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DEPARTMENT OF INDUSTRIAL ENGINEERING

PhD Course in Mechanics and Advanced Engineering Sciences (DIMSAI)

YEARLY PHD STUDENT REPORT - AY *2016/2017*

Curriculum number *1*
Cycle *XXX*

Candidate: *Navid Zarif Karimi*
Supervisor: *Giangiacomo Minak*

ANALYSIS OF DRILLING OF COMPOSITE LAMINATES

IL PRESENTE MATERIALE È RISERVATO AL PERSONALE DELL'UNIVERSITÀ DI BOLOGNA E NON PUÒ ESSERE UTILIZZATO AI TERMINI DI LEGGE DA ALTRE PERSONE O PER FINI NON ISTITUZIONALI

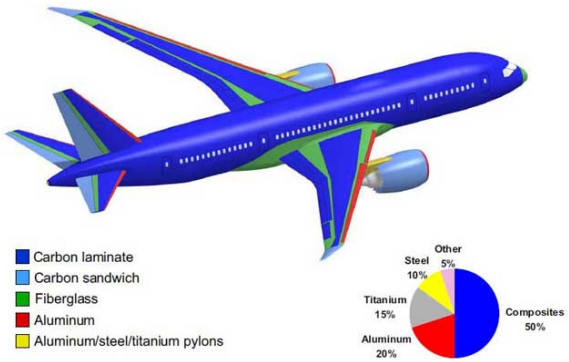
Composite Materials

What is Composite Material?

Composite material is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components.

Why Composite Materials?

- ✓ High specific stiffness
- ✓ High resistance to corrosion
- ✓ Weight saving



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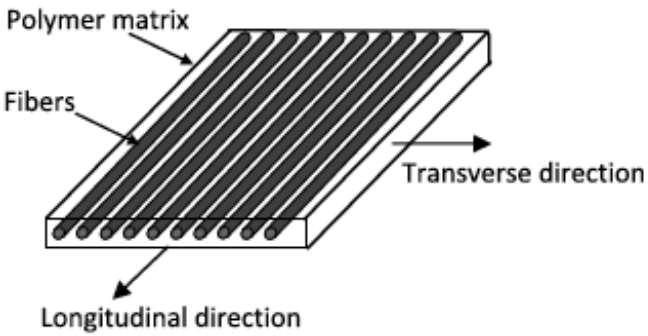
Fabrication and Manufacturing

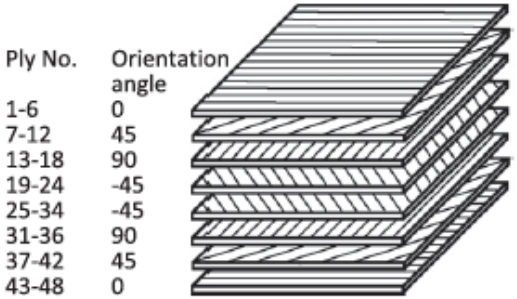
Laminated Composites:

Most fiber reinforced polymers for structural use are laminated. FRP laminates can be tailored for various applications by appropriately choosing their components, their proportions and their distributions.



Fabrication methods:

1. Primary material production (hand layup, Filament winding, Autoclave moulding, …)
2. Secondary consolidation operations (Machining, finishing, …)



Ply No.	Orientation angle
1-6	0
7-12	45
13-18	90
19-24	-45
25-34	-45
31-36	90
37-42	45
43-48	0

Although a near-net shape is obtained in the primary production of composite laminates, machining processes still required due to design considerations.

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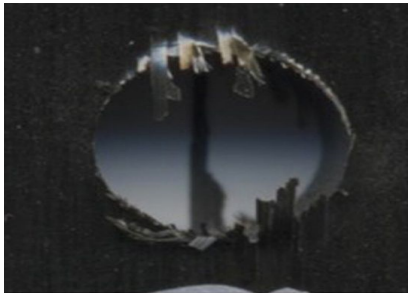
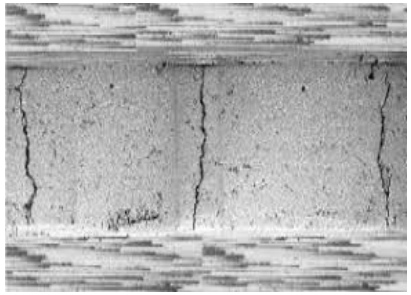
Drilling Process

- Among all machining operations, drilling is the most important process for assembling components made from composite laminates.



