Report on the outcomes of a Short-Term Scientific Mission[1]

Action number: CA21126

COST Action NanoSpace "Carbon molecular nanostructures in space"

Grantee name: Prof.Dr. Abdülkadir Sezai SARAC

Details of the STSM

Title: **The Influence of Thermal and Magnetic Fields on the Dynamic Mechanical Properties of Magnetic Ferrite Nanoparticles Containing Polyacrylonitrile Nanofibers.**

Start and end date: **12/06/2025 to 19/06/2025**

Description of the work carried out during the STSM

The **COST Short-Term Scientific Mission (STSM)**, conducted under the umbrella of **COST Action CA21126 (NanoSpace "Carbon molecular nanostructures in space")**, focused on the advanced characterization of innovative electrospun nanofiber composites. Electrospinning is a highly versatile and increasingly vital technique for fabricating nanofibrous membranes, lauded for their remarkable attributes such as an exceptionally high specific surface area, intricate porous structures, and tight pore size control. These characteristics render electrospun materials particularly attractive for a wide array of applications, spanning from advanced filtration media and acoustic insulation to sophisticated sensing devices, electrocatalysts for energy applications, and effective solutions for water treatment.

A central component of this research involved **Polyacrylonitrile (PAN)**, a polymer celebrated for its robust mechanical properties, chemical resilience, and biocompatibility. However, PAN's primary drawback is its inherent lack of breathability, which severely restricts its standalone use, especially in biomedical applications where material comfort and interaction with biological systems are paramount. To overcome this significant limitation and expand PAN's functional scope, the strategy involved blending it with other materials to engineer **electrospun nanofibrous (NF) PAN membranes featuring enhanced surface area-to-volume ratios**. This blending approach not only addresses the breathability issue but also introduces novel functionalities critical for advanced material performance.This STSM integrated **magnetic nanoparticles (MNPs)**—specifically, **nano-ferrites compared with Fe_2O_3 nanoparticles**—into the PAN polymer matrix as in nanofiber form. The overarching goal was to create **conductive and magnetic polymeric composite fiber mats** with groundbreaking potential. The homogeneous distribution of nanoparticles is clearly indicated by EDX results. Despite a reduction in storage modulus at high temperatures when a magnetic field is applied to $MnZnFe_2O_4$/PAN, the fibers retain a better storage modulus compared to the polymer matrix (PAN NF). Some of the exemplary sample outcomes are presented in Fig. 1

[1] This report is submitted by the grantee to the Action MC for approval and for claiming payment of the awarded grant. The Grant Awarding Coordinator coordinates the evaluation of this report on behalf of the Action MC and instructs the GH for payment of the Grant.

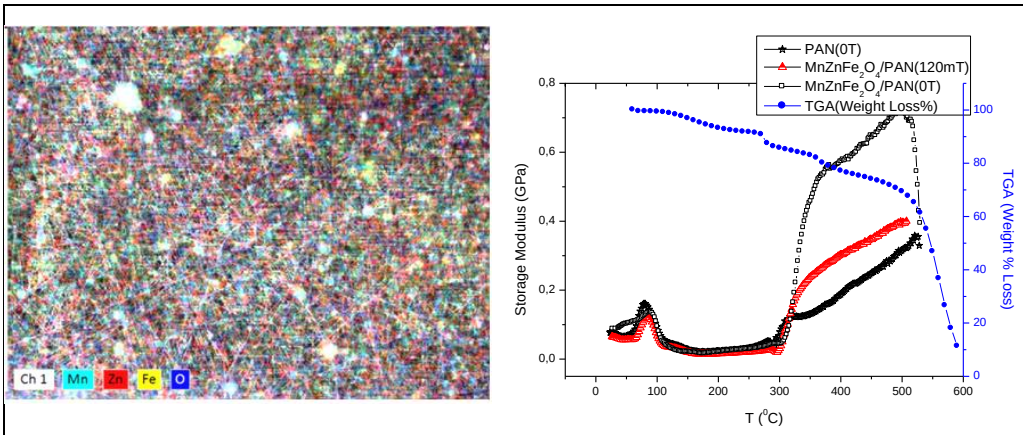


Fig.1.EDX (a) , and Storage Modulus vs.temperature (b) of $MnZnFe_2O_4$/PAN nanofibers and TGA of PAN nanofiber.

The combined conductivity and magnetic properties open doors to diverse applications. For instance, their electrical conductivity is highly promising for the development of **smart textiles designed for health and medical applications**, enabling integrated biosensors or targeted drug delivery systems. Moreover, these dual properties are invaluable for **energy storage solutions**, including advanced **supercapacitors and batteries**, benefiting from increased effective sensing surface area, enhanced charge collection, and efficient energy storage facilitated by the nanostructuring. The inherent radiation resistance of ferrite materials further positions these innovative composites as compelling candidates for robust materials in demanding **space station environments**.

The core work undertaken during the STSM concentrated on the **comprehensive characterization of these advanced polymeric composite electrospun nanofibers containing MNPs**. The specific nanofiber samples, encompassing both nano-ferrite and Fe_2O_3 nanoparticle integrations, were previously synthesized **at Istanbul Technical University (ITU)** to imbue them with tailored electrical conductivity and magnetic attributes. The mission's primary objective was to subject these materials to stringent testing to fully understand their properties.

