INVESTIGATION OF A METALLIC SANDWICH DESIGN WITH THERMOPLASTIC CORE FOR IMPROVED PEDESTRIAN PROTECTION

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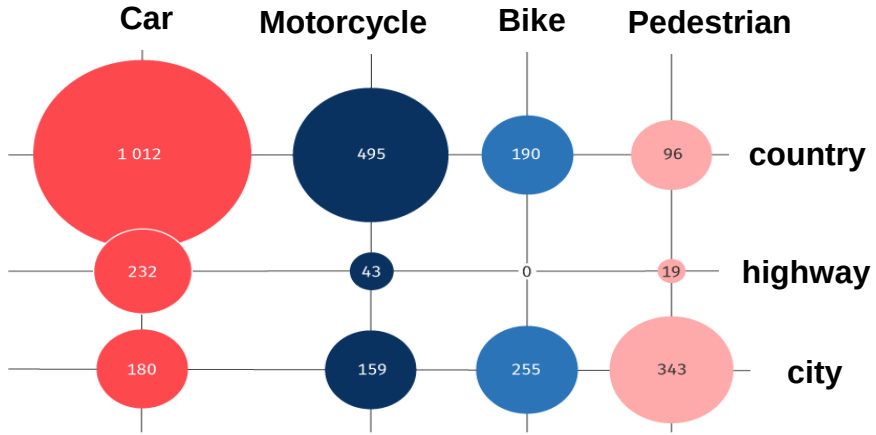
DLR Institute of Vehicle Concepts

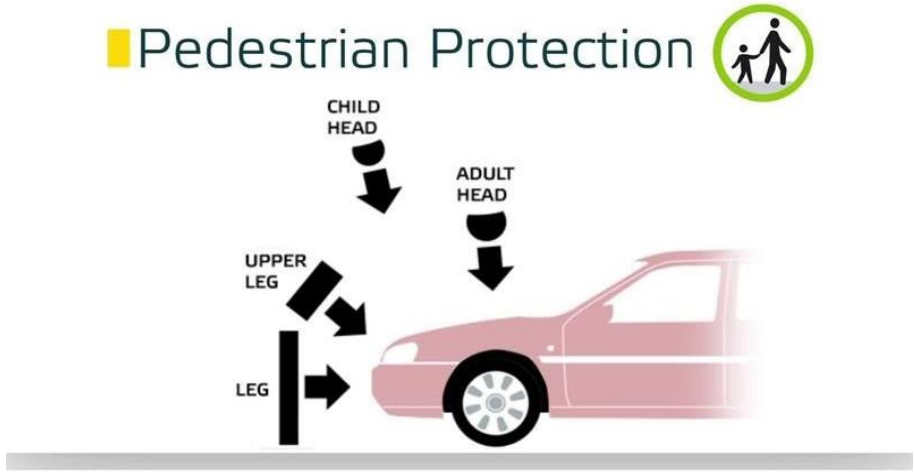
Introduction to pedestrian safety

- Traffic accidents still causing yearly a high number of fatal accidents.
- In Germany, around 13,7% of all fatal traffic accidents involve pedestrians and is currently increasing [1]
- The increased autonomy of cars will further increase the safety requirements for vulnerable road users as pedestrians, bikes …
- Passive safety requirements exists to ensure certain pedestrian safety in Euro NCAP
- Normally the HIC values is used to evaluate the safety using the European HIC limit of 1000 whilst

$$HIC = max\left[\left[\frac{1}{t_2 - t_1} \cdot \int_{t_1}^{t_2} a(t)dt\right]^{2,5} \cdot (t_2 - t_1)\right]$$



Fatalities in road traffic 2018 in Germany [1]

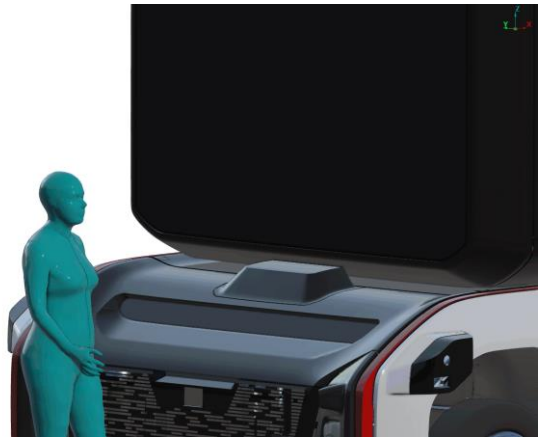


Euro NCAP Safety requirements

[1]https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Verkehrsunfaelle/_inhalt.html

