NEW BUS OPTIMIZED STRUCTURE TO IMPROVE THE ROLL-OVER TEST (ECE R66) USING STRUCTURAL FOAM (TEROCORE) WITH HIGH STRENGTH STEEL

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• INTRODUCTION

The new bus safety regulation introducing the seatbelt modifies the specification on the ECE R66 roll-over test. The weight of the passenger should be taken in account for this passive crash test.

On this study a solution using high strength steels and structural foam has been designed to improve the energy absorption and the final weight of the current bus structure. To make it possible Design of Experiments (DOE) and approximation model have been used to find the most interesting proposal.

The final solution has been validated with the construction of some prototypes of the section join and one bus section prototype.
Applus+ IDIADA, as partner to the automotive industry worldwide, supports its clients in their product development activities by providing:

- design
- engineering
- testing
- homologation services

Our reputation is founded on the skills of our engineers, our state-of-the-art facilities, client focus and the constant drive towards innovation.
NEW BUS OPTIMIZED STRUCTURE TO IMPROVE THE ROLL-OVER TEST (ECE R66) USING STRUCTURAL FOAM (TEROCORE) WITH HIGH STRENGTH STEEL

- IDIADA WORLDWIDE
NEW BUS OPTIMIZED STRUCTURE TO IMPROVE THE ROLL-OVER TEST (ECE R66)
USING STRUCTURAL FOAM (TEROCORE) WITH HIGH STRENGTH STEEL
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• INTRODUCTION HENKEL TECHNOLOGIES

Henkel Worldwide

• 52,000 employees • 125 countries
NEW BUS OPTIMIZED STRUCTURE TO IMPROVE THE ROLL-OVER TEST (ECE R66) USING STRUCTURAL FOAM (TEROCORE) WITH HIGH STRENGTH STEEL

- INTRODUCTION HENKEL TECHNOLOGIES

Three Areas of Competence, four Business Sectors

Home Care | Personal Care | Adhesives, Sealants & Surface Treatment

Persil Megaperls | taft | Pritt

Consumer & Craftsmen | Industry

Quality with Brands & Technologies
NEW BUS OPTIMIZED STRUCTURE TO IMPROVE THE ROLL-OVER TEST (ECE R66) USING STRUCTURAL FOAM (TEROCORE) WITH HIGH STRENGTH STEEL

- INTRODUCTION HENKEL TECHNOLOGIES

### Henkel Technologies Markets

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<tr>
<th>Transportation</th>
<th>Electronics</th>
<th>Metal Industries</th>
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<td><img src="image2" alt="Semiconductor" /></td>
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<th>Durable Goods</th>
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<td><img src="image4" alt="Office building" /></td>
<td><img src="image5" alt="Canned goods" /></td>
<td><img src="image6" alt="Packaging" /></td>
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</table>

### Maintenance, Repair & Overhaul

| ![Maintenance tools](image7) | ![Repair tools](image8) | ![Overhaul tools](image9) |
INTRODUCTION HENKEL TECHNOLOGIES

Global Organization

Sales and Service in over 60 Countries
50 Manufacturing Sites in over 30 Countries
8 NVH Design and Manufacturing Sites
NEW BUS OPTIMIZED STRUCTURE TO IMPROVE THE ROLL-OVER TEST (ECE R66)
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- INTRODUCTION HENKEL TECHNOLOGIES

HENKEL TECHNOLOGIES PARTS GROUP

This Henkel activity is focus to find structural and acoustic solution for car automotive industry. Two ranges of products are used to these objectives, the pillar filler and organic structural foams.

Pillar Filler Part

curing Process

Structural Foam
NEW BUS OPTIMIZED STRUCTURE TO IMPROVE THE ROLL-OVER TEST (ECE R66) USING STRUCTURAL FOAM (TEROCORE) WITH HIGH STRENGTH STEEL

- TEROCORE, Structural Foam
NEW BUS OPTIMIZED STRUCTURE TO IMPROVE THE ROLL-OVER TEST (ECE R66) USING STRUCTURAL FOAM (TEROCORE) WITH HIGH STRENGTH STEEL

• STEPS USED ON THE STUDY

  • INITIAL STUDY
  • SECTION STUDY USING HIGH STRENGTH STEEL
  • D.O.E. STUDY AND APPROXIMATION RESULTS VERSUS JOINT SECTION MODELS
  • REDESIGN REFERENCE STRUCTURE USING TEROCORE SOLUTIONS
  • TEST VALIDATION OF THE TEROCORE SOLUTION
  • CONCLUSIONS
NEW BUS OPTIMIZED STRUCTURE TO IMPROVE THE ROLL-OVER TEST (ECE R66) USING STRUCTURAL FOAM (TEROCORE) WITH HIGH STRENGTH STEEL

• INITIAL STUDY

A Bus structure is made of a frame of tubes. On the study we have taken as Base Line Model a design developed by Idiada. This design has as section reference a rectangular. This structure can pass the current R66 regulation without the weight of the passengers.

