19th INTERNATIONAL SEMINAR

of Applied Mechanics

Wisła, 28.05 – 29.05.2026

Modelling and optimization of physical systems

POLISH SOCIETY of THEORETICAL

and APPLIED MECHANICS

DEPARTMENT OF THEORETICAL AND APPLIED MECHANICS

Silesian University of Technology, Gliwice

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Programme

19th International Seminar of Applied Mechanics

Wisła, 28-29.05.2026

Thursday 28.05.2026

15^{00} Opening session of the 19th International Seminar of Applied Mechanics
and speeches of:

***Sławomir Duda* –** Chief of the Department of Theoretical and Applied Mechanics, Silesian University of Technology, Gliwice, Poland

$15^{30} \div 16^{30}$ Scientific sessions, chairmen: Sławomir Kciuk

- $15^{30} \div 15^{45}$ TOMASZ CZAPLA: *SIMULATION OF WHEEL-SURFACE MODEL FOR VARIOUS GROUND CONDITIONS*
- $15^{45} \div 16^{00}$ MONIKA CHOMIAK, SEBASTIAN JURCZYK, ARIF ROCHMAN: *PLA-BASED BIOCOMPOSITES WITH PISTACHIO SHELL AND PINE CONE FILLERS: THERMAL PROPERTIES AND APPLICATION POTENTIAL*
- $16^{00} \div 16^{15}$ SARA SARRAJ: *BIOACTIVE BIOCOMPOSITES FOR 3D PRINTING MODIFIED WITH ORGANIC ADDITIVES*
- $16^{15} \div 16^{30}$ JAROSŁAW KACZMARCZYK, NIKHIL TATKE: *NONLINEAR BUCKLING ANALYSIS OF THIN-WALLED ALUMINIUM TUBES*

$16^{30} \div 17^{00}$ Coffee break

$17^{00} \div 18^{00}$ Scientific sessions, chairmen: Damian Gąsiorek

- $17^{00} \div 17^{15}$ TOMASZ MACHOCZEK, SŁAWOMIR DUDA, WALDEMAR PASZKOWSKI, GRZEGORZ GEMBALCZYK: *INVESTIGATION AND ANALYSIS OF MASS FLOW EFFICIENCY OF GLASS MICROSPHERES USING DIRECTIONAL ACOUSTIC SENSORS*
- $17^{15} \div 17^{30}$ JONASZ HARTWICH, SŁAWOMIR DUDA, SEBASTIAN SŁAWSKI: *INFLUENCE OF PHASE TRANSITIONS AND CRYSTAL STRUCTURE REORIENTATION ON THE PROPERTIES OF NiTi ALLOY*
- $17^{30} \div 17^{45}$ ZDZISŁAW RAK: *RIGID FINITE ELEMENTS IN MODELLING OF PLANETARY GEARS*
- $17^{45} \div 18^{00}$ GRZEGORZ GEMBALCZYK: *MODAL ANALYSIS AS A REFERENCE METHOD FOR ACOUSTIC IDENTIFICATION OF BEAM STRUCTURES*

20^{00} **Social event**

Friday 29.05.2026

10^{00}÷11^{00} Scientific sessions, chairmen: Jarosław Kaczmarczyk

10^{00}÷10^{15} SEBASTIAN SŁAWSKI, TERESA FRAS: *IMPACT RESPONSE OF THE MULTI-LAYERED COMPOSITE WITH HYBRID REINFORCEMENT – EXPERIMENTAL INVESTIGATION*

10^{15}÷10^{30} CHALA AMSALU TEFERA, SŁAWOMIR DUDA, SEBASTIAN SŁAWSKI: *NUMERICAL ANALYSIS OF THREE-POINT BENDING OF ALUMINIUM SANDWICH PANELS WITH ALUMINIUM FOAM CORE*

10^{30}÷10^{45} PAWEŁ JURECZKO: *THE USE OF POLYURETHANE RESIN IN MEDICINE*

10^{45}÷11^{00} BOUKHALFA AHMED RAMI: *DETERMINATION OF THE INFLUENCE OF CROSS-SECTION ON THE COMPRESSIVE STRENGTH OF STRUCTURAL PROFILES USED IN THE AEROSPACE INDUSTRY*

11^{00} **Closing session of the Seminar**

Book of extended abstracts

SIMULATION OF WHEEL-SURFACE MODEL FOR VARIOUS GROUND CONDITIONS

TOMASZ CZAPLA[1]

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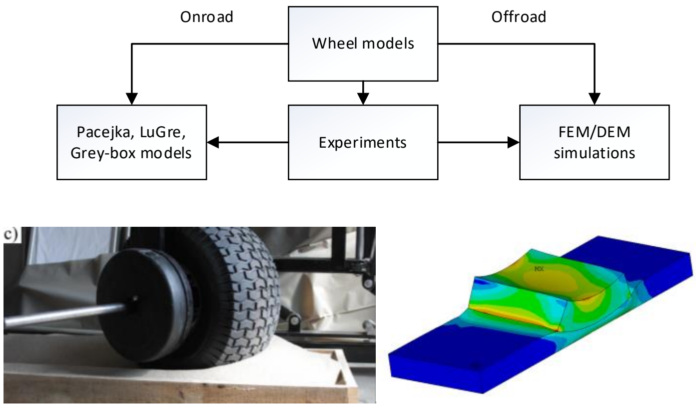
The paper presents a computational methodology for analysing wheel-terrain interaction in skid-steered all-terrain vehicles operating under different environmental conditions. The primary objective of the research is to improve prediction of traction performance and propulsion energy demand for vehicles travelling on deformable surfaces. Classical on-road vehicle models are typically focused on limited wheel slip conditions and rigid pavement interaction, whereas simulation of off-road operation requires consideration of soil deformation, wheel sinkage and terrain-dependent traction phenomena.



Methodology, field test and FEM simulation results

Vehicle dynamics calculations are performed in the Matlab/Simulink environment using analytical stick-slip and rolling resistance models for rigid surfaces. In the case of deformable terrain, Finite Element Method (FEM) and Discrete Element Method (DEM) simulations are applied to determine wheel-terrain interaction characteristics for selected operating conditions. The model input parameters include wheel loads, wheel kinematics, terrain definition and constitutive material parameters describing soil behaviour. Numerical analyses are performed for different wheel sinkage values and loading scenarios to determine reaction forces, stress distribution and wheel deformation.

The proposed approach enables efficient prediction of propulsion energy demand and traction characteristics for vehicles travelling on deformable surfaces.

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PLA-BASED BIOCOMPOSITES WITH PISTACHIO SHELL AND PINE CONE FILLERS: THERMAL PROPERTIES AND APPLICATION POTENTIAL

MONIKA CHOMIAK[1], SEBASTIAN JURCZYK[2], ARIF ROCHMAN[3]

[1]*Department of Theoretical and Applied Mechanics, Silesian University of Technology*
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The development of additive manufacturing has intensified research on biodegradable polymer composites modified with natural fillers. PLA is one of the most commonly used polymers in FDM/FFF due to its biodegradability and favorable processing properties. The environmental performance of PLA may be improved by incorporating waste-derived lignocellulosic fillers.

The aim of this work was to develop PLA biocomposites with pistachio shell and pine cone fillers for 3D printing and evaluate their thermal and thermomechanical properties. The study focused on filler preparation, fabrication of composite granulates, and the influence of filler type and concentration on crystallization behavior and thermal stability. Particular attention was paid to the influence of filler type and filler concentration on the crystallization behavior and thermal stability of the obtained composites.

Commercial PLA Ingeo 4043D was used as the polymer matrix due to its widespread application in additive manufacturing. Two natural waste fillers were chosen: pine cone particles and pistachio shell powder. The fillers were dried, ground, and sieved below 250 µm. Composites containing 5 and 10 wt.% filler were prepared by twin-screw extrusion.

Thermal properties were evaluated using Differential Scanning Calorimetry (DSC), Dynamic Mechanical Analysis (DMA), and Thermogravimetric Analysis (TGA). DSC analysis showed that lignocellulosic fillers significantly affected the crystallization behavior of PLA. Composites filled with pine cone particles exhibited markedly higher crystallinity than those containing pistachio shells. For PLA with 5 wt.% pine cone filler (Fig. 1), the crystallinity degree reached approximately 23%, whereas pistachio shell composites remained predominantly amorphous (4–5%). Additionally, pine cone-filled composites showed reduced cold crystallization intensity, indicating enhanced nucleation activity during cooling.

