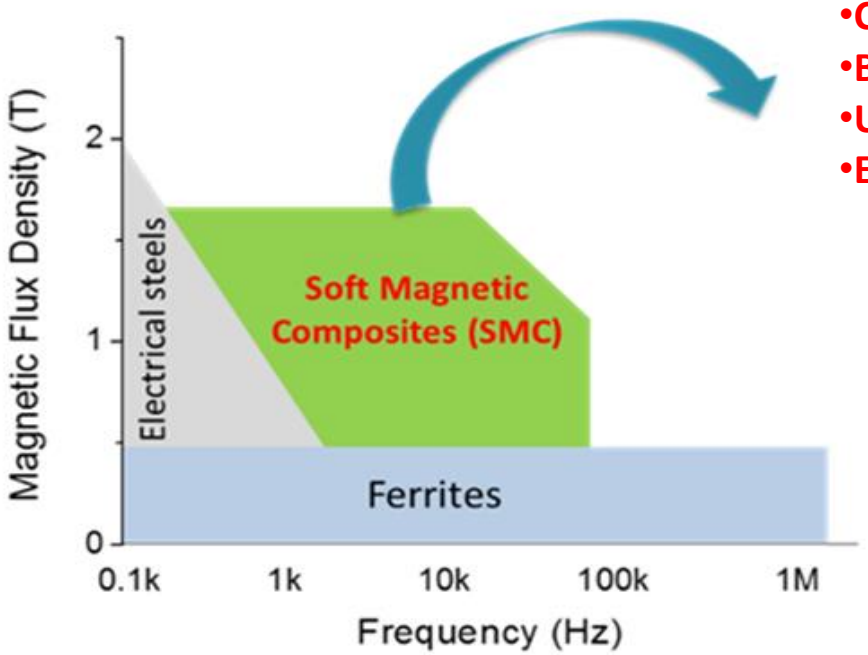
Outline

- Background and motivation
- Experimental details
- Results and discussion
  - AC and DC magnetic characterisation of SMC compacts
  - Fibre-based vs. powder-based soft magnetic composites
- Conclusions

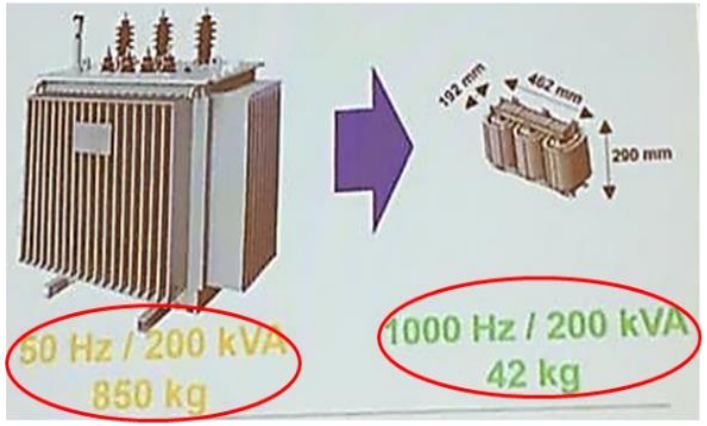
Why soft magnetic composites (SMC)?







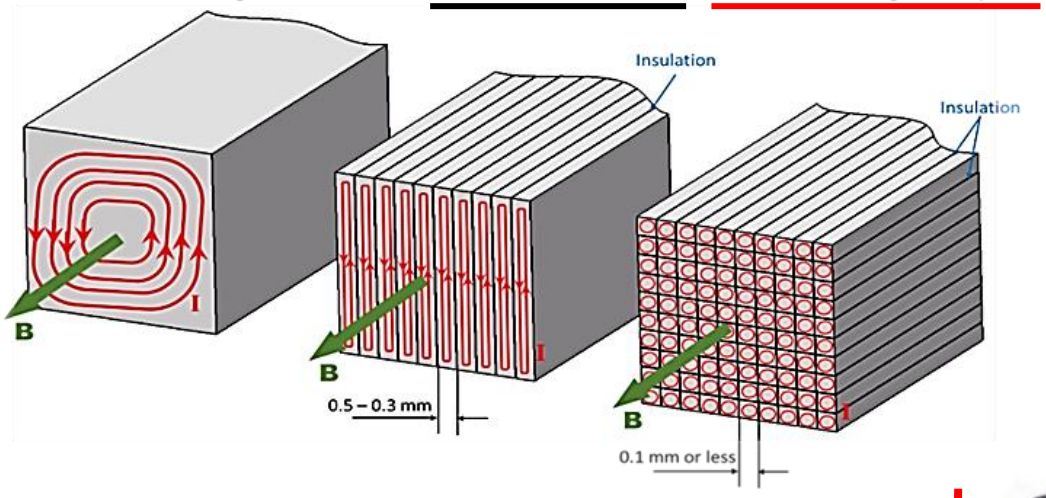
- Run faster
- Consume far less energy
- Become more compact & dense
- Use higher frequencies
- Experience lower core/eddy loss



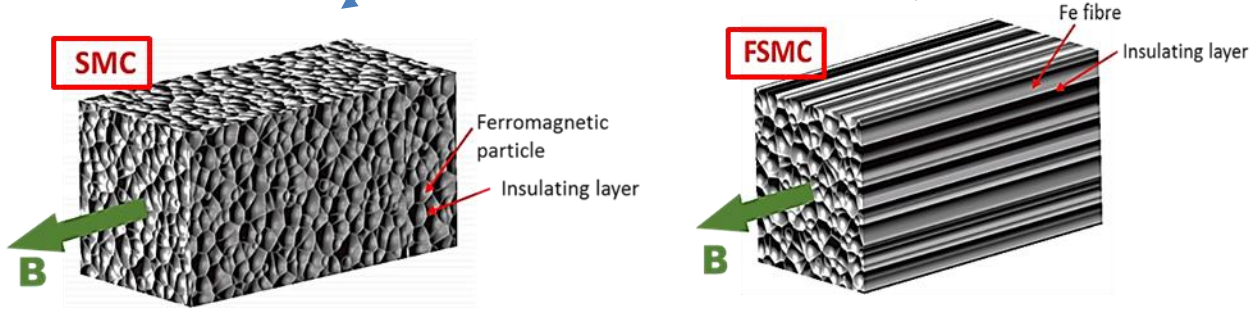
H. Shokrollahi et al, J. Mater. Process. Technol. 189 (2007)1-12.
G. Ouyang et al., Journal of Magnetism and Magnetic Materials 481 **(2019)** 234–250

Why fibres based soft magnetic composites (FSMC)?

