Development of Aluminum Heat Shield Designs Using OptiStruct and HyperForm

4th European HyperWorks Technology Conference

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Outline

Introduction

Problem Definition

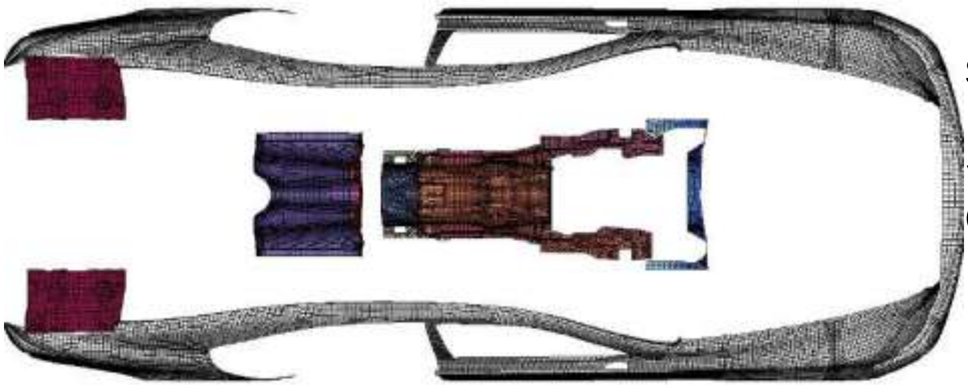
Analysis

Discussions

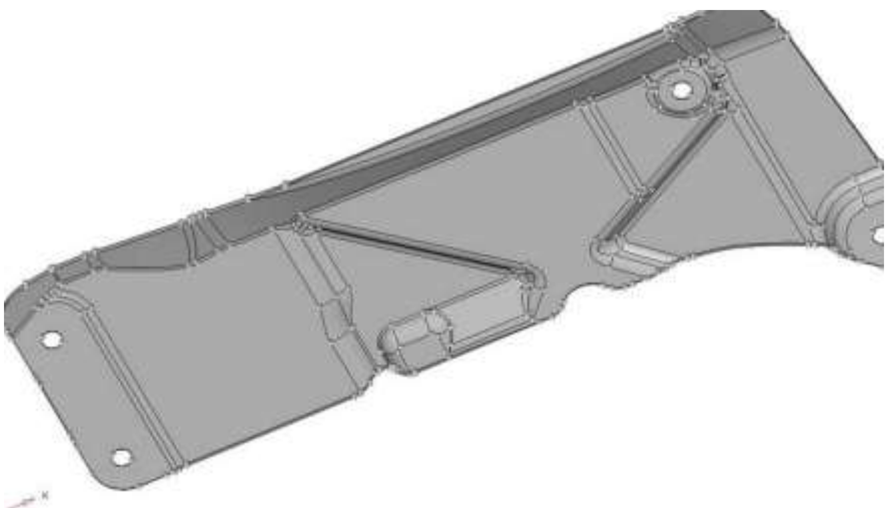
Conclusions

Significance of work

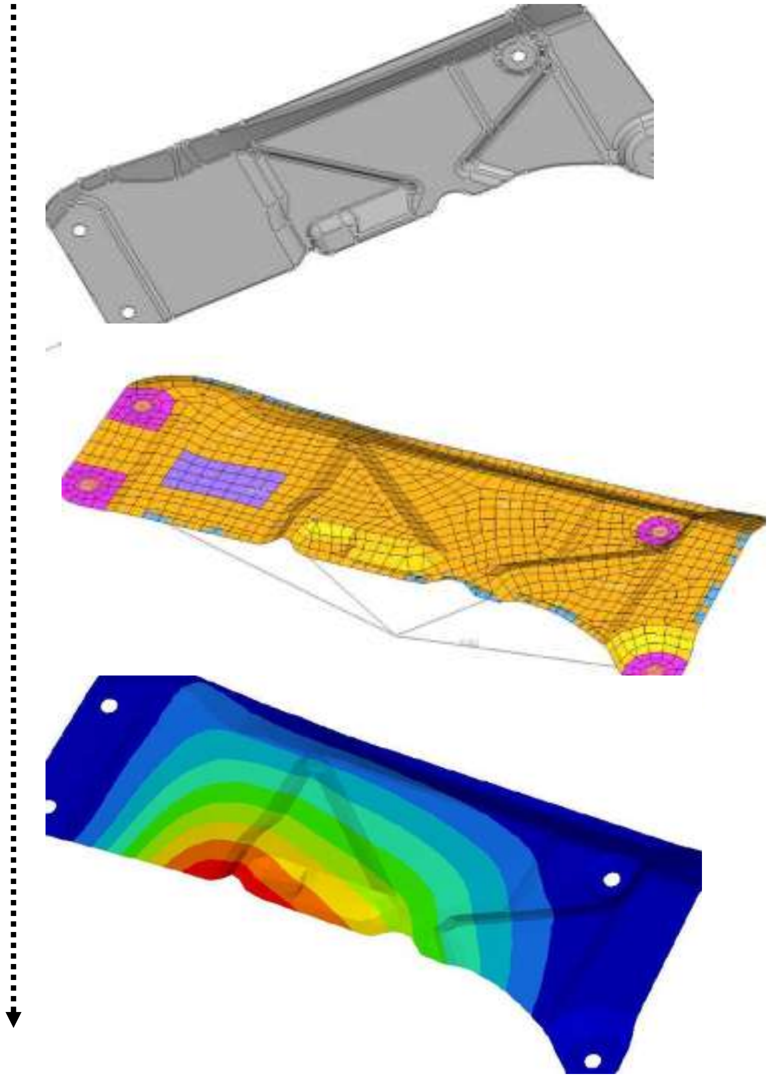
Automotive Heat Shields



- Used as insulating component
- Produced with embossed Aluminum sheet metal
- Susceptible to fatigue damage and cracking
- Formed over different geometries



Heat Shield Simulation



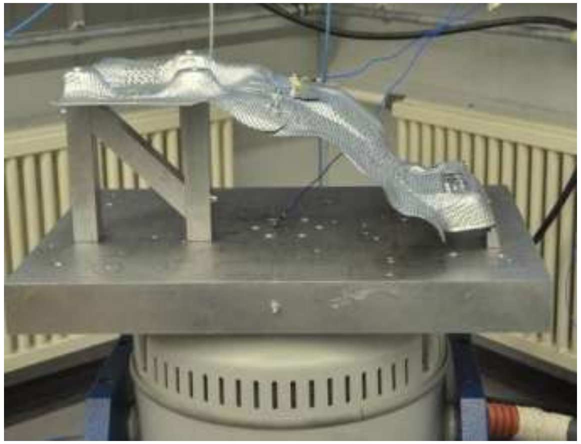
Goals:

- Characterize dynamic response
- Determine stress concentration points

Basic Workfow

- Read in CAD data
- Compare CAD to real part
  - Identify geometrical differences, flat areas, clinched edges, etc.
- Mesh geometry, apply material properties
- Modal behavior, forced response simulation
- Compare simulations results to experimental
  - Modify model parameters if needed

Dynamic Mode and Fatigue Test Characterization



Procedure

- Vertical acceleration of part
- Different acceleration levels used
- Desired dynamic mode excited
- Part fatigue cycled around one mode

Data Analysis

- Number of cycles to failure
- Crack grown after initial failure
- Frequency reduction over entire test