The DMA analysis confirmed the reinforcing effect of both lignocellulosic fillers in the glassy state region of PLA. An increase in storage modulus (E') was observed for all composite systems, indicating improved stiffness due to the presence of rigid lignocellulosic particles. Simultaneously, a reduction in tan δ peak intensity suggested limited molecular mobility of PLA chains and increased structural heterogeneity at higher filler contents.

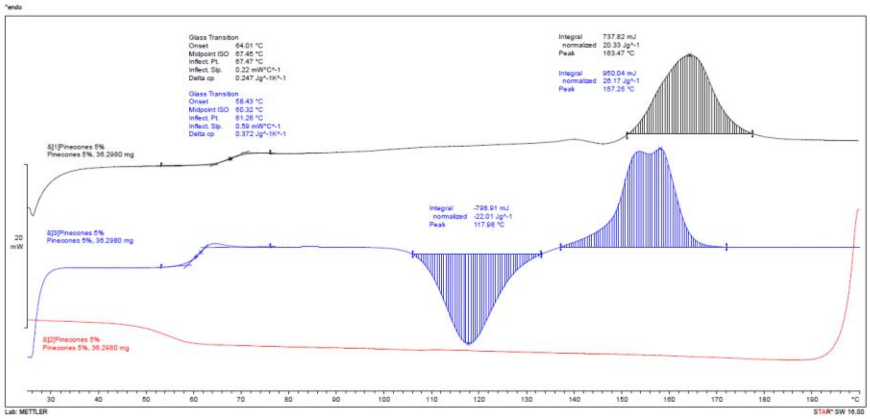

Figure 1. DSC heating curve of PLA composite containing 5 wt.% pine cone particles showing enhanced crystallization behavior and the absence of a pronounced cold crystallization peak.

Thermogravimetric analysis demonstrated that both fillers remained thermally stable within the PLA processing temperature range. The major thermal degradation of pistachio shell powder and pine cone particles started above 250–260 °C, confirming the suitability of these fillers for extrusion-based processing technologies used in additive manufacturing. Additionally, no significant degradation of PLA was observed within the processing temperature range applied during extrusion processing.

The obtained results indicate that waste-derived lignocellulosic fillers may successfully be applied as environmentally friendly modifiers of PLA composites dedicated to 3D printing applications. Pine cone particles exhibited stronger nucleating properties and significantly affected the crystalline structure of PLA, whereas pistachio shell particles mainly acted as reinforcing fillers, improving material stiffness. The developed biocomposites represent a promising approach toward sustainable materials engineering and circular economy strategies through the valorization of agricultural and forestry waste. The presented results confirm the high potential of waste-derived lignocellulosic fillers for sustainable additive manufacturing applications.

The authors acknowledge the support of the Silesian University of Technology, the University of Malta, and the Łukasiewicz Research Network within the framework of the international cooperation project.

References

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BIOACTIVE BIOCOMPOSITES FOR 3D PRINTING MODIFIED WITH ORGANIC ADDITIVES

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The research focuses on the development and characterization of innovative polymer materials for 3D printing modified with organic additives, particularly powdered plant-derived fillers. The main objective is to obtain bioactive biocomposites with antimicrobial properties while maintaining appropriate rheological behavior, curing efficiency, and printability using photopolymerization technologies such as SLA and DLP. The direct incorporation of natural fillers into photocurable resin systems simplifies the material preparation process by eliminating extraction and purification stages, contributing to reduced processing costs and lower environmental impact.

(a) (b)

Example of powdered fillers: (a) thyme and)b) sage

The conducted studies include a detailed evaluation of the influence of organic additives on the physicochemical and technological properties of photocurable resins. Rheological analyses are performed to determine viscosity, flow behavior, sedimentation tendency, and dispersion stability, which are essential parameters affecting the quality and reliability of the 3D printing process. In addition, photopolymerization kinetics and curing behavior are investigated in order to assess the impact of natural fillers on polymer network formation, curing rate, and degree of conversion. The processability of the developed materials in SLA/DLP printing is evaluated through optimization of selected printing parameters and assessment of the dimensional accuracy and surface quality of the printed structures.

Comprehensive characterization of the obtained materials includes mechanical, structural, and surface analyses. Mechanical testing involves the evaluation of tensile, flexural, hardness, and impact properties to determine the effect of bioactive fillers on material performance. Structural and morphological studies using microscopic techniques, including optical microscopy and scanning electron microscopy (SEM), enable assessment of filler distribution, interfacial adhesion, and the presence of structural defects within the polymer matrix. Additional physicochemical analyses include investigations of thermal stability, water absorption, and surface wettability.

The bioactive functionality of the developed biocomposites is also assessed through antimicrobial activity studies against selected bacterial and fungal strains. The obtained results provide valuable information regarding the effectiveness of natural additives in limiting microbial growth on material surfaces. Furthermore, the influence of organic fillers on dimensional stability, long-term durability, and resistance under simulated operating conditions is analyzed. Overall, the research enables evaluation of the potential application of such bioactive materials in high-precision and personalized products, particularly in the medical and biomedical fields, where antimicrobial performance and material functionality are of significant importance.

NONLINEAR BUCKLING ANALYSIS OF THIN-WALLED ALUMINIUM TUBES

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Thin-walled aluminium structures are widely used in modern engineering applications due to their high strength-to-weight ratio, corrosion resistance, and energy absorption capability. Such structures are commonly applied in the automotive, aerospace, civil engineering, and transportation industries, where lightweight design and structural efficiency are essential. However, thin-walled members are highly sensitive to stability-related phenomena, especially buckling under compressive loading. Because of their slender geometry, even small imperfections or eccentricities may significantly influence the critical load and post-buckling response. The accurate prediction of buckling behaviour is therefore an important aspect of structural design. Classical analytical approaches, such as Euler's buckling theory, provide a useful estimation of the critical buckling load for ideal columns under simplified assumptions. Nevertheless, real engineering structures are affected by geometric imperfections, material nonlinearities, eccentric loading conditions, and local instabilities, which cannot be fully captured using analytical equations alone. For this reason, numerical techniques based on the finite element method (FEM) have become essential tools for advanced buckling analysis.

The study focuses on the buckling behaviour of a thin-walled aluminium tube subjected to compressive loading. The analysis was performed using the finite element method implemented in the LS-DYNA system. The main objective of the work was to compare numerical FEM results with analytical solutions obtained from Euler's equation and to investigate the influence of eccentricity and geometric perturbations on the nonlinear buckling response. The investigated structure was a thin-walled aluminium tube modelled using nonlinear finite element analysis. The numerical simulations were carried out in the LS-DYNA environment, which enables the analysis of complex nonlinear phenomena including large deformations, material nonlinearity, and instability effects. The aluminium material was defined using a true stress–true strain constitutive model in order to represent the real nonlinear behaviour of the material under compressive loading. This approach allows a more realistic description of plastic deformation compared with simplified linear elastic material models. In the first stage of the study, the critical buckling load obtained from FEM simulations was compared with the theoretical critical load calculated using Euler's buckling equation. The comparison between analytical and numerical results showed a very good agreement. The difference between the FEM predictions and Euler theory was approximately 3%, confirming the correctness of the developed numerical model and the adopted modelling assumptions. After validating the numerical model, a series of nonlinear analyses was conducted for different eccentricity values. The eccentricity was introduced in order to reproduce more realistic loading conditions, since practical engineering structures are rarely subjected to perfectly axial compression. The obtained results demonstrated that increasing eccentricity leads to a gradual reduction of the maximum peak force. This phenomenon is associated with the earlier initiation of instability and asymmetric deformation modes. An additional part of the investigation focused on the influence of geometric perturbations and imperfections. Two numerical models were compared:

- an ideal tube model without any perturbation imposed on the nodes,
- a more realistic model with imposed geometric perturbations.

