Chocs produits par laser
Une question de plasma avant tout ?

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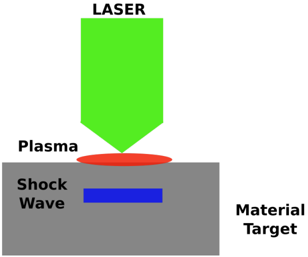
GDR Emili - Palaiseau - October 26, 2021

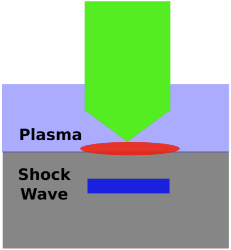
Shock produced by laser in water confinement regime



Parameters

- Pulse Duration : 1-100ns (shape)
- λ : 1.064 nm
- Spot diameter : <mm
- > **Power density : 1-10 TW/cm^2**
- > **Pressure : 100 GPa**
- > **Repetion rate : <1H**

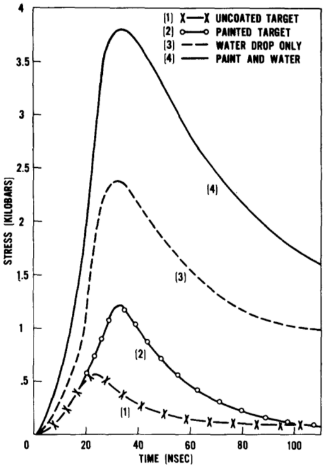
Shock produced by laser in water confinement regime



Parameters for applications

- Pulse Duration : 8-25 ns
- λ : 0.532 -1.064 nm
- Spot diameter : mm
- $>$ **Power density : 1-10 GW/cm^2**
- $>$ **Pressure : 1-8 GPa**
- $>$ **Repetion rate : 1-...1 KHz**

Why confined regime?



APL - Fox- 1974

Avantages

- Pression x4 higher than in direct regime
- Loading x2 longer than pulse laser
- Easy to apply and renew
- Cheap

Limitation

- Protective layer/ablator layer
- Breakdown plasma in confined material layer
- No use in MRO process conditions

Effect of water and paint coatings on laserirradiated targets

Jay A. Fox

Citation: Appl. Phys. Lett. **24**, 461 (1974); doi: 10.1063/1.1655012
View online: http://dx.doi.org/10.1063/1.1655012
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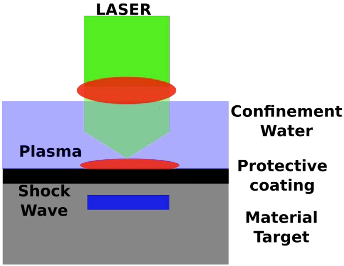
Published by the American Institute of Physics.

Why confined regime?



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ACO-CHOCOLAS
Matériaux sous Hautes Vitesses de Déformation
Groupe de recherche CNRS

High strain rate

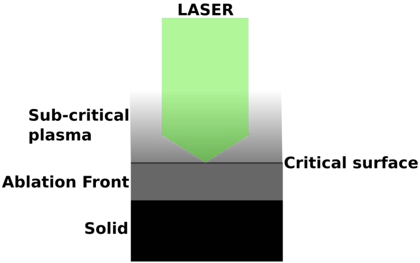
- 50 researchers
- 15 Labs
- CoCNRS 910

Procédés et Ingénierie en Mécanique et Matériaux

1 Res.

- 3 Res. Composite/Polymer
- 3 Res. SHM
- 5 Res. Metallurgist
- 1 Res. Modeling

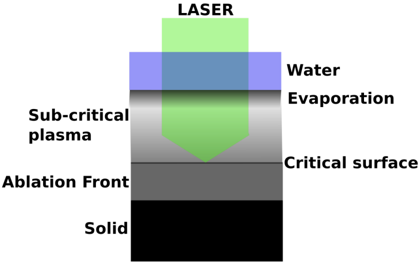
Plasma generation

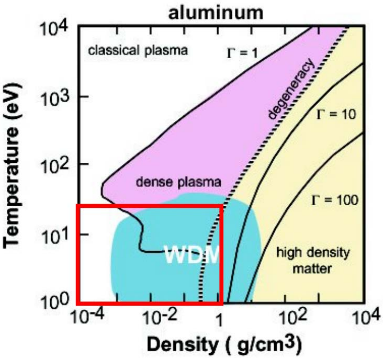


Key Phenomena

- Laser absorption in sub-critical plasma
- Conduction in ablation front
- Conduction at Plasma/water interface

Plasma generation





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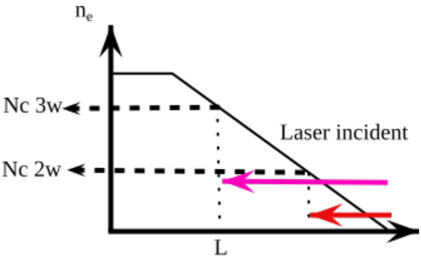
Laser Collisionnal Absorption by Inverse Bremstrahlung