More fatigue resistant if more on the right

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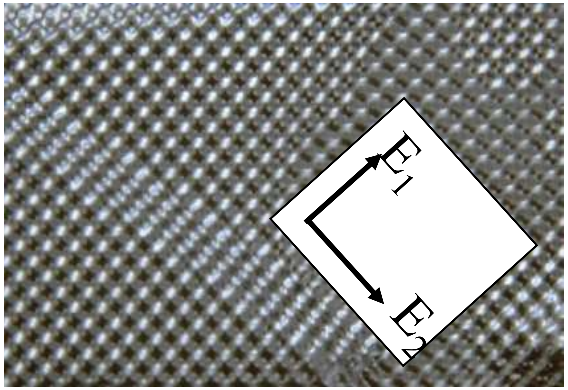
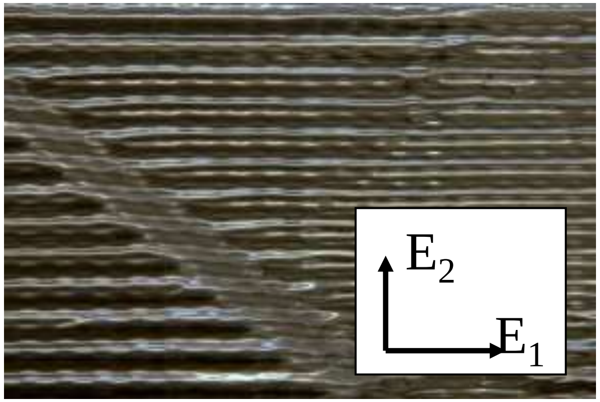
Embossed Aluminum Types

1



Embossing type strongly influences material stiffness

2



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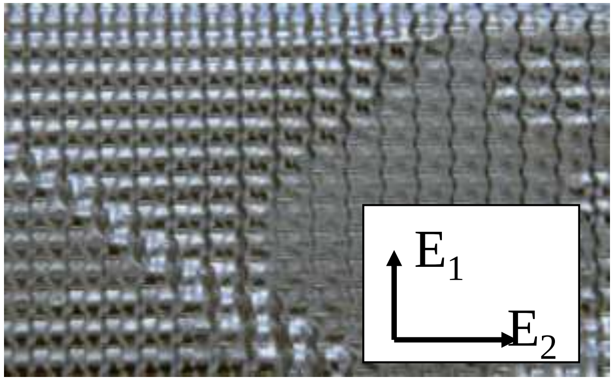
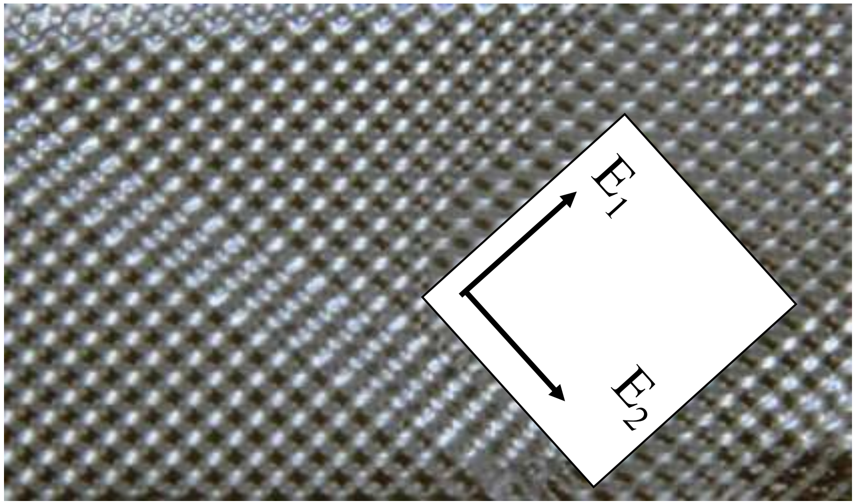
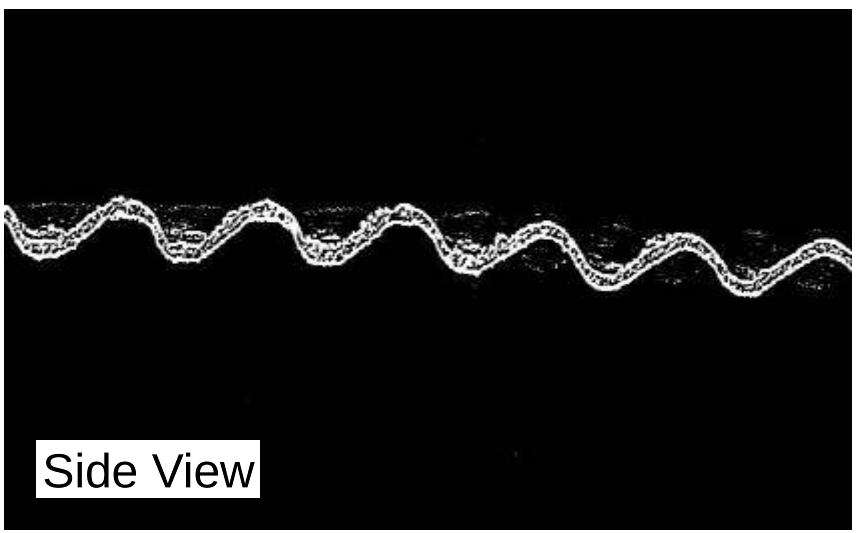


