Comparison of different joining techniques in a crashworthiness perspective

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Comparison of different joining techniques in a crashworthiness perspective

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Pierfranco Mauri – Henkel Loctite Italia
Contents

- Comparison of joining techniques
  - Joining technique for car body construction
  - Mechanical testing
  - Results and discussion

- Design of crash structures with different joining techniques
  - Experimental results from crash boxes
  - Redesign of crash box with adhesive bonding
  - Comparison of the results
Why using alternative joining solutions?

- Adhesive bonding helps increasing stiffness
- During polymerisation other fixing system is needed
- Adhesive bad compatibility with spot-welds
- Adhesive and other mechanical fasteners can join different materials
- Repairing possible
Joints testing

- Spot-weld strength
  - Static
  - Fatigue
  - Dynamic/Impact
- Loading conditions
KS2 specimen

- Formerly used by Hahn et al. for fatigue
- Material ZST340
- Samples from DAIMLERCHRYSLER for DANCE
Testing system

Double sliding frame

Connections with spherical joints

piezoelectric load-cells (during dynamic tests)

Inclined grips (0°-90°)

Details of the 30° loading system
Testing apparatus

- Universal hydraulic material testing equipment DARTEC HA100
  - 100 kN max
  - 100 mm/s $v_{\text{max}}$
  - Load measured with a strain-gage load-cell
  - Stroke measured with LVDT

- Drop-tower
- Height 12 m,
- Mass 60-120 kg
- 300 kN max
- 13 m/s $v_{\text{max}}$
- Equipped for impact testing (in compression)
- Equipped with tensile test grip
- Load measured with piezoelectric load-cells
- Stroke measured with an optical encoder
Spot-welds
Experimental results

- Load & stroke measurement
- Number of loading speed: 3
  - Low-speed: 0.01 mm/s
  - Medium-speed: 80 mm/s
  - High-speed (impact): 5.5×10³ mm/s
- Load-curve characteristic
- Failure surface is derived from maximum load as a function of the loading angle
Spot-weld results
Low speed

- Apparatus: DARTEC HA100
- Loading speed: 0.01 mm/s
Spot-weld results
Medium speed

- Apparatus: DARTEC HA100
- Loading speed: 80 mm/s (=0.08 m/s)
Spot-weld results
High speed

- Apparatus: DARTEC HA100
- Loading speed: 5.5 m/s
Spot-welds
Low speed samples
# Spot-welds

High speed samples

<table>
<thead>
<tr>
<th>KS200d1</th>
<th>Dynamic</th>
<th>0</th>
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<tbody>
<tr>
<td>KS230d1</td>
<td>Dynamic</td>
<td>30°</td>
</tr>
<tr>
<td>KS260d3</td>
<td>Dynamic</td>
<td>60°</td>
</tr>
<tr>
<td>KS290d1</td>
<td>Dynamic</td>
<td>90°</td>
</tr>
</tbody>
</table>

<table>
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</tr>
<tr>
<td>KS290d1</td>
<td>Dynamic</td>
<td>90°</td>
</tr>
</tbody>
</table>
Analysis of the results

- Joint strength is analysed as a function of the loading angle:
- An elliptic limit curve is assumed:

\[
\left(\frac{T}{T_{\text{max}}}\right)^2 + \left(\frac{N}{N_{\text{max}}}\right)^2 = 1
\]

- A different limit curve is obtained for each loading speed
Spot-weld strength vs. loading

- Limit curve as a function of the loading angle

\[ F = \frac{T_{\text{max}}}{\cos \alpha \sqrt{1 + \tan^2 \alpha \left(\frac{T_{\text{max}}}{N_{\text{max}}}\right)^2}} \]

- 0.01 mm/s
- 80 mm/s
- \(5.5 \times 10^3\) mm/s
Spot-weld strength vs. loading components
Failure surfaces

Peel (90°)  Shear (0°)  Peel (90°)  Shear (0°)

Static (0.01 mm/s)  Dynamic (5 m/s)
Alternative joining systems for automotive constructions

- Riveting
- Self-riveting, punch riveting, Henrob joint
- Clinching
- Adhesive bonding
Clinching compared to spot-welds (1/2)

Material: Mild Steel (approx. 300 N/mm²)

