

FUNDING PROGRAMME: National Research, Development and Innovation Plan (PNCDI III)
PROGRAMME 2: Increasing the Competitiveness of Romanian Economy Through Research, Development and Innovation
SUBPROGRAMME 2.1. Competitiveness Through Research, Development and Innovation – Experimental-Demonstrative Project



PROJECT TITLE/ACRONYM: Lightweight reinforced thermoPLASTic MATerials for vacuum thermoformed shells for Unmanned Aerial Vehicle applications / PlastMatUAV

CONTRACT NO.: 601PED/2022

TOTAL PROJECT BUDGET: 598.795 lei

INCDTP'S BUDGET: 249.500 lei

PROJECT STARTING DATE: (21/06/2022)

PROJECT ENDING DATE: (20/06/2024)

PAGINA WEB: <https://old.incas.ro/images/stories/PN-III/PlastMatUAV/index.html>

PARTNERS:

Coordinator: "ELIE CARAFOLI" National Institute for Aerospace Research and Development – I.N.C.A.S. Bucharest



Partner: National Research and Development Institute for Textiles And Leather - I.N.C.D.T.P. Bucharest – Division: Leather and Footwear Research Institute - I.C.P.I.



GENERAL OBJECTIVES

- 1. Formulation and verification of new hypotheses** regarding the production of thermoplastic composite materials with additions of **modified aramid nanofibers**, in the form of sheets, having **optimized physicochemical properties** for processing by **vacuum thermoforming**, as well as conducting **preliminary tests** on the obtained materials.
- 2. Obtaining and testing** thermoplastic composite materials with additions of modified aramid nanofibers, which should present **low density, high mechanical strength** and **stability to environmental conditions**. The activities will include:
 - ✓ Physicochemical and morpho-structural characterization;
 - ✓ Mechanical and thermomechanical testing;
 - ✓ Evaluation of behavior under **accelerated aging**.
- 3. Exploration and validation** of new hypotheses regarding the processing of thermoplastic nanocomposite materials in the form of sheets, by **vacuum thermoforming**, in order to obtain **complex geometries** adapted to the requirements of UAV (unmanned aerial vehicles) applications.
- 4. Definition of the laboratory-scale technology** for the development of complex shapes by vacuum thermoforming of thermoplastic nanocomposite sheets obtained within the project.
- 5. Dissemination of the technical-scientific results** obtained, through the instruments provided in the project proposal (publications, conferences, reports, etc.).

EXECUTION PHASES:

Stage 1 (21.06.2022-31.12.2022)

Stage Name: Selection and characterization of raw materials. Development of thermoplastic sheets and preliminary characterization

Stage Results: Technology for making thermoplastic polymer sheets with properties suitable for subsequent thermoforming. Technical and scientific results will be disseminated through participation in 2 international conferences.

Stage 2 (01.01.2023-31.12.2023)

Stage Name: Development, characterization and testing of thermoplastic nanocomposite sheets. Preliminary experiments for their processing by vacuum thermoforming

Stage Results: Establishing Kevlar/aramid nanofiber surface treatment routes, Technology for making thermoplastic nanocomposite sheets. Obtaining thermoplastic nanocomposites with modified Kevlar nanofibers, with high-performance characteristics. The technical and scientific results will be disseminated by publishing a WoS article, participating in 1 international conference, filing 1 patent application.

Stage 3 (01.01.2024-20.06.2024)

Stage Name: Development of complex-shaped casings from nanocomposite material by vacuum thermoforming

Stage Results: Technology for processing nanocomposite sheets by vacuum thermoforming. Obtaining complex shapes of high quality. The technical and scientific results will be disseminated by publishing 2 WoS articles, participating in 1 international conference.

SCIENTIFIC CONCEPT:

In the current context of accelerated development of technologies for unmanned aerial vehicles (UAVs), there is a pressing need to identify and develop advanced materials that simultaneously meet the requirements of performance, durability, low weight and sustainability. The constant evolution of UAV applications – from the military and aerospace fields to civil, security, environmental, health and precision agriculture applications – requires the integration of adaptable and cost-effective structural solutions and processability.