New material solutions for improved crash safety

- New material solution in critical regions could be a solution to reduce as in the hood could the risk of injury in accidents with vulnerable road users
- Applying sandwich as hood material the head impact loads could be reduced whilst also increasing light weight potentials due to the outstanding material properties of sandwich design
- In the automotive field sandwich structure are challenged by tough cost constraints
- Simplifying the bonding process could be an efficient way to reduce the cost for sandwich materials
- One solution could be using the core material directly as adhesive material during a direct joining process

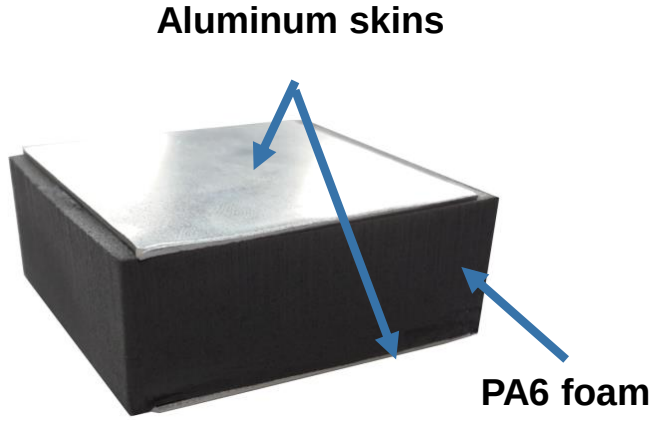


Pedestrian safety of new shuttle design (DLR)

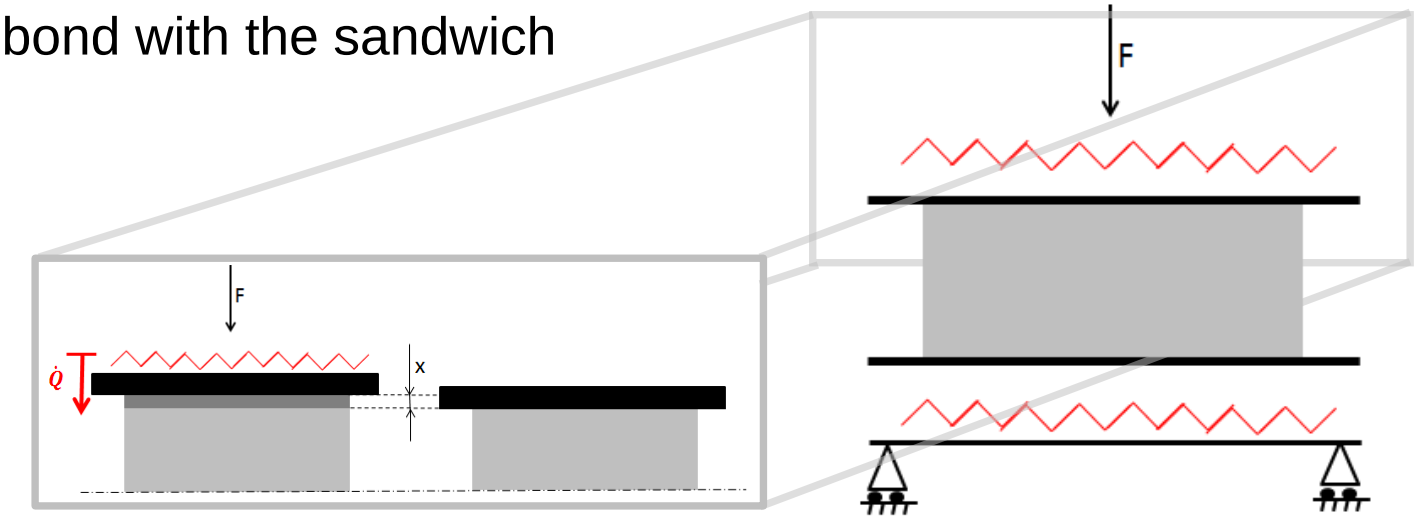
metal thermoplastic sandwich material

Hybrid sandwich design with in-situ thermal bonding

- Metallic and composite skins were used for hybridization
- PA6 thermoplastic foam materials with three different densities were used as core material
- An thermal bonding should be obtained by heating up the skins of the sandwich
- Due to compression force and the heat of the outer foam layers should melt and bond with the sandwich skins