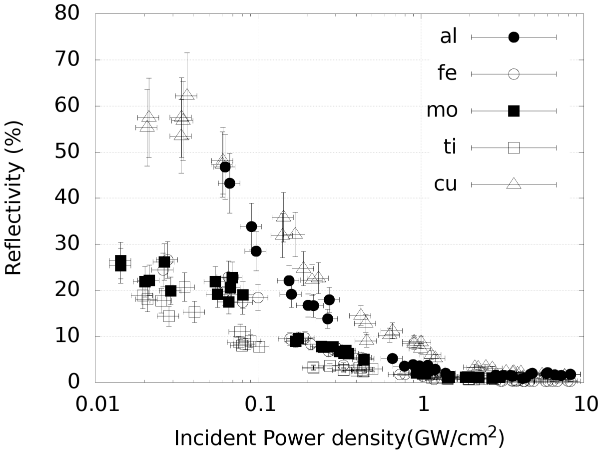
Key Phenomena

- $n_c(cm^{-3}) = \frac{10^{21}}{\lambda^2}$
- $A_{bi} = 1 - e^{\frac{ZL\lambda^2}{T_e^{3/2}}}$

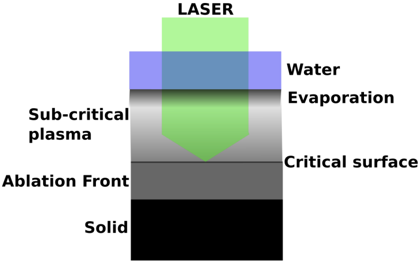
Effect

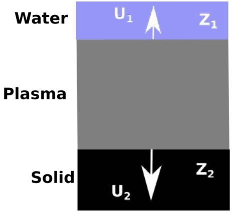
- Best effiency at short wavelength
- Dependant to gradient (Pulse duration, Power density)

Absorption - 532 nm - 10 ns : 100 %



Plasma Fabbro'model





Hypothesis

- Total absorption
- Perfect Gas
- α adjustable parameters given part of laser energy for pressure rise
- Adiabatic cooling

Physical study of laserproduced plasma in confined geometry

R. Fabbro, J. Fournier, P. Ballard, D. Devaux, and J. Virmont

Citation: J. Appl. Phys. **68**, 775 (1990); doi: 10.1063/1.346783
View online: http://dx.doi.org/10.1063/1.346783
View Table of Contents: http://jap.aip.org/resource/1/JAPIAU/v68/i2
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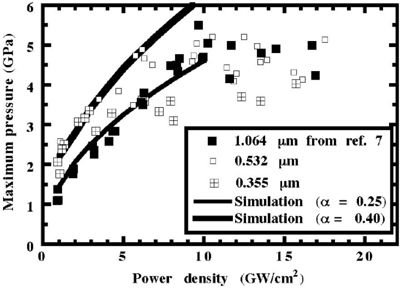
Plasma pressure - 10 ns



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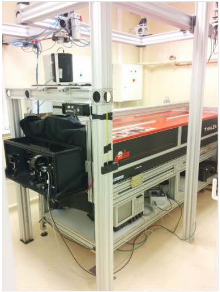
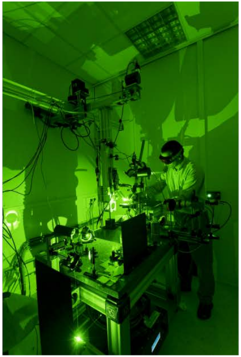
- $n_c(cm^{-3}) = \frac{10^{21}}{\lambda^2}$
- $A_{bi} = 1 - e^{\frac{ZL\lambda^2}{T_e^{3/2}}}$

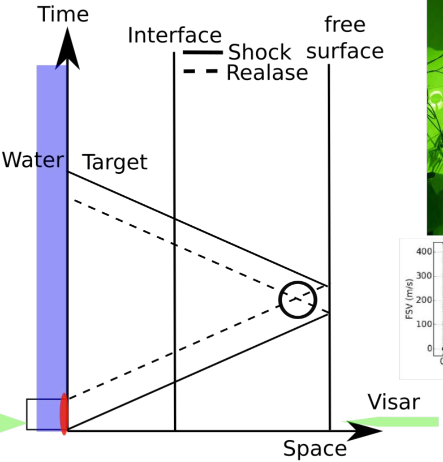
Effect

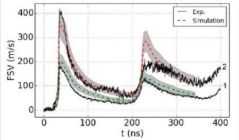
- Higher pressure at shorter wavelength
- Plasma Breakdown in water
- Good agreement with modeling but...Adjustable parameter α

Free velocity by Doppler Velocimetry









Modeling

- Analytical modeling from Fabbro

ESTHER (From CEA)

- 1D Hydrodynamic
- Helmotz/tracying
- EOS/law from Solid to plasam
- Shock wave/damage

on Abaqus

- 3D Hydro
- Shock wave propagation
- Damaging

LsDyna

- 3D Hydro
- Shock wave propagation
- Damaging

Plasma

- Pressure/thermal profile
- Microscopic parameter
- Ablated thickness

Shock wave

- Attenuation
- Interaction multi-interface
- Damage (size/location)
- Stack of multimaterial

Exp/Modeling

- Free surface Velocity
- Material transformation (phase/damage)

