Assessment of fiber metal laminate panels reinforced with metallic pins deposited by welding

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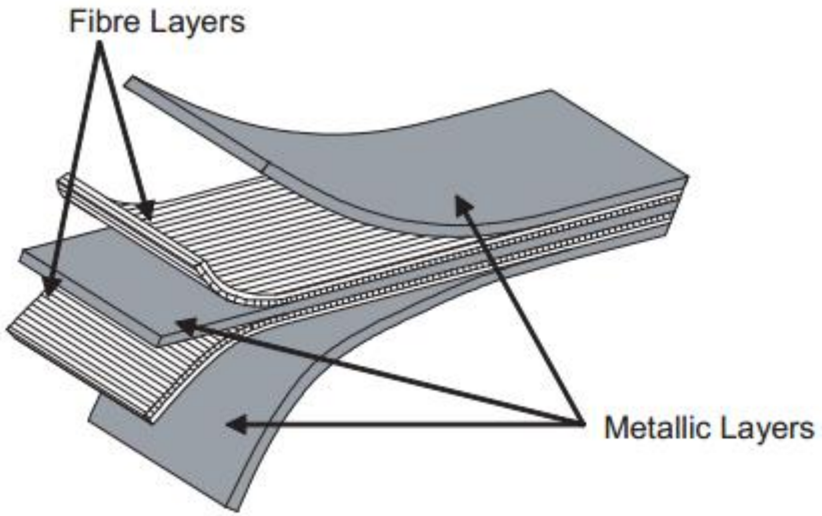
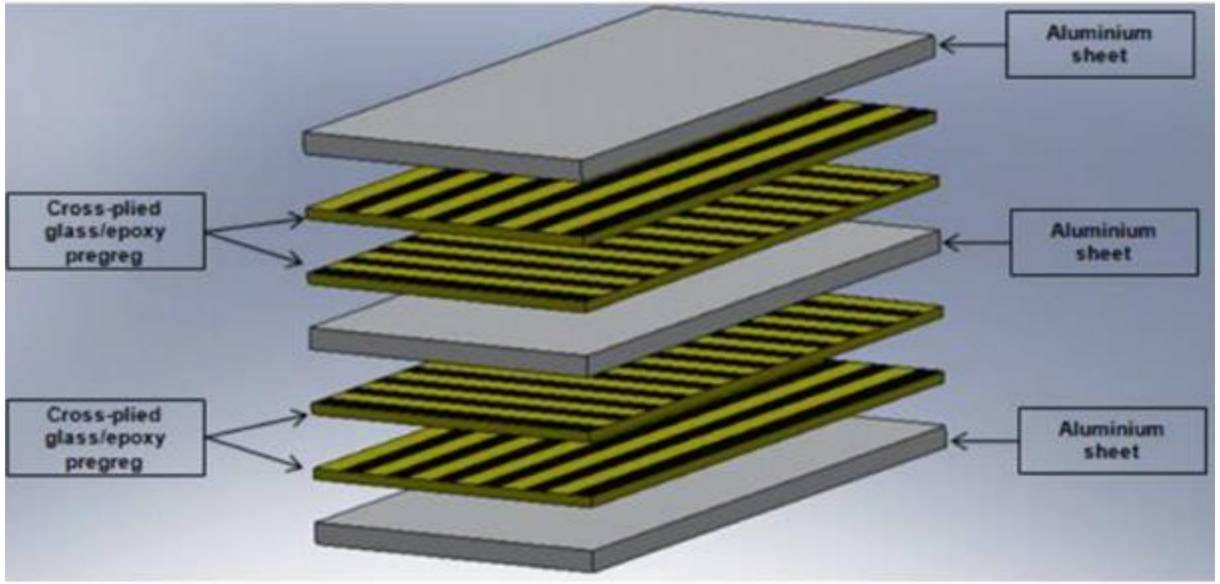
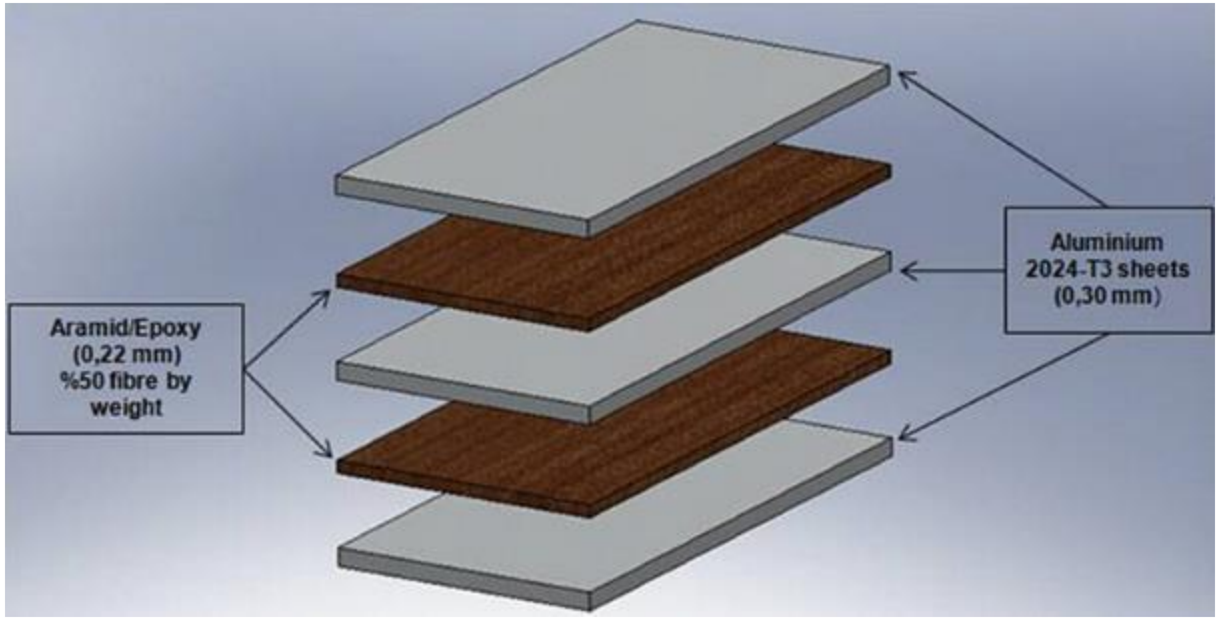
Metal-Composite Laminate Panels



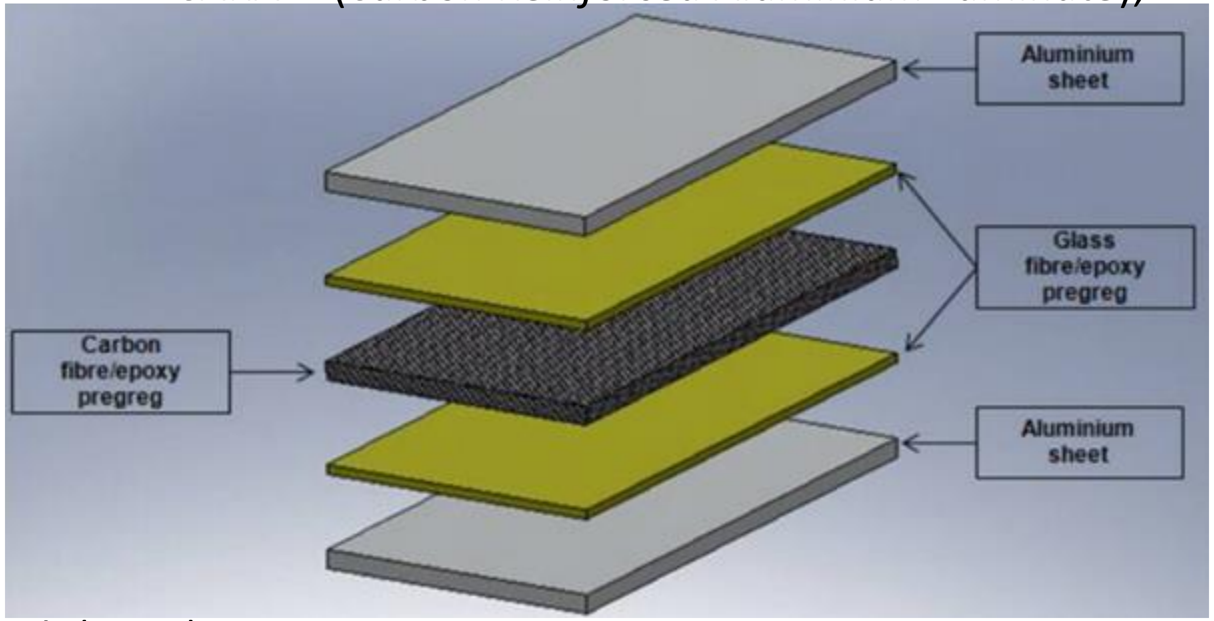
- GLARE (*Glass Reinforced Aluminium Laminate*);



- ARALL (*Aramid Reinforced Aluminium Laminate*);

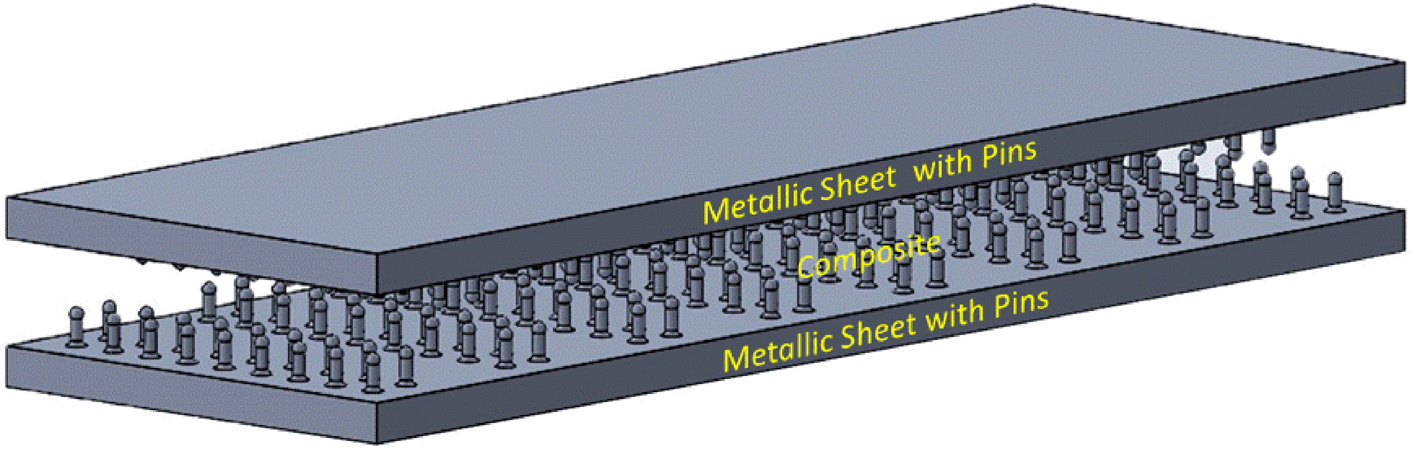


- CARALL (*Carbon Reinforced Aluminium Laminate*);

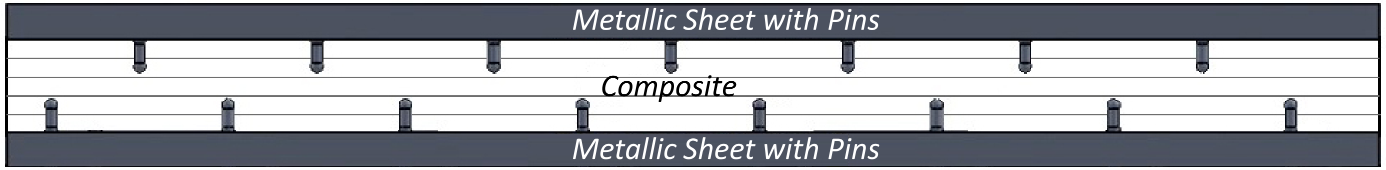


After SINMAZÇELIK et al. (2011)