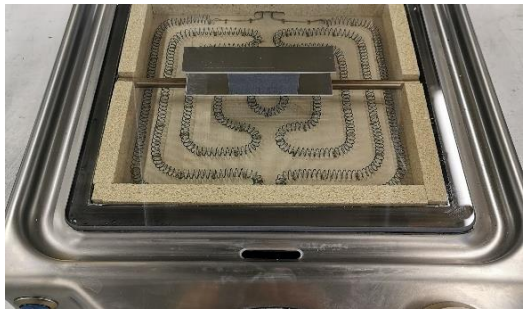
Metal-PA6 sandwich material specimen



Schematic sandwich bonding process

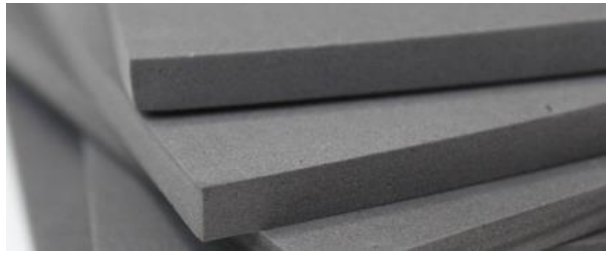
Manufacturing of thermally joined test specimens

- A heating device was used to introduce the heat into the sandwich
- As foam material the close cell nitrogen PA6 foam from the company Zotek was used
- Thermal bonding should be obtained by heating up the skins
- Due to compression force and the heat the outer layer of the foam melts and bonds with the skins



Heating device

Zotek N Foam (PA6):

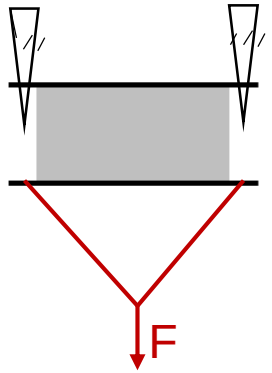


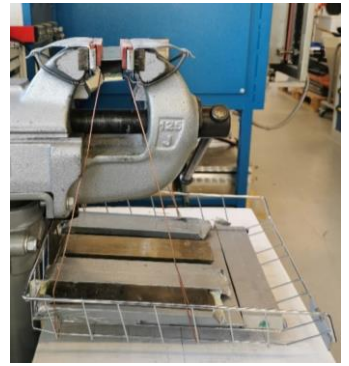
Close cell nitrogen foam

Test specimen

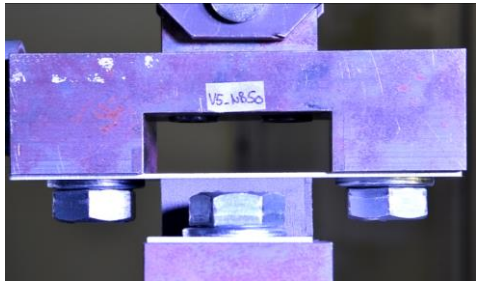
Test matrix for processes identification

- First evaluation for the identification suitable core and skin materials
- Investigated Materials:
  - AlMg3
  - AlMg4.5Mn0.7
  - Steel 1.407
  - Steel DP800
  - CFRP
  - GFRP
- Tested PA foam densities: $35\ \frac{kg}{m^3}$; $50\ \frac{kg}{m^3}$; $70\ \frac{kg}{m^3}$
- For efficiency process parameters and material identification was done with a simplified setup
- Tests showed best bonding results using Aluminum and PA foam
- Problems were obtained with composite and steel
- After identification of process parameters detailed tests were performed using a universal testing machine





Simplified test setup for fast bonding assessment



Tensile test setup

Standard: DIN 14272

Tensile shear test

Standard: DIN 1465

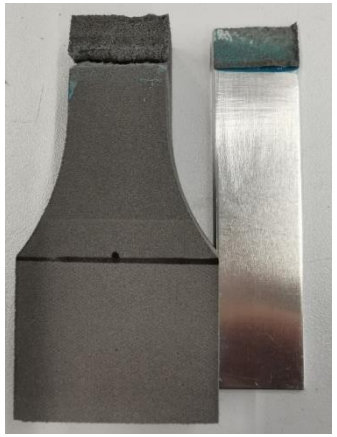
Assessment of tensile shear properties of the core bonding