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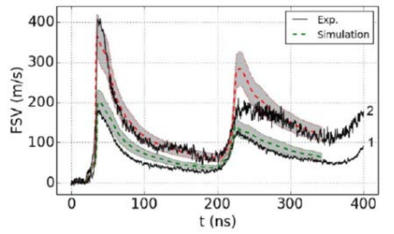
J. Phys. D: Appl. Phys. 54 (2021) 055204 (14pp) https://doi.org/10.1088/1361-6463/abc040

Laser induced plasma characterization in direct and water confined regimes: new advances in experimental studies and numerical modelling

Marine Scius-Bertrand[1,2], Laurent Videau[1,3], Alexandre Rondepierre[2,4], Emilien Lescoute[1,3], Yann Rouchausse[2], Jan Kaufman[5], Danijela Rostohar[5], Jan Brajer[5] and Laurent Berthe[2]

- Hephaistos facility
- 532nm, 10 ns

Velocity profile



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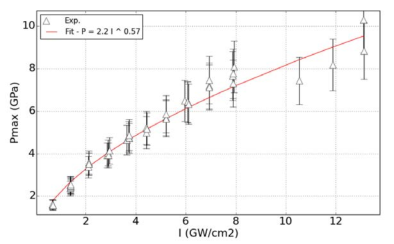

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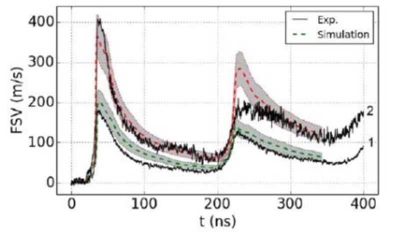
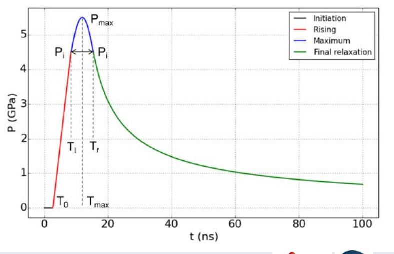
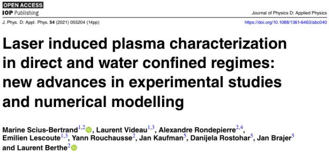


Normalized pressure profile

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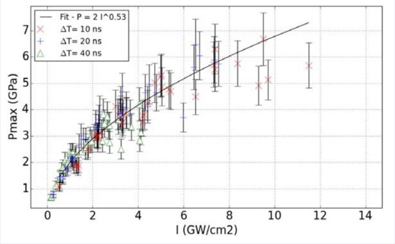
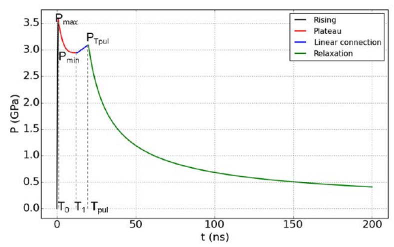
- Hilase, GCLT (CEA)
- Top Hat
- 1064nm, 10 ns, 20 ns, 40ns

Pressure profile



Pressure profile



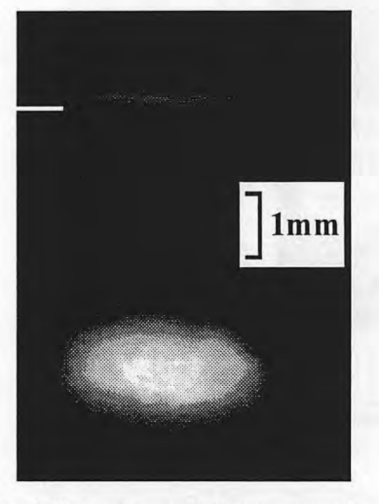
Extraction

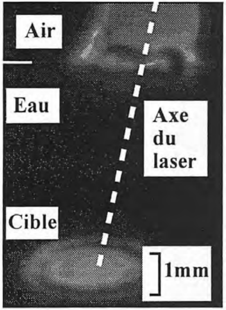
- As input for simulation
- Plasma parameter

Plasma Parameters

Laser parameter	$\lambda = 523$ nm $- \Delta T = 7$ ns	$\lambda = 1029$ nm—$\Delta T = 10$ ns	$\lambda = 1053$ nm—ΔT $= 10$ ns	$\lambda = 1053$ nm—ΔT $= 20$ ns	$\lambda = 1053$ nm—ΔT $= 40$ ns
Breakdown threshold (GW cm^{-2})	8–10	5–6	5–6	3–4	2–3
Breakdown threshold (J/cm^{-2})	56–70	50–60	50–60	60–80	80–120
Ablation pressure at the threshold (GPa)	7.2–8.2	4.7–5.2	4.7–5.2	3.6–4.2	2.9–3.6
Range of simulated intensities (GW cm^{-2})	2.5-6.0	//	1.3-5.0	1.5-2.3	0.8-2.0
Plasma temperature range (eV)	10–14	//	8–12	10–12	8–13
Range of plasma thickness (μm)	8–12	//	9-13	17-20	20-30
Range of ablated aluminum thickness (μm)	1.7–3.0	//	2.2–2.3	3.5-3.9	3.2-5.5