The comparison revealed significant differences in the obtained buckling response. The idealised model without perturbations generated substantially higher peak force values, indicating unrealistically high structural stiffness and stability. In contrast, the model including perturbations exhibited lower peak forces and a more realistic deformation pattern. These results confirm that geometric imperfections play a critical role in nonlinear buckling analysis. Even small perturbations may significantly reduce the critical load and alter the post-buckling behaviour of thin-walled structures. Therefore, the inclusion of imperfections in FEM simulations is essential for obtaining reliable and engineering-relevant results. The nonlinear analyses highlighted the sensitivity of thin-walled tubes to eccentricity and imperfections. Increasing eccentricity caused a progressive reduction in the maximum compressive force, indicating lower load-carrying capacity and earlier instability development. This behaviour is particularly important for lightweight structural components, where even small deviations from ideal geometry may considerably affect structural performance. The comparison between ideal and perturbed models showed that analyses without imperfections may significantly overestimate the real buckling resistance. Consequently, numerical simulations intended for practical engineering applications should always include geometric perturbations or initial imperfections in order to reproduce realistic structural behaviour. The obtained results are consistent with the general understanding of nonlinear stability problems and confirm the necessity of combining analytical and numerical approaches in structural mechanics. While Euler's equation provides a convenient theoretical reference, advanced FEM simulations are required for accurate prediction of real structural response. The presented methodology may be further extended to more complex thin-walled components and different loading conditions. Future work may include experimental validation of the numerical model, dynamic buckling analysis, and investigation of different material models or cross-sectional geometries.

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INVESTIGATION AND ANALYSIS OF MASS FLOW EFFICIENCY OF GLASS MICROSPHERES USING DIRECTIONAL ACOUSTIC SENSORS

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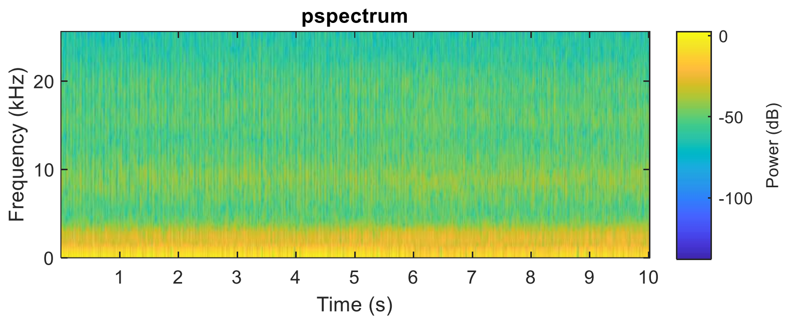
The subject of the study concerns investigations and analysis of the mass flow efficiency of glass microspheres using directional acoustic sensors. The main objective of the conducted research is the identification of relationships between flow parameters and characteristics of recorded acoustic signals, with particular emphasis on frequency-domain analysis [1-5].

The research included experimental investigations of glass microsphere flow in a pneumatic conveying system together with the acquisition of generated acoustic signals. The analysis covered time-domain waveforms, frequency spectrum estimation, and power spectral density of the recorded signals. Preliminary results revealed the occurrence of characteristic frequency peaks as well as significant changes in spectral power distribution depending on flow velocity and the amount of transported material.

It was observed that higher flow velocities generate distinct maxima within specific frequency bands (Fig. 1.), whereas lower frequencies are characterized by an increase in spectral power associated with air flow. Further research will involve extended experimental analyses and modelling of relationships between flow parameters and acoustic signal properties.

The obtained results may contribute to the development of monitoring, diagnostics, and optimization methods for pneumatic conveying processes of granular materials using non-invasive acoustic techniques.

a)



b)

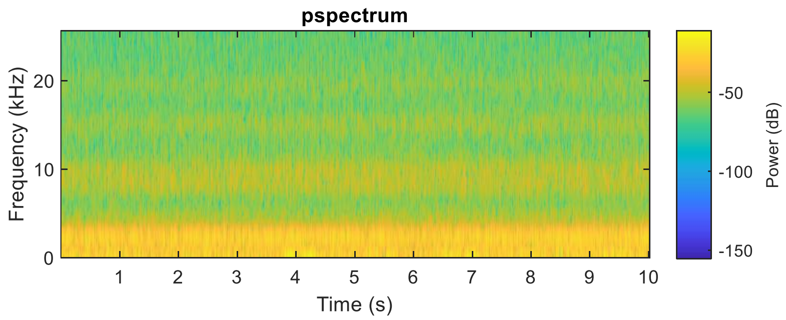


Fig. 1. Spectrograms of selected flow tests, where: a) microphone 1, b) microphone 2

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INFLUENCE OF PHASE TRANSITIONS AND CRYSTAL STRUCTURE REORIENTATION ON THE PROPERTIES OF NiTi ALLOY

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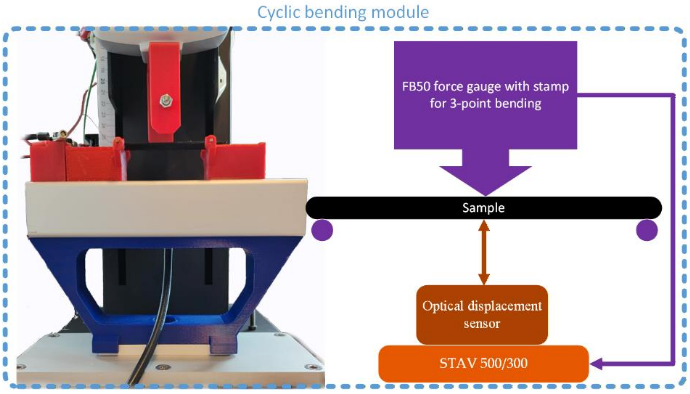
For many years, industrial sectors focused on so-called “smart” solutions have experienced rapid development and a proliferation of innovative applications [1]. This trend aligns with modern technological paradigms, such as the Fourth Industrial Revolution and the Internet of Things. The growing demand for smart structures has also increased the need for sensors, actuators, and controllers. However, their integration affects the weight, volume, and energy consumption of devices [2], creating a market niche for so-called “smart materials,” which are capable of combining the functions of actuators, sensors, and controllers within a single component [3, 4].

Smart materials include magnetorheological fluids, piezoelectric materials, and shape memory alloys (SMAs). Among SMAs, most industrial applications rely on nickel–titanium (NiTi) alloys. Owing to their unique properties, these alloys are used in the manufacture of orthodontic devices, vascular stents, hybrid aircraft bearings, temperature-activated valves, vibration damping systems, and actuators..

This paper discusses the possibility of using NiTi alloys in sensor systems and actuators made of polymer composites. As part of this work, a series of experimental tests were conducted at the author's research station, using NiTi alloy wires with a small diameter not exceeding 375 μm.



Test stand cyclic bending module

Issues related to the use of NiTi alloys in sensory systems and actuators were addressed, as well as issues connecting these two areas. Initial studies showed the effect of deformation and reorientation of structures on the change in resistance of thin NiTi alloy wires. During cyclic stretching of a NiTi alloy sample with constant displacement, a decrease in electrical resistance was observed after each successive stretching cycle. Further studies of the electrical properties of NiTi alloys focused on composite structures. For this purpose, samples were developed consisting of simple composites with a PLA matrix with a NiTi alloy wire embedded inside. Cyclic bending tests of composite samples confirmed that for NiTi alloy wire embedded in a polymer matrix (PLA), a decrease in resistance was also observed after each successive load cycle. By testing NiTi alloy actuators in a series arrangement with a spring, a relationship was demonstrated between the contraction of the wire and the force it generates and the temperature of the wire, and thus the current used to heat the wire. It was shown that as the current intensity falls below the nominal value and the temperature decreases, the resulting shortening and the generated force also decrease. An actuator was developed which is a simple composite consisting of a NiTi alloy wire embedded inside the matrix, loaded with a constant force applied by a stamp in the central part of the sample. The deformation caused by the load was partially compensated by activating the actuator, causing changes in the NiTi alloy. In order to facilitate the design of actuators and sensors using NiTi alloys, the parameters of the NiTi alloy material model were determined. For this purpose, the tensile curve of the NiTi alloy was determined experimentally. The first simulations confirmed good agreement between the model and the experimental results.

