European Vehicle Passive Safety Network

Comparison of different joining techniques in a crashworthiness perspective

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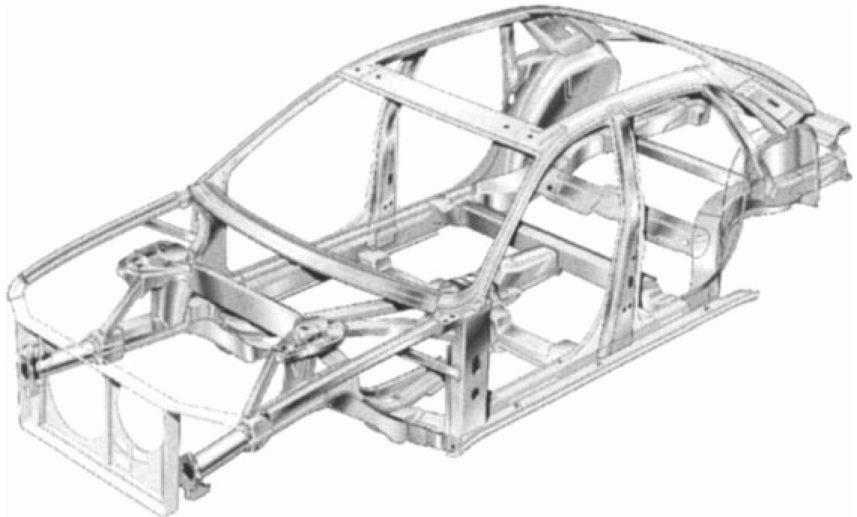
- Comparison of joining techniques
  - Joining technique for car body construction
  - Mechanical testing
  - Results and discussion
- Design of crash structures with different joining techniques
  - Experimental results from crash boxes
  - Redesign of crash box with adhesive bonding
  - Comparison of the results

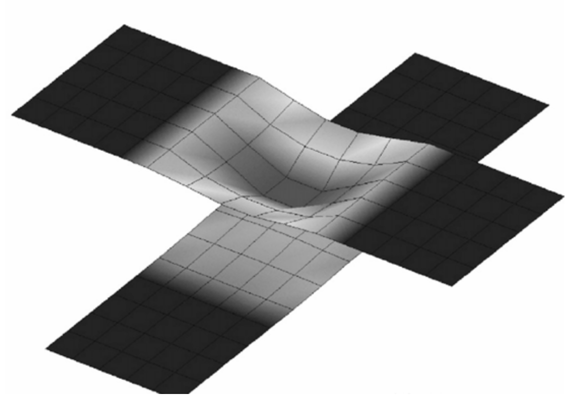
Why using alternative joining solutions?

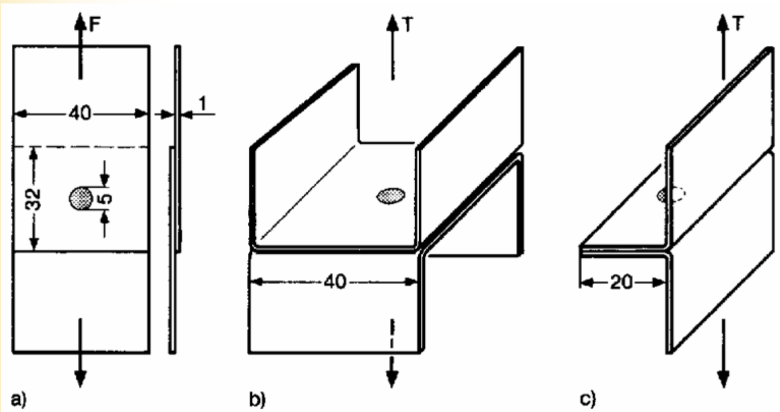
- Adhesive bonding helps increasing stiffness
- During polymerisation other fixing system is needed
- Adhesive bad compatibility with spot-welds
- Adhesive and other mechanical fasteners can join different materials
- Repairing possible

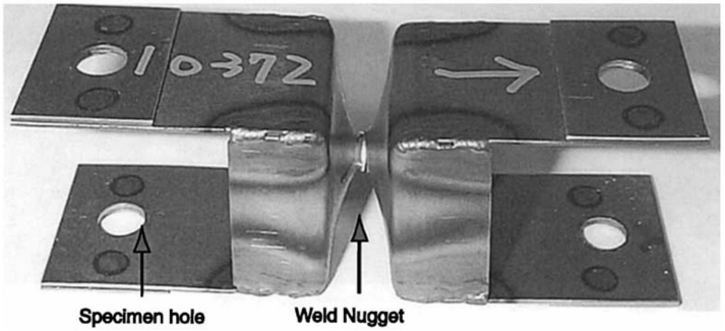


Joints testing

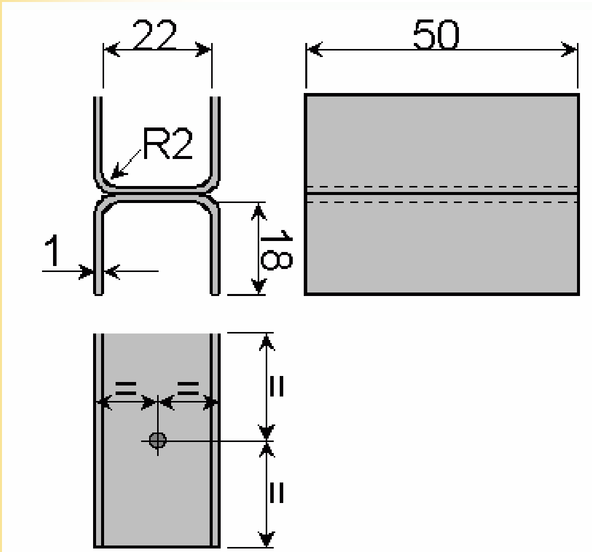
- Spot-weld strength
  - Static
  - Fatigue
  - Dynamic/Impact
- Loading conditions

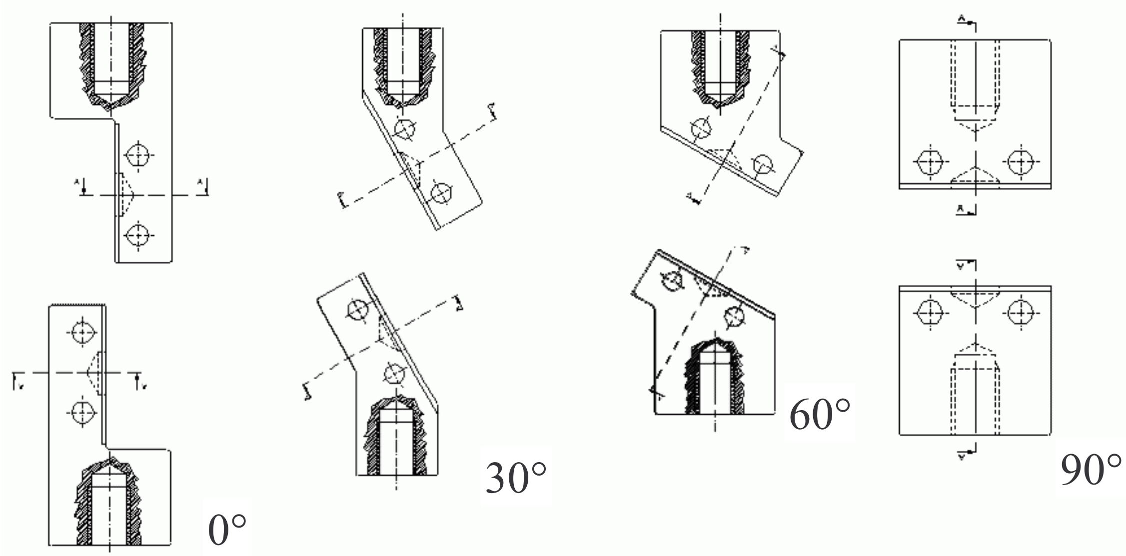




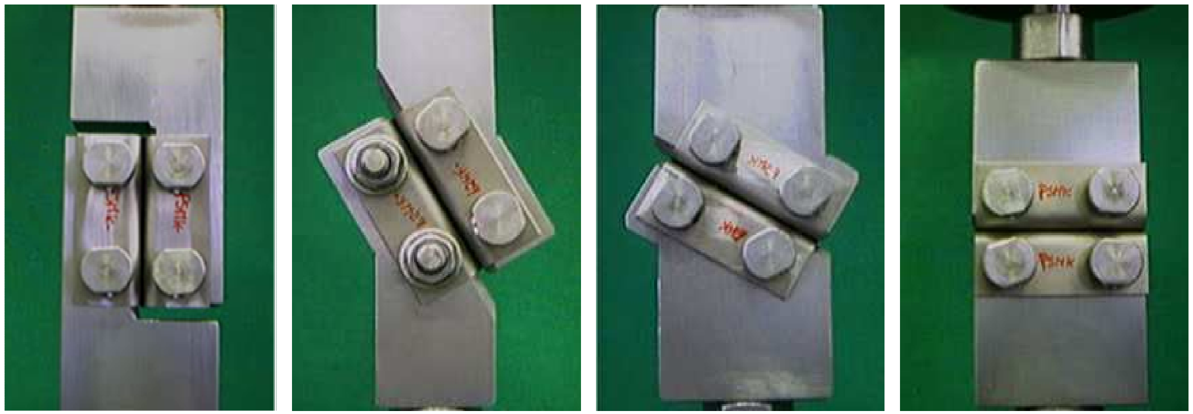


KS2 specimen

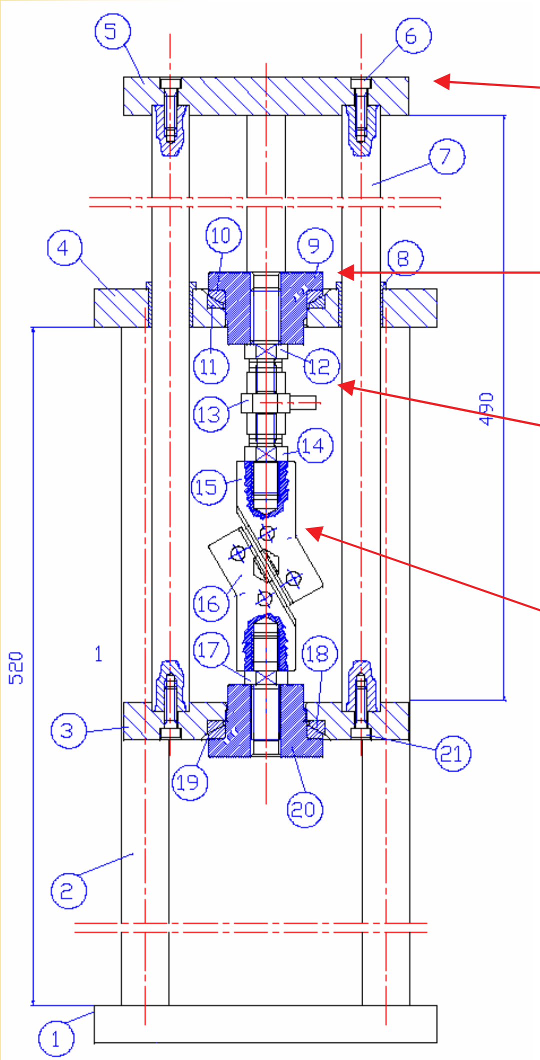




- Formerly used by Hahn *et al.* for fatigue
- Material **ZST340**
- Samples from DAIMLERCHRYSLER for ADVANCE



Testing system

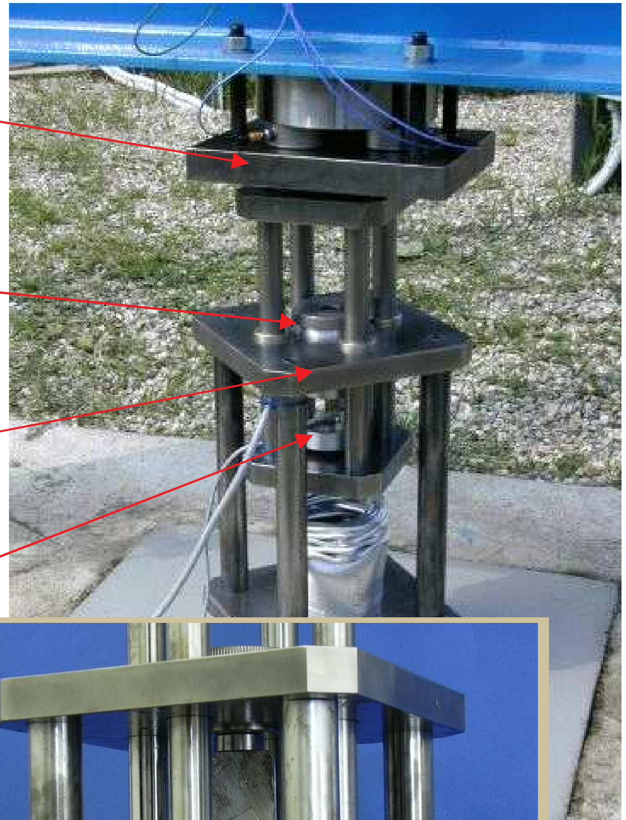


Double sliding frame

Connections with spherical joints

piezoelectric load-cells (during dynamic tests)

Inclined grips (0°-90°)



Details of the 30° loading system

Testing apparatus

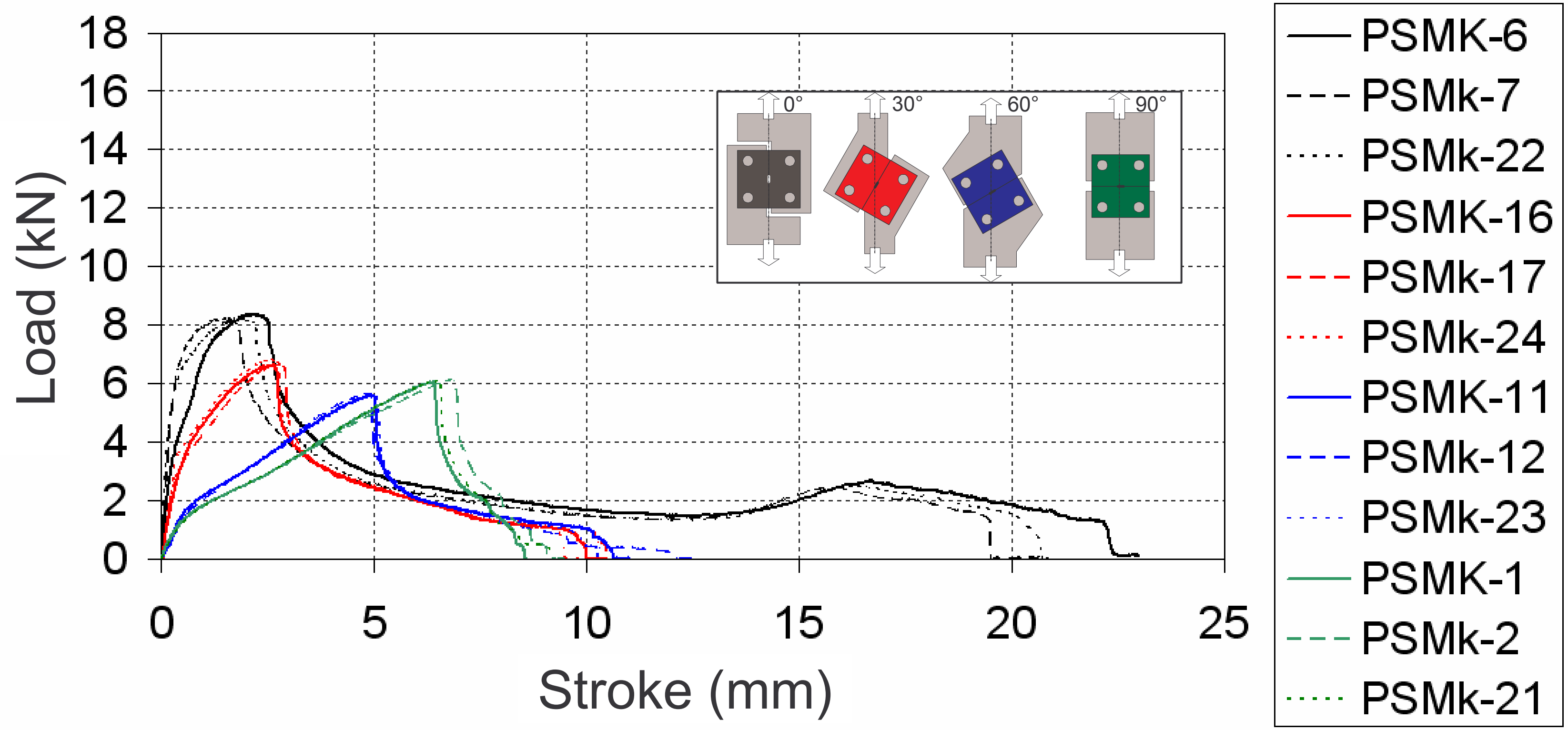
- Universal hydraulic material testing equipment DARTEC HA100
- 100 kN max
- 100 mm/s v_{max}
- Load measured with a strain-gage load-cell
- Stroke measured with LVDT

- Drop-tower
- Height 12 m,
- Mass 60-120 kg
- 300 kN max.
- 13 m/s v_{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

