Test d’adhérence par choc laser d’assemblages composite pour les besoins aéronautiques
Développements et maturité technologique

Forum ILP – June, 2018
Presentation Overview

- Why it matters?
- LASAT history, principle, & methodology

- LASAT Performances
  - Mono pulse results
  - Double pulse solution
  - Symmetrical pulse approach

- Toward industrialization…
  - …with remaining open points

- The laser shock applications landscape and trends
Introduction & Methodology
Why it matters?
Why it matters?

Typical A350 bonded assemblies + Future programs

Production

Bonding assessment by laser shock adhesion test

Bonded repairs

Space structures

Main characteristics
- L 10m, R 3m
- Thick (mm → cm)
- Bond depth fixed
- CFRP (IMA/M21E)

Why it matters
- Enable structural bonding
  ➔ Less fasteners/ “rivetless”: 1. eco-efficiency, 2. lean processes
  - Step 1: replace PCS (process control specimen)
  - Step 2: Online bonding control (CFRP, hybrid assemblies)

Why it matters
- Enable structural repair (bigger and rivetless repairs)
  ➔ Lighter repairs, more efficient repair
  - Step 1: grounded panel
  - Step 2: directly on structure

Why it matters

Main characteristics
- 0.5m × 0.5m, R 3m
- Thick (mm → cm)
- High geometry variability
- CFRP (IMA/M21E)
LASAT Brief History

- **1978**: J. L. Vossen, 1st demonstration, **1995**: V. Gupta, 1st patent for metals
- **2000**: E. Auroux, M. Arrigoni, C. Bolis, S. Barradas, thermal barriers, ceramic layers, metals...
- **2009**: D. Laporte, Starting with the thick systems (alu/glue/alu)
- **2009**: M. Perton, E. Gay (SATAC Project)
- **2009**: R. Bossi (Boeing), and LSPT
- **2011-2014**: R. Ecault PhD – ENCOMB Project
  
  *First demonstration of discrimination performances*
  
  *Identification of optimal configurations*

- **2012-2015**: D. Courapied, Arcol project
- **2015-2019**: Improving technology maturity
  
  ComBoNDT: Multi-technique project for bonding assessment
  
  COMPOCHOC: LASAT demonstrator expected in 2019
  
  MONARQUE: symmetrical laser shock

And many others…
**LASAT Principle & Methodology**

**Bond/ interface mechanical characterization**
Evaluate bonding strength  
Can be used on coupons

**LASAT for bonding assessment**
Ensure correct interface/bonding strength  
*Proof test* (non-destructive for the correct assemblies) → reveal weak bonding

**«Calibration» for the given assembly**
Expert dimensioning to identify the best configuration

**Laser Shock on target**
REVEAL WEAK BONDS

**Adapted diagnosis**
IDENTIFY DISBONDED AREAS

Post-shock ultrasound C-scan

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Romain Ecault  
Forum ILP – CNRS – 13 Juin 2018
LASAT Tools

NUMERICAL APPROACH
Numerical model validation
Mastering the stresses

EXPERIMENTAL APPROACH
Assembly response characterization
Damage threshold determination

QUANTIFICATION OPTIMIZATION

Laser/matter interaction
- Esther 1D (CEA)

Mechanics simulation
- Homemade 1D code (Hugo...)
- Commercial code with simple model (Dyna, Radioss, abaqus, elastic ortho)
- Commercial code + customized models (strain rate effect, viscosity,...)
- Academic tools (PGD, discrete elements,...)

NUMERICAL APPROACH
Shock wave

EXPERIMENTAL APPROACH
Assembly response characterization
Damage threshold determination

PDV or VISAR

Mechanics simulation
- Homemade 1D code (Hugo...)
- Commercial code with simple model (Dyna, Radioss, abaqus, elastic ortho)
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Nanosecond laser source
- 7 ns, 7J, 4mm, GW/cm²

NDT

Shadowgraphy

Nanosecond laser source
- 7 ns, 7J, 4mm, GW/cm²

PDV or VISAR

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LASAT Methodology & Optimization

**NUMERICAL APPROACH**
Numerical model validation
Mastering the stresses

**EXPERIMENTAL APPROACH**
Assembly response characterization
Damage threshold determination

**QUANTIFICATION OPTIMIZATION**

**APPLICATION DESCRIPTION**
Mat_1
Mat_2
Mat_3

**TEST MODEL**

**VALIDATION**

**CONFIGURATION SELECTION**

**TEST**

**MODEL**

**FLYING**

**TESTING**

Romain Ecault
Forum ILP – CNRS – 13 Juin 2018
LASAT Configurations

Mono pulse

- Historical configuration
- Stress distribution mainly depends on laser parameters
- Ok for assemblies for which substrates are much stronger than interfaces

Symmetrical pulses

- Most versatile configuration (Patented)
- Stress distribution can be fully adapted to the application
- Production/Repair bonding assessment
- Test of coupons (GIC replacement)

Double pulses

- Optimized configuration
- Stress distribution can be partially adapted to the application
- In-service bonding assessment (one side access)
Performances 1/4