MAGNETIC LOSES



MAGNETIC PERMEABILITY



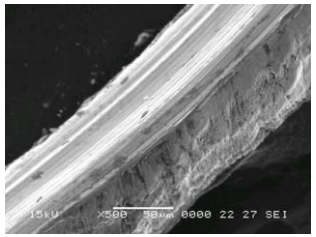
LOWER MAGNETIC LOSES
AS COMPARED TO Fe-Si LAMINATES

HIGHER MAGNETIC PERMEABILITY
AS COMPARED TO SMC

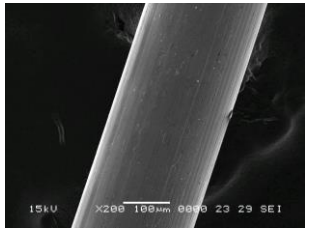
Experimentally details

Fe fibers → **Heat treatment** → **Coating of the fibres** → **Compaction** → **Characterisation**

99.81 – 99.9 %Fe
diameter of 65, 125, 250, 500 µm



Irregular fibres



Cylindrical fibres

- Heat treatment: recrystallization
- Temperature: 650 °C
- Duration: 2 h
- Atmosphere: Ar

- Polymer
- SiO_2
- Hybrid
- Fe_3O_4
- ZnO

Cold pressing at
- 500 MPa
- 600 MPa
- 700 MPa

FSMC

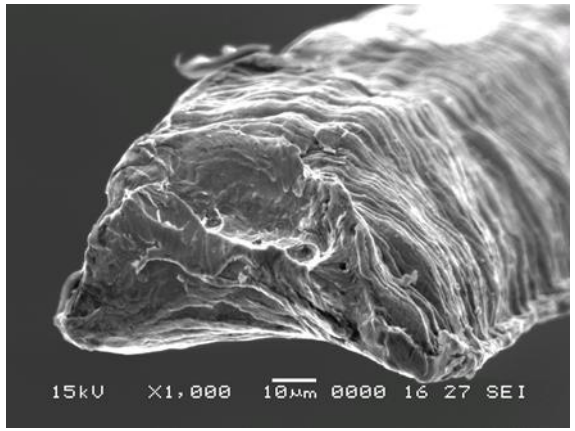
Alternative current (AC):
B_{max} = 0.1 T
f = 50 … 10000 Hz
Direct current (DC):
f = 0.5 Hz

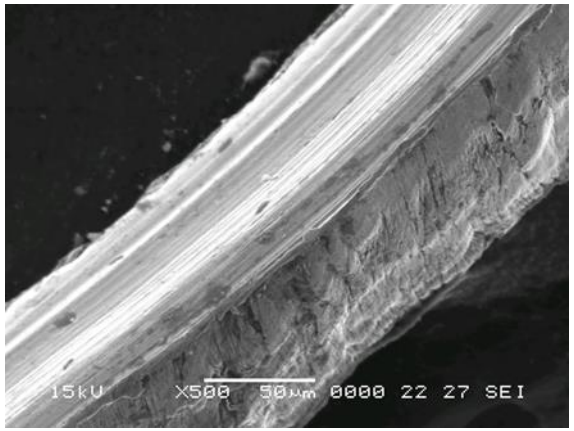
FSMC

Results and discussions

Coatings with polymer

As received fibers

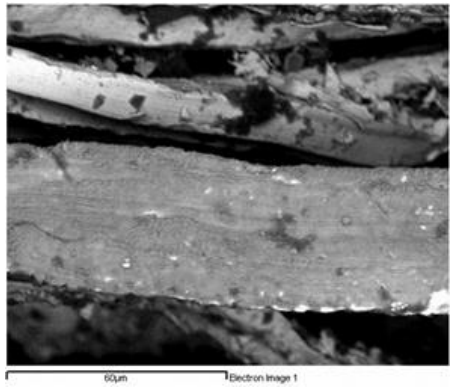


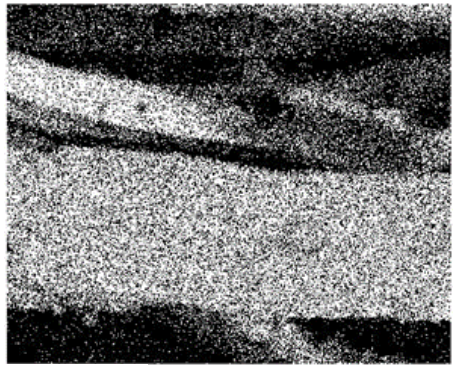


The fibers have semicircular section;
Fibers thickness = 80 – 100 µm;
The length of Fe fibres is in the range of several meters;

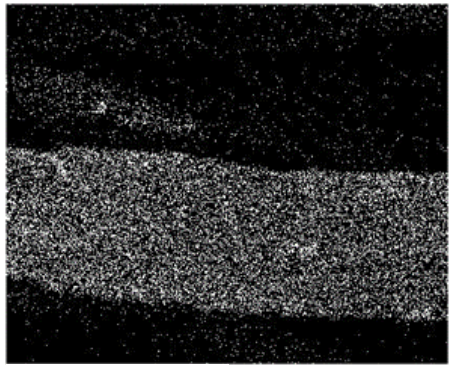
Coated fibers

EDX Analysis





IRON



CARBON

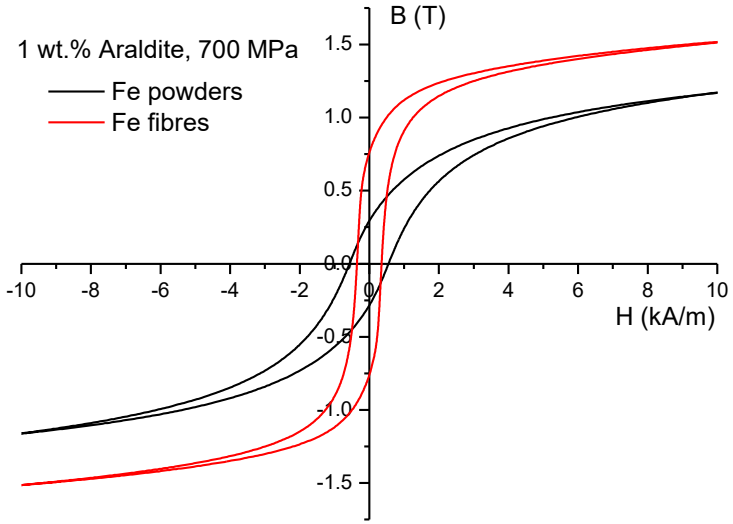
The fibres are uniformly coated with polymer.