Laser Plasma breakdown at the surface of water





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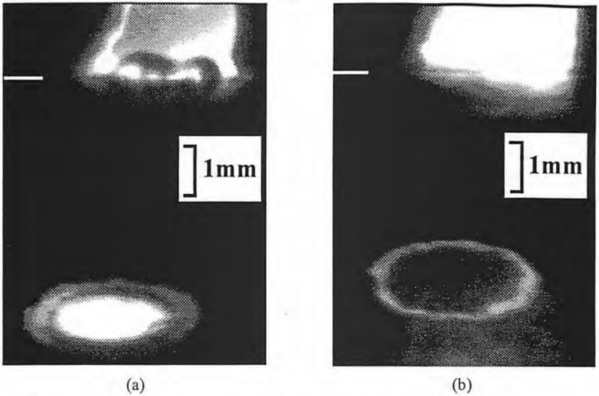
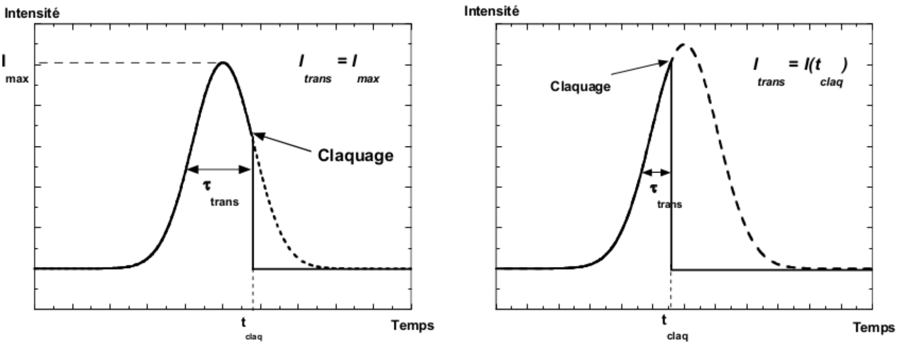


Figure IV-4: Observation de l'interaction confinée par eau avec la caméra rapide: I_{inc} = 28 GW/cm², (a) t=-10 ns, (b) t=0 ns.

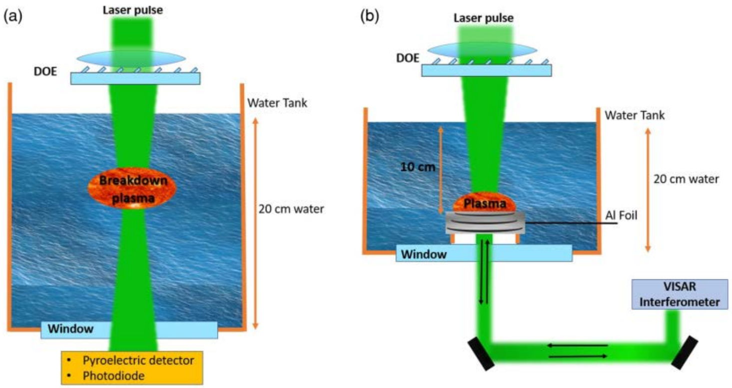
$$\frac{dn_e}{dt} = MultiPHotonionisation + AvalancheElectronique + ...Pertes$$

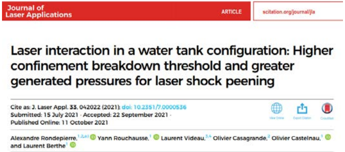
$$MPH : A + h\nu -> A^+ + e^-$$
$$AV : A + e^- h\nu -> A^+ + 2e^-$$

Transmission=0 at n_c



Tank configuration




Journal of Laser Applications ARTICLE scitation.org/journal/jla

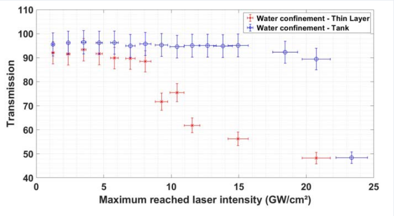
Laser interaction in a water tank configuration: Higher confinement breakdown threshold and greater generated pressures for laser shock peening

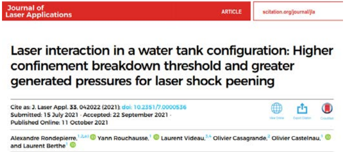
Cite as: J. Laser Appl. 33, 042022 (2021); doi: 10.2351/7.0000536
Submitted: 15 July 2021 · Accepted: 22 September 2021 · Published Online: 11 October 2021

Alexandre Rondepierre,[1,2,a)] Yann Rouchausse,[1] Laurent Videau,[3,4] Olivier Casagrande,[2] Olivier Castelnau,[1] and Laurent Berthe[1]

- Hephaistos facility
- 532nm, 10 ns

Transmission

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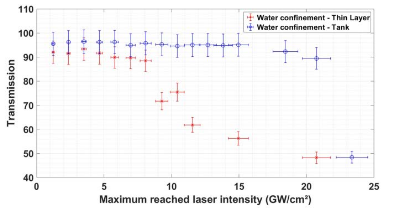
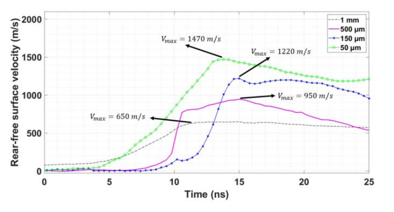
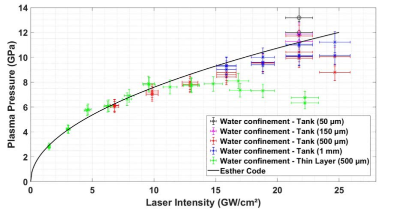