- Material characterization under laser shock
- First discrimination performances
- Composite delamination
- First numerical validation
- First optimization loop & expected performances

**T700/M21 – FM300 Assemblies ~ 4mm thickness**

- No debonding evidenced
- Debonding evidenced
- Laser intensity (GW/cm²)

- Release agent contamination
- High moisture content
- Wrong curing state

**First optimization loop & expected performances**
Performances 2/4

M. Sagnard PhD, ComBoNDT

- New contamination tested
- Sharper contamination range tested
- Multiple contamination tested
- Curved & scarfed samples tested
- No more composite delamination

**Graph:**

- Laser Flux per Beam (GW/cm²)
- **IMA/M21E - FM300 & IMA/M21E - FM300-2M - 3mm thickness**

**Legend:**
- Release agent
- Moisture
- Finger Print
- De-icer
- Thermal degradation
Performances 3/4

M. Sagnard PhD, ComBoNDT
Performances 4/4
S. Bardy PhD, Compochoc

IMA/M21E – FM300 – Assemblies ~ 4mm thickness

- Numerical modeling of laser/matter interaction at low intensity
- Significant development of the time resolved diagnostic (PDV)
- Significant progress on composite modeling to take into account strain rate
- Residual mechanical performance assessment by testing post-shock
- Prototype assembly for full scale demonstration industrial env.

To come

Disbonding alone
Disbonding + delamination
Delamination alone
No Damage
Toward industrialization… 1/3

Compochoc prototype
Toward industrialization… 2/3

ComBoNDT full scale demonstration

<table>
<thead>
<tr>
<th>Symmetrical config Threshold</th>
<th>Total test shots sym 80%</th>
<th>Opened bond sym 80%</th>
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<td>Sound area</td>
<td>0.85GW/cm²</td>
<td>32</td>
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<tr>
<td>Contaminated area</td>
<td>0.74GW/cm²</td>
<td>21</td>
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<tr>
<td>Sound area</td>
<td>0.72GW/cm²</td>
<td>8</td>
</tr>
<tr>
<td>Contaminated area</td>
<td>0.61GW/cm²</td>
<td>8</td>
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</table>
Toward industrialization… 3/3

Hephaistos video
… with remaining open points

Laser source
- Robustness & reliability
- Stability of the parameters
- Repetition rate

Process
- Solid confinement is a must for some application
- Sensibility to laser parameter deviation on the process performance

Modeling
- Progress on phenomena description
- Two speed development necessary:
  1. Pre-dimensioning
  2. Dimensioning + quantification

Diagnostic
- Robustness (PDV, VISAR)
- Single face access
- Automation of the diagnostic (decision making on bond quality)

Transportation
- Optical arm
- Fiber delivery
  - state of the art 200 mJ
  - 1J target

Expert dimensioning / calibration
- Sensibility to the damage initiation (for calibration, not for run mode)
- Database management
- Meta Model approaches
The laser shock applications landscape and trends

- **Mono pulse**
  - **LASAT**: metal to metal assembly, metal to composite
    - *Every assembly where rupture threshold of the substrate is much higher than the one of the interface*
  - **Laser Shock Peening (LSP)** for fatigue enhancement + life extension

- **Symmetrical pulses**
  - **LASAT**: when double side access
    - *Mainly production cases*
  - **LASAT**: composite to composite
    - *Every assembly requiring optimization due to weakness of the substrate*
  - **LASAT**: process control specimen
  - **Laser Shock Peening (LSP)** for thin products to master the deformation
  - **Selective de-assembling**
  - **Calibrated defect generation**

- **Double pulses**
  - **LASAT**: when single side access
    - *Mainly repair cases*
  - **LASAT**: composite to composite
    - *Every assembly requiring optimization due to weakness of the substrate*
  - **LASAT**: repair
  - **Laser ultrasounds**: NDT technique for material quality
The laser shock applications landscape and trends

- **Ecault, Romain**
- **Forum ILP – CNRS – 13 Juin 2018**

### Energy
- **LSP**
  - 30 mJ
  - 1 J
  - 7 J
  - 10 J
  - 25 J
- **LASAT**
  - 7 J
  - 1 J

### Pulse duration
- **LSP**
  - 5 ns
  - 20 ns
  - 40 ns
- **LASAT**
  - 40 ns
  - 90 ns

### Focal spot
- **LSP**
  - 0.5 mm
  - 2 mm
  - 6 mm
- **LASAT**
  - 6 mm
  - 10 mm
  - 20 mm

### Intensity
- **LSP**
  - 1 GW/cm²
  - 4 GW/cm²
- **LASAT**
  - SID (shock induced damage)
  - 200 mJ
  - 90 ns
  - 10 mm
  - 1 kHz

### Repetition rate
- **LSP**
  - 10 Hz
  - 100 Hz
- **LASAT**
  - 10 Hz
  - 100 Hz
  - 1 kHz

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Intensity

Energy

Pulse duration

Focal spot

Repetition rate

**Fiber state of the art limit**
Thank you

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