B.V. Neamţu, et al, J. Mater. Sci. 55 (2020) 1414-1424.

Results and discussions

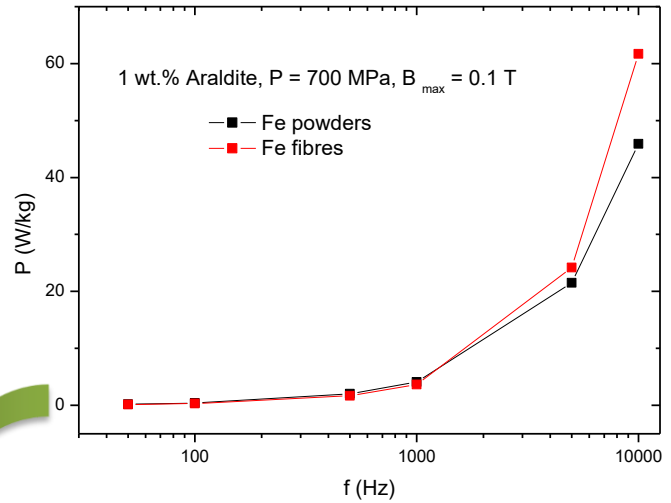
SMC vs. FSMC

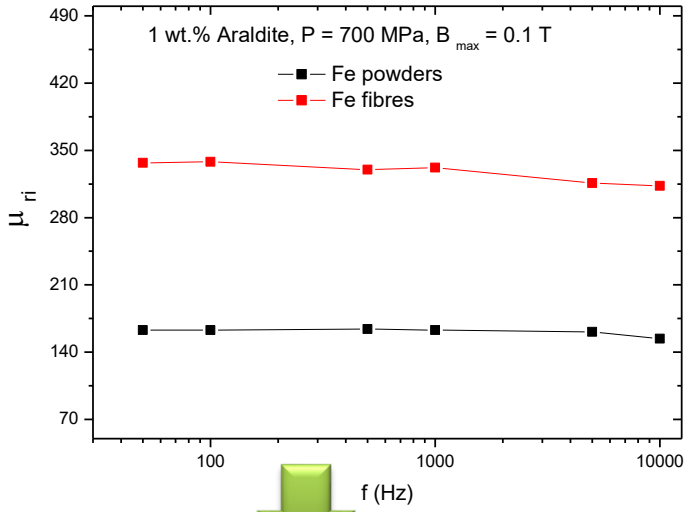
DC magnetic characteristics



	SMC	FSMC
ρ (g/cm^3)	6.92	**7.05**
B_s (T)	1.17	**1.52**
H_c (A/m)	559	**353**
$\mu_{r\ max}$	238	**893**

AC magnetic characteristics





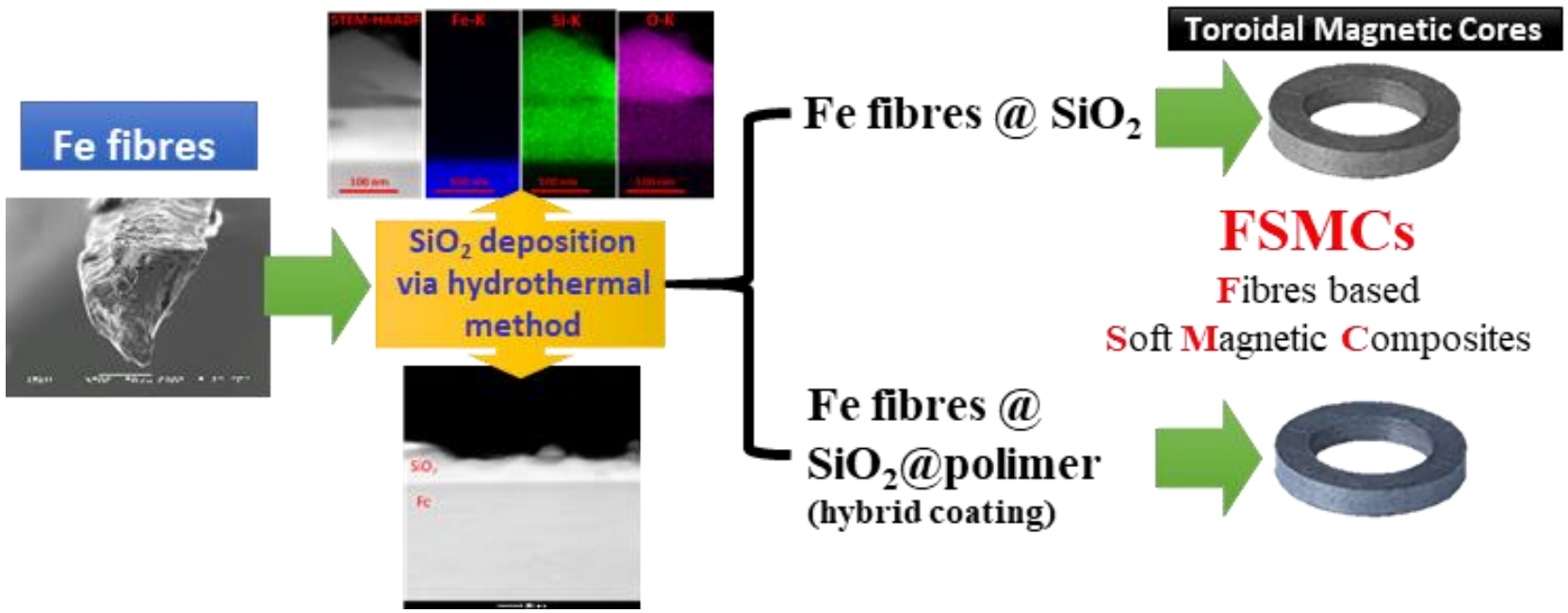
FSMC have superior magnetic permeability in the frequency range 50 Hz – 10 kHz