The challenge of the project: to increase the resistance of panels through the use of metallic pins in the composite fibres



Advanced hybrid joint - adhesive bonding + mechanical interlock



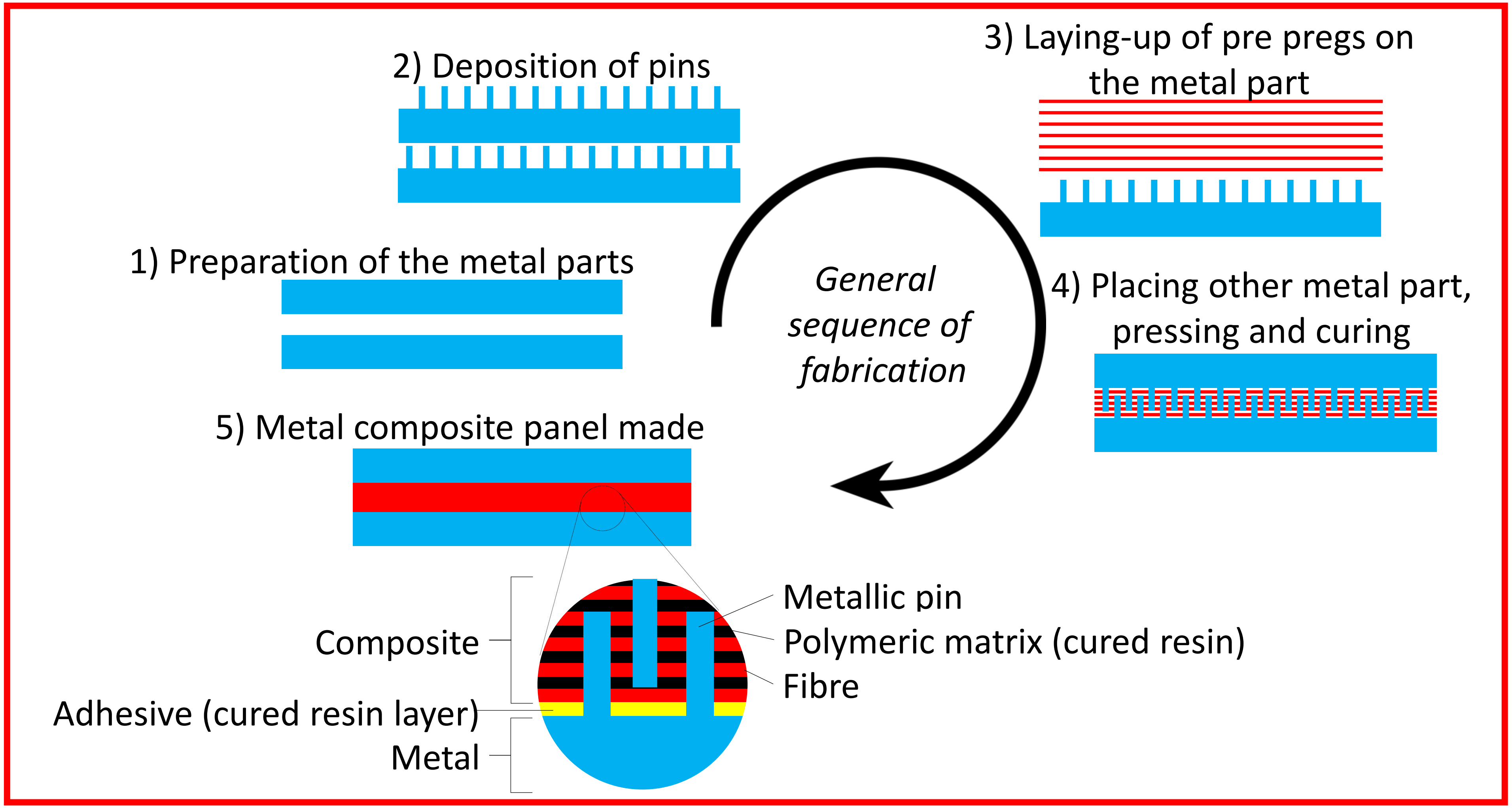
Potential advantages of the pin based mechanical interlock:

- Increase of the specific (per unit of cross section area) mechanical stiffness;

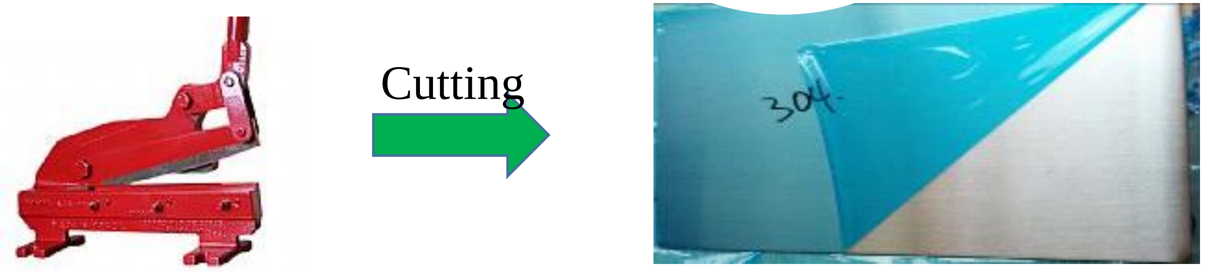
- Increase of the specific mechanical strength;

- Increase of the adherence of the sheets to the composite fibers (larger contact areas);

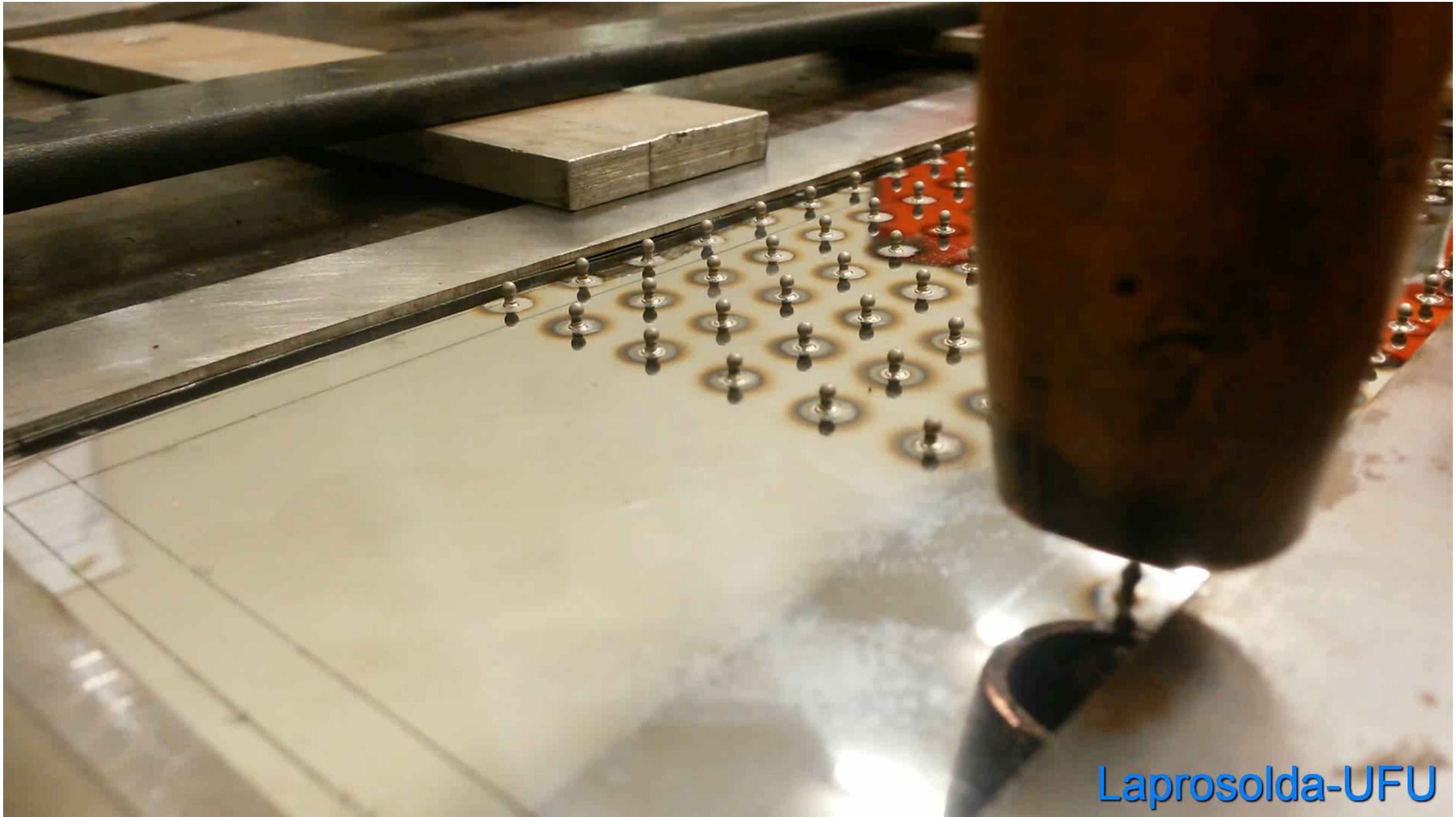
- Reduction of pre-peg (higher cost material);



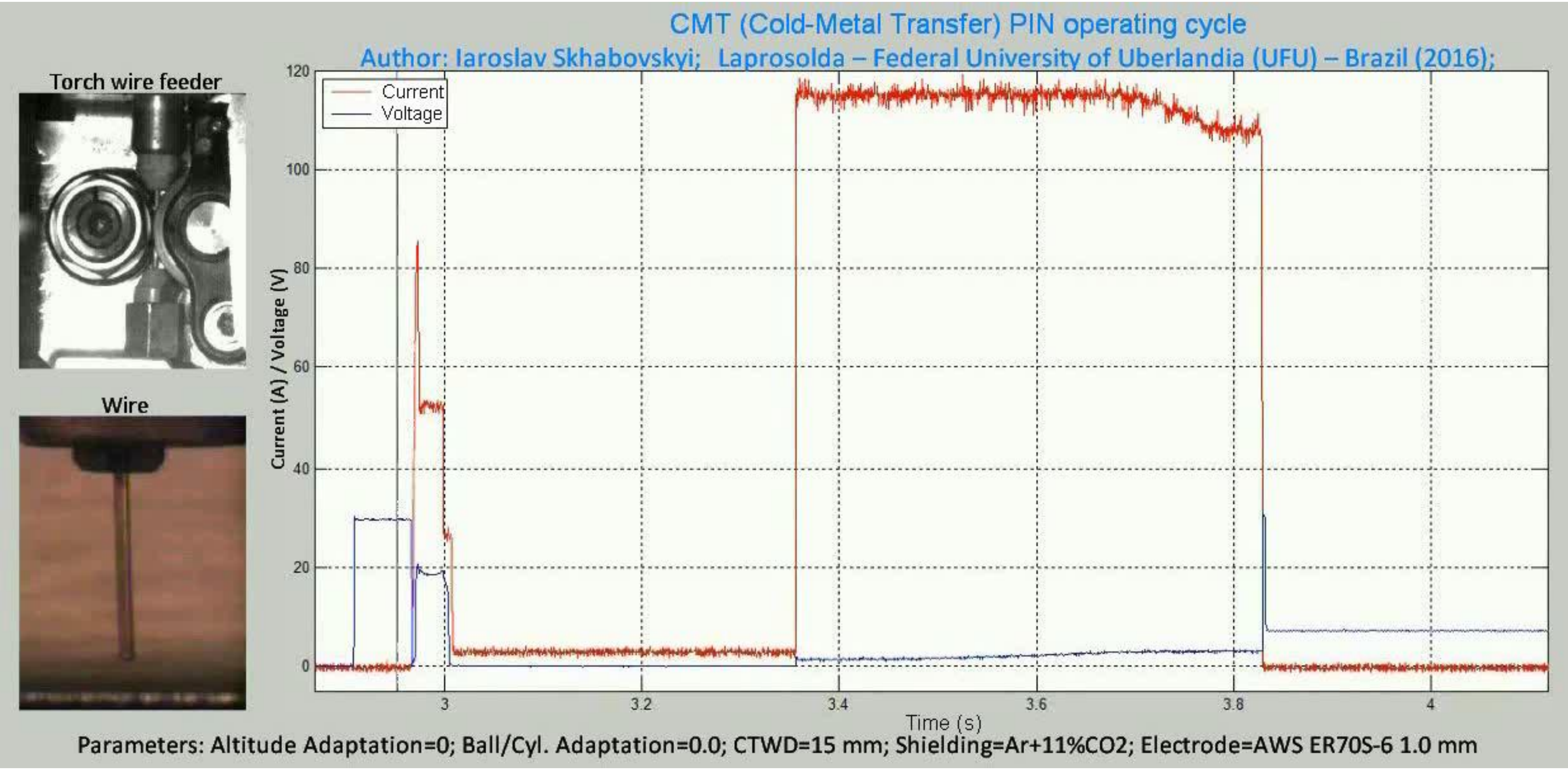
1) AISI 430: 200 × 80 × **0.4 mm**:



