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"Experimental and Numerical Studies of the Strength and Tribological Properties of Composite Materials"

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This volume presents the materials of the roundtable discussion “Experimental and Numerical Studies of the Strength and Tribological Properties of Composite Materials.” The meeting addressed major scientific and technological achievements in the field of experimental and numerical investigations of composite materials and tribology.

The contributions included in this collection consider current issues related to the strength and tribological properties of composite materials used in aviation. Particular attention is given to the impact resistance of composites, the strength of high-pressure spherical composite vessels, and other relevant problems in the field of composite material mechanics and tribology.

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Presidium

Content

EXPERIMENTAL AND NUMERICAL STUDIES OF STRENGTH AND TRIBOLOGICAL PROPERTIES OF A HIGH-PRESSURE SPHERICAL COMPOSITE VESSEL

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Keywords: composite materials, strength, liner, vessel classification, aviation systems, design, mechanical properties

The use of high-pressure aviation vessels for storing compressed gases in aviation systems is a relevant area for improving the efficiency of onboard systems by reducing structural weight. The application of composite materials in Composite Overwrapped Pressure Vessel (COPV) designs allows the creation of structures with significantly reduced weight while maintaining the required strength and safety. In such designs, the main loads from internal pressure are transferred to the high-strength fiber overwrap, while the hermetic seal is provided by a metallic liner [1].

According to the classification, vessels with fully composite-wrapped metallic liners belong to Type III, which is suitable for aviation applications due to a high specific strength-to-weight ratio [1].

The object of study is a spherical high-pressure composite vessel with a working pressure of 200–210 kgf/cm² (19.6–20.6 MPa). The spherical shape ensures uniform distribution of membrane stresses and minimizes mass for a given internal pressure, as confirmed by classical studies of thick-walled spherical composite vessels [2].

The manufacturing technology of spherical vessels is complicated by the formation of non-geodesic winding trajectories and maintaining stable fiber tension in the polar zones, where surface curvature increases. Deviations from optimal parameters can cause local stress concentrators, wrinkling, layer slippage, or non-uniform wall thickness [3].

Additionally, ensuring a hermetic and reliable connection of the composite shell with metallic or polymer inserts (stringers, fittings), which bear local loads, creates a complex stress–strain state, combining membrane and bending components.

The goal of this work is the experimental and numerical determination of the strength characteristics and contact-tribological parameters of the interaction between the composite shell and the metallic liner (friction coefficient, adhesion strength), as well as the establishment of rational design and technological parameters (shell thickness, winding angles, layer sequence, autofrettage regime) to ensure a safety factor of at least 1.5 and, if necessary, up to 2.0–2.35 depending on operating conditions.

Experimental samples will be manufactured based on spherical stainless-steel liners with a thickness of 3–4 mm. The composite shell will be formed using filament winding with an epoxy matrix and carbon fiber. Winding angles will vary from 15° to 75° relative to the equatorial line, forming symmetric multilayer structures [±θ]n. The influence of winding trajectories on the stress–strain state has been confirmed by numerical and experimental studies [4].

Experimental tests will be carried out in accordance with the ANSI/AIAA S-081B-2018 standard, which regulates the design, analysis, manufacturing, and qualification testing of COPVs. The minimum safety factor for burst pressure (burst factor) must be at least 1.5 relative to the maximum expected operating pressure (MEOP), taking into account the temperature coefficient (ECF). Proof tests at elevated pressure, hydrostatic tests to failure, cyclic pressure tests to evaluate durability and verify the "leak-before-burst" requirement, as well as non-destructive inspections before and after loading, are planned. Deformation fields will be determined using Digital Image Correlation (DIC) to verify the numerical model and confirm compliance with strength criteria [5].

The numerical modeling of the vessel's stress–strain state will be performed using the finite element method in ANSYS. A three-dimensional parametric model will be created with a layered description of the composite shell, taking into account the actual winding sequence. For the steel liner, an elastic-plastic model with isotropic hardening will be applied, allowing correct consideration of autofrettage and residual stress formation. The composite shell is described using an orthotropic linear-elastic model with engineering constants for individual layers. Failure initiation is evaluated using the Hashin criterion, while the Tsai–Wu criterion is used for comparative integral assessment of the structure's limit state [6].

The numerical model will be verified against the results of hydrostatic tests. Tribological studies include determining the friction coefficient at the "liner–composite" interface and evaluating contact interaction using a laboratory tribometer. The obtained friction coefficient values will be included in the numerical model for accurate description of autofrettage and redistribution of residual stresses in the liner and shell. The effectiveness of autofrettage in improving the cyclic durability of composite vessels has been confirmed by experimental studies [7].

Expected results include determining rational parameters of the composite shell of a spherical vessel with a working pressure of 200–210 kgf/cm² (19.6–20.6 MPa), experimental confirmation of a 30–38 % weight reduction compared to a fully steel structure, development and verification of a finite element model for predicting burst pressure, and determination of optimal autofrettage pressure to ensure the required safety factor and increased vessel durability.

Conclusions. A comprehensive experimental and numerical approach to study the strength and tribological characteristics of a high-pressure spherical composite vessel has been proposed. Experimental samples with variable winding parameters will be fabricated, and tests will be carried out according to international COPV standards. The finite element model developed in ANSYS will allow parametric optimization of the design, considering composite orthotropy, liner plasticity, and contact interaction. The results can be used in the design of high-pressure spherical vessels for aviation systems, ensuring strength, reliability, and reduced structural weight.