The bulk of the characterization was performed at the **University of Vienna**, utilizing specialized equipment for **thermomechanical (DMA) measurements conducted under a magnetic field**. This precise testing methodology was vital for elucidating the dynamic mechanical response of the MNP/PAN composite nanofibers and, critically, how their mechanical properties are influenced by an external magnetic field. By analyzing the viscoelastic behavior—including storage modulus, loss modulus, and tan delta—across varying temperatures and magnetic field strengths, invaluable insights were gained into the **material's structural integrity, flexibility, and overall stability** under diverse operational conditions. The detailed investigation focused on the impact of MNP inclusion on these properties, alongside their direct contributions to electrical conductivity and magnetic responsiveness. The meticulously tailored porous structure of these nanofiber mats, optimized for high surface-to-volume ratios, was also indirectly assessed through their observed mechanical performance, which is essential for applications demanding augmented interfaces, such as high-performance supercapacitors and ultrasensitive sensors.

The insights gleaned from this detailed characterization are profoundly significant. A thorough understanding of the **thermomechanical behavior under magnetic fields** is indispensable for designing materials that can endure the extreme and fluctuating temperatures and electromagnetic interference prevalent in **space applications**. For **smart textiles and advanced biomedical diagnostics**, particularly those leveraging **Magnetic Resonance Imaging (MRI) technology**, the synergistic magnetic and mechanical properties are correlated with their efficacy and biocompatibility. The enhanced suitability of these MNP/PAN-porous nanofiber mats for magnetic diagnostics—owing to their compelling biocompatibility, mechanical robustness, and tailored porous architecture—represented a key area of focus. Ultimately, this detailed characterization effort contributes directly to the overarching aim of fabricating smart fibers with enhanced functionalities, reinforcing their considerable potential across energy storage, advanced sensing, and, most importantly, paving the way for their innovative implementation in both space and biomedical applications.

Description of the STSM main achievements and planned follow-up activities

STSM Main Achievements

The **Short-Term Scientific Mission (STSM)**, conducted under the umbrella of **COST Action CA21126 (NanoSpace "Carbon molecular nanostructures in space")**, successfully focused on the advanced characterization of novel electrospun polymeric composite nanofibers. This involved **Polyacrylonitrile (PAN)** fibers integrated with magnetic nanoparticles (MNPs), specifically nano-ferrites and Fe_2O_3 nanoparticles. The initial crucial step, completed at the home institution, Istanbul Technical University (ITU), was the **successful fabrication of these conductive PAN/MNP composite nanofibers** using the electrospinning technique. This foundational work, leveraging the extensive expertise of Prof. Dr. A. S. Sarac's research group at ITU, provided the essential samples for the in-depth analysis conducted during the STSM.

The core achievement during the mission at the host institution, the University of Vienna, was the **comprehensive thermomechanical characterization via Dynamic Mechanical Analysis (DMA)**. These vital measurements were performed under both magnetic and thermal conditions – a unique capability unavailable at the home institution. This analysis is expected to provide critical insights into the interaction between the metal oxides (MNPs) and the cyanide groups within the PAN polymer. By meticulously analyzing the thermomechanical behavior, including storage and loss modulus values, across varying temperatures, the STSM gained valuable data on the **material's mechanical properties, thermal stability, and overall viscoelastic response**, all crucial for understanding its performance in anticipated applications.

Planned Follow-up Activities

The STSM has effectively laid a robust foundation for extensive follow-up activities, aiming to maximize the research impact and cultivate enduring collaborative relationships. A crucial next step involves **further detailed characterization of the fabricated composite nanofibers**. This will include using **high-resolution Scanning Electron Microscopy (SEM)** and **X-ray Diffraction (XRD)** at the Erich Schmid Institute of Materials Science (ESI). These techniques will provide essential insights into fiber morphology, MNP dispersion, and the crystallinity of the composites, helping to elucidate the intricate MNP-polymer interaction mechanisms.

A key strategic objective is to initiate a **collaborative research and development project** between Istanbul Technical University and the University of Vienna. This partnership will be instrumental in developing advanced textile fibers, pooling shared knowledge and experience to accelerate the transition of these specialized fibers from fundamental research to practical applications. This endeavor aims to contribute significantly to the textile industry's shift towards a value-added, high-tech landscape, particularly by creating **innovative fibers with enhanced breathability and electro-active properties**. These advancements are intended to facilitate the development of electro-active and interactive nanofibrous sensors, enabling ubiquitous sensing capabilities across diverse surfaces.This research aligns directly with the objectives of **WG2 (Processing, reactivity and relaxation pathways of nC)** within the **COST Action NanoSpace**. The insights gained from the STSM are expected to significantly advance the understanding and application of carbon-based composites embedded with magnetic nanoparticles. The unique properties of these MNP-containing composites make them highly promising for **smart textiles in healthcare and medical fields**, as well as for next-generation **energy storage devices like supercapacitors and batteries**. Furthermore, given the radiation-resistant nature of ferrite materials, these composites demonstrate significant potential for demanding **space industry applications**, particularly in space station components. Looking ahead, our collaborative research activities will continue to be strengthened through the COST Nanospace action. We are actively planning to **prepare publications where** the **STSM support of CA21126 will be acknowledged.** based on these compelling results for submission to international peer-reviewed journals and will strategically pursue **future project preparation** to secure additional funding for further research and development in this field.