Embossed Aluminum

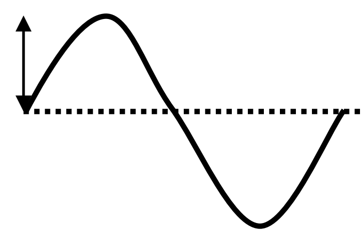




Aluminum
- Isotropic properties when flat
- Orthotropic when embossed

Embossing
- Work-hardens the aluminum
- Increases bending stiffness
- Affects crack behavior

Orientation of Emboss Pattern
- Influences dynamic response
- Crack nucleation point
- Crack growth patterns



Bending stiffness increases with height

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- Nastran
- HyperMesh
- Radioss
- OptiStruct

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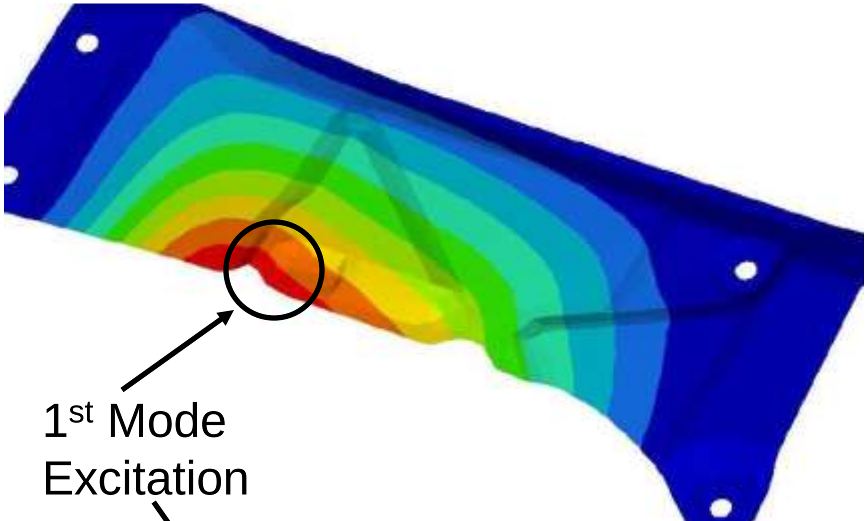
Heat Shield Dynamic Response

