ELECTRICAL RESISTANCE MEASUREMENT FOR STRUCTURAL HEALTH MONITORING OF COMPOSITE MATERIALS

CTU
CZECH TECHNICAL UNIVERSITY IN PRAGUE

AUTHOR:
ING. NIKOLA SCHMIDOVÁ[1]

SUPERVISOR:
PROF. ING. MILAN RŮŽIČKA, CSC.

DOCTORAL STUDY PROGRAMME:
MECHANICAL ENGINEERING

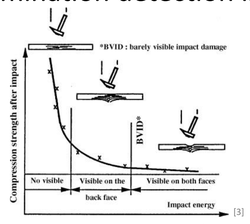
STUDY FIELD:
MECHANICS OF RIGID AND DEFORMABLE BODIES AND ENVIRONMENT

MOTIVATION

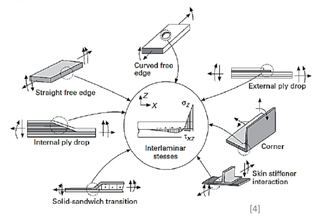
Carbon fiber composites - used for structural components across the aircraft, automotive, manufacturing industries and in civil infrastructure (reinforcement of bridges and roofs), because they excel by their high strength, rigidity, low density, damping properties, and fatigue resistance. They have also notable drawback - tendency to exhibit minimal signs of damage before failure. Structural Health Monitoring for imapact damage detection, cracks and delamination detection is needed.


[1]


[2]



[3]



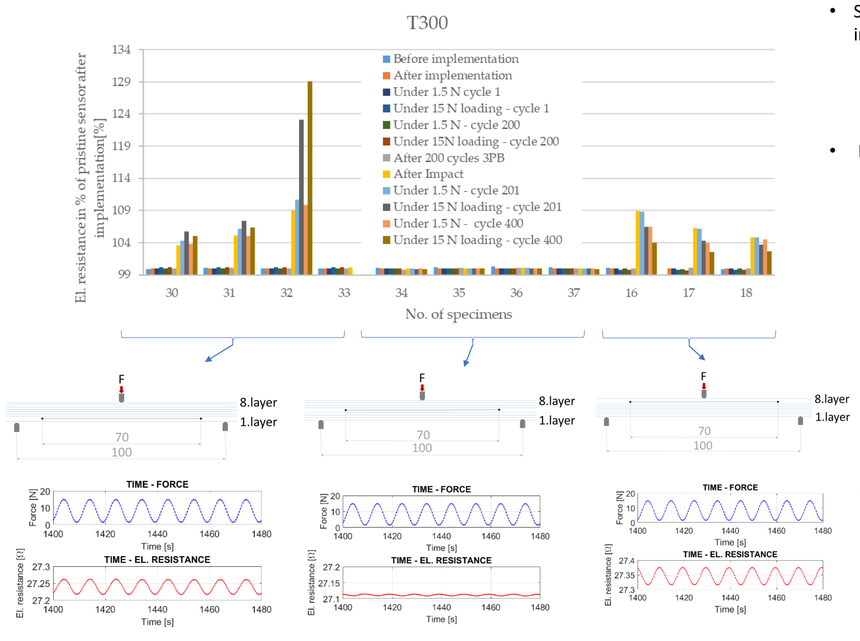
[4]

In this work we focus on two specific approaches: carbon fiber roving for damage detection (**CF SENSOR**) and the measurement of the electrical resistance response of the whole composite (**ERCM METHOD**), because these methods have sveral advantages:

- They utilize the intrinsic bearing material of the structure.
- The methods can be tailored to specific applications, which are known to be challenging for other methods (e.g., impact damage detection, delamination of complex shaped structures).
- The equipment and materials required are available and relatively inexpensive, a factor often decisive for practical applications.

A. IMPACT DAMAGE DETECTION USING CF SENSORS

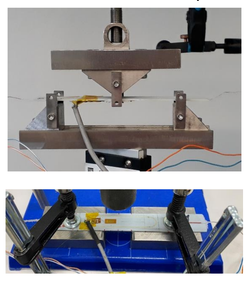
Is it possible to detect impact using sensor made of carbon fiber tow? – YES (also for BVID)



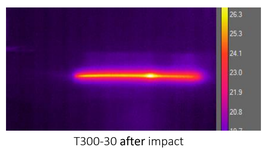
- Seven types of carbon fiber tow were investigated in three experimental campaigns.

cyclic mechanical loading → impact loading (BVID) → cyclic mechanical loading

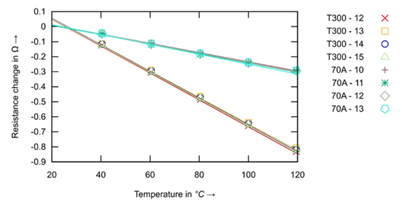
- Best results for PAN CF tow Toray T300 1000-50A



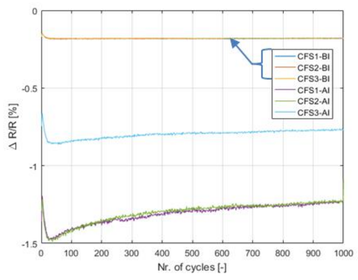
Thermographic inspection of the integrated CF sensors in GFRP composite was verified.