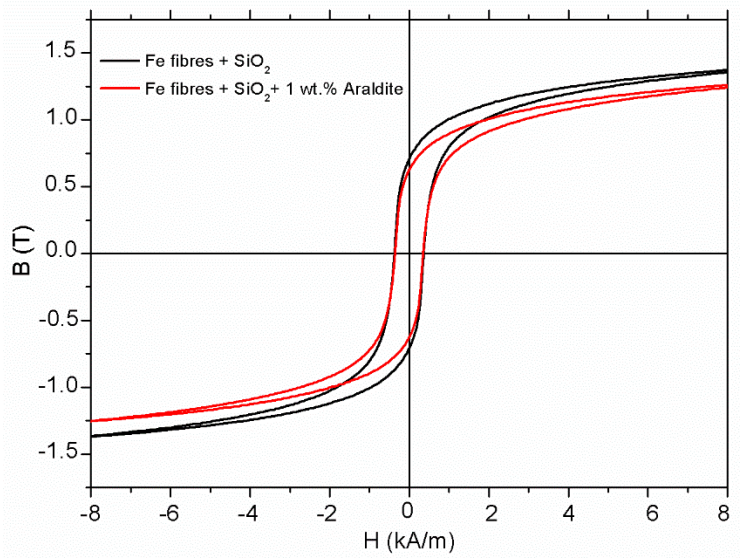
FSMC have lower magnetic loses in the frequency range 50 Hz – 1 kHz

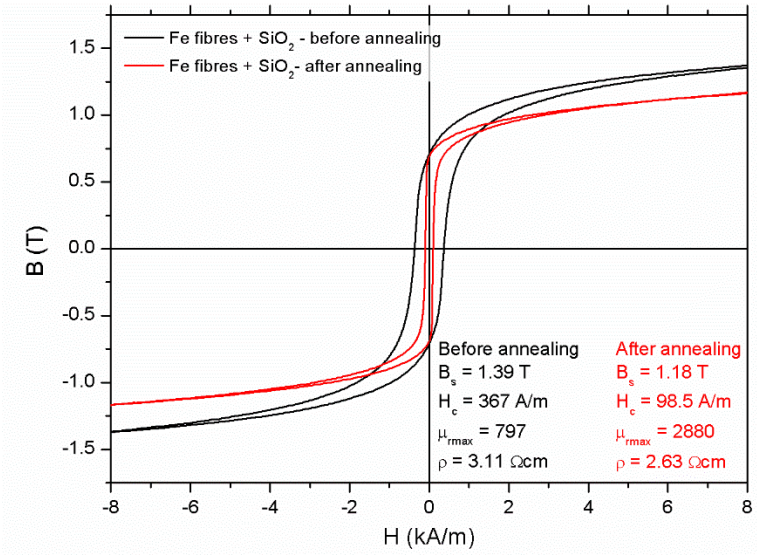
B.V. Neamţu, et al, J. Mater. Sci. 55 (2020) 1414-1424.

Results and discussions

Coatings with SO_2 and hybrid







B.V. Neamţu, et al, J. Alloy. Compd., 840 (2020) 155731

Results and discussions

Coatings with Fe_3O_4

Fe fibres

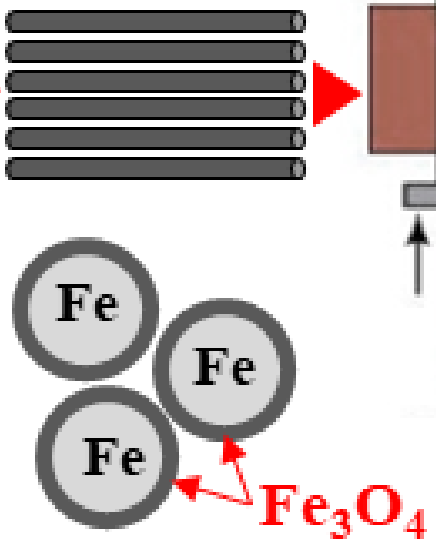
Blackening process

($NaOH + NaNO_3 + NaNO_2$ + distilled water, heated to 140°C)

$$Fe + 2OH^- \rightarrow Fe(OH)_2 + 2e^-$$
$$3Fe(OH)_2 \rightarrow Fe_3O_4 + H_2 + 2H_2O$$

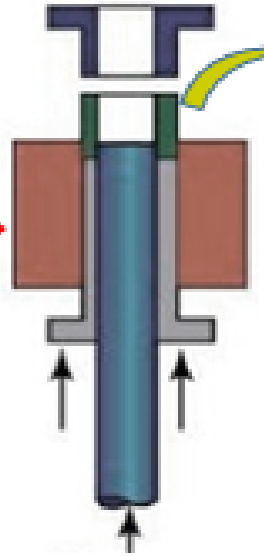
Blackened fibres

Fe fibres coated with 3 µm layer of Fe_3O_4



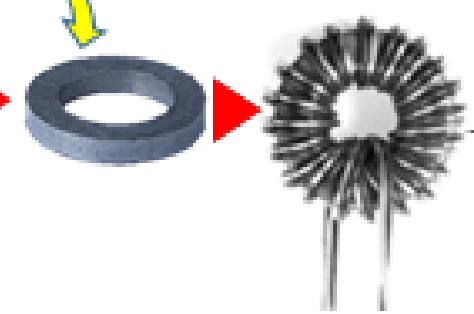
Compaction

(700 MPa)



Toroidal cores

$D_i = 12$ mm,
$D_e = 18$ mm
$h = 2.2 - 2.5$ mm



FSMCs

Fibres based
Soft Magnetic Composites

Measurements

DC

Coercivity;
Saturation induction;
Max. rel. permeability.