In this context, thermoplastic composite materials reinforced with modified aramid nanofibers are emerging as a promising solution for applications to protect sensitive electronic components of UAVs. These nanocomposites offer an excellent ratio between mechanical properties and specific weight, as well as good stability to environmental factors, essential characteristics for operation in various operating regimes. Also, the thermoformability of thermoplastic materials allows for easy processing into complex shapes, through technologies with a reduced energy footprint, such as vacuum thermoforming.

Internationally, research in the field of functional nanocomposites with thermoplastic matrices has intensified, with an emphasis on improving the fiber-matrix interface, optimizing processing processes and increasing resistance to mechanical, thermal and chemical stresses. Chemical modification of aramid nanofibers is an emerging field, with the potential to increase compatibility with the polymer matrix and generate high-performance hybrid networks.

The project is thus part of the priority directions of advanced research in the field of smart and multifunctional materials, aiming at a coherent integration of knowledge from the fields of materials science, macromolecular chemistry and manufacturing process engineering. By generating new scientific data on the structuring, properties and behavior over time of thermoplastic nanocomposites, the project contributes to strengthening the knowledge base necessary for the development of innovative, reliable and sustainable solutions in the UAV field.

EXPECTED EXPLOITABLE RESULTS:

The project is oriented towards obtaining results with high applied value, which can be transferred to interested industries (aeronautics, security, smart equipment), while contributing to the advancement of knowledge in the field of advanced materials. The expected exploitable results are the following:

1. **Formulas of optimized thermoplastic composite materials**, with additions of modified aramid nanofibers, adapted to the requirements of processability by vacuum thermoforming and functional performance (mechanical strength, durability, environmental stability). These formulas can constitute **technological bases for the development of lightweight and durable commercial products**.
2. **Thermoformable nanocomposite sheets** with experimentally validated characteristics, which can be used as **protective elements (covers, casings, housings)** for sensitive electronic components in UAVs. These products can be directly integrated into existing technological chains in the UAV sector or adapted for other industrial applications.
3. **Laboratory-scale processing technology** for vacuum thermoforming of composite sheets, including process parameters (time, temperature, pressure), functional models, heat transfer solutions and geometric control. This result can be the foundation for the **expansion to pre-industrial or TRL 5-6 demonstrator level**.
4. **Demonstrative functional model** (prototype) representing a UAV component made by vacuum thermoforming from composite material developed in the project. This prototype will allow **testing under real or simulated conditions**, thus validating the applicability of the results.
5. **Original scientific and technical data** on the structure, properties and in-service behavior of thermoplastic nanocomposite materials, which can be continuously exploited through:
 - articles in indexed journals (ISI, IBD),
 - communications at international conferences in the field,
 - applications for intellectual property protection (patents, utility models).
6. **Multidisciplinary characterization methodology**, applicable to other nanocomposite systems, useful in subsequent research and development activities in the field of materials science, with potential for **inter-sectoral transfer** (automotive, medical, integrated electronics, etc.).

OBTAINED RESULTS:

- ✚ 1 Technology for modifying the surface of aramid fibers using the sol-gel technique in the presence of the TiO_2 precursor (titanium isopropoxide) and microcellulose with a role in stabilizing the particle size (Figure 1);
- ✚ 1 Technology for modifying the surface of aramid fibers using the sol-gel technique in the presence of the SiO_2 precursor (tetraethyl orthosilicate) in order to reduce the degree of agglomeration and implicitly the dispersion in the polymer matrix (Figure 2);
- ✚ 1 Technology for making thermoplastic composite sheets based on simple or modified aramid fibers by melt compounding followed by thermal pressing in metal molds (Figure 3);
- ✚ 3D printed molds for making the drone cover by thermoforming (1 upper mold and 1 lower mold made of Onyx polymer, by 3D printing (FDM technique), according to the CAD design of the drone body cover) (Figure 4);
- ✚ 7 Variants of covers to enclose the drone body – plates based on 50/50 PP/PE-g-AM, various dyes (1% Mastersafe MP-10-20B / 0.2% Oppasin Blau 6900/0.2% Eupolen Red 41-6001), aramid fibers modified with TiO_2 or SiO_2 , processing additives (Genioplast, PE-based wax, etc.) obtained by thermoforming (Figures 5 and 6).