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RIGID FINITE ELEMENTS IN MODELLING OF PLANETARY GEARS

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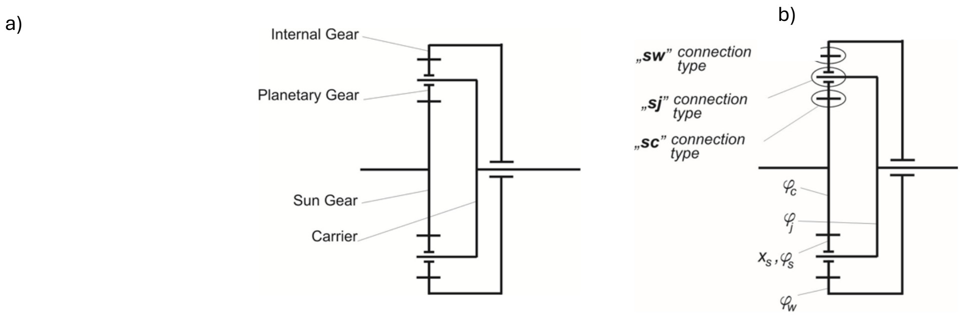
In the paper a method of building the torsional vibration mathematical models of planetary gears, also for multi stage gears is presented. The method is based on calculations of stiffness matrices which correspond to the mesh stiffness and bearing stiffness of satellites.

By now, a lot of mathematical models describing the dynamics of planetary gears were elaborated. From simplest, single stage gearboxes of torsional vibrations only, through models of multistage gearboxes, to the spatial ones. The aim of this paper was to represent a method of building mathematical models of planetary gears in case of torsional vibrations in matrix form. The method is assumed to work in a general way for an arbitrary planetary gear. It was assumed that the system consists of rigid elements (gears and a carrier) which are connected each to other by means of weightless elastic-damping elements.



Physical model of the planetary gear based on a real complex object, a) signle stage planetary gear, b) connetction types between the elements of a planetary gear and general coordinates

The Lagrange's equation of the second kind was used to elaborate a mathematical model of the planetary gear in a matrix form. It was assumed that the system consists of rigid elements (gears and a carrier) which are connected each to other by means of weightless elastic-damping elements.

The characteristics of the elements result from the meshes and satellite bearings. On the basis of the above, three following types of mutual elastic-damping connections of elements of the planetary gear, were defined:

- mesh stiffness of the pair *satellite – sun gear* (connection type *„sc"*),

- mesh stiffness of the pair *satellite – internal gear* (connection type *„sw"*),

- satellite's bearing stiffness in the carrier (connection type *„sj"*) (Fig).

The general coordinates arranged in a column matrix are represented by the following equation

$$\boldsymbol{q} = \left[x_s, \varphi_s, \varphi_c, \varphi_w, \varphi_j\right]^T.$$

Because of the arrangement of the general coordinates in column matrix shown above, the global mass matrix of a planetary gear has a form as follows:

$$\boldsymbol{M} = diag(s \cdot m, s \cdot I_s, I_c, I_w, I_j),$$

where: m_s – mass of a satellite, I_s,I_c,I_w,I_j –moments of inertia of a satellite, a sun gear, an internal gear and a carrier, respectively, *s* – number of satellites.

Calculating derivatives of the potential energy of the connection *satellite – sun gear* with respect to the general coordinates: x_s, ϕ_s, ϕ_s , then calculating derivatives of the potential energy of the connection *satellite – internal gear* with respect to the general coordinates: x_s, ϕ_s, ϕ_c and at the end calculating derivatives of the potential energy of the connection *satellite – carrier* with respect to the general coordinates: x_s, ϕ_j and substituting the results into the second kind of Lagrange's equation, one can obtain a global stiffness matrix **K**. The global damping matrix **B** one can calculate in the same way as the stiffness one, taking into account the damping coefficients instead the stiffness ones.

Finally, the dynamic equation of motion of the planetary gear in matrix form is described by the well-known following equation:

$$\boldsymbol{M}\ddot{\boldsymbol{q}} + \boldsymbol{B}\dot{\boldsymbol{q}} + \boldsymbol{K}\boldsymbol{q} = \boldsymbol{Q}$$

where: $\boldsymbol{Q}$ – column matrix of the general forces.

The presented method in this paper enables building the mathematical models of the planetary gearboxes in a very simple way, even complex multistage ones. The method presented in this article allows for the very simple development of mathematical models of planetary gears, even for complex multi-stage gears. This method is particularly useful for computer-aided automated analysis.

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MODAL ANALYSIS AS A REFERENCE METHOD FOR ACOUSTIC IDENTIFICATION OF BEAM STRUCTURES

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This study presents a comparative investigation of classical experimental modal analysis and acoustic-based identification methods applied to beam structures. In earlier work by the author, an attempt was made to verify whether acoustic methods can be used for detecting changes in the structural properties of mechanical systems. The main advantage of such an approach lies in the possibility of assessing the technical condition of a structure without the need for complex and time-consuming measurement setup preparation.

At the same time, acoustic-based methods have significant limitations. In many cases, they are qualitative in nature and strongly dependent on the experience of the operator performing the measurement and interpreting the results. Therefore, the present study aims to investigate the possibility of correlating acoustic responses generated during impact excitation with modal parameters obtained using reference experimental modal analysis.

The investigations were conducted on simplified beam structures in the form of cantilever beams, characterized by different geometric parameters and boundary conditions. The variation of these parameters allowed for the analysis of the influence of structural stiffness on the obtained dynamic responses.

The beams were excited using an instrumented modal hammer, which enables precise application and measurement of impact force. The dynamic responses of the system were recorded simultaneously using two types of sensors: accelerometers measuring structural vibration accelerations, and measurement microphones capturing the acoustic signal generated by the vibrating structure. This approach enabled simultaneous analysis of both structural vibrations and the sound emitted by the structure.

Experimental modal analysis was performed using the SCADAS XS data acquisition system and Siemens Simcenter Testlab software. Within the analysis, frequency response functions (FRFs), natural frequencies, and selected modal parameters describing the dynamic behaviour of the tested beams were determined.

FRF analysis enabled the identification of characteristic resonance peaks corresponding to successive natural vibration modes of the structure. Based on this, natural frequencies were determined and subsequently compared with results obtained from acoustic signal analysis.

In parallel with vibration measurements, acoustic signal analysis was carried out. For this purpose, Fast Fourier Transform (FFT) spectral analysis was applied, allowing transformation of the time-domain signal into the frequency domain.

The obtained acoustic spectra contained dominant frequency components, which were then compared with modal frequencies identified through experimental modal analysis. Particular attention was given to the agreement between resonance frequencies determined from FRFs and dominant peaks observed in the acoustic spectra.

The influence of beam stiffness and support conditions on the dynamic response of the system was also investigated. Variations in these parameters significantly affected both the values of natural frequencies and the intensity of peaks observed in the acoustic signal.

Preliminary results indicate that acoustic measurements allow for the identification of changes in the structural properties of mechanical systems. However, no linear relationship between the recorded acoustic signals and changes in structural stiffness could be demonstrated. Nevertheless, the obtained results indicate that the acoustic signal may contain relevant information about the dynamic state of the structure.

The conducted modal analysis allowed for the identification of natural frequencies and mode shapes of beams with different parameters. However, the study was limited to individual beam specimens. Considering that both vibration modes and the impact location of the modal hammer influence the responses recorded by accelerometers, a similar dependence is expected to exist for acoustic measurements. Therefore, it appears justified to verify this relationship for microphone-based measurements as well. In particular, it is reasonable to perform acoustic measurements using several microphone positions in order to assess the spatial variability of the recorded acoustic responses.