AC

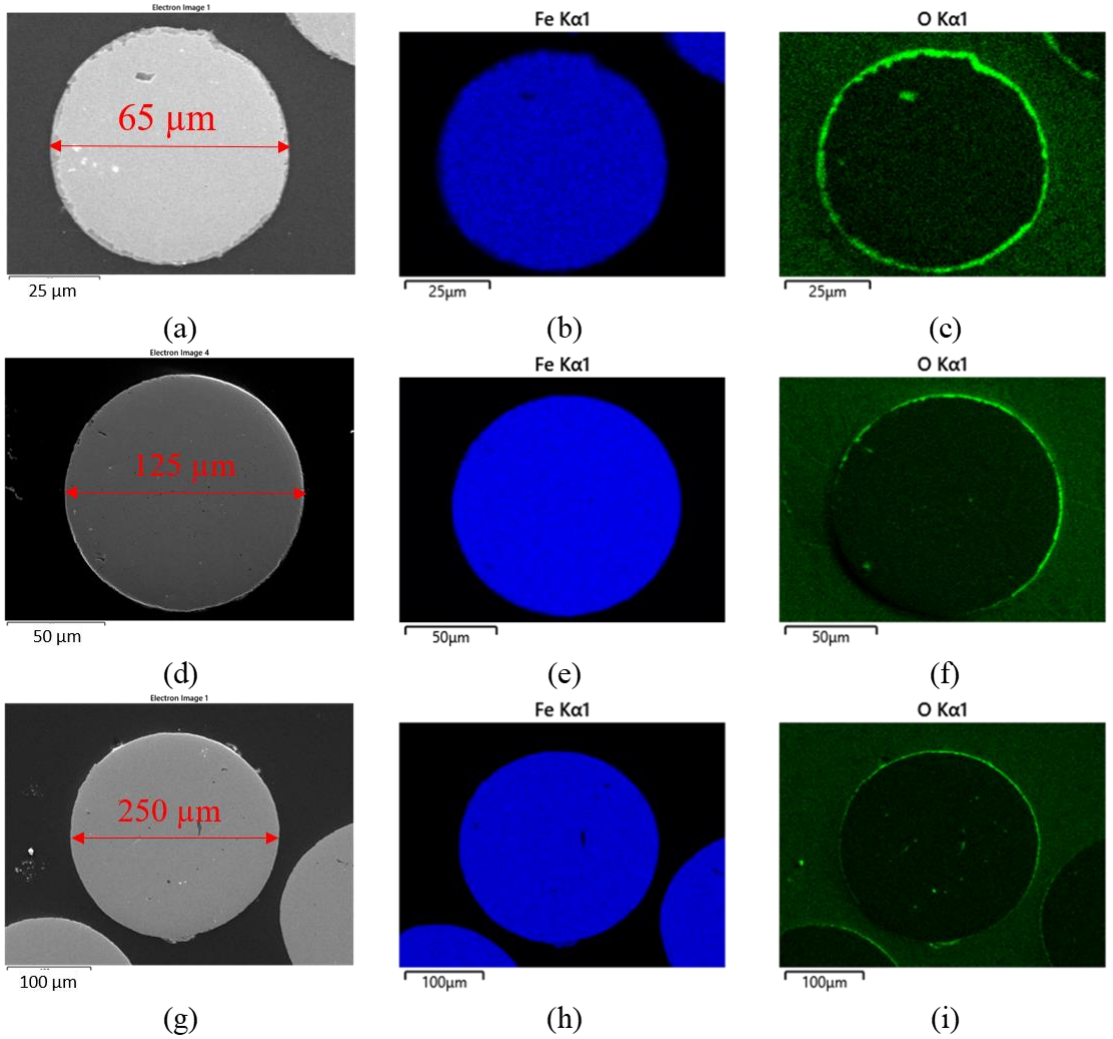
Core losses;
Init. rel. permeability;
Loss separation model

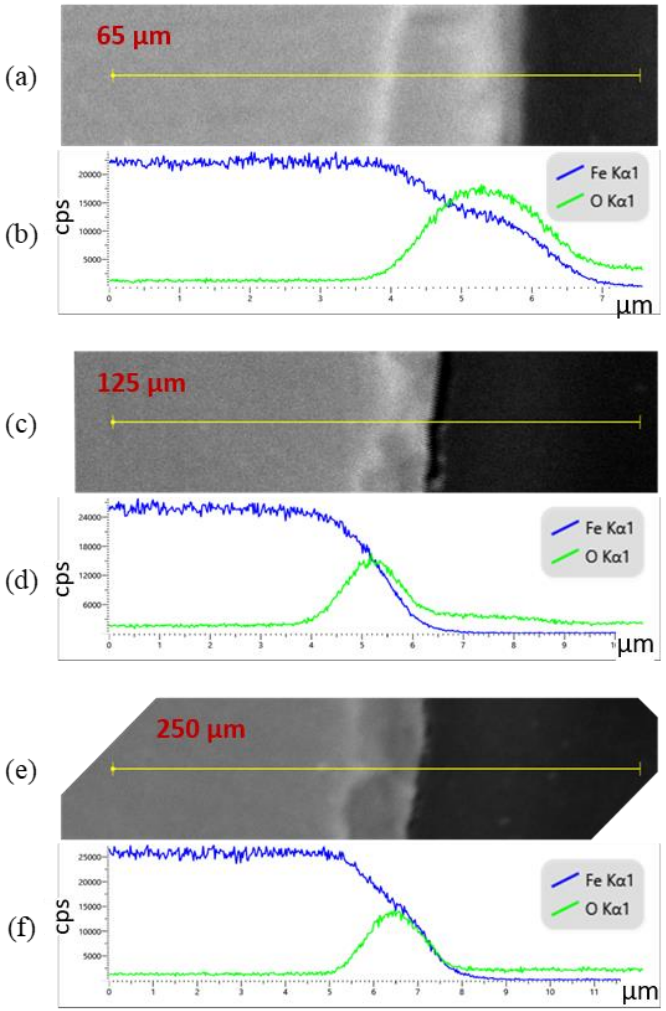
B.V. Neamţu, et al, Ceramics International, 47 (2021) 581-589
B.V. Neamţu, et al, Ceramics International, 47 (2021) 1865-1874