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EXPERIMENTAL STUDY ON ANTI-WEAR PROPERTIES OF SUSTAINABLE AVIATION FUELS

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Keywords: sustainable aviation fuels, anti-wear properties, aviation kerosene, butyl esters, fuel lubricity, tribological properties, renewable feedstock

Introduction. The rapid development of aviation and the increasing demand for environmental sustainability are driving intensive research into sustainable aviation fuels (SAF) and their operational properties. Along with environmental performance, SAF must ensure reliable operation of aircraft fuel systems, the durability of friction units, and stable tribological behavior under severe operating conditions. The anti-wear properties of aviation fuels play a critical role in ensuring the reliability and service life of precision friction pairs operating under boundary and mixed lubrication conditions.

Conventional petroleum-derived jet fuels often demonstrate limited lubricating capacity, which may lead to increased wear of fuel system components. At the same time, numerous studies indicate that bio-derived fuel components, particularly fatty acid esters of vegetable oils, exhibit enhanced lubricity due to their high polarity and ability to form stable adsorption films on friction surfaces. These surface-active compounds contribute to the formation of protective boundary layers that reduce friction and wear.

Despite significant progress in developing SAF, the tribological behavior of many bio-derived components remains insufficiently studied. In particular, there is limited experimental data on the anti-wear properties of aviation fuel blends containing esters of different molecular structures and feedstock origins, including waste-derived and animal-based components. Therefore, further research is required to evaluate the influence of various bio-additives on the anti-wear performance of aviation fuels and to identify promising sustainable fuel components.

Previous Studies Overview. Previous research by the authors has focused on the experimental investigation of the anti-wear properties of aviation fuels containing bio-derived ester components derived from vegetable oils. In particular, the lubricating performance of aviation fuel blends containing fatty acid methyl esters and fatty acid ethyl esters derived from rapeseed oil was studied [1, 2]. These investigations demonstrated that the addition of bio-derived esters significantly improves the anti-wear properties of conventional jet fuel by enhancing the formation of stable boundary lubrication films and increasing the resistance of friction surfaces to scuffing.

Further studies focused on aviation fuel blends containing fatty acid ethyl esters derived from camelina oil [3]. The results showed that bio-additives based on vegetable oil esters exhibit higher lubricity than conventional aviation fuel, due to strong adsorption of polar molecules on metal surfaces and the formation of elastic protective films. The improvement of anti-wear performance was associated with the chemical composition and surface activity of the ester molecules.

Overall, previous investigations confirmed the effectiveness of plant-derived methyl and ethyl esters as lubricity improvers for aviation fuels and demonstrated the potential of bio-based components to enhance tribological performance [4]. However, these studies were primarily limited to esters obtained from vegetable oils and lower alcohols, while the influence of esters with different molecular structures and feedstock origins remains insufficiently explored.

Aim of the Present Study. The present study continues a series of investigations on the anti-wear properties of aviation fuels containing bio-derived ester components and extends the research to new types of bio-additives with different molecular structures and feedstock origins.

The aim of this work is to experimentally investigate the anti-wear properties of aviation kerosene blended with butyl esters derived from renewable, waste, and animal feedstocks. The study evaluates the influence of iso-butyl esters of waste sunflower oil, iso-butyl esters of rapeseed oil, and n-butyl esters of beef fat on the tribological behavior of aviation fuel at varying concentrations.

Materials and Methods. The experimental investigation was carried out using aviation kerosene as a base fuel and blended samples containing bio-derived ester additives of different origins and molecular structures.

The following fuel samples were tested: base aviation kerosene (F-35) without additives, blends containing iso-butyl esters of waste sunflower oil (10% and 30% vol.), blends containing iso-butyl esters of rapeseed oil (10% and 30% vol.), blends containing n-butyl esters of beef fat (10% and 30% vol.).

The anti-wear properties of the tested fuel samples were evaluated using a tribological testing system under controlled operating conditions. The anti-wear performance was assessed by analyzing friction characteristics and wear-related parameters of the friction pair operating in the fuel medium. Comparative analysis of the obtained results allowed evaluation of the influence of additive type, concentration, and feedstock origin on fuel lubricity.

Results and Discussion. The obtained experimental results confirmed that the anti-wear properties of aviation fuel strongly depend on the presence and composition of bio-derived ester additives.

The base aviation kerosene demonstrated the lowest anti-wear performance due to its limited lubricating capacity and weak boundary film formation on friction surfaces. The introduction of bio-additives significantly improved the tribological characteristics of the fuel blends.

As shown in Fig. 1, the addition of butyl ester bio-components leads to a noticeable reduction in the volumetric wear of the stationary flat specimen compared to the base fuel. The decrease in volumetric wear indicates improved anti-wear performance of the fuel blends. This improvement can be attributed to the high polarity and surface activity of ester molecules, which promote the formation of stable protective boundary films separating friction surfaces.