Composite drilling challenges?

- ✓ Nonhomogeneous and
- ✓ anisotropic behavior
- ✓ Different thermal expansion



Drilling induced damages:

- ✓ Matrix cracking
- ✓ Fiber breakage
- ✓ Hole shrinkage
- ✓ Delamination

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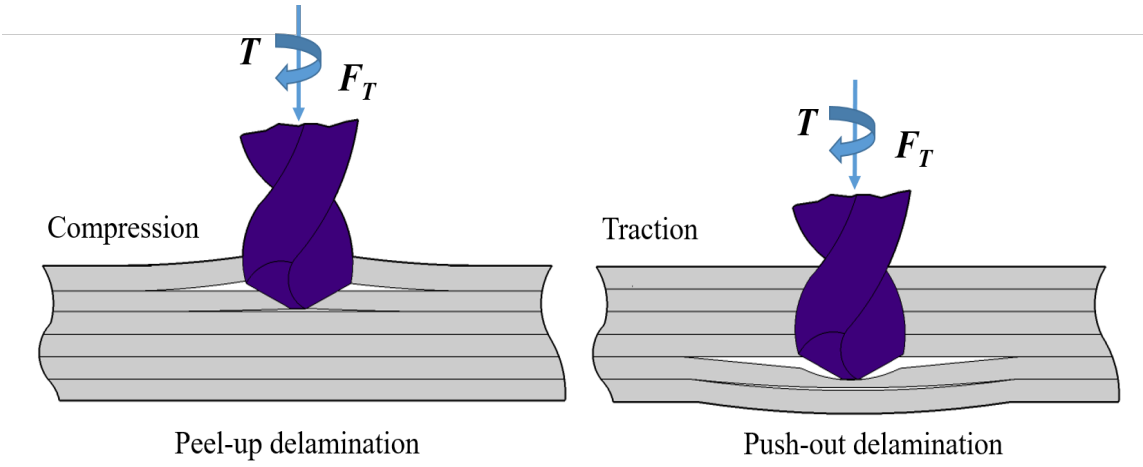
Delamination

Drilling-induced delamination

- The typical damage encountered during the drilling of composite laminates consists of delamination of layers due to the relatively poor strength of these materials in the thickness direction.
- Such damage is generally initiated when the drilling force **exceeds a threshold value** at critical stages.



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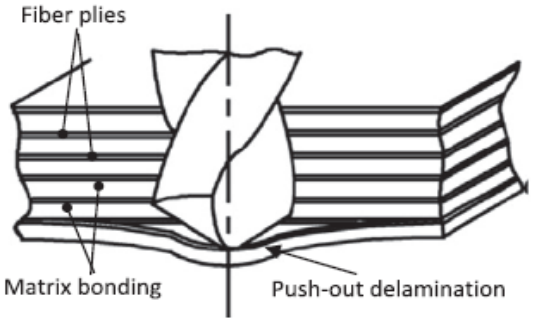
Delamination Mechanism

Exit side delamination: Push-out

- Delamination occurs as the drill reaches the exit side of the material.
- Drill bit always exerts a compressive thrust force on the workpiece.
- The laminae under the drill are subjected to bending deformation and tend to be pushed away from the interlaminar bond around the hole.
- As the drill approaches the exit, the uncut thickness becomes smaller and the resistance to deformation decreases.
- At a critical thickness, the interlaminar bond fails by the action of thrust force and an interlaminar crack is initiated around the hole.



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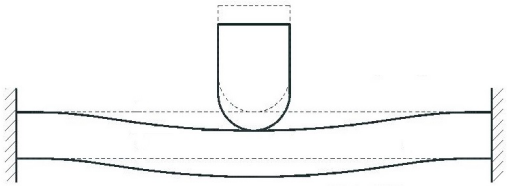
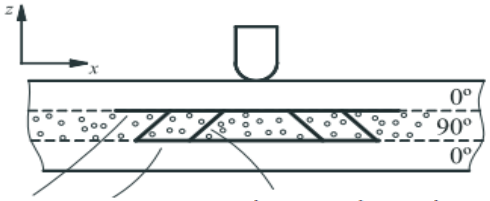
Motivation