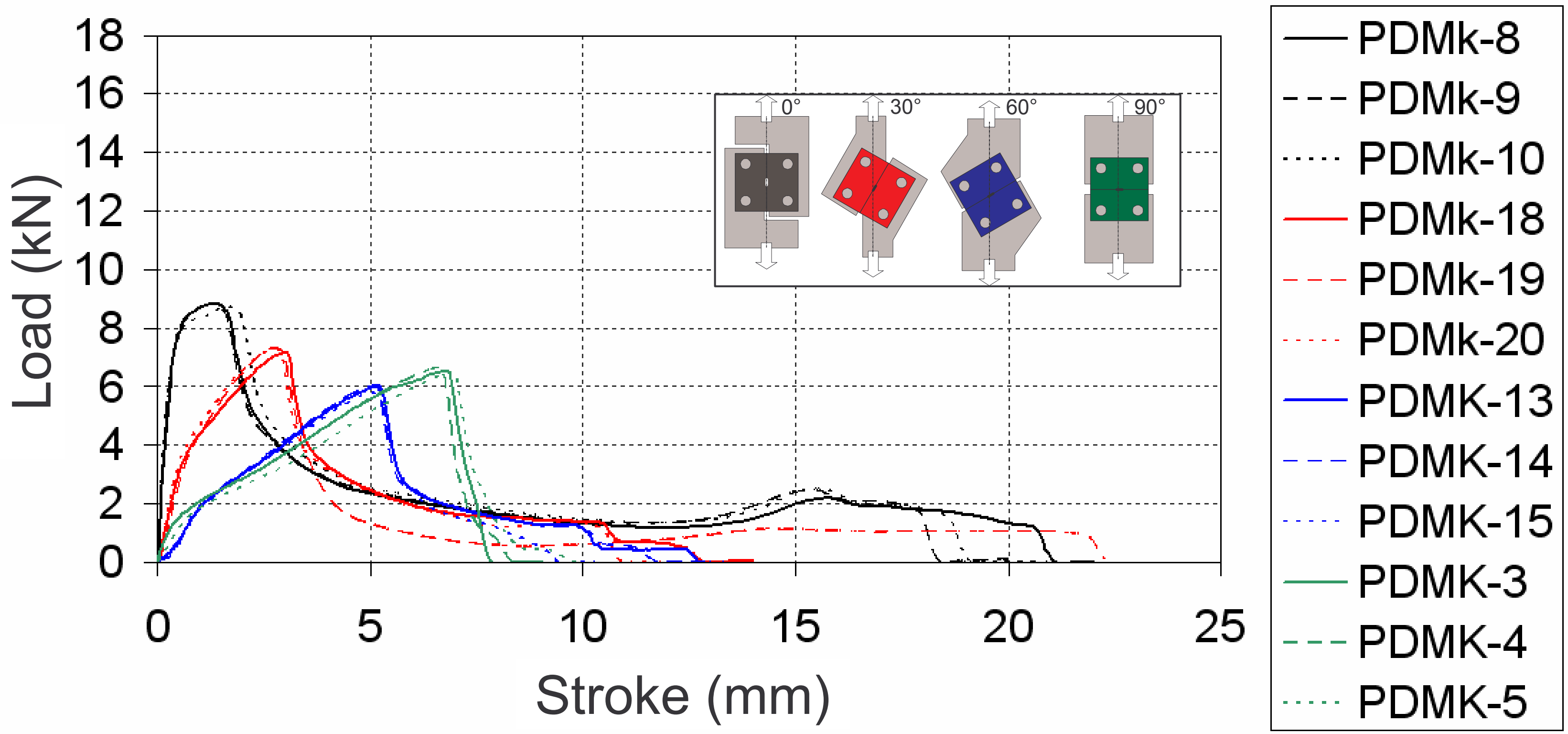
- Load & stroke measurement
- Number of loading speed: 3
  - Low-speed: 0.01 mm/s
  - Medium-speed: 80 mm/s
  - High-speed (impact): 5.5×10^3 mm/s
- Load-curve characteristic
- Failure surface is derived from maximum load as a function of the loading angle

Spot-weld results
Low speed



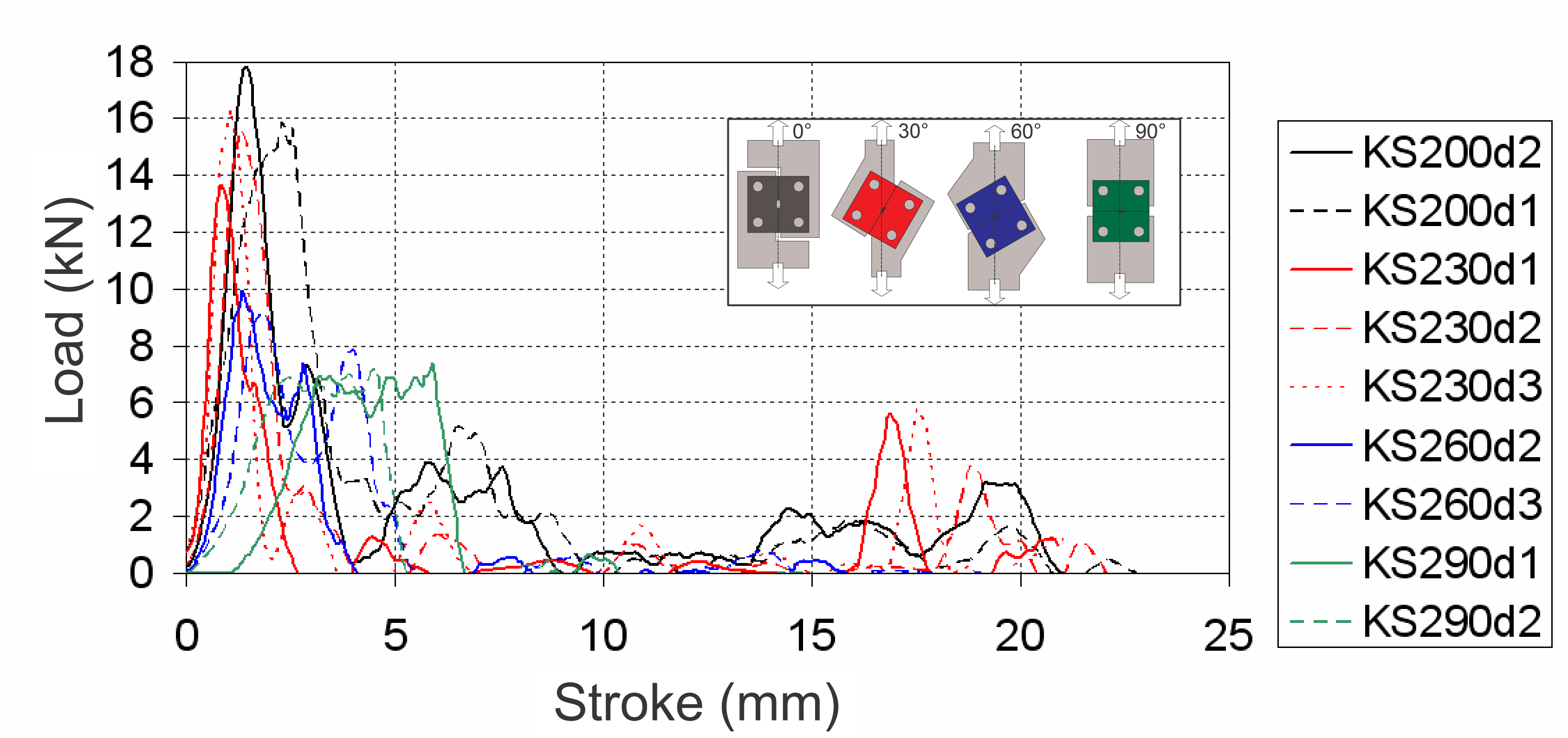
- Apparatus: DARTEC HA100
- Loading speed: 0.01 mm/s

Spot-weld results
Medium speed



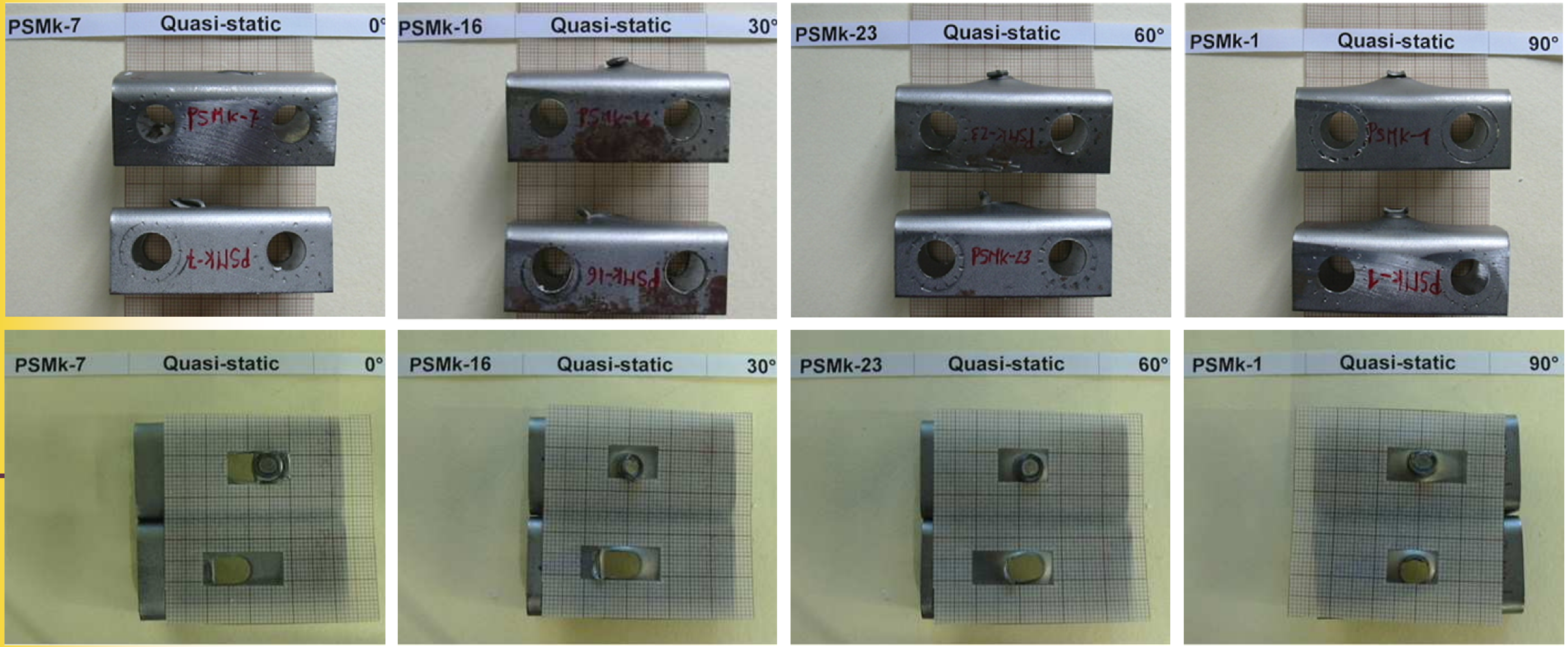
- Apparatus: DARTEC HA100
- Loading speed: 80 mm/s (=0.08 m/s)

Spot-weld results
High speed

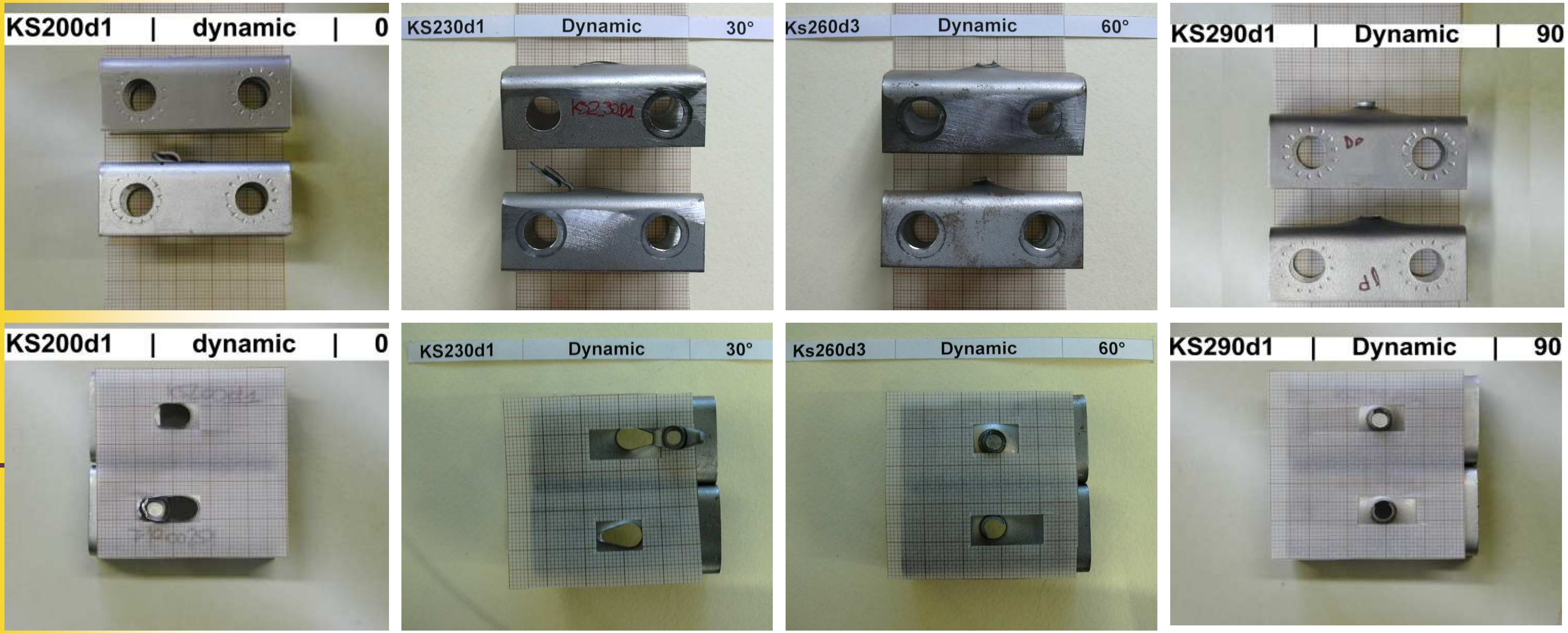


- Apparatus: DARTEC HA100
- Loading speed: 5.5 m/s

Spot-welds
Low speed samples



Spot-welds
High speed samples



Analysis of the results

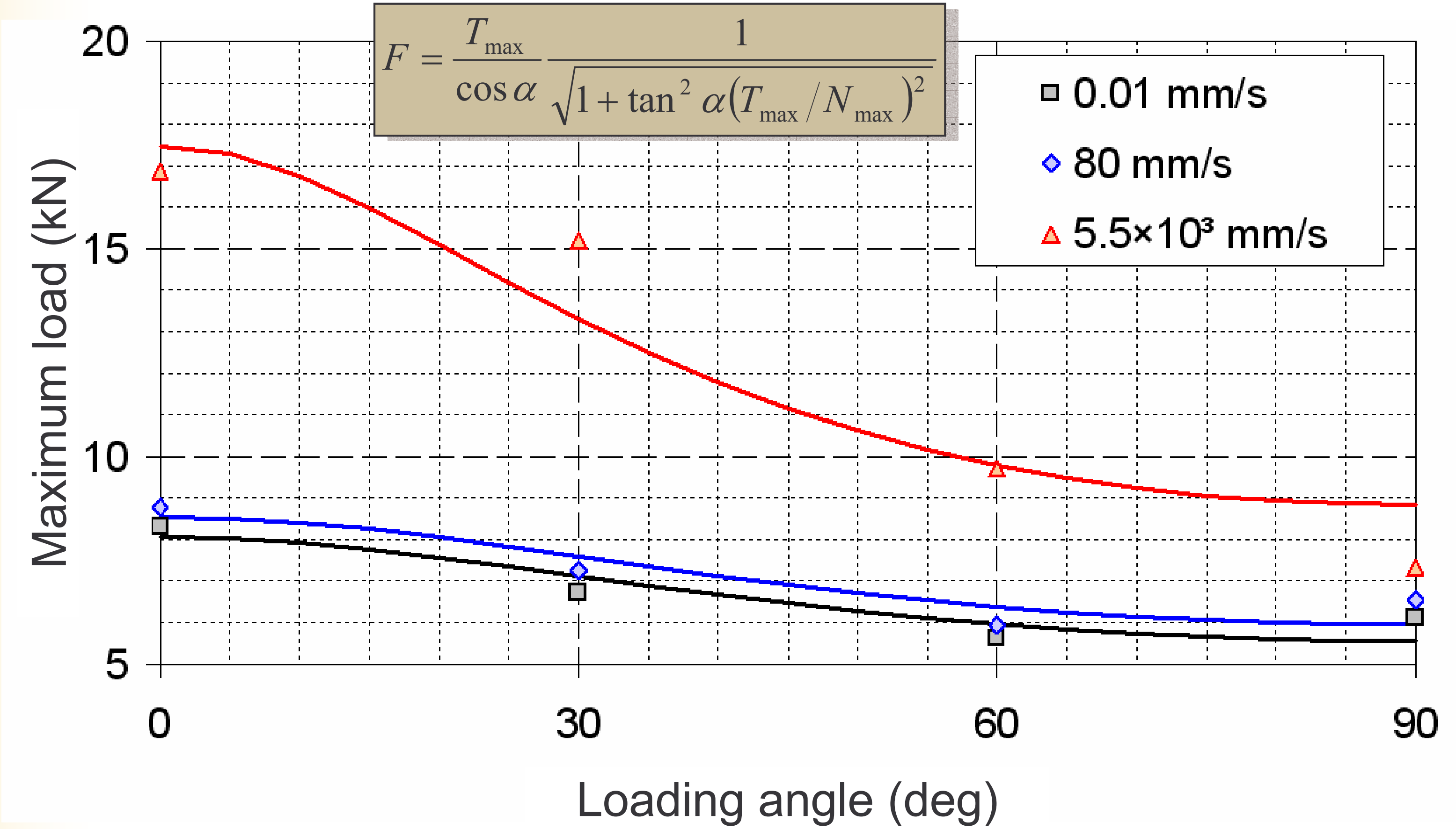
- Joint strength is analysed as a function of the loading angle:
- An elliptic limit curve is assumed:

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

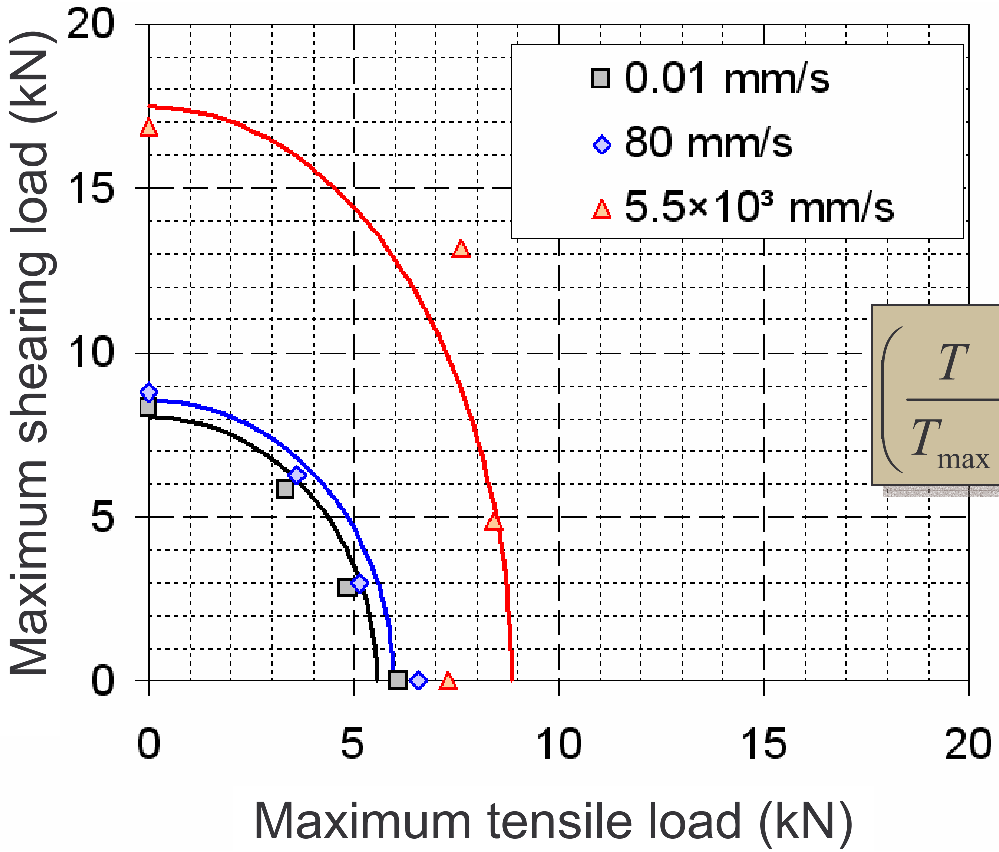
- A different limit curve is obtained for each loading speed

Spot-weld strength vs. loading

- Limit curve as a function of the loading angle



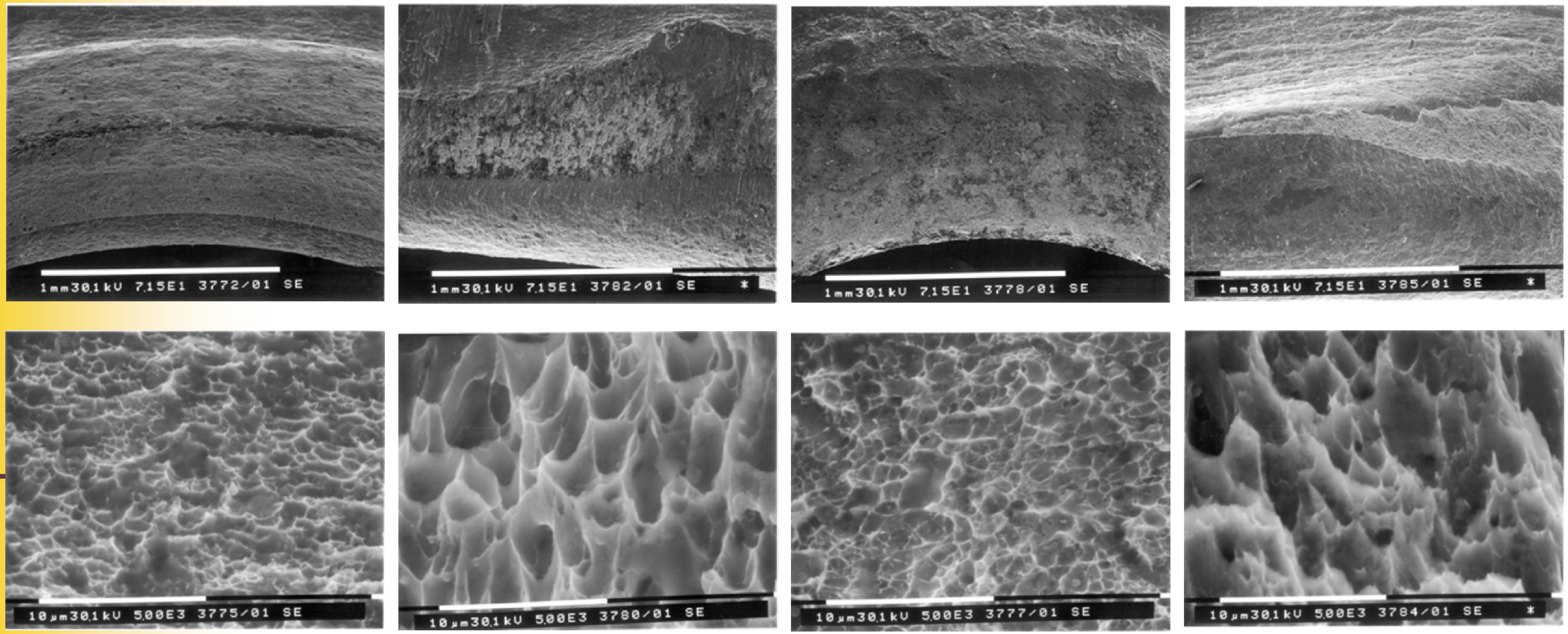
Spot-weld strength vs. loading components



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

Failure surfaces

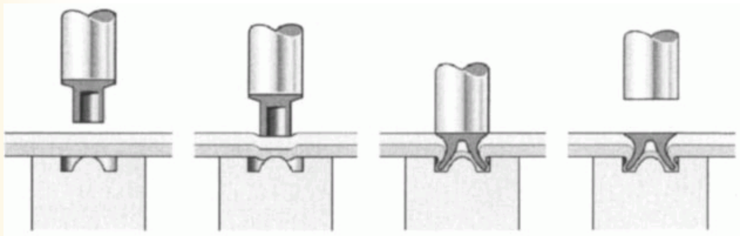
Peel (90°) | Shear (0°) | Peel (90°) | Shear (0°)



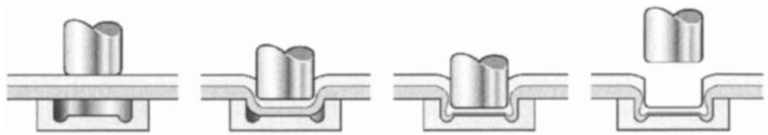
Static (0.01 mm/s) | Dynamic (5 m/s)

Alternative joining systems for automotive constructions

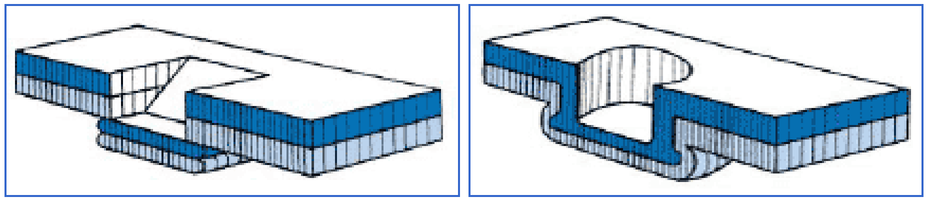
- Riveting
- Self-riveting, punch riveting, Henrob joint
- Clinching
- Adhesive bonding



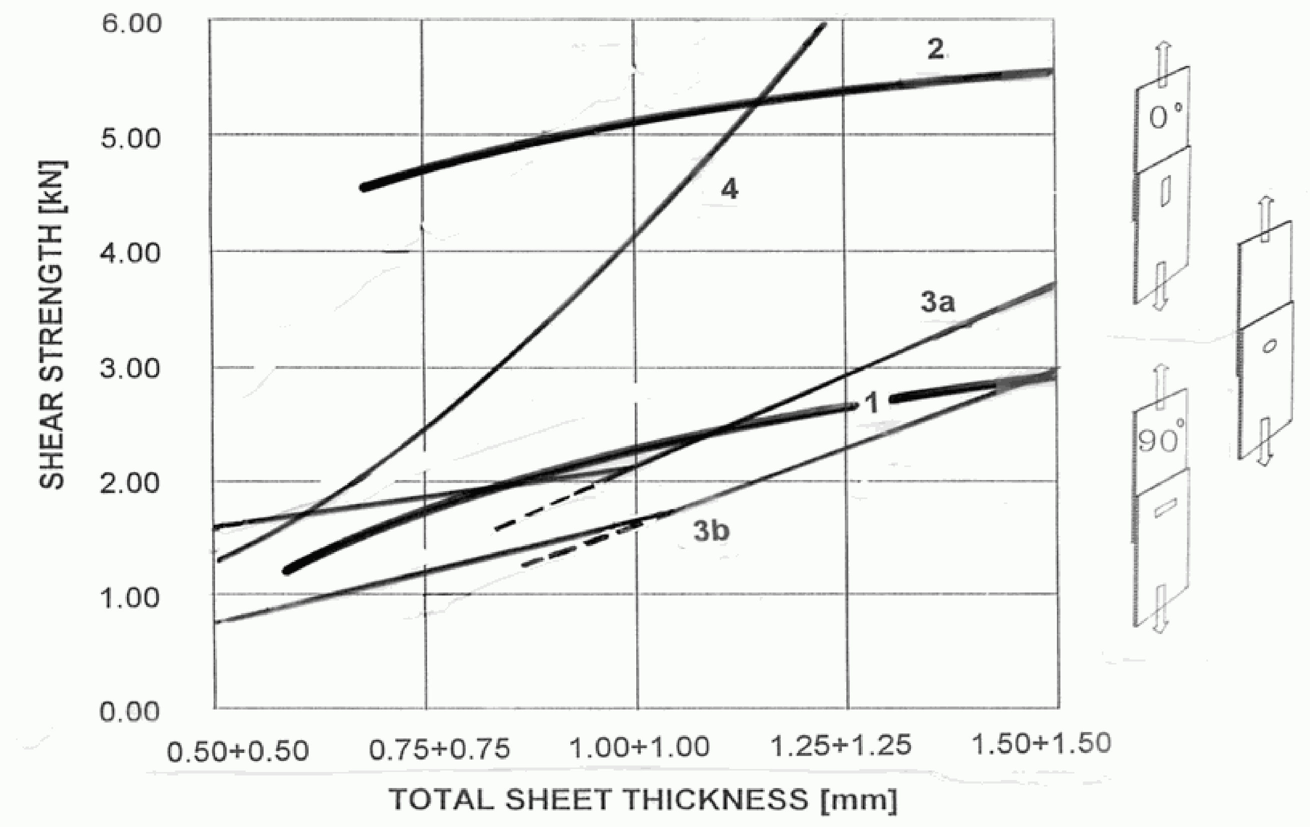
punch riveting



Clinching

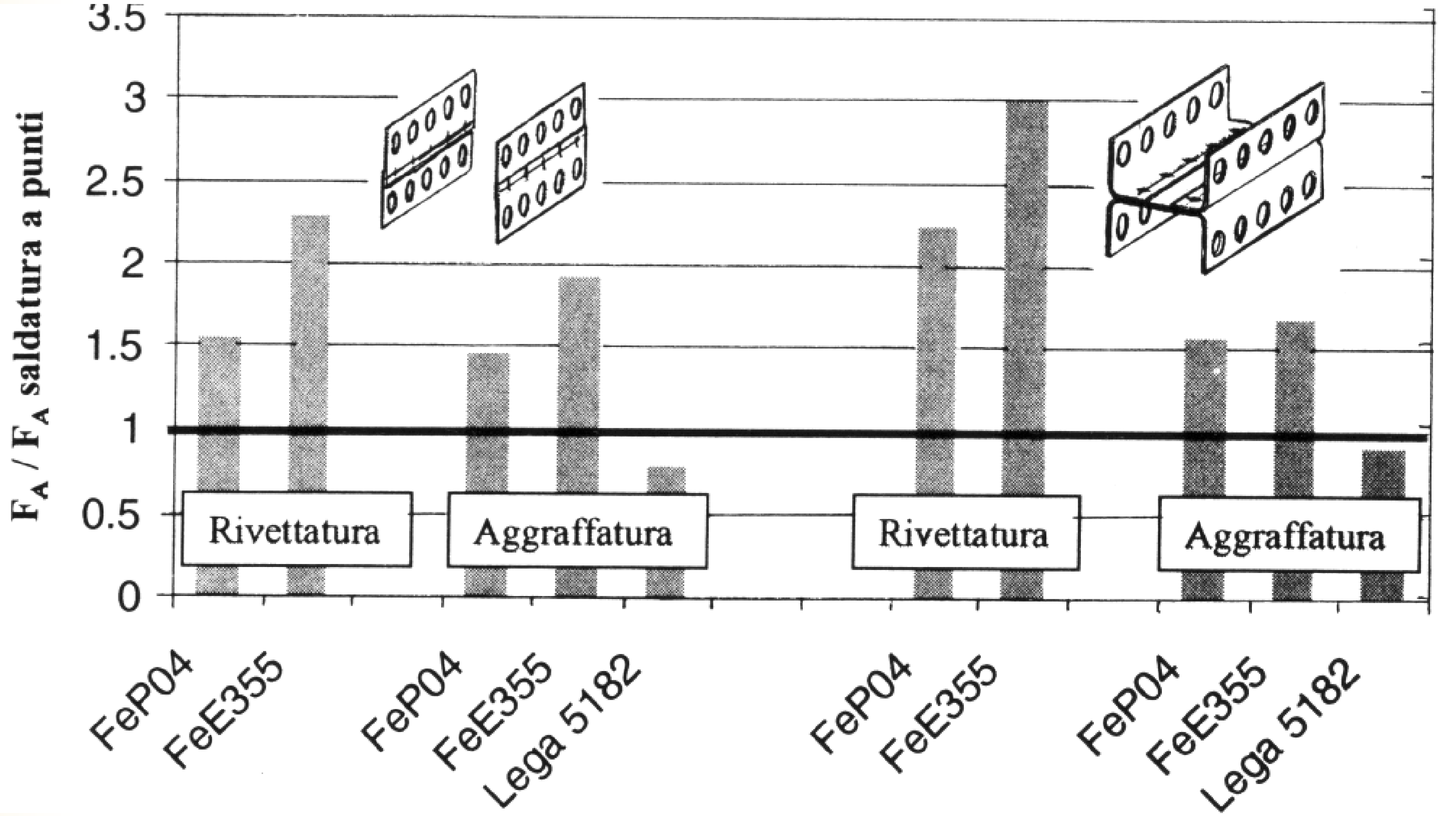


Clinching compared to spot-welds (1/2)



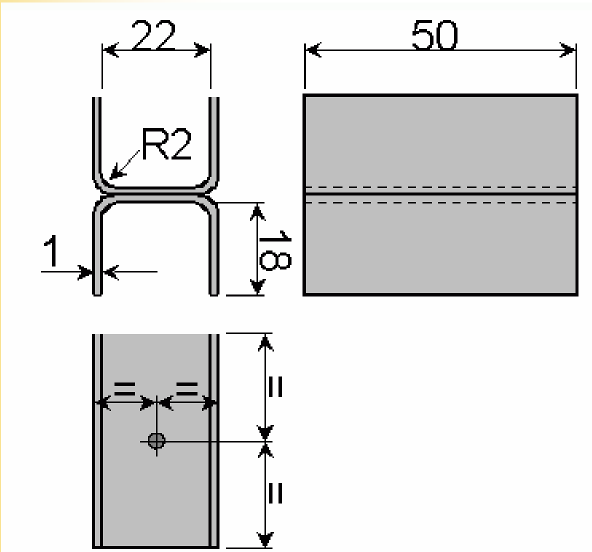
Material: Mild Steel (approx. 300 N/mm2)
1. Round die, ∅ 5mm /2. Round die, ∅ 8mm, /3a. Rectangular die, w. 4mm, shear 90 ° /3b. Rectangular die, w. 4mm, shear 0 °/ 4. Spot Weld, Standard spec. minimum, ∅3 & 4mm

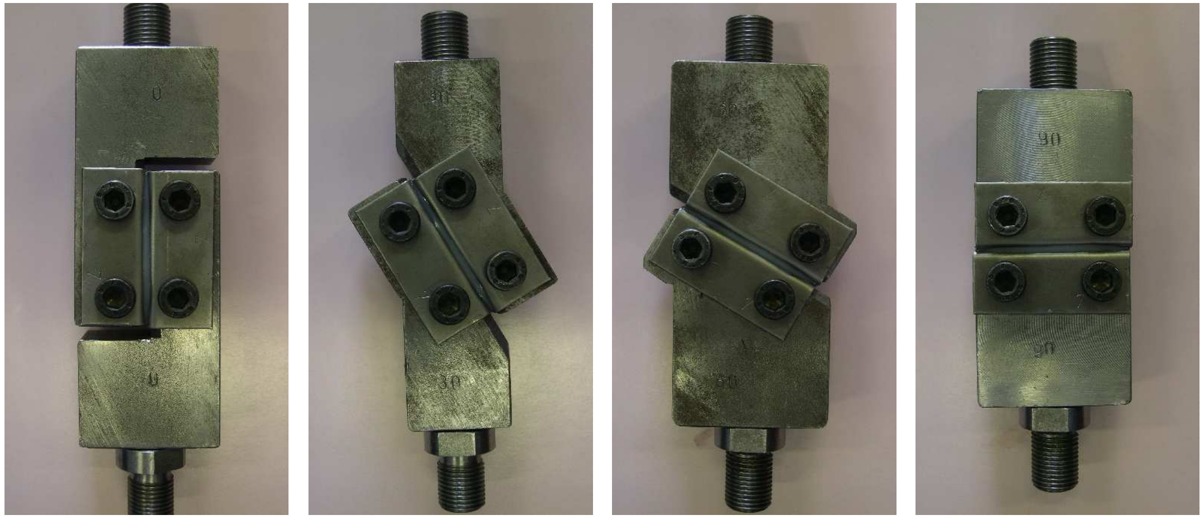
Clinching compared to spot-welds (2/2)



