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) Preparation of the metal parts

1) AISI 430: 200 × 80 × 0.4 mm:

Cutting

2) Deposition of pins

3) Laying-up of prepregs on the metal part

4) Placing other metal part, pressing and curing

5) Metal composite panel made

Metallic pin
Polymeric matrix (cured resin)
Fibre
Adhesive (cured resin layer)

Metal

Composite
The pins are built over the internal metal sheet surfaces by arc welding:
Process CMT (Cold-Metal Transfer) PIN

CMT (Cold-Metal Transfer) PIN operating cycle
Author: Iaroslav Skhabovskyi; Laprosolda – Federal University of Uberlandia (UFU) – Brazil (2016);

Parameters: Altitude Adaptation=0; Ball/Cyl. Adaptation=0.0; CTWD=15 mm; Shielding=Ar+11%CO2; Electrode=AWS ER70S-6 1.0 mm
3) Application of pre pegs (7781-38” – F155 from HEXCEL Corporation)

Mats of 210 × 90 mm

4) Polymer processing: “sandwich” pressing and curing:

One layer applied over the metal sheet with pins
Types of panels

- 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

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

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.

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
- Aluminum = 2.7 g/cm³
Resistance to bending (3 point bending test)

Applied force

Specimen (Panel)

Support roller

Support roller

Loading roller

ISO 7438:1985 “Metallic Materials – Bend Test”
Resistance to bending

- 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)

- Panel (specimen)
- Impactor
- Impactor catcher
- Triggers

$\approx 1.8 \text{ m} \quad (\text{target } = 8.5 \text{ J/unit of specimen thickness})
Bouncing speed measured by high speed camera

Panel

Light spots 1kW

High speed camera

Monitor
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
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 submit 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