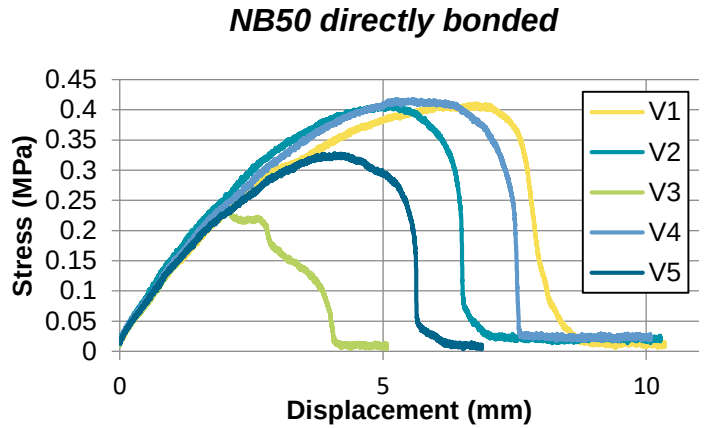
- Standard tests were conducted using Zotec foam and AlMg3 skins
- Identical tests were conducted comparing thermal bonding properties with a commercially available automotive adhesive
- Test results show core failure for both bonding types
- Still, the state of the art automotive adhesive shows 30% better properties than the thermal bonding

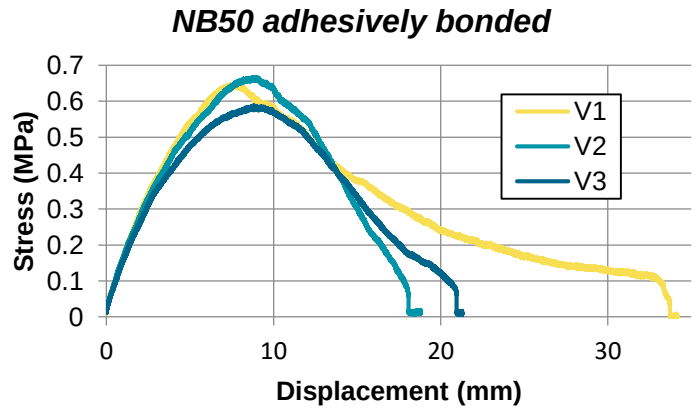
Test **Failure**

Thermally directly bonded

Adhesively bonded BETAMATE™ 2096







used standard: DIN 1465

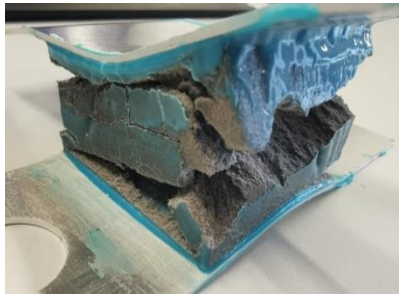
Assessment of head tensile properties of the core bonding

- Comparison studies were conducted for head tensile properties between thermally bonded and with the same commercially available automotive adhesive
- Results show an core failure mode for the adhesive and a adhesive failure mode for the thermally bonded core
- Failure mode indicates insufficient bonding properties for head tensile loads