1. Round die, ∅ 5mm
2. Round die, ∅ 8mm
3a. Rectangular die, w. 4mm, shear 90°
3b. Rectangular die, w. 4mm, shear 0°
4. Spot Weld, Standard spec. minimum, ∅3 & 4mm

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Clinch Systems SA
Clinching compared to spot-welds (2/2)

Mondino, I., Properzi, M., Giunti, T., Calderale, P.M., “La fatica di giunzioni meccaniche per strutture veicolistiche innovative” (Fatigue of mechanics joints for innovative car body structures) Proceedins XXVIII AIAS Conf., 1999
KS2 specimen

- Formerly used by Hahn et al. for fatigue
- Material DC04
- Samples from
Clinching and Bonding Experimental plan

- KS2 specimen loaded at different angles
  - Clinched: 21 samples
  - Bonded LOCTITE Hysol® 9466: 21 samples
  - Clinched+bonded: 22 samples
- Loading speed: quasi-static 0.01 mm/s
- Bonding procedure
  - Sanding (paper sand P80)
  - Degreasing (LOCTITE® 7063) and bonding
  - Polymerisation: 90 minutes @ 100°C
Clinched and bonded KS2 specimen

Clinched

Clinched+bonded
Clinched & clinched+bonded samples

Clinched+bonded, 0°
Clinched+bonded, 30°
Clinched+bonded, 60°
Clinched+bonded, 90°
Clinched, 30°
Clinched, 0°
Clinched, 60°
Clinched, 90°
Clinching Test results

- Apparatus: DARTEC HA100
- Loading speed: 0.01 mm/s
Bonding Test results

- Apparatus: DARTEC HA100
- Loading speed: 0.01 mm/s
Clinching+bonding Test results

- Apparatus: DARTEC HA100
- Loading speed: 0.01 mm/s
Clinched and bonded joint strength vs. loading

- Limit curve vs. Loading angle

Graph showing the maximum load (kN) vs. loading angle (deg) for different joint types:
- Clinched
- Bonded
- Clinched+bonded

Mathematical equation:

\[ F = \frac{T_{\text{max}}}{\cos \alpha \sqrt{1 + \tan^2 \alpha (T_{\text{max}} / N_{\text{max}})^2}} \]
Clinched and bonded joint strength vs. load components

\[
\left(\frac{T}{T_{\text{max}}}ight)^2 + \left(\frac{N}{N_{\text{max}}}ight)^2 = 1
\]
Clinched and bonded joint energy vs. loading angle

- Failure energy vs. Loading angle

![Graph showing the relationship between failure energy and loading angle for different joint types: Clinched, Bonded, and Clinched+bonded.](image)
Different joining solutions: conclusions

- Joining by clinching is effective and a good alternative to spot-weld.
- The use of adhesive strongly increase strength and energy absorption capability.
- Clinching can be use to make bonding operations easier: the pieces are kept in place up to complete polymerisation.
- Clinching in addiction to bonding offers additional safety as an extreme protection in the case of adhesive premature failure.
Behaviour of crash boxes with alternative joining solutions

- Is it possible to substitute spot-welds with other joining systems directly in the common constructive solutions?
- Crash behaviour can be improved?
Bonded crash-box production

- Cleaning and surface preparation with sand paper
- Degreasing with Loctite 7063
- Activation with Loctite 7388
- Application of Loctite 330 adhesive
- NDT ultrasonic inspection

- Cleaning and surface preparation with sand paper
- Chemical degrease
- Mixing of components and application of CIBA araldite adhesive
- NDT ultrasonic inspection
Ultrasonic NDT inspection

NDT procedure by Rossetto & Goglio (ref. XXIX AIAS et al.)
Stress analysis of the bonded flanges

![Stress analysis diagram](image)

- **Position (mm):**
  - 15
  - 60
  - 15
  - 30
  - 30

- **Equivalent stress (MPa):**
  - adhesive layer thickness 0.2 mm
  - adhesive layer thickness 0.4 mm

- **Coordinate y [mm]:**
  - -10
  - -8
  - -6
  - -4
  - -2
  - 0
  - 2
  - 4
  - 6
  - 8
  - 10
  - 12
  - 14
  - 16
  - 18
  - 20

- **Von Mises equivalent stress [MPa]:**
  - 0
  - 40
  - 80
  - 120
  - 160
  - 200
Improvements by filleting
Quasi-static crushing
Spot-welded crash-box
Quasi-static crushing
Adhesively bonded crash-box
Quasi-static crushing Comparisons (1/2)
Quasi-static crushing
Comparisons (2/2)