The pins are built over the internal metal sheet surfaces by arc welding:



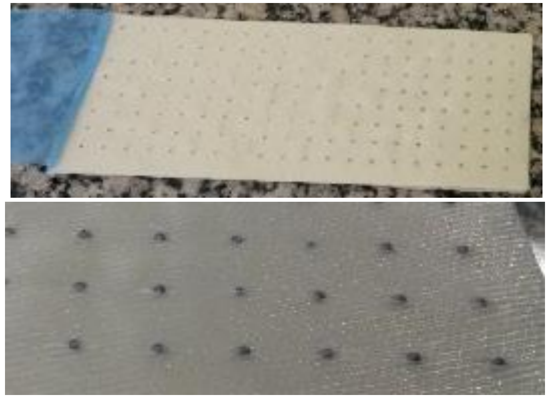
Process CMT (*Cold-Metal Transfer*) PIN



3) Application of pre pegs (*7781-38" – F155* from *HEXCEL Corporation*)

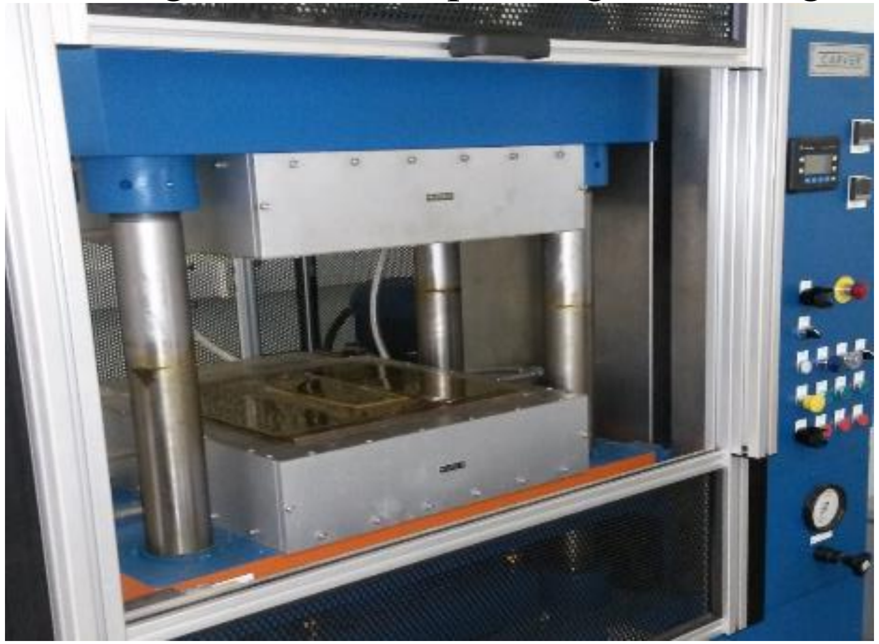
Mats of 210 × 90 mm

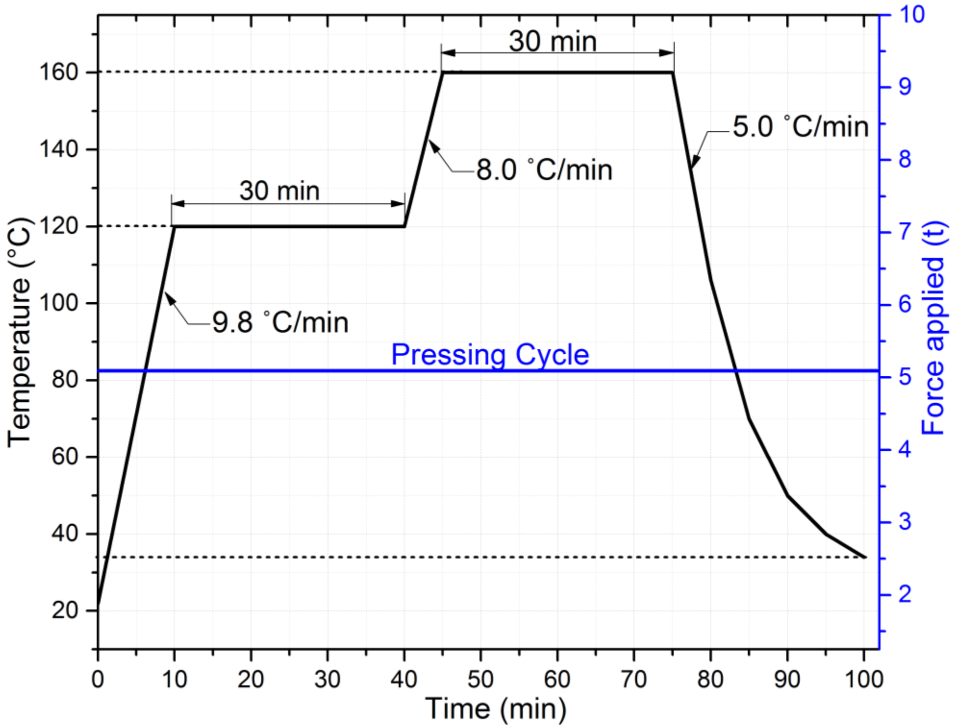
Application



One layer applied over the metal sheet with pins

4) Polymer processing: "sandwich" pressing and curing:

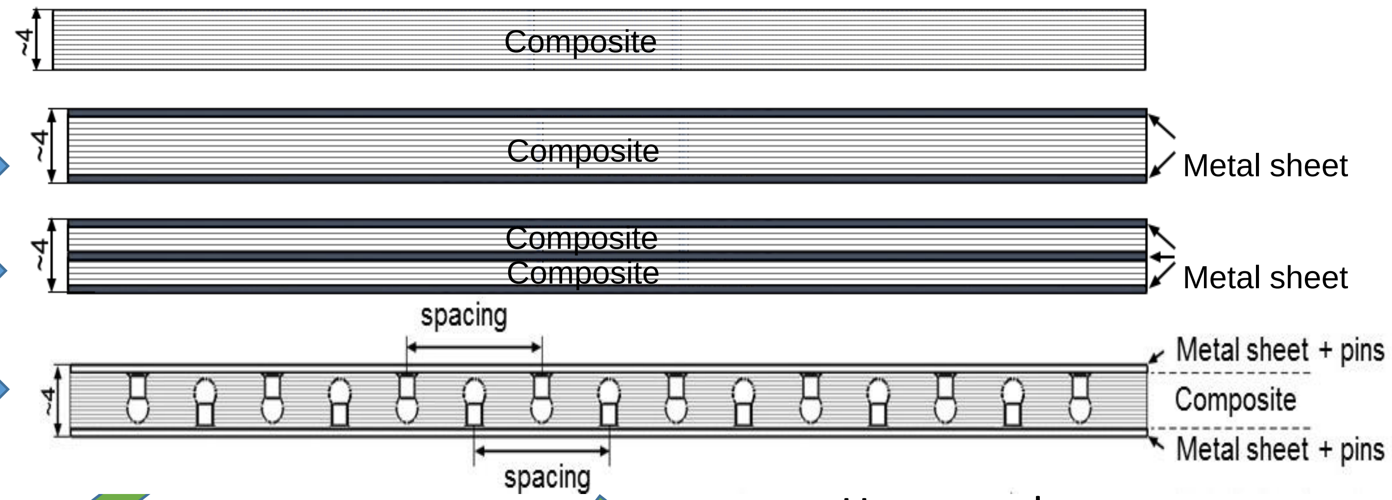




Types of panels

R
E
F
E
R
E
N
C
E
S

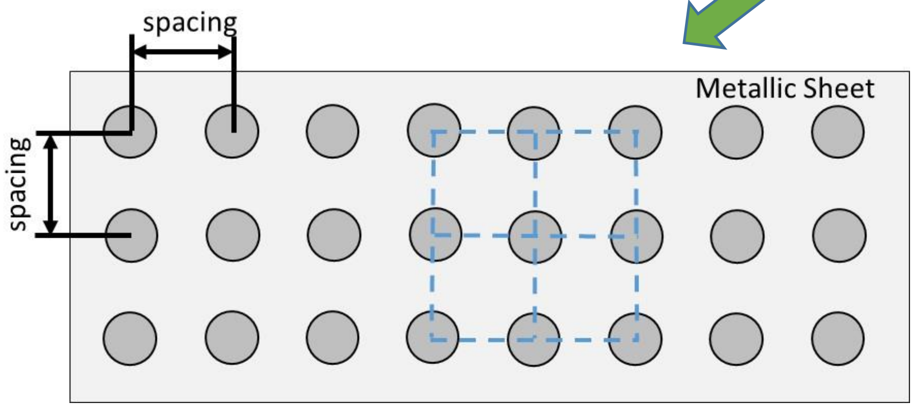
- Composite only
- metal-composite-metal
- metal-composite-metal-composite-metal
- Metal-composite+Pins-metal

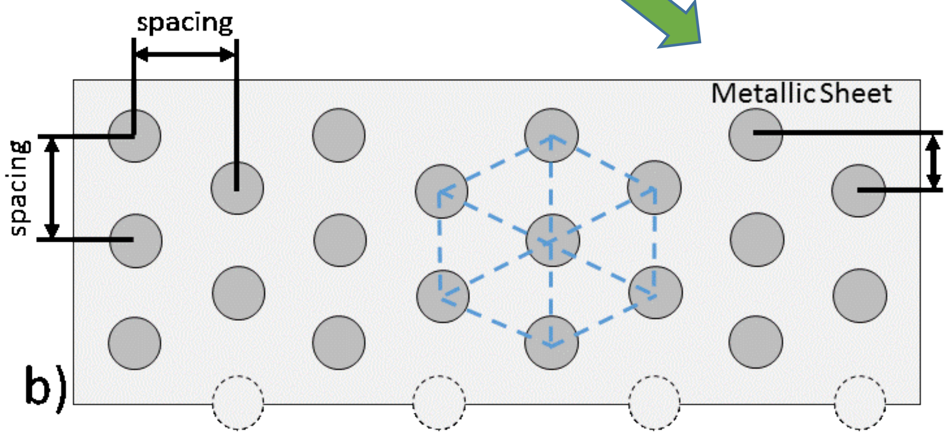


Squared pattern deposition

Spacing = 10 and 20 mm

Hexagonal pattern deposition





Characteristics raised for comparisons:

1. Panel density;

2. Mechanical properties:

- Resistance to bending;

- Mechanical energy absorption;

- Resistance to damage (dimension of damage);