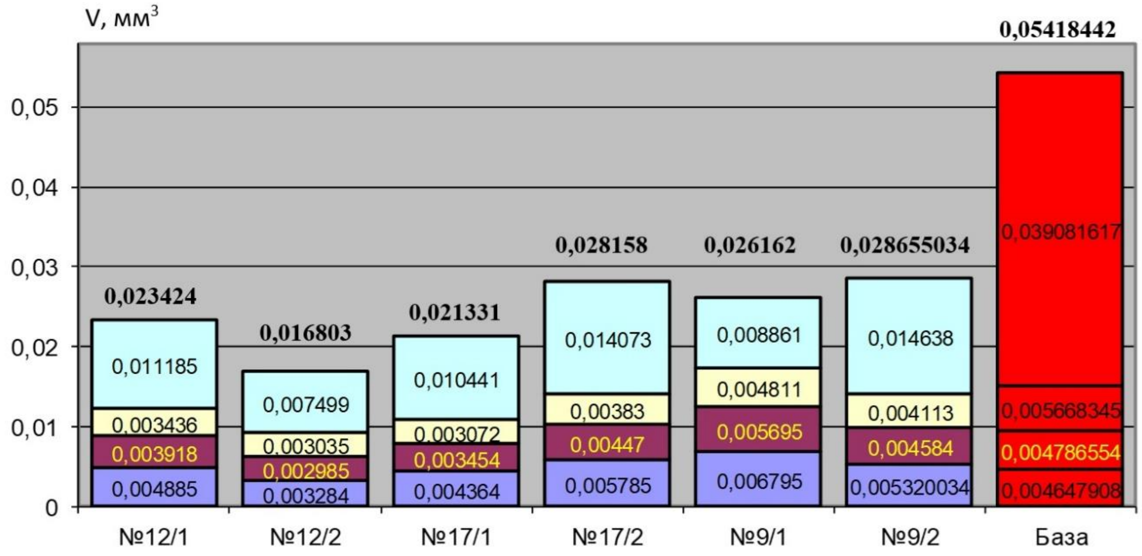

Figure. 1. Results of volumetric wear measurements of the stationary flat specimen in experimental bio-additive media compared with base aviation fuel

As shown in Fig. 2, the tested fuel blends exhibit higher critical loads than the base aviation fuel, indicating improved load-carrying capacity and enhanced resistance to wear and surface damage under severe friction conditions. The increase in critical load reflects the bio-additive components' ability to form durable protective boundary layers on friction surfaces, thereby improving the fuel's anti-wear performance.

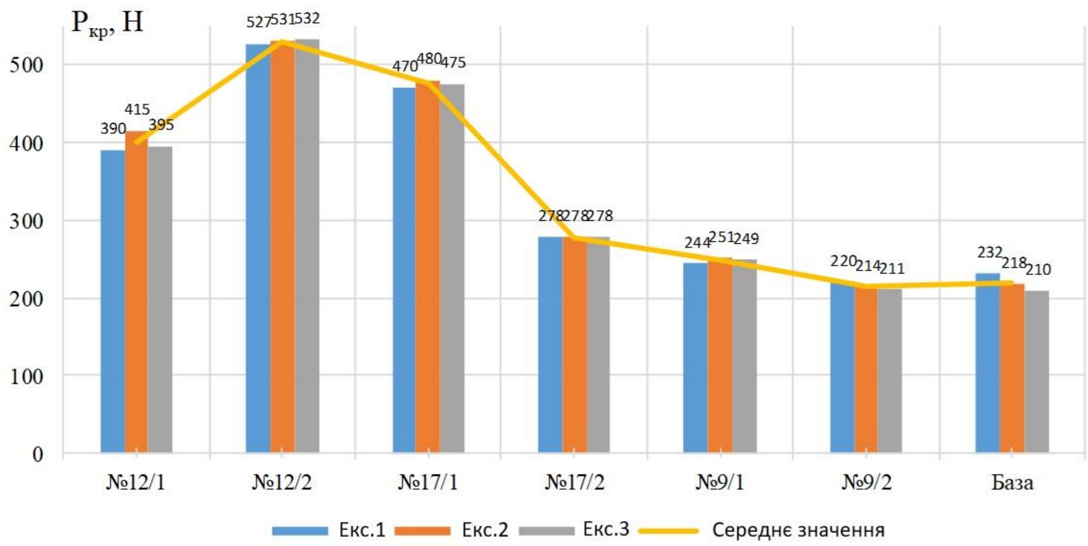

Figure 2. Results of critical load testing of experimental bio-additive blends and base aviation fuel

Differences in tribological behavior were also observed depending on the esters' feedstock origin. Vegetable oil- and animal-fat-derived components demonstrated high lubricating efficiency, confirming their potential as sustainable additives to improve aviation fuel lubricity.

Overall, the results confirm and extend previous findings on the positive effect of bio-derived esters on aviation fuel anti-wear properties and demonstrate the effectiveness of butyl ester additives obtained from renewable and waste feedstocks.

Conclusions. The conducted experimental study demonstrated that the addition of bio-derived butyl esters significantly improves the anti-wear properties of aviation kerosene. The reduction in volumetric wear and the increase in critical load values confirm the enhanced lubricating performance and load-carrying capacity of fuel blends containing bio-additives. The results indicate that esters derived from renewable, waste, and animal feedstocks are promising sustainable components for improving the lubricity of aviation fuel. The findings extend previous studies and confirm the potential of bio-derived esters as effective additives for SAF.