Results and discussions

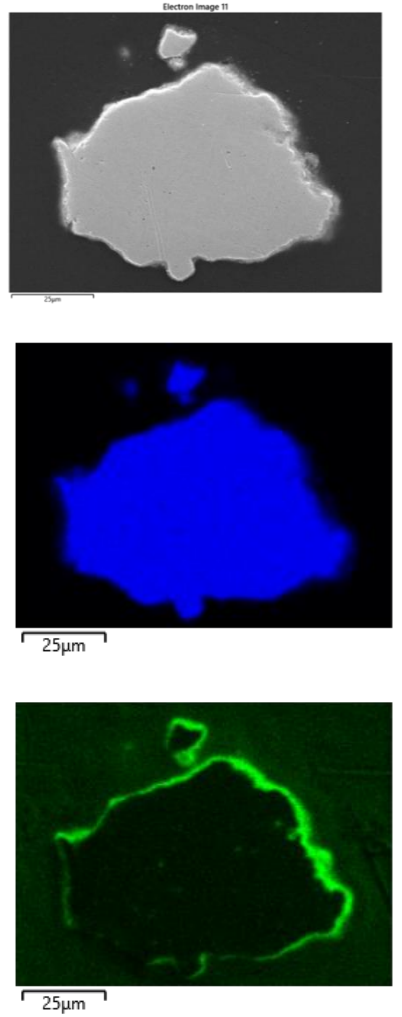
Coatings with Fe_3O_4

Fibres coating





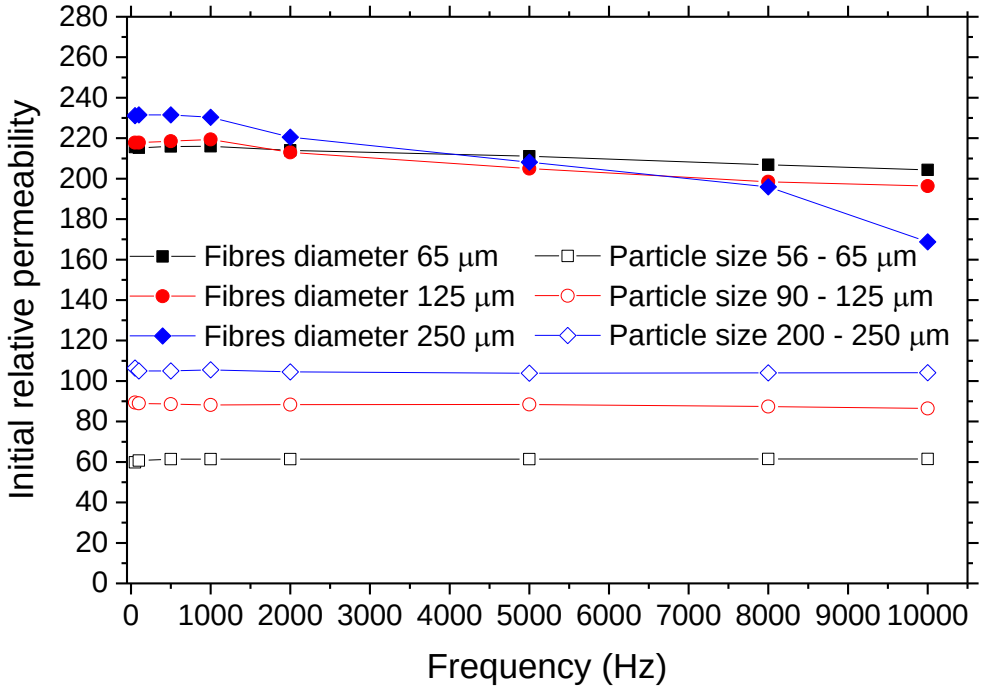
Powders coating



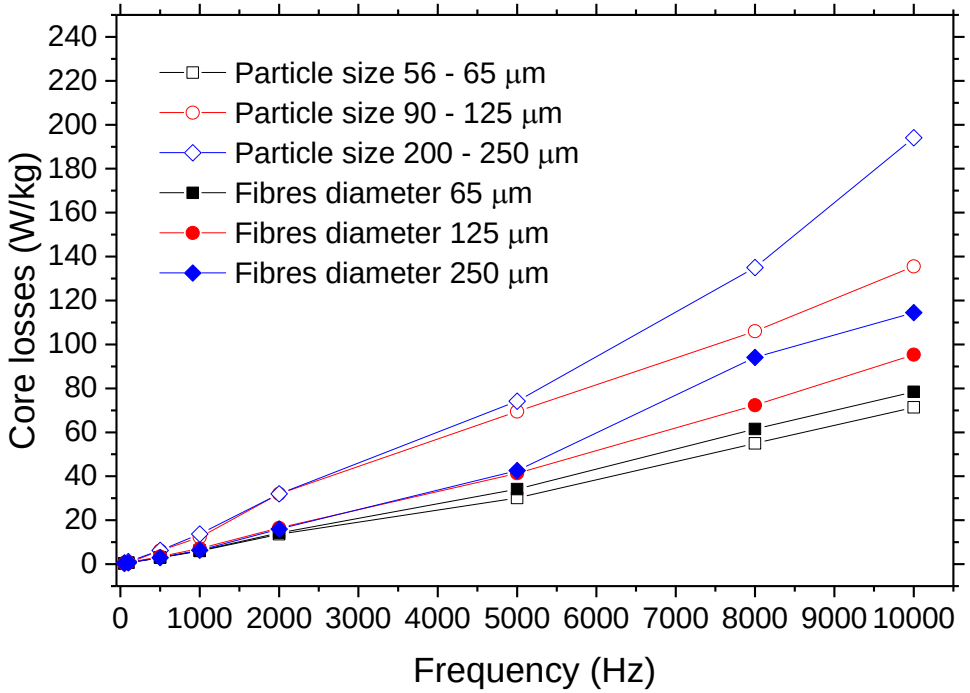
B.V. Neamţu, et al, Ceramics International, 47 (2021) 1865-1874