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





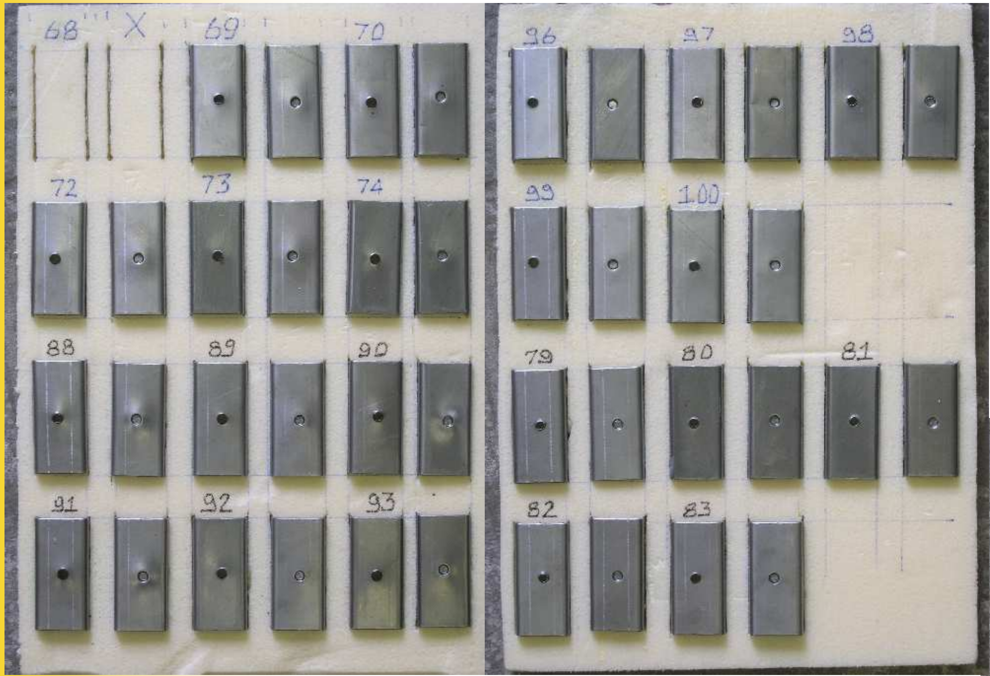
0° 30° 60° 90°

- Formerly used by Hahn *et al.* for fatigue
- Material **DC04**
- Samples from BÖLLHOFF Sistemi e componenti di assemblaggio

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

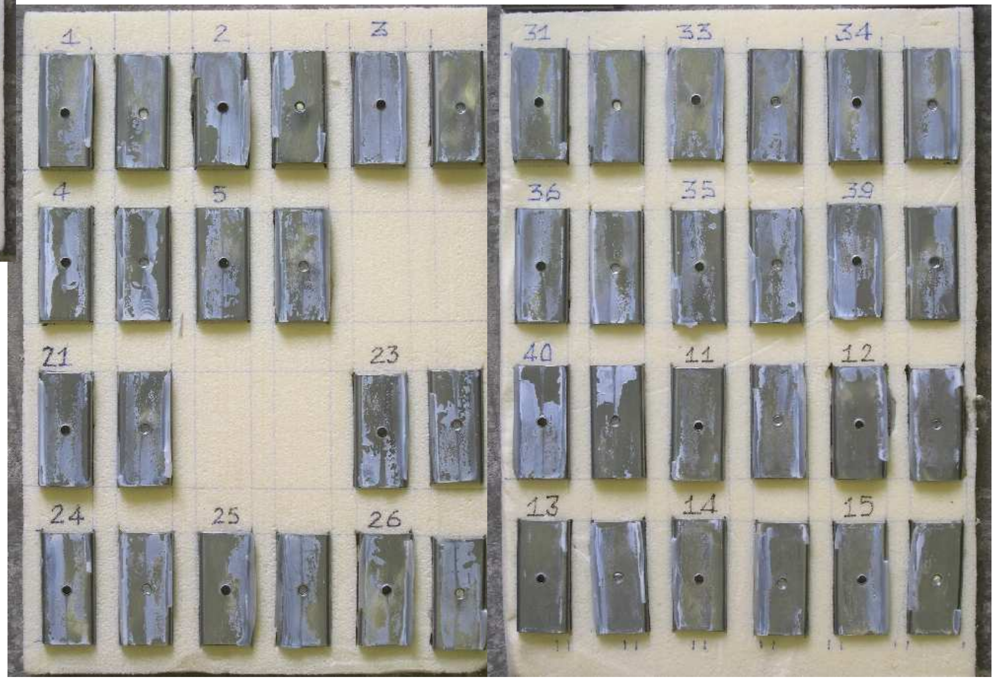


Clinched

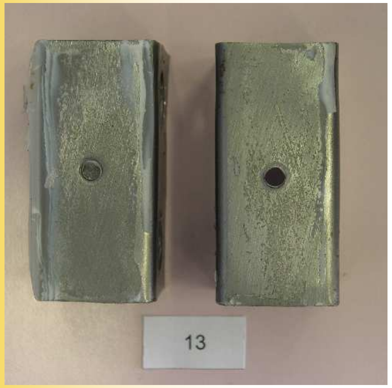
BÖLLHOFF
Sistemi e componenti di assemblaggio

Henkel LOCTITE

Clinched+bonded



Clinched & clinched+bonded samples



Clinched+bonded, 0°

Clinched+bonded, 30°

Clinched+bonded, 60°

Clinched+bonded, 90°

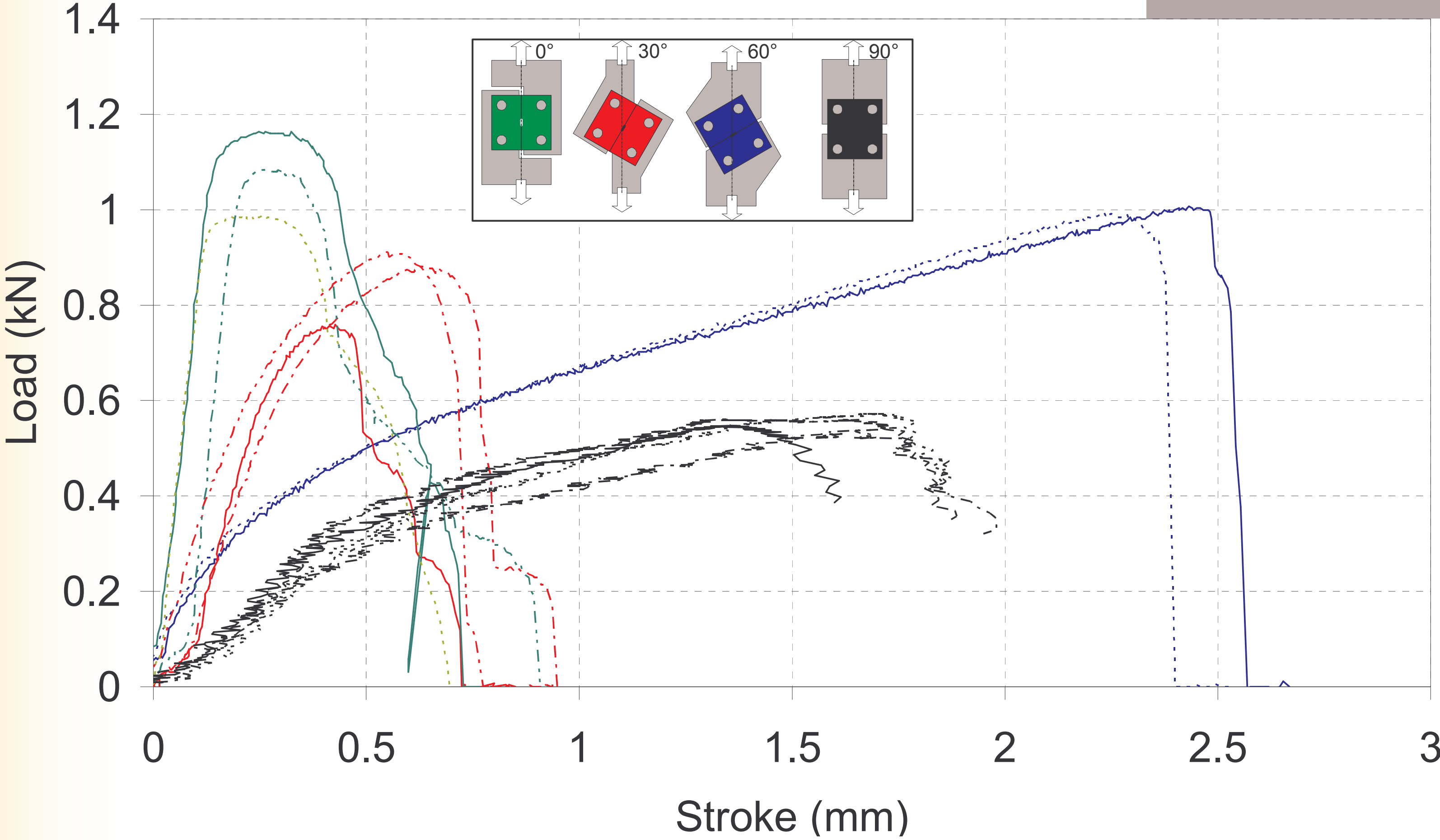
Clinched, 0°

Clinched, 30°

Clinched, 60°

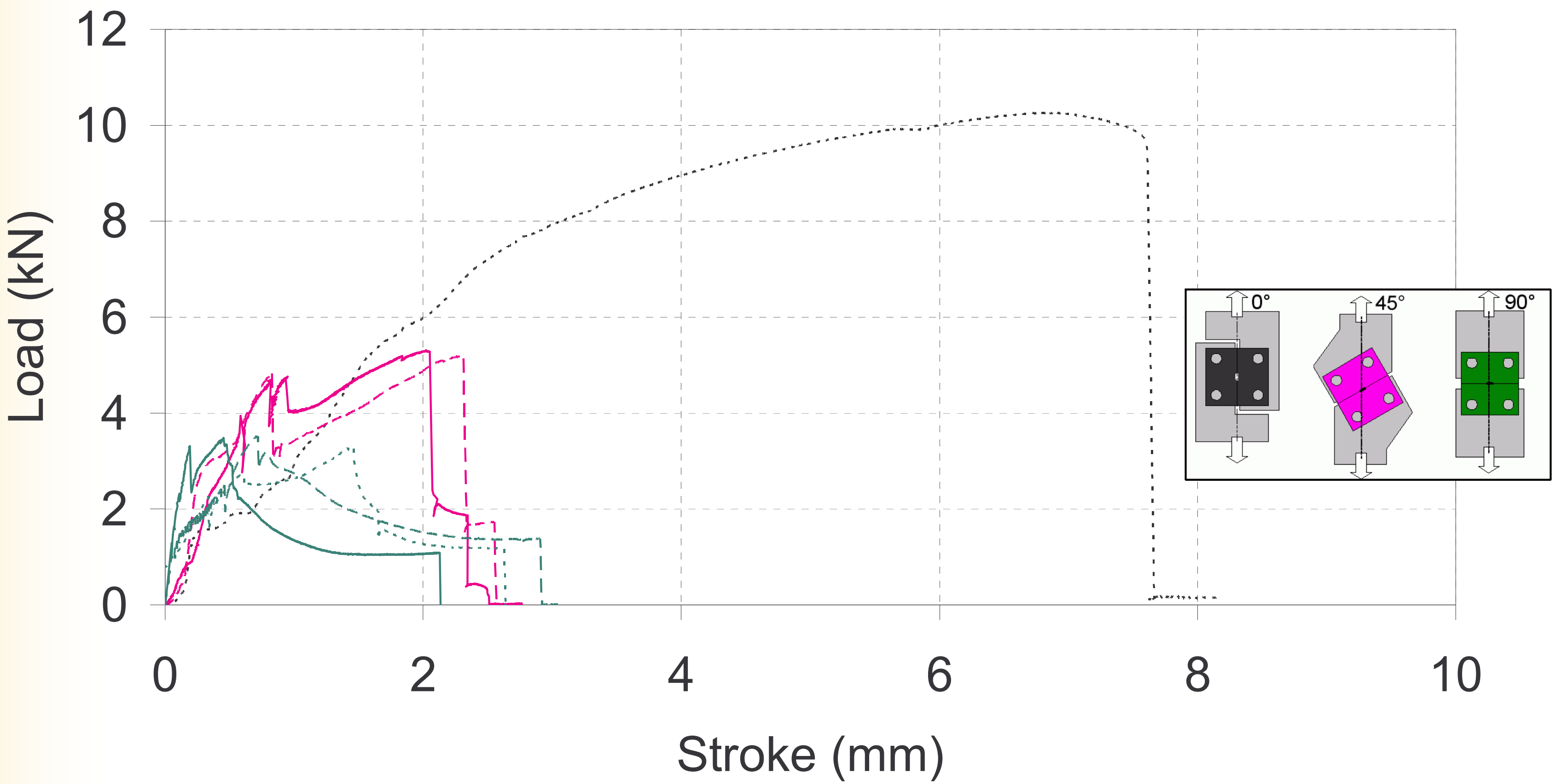
Clinched, 90°

Clinching
Test results



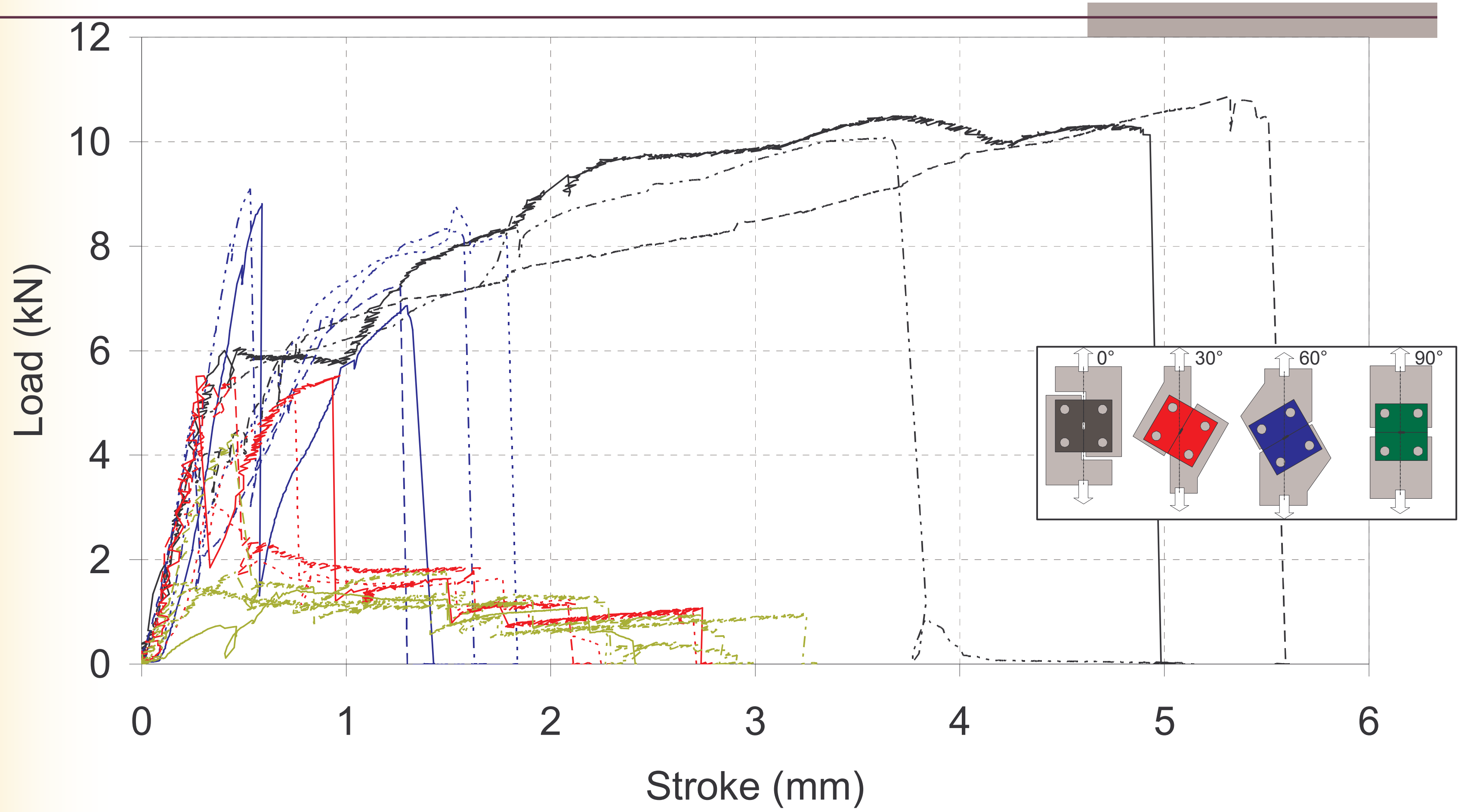
- Apparatus: DARTEC HA100
- Loading speed: 0.01 mm/s