The first step of the study was to test the Tero core 2K influence on the Base Line configuration. A three bending point test was been selected to make this comparison. This simple test can easily compare different configurations.
NEW BUS OPTIMIZED STRUCTURE TO IMPROVE THE ROLL-OVER TEST (ECE R66) USING STRUCTURAL FOAM (TEROCORE) WITH HIGH STRENGTH STEEL

- INITIAL STUDY

FIRST SOLUTION TO INCREASE THE ENERGY ABSORPTION ON THE BASE LINE DESIGN

- STEEL SOLUTION Increase the thickness
- TEROCORE SOLUTION Keep the current design and fill the section with Terocore

**Bending Moment**

![Bending Moment Graph](image)

**Energy Absorbed**

![Energy Absorbed Graph](image)
NEW BUS OPTIMIZED STRUCTURE TO IMPROVE THE ROLL-OVER TEST (ECE R66) USING STRUCTURAL FOAM (TEROCORE) WITH HIGH STRENGTH STEEL

**INITIAL STUDY**

Conclusion:

- With Terocore 2K the section never has lost his performance, it is needed to increase the force during all the test, this is the opposite with the models without Terocore after the initial force value the sample lost his performance.

- With the Terocore there is not a big change for the initial load to start the deformation. This initial load depends of the geometry and the steel properties.

- If the important issue is the final it is possible to have the same energy absorption with a Terocore solution using initial thickness and one steel solution using high thickness.

Model B has the same final energy absorption that model C.
NEW BUS OPTIMIZED STRUCTURE TO IMPROVE THE ROLL-OVER TEST (ECE R66) USING STRUCTURAL FOAM (TEROCORE) WITH HIGH STRENGTH STEEL

• INITIAL STUDY

Three Bending Point Test Results

Experimental results on the initial section used on the current bus structure. The section has been filled with Terocore to compare the two configurations.

![Bending Moment Graph]

- Final Deformation
- Steel Base Line
- Steel Base Line + Terocore (TCO)
• INITIAL STUDY

Three Bending Point Test Results

To prepare the calculation model, a detail study of the foam properties on the samples has been done. The properties have a direct relation with the final density and the final density can have some variation on the sample.

TEROCORE 2K Material characterization from Three Bending Point Test

Preparation of Sample for Compression Test

1) Extraction of the Terocore
2) Cutting the sample

Compression test

Stress VS. deformation

Density (kg/m³)

Stress (MPa)

0 0,02 0,04 0,06 0,08 0,1 0,12 0,14

deformation
INITIAL STUDY

Three Bending Point Test Results

The steel plasticity has been analyzed too to obtain the best calculation correlation.

Steel Material characterization from Three Bending Point Test
NEW BUS OPTIMIZED STRUCTURE TO IMPROVE THE ROLL-OVER TEST (ECE R66) USING STRUCTURAL FOAM (TEROCORE) WITH HIGH STRENGTH STEEL

- INITIAL STUDY

Correlation test v.s. Calculation Three Bending Point Test

![Diagram showing Bending Moment vs. Rad. with different curves for Steel + TCO, Steel, FEA Steel + TCO, and FEA Steel, along with images of test and FEA deformations.](image)
SECTION STUDY USING HIGH STRENGTH STEEL (HSS)

On the second step of the study two new steel qualities has been selected to increase the performance of the initial solution. The steel selected are:

One hot rolled steel, the same family of the initial steel but with higher stress limits.