- Pressure up to 12 GPA
- Patented configuration

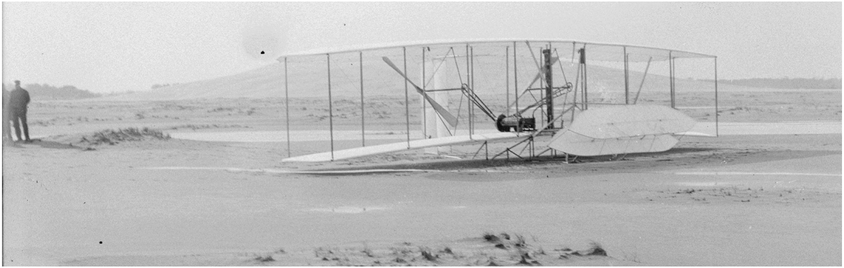
Pressure Profile



Normalized pressure profile

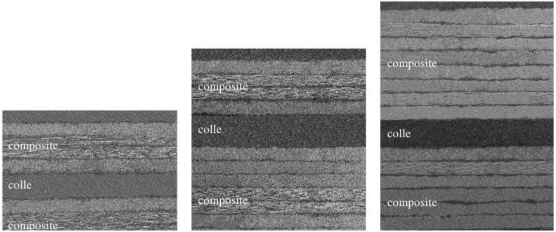


A long time ago...



Wright Flyer 1903
all with natural material/bonding

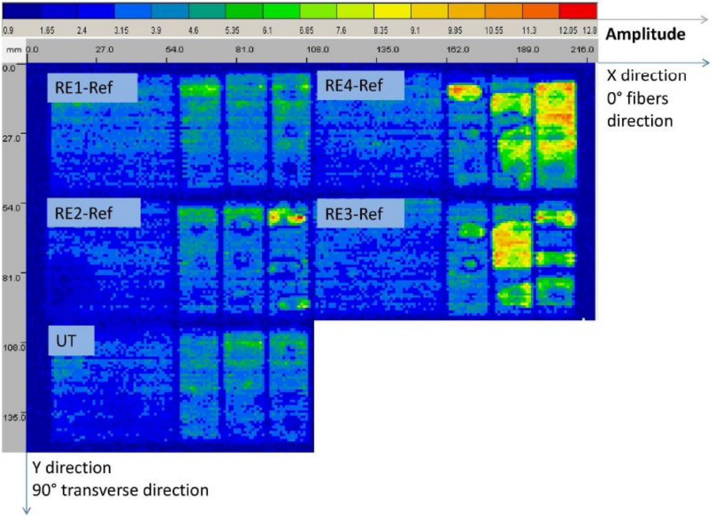
Weak bond detection for
Carbone Fibers Reinforce Polymer assemblying



Issues ?

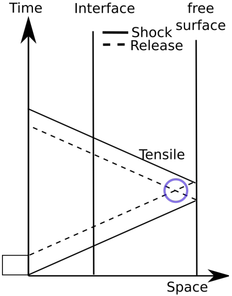
- How to ensure properties during manufacturing and use ?
- How to quantify the state of composite structure ?
- NDT can not discriminate weak bond because two parts are in contact

US C-scan of weakbond



LASAT > selective sollicitation

Simple impact



Double Impact

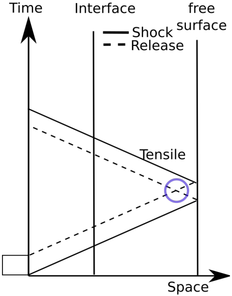
Symetrical Impact - Patented

adhesion test

- Well-controlled Mechanical Sollicitation
- Local - Proof test - no contact
- Target recovering and diagnostic

LASAT > selective sollicitation

Simple impact



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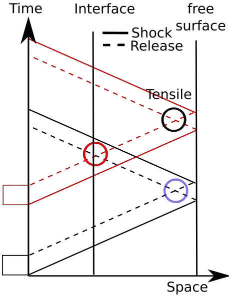

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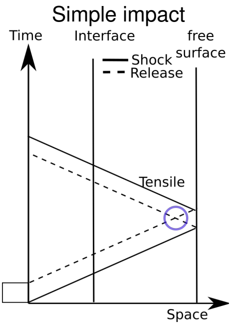

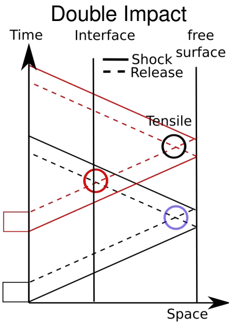

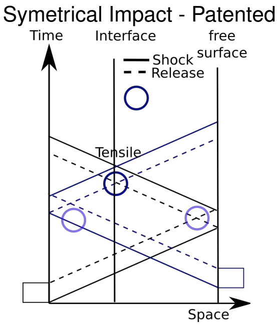

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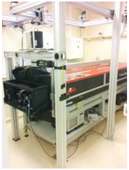
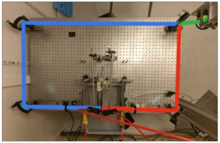
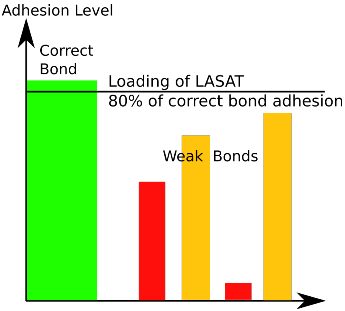




How does it work?