IMPACT RESPONSE OF THE MULTI-LAYERED COMPOSITE WITH HYBRID REINFORCEMENT – EXPERIMENTAL INVESTIGATION

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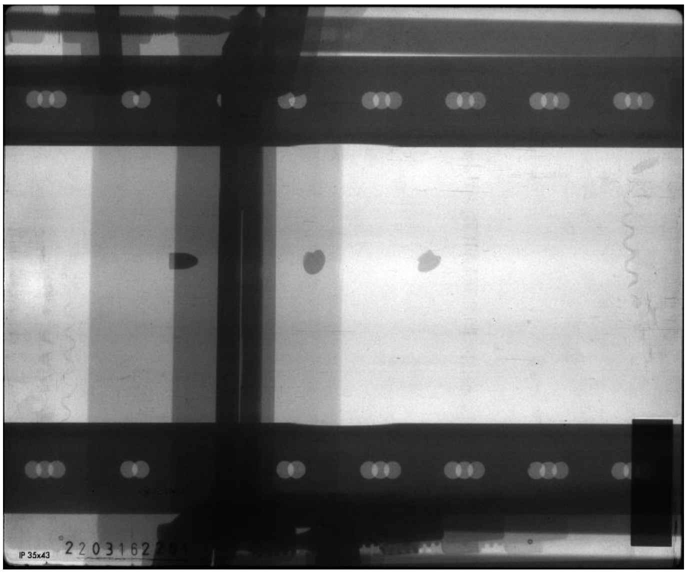
Multi-layered composite reinforced with continuous fibers are commonly used in many branches of industry. High popularity of these materials results from their mechanical properties such as low density, high strength and stiffness [1]. Regardless of the application, these materials are exposed to impact loads. The most demanding case is to use multi-layered composites as energy-absorbing panels and personal protective equipment. Multi-layered composite materials impact load resistance is a complex issue which depends on many factors such as e.g.: type of the used reinforcing fibers, materials used as a matrix or selected manufacturing technology. During the impact into the multi-layered composite material, the following energy-absorbing phenomena can be observed: tensile failure of primary yarns, deformation of secondary yarns, shear plugging delamination, matrix cracking, friction and plastic deformation of the striker [2]. Thus, a lot of energy-absorbing phenomenon depends on used reinforcement. Therefore, conducted research is focused on the impact response of the epoxy based multi-layered composite with hybrid reinforcement made of aramid and carbon fibers.

Performed investigation was aimed at determining the decrease in projectile velocity during the penetration of an energy-absorbing plate. Test was carried out for 11 different variants of multilayer composite materials. Sixteen-layer energy-absorbing panels with dimensions of 200 × 200 mm were manufactured using the hand lay-up method with vacuum assistance. LG285 epoxy resin and the HG285 hardener recommended by the manufacturer were used as the matrix material. Fabrics made of aramid fibers and carbon fibers were used as reinforcement. Energy-absorbing panels consisting exclusively of aramid fibers or carbon fibers were produced, as well as hybrid-reinforced panels composed of eight reinforcing layers of aramid fibers (A) and eight reinforcing layers of carbon fibers (C). The stacking sequence of the reinforcing layers in the hybrid panels differed in each of the analyzed cases. During the tests, 9 × 19 mm Parabellum ammunition was used. In order to increase the repeatability of the projectile velocity, the amount of gunpowder contained in each cartridge was precisely measured. The average initial projectile velocity was 370 m/s. The tested energy-absorbing panels were mounted in a steel frame positioned at an angle of 90° to the projectile trajectory. A velocity measurement barrier used to determine the projectile's initial velocity was placed at a short distance from the tested specimen. The impact was recorded using high-speed Shimadzu HPV-X2 camera and X-ray equipment. Based on the recorded video and images, the projectile velocity after penetration of the tested panels was determined. Exemplary image registered by X-ray is presented in Figure 1.



X-ray image of a projectile penetrating the multilayer composite panel reinforced by aramid fibers

The greatest decrease in the velocity of the Parabellum projectile during penetration of the tested energy-absorbing panels was recorded for the variant reinforced exclusively with aramid fiber fabric. The mushrooming process of the projectile was also the most advanced in this case. The smallest reduction in projectile velocity was recorded for the variant reinforced exclusively with carbon fiber fabric. Among the hybrid-reinforced panels, the greatest reduction in projectile velocity was recorded for the configuration in which eight reinforcing layers made of aramid fibers were placed between two four-layer carbon fiber face sheets (4C8A4C). A slightly smaller reduction in projectile velocity was recorded for the 8C8A configuration.

The smallest reduction in projectile velocity was observed for the configuration in which the aramid and carbon fiber reinforcing layers were arranged alternately (ACACACACACACACAC). Based on the results obtained for the hybrid-reinforced energy-absorbing panels, it can be concluded that the greatest reduction in projectile velocity was observed in the cases where the aramid fiber reinforcing layers were located on the side opposite to the impact side. Furthermore, greater reductions in projectile velocity were observed for configurations in which the aramid fiber reinforcing layers were arranged consecutively.

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NUMERICAL ANALYSIS OF THREE-POINT BENDING OF ALUMINIUM SANDWICH PANELS WITH ALUMINIUM FOAM CORE

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Aluminum foam sandwich panels offer an attractive combination of low mass and high flexural stiffness, making them suitable for lightweight structural applications. Despite growing interest in their mechanical behaviour, the quantitative influence of foam-core thickness on stress distribution, deformation response, and bending stiffness under three-point bending remains insufficiently characterised through systematic numerical analysis. This study presents a finite element investigation of aluminum sandwich panels subjected to quasi-static three-point bending, conducted in ANSYS Workbench 2025 R2. Each panel consisted of two aluminum face sheets of constant 2 mm thickness bonded to a closed aluminum-foam core modelled using a crushable-foam plasticity constitutive law. Three core thicknesses were examined: 12 mm, 14 mm, and 16 mm, with identical support spans and loading geometries across all configurations to isolate the effect of core thickness. Mesh convergence was verified prior to parametric analysis. The results demonstrate that increasing core thickness from 12 mm to 16 mm reduces peak directional deflection and improves global bending stiffness. The 12 mm configuration exhibited the highest localized deformation and core shear, whereas the 16 mm panel sustained the most favorable von Mises stress distribution, with load transfer extending over a greater structural depth. Stress concentrations in all cases were highest at the loading contact zone and face-core interfaces. These findings confirm that foam-core thickness is a governing parameter in the flexural performance of aluminum sandwich panels and provide quantitative design guidance for selecting core geometry under bending-dominated service conditions.

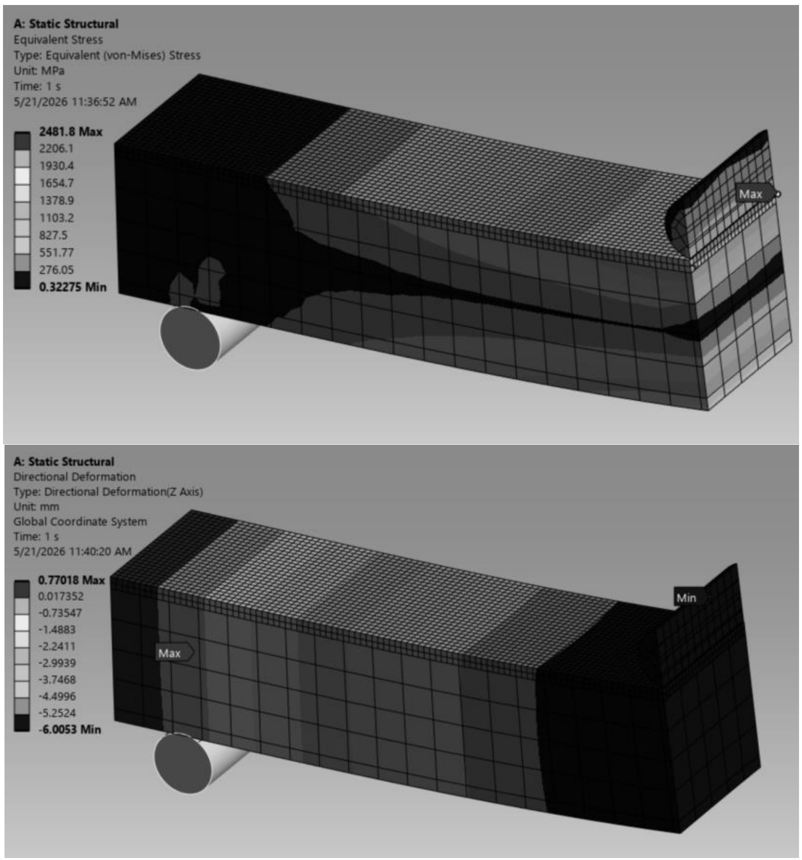

Fig. 1. Equivalent von Mises stress distribution and Z-directional deformation of the aluminum foam sandwich panel with a 16 mm core under three-point bending.