### LOCTITE 330 adhesive

<table>
<thead>
<tr>
<th></th>
<th>Mean load (kN)</th>
<th>Max load (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>11.62</td>
<td>28.57</td>
</tr>
<tr>
<td>B3</td>
<td>10.80</td>
<td>27.62</td>
</tr>
<tr>
<td>B5</td>
<td>11.79</td>
<td>41.75</td>
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<tr>
<td>mean value</td>
<td>11.40</td>
<td>32.65</td>
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<tr>
<td>stand. dev.</td>
<td>0.53</td>
<td>7.90</td>
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### Spot-weld

<table>
<thead>
<tr>
<th></th>
<th>Mean load (kN)</th>
<th>Max load (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N1</td>
<td>8.09</td>
<td>20.92</td>
</tr>
<tr>
<td>N2</td>
<td>7.92</td>
<td>21.92</td>
</tr>
<tr>
<td>N3</td>
<td>7.57</td>
<td>21.41</td>
</tr>
<tr>
<td>mean value</td>
<td>7.86</td>
<td>21.42</td>
</tr>
<tr>
<td>stand. dev.</td>
<td>0.26</td>
<td>0.50</td>
</tr>
</tbody>
</table>
Alternative solutions for improved bonded box (1/2)

- Made with an $\Omega$ elements bonded to a flat plate (top-hat section)

- New shape with two $\Omega$ elements one (smaller) inserted into the other
Alternative solutions for improved bonded box (2/2)

- Bonding flanges as simple substitution of spot-welds
- Made with two $\Omega$ elements (double hat section)

- Double U section
- Can be obtained by joining two identical U elements
Components characteristics

- Crash-boxes length 300 mm
- Sheet thickness 0.8 mm
- Material DC04 (ex FeP04)
- LOCTITE 330 adhesive

procedure:
- cleaning and sanding (sand-paper P100)
- Application of “cleaner” 7063 and activator 7388
- Polymerisation for at least 3 days
Quasi-static tests
Load and energy curves

- C shape: 2 folds followed by global instability and debonding
- other sections: regular folding some debonding (except D shape)
Quasi-static tests

- C shape: 2 folds followed by global instability and debonding
- Other sections: regular folding some debonding (except D shape)
Medium-speed tests
Load and energy curves

- C shape: 2 folds followed by global instability and debonding
- other sections: regular folding some debonding (except D shape)
Medium-speed tests

- C shape: 2 folds followed by global instability and debonding
- other sections: regular folding some debonding (except D shape)
Impact tests (6 m/s)
Load and energy curves

- A, B, C shapes: irregular debonding in the crushed part
- D shape: no debonding
Impact tests (6 m/s)

- A, B, C shapes: irregular debonding in the crushed part
- D shape: no debonding
Impact tests (9 m/s)
Load and energy curves

- A, B, C shapes: irregular debonding in the crushed part
- D shape: complete regular folding, no debonding at all
Impact tests (9 m/s)

- A, B, C shapes: irregular debonding in the crushed part
- D shape: complete regular folding, no debonding at all
Comparison of the different shapes: low speed

Quasi-static and medium-speed tests

- A, B shapes: maximum load in the average (≈30 kN), good energy absorption characteristics (2÷2.7 kJ)
- C shape: high maximum load (35 kN), low energy absorption (1.6-0.7 kJ), complete debonding and global instability
- D shape: lowest maximum load (24-28 kN), good energy absorption (1.6-1.8 kJ), regular folding
Comparison of the different shapes: high speed

- **C shape**: high maximum load (53-63 kN), low compression (50-104 mm);
- **B shape**: low maximum load (39 kN) and crushing (57-115 mm);
- **A shape**: average maximum load (38-51 kN), high crushing (111-184 mm)
- **D shape**: quite low maximum load (39-44 kN), high crushing (83-181 mm), *regular folding*
Conclusions

- Similar results both from low and medium speed and impact tests
- Adhesive bonding is a good solution also for energy absorption during crash
- Sensitive improvements by means of suitable (but simple) geometrical modification of more common shapes used for spot-welded structures:
  - C shape: bonded sections normal to sides → bad design
  - D shape: bonded sections parallel to sides → optimal design