Calibrate	Reference threshold evaluation
Sollicitate	Interface test with laser shock
Reveal	Damage reveal weak or kissing Bonds
Detect	Damage detection by NDT technique

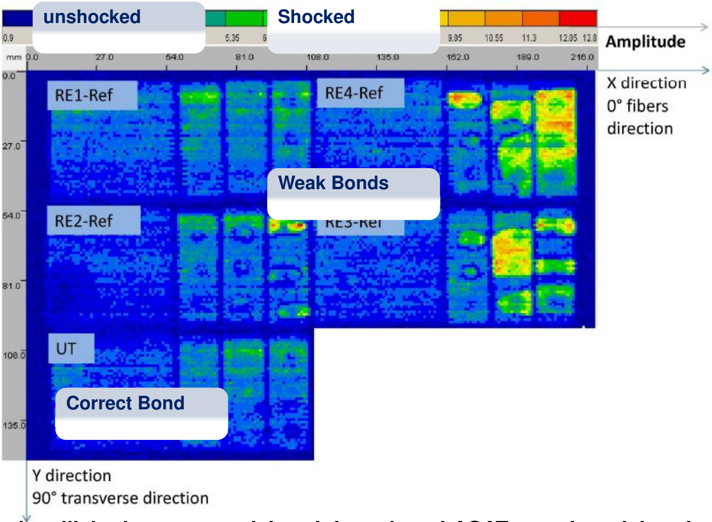
- Damage weak Bond
- No Damage for correct Bond



Sollicitate, Reveal, Detect : Shock laser + US C-scan - PhD R.Ecault

- **Without shock sollicitation > no weak bond detection >LASAT reveal weak bond**
- but... 3 mm is limit detection

Sollicitate, Reveal, Detect : Shock laser + US C-scan - PhD R.Ecault



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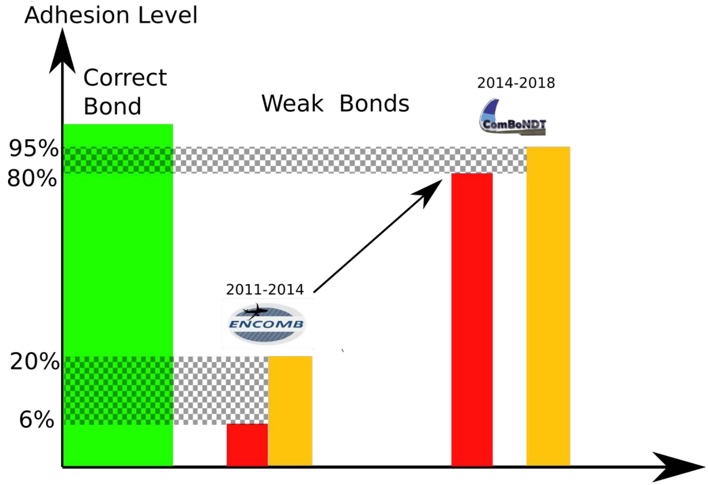
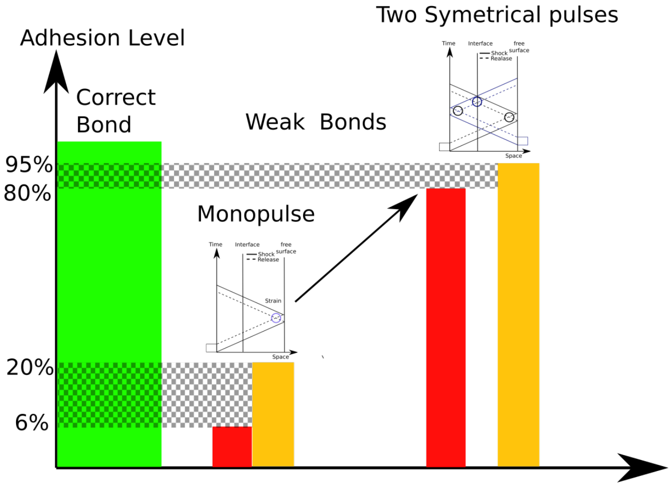
EUs Projects to NDT assessments



- Controled contamination of assemblying
- ENCOMB - Monopulse - "Very weak" Production scenarios
- ComBoNDT - 2 symetrical pulses - Weak and Extented to Repair scenarios