Critical range 0-200 Hz

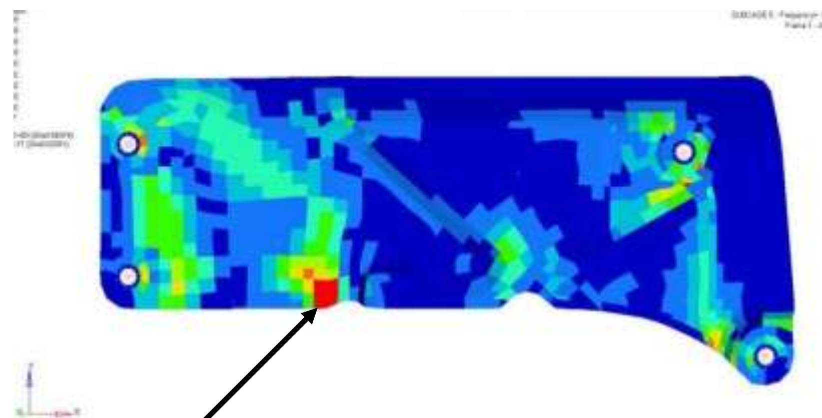
Highest loads during mode excitation

Priority: Limit modes in critical range



1st Mode Excitation

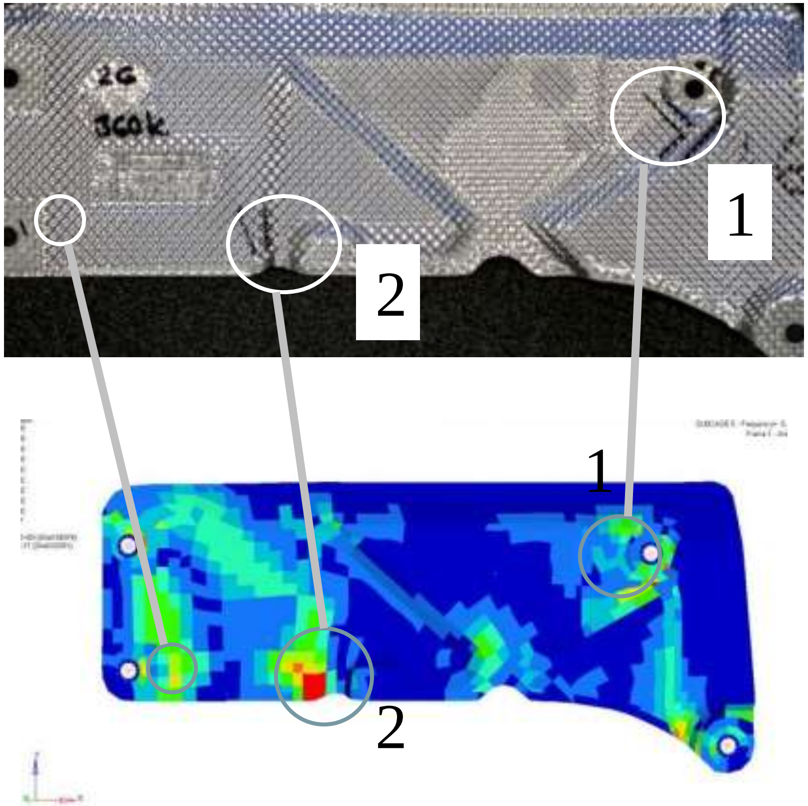
1st Mode Simulation



High Stress Area

Fatigue Test - Failure Characteristics

By Means of FE Simulation, the stress analysis has been performed for the same fatigue test condition.



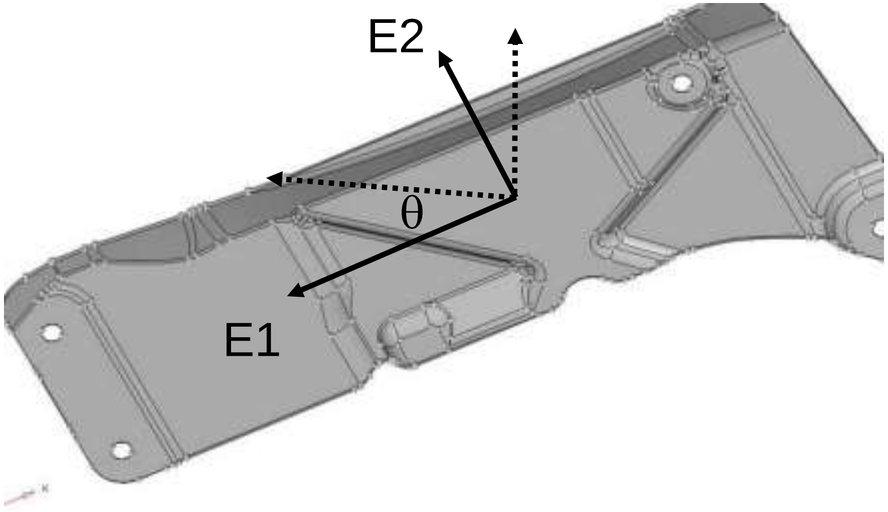
Bolt connection point (1) most critical and retains the longest cracks

High stresses seen on the part edge (2), easy crack nucleation where folded edges do not exist

In general, the material at the edge of washers will be very susceptible to crack nucleation.

General agreement between location of cracks and stress concentration in Test and Simulation

Optimization of Material Direction



Q: What is the optimal material angle to increase part rigidity?

