

Université de technologie de Compiègne – Thesis proposal

Part 1: Scientific sheet			
Thesis proposal title	Structural health monitoring of polymer-matrix composites (PMCs) using embedded piezoelectric transducers: experimental and numerical approaches		
PhD grant	Cotutelle thesis between “Université de Technologie de Compiègne” (UTC) - France and “Politecnico di Torino” - Italy		
Research laboratory	Research units: Roberval (Mechanics, energy and electricity) laboratory (FRE UTC-CNRS 2012) and Mul2 Research Group (Polytechnic School of Turin). Research team : “Materials and Surfaces” team of Roberval laboratory Web sites: https://roberval.utc.fr http://www.mul2.polito.it/index.php/home		
Thesis supervisors	<table style="width: 100%; border: none;"> <tr> <td style="width: 50%; vertical-align: top;"> Erasmus Carrera, Professor Politecnico di Torino Mul2 Research Group Corso Duca degli Abruzzi, 24, 10129 Turin, Italy Phone: +39 011 090 6836 e-mail: erasmo.carrera@polito.it http://www.mul2.polito.it/index.php/home </td> <td style="width: 50%; vertical-align: top;"> Walid Harizi, Associate professor Université de Technologie de Compiègne Roberval laboratory CS 60319, 60203 Compiègne Cedex Phone: +33 (0)3 44 23 46 23 e-mail: walid.harizi@utc.fr https://www.researchgate.net/profile/Walid_Harizi </td> </tr> </table>	Erasmus Carrera , Professor Politecnico di Torino Mul2 Research Group Corso Duca degli Abruzzi, 24, 10129 Turin, Italy Phone: +39 011 090 6836 e-mail: erasmo.carrera@polito.it http://www.mul2.polito.it/index.php/home	Walid Harizi , Associate professor Université de Technologie de Compiègne Roberval laboratory CS 60319, 60203 Compiègne Cedex Phone: +33 (0)3 44 23 46 23 e-mail: walid.harizi@utc.fr https://www.researchgate.net/profile/Walid_Harizi
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Scientific domain(s)	Science and technology Computer science and information technologies		
Research work	<p>General context</p> <p>Polymer-matrix composite (PMC) materials are nowadays an exciting alternative to metallic materials conventionally used in the industry. They bring many structural and functional advantages: mechanical resistance, lightness, electrical insulation and freedom of forms. Their growth is mainly linked to the development of the transport industry: aeronautics, aerospace, rail, naval and automotive. However, due to their heterogeneous, anisotropic and multilayer structure, the damage of PMCs under mechanical stresses is a fairly complex phenomenon whose experimental characterization is far from being mastered despite the abundance of research work carried out on the subject since now a few years. Indeed, the nature of the damage and the mechanisms behind its appearance and propagation are very different from those encountered in metallic materials. Thus, depending on the considered scale, damage such as rupture of the reinforcement, matrix cracking, interfacial debonding, or even delamination can be the cause of the premature failure of a PMC structure.</p> <p>The complexity of this phenomenon and the absence of a “reference” characterization method, applying both at the laboratory stage for the R&D aspect and in-situ for the monitoring and health control aspects of the structures (SHM: Structural Health Monitoring), motivate the positioning of this study in the field of non-destructive characterization of the damage of composite materials. Nevertheless, all conventional Non-Destructive Testing & Evaluation (NDT&E) methods, in particular, acoustic emission (AE), infrared thermography (IRT), ultrasound (US) are based on surface instrumentation: the transducers are conventionally glued to the surface of the material or placed at a distance well determined with remote electronics. Likewise, only a few NDT&E techniques are able to monitor damage in real-time, with specific technical constraints: no accessibility to the hottest and/or loaded areas, coupling problem for the US in contact, the dramatic drop in the ratio signal/noise due to the unsuitability of the impedances for the generated US in the air, etc.</p> <p>Methodology</p> <p>In order to overcome these constraints, the solution is to integrate, from the manufacturing stage, piezoelectric transducers inside the material and thus develop smart searchable composite structures. The main objective of this thesis would be to instrument PMC structures with a network of piezoelectric sensors (Lead Zirconate Titanate LZT or PZT and/or PolyVinylidene Fluoride PVDF) to monitor their health state in real-time during their lifespan. These sensors can be used in passive (as acoustic emission sensors or planar capacitors) or active modes (Lamb wave generators). The scientific and technological challenges to develop the SHM of composite structures are very numerous. These include:</p> <ul style="list-style-type: none"> ☞ The integration of sensors in a fibrous environment: what about intrusiveness? 		