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COMPREHENSIVE ANALYSIS OF ABRASIVE WEAR RESISTANCE IN ELECTROSPARK COATINGS ON STEEL 1045

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Keywords: electrospark alloying, abrasive wear resistance, steel 1045 coatings, VK15 hard alloy, microhardness, coating porosity, surface modification

Materials and Methods. Steel 1045 was normalized to achieve a ferrite-pearlite structure with 95 HRB hardness. VK15 electrodes contain 85% WC and 15% Co, while R6M5 features carbides of V, Cr, Mo, W (about 18-20% carbide phase). Coatings were applied using Elitron-22 equipment at 1 A current for 10 or 20 minutes (specific treatment time of 1 or 2 min/cm²).

Wear testing followed GOST 23.208-79 with quartz sand (250 μm grains) on a rubber roller at 44.1 N load and 0.158 m/s speed. Microhardness was measured via Micro-Vickers (PMT-3 device). Porosity was assessed using the Rosiwal method, and morphology via optical microscopy.

Coating Morphology and Properties. Coatings exhibit discrete structures with uneven microrelief from overlapping molten droplets. Doubling treatment time from 1 to 2 min/cm² reduces porosity by 43-45%: VK15 from 35% to 20%, R6M5 from 45% to 25%. VK15 coatings show 20-22% lower porosity than R6M5 (Table 1).

Table 1. Porosity and Microhardness of electric spark coatings depending on processing time

Parameter	**VK15 (1 min/cm²)**	**VK15 (2 min/cm²)**	**R6M5 (1 min/cm²)**	**R6M5 (2 min/cm²)**
Porosity, %	35	20	45	25
Thickness, μm	20-40	35-70	18-35	27-72
Surface Microhardness, GPa	~12	22.8	~9.7	~10.6

Layer thickness doubles: VK15 from 20-40 μm to 35-70 μm, R6M5 from 18-35 μm to 27-72 μm. Surface microhardness reaches 22.8 GPa for VK15 (4.8-fold increase over base) and 10.6 GPa for R6M5 (2.25-fold). In-depth hardness is 4-5 times higher for VK15 and 2.5-4 times for R6M5 compared to the substrate.

Abrasive Wear Results. Base steel 1045 mass loss: 0.0056 g (10 min) and 0.0110 g (20 min), corresponding to 95 m and 190 m friction paths. VK15 at 2 min/cm² reduces wear by 24 and 40 times (0.0013 g and 0.0049 g). R6M5 performs equal to or worse than the base, with 1.16-1.25 times higher wear (Table 2).

Table 2. Mass of material wear during abrasive friction

Material	**Wear 10 min (g)**	**Wear 20 min (g)**	**Wear Reduction vs. 1045 (2 min/cm², 190 m)**
1045	0.0056	0.0110	1
VK15 (2 min/cm²)	0.0013	0.0049	40x
R6M5 (2 min/cm²)	0.0065	0.0090	~1.22x higher

Friction causes abrasive embedding, grooving, and hardness drop: VK15 loses 2082-5445 MPa but retains superiority; R6M5 falls to base level (4729 MPa). VK15 resists embedding better due to higher WC carbide content (85% vs. 18-20% in R6M5).

Conclusions. ESA with VK15 effectively boosts steel 1045's abrasive wear resistance through low porosity, high hardness, and carbide content. Optimal regime is 2 min/cm² for dense layers up to 70 μm thick. R6M5 coatings fail due to destruction and low carbide levels.

Recommend VK15 for machine parts (shafts, gears) in abrasive environments; further optimize ESA parameters for R6M5. The method is eco-friendly with minimal thermal impact and targeted application.

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IMPROVING THE DETECTION AND ANALYSIS OF IMPACT DAMAGE TO COMPOSITE ELEMENTS FOR STRENGTH AND STIFFNESS USING SENSOR SYSTEMS

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Keywords: impact damage, composite materials, structural health monitoring (SHM), sensors, finite element modelling

This work is concerned with the development of a hybrid experimental–numerical methodology for the real-time detection, localization, and progressive analysis of impact damage in carbon fibre-reinforced polymer (CFRP) structural elements. The central problem motivating the study is the susceptibility of composite laminates to barely visible impact damage (BVID)—subsurface de-lamination, matrix cracking, and fibre breakage that are not detectable by routine visual inspection—and the significant influence of such damage on stiffness degradation and residual load-bearing capacity under cyclic fatigue loading. The proposed approach involves the integration of a piezoelectric (PZT) sensor network, acoustic emission monitoring, and distributed fibre-optic sensing with a validated finite element model of progressive damage, thereby enabling continuous, quantitative structural condition monitoring without interrupting the operational cycle of the component.

Introduction and Motivation. Composite materials occupy an increasingly central role in the structural design of aerospace, automotive, and civil engineering applications owing to their outstanding specific strength and stiffness. Unlike metallic structures, however, CFRP laminates can sustain substantial internal damage at impact energy levels that produce only a superficial surface indentation, rendering conventional non-destructive testing (NDT) approaches insufficient when applied intermittently or retrospectively [1, 2]. The consequence of such undetected BVID is an accelerated, often non-linear degradation of both in-plane stiffness and interlaminar shear strength under subsequent operational loading [3].

Existing NDT approaches are generally discontinuous and require the removal of the structure from service, which precludes timely tracking of damage state in real time. In response to this limitation, the aerospace engineering community has been actively advancing the concept of Structural Health Monitoring (SHM) systems capable of providing continuous, autonomous damage state awareness throughout the operational life of a component [4]. Piezoelectric transducer networks, acoustic emission (AE) monitoring, and fibre Bragg grating (FBG) systems have each individually demonstrated their fundamental suitability; however, their systematic integration into a unified, validated SHM framework for conditions of combined impact and fatigue loading remains an open research problem [5, 6].