OptiStruct

- Topology optimization
- Maximize 1st mode objective
- Allow material angle to vary

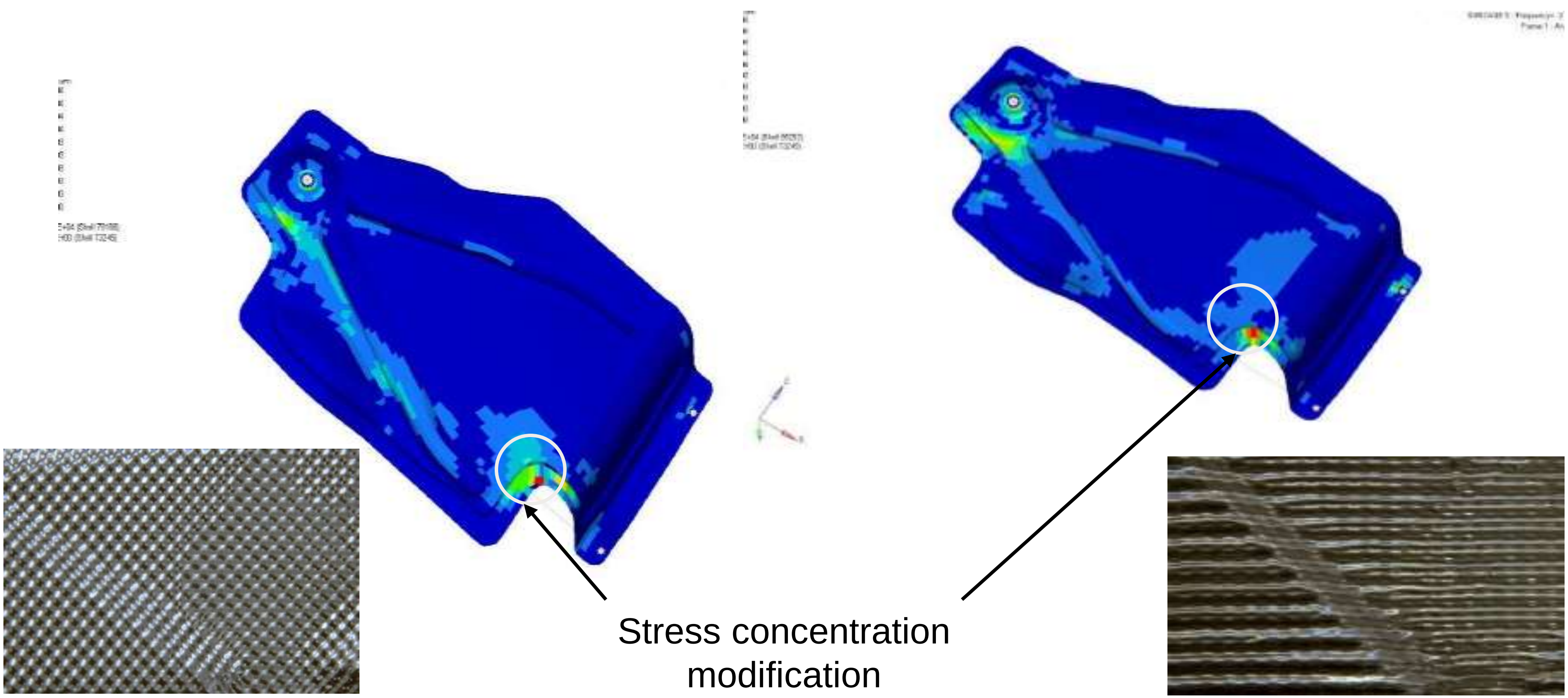
- PCOMP - combines tensile and bending stiffness for optimization
- DVMREL2 - Relates DESVAR to the material property model
- DESVAR - Defines variables to be used in the DEQATN (design equation)
- DEQATN

Tensile Moduli (E1, E2)