Bonding
Test results



- Apparatus: DARTEC HA100
- Loading speed: 0.01 mm/s

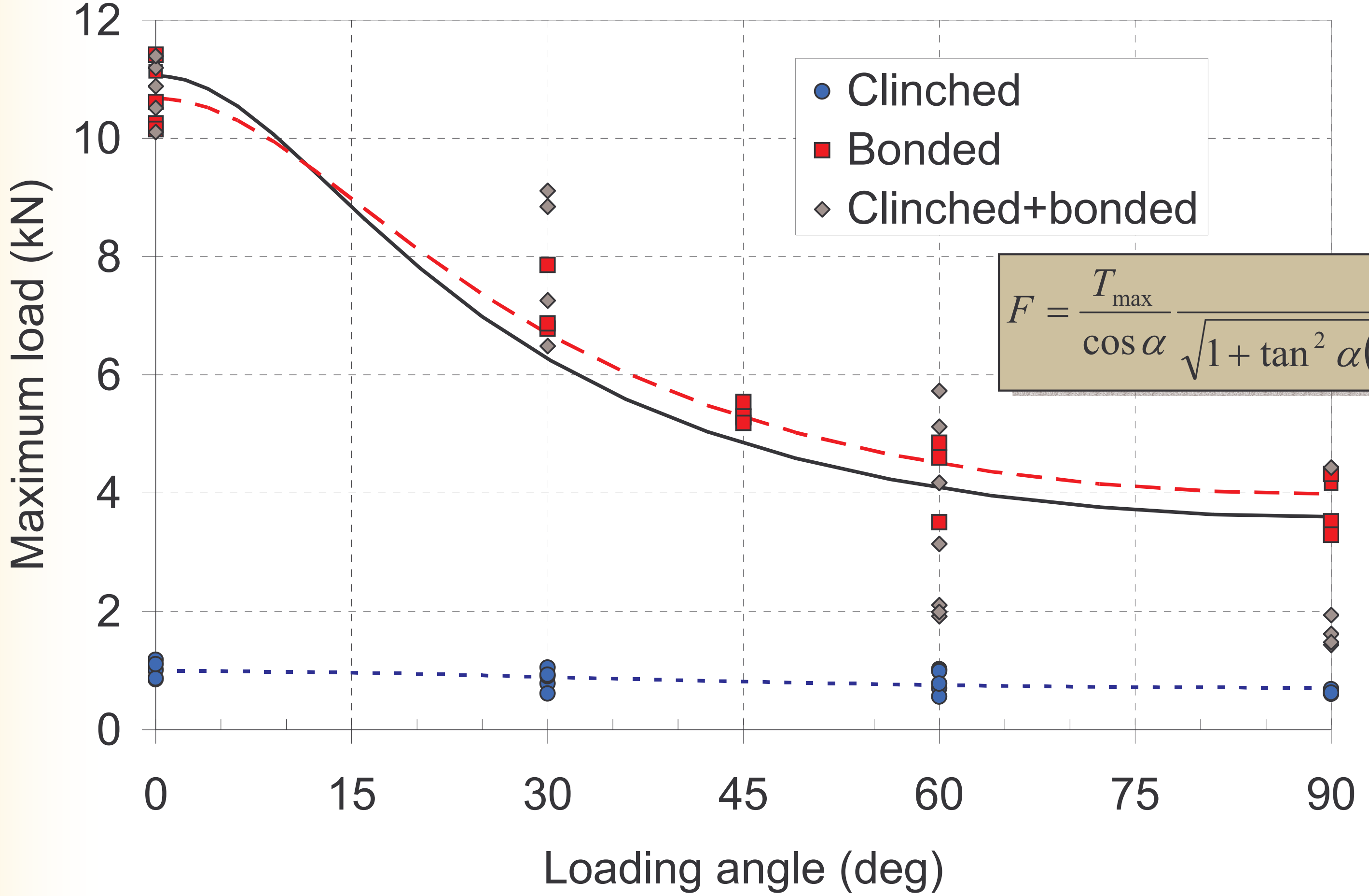
Clinching+bonding
Test results



- Apparatus: DARTEC HA100
- Loading speed: 0.01 mm/s

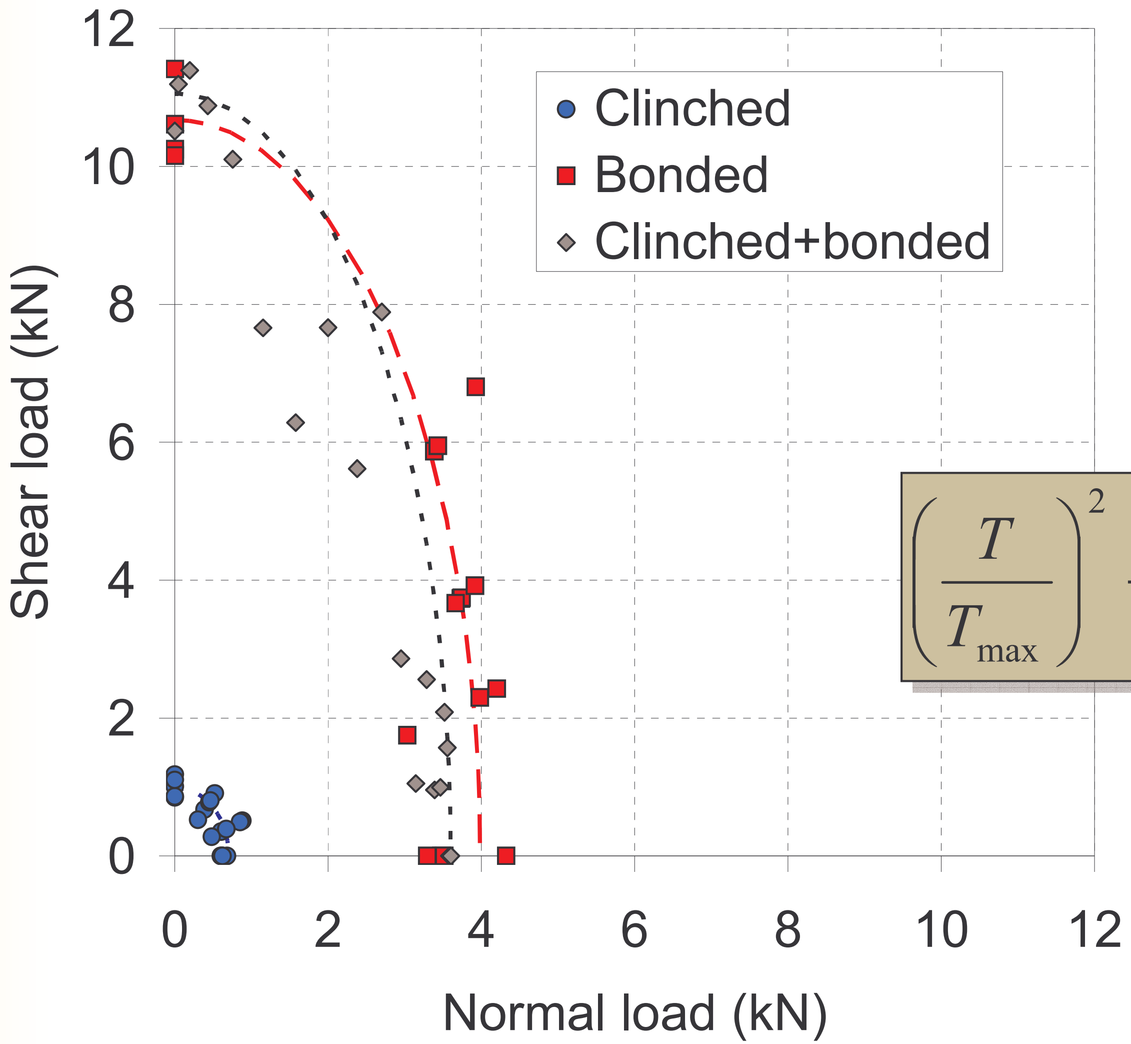
Clinched and bonded joint strength vs. loading

- Limit curve vs. Loading angle



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

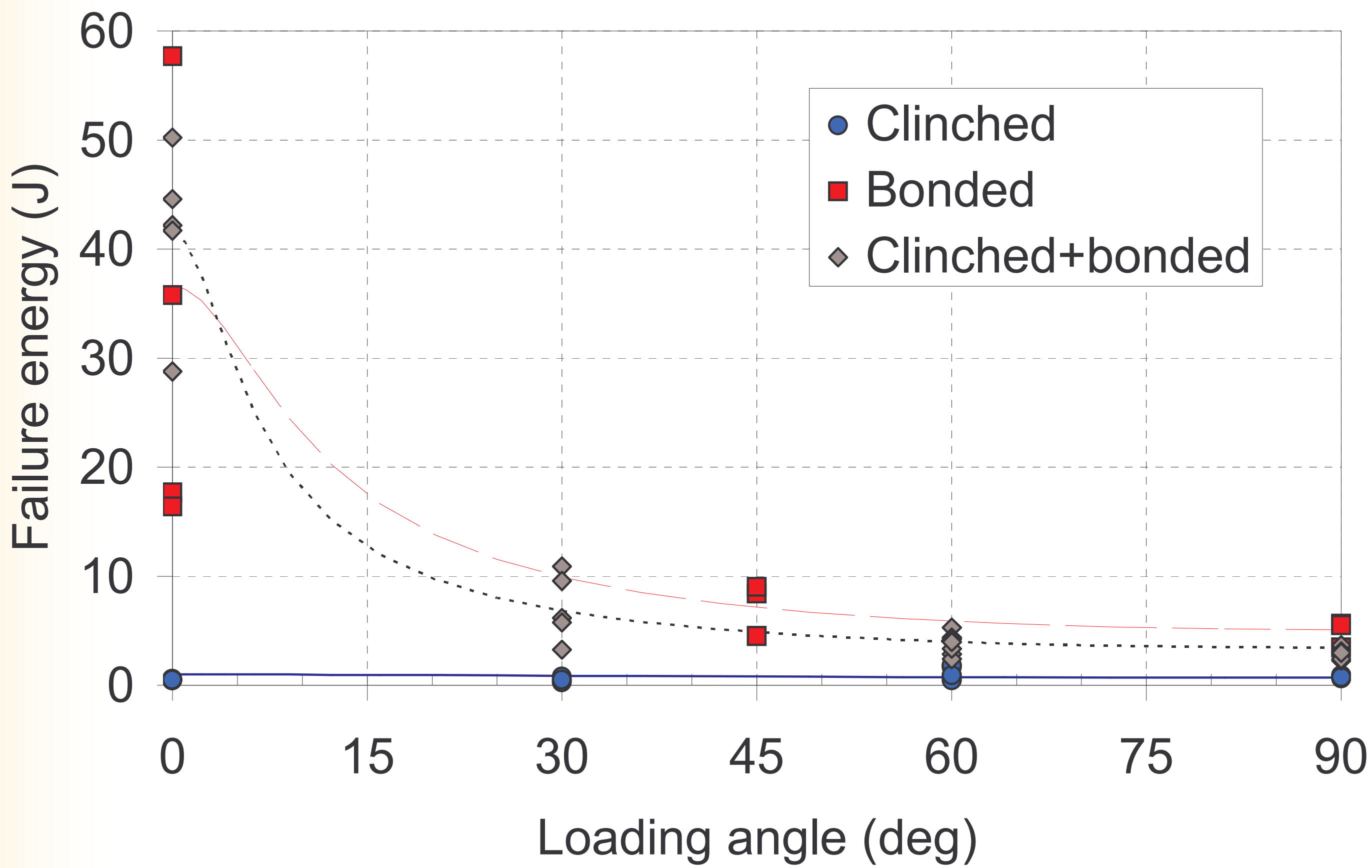
Clinched and bonded joint strength vs. load components



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

Clinched and bonded joint energy vs. loading angle

- Failure energy vs. Loading angle



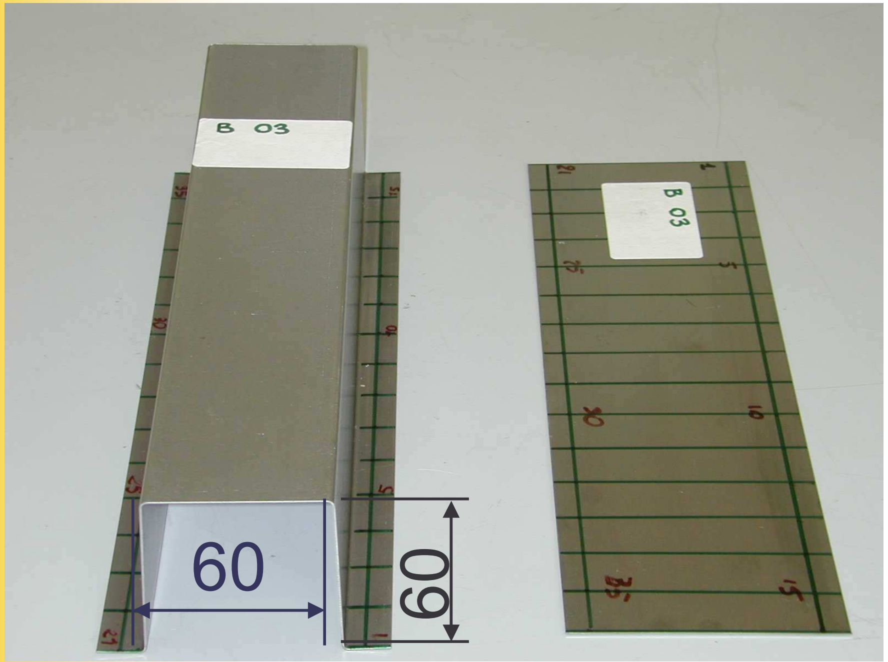
Different joining solutions: conclusions

- 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 solutsions

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

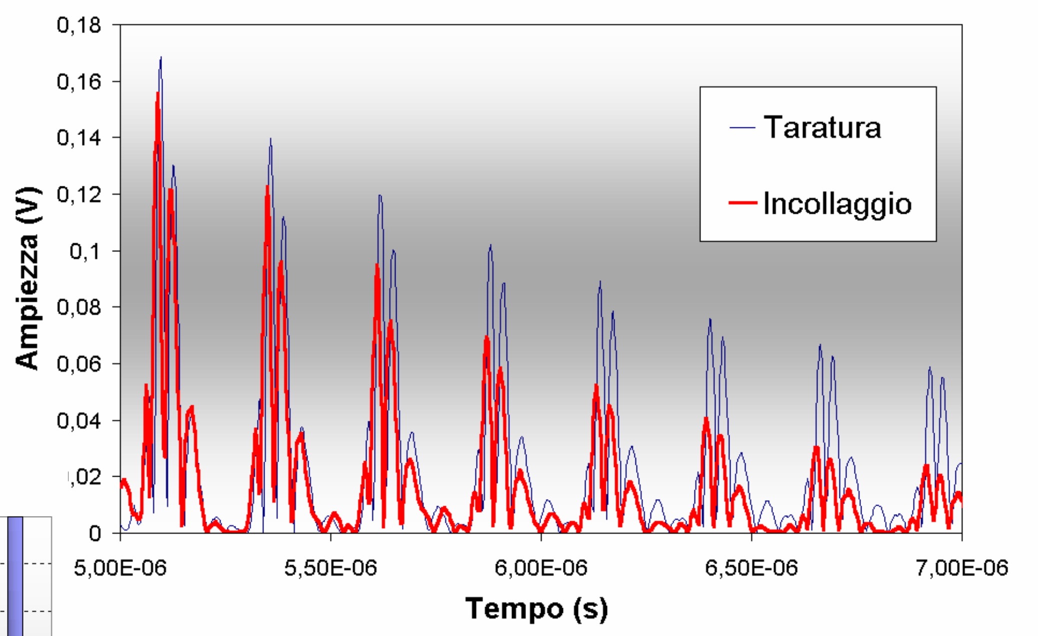
Bonded crash-box production

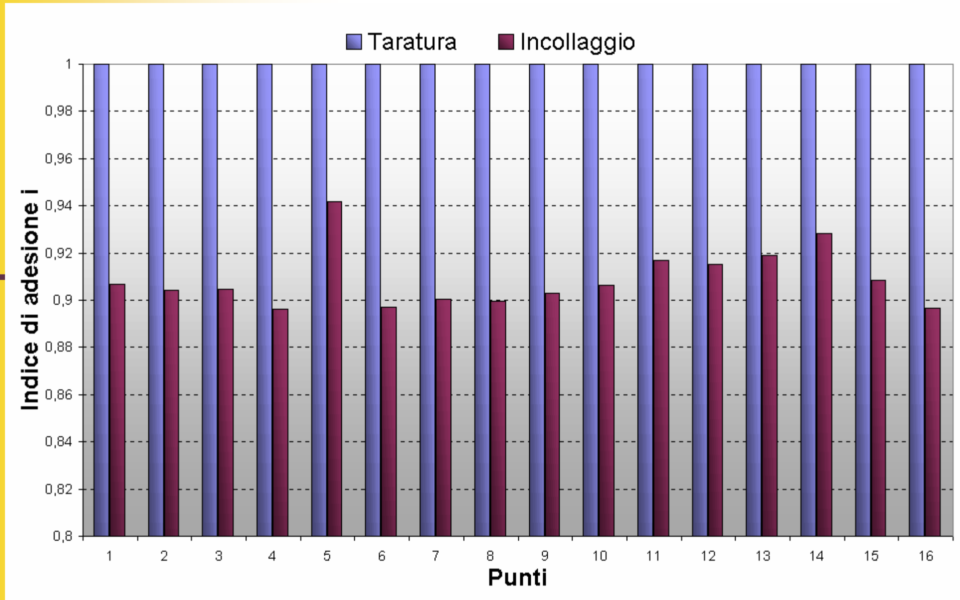


- Cleaning and surface preparation with sand paper
- Chemical degrease
- Mixing of components and application of CIBA araldite adhesive
- NDT ultrasonic inspection