Results and discussions

SMC vs. FSMC



FSMCs HAVE HIGHER MAGNETIC PERMEABILITY
AS COMPARED TO SMCs



FSMCs HAVE LOWER MAGNETIC LOSES
AS COMPARED TO SMCs

B.V. Neamţu, et al, Ceramics International, 47 (2021) 581-589
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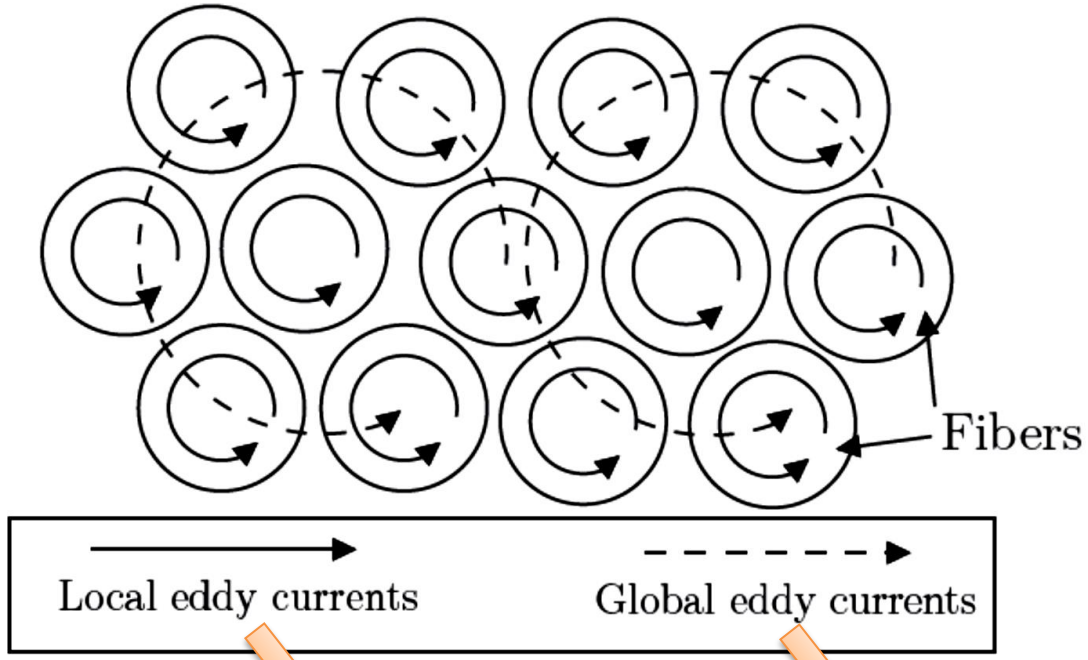
Results and discussions

Analytic model for the core losses separation



$$P_{FSMC} = C_{hyst} f \hat{B}^2 + \frac{\pi^2 \cdot d_{fibre}^2 \cdot \sigma_{Fe}}{16 \cdot \rho_{Fe}} f^2 \hat{B}^2 + \frac{\pi^2 \cdot d_{FSMC}^2 \cdot \sigma_{FSMC}}{6 \cdot \rho_{FSMC}} f^2 \hat{B}^2$$

Hysteresis losses

Eddy current losses

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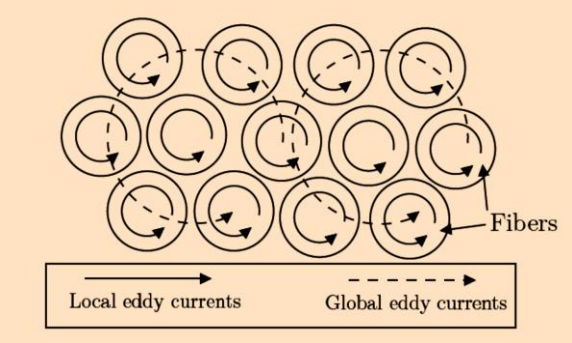
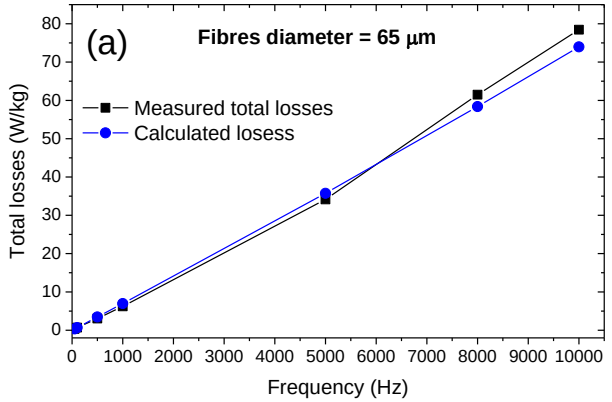
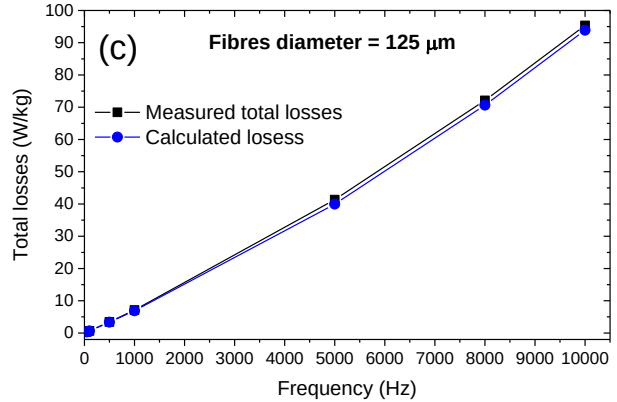
Results and discussions

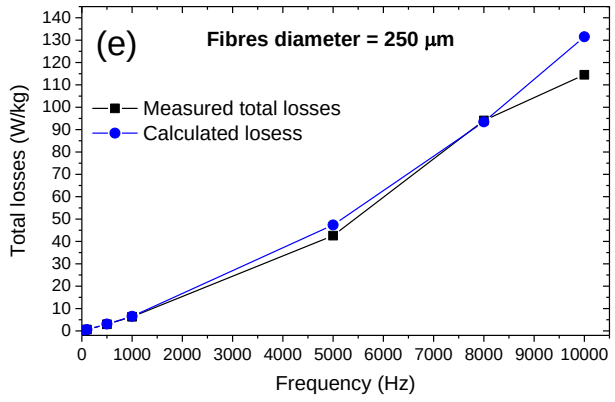
Analytic model for the core losses separation

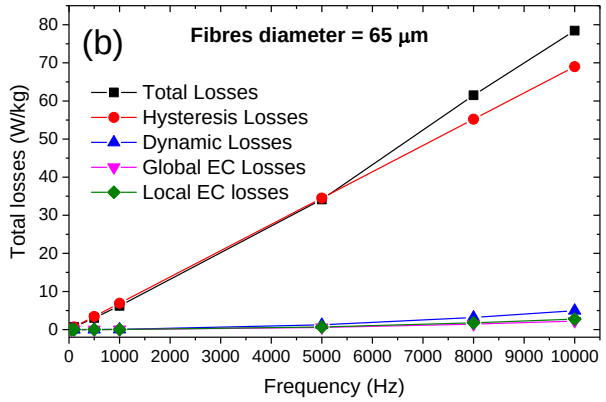
$$P_{FSMC} = C_{hyst} f \hat{B}^2 + \frac{\pi^2 \cdot d_{FSMC}^2 \cdot \sigma_{FSMC}}{6 \cdot \rho_{FSMC}} f^2 \hat{B}^2 + \frac{\pi^2 \cdot d_{fibre}^2 \cdot \sigma_{Fe}}{16 \cdot \rho_{Fe}} f^2 \hat{B}^2$$