The present work aims to address this gap through the development and validation of a multi-modal, sensor-based approach supported by finite element (FE) numerical modelling for the comprehensive detection and progression tracking of BVID in CFRP laminates. Proposed Methodology

Specimen Preparation and Impact Damage Induction. Quasi-isotropic CFRP laminates with a $[0/45/90/-45]_{2s}$ stacking sequence are to be manufactured by autoclave-cured prepreg tape layup in accordance with the specimen geometry specified in ASTM D7136 [7]. To reproduce low-energy impact events representative of tool-drop or runway debris scenarios, a precision gas gun apparatus fitted with a hardened steel ball impactor of 12.7 mm diameter is to be employed. Impact energies will be varied over the range of 5–20 J to generate BVID conditions, operationally defined as a surface indentation depth not exceeding 0.3 mm.

The indentation geometry will be measured using an optical profilometer (vertical resolution < 10 nm) and a structured-light 3D scanner with a point-cloud spatial resolution of 0.05 mm [8]. The resulting surface topography will be digitized and retained as reference input data for subsequent finite element model updating. Ultrasonic C-scan imaging will be performed to provide an initial characterization of the projected delamination area, establishing a ground-truth damage map against which sensor-based predictions will be vali-dated.

Fatigue Testing and Loading Protocol. Damaged and pristine (undamaged) reference specimens will be subjected to constant-amplitude cyclic compressive loading on a servo-hydraulic test stand (load capacity ±250 kN), simulating in-service fatigue conditions analogous to those experienced by primary aerospace structural panels. The loading protocol will employ a stress ratio of $R = 0.1$ at maximum applied stress levels of 60%, 70%, and 80% of the measured compressive strength after impact (CAI strength), at a test frequency of 5 Hz [9]. The selected frequency is sufficiently low to preclude adiabatic heating effects in the specimen while maintaining acceptable test duration. Testing will be conducted to either specimen failure or a predetermined limit of 10^6 cycles, whichever is reached first.

Multi-Modal Sensor Integration and SHM Implementation. A central element of the proposed methodology is the deployment of a net-work of PZT wafer-active sensors (diameter 10 mm, thickness 0.2 mm) bonded to the surface of each specimen in a preoptimized grid configuration. The PZT array will serve a dual function: active interrogation of the laminate via Lamb wave propagation for damage localisation, and passive acoustic emission monitoring for the real-time detection of discrete damage events such as matrix cracking and delamination growth [10]. Complementary strain field data will be obtained from a network of resistance-foil strain gauges at critical locations and a distributed FBG sensing array to be embedded within the laminate mid-plane, providing through-thickness strain gradient information [11].

Data acquisition will proceed continuously throughout fatigue cycling, with Lamb wave pitch-catch signals processed using a delay-and-sum beam-forming algorithm to generate damage probability maps at prescribed cycle intervals. To quantify the structural condition, a stiffness degradation index (SDI) is introduced:

$$SDI(n) = 1 - \frac{E(n)}{E_0'} \quad (1)$$

where $E(n)$ denotes the secant modulus at cycle n and E_0 is the initial modulus of the undamaged reference specimen. The key advantage of this metric is that it will be computed in real time directly from sensor data through continuous comparison against the pristine baseline, thereby decoupling inherent material variability from damage-induced stiffness loss.

Finite Element Modelling. The numerical component of the study involves the development of a three-dimensional progressive damage model within Abaqus/Standard, employing a continuum damage mechanics (CDM) framework with Hashin failure criteria for fibre and matrix failure modes and a cohesive zone model (CZM) for interlaminar delamination growth [12]. The initial damage state, as characterized by C-scan imaging and profilometry data, will be imported directly into the FE mesh via a scripted pre-processing routine, ensuring geometric fidelity of the delamination front without recourse to simplifying analytical assumptions. Model validation will be carried out by comparing predicted load-displacement response, stiffness evolution curves, and Lamb wave signal time-of-flight changes against the corresponding experimental measurements.

Expected Outcomes. Successful execution of the proposed methodology is expected to yield a comprehensive, mutually corroborated dataset combining sensor monitoring results with a validated numerical prediction of damage progression. Continuous tracking of the SDI against the undamaged baseline is anticipated to provide a quantitative characterization of the non-linear stiffness degradation trajectory as a function of initial impact energy level and applied load. The PZT Lamb wave monitoring system is expected to enable localization of the propagating delamination front, while acoustic emission signals are anticipated to reflect the three-stage damage evolution pattern characteristic of this class of material [10]. FBG sensors will provide data on the redistribution of through-thickness strain in the vicinity of the growing damage zone, which is essential for FE model verification and for elucidating the operative failure mechanisms. Agreement between sensor-derived damage maps and numerical predictions will serve as the primary quantitative criterion for assessing the fidelity of the developed SHM framework.

The proposed research aims to address a recognized gap in the scientific literature concerning continuous, integrated SHM monitoring of CFRP structural elements under combined impact and fatigue loading. The hybrid methodology—integrating gas-gun impact induction, high-resolution surface profilometry, servo-hydraulic fatigue testing, and a multi-modal sensor system with a validated FE model—

will provide mutual cross-validation of the ac-quired data and thereby enhance the reliability of conclusions drawn regarding degradation mechanisms.