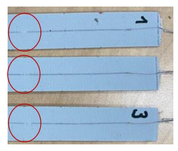

T300-30 after impact

Influence of temperature on CF sensors



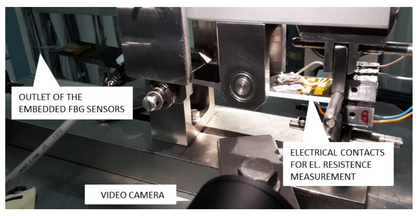
Influence of cyclic loading on CF sensors



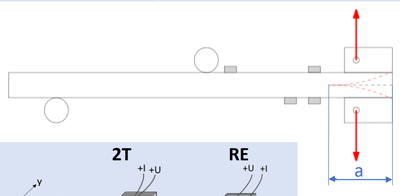

Bottom side of the specimen after 2J impact

B. DELAMINATION DETECTION USING ERCM METHOD

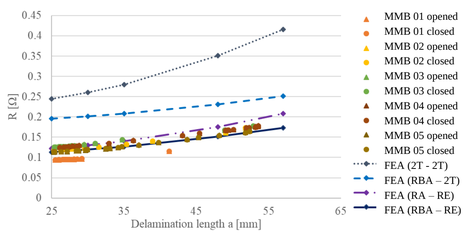
Influence of the values of nominal resistivities was studied using numerical simulation of delamination growth. Numerical simulations were conducted using the nominal resistivities obtained by several methods published in literature.



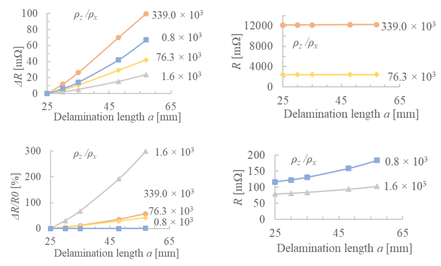
ρ_x [Ωm]	2T / RA	RBA	RCA
AV	0.00020 / 0.0001	0.000076	0.000079
ST. DEV.	0.00004 / -	0.000007	0.000004



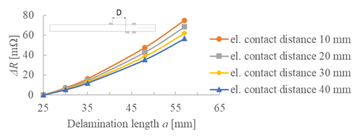
ρ_z [Ωm]	2T	RE
AV	0.120	0.060
ST. DEV.	0.034	0.005



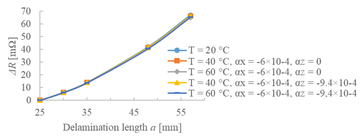
Influence of the electrical resistivities



Influence of the electrical contact configuration

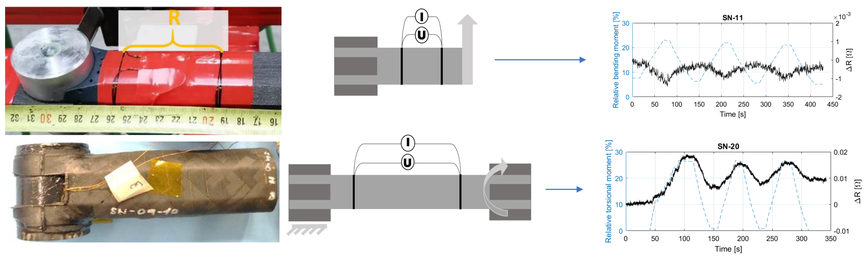


Influence of the temperature coefficients of the rezistivity and temperature change



C. EXPERIMENTAL VERIFICATION ON COMPONENT LEVEL

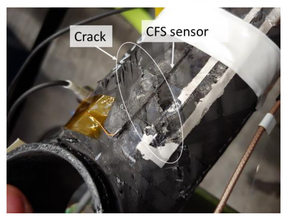
The electrical contacts were integrated into the composite structure during filament winding process → ERCM during torsional and flexural loading of the component.