	<ul style="list-style-type: none"> ☞ Relationship between the physical phenomena due to damage and the response of the PZT sensors integrated within the material? ☞ In the case of a complex PMC structure, the positioning choice of the sensors related to the damage to be detected? <p>The design of health monitoring systems for composite structures, based on embedded piezoelectric sensors, requires the use of numerical tools able to deal with the complex mechanics of layered materials, as well as, multifield problems. Classical Finite Element Models have been proved to be inaccurate in the analysis of layered structures and extremely computationally expensive when high accuracy, obtained using three-dimensional elements, is required. A new generation of numerical models is thus required to predict/detect the failure of composite materials. These models must ensure the following capabilities:</p> <ol style="list-style-type: none"> 1) Three-dimensional stress field prediction. The actual numerical tools are mainly based on classical structural models, that is, when two-dimensional models are considered, through-the-thickness stresses are neglected even though they play a crucial role in the failure mechanics, e.g., in the delamination. 2) Stress concentrations. The use of embedded sensors leads to local stress concentrations at the interface between the active material and the structure. These stress concentrations make the sensor a possible source of failure itself. 3) Multifield capabilities. The simulation of the piezoelectric actuator/system requires to extend the analysis at the electric field and to predict its interaction with the mechanical one. A fully coupled electro-mechanical formulation must be used to predict the electrical response that comes from a deformation of the structure. 4) Numerical efficiency. The requirements at points 1 to 3 can nowadays be fulfilled using three-dimensional classical finite elements. At the same time, the high computational cost of solid elements makes their use unpractical for real structures and is relegated to the study of coupons or specimens. <p>The development of a new family of numerical tools able to deal with the points listed above requires switching from classical to advanced models. The Carrera Unified Formulation (CHF) provides a numerical tool to generate refined kinematic models with an arbitrary level of accuracy. The use of refined kinematic models leads to the prediction of complex displacement/stress fields. The following features of the CUF could be exploited to address the problem:</p> <ul style="list-style-type: none"> • Equivalent Single Layer (ELS) VS Layer-Wise (LW) models. The use of different kinematic models makes it possible to consider a layered structure as an equivalent laminate (ESL) or, eventually, each lamina can be considered as an independent entity (LW). Layer-wise models can be used to predict accurate three-dimensional stress fields, including the interlaminar stress that causes delamination. • Global-to-local models. The efficiency of the numerical models can be increased using refined kinematic models only in those areas where complex stress fields are expected to reduce the computational costs using classical models elsewhere. The local refinement of the model can be achieved using the Node-dependent kinematic approach, recently developed in the CUF framework, and the multi-dimensional approach where 1D, 2D and 3D elements can be connected exploiting models with compatible kinematics. • Multifield models. Refined kinematic elements have been successfully used in the solution of electro-mechanical problems. The use of advanced models and three-dimensional constitutive equations provide a 3D solution in both sensor/actuator cases.
Keywords	Polymer-matrix composites (PMCs); Piezoelectric transducers; Intelligent materials; Damage; SHM; NDT&E; Carrera Unified Formulation; Multifield models.