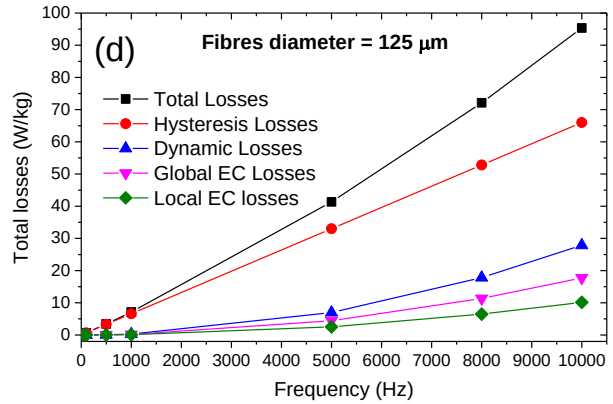


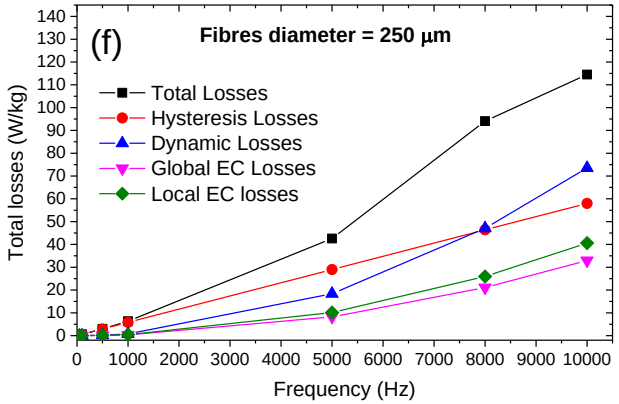












B.V. Neamţu, et al, Ceramics International, 47 (2021) 1865-1874

Results and discussions

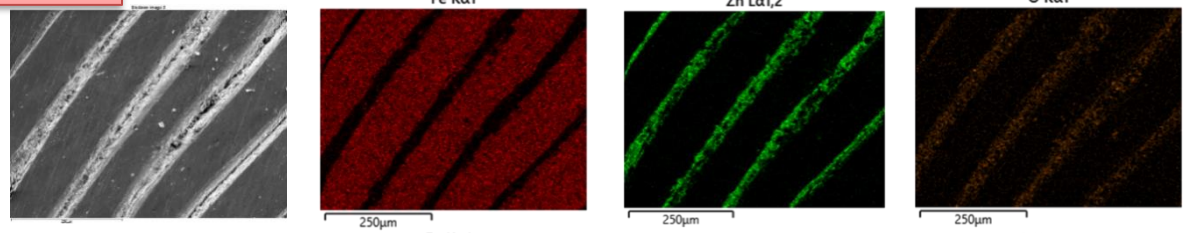
Next steps = Amorphous fibres + Cold sintering

Superior magnetic properties as compared to Fe fibres
- Higher magnetic permeability;
- Lower coercive field;
- Lower core losses;
- Lower magnetostriction
- (Also more expensive!)

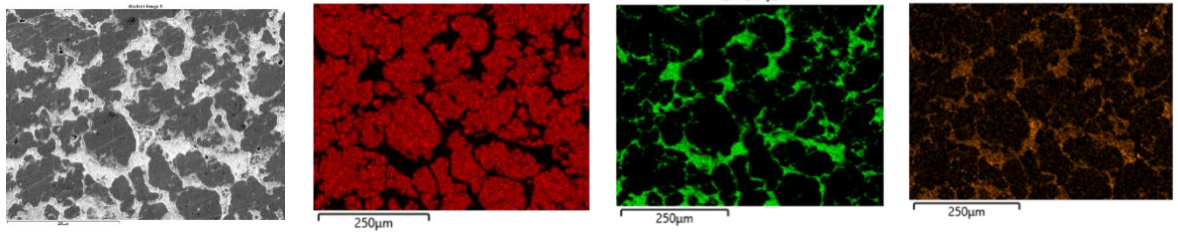
Allows the sintering of ceramic coating →
- high electrical resistivity;
- high mechanical strength;
- high thermal stability;

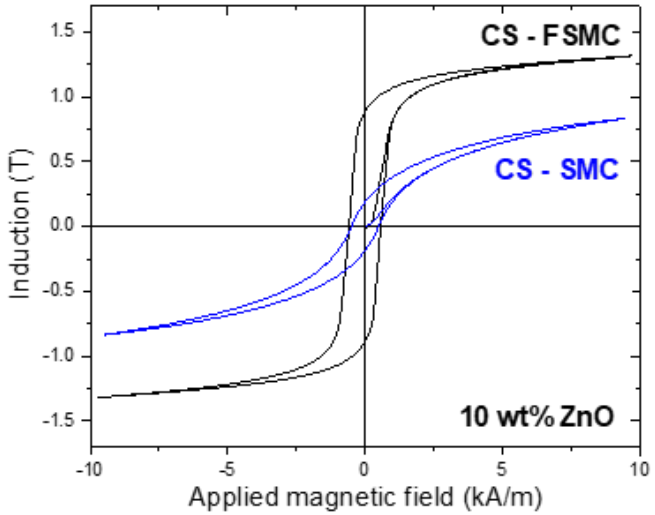
Cold sintered (CS)

FSMC



SMC





B.V. Neamtu, PN-III-P4-ID-PCE-2020-0175 / PCE 32

Conclusions

- **Fibers based soft magnetic composites (FSMC) were successfully prepared;**
- **The magnetic permeability of FSMC, in DC magnetisation regime, is superior to the one corresponding to a Fe based SMC.**
- **The AC magnetic properties can be improved by:**

  - proper dielectric content,

  - compaction pressure

  - heat treatments;

- **The use of Cold Sintering process is a promising route for the preparation of the next generation of SMCs and FSMCs.**

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MagMatNano
magnetic materials and nanomaterials

Thank you for your attention!

This work was supported by a grant of the Romanian Ministry of Education and Research, CNCS - UEFISCDI, project number **PN-III-P1-1.1-TE-2016-0649** / TE 133 and **PN-III-P4-ID-PCE-2020-0175** / PCE 32, within PNCDI III".

PN-III-P1-1.1-TE-2016-0649 - Fibres based soft magnetic composites prepared by cold pressing and spark plasma sintering

PN-III-P4-ID-PCE-2020-0175 - Cold sintered soft magnetic composites based on amorphous ferromagnetic fibres