- Resistance to buckling after damage

Characterization of the manufactured panels

Type of Panel	Number of pre preg layers per panel	Pin density (pin/cm²)	Actual thickness (mm)	Density (g/cm³)
Composite only	22	--	4.24	2.1
metal-composite-metal (no pins)	19	--	4.34	3
metal-composite-metal-composite-metal (no pins)	16	--	4.17	3.7
Metal-composite+Pins-metal Squared pattern/spacing of 10 mm	16	0.91	4.49	3.0
Metal-composite+Pins-metal Squared pattern/spacing of 20 mm	16	0.21	3.98	3.2
Metal-composite+Pins-metal Hexagonal pattern/spacing of 10 mm	16	0.89	4.29	3.1
Metal-composite+Pins-metal Hexagonal pattern/spacing of 20 mm	16	0.20	3.93	3.2

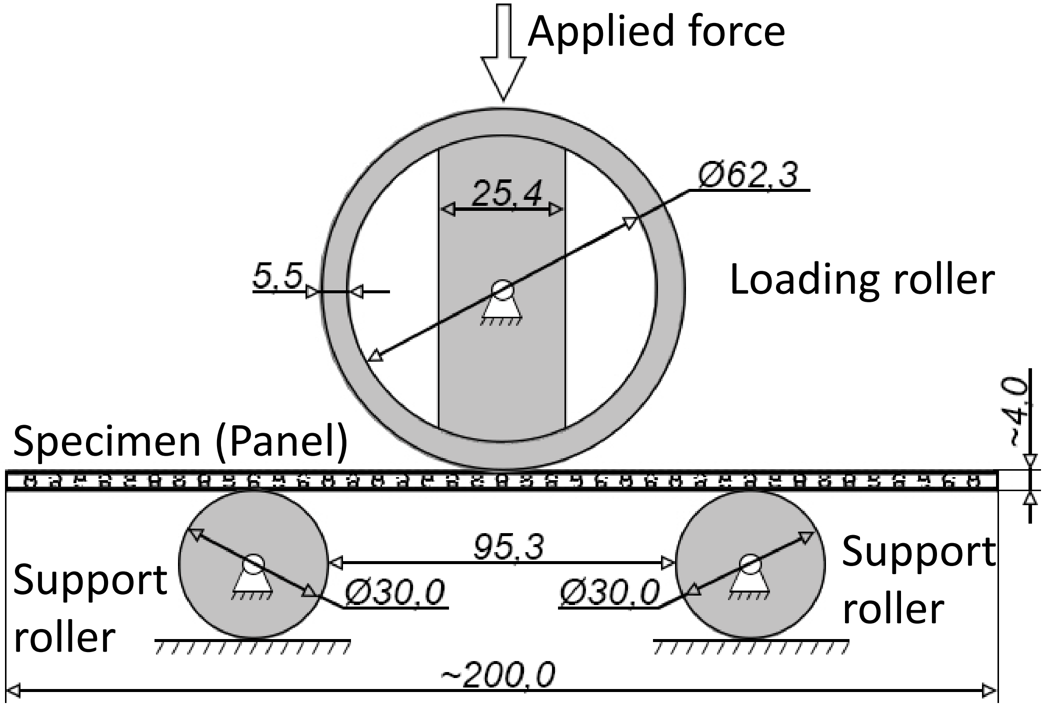
The target thickness (4 mm) was not truly reached, since pressure, not clearance, was set in the pressing device

Pins did not lead to density increase, since the number of composite layers became lower

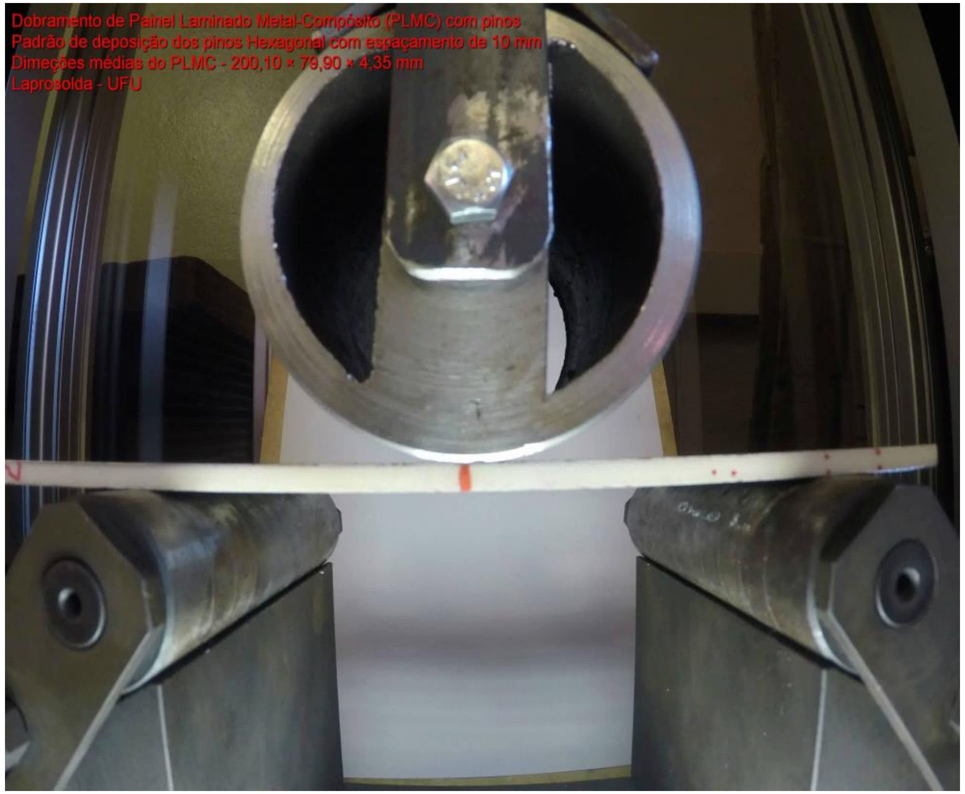
Reference:
Carbon steel = 7,86 g/cm3
and Aluminum = 2,7 g/cm3

Note: the number of pre preg layers is reduced when pins are introduced so that the same target thickness (4 mm) could be reached to all panels

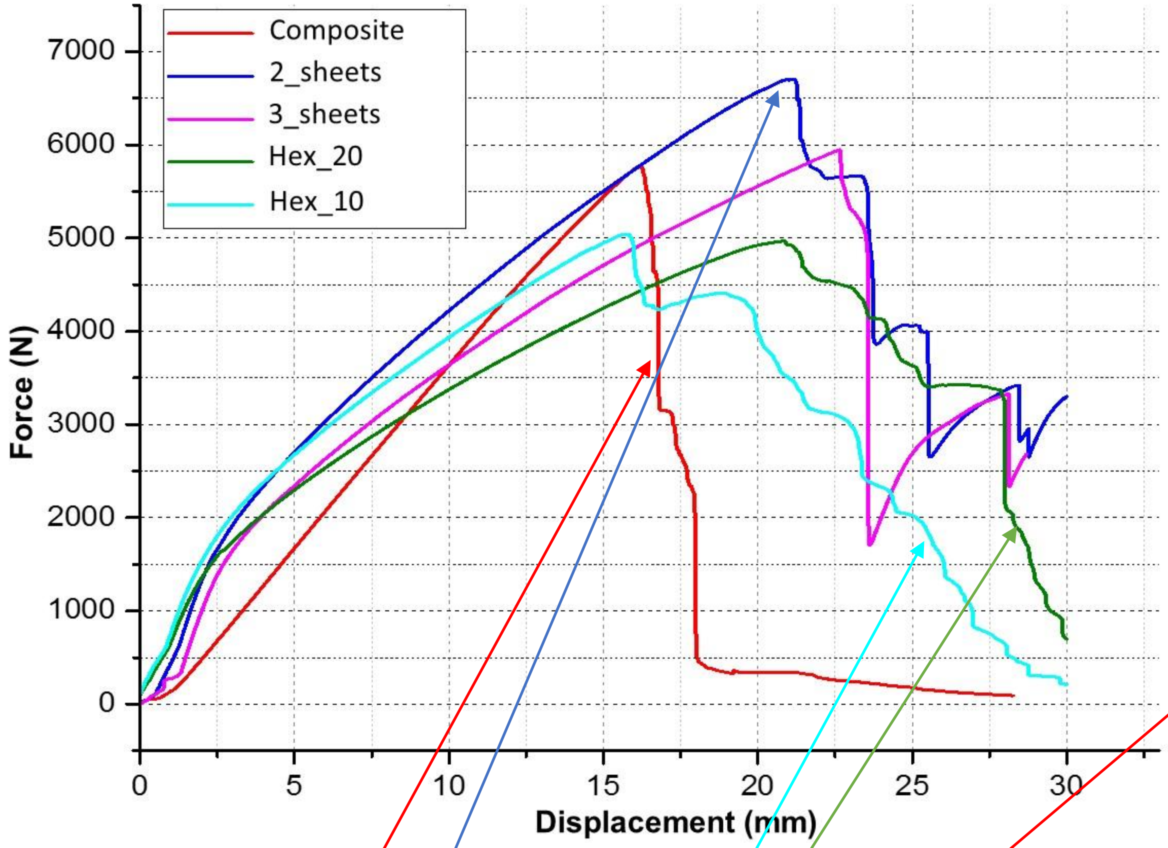
Resistance to bending (3 point bending test)



ISO 7438:1985 *“Metallic Materials – Bend Test”*



Resistance to bending

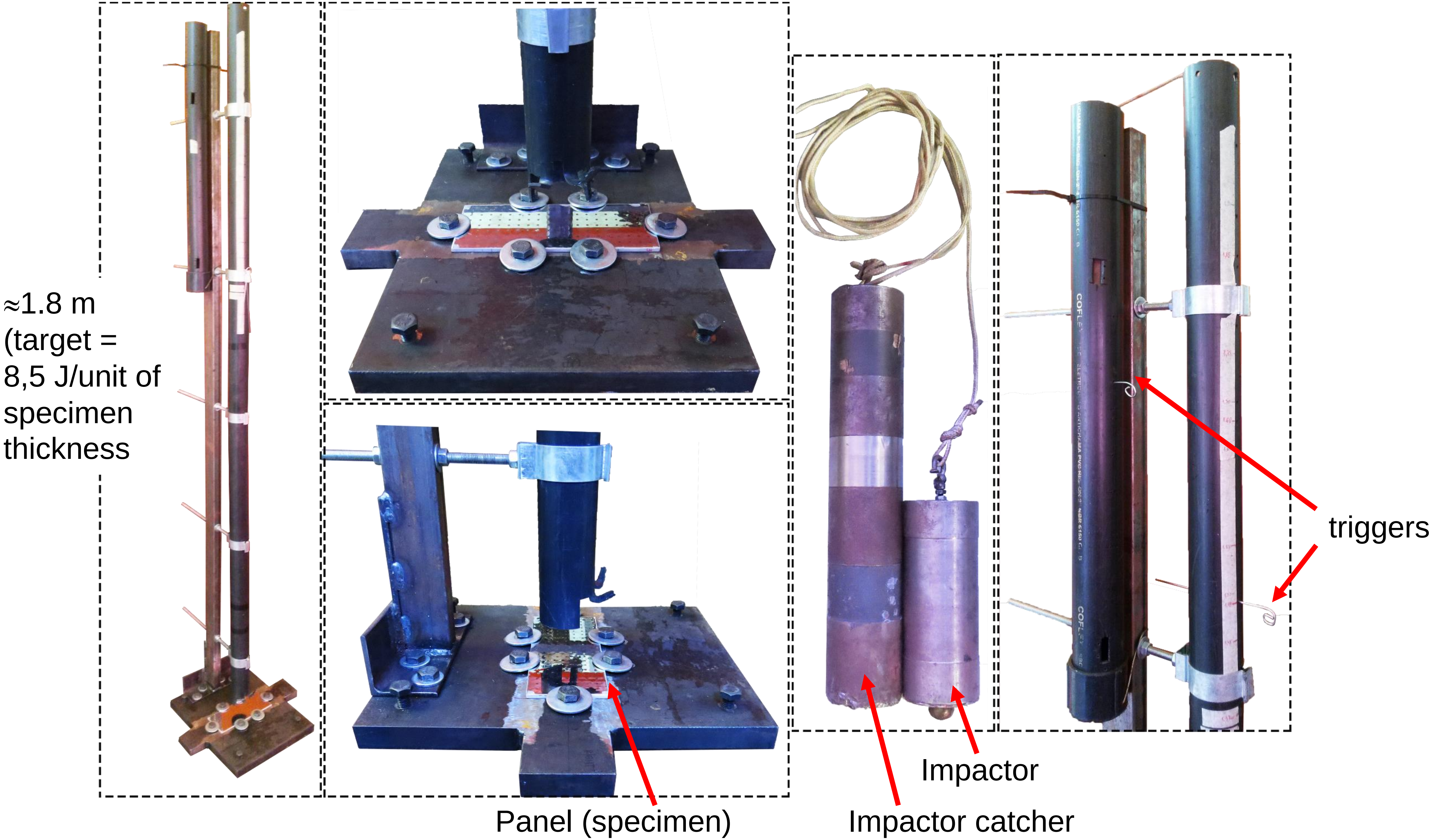


metal-composite-metal (no pins)

