Full-field kinematic measurements
by \textit{D}igital \textit{I}mage \textit{C}orrelation
for \textit{m}A\textit{t}erial characterization at different scales

Roberto Fedele
Civil and industrial applications of Digital Image Correlation (DIC) to be discussed

1. Assessment of **innovative CFC/Cu joints** and Finite Element Model Updating

2. **Adhesive joints** for aerospace engineering

3. Study of delamination tests on **FRP-reinforced masonry** pillars

4. X-ray microtomography of **foam** samples under *in situ* loading
Characterization of innovative CFC/Cu joints by full-field measurements and finite elements

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# Dept. of Applied Science and Technology (DISAT)
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ITER (International Thermonuclear Experimental Reactor)
Single-lap shear tests on flat-tile joined samples
uncertain boundary conditions due to the glue layers and compliant grips!

Macroscopic response

Intrinsic CFC shear strength 15-20 MPa!

\[ \overline{\tau}_{\text{max}} = \frac{P_{\text{max}}}{A_{\text{joint}}} \approx 23.6 \, \text{[MPa]} \]

Comparative assessment by different tests \( \overline{\tau}_{\text{max}} = 34 \pm 4 \, \text{[MPa]} \)
2D-surface Digital Image Correlation

“passive” advection of the local texture
(optical flow conservation)

✔️ local form
\[ f(x) \approx g(x + u[x]) \]

reference image

deformed image

✔️ weak form
\[ \arg \min \eta(u) = \int_{\Omega} \left[ f(x) - g(x + u) \right]^2 dx \]

similarity measure

variational problem
\[ u_{i+1} = u_i + \delta u_{i+1} \]
incremental form
Local approach: FE simulations driven by boundary displacements

('anisotropic) elastic-plastic behavior

finite thickness joint

plane stress schematization
Displacement fields measured by DIC and computed

$U^\text{exp}_y$  $\kappa = 16$  $U^\text{comp}_y$
Tangential traction and 95% confidence strip

\[ p_t \]

\( k = 12 \)

95% confidence traction distribution
Normal traction and 95% confidence strip

\[ p_n \quad [\text{MPa}] \]

\[ \kappa = 12 \]

95% confidence traction distribution

interface abscissae \ [\text{mm}]
Simultaneous assessment of interface properties & boundary conditions through Digital Image Correlation

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# Laboratoire de Mécanique et Technologie (LMT)
École Normale Supérieure (ENS), Cachan (France)
Non-conventional debonding test
$t = 19$
Delamination tests on FRP-reinforced masonry experiments and modelling

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§ Dept. of Architecture, Built Environment and Construction Engineering (ABC)
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CFRP-reinforced pillar: historical bricks (XVII century) and high strength mortar

single-lap shear test
X-ray tomography and motion estimation by 3D-Volume DIC

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§ Dept. of Physics, X-ray Radiation Group INFN
Photon spectrum and X-ray region

Planck-Einstein equation

\[ E = h \nu = \frac{hc}{\lambda} \]

\[ h = 4.13 \times 10^{-18} \text{ keV} \cdot \text{sec} \]

speed of light in vacuum

wave/particle duality

\[ p = \frac{h}{\lambda} \]

De Broglie’s linear momentum

\[ \sigma_x \cdot \sigma_p \geq \frac{h}{2\pi} \]

Heisenberg’s uncertainty principle
Accurate scaling for metrology

aluminum reference object

Linear measurements at the macroscale by high-accuracy gages

Cube Side = (9.9984 ± 0.00163) mm

estimated voxel size = (9.123 ± 0.0183) μm
Viscoelastic relaxation (prescribed loading)

Closed cell, polymer foam
AIREX C70

\[ E = \frac{\sigma(t)}{\varepsilon} \]

\[ \varepsilon = \frac{\Delta L}{L_0} = 7 \% \]

apparent Young modulus

\[ L_0 = 10 [\text{mm}] \]

1.0 [hour]  3.3 [hour]
3D Tomographic reconstruction

Feldkamp algorithm for cone beam geometry (whole sample)
or FBP for fan beam assumption (central layer)
Same slice of reconstructed tomos at different loading stages
3D-Volume Digital Image Correlation

“passive” advection of the local texture
(resulting from 3D tomographic reconstruction)

**local form**

\[ f(x) \approx g(x + u[x]) \]

**weak form**

\[
\arg\min_u \left\{ \eta(u) = \iiint_{\Omega} \left[ f(x) - g(x + u) \right]^2 \, dx \right\}
\]

variational problem
Local cross-correlation as block matching

\[
\arg \max_u \eta_b(u) = \iiint_{\Omega_b} [f(x)g(x+u)] \, dx
\]

\[
\overline{f}(-x)*g = F^{-1}[\overline{Ff} \cdot \overline{Fg}]
\]

convolution via Fourier Transform

blockwise constant field: not continuous!
2D Debonding process of an adhesive joint

image pyramid

scale

$S_n$
Vertical displacement along a vertical section