One high strength steel. This type steel is used on the automotive industry to increase the energy absorption on the car design. This family of the steel preset one limitation on the maximum thickness (2.0 mm.).
NEW BUS OPTIMIZED STRUCTURE TO IMPROVE THE ROLL-OVER TEST (ECE R66) USING STRUCTURAL FOAM (TEROCORE) WITH HIGH STRENGTH STEEL

- SECTION STUDY USING HIGH STRENGTH STEEL (HSS)

Samples with Terocore after the test. On the images it is possible to see the different behavior of the same section in function of the steel quality.
NEW BUS OPTIMIZED STRUCTURE TO IMPROVE THE ROLL-OVER TEST (ECE R66)
USING STRUCTURAL FOAM (TEROCORE) WITH HIGH STRENGTH STEEL

• SECTION STUDY USING HIGH STRENGTH STEEL (HSS)

Curve test results for the second hot rolled steel. Comparison between the section with Terocore and without. The sample without Terocore has a big reduction on the force after to achieve the maximum moment. The samples with Terocore this reduction is less important and the maximum is higher.

![Graph showing test results for hot rolled steel with and without Terocore.](image-url)
NEW BUS OPTIMIZED STRUCTURE TO IMPROVE THE ROLL-OVER TEST (ECE R66) USING STRUCTURAL FOAM (TEROCORE) WITH HIGH STRENGTH STEEL

- SECTION STUDY USING HIGH STRENGTH STEEL (HSS)

Curve test results for the high strength steel. Comparison between the section with Terocore and without. The sample without Terocore has a reduction on the force after to achieve the maximum moment. The samples with Terocore have the maximum moment at the end of the test. This type of deformation is the best to obtain the maximum energy absorbed during the test.

![TEST RESULTS HSS (1,8 mm)](image-url)
SECTION STUDY USING HIGH STRENGTH STEEL (HSS)

The same process used on the first study has been utilized to obtain a good correlation. The better plasticity and the absence of failure during the test make easier the correlation.
SECTION STUDY USING HIGH STRENGTH STEEL (HSS)

Comparison between the results with second hot rolled steel and the high strength steel. The calculation curve with 2.0 mm has been including to compare both materials with the same thickness.
NEW BUS OPTIMIZED STRUCTURE TO IMPROVE THE ROLL-OVER TEST (ECE R66) USING STRUCTURAL FOAM (TEROCORE) WITH HIGH STRENGTH STEEL

• D.O.E. STUDY AND APPROXIMATION USING REDUCED SECTION MODEL
NEW BUS OPTIMIZED STRUCTURE TO IMPROVE THE ROLL-OVER TEST (ECE R66) USING STRUCTURAL FOAM (TEROCORE) WITH HIGH STRENGTH STEEL

- D.O.E. STUDY AND APPROXIMATION USING REDUCED SECTION MODEL

For the D.O.E. STUDY AND APPROXIMATION five design variables has been selected:

- Steel quality (Four levels)
- Terocore final density (Three levels)
- Steel thickness (Three levels)
- Geometrical modification 1 (Two levels)
- Geometrical modification 2 (Two levels)
NEW BUS OPTIMIZED STRUCTURE TO IMPROVE THE ROLL-OVER TEST (ECE R66) USING STRUCTURAL FOAM (TEROCORE) WITH HIGH STRENGTH STEEL

- D.O.E. STUDY AND APPROXIMATION USING REDUCED SECTION MODEL

For the D.O.E. STUDY AND APPROXIMATION three responses variables has been selected:

- Total Mass
- Maximum Moment
- Total Internal Energy (energy absorbed by the system)

TWO D.O.E. STUDIES HAS BEEN DONE

- STEEL SOLUTION

  In this case the design variable there are only four design variable (no Terocore density influence)

  To make this study 48 calculation has been run to obtain the information and to make the approximation.

- STEEL + TEROCORE SOLUTION

  To make this study 144 calculation has been run to obtain the information and to make the approximation.
NEW BUS OPTIMIZED STRUCTURE TO IMPROVE THE ROLL-OVER TEST (ECE R66) USING STRUCTURAL FOAM (TEROCORE) WITH HIGH STRENGTH STEEL

- D.O.E. STUDY AND APPROXIMATION USING REDUCED SECTION MODEL

STEEL + TEROCORE
Response Variable: Total Mass

D.O.E. STUDY RESULTS

APPROXIMATION STUDY RESULTS
NEW BUS OPTIMIZED STRUCTURE TO IMPROVE THE ROLL-OVER TEST (ECE R66) USING STRUCTURAL FOAM (TEROCORE) WITH HIGH STRENGTH STEEL

- D.O.E. STUDY AND APPROXIMATION USING REDUCED SECTION MODEL

STEEL + TEROOCRE

Response Variable Maximum Moment

D.O.E. STUDY RESULTS

![D.O.E. Study Results Graph]