Requirements	Looking for an engineer level student (bac + 5) or master 2, with strong scientific skills in the science of materials, composite materials, NDT&E methods and above all good skills in modeling and numerical simulation by finite element method.
Starting time	October 2020
Location	"Université de Technologie de Compiègne" – France and "Politecnico di Torino" - Italy

Part 2: Job description	
Duration	36 months
Additional missions available	To be defined with the candidates (teaching possibility)
Research laboratory	The Roberval laboratory (research unit in mechanics, energy and electricity - FRE UTC-CNRS 2012) aims to develop innovative experimental and numerical methods for the analysis, modeling and design of complex structures and systems. Mul2 (Multilayered structures and multifield analyses) Research Group (Polytechnic School of Turin) focalizes on the development of advanced structural models for the multilayered structures with particular attention given to the multifield analysis and the fluid-structure interactions.
Material resources	Experimental platform of the "Materials and Surfaces" team research of Roberval laboratory using the multi-instrumentation approach (AE, DIC, IRT, video-microscopy, testing machines, electrical measurement means ...) & Equipment of modeling and numerical simulation at Polytechnic School of Turin.
Human resources	The doctoral student will be integrated the Roberval laboratory of UTC and Mul2 Research Group of Polytechnic School of Turin, and will benefit from all the scientific and technical environments of these two research units. Support by students on a Master internship is also planned.
Financial resources	This thesis is a Cotutelle between UTC and Polytechnic school of Turin, therefore the salary of the PhD student will be ensured by the two partners with an equal half (50/50). As for the operating costs of the thesis, financing on own funds will ensure the purchase of the piezoelectric transducers and the raw material used for the manufacturing process of the PMC structures.
Working conditions	The PhD student will start his/her thesis at UTC for 18 months. After, he/she will settle in Italy for the rest of the thesis period. Whether in France or Italy, after a training phase, very regular meetings between the PhD student and their supervisors will be organized throughout the period of his/her stay.
Research project	Cotutelle
National collaborations	No
International collaborations	Yes
International cosupervision (cotutelle)	Yes, Politecnico di Torino - Italy Aerospace Engineering Department Mul2 Research Group
References	C.Tuloup, W. Harizi, Z. Aboura, Y.Meyer, B. Ade, K. Khellil. " Detection of the key steps during Liquid Resin Infusion manufacturing of a polymer-matrix composite using an in-situ piezoelectric sensor ". March 2020. Materials Today. DOI:10.1016/j.mtcomm.2020.101077. C. Tuloup, W. Harizi, Z. Aboura, Y. Meyer, K. Khellil, R. Lachat. " On the use of in-situ piezoelectric sensors for the manufacturing and structural health monitoring of polymer-matrix composites: A literature review ". Composite Structures vol. 215, pp. 127–149, 2019. C. Tuloup, W. Harizi, Z. Aboura, Y. Meyer, K. Khellil and R. Lachat. " On the manufacturing, integration, and wiring techniques of in situ piezoelectric devices for the manufacturing and structural health monitoring of polymer-matrix composites: A literature review ". Journal of Intelligent Material Systems and Structures 30(16), pp. 2351-2381, 2019. Carrera E., Zappino E., Li G. " Analysis of beams with piezo-patches by node-dependent kinematic finite element method models ", 2018, Journal of Intelligent Material Systems and Structures, 29 (7), pp. 1379-1393. DOI: 10.1177/1045389X17733332. Zappino E., Li G., Pagani A., Carrera E. " Global-local analysis of laminated plates by node-dependent kinematic finite elements with variable ESL/LW capabilities ", 2017, Composite Structures, 172, pp. 1–14. Carrera E., Cinefra M., Petrolo M., Zappino E. " Finite Element Analysis of Structures Through Unified Formulation ", 2014, John Wiley & Sons, Chichester, West Sussex.
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Please contact first the thesis supervisors before applying online
on <https://webapplis.utc.fr/admissions/doctorants/accueil.jsf>