Conclusions. Further development of the research programme will encompass the extension of the proposed SHM framework to complex structural geometries representative of real aerospace components, the implementation of machine learning algorithms for automated damage state classification, and the investigation of environmental conditioning—humidity and elevated temperature—on both sensor system performance and damage progression rates. The outcomes of this research are expected to contribute directly to the development of certification-relevant SHM methodologies for the design of next-generation composite air-frame structures.

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MODELING WRAP OF TECHNICAL COMPOSITE FABRIC ON CURVED SURFACES

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Modeling of the behavior of technical composite fabrics during their layup on curved surfaces represents a complex interdisciplinary problem at the intersection of solid mechanics, materials science, and computational methods. Unlike homogeneous materials, composite fabrics exhibit pronounced anisotropy: their mechanical properties differ significantly along and across the fiber directions. As a result, when forming over geometrically complex surfaces, the fabric undergoes not only bending but also shear, tensile deformation, and local instabilities manifested as wrinkling [1].

The occurrence of wrinkles constitutes a critical issue in the manufacturing of composite structures, as it can significantly degrade the mechanical performance of the final product. Wrinkles arise when the fabric is unable to conform uniformly to the surface geometry without excessive deformation. This effect is particularly pronounced in regions with double curvature, where the material compensates for geometric incompatibility through local fiber rearrangement. Therefore, accurate prediction of wrinkle initiation and evolution is a key objective at the design stage.

In modern computer-aided engineering (CAE) systems, the need to accurately account for the real behavior of composite fabrics during layup on curved surfaces is becoming increasingly important. Traditional modeling approaches often assume an idealized defect-free layer distribution, which is only valid for simple geometries. However, under real forming conditions - especially for doubly curved surfaces - wrinkling, local fiber misalignment, and excessive shear are unavoidable. Neglecting these effects in numerical models leads to significant discrepancies between predicted and actual structural performance.

The relevance of accounting for wrinkling lies in the fact that even minor geometric imperfections can lead to stress concentrations and a reduction in load-bearing capacity. In composite materials, where mechanical performance is highly dependent on fiber orientation, deviations in fiber alignment within wrinkle zones can drastically deteriorate material properties. From a CAE perspective, this implies that without incorporating the actual layup configuration, it is impossible to accurately predict strength, stiffness, and durability. This is particularly critical for highly loaded structures in aerospace and transportation industries, where reliability requirements are extremely stringent.

The objective of this study is to model the layup of a technical composite material in ANSYS with explicit consideration of wrinkling effects.

The first task of the study was to evaluate the influence of the shear angle between warp and weft in the presence of wrinkles during the layup of composite fabric on complex curved surfaces. Within this task, the behavior and characteristics of Woven Carbon Fabric (Fig. 1) were investigated for layup angles ranging from −25° to +25°.

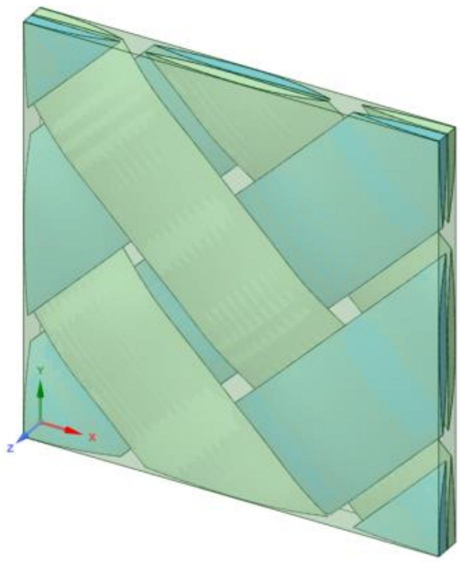

Figure 1. Representative Volume Element (RVE) of the Woven Carbon Fabric

The obtained results are presented in Figures 2–3.