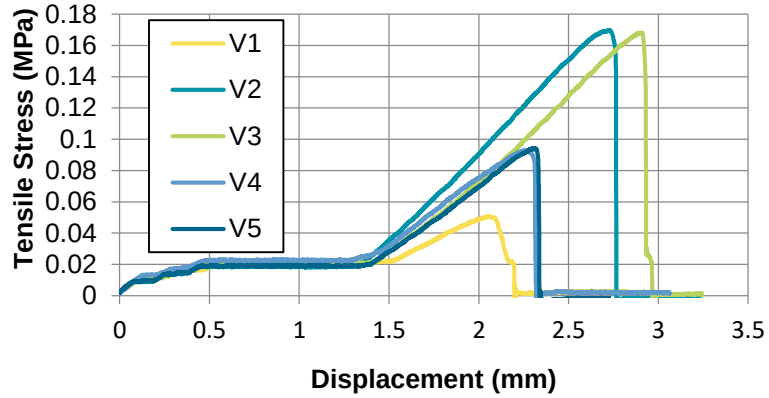
Failure

Thermally directly bonded

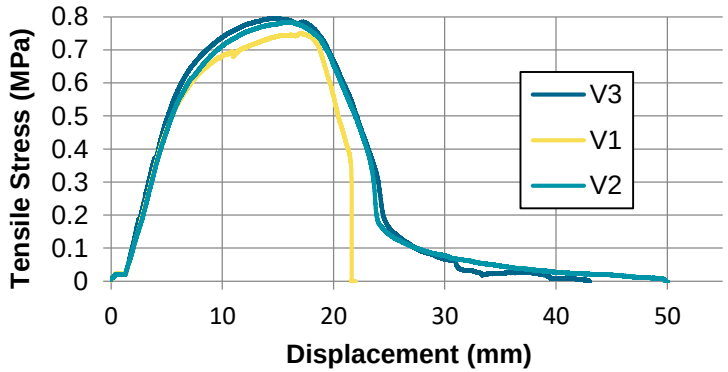
Adhesively bonded BETAMATE™ 2096



NB50 directly bonded



NB50 adhesively bonded



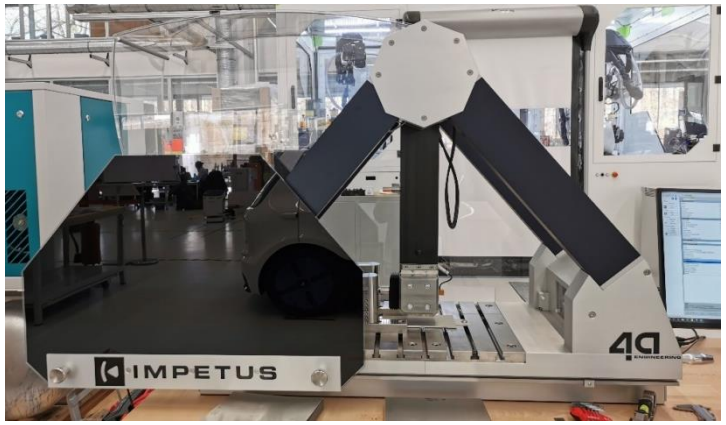
Additional research is required to improve head tensile properties by surface preparation techniques

used standard: DIN 14272

Dynamic validation tests

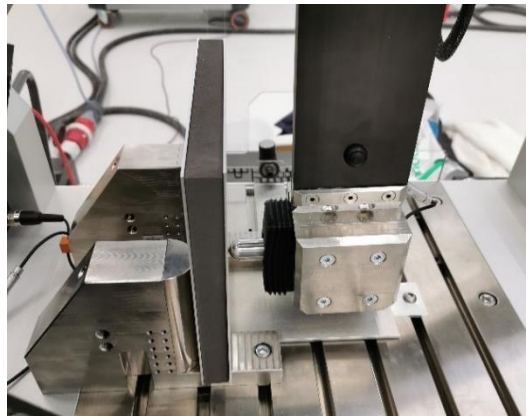
- Dynamic impact tests were conducted for three impact speeds $v_1 = 4\ \frac{m}{s}$, $v_2 = 3\ \frac{m}{s}$, $v_3 = 1\ \frac{m}{s}$ using the 4a Impetus pendulum
- Specimen size of 200 mm x 200 mm
- Two aluminum alloys and three PA6 foam densities were investigated
- A rigid round impactor was used
- Obtained core delamination indicating insufficient thermal bonding properties