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

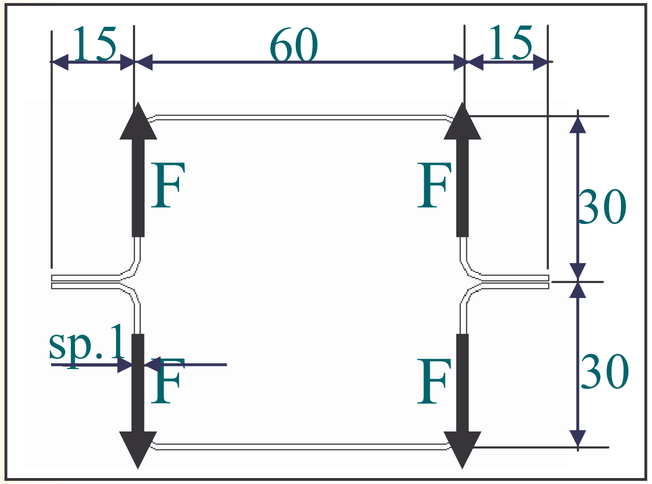
Ultrasonic NDT inspection

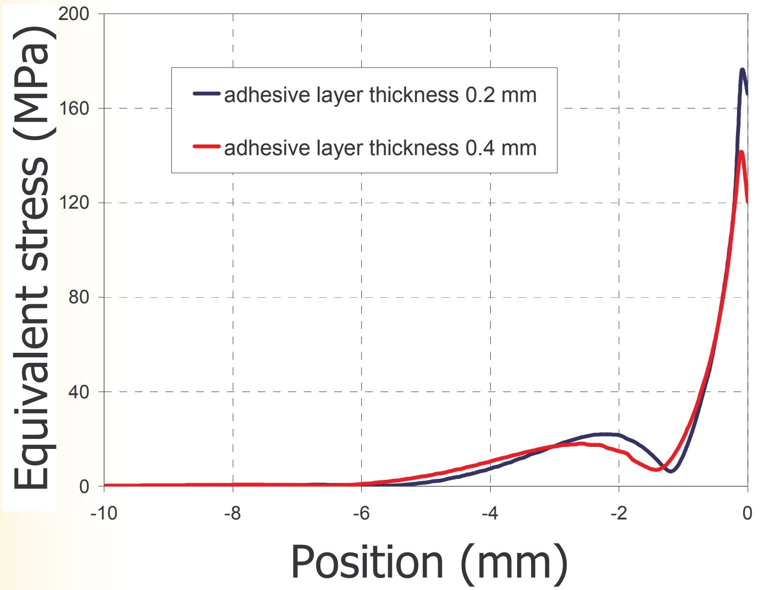


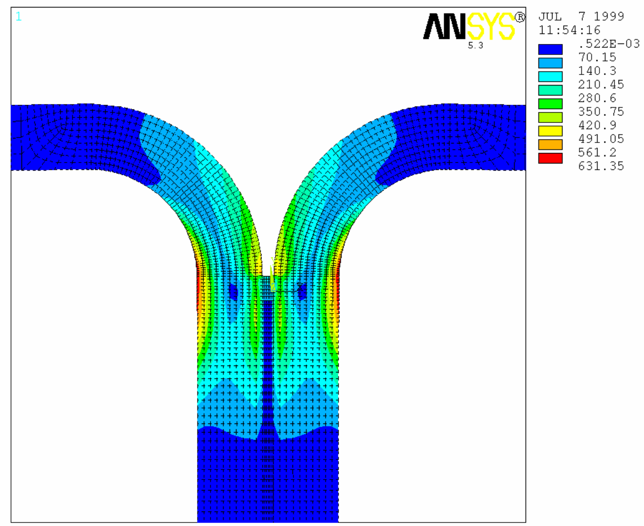


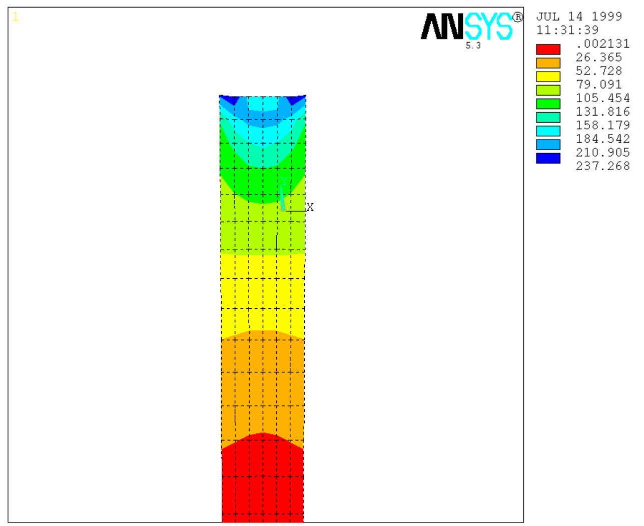
NDT procedure by Rossetto & Goglio (ref. XXIX AIAS *et al.*)

Stress analysis of the bonded flanges

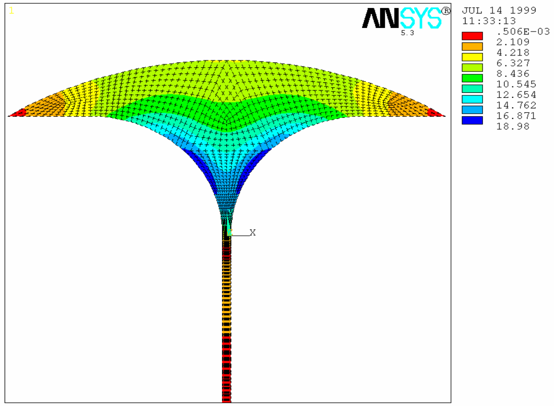


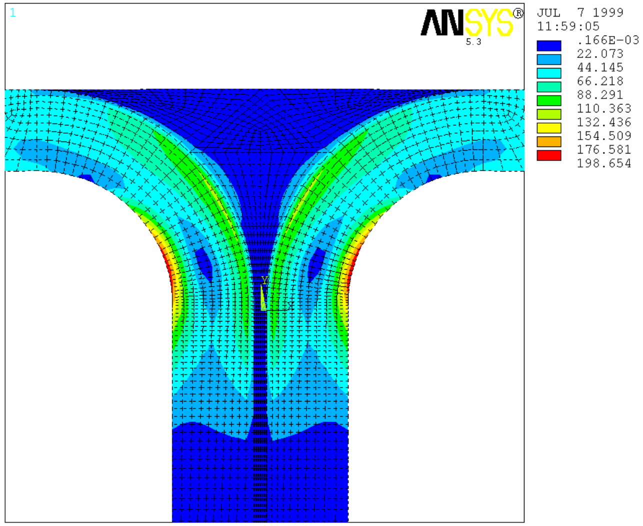


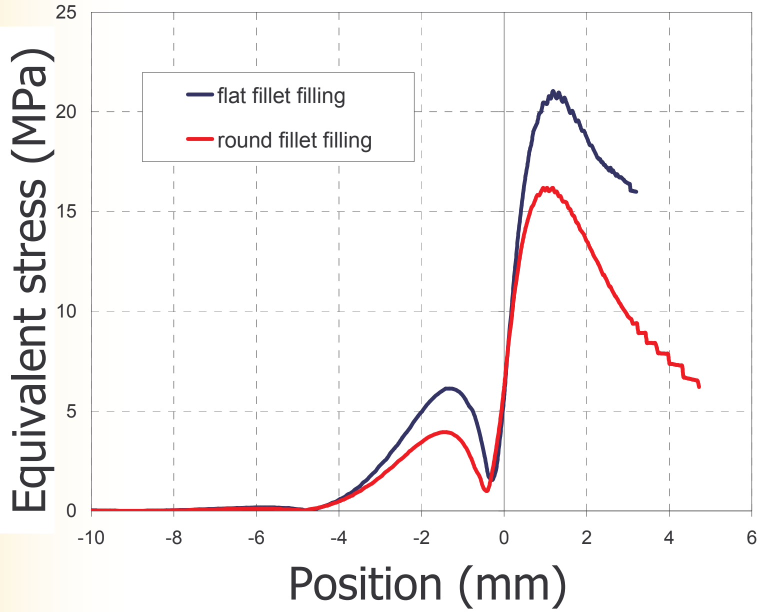


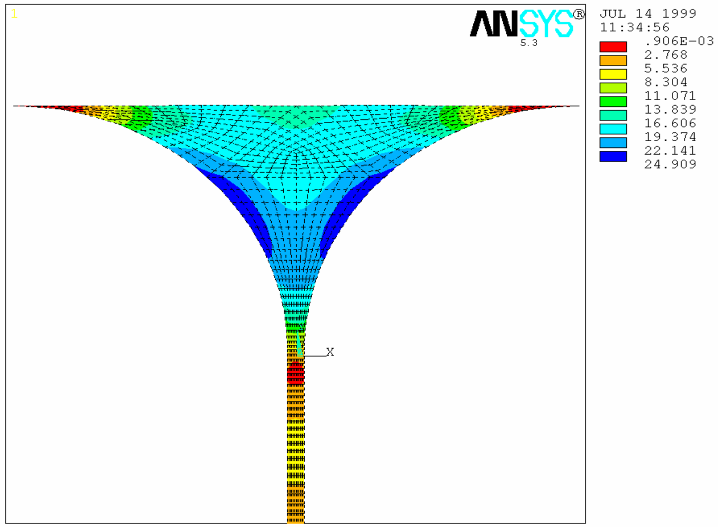


Improvements by filleting

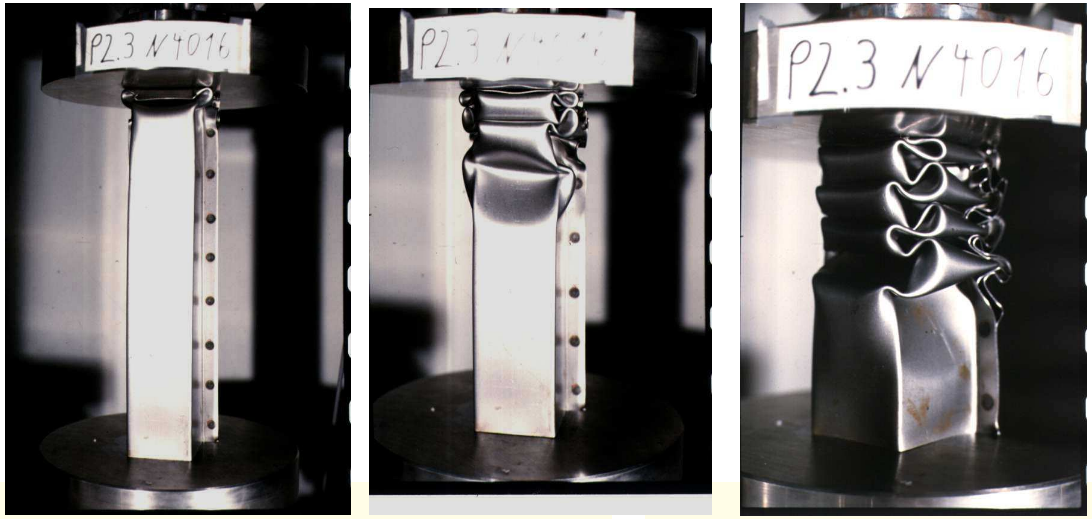


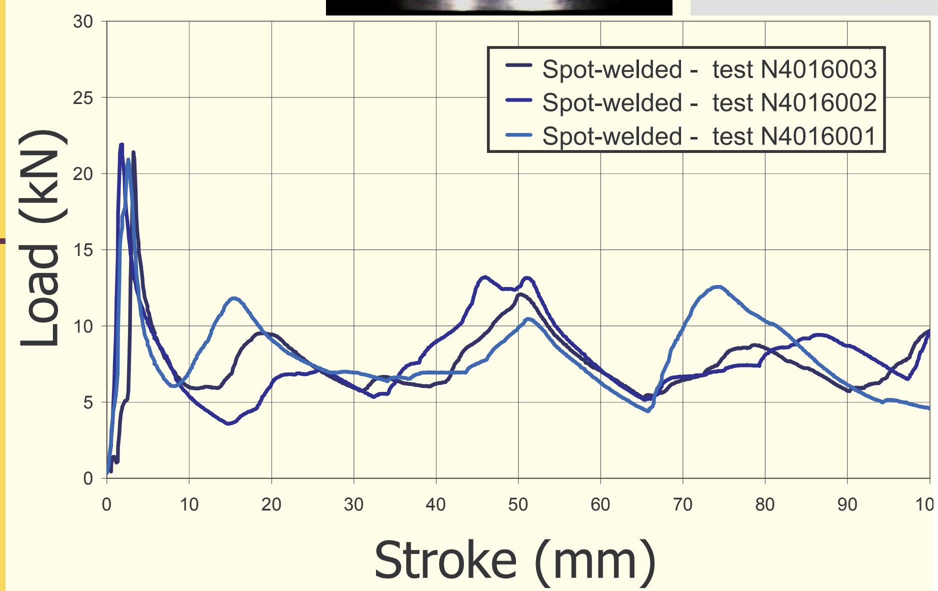


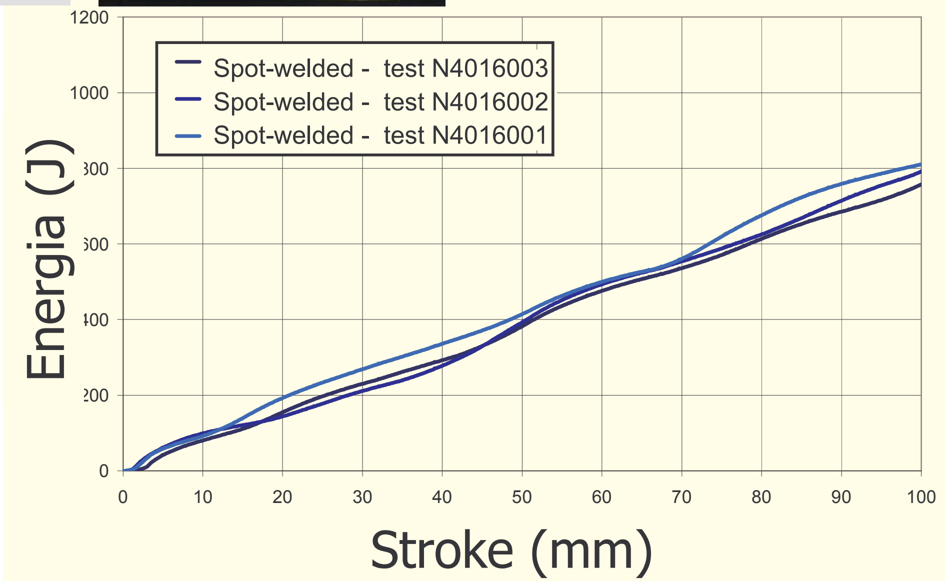




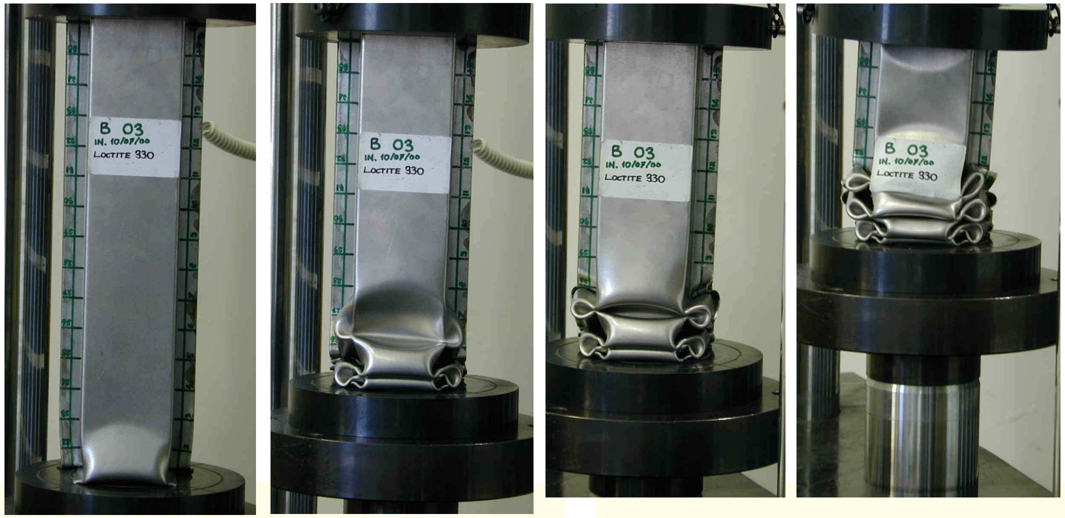
Quasi-static crushing
Spot-welded crash-box