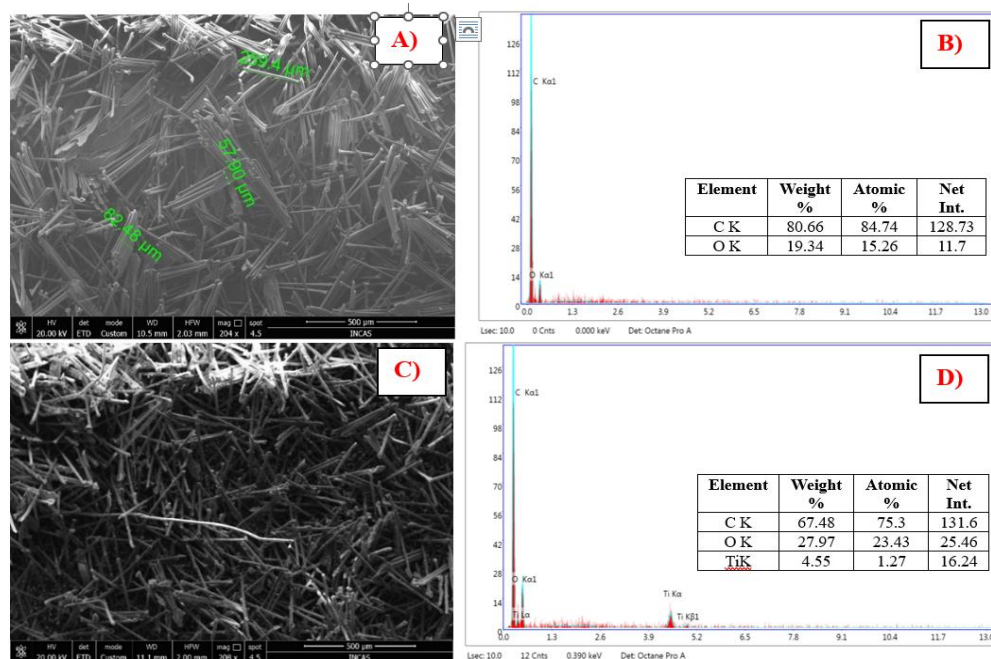


Figure 1. SEM images and EDS spectra of untreated aramid fibers (A and B) and aramid fibers treated with TiO_2 (C and D)