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THE USE OF POLYURETHANE RESIN IN MEDICINE

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Polyurethane resins belong to a group of modern polymer materials widely used in many branches of industry, including medicine. Due to their mechanical, chemical, and biological properties, polyurethanes have become one of the key materials used in the production of medical devices. Their flexibility, abrasion resistance, sterilization capability, and biocompatibility make polyurethane resins highly valued in general medicine as well as in specialized fields such as cardiac surgery, orthopedics, and dentistry [1].

Polyurethanes are materials produced through the reaction of polyols with isocyanates. Depending on the components used, materials with very different properties can be obtained — from soft and flexible to rigid and highly durable. In medicine, the following characteristics are especially important:

- high mechanical resistance,
- resistance to bodily fluids,
- good compatibility with the human body,
- ease of shaping and processing,
- resistance to bacteria and disinfectants.

One of the most important applications of polyurethane resins is the production of disposable and reusable medical equipment. Polyurethanes are used in the manufacturing of:

- catheters,
- medical drains,
- blood and infusion bags,
- cable and wire coatings,
- components of diagnostic equipment.

This material is valued for its flexibility and resistance to bending. In the case of catheters, reducing the risk of tissue irritation is also very important.

Polyurethanes in Implantology

Polyurethane resins are also used in implantology. They are applied in the production of vascular implants, prosthetic components, and artificial heart valves. Polyurethane materials interact well with body tissues and demonstrate relatively high biological durability.

In orthopedics, polyurethanes are used as components of modern limb prostheses and as cushioning materials in joint elements. Due to their flexibility, they can partially imitate the natural properties of human tissues.

Application in Dressings and Wound Treatment

Modern polyurethane dressings are widely used in the treatment of chronic wounds, burns, and pressure ulcers. Polyurethane foams are characterized by their ability to absorb exudate while maintaining an appropriate moisture level within the wound. Such dressings:

- accelerate the healing process,
- reduce the risk of infection,
- protect the wound from external factors,
- improve patient comfort.

Additionally, thin polyurethane films are used as transparent dressings that allow wound monitoring without the need for removal.

Use in Dentistry

In dentistry, polyurethane resins are used in the production of impression materials, orthodontic appliance components, and dental prostheses. Their advantages include abrasion resistance and the ability to accurately reproduce shapes.

Polyurethanes are increasingly used in modern 3D printing technologies for creating individually customized prosthetic components.

The Future of Polyurethanes in Medicine

The development of biomaterials engineering has made polyurethane resins increasingly technologically advanced. Research is currently being conducted on biodegradable polyurethanes, materials with antibacterial properties, and smart implants capable of responding to changes occurring within the body [2].

In the future, polyurethanes may play an even greater role in regenerative medicine, 3D tissue printing, and the development of modern personalized implants.

Conclusion

Polyurethane resins are extremely important materials in modern medicine. Thanks to their properties, they are used in the production of medical equipment, implants, dressings, and dental solutions. The dynamic development of technology means that the importance of polyurethanes will continue to grow, and their applications will become even more innovative and effective in patient treatment.

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DETERMINATION OF THE INFLUENCE OF CROSS-SECTION ON THE COMPRESSIVE STRENGTH OF STRUCTURAL PROFILES USED IN THE AEROSPACE INDUSTRY

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Abstract. This study examines the influence of cross-sectional geometry on the compressive performance of aerospace structural profiles. I-, T-, and Z-shaped sections are analyzed under axial loading using finite element simulations in LS-DYNA, with Aluminum Alloy 2024-T4 as a constant material. Parametric variations in dimensions are applied to represent realistic conditions. The analysis focuses on deformation behavior and failure modes, including buckling. Results are compared to identify the most efficient configurations. The findings emphasize the importance of geometry in structural optimization and support simulation-driven design of lightweight aerospace structures.

Keywords: Structural profiles, Finite Element Method, Aerospace structures.

1. Introduction

Structural profiles are essential in engineering design due to their efficiency in load-bearing and deformation resistance. Since their development in the 19th century, standardized shapes such as I-, T-, and Z-sections have been widely used, including in aerospace applications where high strength-to-weight ratios are critical.

Advances in computational methods, particularly finite element analysis using tools such as LS-DYNA, have enabled more accurate evaluation of structural behavior under complex loading conditions. In aerospace structures, compressive loads and associated failure modes like buckling are key design considerations.

This work investigates the mechanical response of selected thin-walled profiles under axial compression through numerical simulation. By comparing different geometric configurations under consistent material conditions, the study aims to identify structural characteristics that improve stiffness, deformation resistance, and overall efficiency in lightweight aerospace applications [1].

2. Simulation Setup

The simulation setup was developed to evaluate the compressive behavior of selected aerospace structural profiles under controlled loading conditions using LS-DYNA. To ensure consistent and reliable comparison between the analyzed configurations, the numerical model was defined through three main aspects: material selection, geometric modeling, and boundary conditions. These parameters were carefully established to represent realistic structural behavior while isolating the influence of cross-sectional geometry on performance and failure response.

2.1 Material selection

Aluminium alloys are among the most widely used structural materials in the aerospace industry due to their excellent strength-to-weight ratio, corrosion resistance, and manufacturability. These properties make them a cost-effective and reliable choice for lightweight, high-performance aircraft structures subjected to demanding loading conditions. The material selected for this study is Aluminium Alloy 2024-T4, a commonly used aerospace-grade alloy known for its high mechanical strength and good fatigue resistance. Owing to its extensive application in aircraft fuselage and wing structures, it provides a suitable material model for evaluating the compressive behavior of thin-walled structural profiles under realistic operating conditions.

Table 1. Mechanical and physical properties of aluminium alloy 2024-T4 [2] used for the numerical analysis

Property	Value
Density	2780 kg/m^3
Young's modulus (E)	73,000 MPa
Yield strength	325 MPa
Tangent modulus	1000 MPa
Poisson's ratio (v)	0.33

2.2 Geometry

Three thin-walled structural profiles with I-, T-, and Z-shaped cross-sections were selected for the numerical investigation. All profiles were modeled with a uniform thickness of 2 mm and analyzed at two different span lengths: 250 mm and 500 mm. These geometries were chosen due to their common use in lightweight aerospace structures and their distinct load-bearing characteristics, allowing the influence of cross-sectional shape and span length on structural performance to be evaluated.

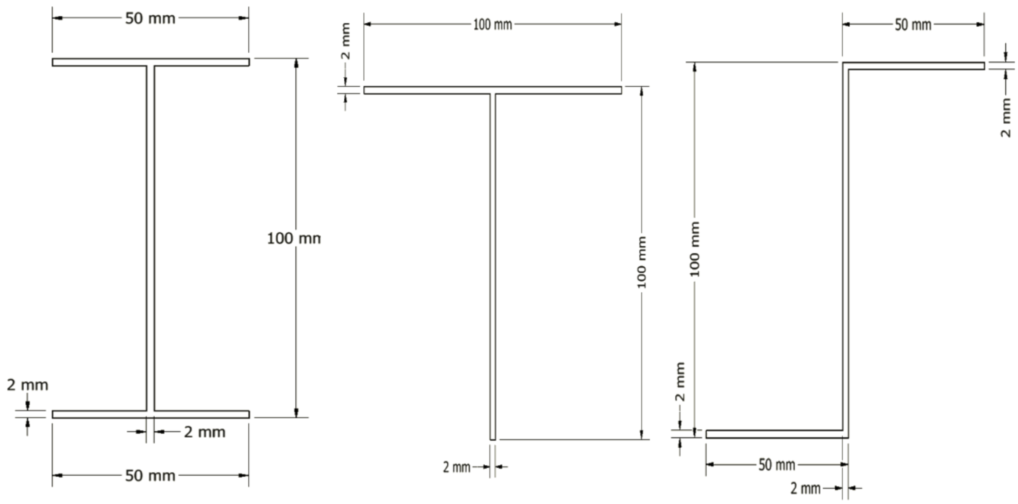

Fig. 1. I beam, T, Z section geometry

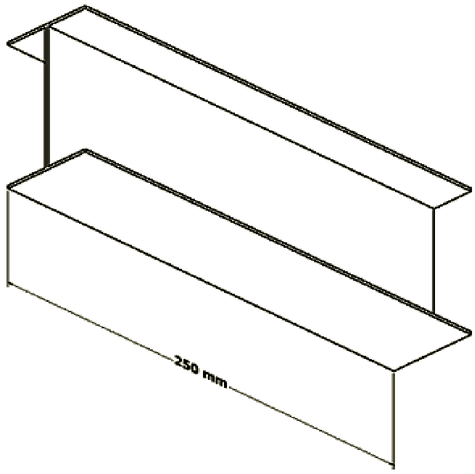

Fig. 2. 250 mm I beam, which will be applied for all other sections

2.3 Boundary Conditions

The simulations were performed in LS-DYNA using thin-shell finite elements to efficiently represent the behavior of thin-walled structures under compression. Each profile was positioned between a fixed plate and a moving plate, where axial displacement was applied at a constant velocity of 10 mm/s. Reaction forces generated force–displacement curves, while Von Mises stress and plastic strain distributions were used to identify stress concentrations, deformation patterns, and failure initiation during loading.

