Crack Propagation in Composite Aerospace Materials under Fluid-Structure Interaction Loads using a Peridynamic Approach

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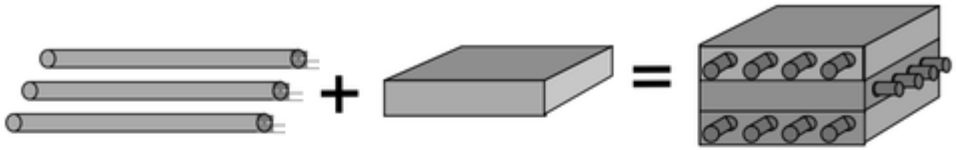
Special Mechanical Properties



Fiber/Filament Reinforcement

- High strength
- High stiffness
- Low density

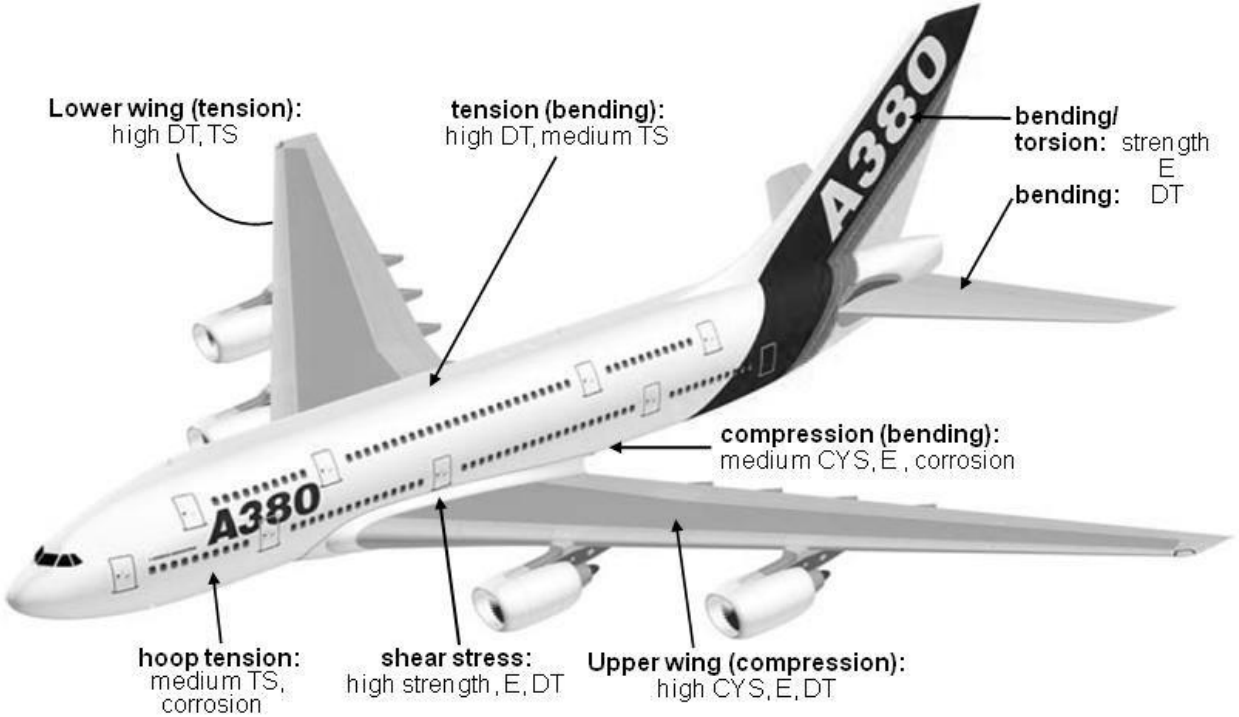
Matrix

- Good shear properties
- Low density

Composite

- High strength
- High stiffness
- Good shear properties
- Low density

Composite Materials in Aerospace Structures



(Airbus A380): CYS = compressive yield strength; E = elastic modulus; TS = tensile strength; DT = damage tolerance properties (fatigue, fatigue crack growth, fracture toughness)

Aerodynamic Loads

Aerodynamic loads on Aerospace structures

Fluid-structure interaction

Interaction occurs via the exchange of momentum through interfaces.