IMPETUS™ pendulum setup



Sandwich Test specimen

Dynamic test setup

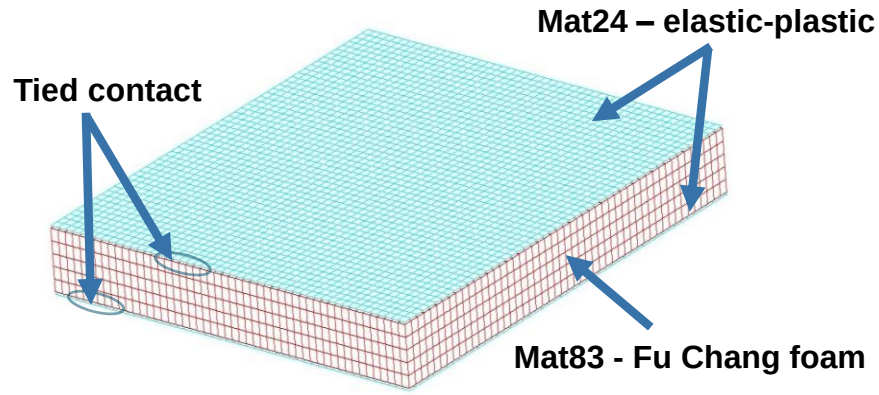


Example for impacted specimens

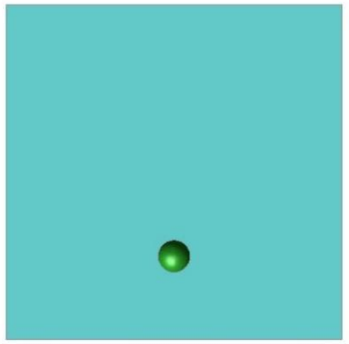
Simulation model of the hybrid metal–thermoplast sandwich

- Explicit FE (LsDyna) model with 4 mm element size
- Skins modelled with shell (Mat24) and solid mesh for the foam core (Mat83)
- Material cards were calibrated using the material lab for automated material card generation
- Impact diameter Ø = 20 mm
- Test specimens are laying loosely on rigid cylinders
- Numerically analyzed different skin-core joining types:
    - Without joining
    - Tiebreak contact
    - Rigid tied connection

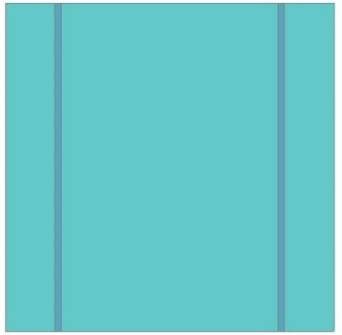
Explicit FE model of the validation experiment



Round impactor



Linear test sample



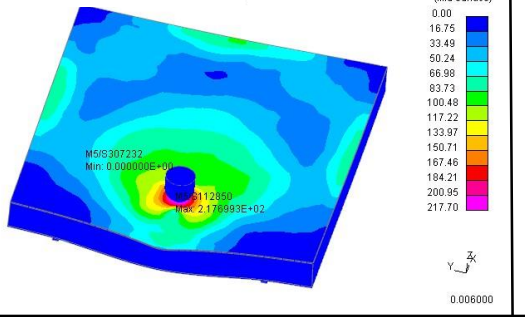
Analysing the effect of core bonding quality on impact resistance performace

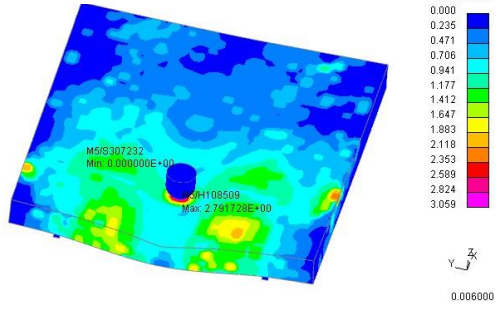
Specimen definition:

- **Skins AlMg3**
- **Foam NB70**

Rigid bonding

Tied connection

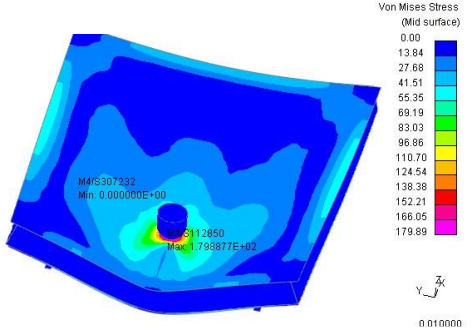




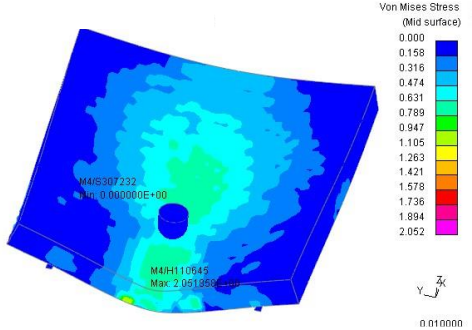
Max. deformation by 13 mm

Tiebreak connection
(Tensile and shear strength arcording to tests on universal testing machine)