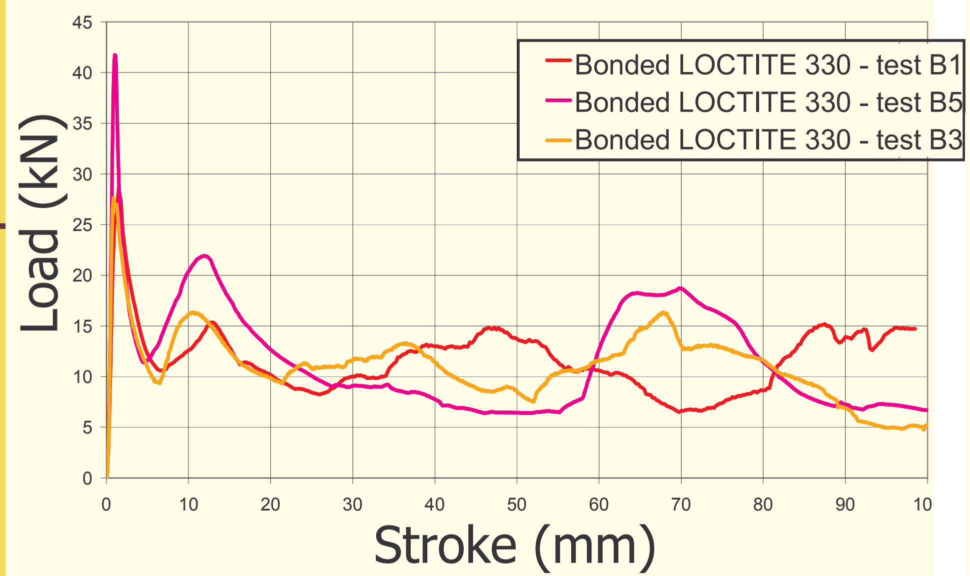


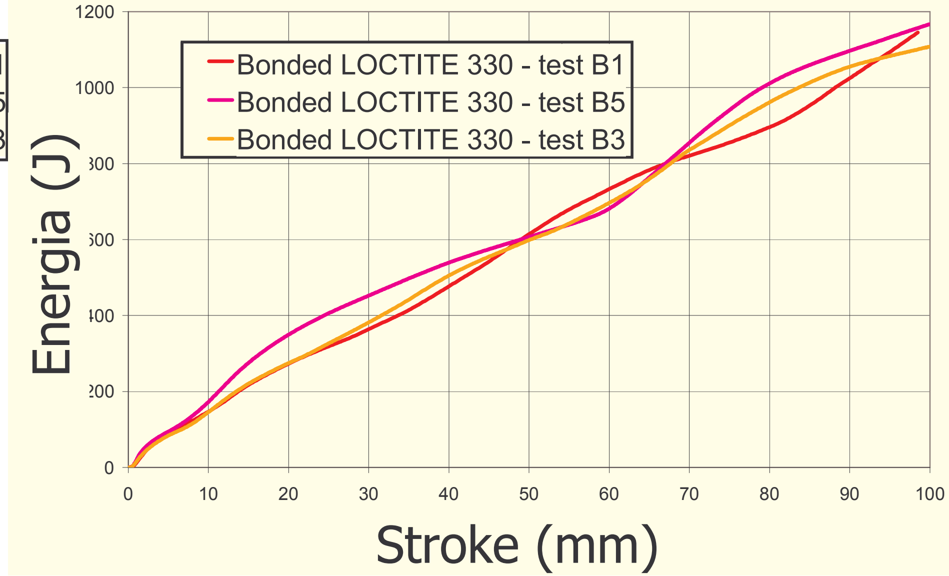




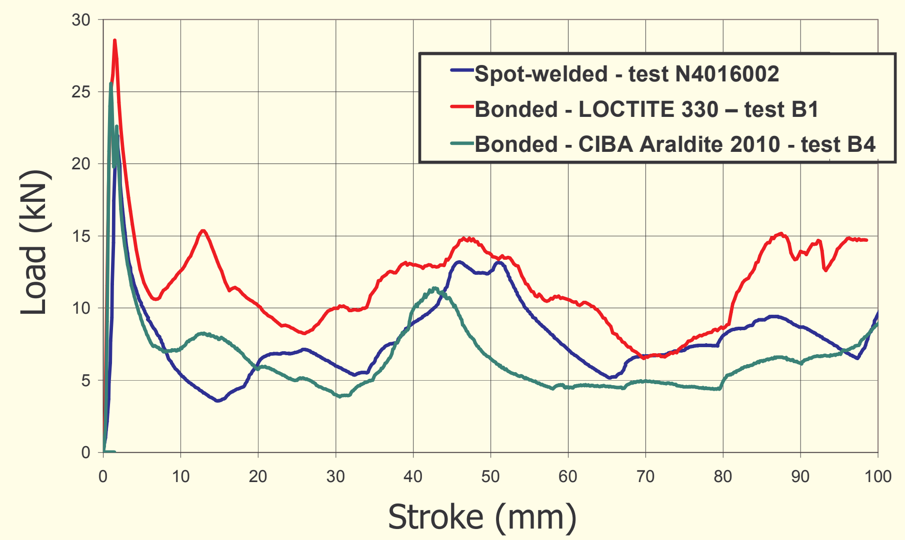
Quasi-static crushing
Adhesively bonded crash-box

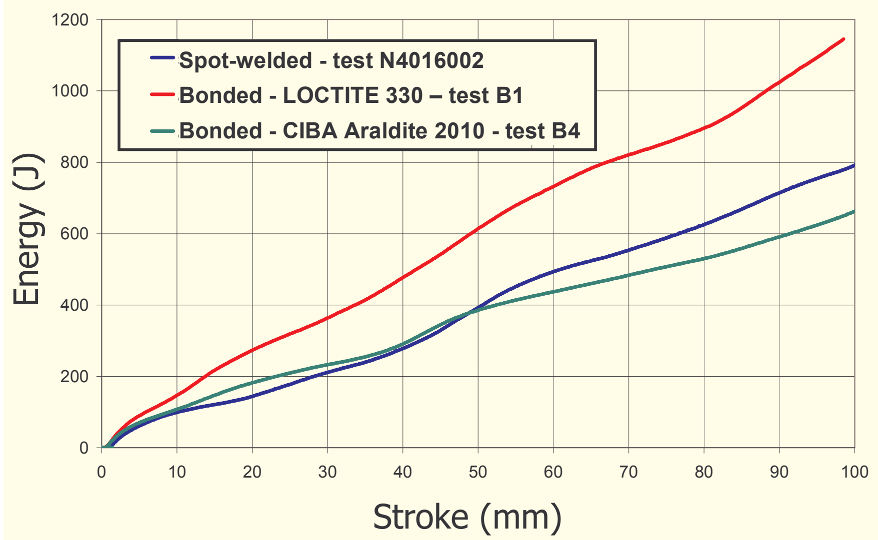


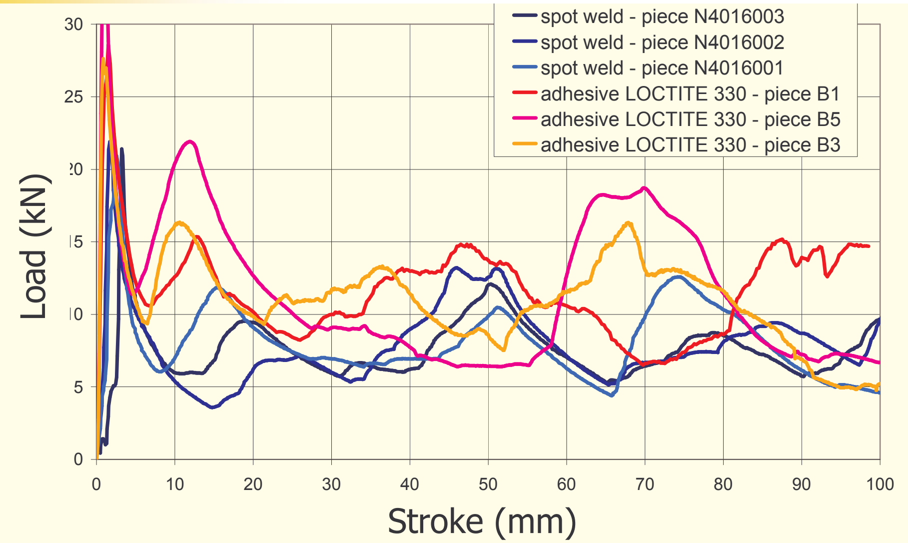


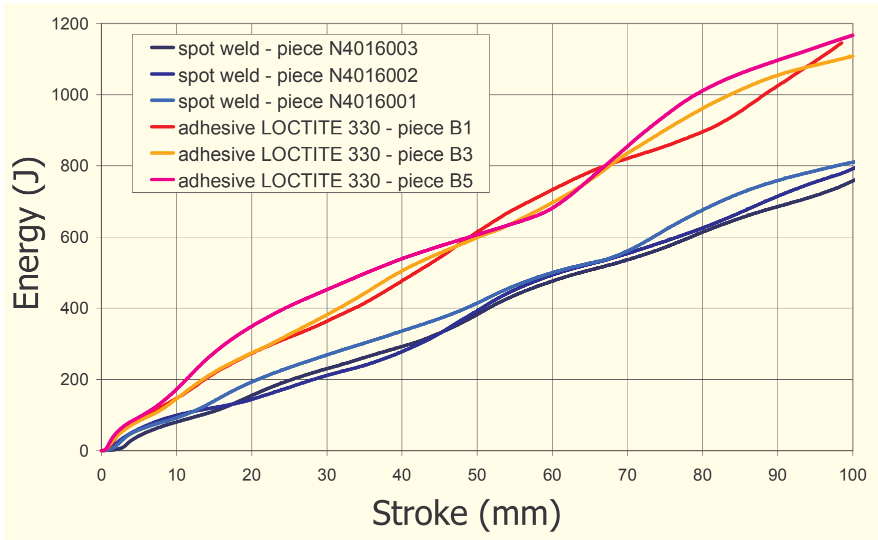


Quasi-static crushing Comparisons (1/2)









Quasi-static crushing Comparisons (2/2)

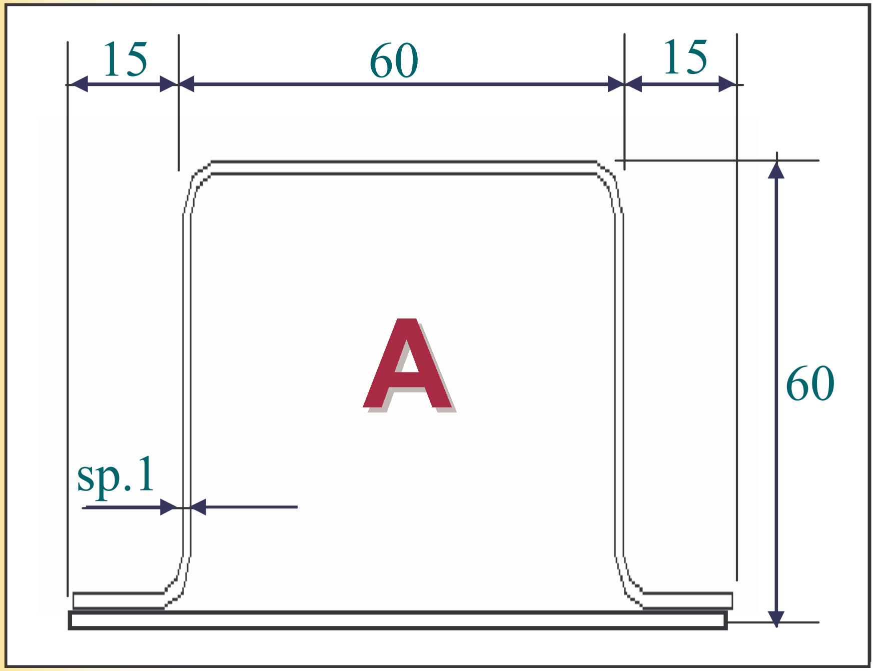
LOCTITE 330 adhesive

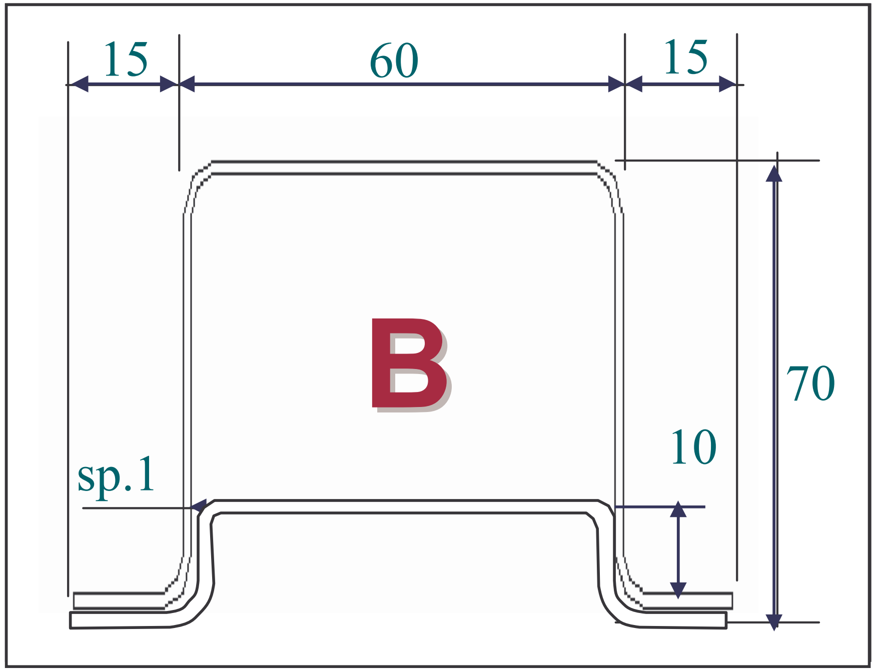
	Mean load (kN)	Max load (kN)
B1	11.62	28.57
B3	10.80	27.62
B5	11.79	41.75
mean value	11.40	32.65
stand. dev.	0.53	7.90

Spot-weld

	Mean load (kN)	Max load (kN)
N1	8.09	20.92
N2	7.92	21.92
N3	7.57	21.41
mean value	7.86	21.42
stand. dev.	0.26	0.50

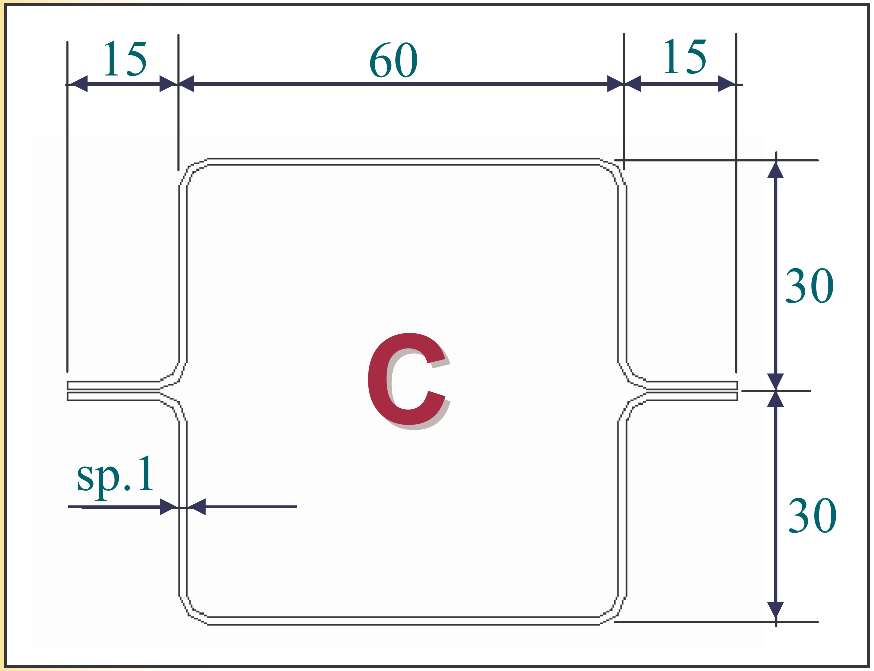
Alternative solutions for improved bonded box (1/2)

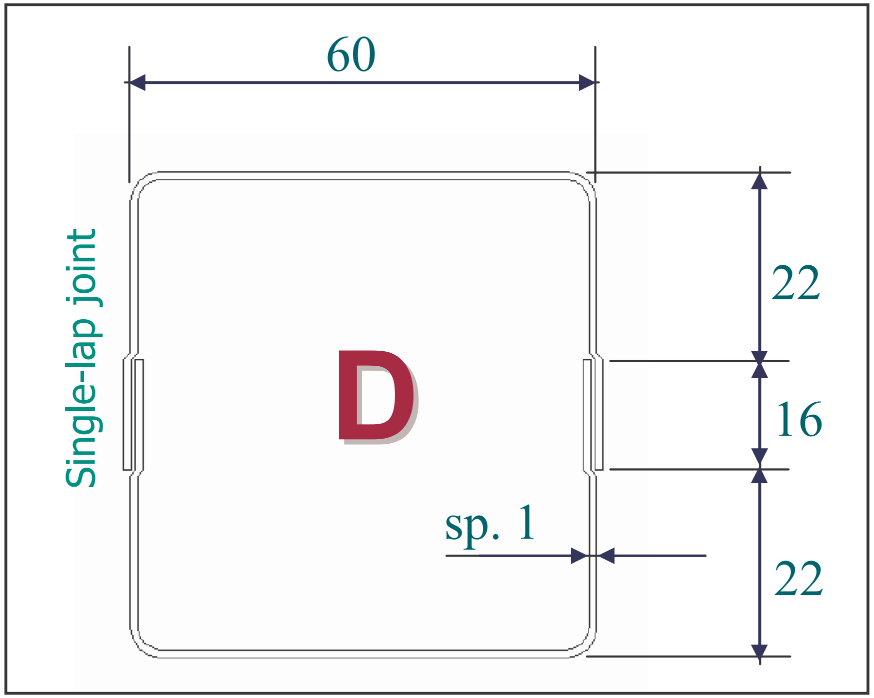




- **Made with an Ω elements bonded to a flat plate (top-hat section)**
- **New shape with two Ω elements one (smaller) inserted into the other**

Alternative solutions for improved bonded box (2/2)