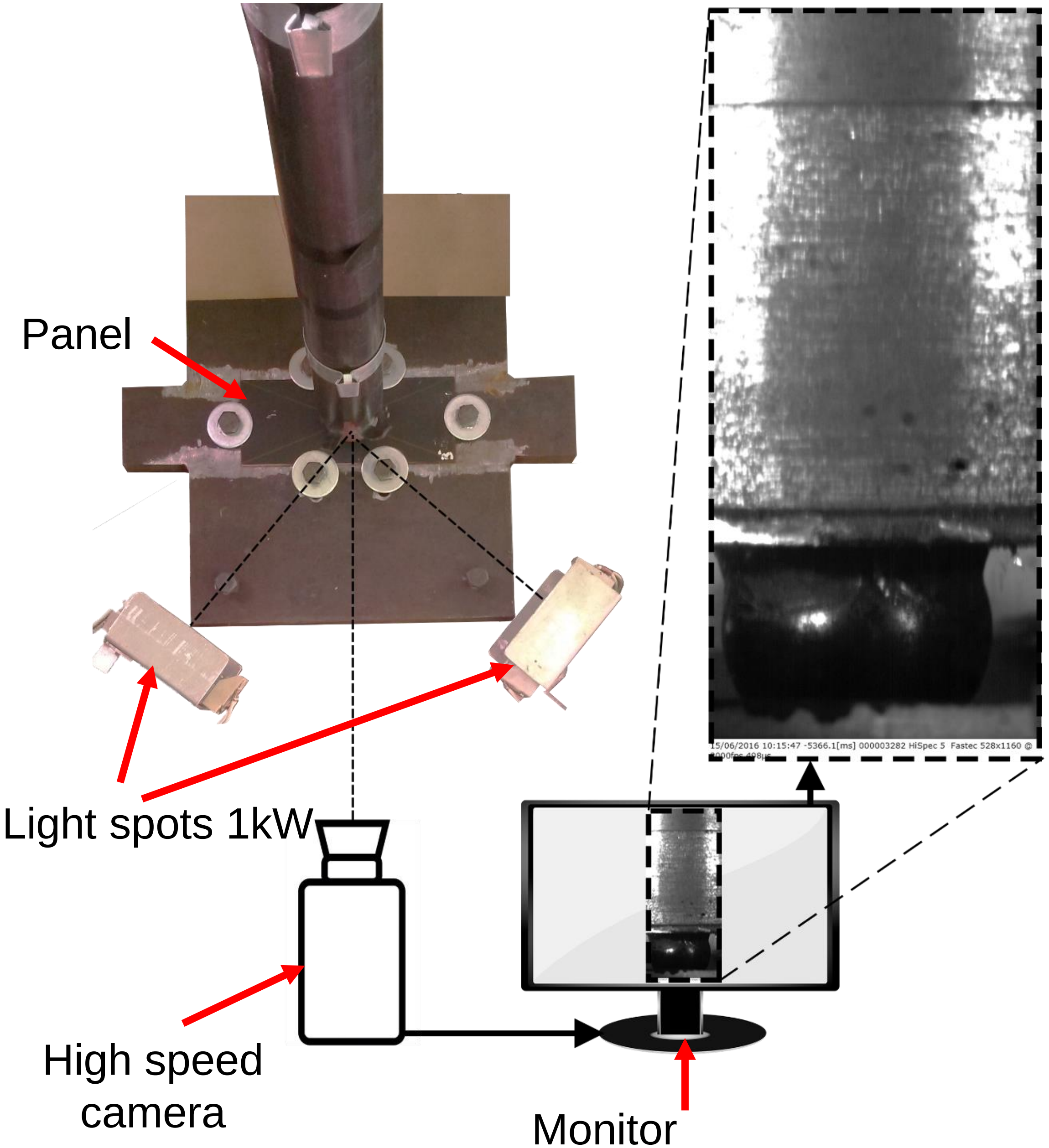
Metal-composite+Pins-metal
Hexagonal pattern/spacing of 10 mm

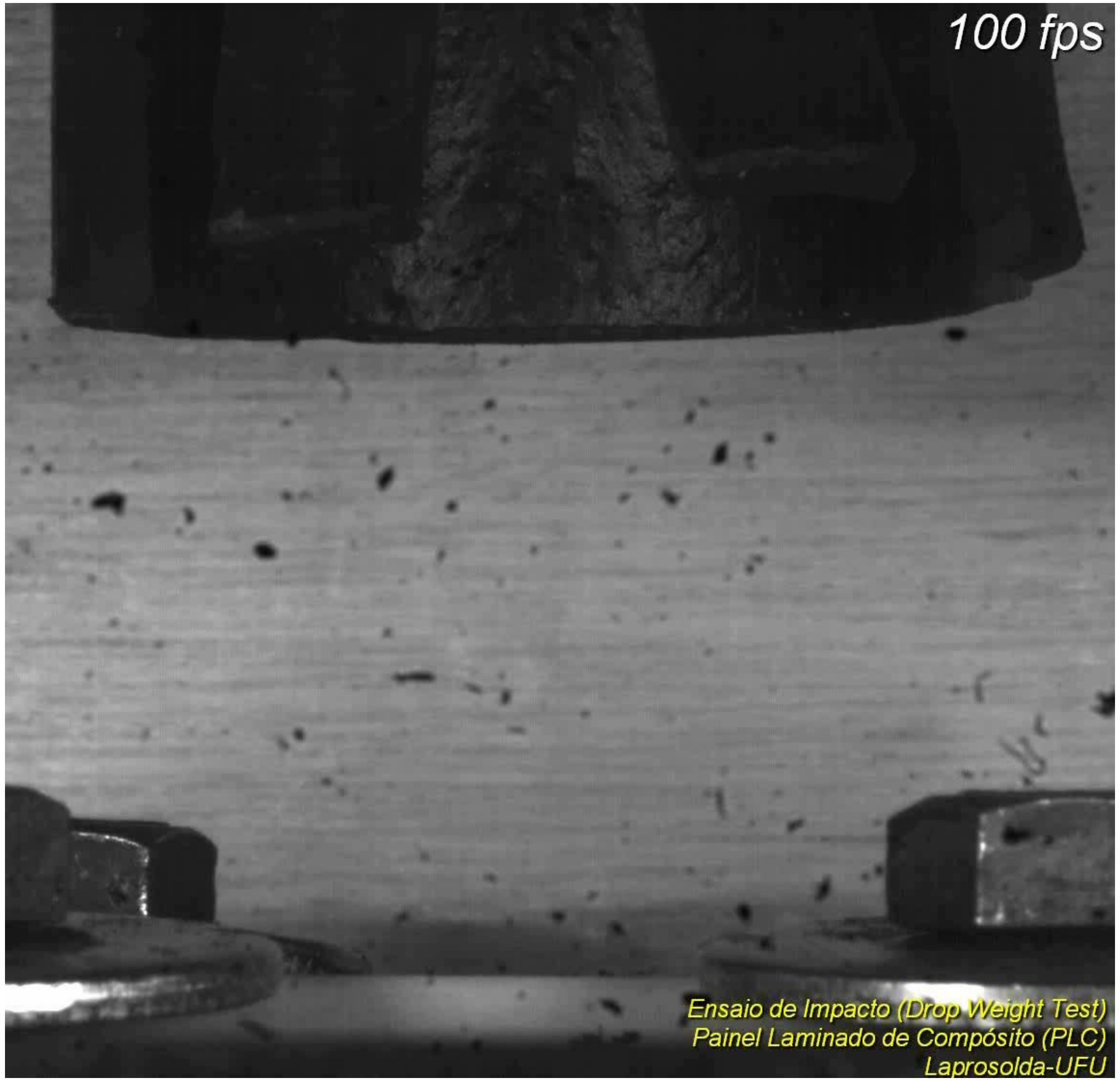
- The Composite has a catastrophic behavior, confirming the benefit of combining composite and metal sheets;
- The combination metal-composite (reference) without pins showed higher resistance (force and energy before the collapse) than when pins were present;
- However, the presence of Pins made the collapse less catastrophic (longer displacement after the rupture and less plate-polymer detachment);

Mechanical energy absorption (drop-weight test)

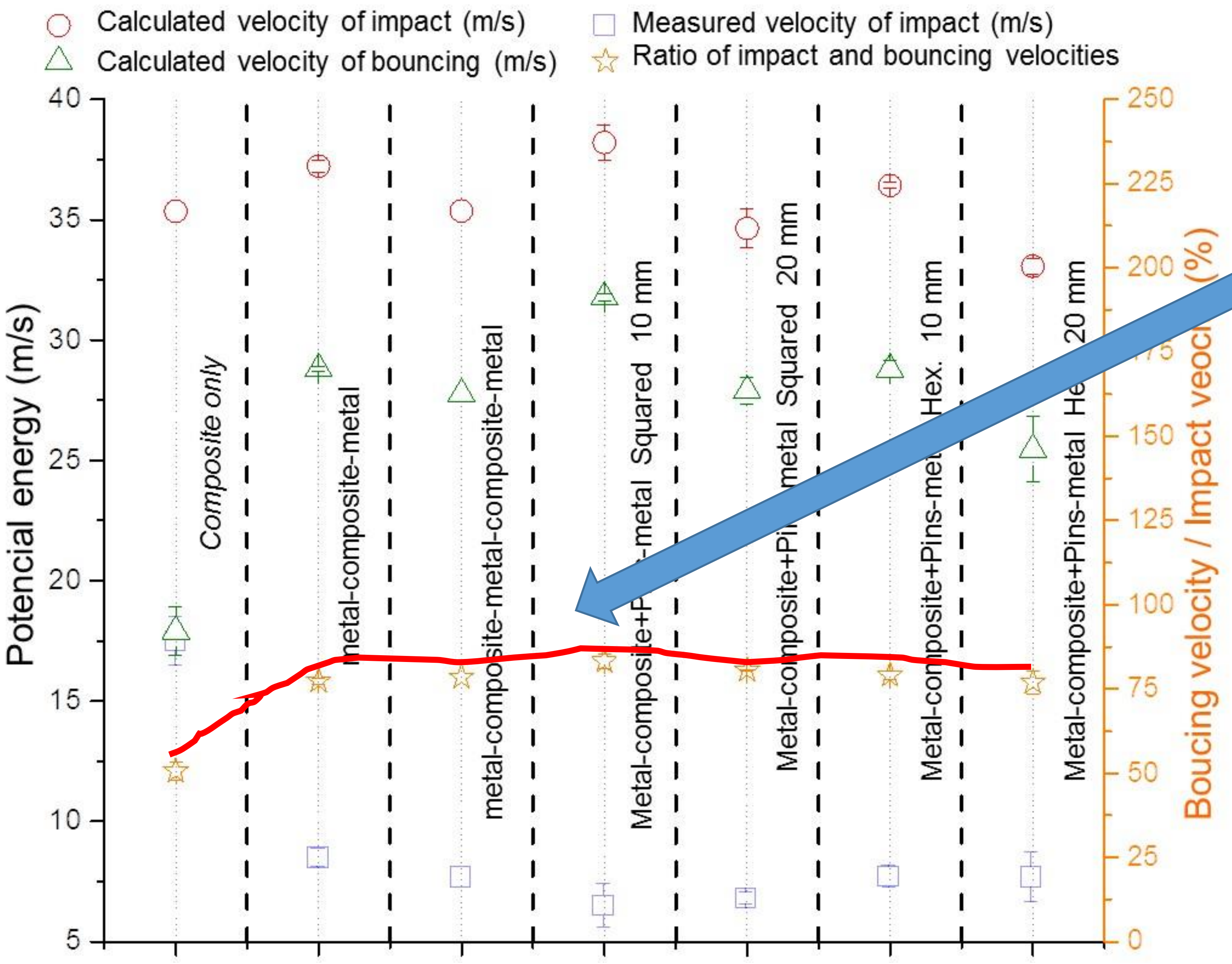


Bouncing speed measured by high speed camera





Mechanical energy absorption after impact (bouncing weight)