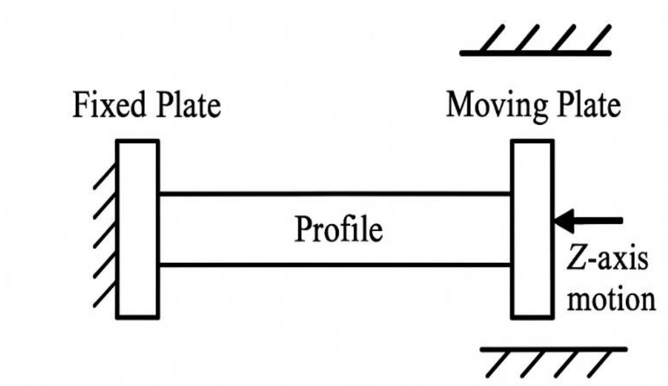

Fig. 3. Schematic representation of the test setup used for the analysis, showing the profile positioned between a fixed plate and a moving plate strictly in the longitudinal (Z-axis) direction without deflection in any other direction

3. Analysis

The analysis focused on the deformation behavior of the structural profiles under axial compression. Structural response was evaluated through longitudinal force–displacement curves, which describe the compressive force transmitted during loading and provide insight into stiffness and failure progression.
To further assess structural performance, Von Mises stress and plastic strain distributions were analyzed using contour maps on the deformed geometries. Von Mises stress was used to identify regions approaching yielding, while plastic strain highlighted areas of permanent deformation and damage initiation. These results enabled direct comparison of the mechanical behavior and failure characteristics of the I-, T-, and Z-section profiles under different span conditions [3].
For brevity, this article presents the analysis of the 500 mm I-section configuration as a representative example of the simulation procedure and structural response.

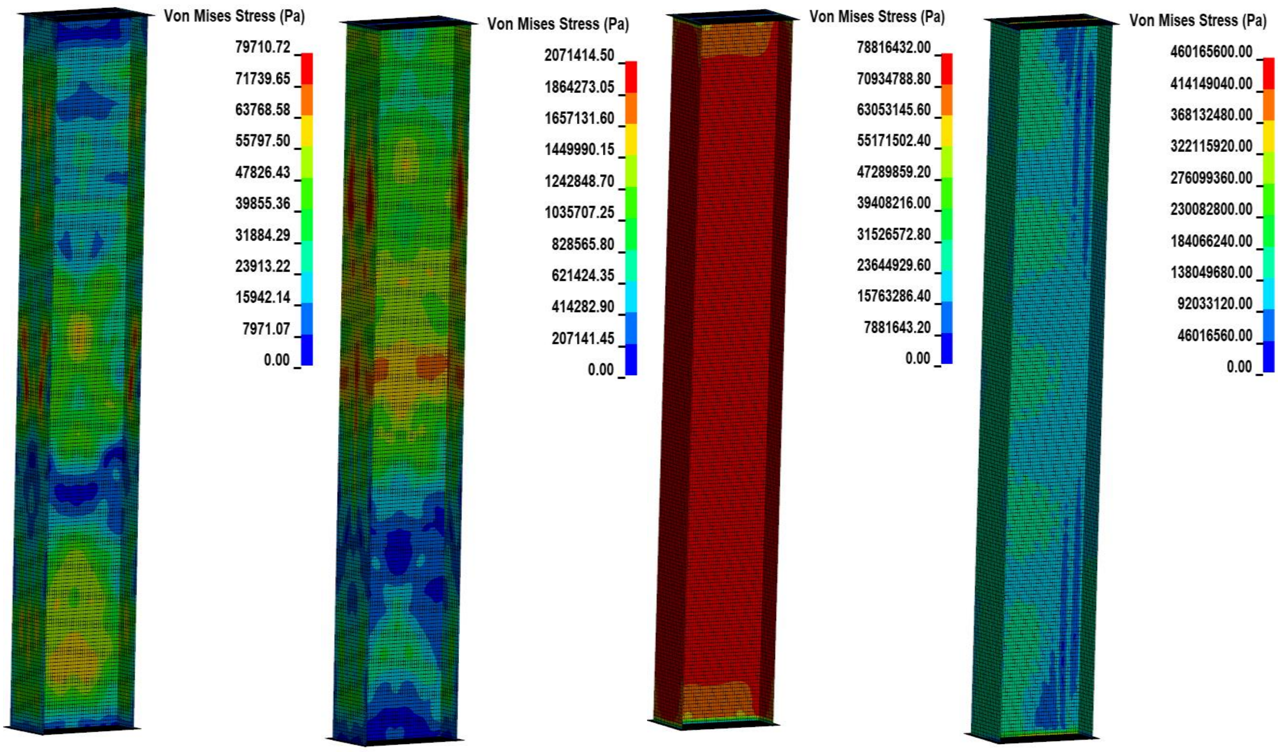

Fig. 4. Von Mises Stress Distribution for different amounts of compression for the 500 mm I-beam

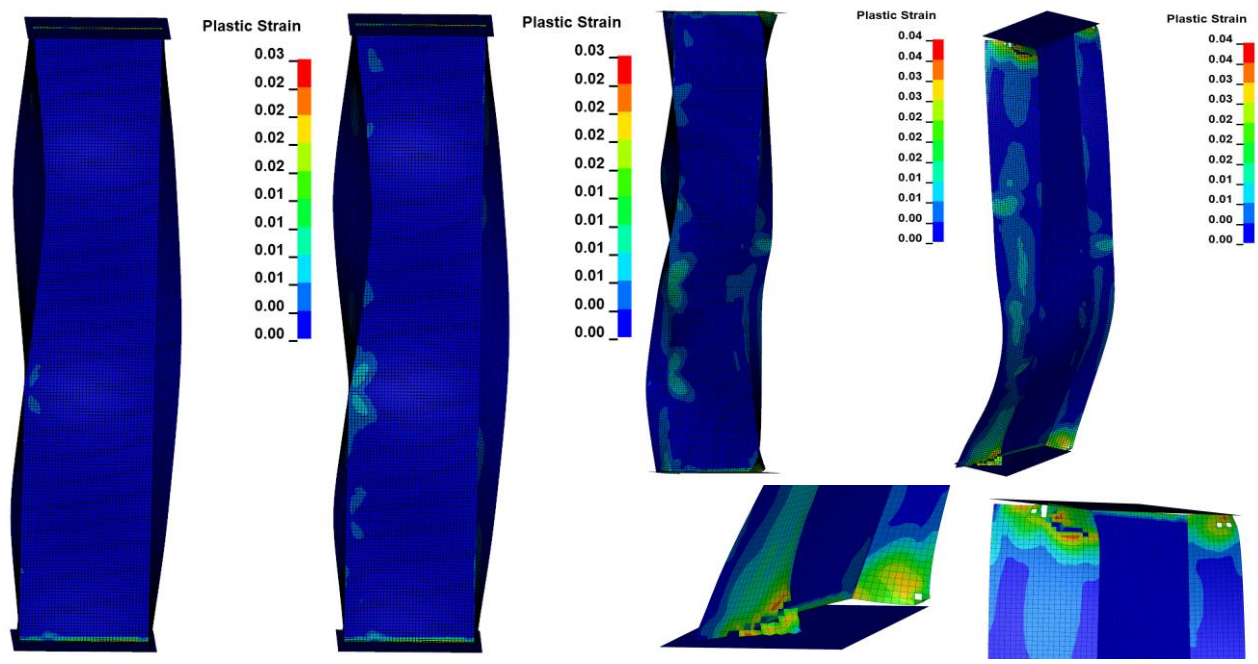

Fig. 5. Plastic strain distribution before and after failure, highlighting the cracks that occurred on the 500mm I-beam

4. Results and comparison

Fig. 6 presents the comparison of displacement-to-length ratios at failure for the 250 mm and 500 mm span configurations. The results show that the longer 500 mm profiles exhibit lower displacement-to-length ratios than the 250 mm profiles, indicating better geometric stiffness efficiency. Although the absolute displacement values are greater for the longer spans, their deformation relative to total length is proportionally smaller.