CF sensors with braided sleeve during integration

Detail of connecting wire of CF sensors with braided sleeve after manufacturing

CF sensor installed on the surface for detection of cracks



CF cloth with deposition of copper

CONCLUSIONS

- The aims of the thesis were accomplished.
- The main contribution of the thesis are:
  - Verification of possibility of impact damage detection using CF sensor and mapping the effects influencing the feasibility of the detection (temperature, positioning in the lay-up, length of the sensor).
  - Determination of the influence of the methodology of electrical resistivity determination on delamination detection using ERCM method. Specification of the influece of temparature change and electrical contact configuration.
  - A novel approach for electrical contact manufacturing on the inner side of CF filament wound profile was suggested and verified for ERCM method.

SELECTED PUBLICATIONS

- N. Schmidová, et al. "Impact Damage Detection of a Glass Fabric Composite Using Carbon Fiber Sensors with Regard to Mechanical Loading", Applied Sciences, 2022, 2022(12), ISSN 2076-3417. DOI 10.3390/app12031112
- [A6] N. Schmidová, A. Horoschenkoff, and M. Růžička, "Investigation of The Electrical Resistivity of Damaged Carbon Fibers Sensors with Regard to SHM", In: Proceedings of the 18th European Conference on Composite Materials, Athens, 2018-06-23/2018-06-28. University of Patras, 2018. Available from: http://www.eccm18.org
- [A14] N. Schmidová, et al., "Damage Detection of CFRP Filament Wound Tubes Using Electrical Resistance Measurement", In: MOREIRA, P. and L.F. GALRAO DOS REIS, eds. Procedia Structural Integrity. European Structural Integrity Society, 2022. p. 1306-1313. ISSN 2452-3216. DOI 10.1016/j.prostr.2022.12.166
- N. Schmidová, et al., "Funkční vzorek integrovaného spoje vybaveného snímači pro SHM". [Functional Sample] 2021.

[1]"Aero Vodochody AEROSPACE a.s.", aero.cz, 2018. [Online]. Available: http://www.aero.cz/cz/o-nas/media/novinky/novy-velitel-vzdusnych-sil-cr-potvrdil-zajem-o-l-39ng/. [Accessed: 2018-08-31].
[2] "Compotech", Compotech.com, 2023. [Online]. Available: https://compotech.com/what-we-do/machine-tool/automation-and-manipulation/. [Accessed: 2023-12-09].
[3] S. Petit, C. Bouvet, A. Bergerot, and J. -J. Barrau, "Impact and compression after impact experimental study of a composite laminate with a cork thermal shield", Composites Science and Technology, vol. 67, no. 15-16, pp. 3286-3299, 2007.
[4] Raju, "Interlaminar Progressive Failure Analysis of Composite Curved Aircraft structural components using MSC MARC", Documents.pub. .

AIMS OF THE THESIS

A. DEVELOPMENT OF IMPACT DETECTION METHOD USING CF SENSORS

- Verify possibility of impact damage detection using CF sensors – find appropriate CF tow.
- Determine following influences to damage detection:
  - the influence of cyclic mechanical loading of the structure, temperature and positioning of the sensor in the stacking sequence of the composite
- Propose inspection of CF sensors and verify the proposal.
- Quantify the influence of the length of the sensor to change of electrical resistance after impact.
- Describe the relationship between electrical resistance change measured on integrated CF sensor after impact and mechanical response of the structure to the impact.

B. METHODOLOGY OF DELAMINATION DETECTION USING ELECTRICAL RESISTANCE MEASUREMENT ON THE CFRP COMPOSITE

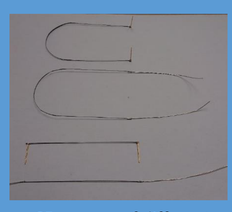
- Based on experimental investigation and numerical simulation determine the appropriate procedure for electrical resistivity determination in longitudinal and through-thickness direction.
- Determine the electrical resistivity of CF composite with thermoplastic matrices and compare it to the electrical resistivity of the CFRP composite.
- Specify the influence of temperature change, electrical resistivities of the material and electrical contact configuration.

C. EXPERIMENTAL VERIFICATION ON COMPONENT LEVEL

- Propose and verify the method of electrical insulation of CF sensors incorporated into a carbon fiber composite structure.
- Propose and verify a methodology for electrical contact preparation for ERCM method on the filament wound components.

CF SENSOR

Carbon fiber tow + nickel coated ends + soldered copper wire contacts. CF sensor shows piezoresistive behavior. Can be used for strain sensing.


CF sensors of different shapes before integration

ERCM METHOD

Electric Resistance Change Measurement method – electrical resistance is measured directly on the composite material.

[1] Nikola.Schmidova@fs.cvut.cz