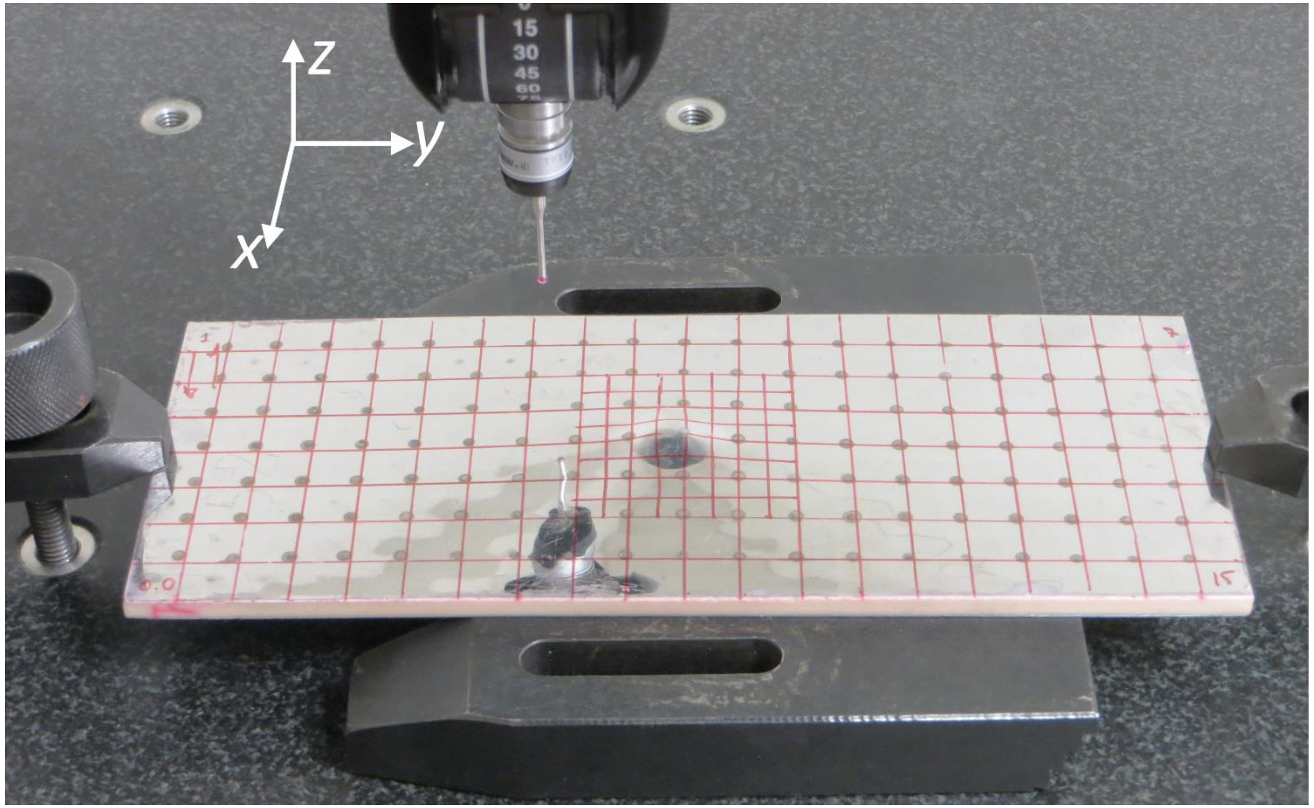


The absorbed energies of the panels are similar, yet lower (less elastic) than of the composite

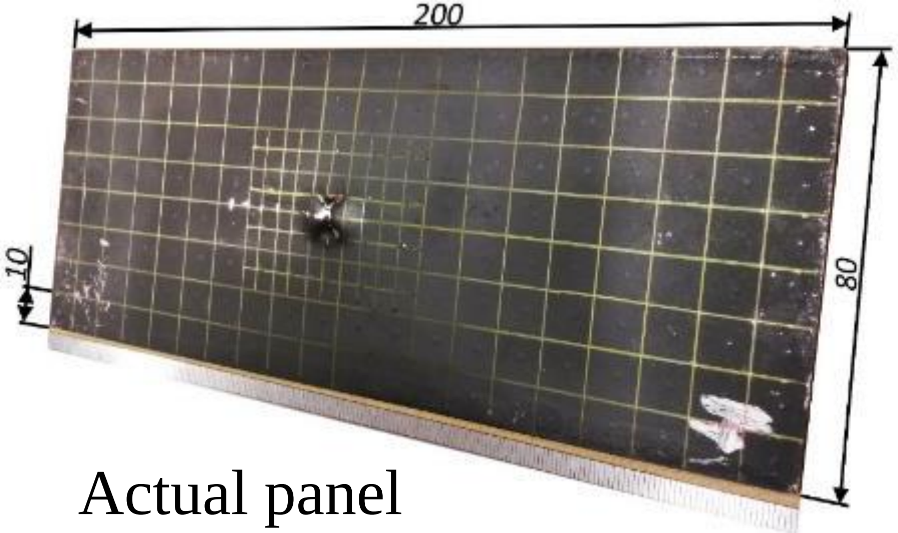
In this case, the pins did not impair the mechanical properties

Absorbed energy by the panel during bouncing

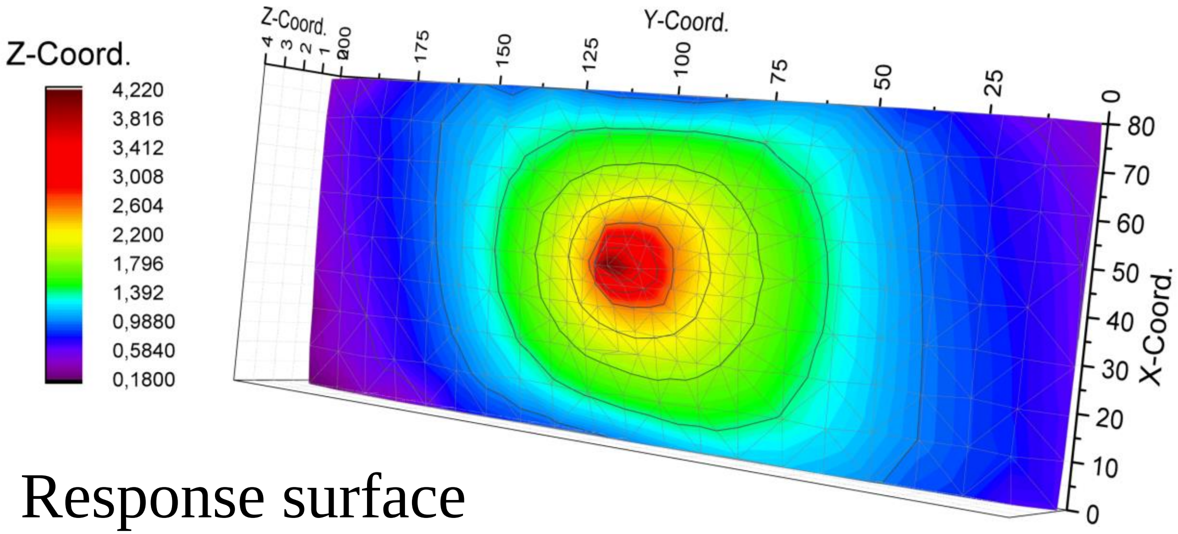
Characterization of the damage caused by *Drop-Weight Test*: Contact probe 3D scanning