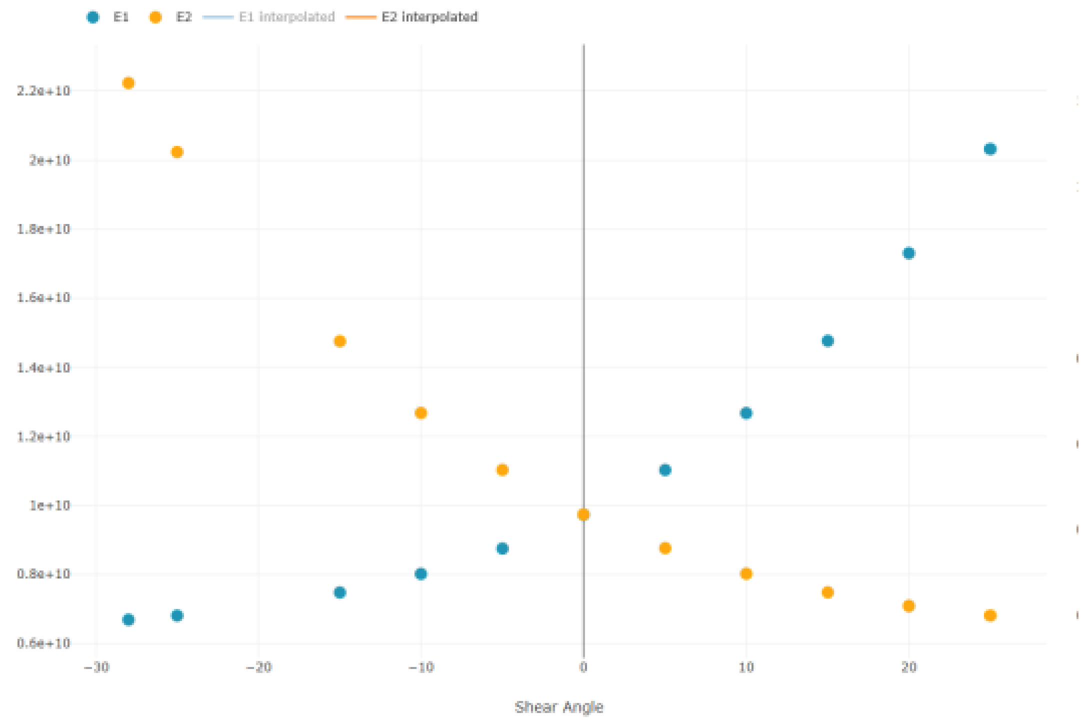

Figure 2. Young's Modules vs shear angle

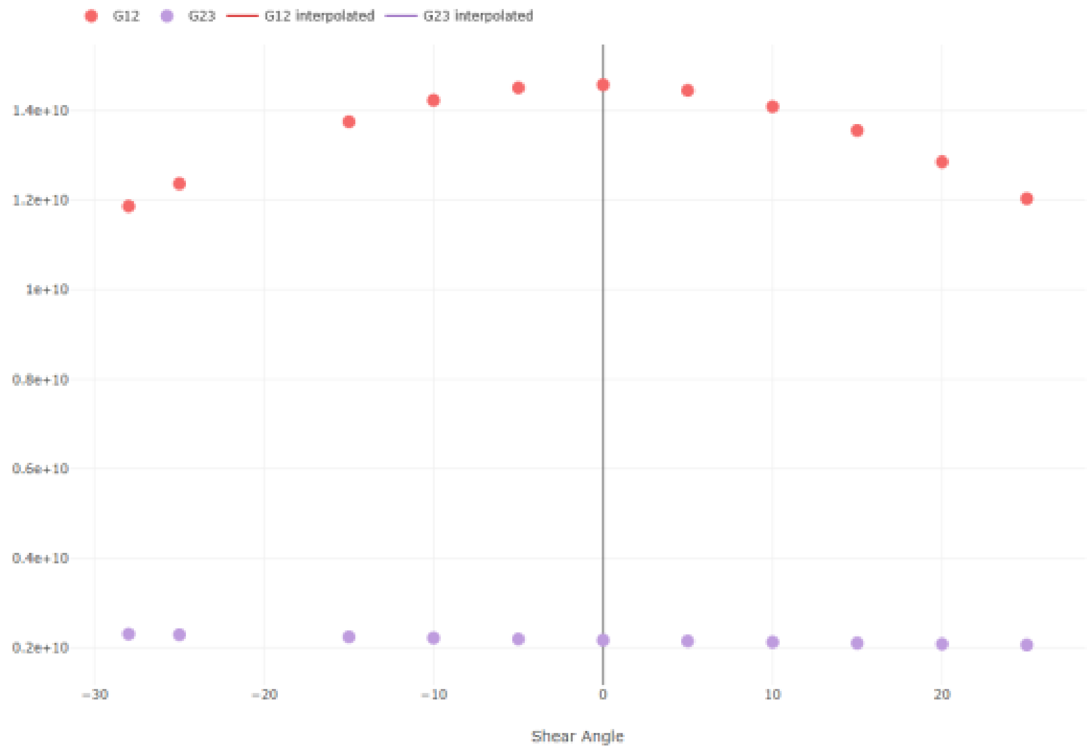

Figure 3. Shear Modules vs shear angle

The subsequent stage of the study focused on modeling the layup of composite fabric in the corner region of the tank (Fig. 4-6).