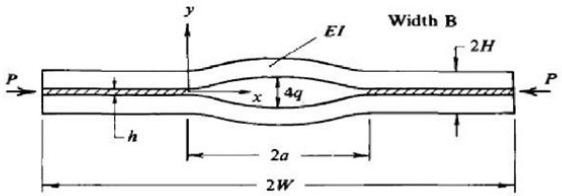
- The presence of delamination reduces the residual stiffness and strength of a laminate and thus degrade its load carrying capacity.
- Delamination can be a limiting factor in the use of composite laminates for structural applications, particularly when subjected to **compression** and **bending loads** and when exposed to moisture and other aggressive environments over a long period of time.

As delamination is so detrimental, an attempt should be made to avoid delamination in the first place.



Global response





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Objectives

The present study attempts to address some problems associated with the drilling of composite laminates and to solve those problems. It consists of **analytical investigations** as well as their **experimental verifications**.

The specific objectives of the thesis are:

1. Experimental Investigation on drilling performance of composite laminates

2. Delamination-free drilling experiments

3. Proposing novel approaches to reduce delamination in drilling of composite laminates

4. Developing an analytical model for delamination propagation

5. Online detection and monitoring of drilling process

6. Damage characterization using acoustic emission technique

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Research Activities

The research activities I have followed through during the past three years of my Ph.D. involve

(1) designing and implementing experiments

(2) developing theoretical models for delamination free drilling

(3) delivering some lectures on statistical techniques for master students of UNIBO

(4) supervising a bachelor student at UNIBO

(5) making oral presentations and posters at several international conferences

(6) publishing six research paper in high-impact scientific journals

(7) attending University of Bristol, *Advanced composite Centre for Innovation and Science*, as a visiting researcher: this involves research on laminated composites, conducting experiments and supervising two interns.

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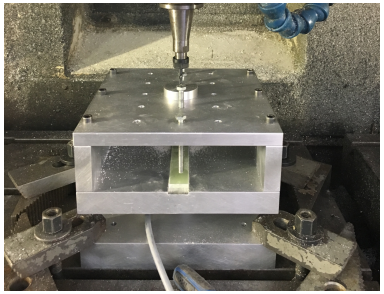
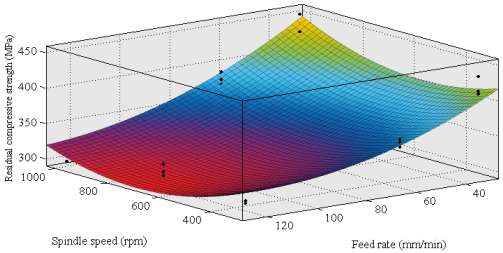
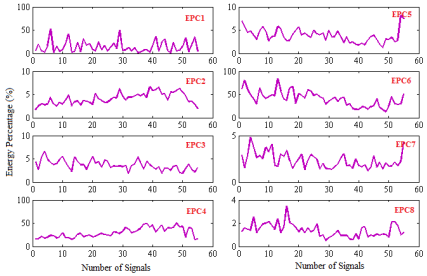
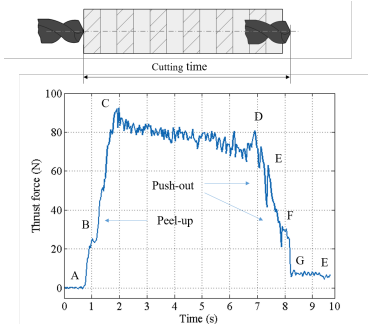
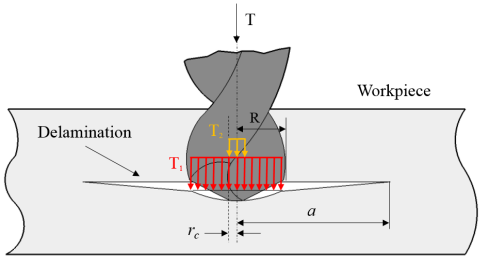
Results