EUs Projects to NDT assessments



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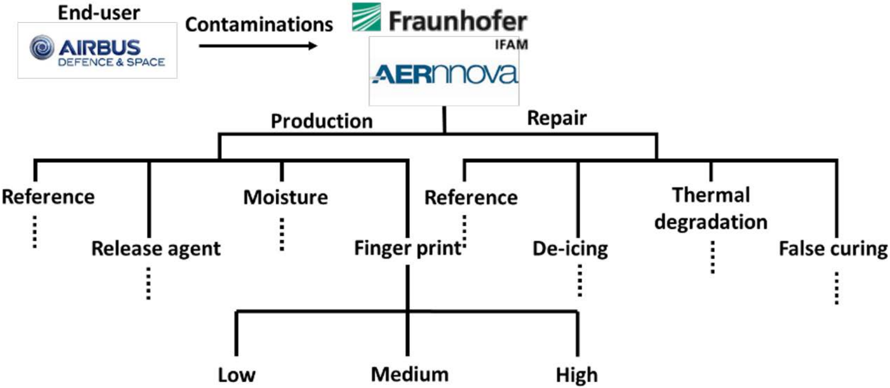
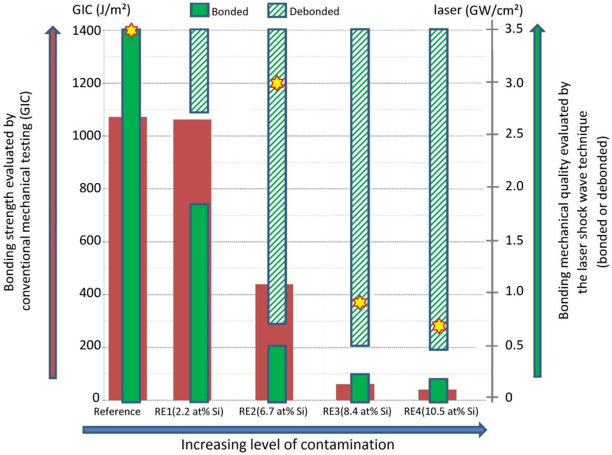
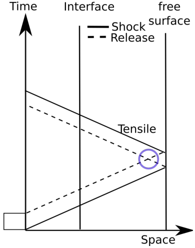
Contamination



Release agent detection sensitivity- Laser Shock





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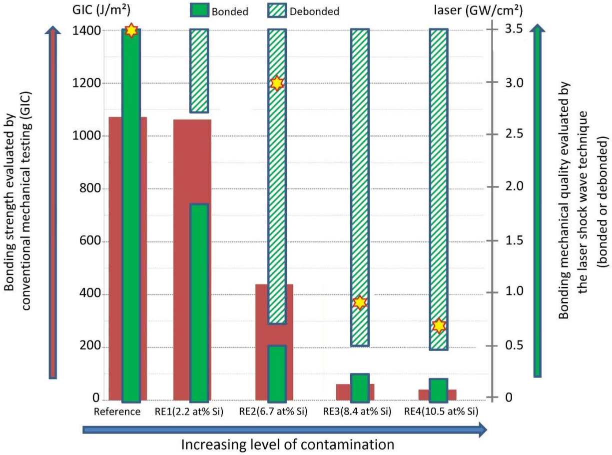
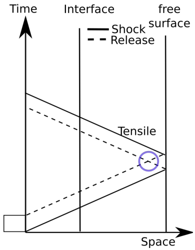
Issue: 4, pp.253-261

- No damage inside base material
- Threshold damage decreases with release agent level contamination
- But...adhesion at 20% of correct bond.
- No threshold for Correct Bond

Release agent detection sensitivity- Laser Shock





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- No damage inside base material
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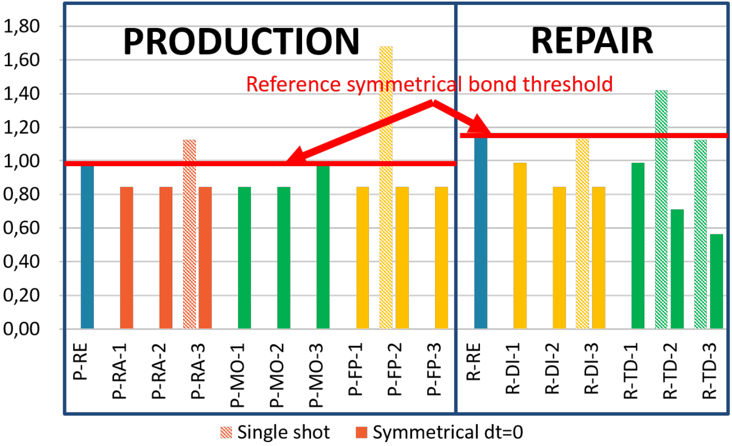
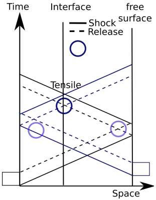
All contaminations ComBoNDT - PhD Maxime Sagnard



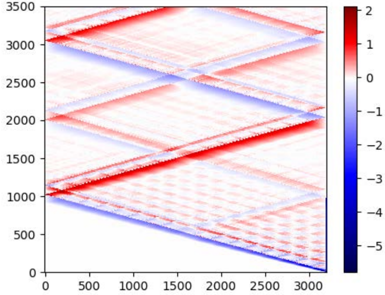


- No damage inside base material
- Impossible Test with monopulse
- Detection of all levels of contanimation