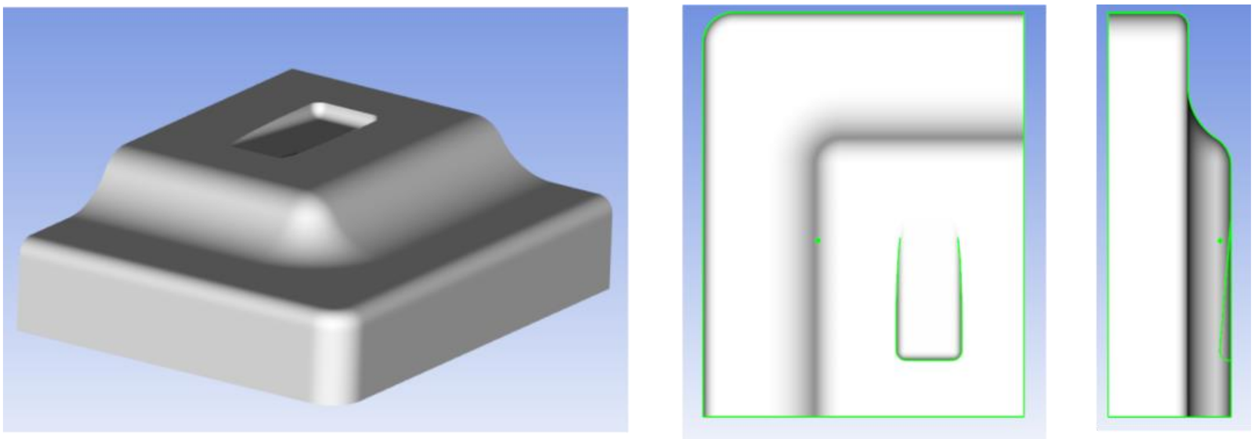

Figure 4.**CAD model of the tank's corner**

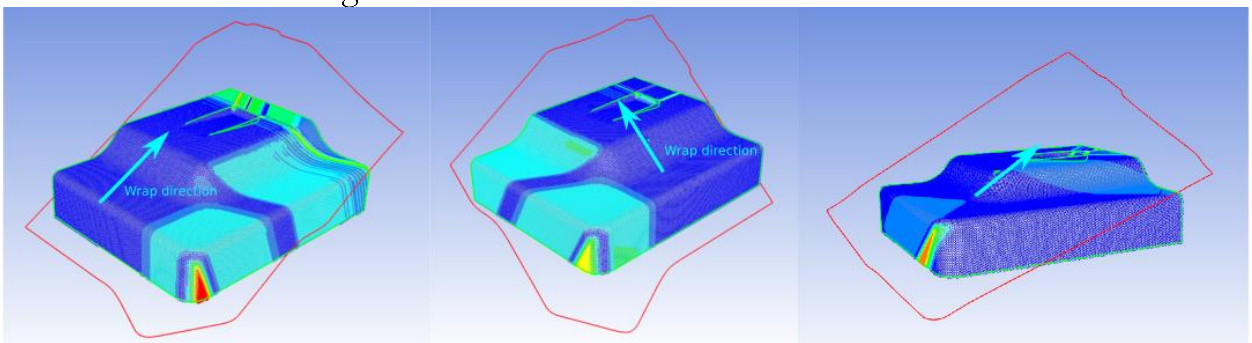

Figure 5. Visualization of wrinkle formation in the composite fabric as a function of the initial layup position

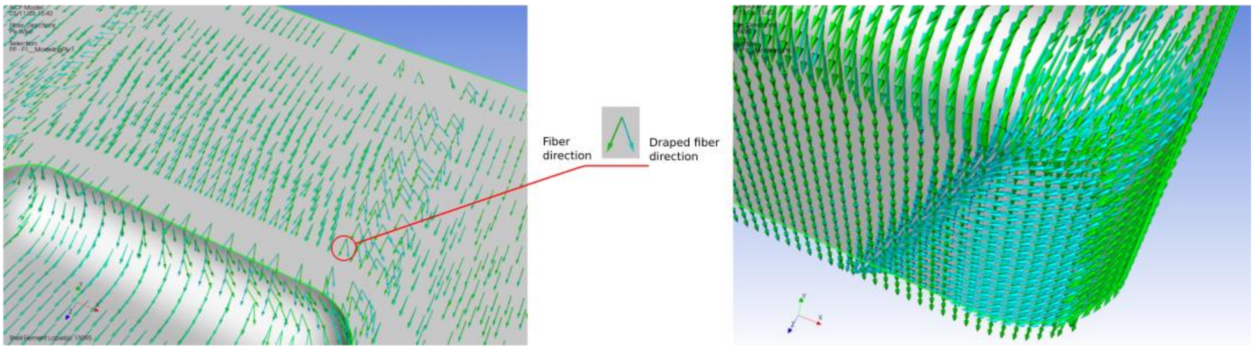

Figure 6. Vector field representation of fabric distribution considering wrinkles (blue vectors) and ignoring wrinkles (green vectors)

The results of the study indicate that, when modeling the distribution of fabric on curved surfaces, accounting for the effect of wrinkles significantly influences the layup angles of the fabric. Neglecting the wrinkle effect can lead to substantial inaccuracies in predicting the mechanical properties of composite materials and the performance of composite structures.

Proper consideration of wrinkles in modeling the layup of composite fabrics on curved surfaces is not merely a geometric refinement; it is a fundamentally important factor affecting the reliability of the entire engineering analysis. Ignoring this phenomenon introduces systematic errors in the assessment of strength, stiffness, and structural integrity.

Conclusions. This study presents the results of ANSYS simulations of technical composite layup on the curved surface of a tank corner, explicitly accounting for wrinkle formation. The findings demonstrate that including the wrinkle effect impacts the distribution of fabric layup angles, and omitting this effect may result in significant errors in the calculation of the properties of composite materials and structures.

References

1. Katnam, K. B., Comer, A. J., Roy, D., Da Silva, L. F. M., & Young, T. M. (2015). Composite repair in wind turbine blades: an overview. *The Journal of Adhesion, 91(1-2)*, 113-139. doi: 10.1080/00218464.2014.900449

ROUNDTABLE DISCUSSION
"EXPERIMENTAL AND NUMERICAL STUDIES
OF THE STRENGTH
AND TRIBOLOGICAL PROPERTIES
OF COMPOSITE MATERIALS"
Book of Abstracts

(Англійською мовою)

Оригінал-макет виготовлено на кафедрі прикладної механіки та інженерії матеріалів Аерокосмічного факультету Національного університету «Київський авіаційний інститут»

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