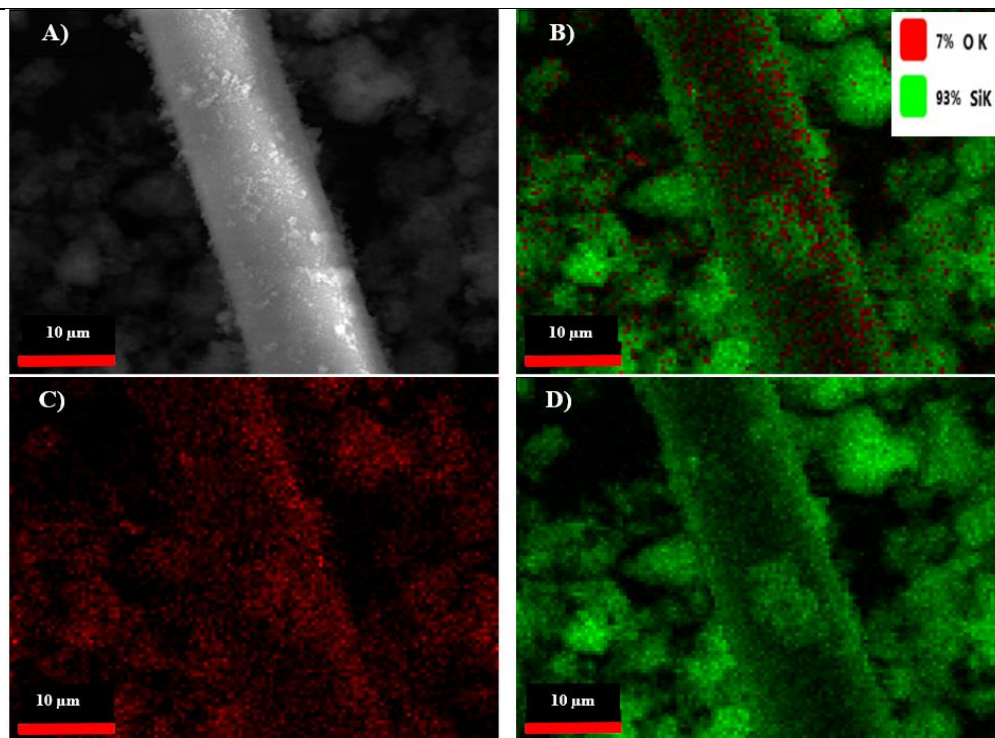


Figure 2. SEM image (A) and EDS maps of the constituent elements of SiO_2 modified aramid fiber (B - obtained by superimposing O and Si elements), individual distribution of O and Si in the sample (C, D). All images were captured at a magnification level of 5000x.



Figure 3. Plates/sheets processed by compounding/thermal pressing used for thermoforming covers made in various color combinations

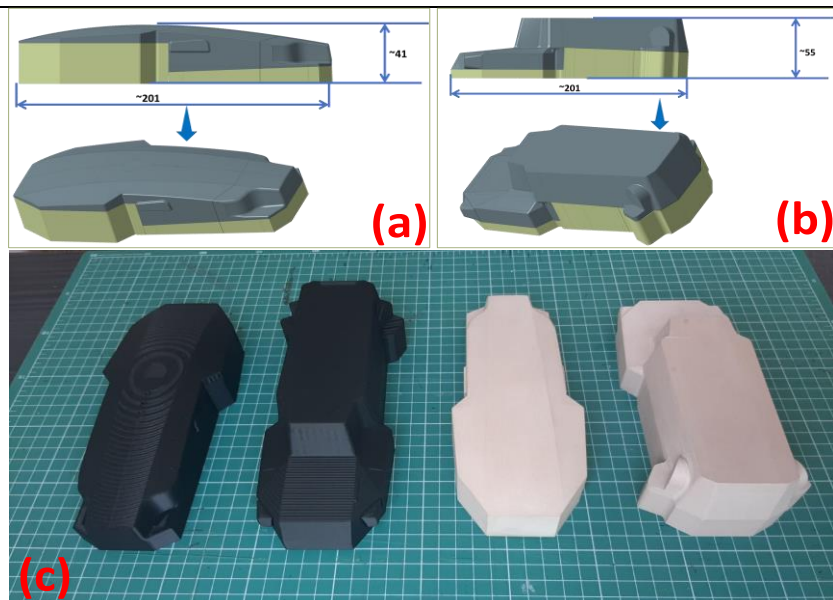


Figure 4. Final cover mold geometry: (a) Top cover design, (b) Bottom cover design, (c) final molds used for thermoforming the drone covers: left, 3D printed top-bottom mold pair made of polymer material, and right, CNC cut top-bottom mold pair made of Necuron 301 polymer foam



Figure 5. Thermoformed multi-colored casings, along with the molds and the 3 covers previously placed onto the drone



Figure 6. Images from drone flight tests with the cover set

DISSEMINATION, PATENT APPLICATIONS, AWARDS:

- **WoS published papers:**

1. **Sonmez Maria**, Cristina-Elisabeta Pelin, George Pelin, Bogdan Rusu, Adriana Stefan, **Maria Daniela Stelescu**, **Madalina Ignat**, **Dana Gurau**, **Mihai Georgescu**, **Mihaela Nituica**, *et al.* "Development, Testing, and Thermoforming of Thermoplastics Reinforced with Surface-Modified Aramid Fibers for Cover of Electronic Parts in Small Unmanned Aerial Vehicles Using 3D-Printed Molds" *Polymers*, 2024,16, no. 15: 2136. <https://doi.org/10.3390/polym16152136>, (IF=4.7, **Q1**);
2. Pelin George, **Maria Sonmez**, and Cristina-Elisabeta Pelin "The Use of Additive Manufacturing Techniques in the Development of Polymeric Molds: A Review", *Polymers*, 2024, 16(8): 1055. <https://doi.org/10.3390/polym16081055>, (IF=4.7, **Q1**)
3. Cristina-Elisabeta Pelin, **Maria Sonmez*** (corresponding author) *et al*, Compatibilized polypropylene composites reinforced with TiO₂ modified aramid fibers, *Polymer Composites*, 2024, 45(8):7116-7136, <https://doi.org/10.1002/pc.28254>, (IF=5.2, **Q1**).

- **IBD published papers:**

1. **M. Sonmez**, C-E. Pelin, **M. Georgescu**, G. Pelin, **M. D. Stelescu**, **M. Nituica**, G. Stoian, **L. Alexandrescu**, **D. Gurau**, Unmanned Aerial Vehicles – classification, Types of Composite Materials used in their structure and Applications, ICAMS Proceedings of the International Conference on Advanced Materials and Systems, 2022, <https://doi.org/10.24264/icams-2022.I.11>, pp 77-82.

- **Scientific communications:**

1. C.-E. Pelin, **M. Sonmez**, G. Pelin, A. Stefan, **M. D. Stelescu**, **M. Georgescu**, Pigment Based Composites with Polyolefin Matrix and Surface Modified Aramid Fibers, Applications of Chemistry in Nanosciences and Biomaterials Engineering NanoBioMat 2024 – Summer Edition, 19-20 June 2024.
2. C.-E. Pelin, **M. Sonmez**, G. Pelin, A. Stefan, A. Dragomirescu, **M. D. Stelescu**, **M. Nituica**, **M. Georgescu** - Manufacturing and testing of thermoplastic blends for vacuum thermoforming of covers for UAVs parts – oral presentation at the 10th International Conference on Structural Analysis of Advanced Materials in Zakynthos, Greece, 10-15 September 2023.
3. C.-E. Pelin, **M. Sonmez**, G. Pelin, B. Rusu, A. Dragomirescu, **M. D. Stelescu**, **M. Georgescu**, **M. Nituica** - Sustainable technologies used for manufacturing of parts in small unmanned aerial vehicle structures- poster presentation at the 6th International Conference Emerging Technologies in Materials Engineering, 9-10 November 2023, Bucharest, Romania.

- **Patent Applications:**

- Patent application no. A/00606 from 26.10.2023, titled: Composite based on polypropylene reinforced with functionalized aramid fibers, authors: **Sonmez Maria**, Pelin Cristina-Elisabeta, Pelin George, Cristea George-Catalin, Stefan Adriana, **Nituica Mihaela**, **Alexandrescu Laurentia**, **Stelescu Daniela Maria**, **Georgescu Mihai**.

- **Awards**

1. **Maria Sonmez**, Cristina-Elisabeta Pelin, George Pelin, George Catalin Cristea, Adriana Stefan, **Mihaela Nituica**, **Laurentia Alexandrescu**, **Daniela Maria Stelescu**, **Mihai Georgescu** - Composite based on polypropylene reinforced by functionalized aramid fibers, participation in: International Innovation and Invention Show, EURO POLITEHNICUS 2024, 22-23 November 2024, Bucharest, Romania – Gold medal.
2. **Gold medal** in the first edition of EURO POLITEHNICUS 2024, International Innovation and Invention Show, 22-23 November 2024 granted to - **Sonmez M**, Pelin C-E, Pelin G, Cristea G-C, Stefan A, **Nituica M**, **Alexandrescu L**, **Stelescu DM**, **Georgescu M** - Composite based on polypropylene reinforced by functionalized aramid fibers, UGAL INVENT innovation and research fair.

CONTACT PERSON:

Person responsible from the Partner: Dr. eng. Maria SONMEZ, CSI, maria.sonmez@icpi.ro,
Rubber Research Department