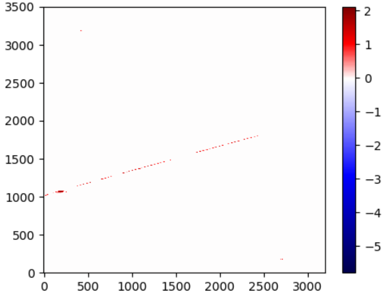
Design by Simulations - monopulse configuration

- Simulation using Abaqus
- Sollicitation tracking to design

Space time diagram - full scale



80% of the maximum stresses

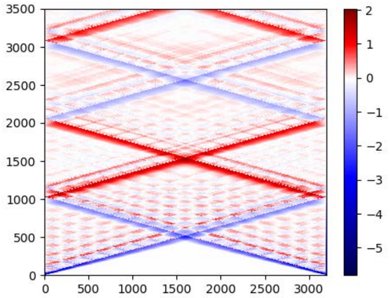


Same sollicitation in depth - selection by bond weakness

Design by Simulations - Symetrical configuration

- Simulation using Abaqus
- Sollicitation tracking to design

Space time diagram - full scale



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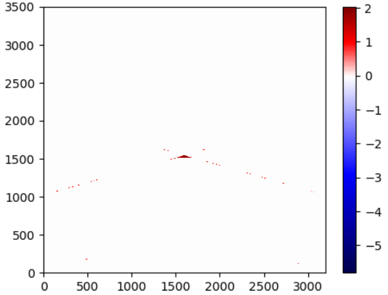


Sollicitation at the interface

Representative Panels

Production Panel

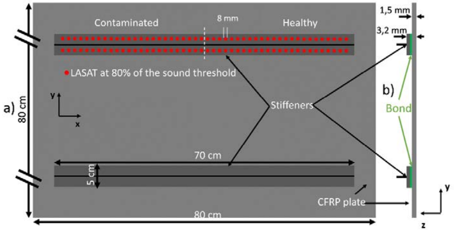


Fig. 10. Production panel: (a) front view with laser shot position and (b) side view with specified thicknesses.

Repair Panel

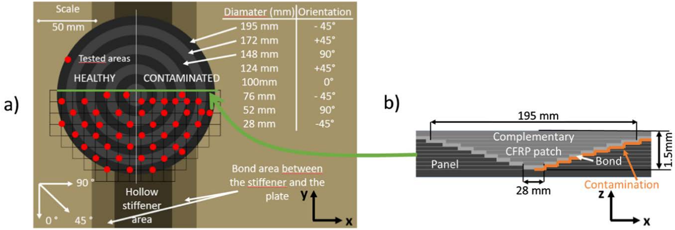
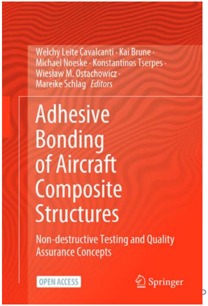


Fig. 11. (a) figure of the shot pattern realised on the repair panel and (b) cross-section of the repair patch geometry.

Lien Vidéo

demonstration/validation

		SYMMETRICAL SHOT SETUP			SINGLE SHOT SETUP		
Panel	Area	S-LASAT threshold I_t (intensity per beam)	Total number of shots at 80% of I_t	Number of opened bonds	LASAT threshold I_t (total intensity)	Total number of single shots at 80% of I_t	Number of opened bonds
Production	Healthy	0.85GW/cm²	32	0			
	Contaminated		21	21			
Repair	Healthy	0.72GW/cm²	8	0	0.84GW/cm²	7	0
	Contaminated		8	8		10	2
		Success rate: 100%			Success rate: 20%		



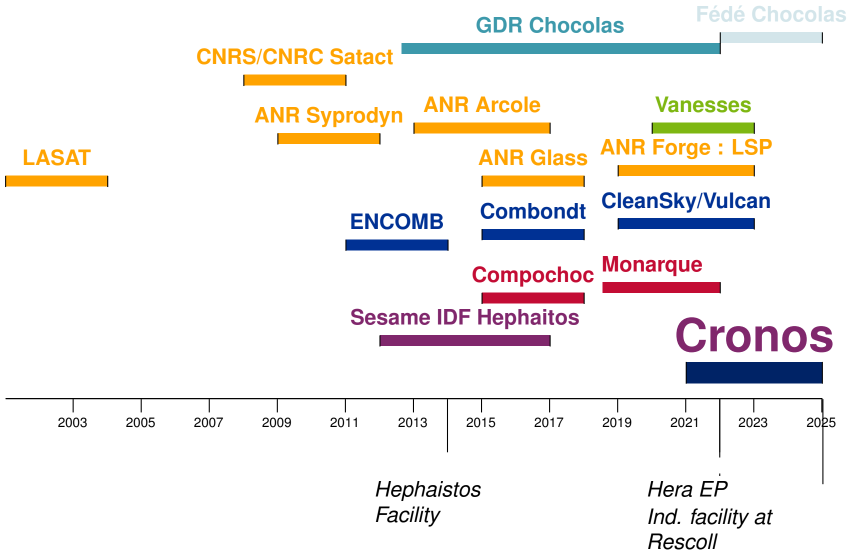
Conclusion

- New progress on processes related to laser control and Hydrodynamic simulations
- Laser shock peening : repetition rate, small spot, fiber

Perspectives

- New lab and academic facility
- Multiscale simulations for design ....

Laser shock projects



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