Criterion: the height of the peak

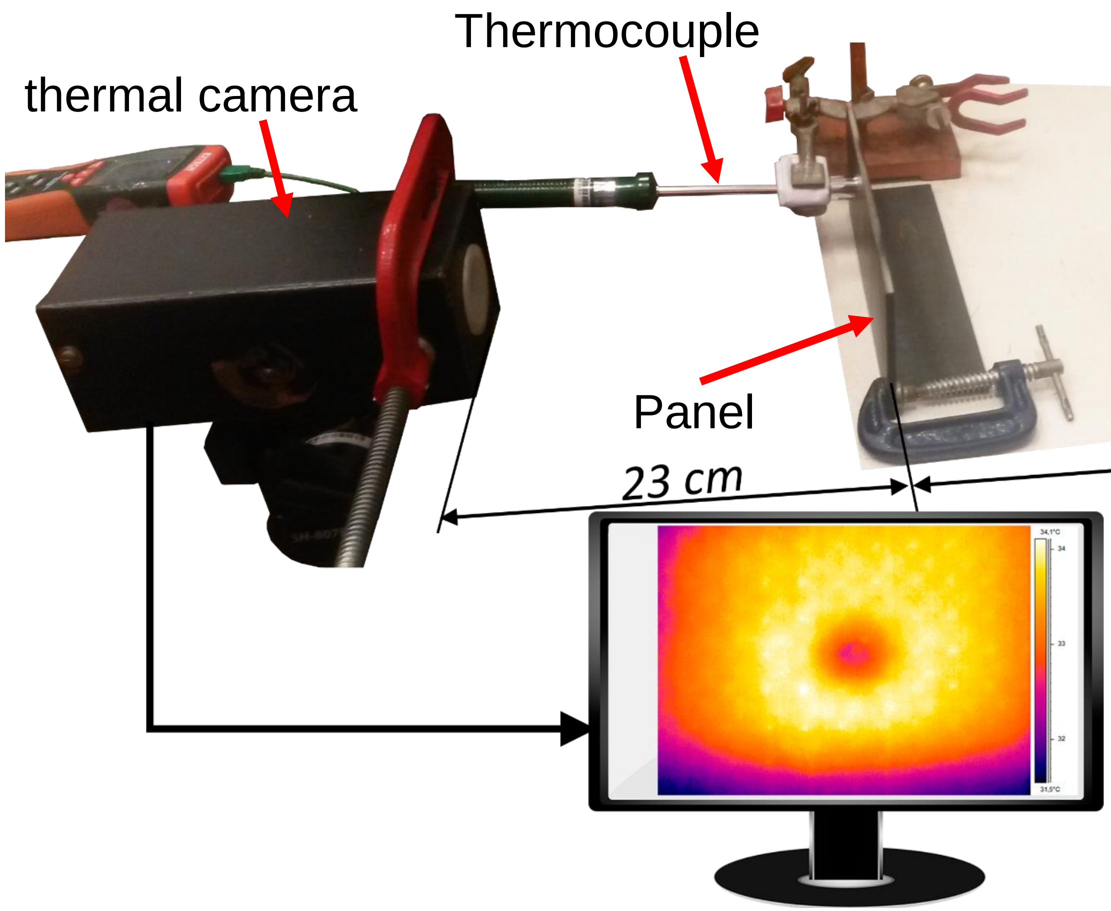


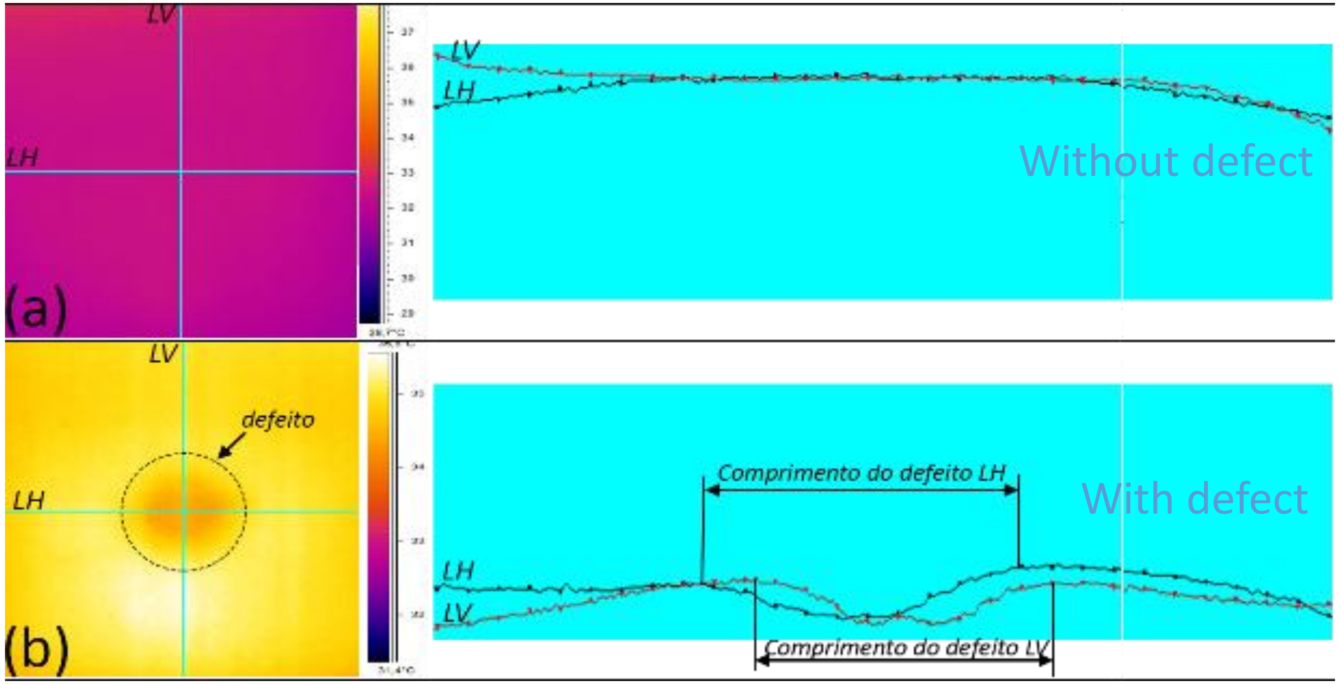
Actual panel



Response surface

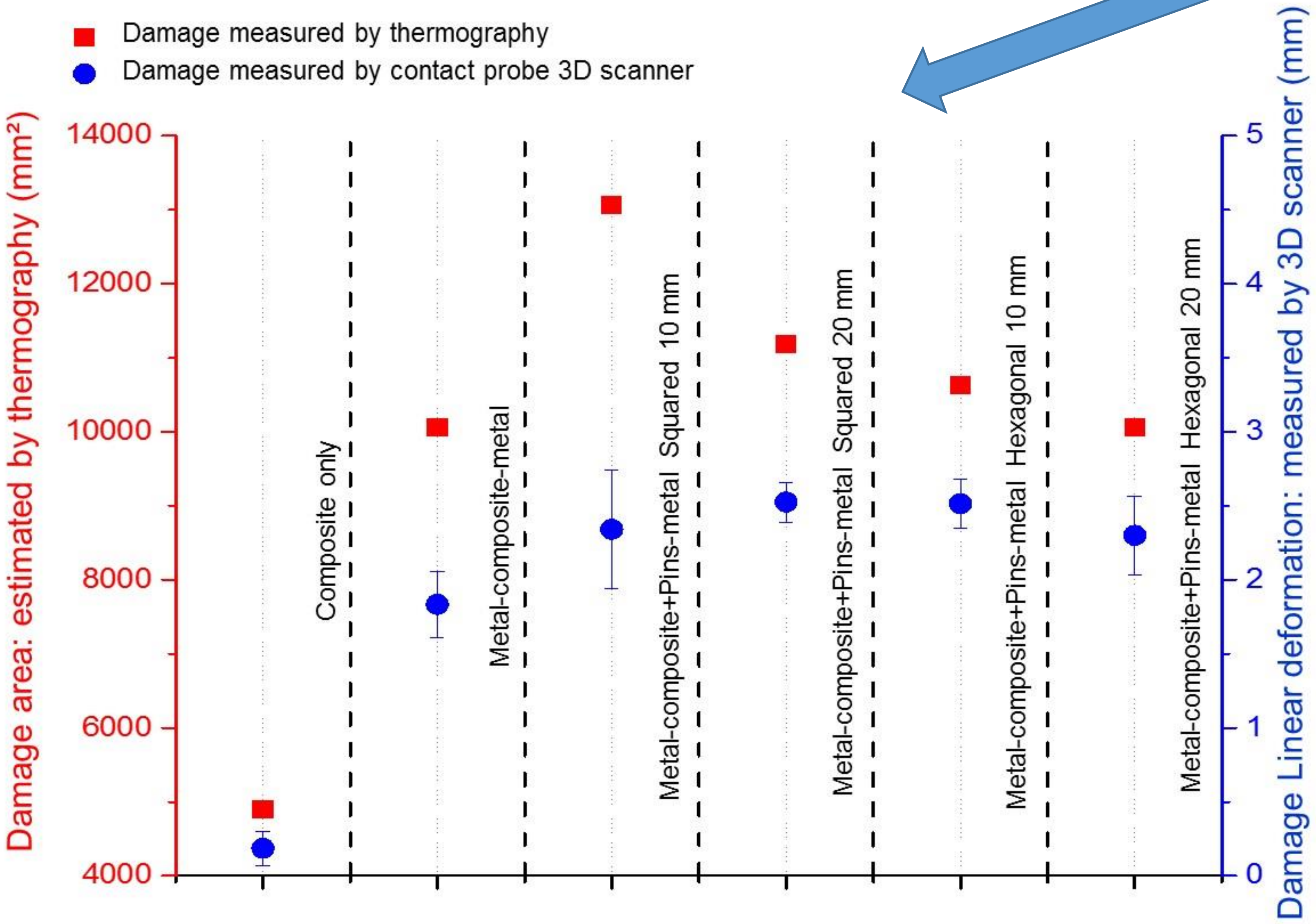
Characterization of the damage caused by *Drop-Weight Test*: thermography





Criterion: detected area of the damage

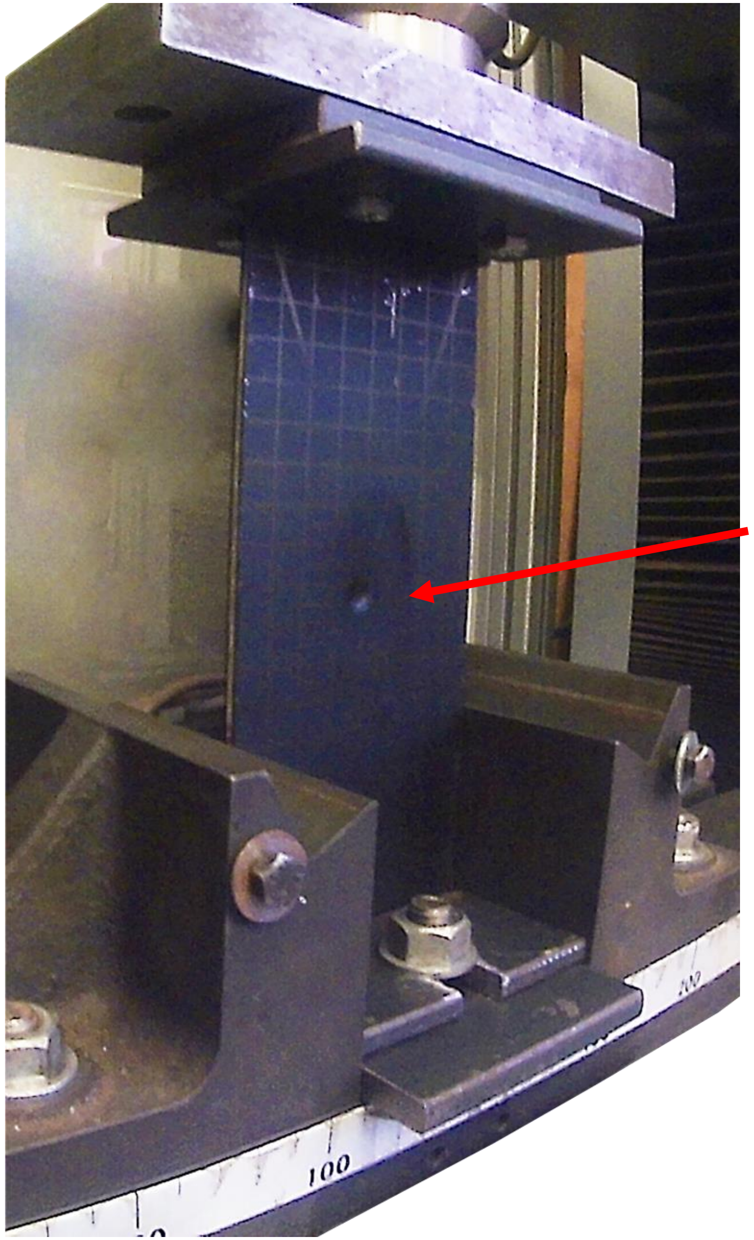
Comparison of damage dimension measured by both methods (upper surface)



The same trends from both methods, but thermography still demands further development