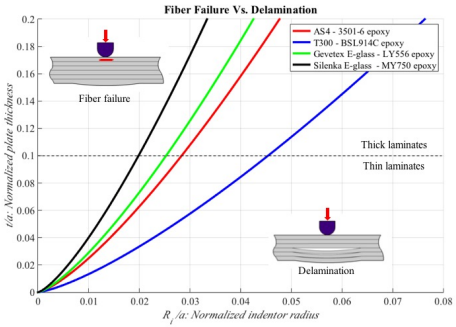


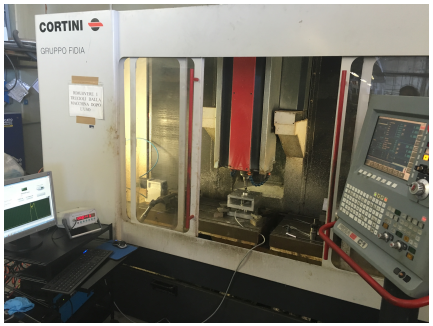


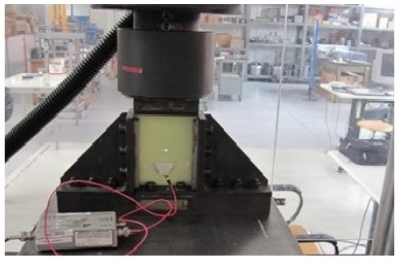


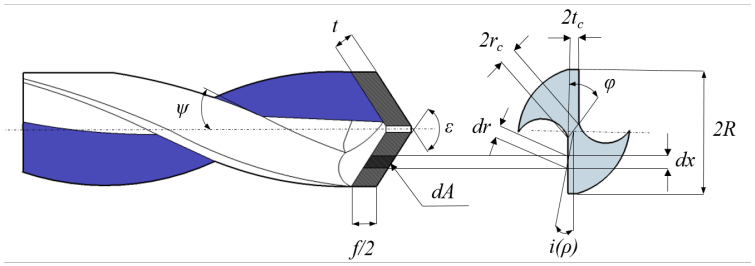


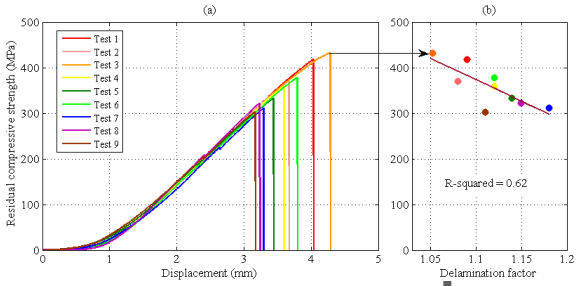
$$F_{cr}^{S} = \frac{\pi\sqrt{32G_{IC}D'}}{\sqrt{\left(J^2\left(1-\frac{1}{2}s^2\right)^2 + (1-J)^2\left(1-\frac{1}{2}\tau^2 s^2\right)^2\right)}}$$











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Achievements

Journal Papers:

1. N. Zarif Karimi, H. Heidary, G. Minak, Investigation on delamination and flexural properties in drilling of carbon nanotube/polymer composites, In press.
2. N. Zarif Karimi, H. Heidary, M. Fotouhi, G. Minak, Experimental analysis of GFRP laminates subjected to compression after drilling, Composite Structures, 169 (2017) 144-152.
3. Mahdian, J. Yousefi, M. Nazmdar, N. Zarif Karimi, M. Ahmadi, G. Minak, Damage evaluation of laminated composites under low-velocity impact tests using acoustic emission method, Journal of Composite Materials, 51 (2017) 479-490.
4. N. Zarif Karimi, H. Heidary, G. Minak, Critical thrust and feed prediction models in drilling of composite laminates, Composite Structures, 148 (2016) 19-26.
5. N. Zarif Karimi, H. Heidary, P. Kianfar, M. Hasani, G. Minak, The effect of support plate on drilling-induced delamination, Acta Polytechnica CTU Proceedings, 3 (2016) 19-24.
6. N. Zarif Karimi, G. Minak, P. Kianfar, Analysis of damage mechanisms in drilling of composite materials by acoustic emission, Composite Structures, 131 (2015) 107-114.

Conferences and Proceedings:

I actively engaged in top ranking international conferences and industrial meetings. I have drafted **18 conference papers** from the research results, in collaboration with my colleagues.

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Thank You for your Attention

Navid Zarif Karimi
Prof. Giangiacomo Minak

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