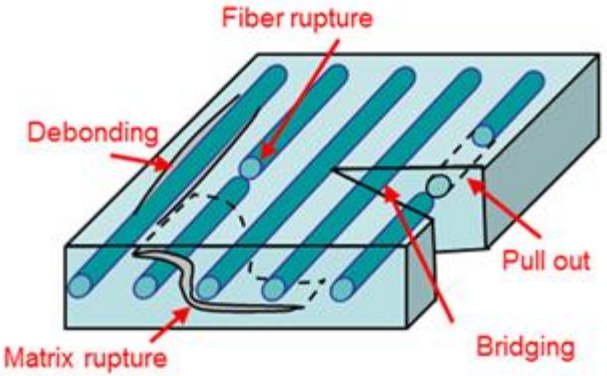
- **Resonances** due to wide range of frequencies
- Large deformations cause **large stresses**
- High-intensity **turbulences** increase **wall-stresses** on solid surfaces

Cracks initiation and propagation in aerospace structures

Cracks in Composite Materials

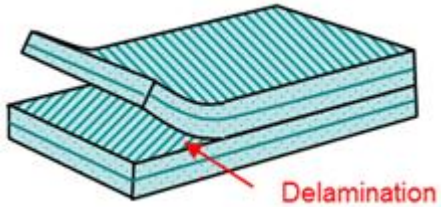
Intralaminar mechanisms:

- Matrix cracking
- Fiber splitting
- Fiber/matrix interfacial debonding



Intreralaminar mechanism:

- Delamination



Fluid-Structure Interaction

- Simplified fluid models coupled with XFEM are mostly used

To calculate hydraulic stresses and lubrication forces

- **Direct Numerical Simulation (DNS)**

To solve Navier-Stokes equations with Peridynamic equations

- **A Normal-Probe approach**

To compute fluid-dynamic stresses on immersed solid surfaces

- **The Immersed Boundary Method (IBM)**

To impose wall boundary conditions on the fluid-solid interfaces

To couple the dynamic of the solid and fluid phases

No need for re-gridding

Motivation for Peridynamic

Classical theory of continuum mechanics

Some limitations for crack propagation

- It has partial derivatives with respect to spatial coordinates, which are undefined along the cracks
- To compensate this weakness, the problem is redefined
- Not appropriate for spontaneous cracks
- Some assumptions like the time crack initiates and crack growth speed

Motivation for Peridynamic

Simulating crack propagation is a challenging task

Finite Element Method (FEM) is mostly used for analysis

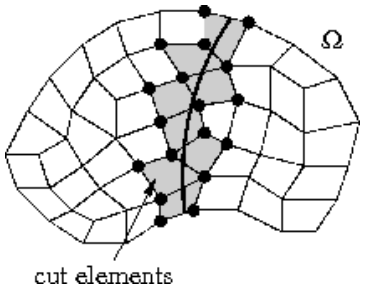
- Crack should be along element boundaries
- There is the need for re-meshing for crack growth

Extended FEM (XFEM)

- For large number of cracks, it is not appropriate

Meshless Methods

- Element free Galerkin method (FEG)
- Meshless local Petro-Galerkin method (MLPG)
- Finite point method (FPM)



Peridynamic

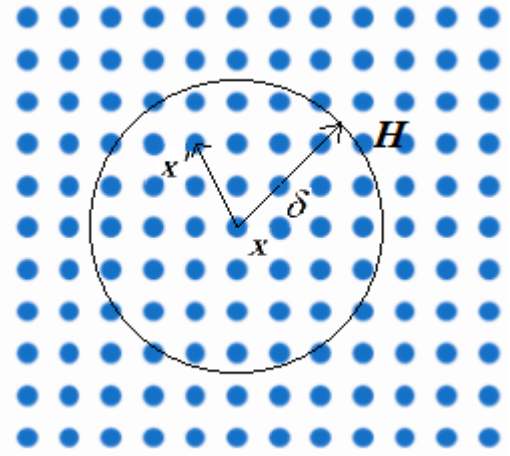
Peridynamic is a nonlocal continuum mechanics formulation (developed by Silling in 2000).

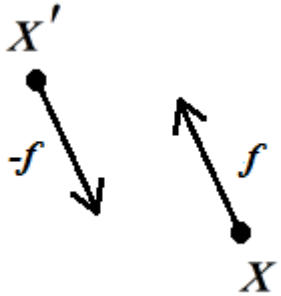
- Modeling problems with singularities like cracks
- Appropriate for large number of cracks
- Crack initiation and propagation
- Integration is used instead of differentiation

Peridynamic Formulation

$$\rho \frac{\partial^2 u(x,t)}{\partial t^2} = \int_H f\,(u(x',t)-u(x,t), x'-x, t)\, dV_{x'} + b(x,t)$$

$$f\,(u'-u, x'-x, t) = \frac{x'-x+u'-u}{|x'-x+u'-u|} c(|x'-x|) \frac{|x'-x+u'-u|-|x'-x|}{|x'-x|}$$





Purposes

- The purpose of this research is developing a **Peridynamic meshless** approach to study crack propagation in composite materials.
- A **normal-probe approach** and **Immersed Boundary Method** are used to consider fluid-solid interaction.
- It is necessary to develop a detailed mathematical model between load and crack propagation.
- Keeping a balance between **accuracy** and **computational efficiency** is an important factor.

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Thanks for the attention