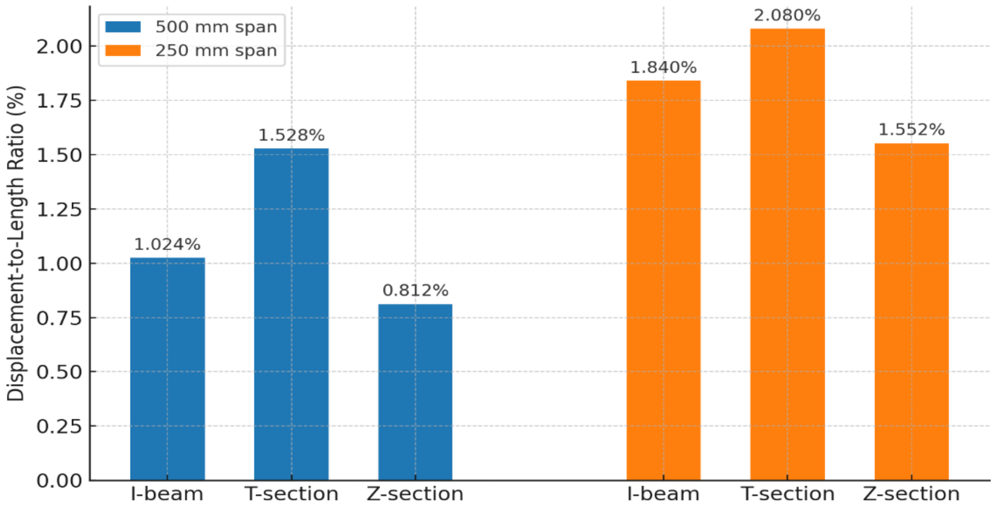

Fig. 6. Comparison of displacement-to-length ratios at failure for 500 mm and 250 mm long spans

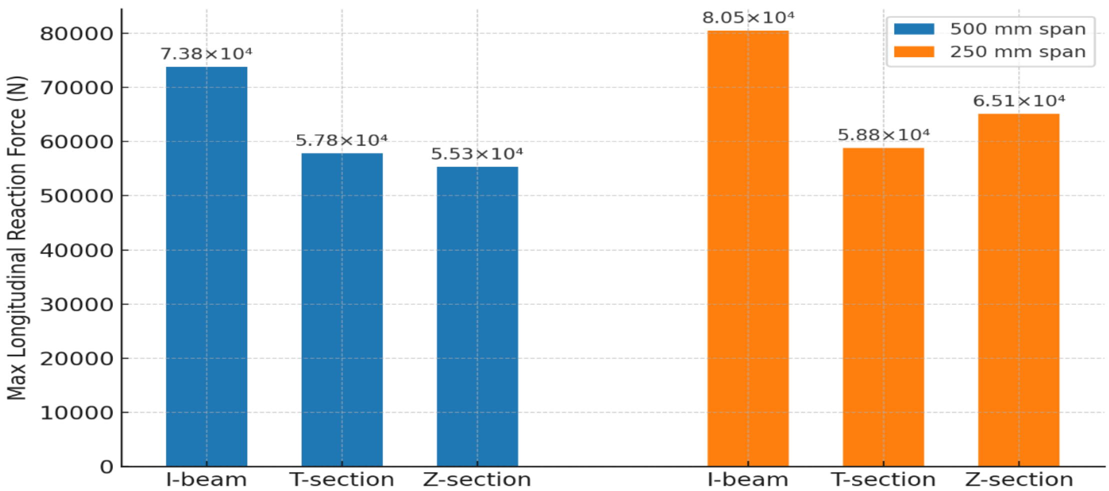

Fig. 7. Comparison of the maximum Force endured by 500 mm and 250 mm long spans

As presented in Fig.7. For the 500 mm span, the peak force ranking was I-section > T-section > Z-section, while at 250 mm the Z-section surpassed the T-section, becoming the second strongest configuration. Reducing span length increased the maximum force capacity for all profiles, with the Z-section showing the greatest improvement (approximately 18%) and the T-section the smallest. These results demonstrate the significant influence of cross-sectional geometry on compressive performance.

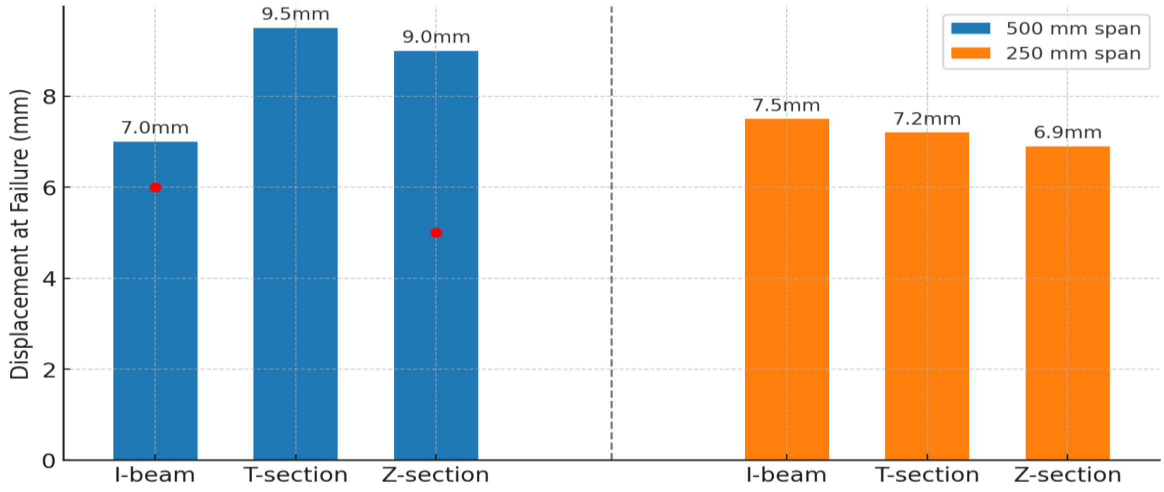

Fig. 8. Displacement at failure for I, T, And Z sections with red dots indicating local failure

Fig.8 illustrates the displacement at failure for all analyzed profiles, with red dots indicating the onset of local failure prior to global collapse. These points correspond to irreversible damage initiation, such as cracking or plastic strain concentration near the flange–web junctions. For the 500 mm span, the I-section failed at 7 mm displacement, while the T-section exhibited the longest deformation capacity at 9.5 mm, followed by the Z-section at 9 mm. In the 250 mm configurations, all profiles failed at lower displacement values, with the Z-section showing the shortest failure displacement at 6.9 mm.

5. Conclusion

The results demonstrate that cross-sectional geometry strongly influences the compressive performance and deformation behavior of thin-walled aerospace profiles. The I-section exhibited the highest load capacity and the most consistent failure response across different spans, making it the most predictable and structurally stable configuration. The T-section showed the longest failure duration at larger spans but lower stiffness and limited improvement with span reduction, while the Z-section proved most efficient in minimizing deformation relative to span length and benefited most from shorter spans, despite showing local instability in longer configurations.

Overall, the study confirms that there is no universally optimal profile; suitability depends on the structural role and performance requirements of the aerospace component. I-sections are advantageous for fuselage frames requiring predictable strength, Z-sections are well suited for short-span wing stiffeners where deformation control is critical, and T-sections may be beneficial in secondary structures requiring gradual energy absorption.

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