With bonding failure



Core

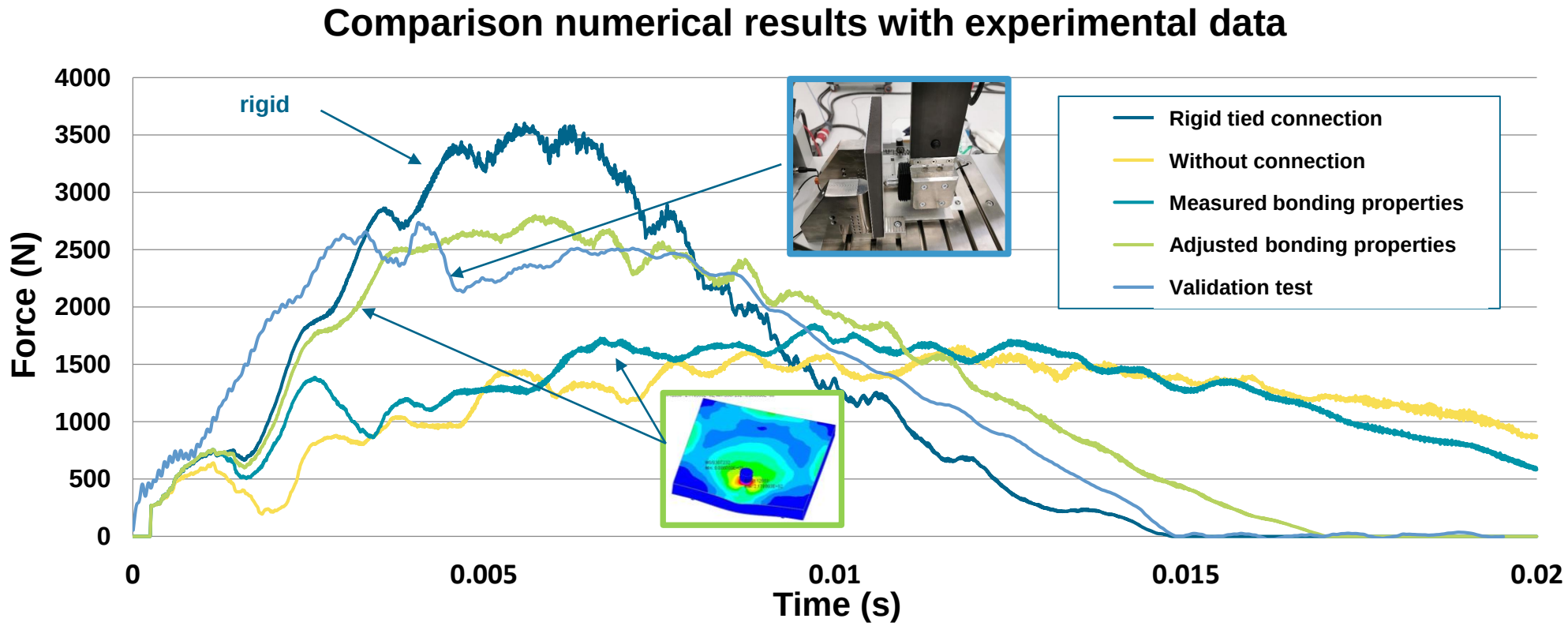


Cover layer hidden

Max. Deformation by 25 mm

- Bonding characteristics significantly influences the impact resistance of the sandwich
- Tested bonding quality is not sufficient for stable sandwich impact behavior

Validation of the numerical approach



- By adjusting the failure properties of the bonding (Tiebreak) a good correlation between simulation and experiments could be obtained
- Simulations show, that with further improvement of the bonding more energy could be absorbed

Summary

- A novel thermal bonding concept for a hybrid thermoplastic metal sandwich material was developed
- A two stage process was developed to identify suitable materials and process parameters for stable core bonding properties
- Material models of the core, sandwich sheets and the adhesive interface were developed
- Validation impact test were performed on sandwich plates
- Impact test showed, that further energy absorption performance could be obtained by improving the bonding properties
- Therefore, additional research is required to improve the bonding. Possible solutions could be
    - Application of primer systems
    - Laser structuring of the skins

Thank you for your attention

Laboratory of automated material card calibration

Webpage:

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