APPROXIMATION STUDY RESULTS

![Approximation Study Results Graph]
NEW BUS OPTIMIZED STRUCTURE TO IMPROVE THE ROLL-OVER TEST (ECE R66) USING STRUCTURAL FOAM (TEROCORE) WITH HIGH STRENGTH STEEL

- D.O.E. STUDY AND APPROXIMATION USING REDUCED SECTION MODEL

STEEL + TEROOCRE

Response Variable Total Internal Energy

D.O.E. STUDY RESULTS

APPROXIMATION STUDY RESULTS
NEW BUS OPTIMIZED STRUCTURE TO IMPROVE THE ROLL-OVER TEST (ECE R66) USING STRUCTURAL FOAM (TEROOCORE) WITH HIGH STRENGTH STEEL

- D.O.E. STUDY AND APPROXIMATION USING REDUCED SECTION MODEL

STEEL + TEROOCRE

Response Variable: Total Internal Energy

D.O.E. STUDY RESULTS
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STEEL + TEROCORE

Response Variable Total Internal Energy

APPROXIMATION STUDY RESULTS
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- D.O.E. STUDY AND APPROXIMATION USING REDUCED SECTION MODEL

An interesting curve has been obtained with all the D.O.E. results. All the results have been plotted on a graphic; the curve is the N° of calculation versus the total energy absorbed. It possible to see the influence of each design variables.
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• D.O.E. STUDY AND APPROXIMATION USING REDUCED SECTION MODEL

Using all the curves and graphics it is possible to make an accurate analysis of the design possibilities for a solution and find the most interesting.

COMPARISON ALL RESULTS

APPROXIMATION STUDY RESULTS

STEEL + TEROCORE

Response Variable Total Internal Energy
NEW BUS OPTIMIZED STRUCTURE TO IMPROVE THE ROLL-OVER TEST (ECE R66) USING STRUCTURAL FOAM (TEROCORE) WITH HIGH STRENGTH STEEL

- REDESIGN REFERENCE STRUCTURE USING TEROCORE SOLUTIONS

With the information coming for the D.O.E. study and using the approximation model we can redesign the current reference structure quickly. The current structure has two different configurations for the two sections.

**Initial Configuration**
- Section A
- Section B

**Configuration with Terocore**
- Section A
- Section B

**Mass Comparison**
- Initial Configuration: 1887 Kg
- Configuration with Terocore: 1811 Kg
- Mass Reduction: 76 Kg
NEW BUS OPTIMIZED STRUCTURE TO IMPROVE THE ROLL-OVER TEST (ECE R66) USING STRUCTURAL FOAM (TEROCORE) WITH HIGH STRENGTH STEEL

- REDESIGN REFERENCE STRUCTURE USING TEROCORE SOLUTIONS

The new configuration with Terocore improves the performance of the initial model. In this section, with the increment of weight, the initial configuration is on the limit to pass the test; on the Terocore solution remains a safety distance after the solicitation.

Section A

Initial Configuration

Configuration with Terocore
NEW BUS OPTIMIZED STRUCTURE TO IMPROVE THE ROLL-OVER TEST (ECE R66) USING STRUCTURAL FOAM (TEROCORE) WITH HIGH STRENGTH STEEL

• REDESIGN REFERENCE ESTRUCTURE USING TEROCORE SOLUTIONS

On the section B the difference between the two models has been increased. The initial configuration passes the floor limit, and then the solution can not pass the test regulation. The Terocore solution has a similar behavior and remains a distance until the floor.

Section B

Initial Configuration

Configuration with Terocore
NEW BUS OPTIMIZED STRUCTURE TO IMPROVE THE ROLL-OVER TEST (ECE R66) USING STRUCTURAL FOAM (TEROCORE) WITH HIGH STRENGTH STEEL

• TEST VALIDATION OF THE TEROCORE SOLUTION

The results obtained on the FEM calculation will be validated on two different prototypes.

JOIN PROTOTIPE MODEL

BUS SECTION PROTOTIPE MODEL
CONCLUSION

- The methodology used on the study give us the necessary information to understand the influence of the different design variables on the section deformation energy.

- The reduce model is good to analyze the deformation energy but not for weight and the maximum moment. Another model will be defined to include these responses.

- With the information on the reduced model we have designed a new solution on the current reference design, with a weight reduction of 76 Kg.

- The tools like Hyperstudy help to understand better the important factor on a design and it can help to manage big quantity of calculation results.
Thank You!