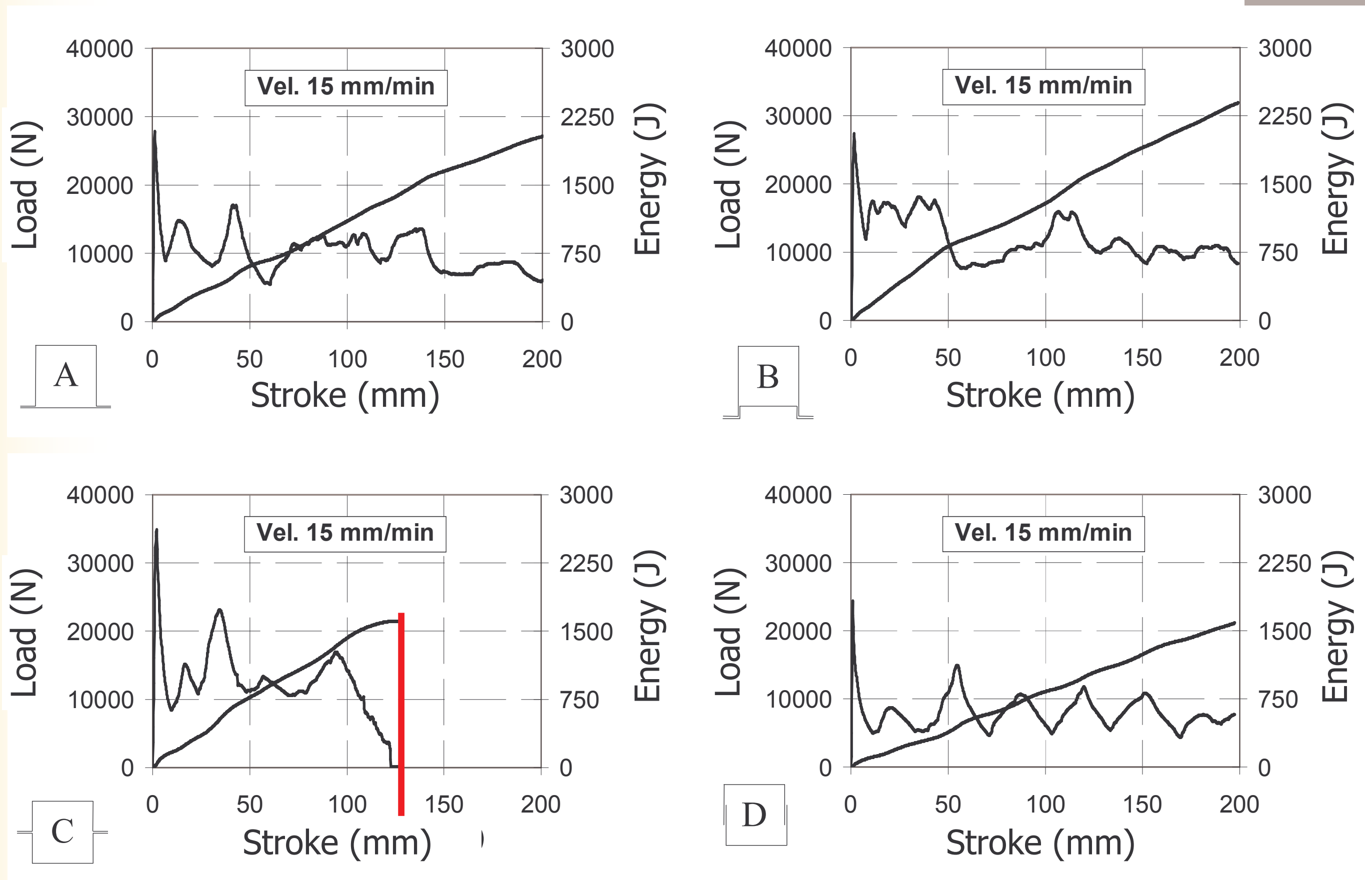
- **Bonding flanges as simple <u>substitution</u> of spot-welds**
- **Made with two Ω elements (double hat section)**

- **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

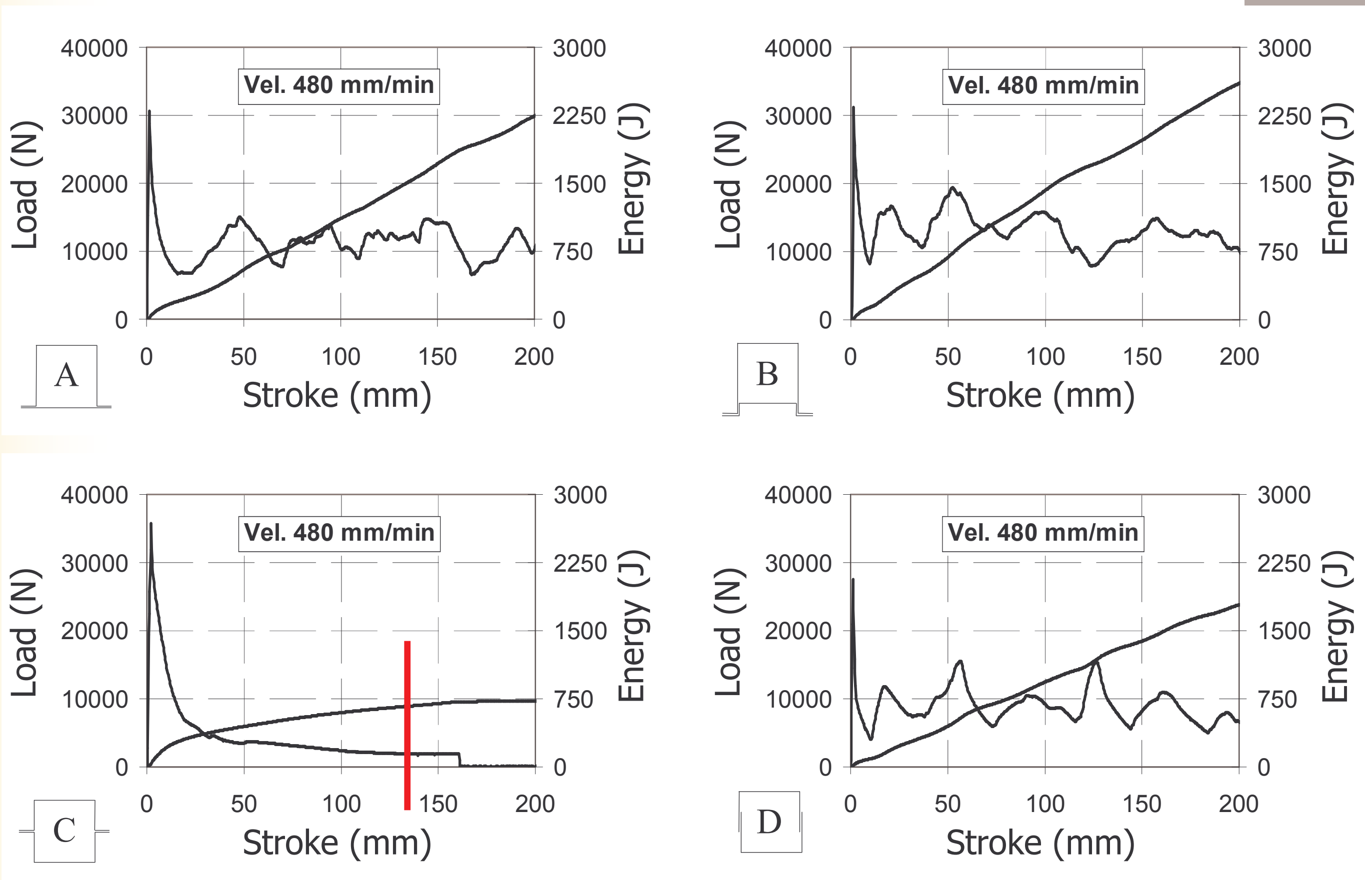


- C shape: 2 folds followed by global instability and debonding
- other sections: regular folding some debonding (except D shape)

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

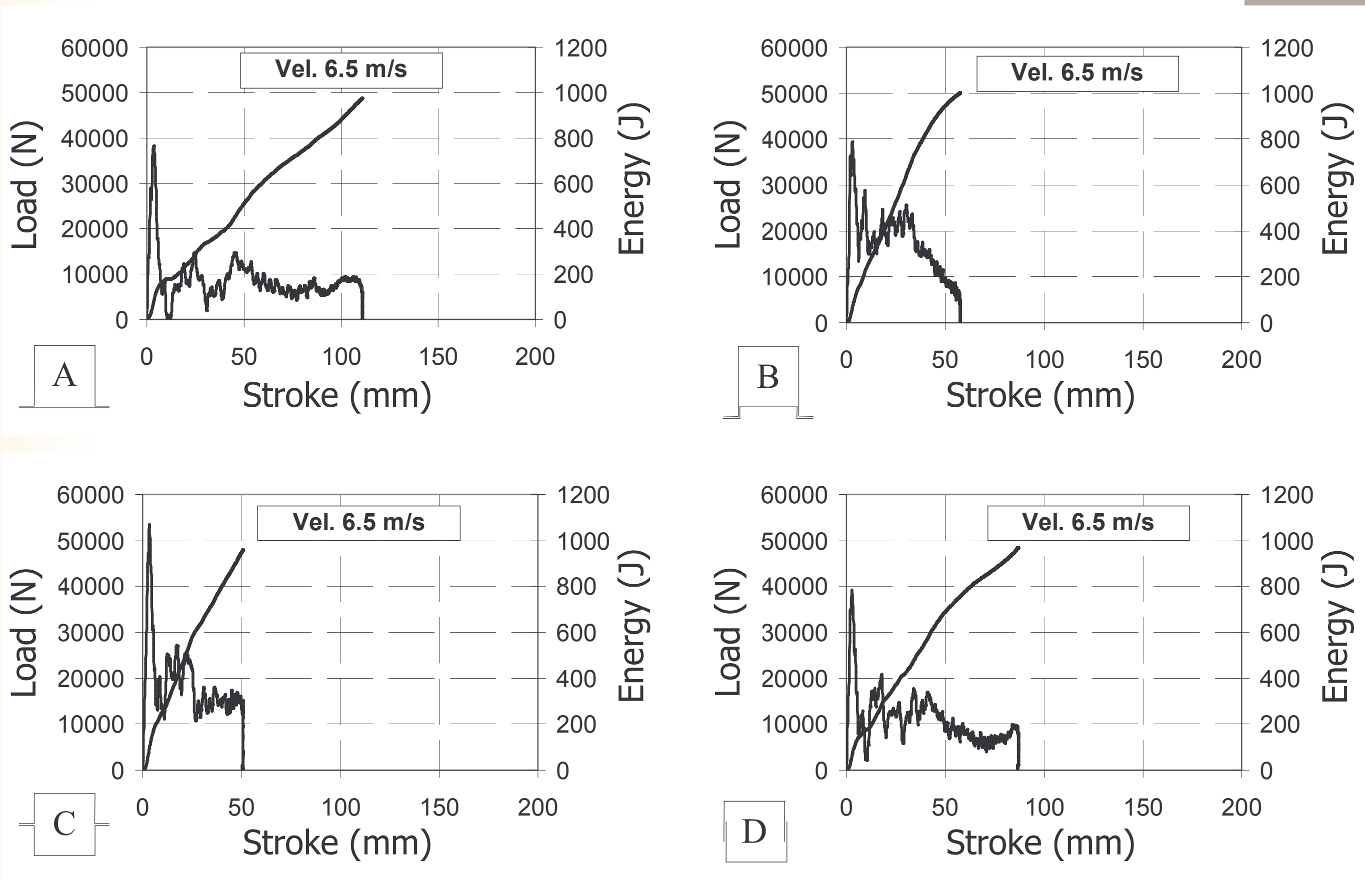


- C shape: 2 folds followed by global instability and debonding
- other sections: regular folding some debonding (except D shape)

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

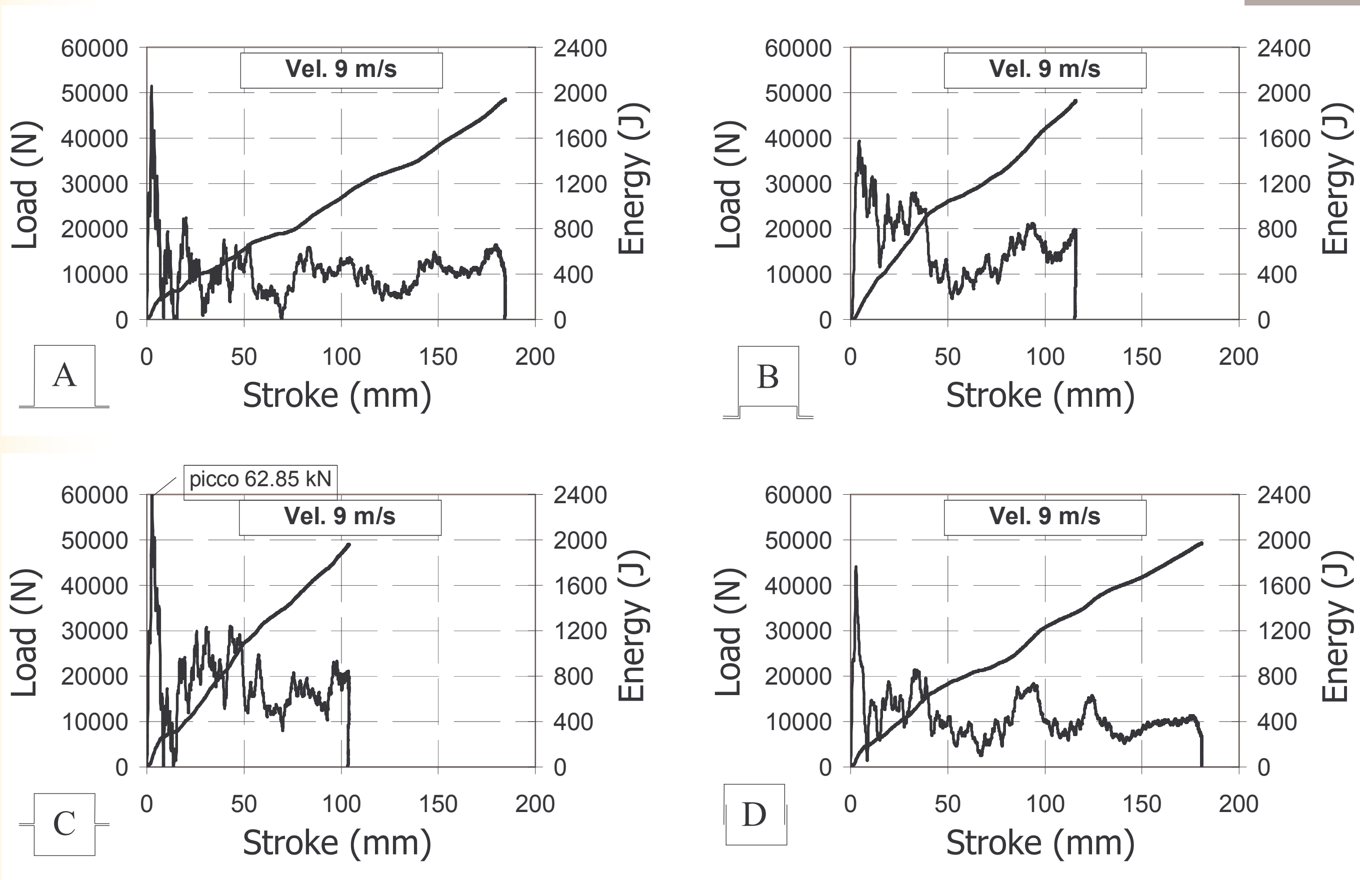


- A, B, C shapes: irregular debonding in the crushed part
- D shape: no debonding

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

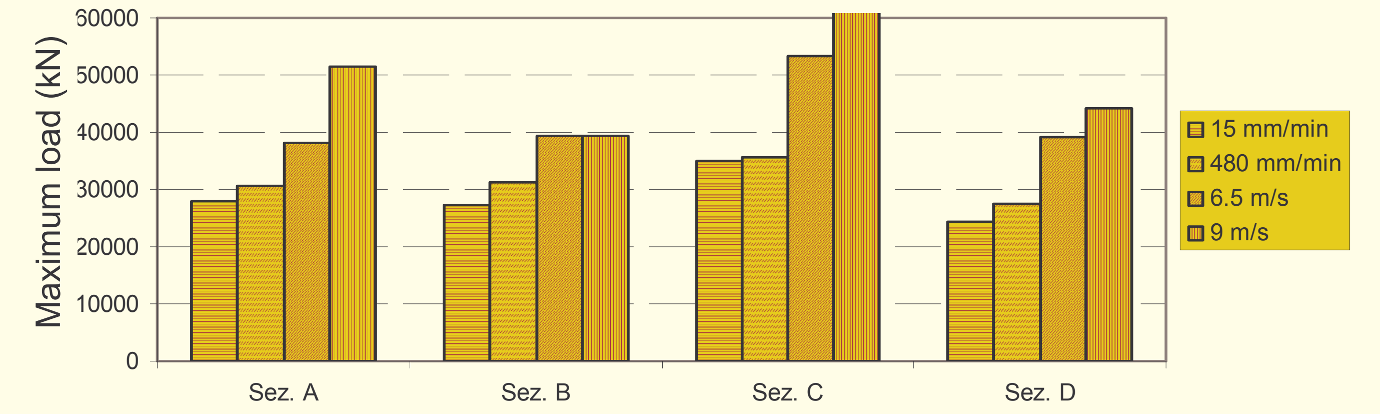


- A, B, C shapes: irregular debonding in the crushed part
- D shape: complete regular folding, no debonding at all

Impact tests (9 m/s)

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

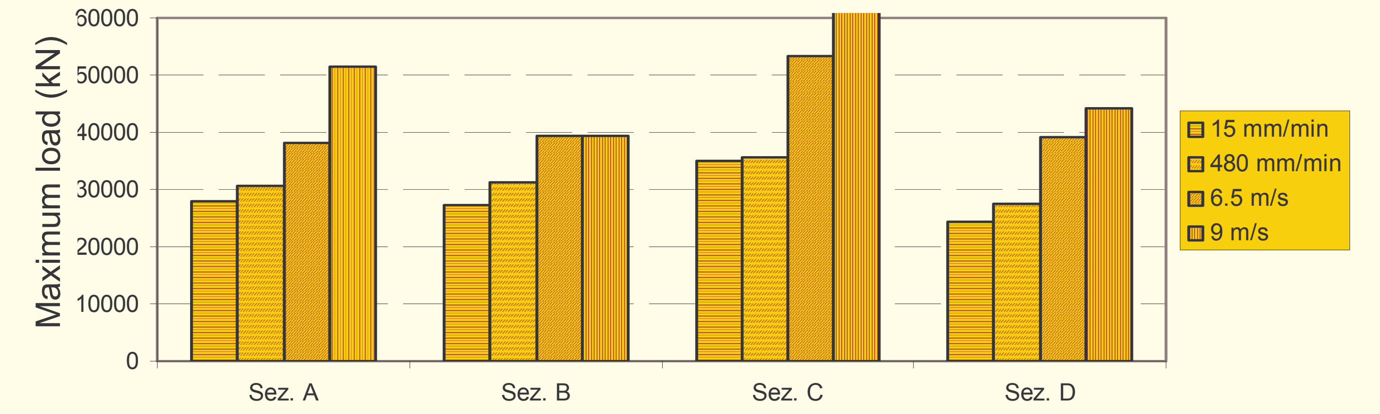
Comparison of the different shapes: low speed



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