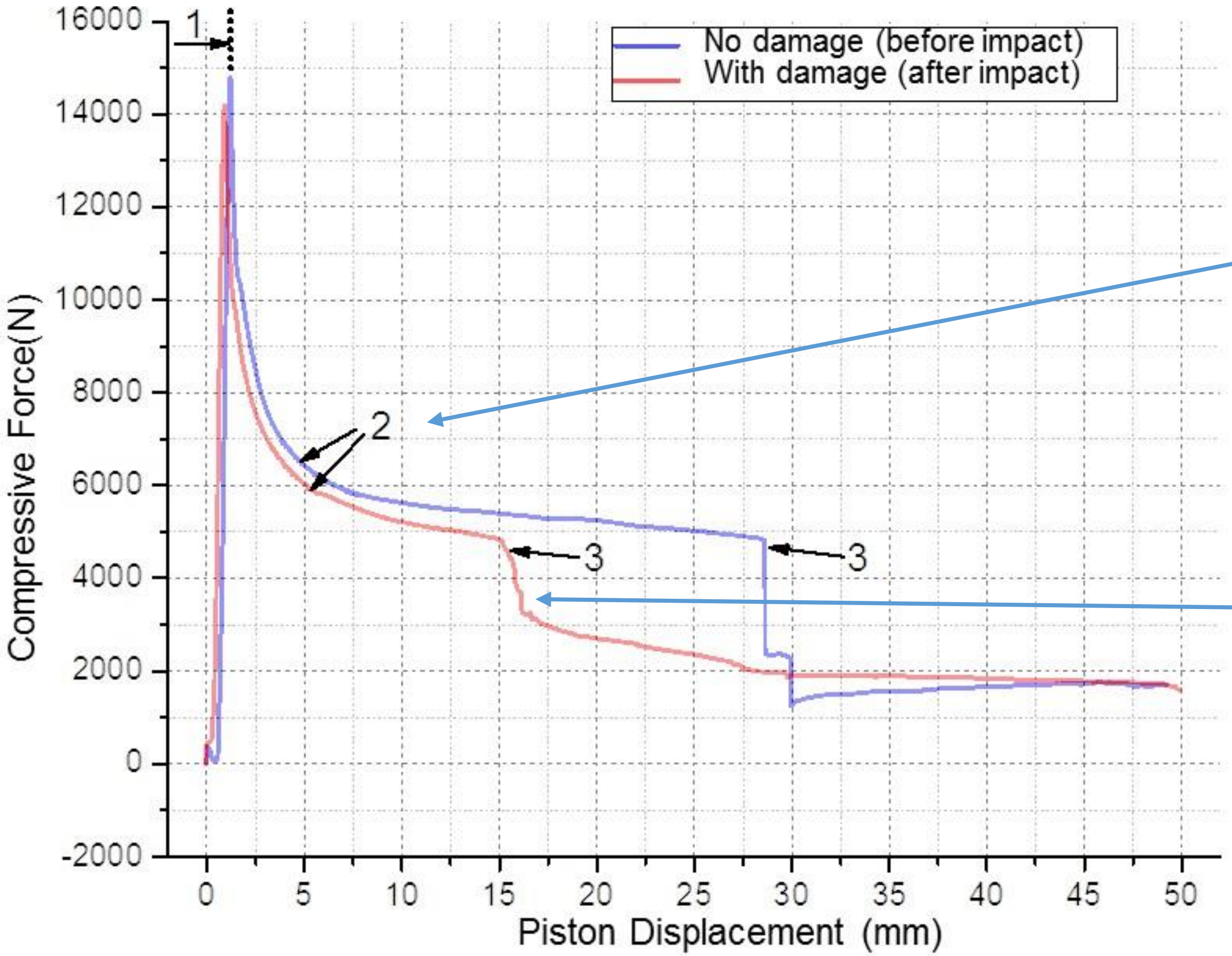
Damages are bigger in reinforced panels (either with pins, but also with a inner plate)

Resistance to buckling after damage



Damaged Panel

Sensitivity analysis of the test



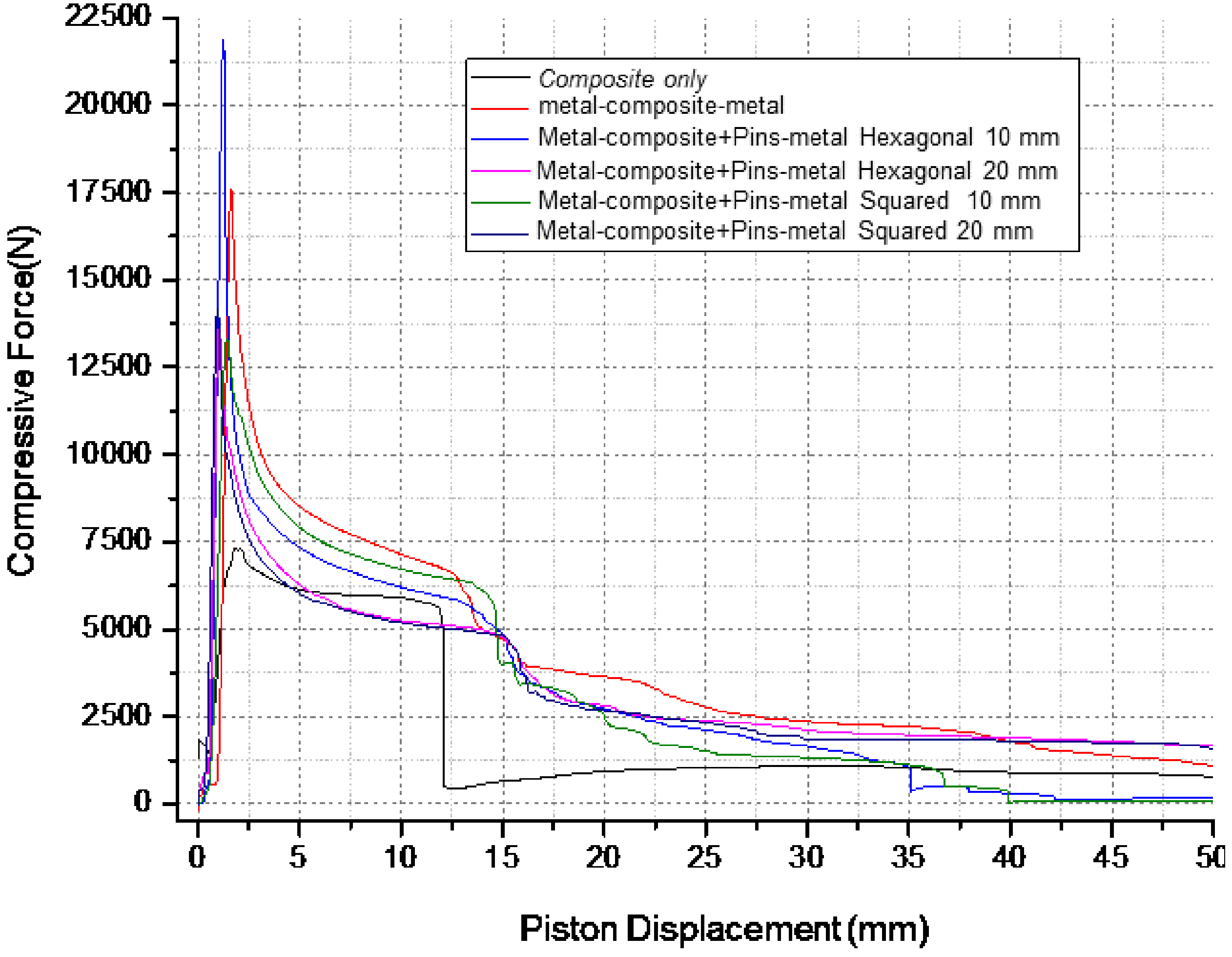
The test approach allowed to differentiate damaged from undamaged specimens

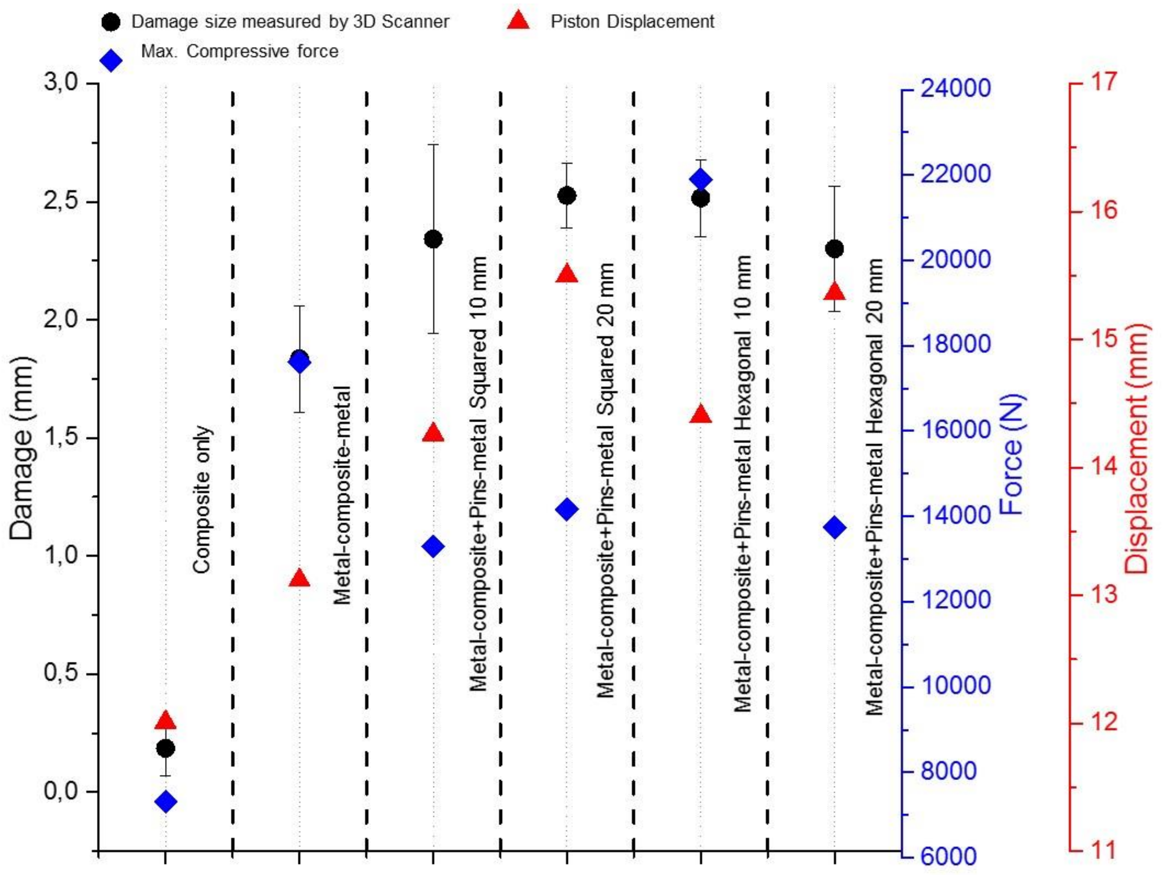
Damage affects more the buckling stage (shortening)

Catastrophe due to damage happens with shorter load displacement.

1 – compression stage;
2 – buckling stage;
3 – failure stage.

Resistance to buckling after damage





In general:

- The metal-composite-metal panel support higher force before buckling, yet less deformation before collapsing;
- The bigger the damage, the longer the deformation before collapsing (damage is a means of absorbing energy without catastrophic failure)

Conclusion:

1. Fabrication of reinforcement pins on sheet surfaces of laminate panel is technically and economically feasible, even on very thin plates (0.4 mm in this project);

2. Pin-reinforced panels showed to demand less pre preg material to reach the same panel thickness (potential economical advantage);

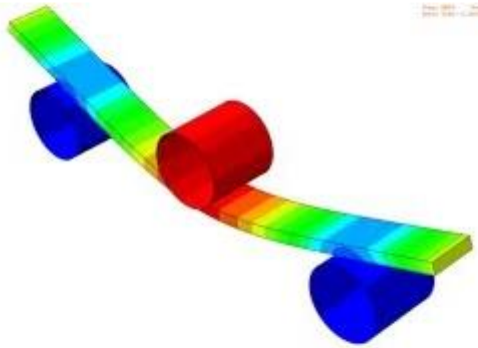
3. When resistance of the pin-reinforced panels were measured comparatively to the reference panel (combination metal-composite without pins):

   a) The maximum forces supported by the panel specimens during bending test were lower, yet with less catastrophic failure characteristic;
   b) The absorbed energies by the panel specimens during drop-weight test were similar in values;
   c) Damage after high speed transverse impact is larger;
   d) The maximum compressive force on damaged specimens before buckling initiation was also lower, yet again with a less catastrophic characteristic.

4. Use of thermography to measure damage in panels seems to be promising, yet demanding further development (the main advantage would be that measurement can be carried out in situ)

Further studies:

Considering the demonstrated potentiality of pin reinforcement of panels, the following studies are programmed for the project (and open to collaborations):



- Numerical simulation to study the optimized pin density and deposition pattern concerning mechanical resistance and catastrophic failure

- Application of the approach in thicker panels, where the stress concentration characteristics of pins could be balanced with a higher volume of composite;

- Application of the approach in larger specimens and submmit them to other properties assessment test type and parameters;

- To study further thermography as a means of measuring panel damage after impact.

Thank you for your kind attention

Acknowledgements

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