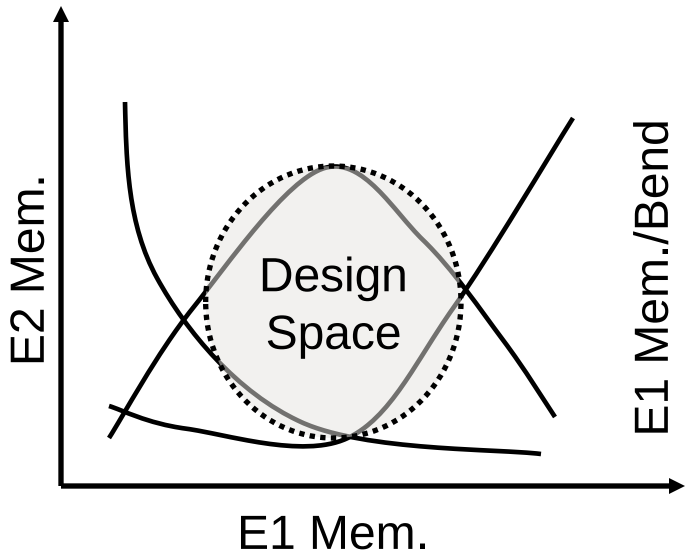
Bending Moduli (B1, B2)

Design Case I: OptiStruct Material Orientation

- Material direction optimized - objective of maximizing 1st normal mode
- Material orientation can be varied against a stress constraint outside of the design region (at bolt locations).



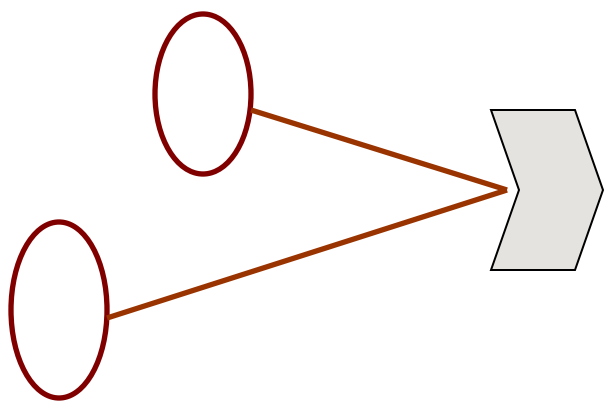
Design Case II: Define Material Property Design Space



- Determine ideal stiffness combination
- 1st mode maximized as objective function
- Basic relationship between tensile and bending moduli used as design space range
- Tensile and bending moduli allowed to vary in design space DEQATN
- DVMREL2 - Relates DESVAR to the material property model
- DESVAR - Defines variables to be used in the DEQATN (design equation)

Moduli Target of New Design

7059366 7059356



Tensile (GPa)

•E1 = .04, E2 = .02

Bending (GPa)

•E1 = 0.25-0.46, E2 = 0.34-0.38

Heat Shield Development

Heat Shield Characterization

- Fatigue Testing
- Test Parameters
- FE Simulation

Emboss Characterization

- Material Properties
- FE Simulation
- New Shape Design

TriForm Development

- Mat. Prop. Optimization
- Prototyping
- Testing/Validation

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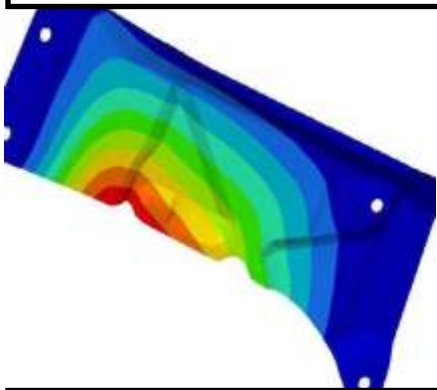
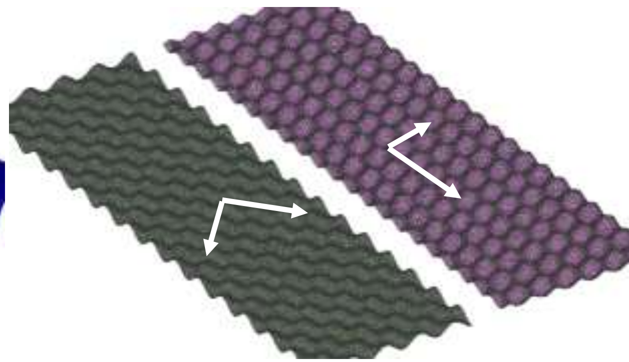
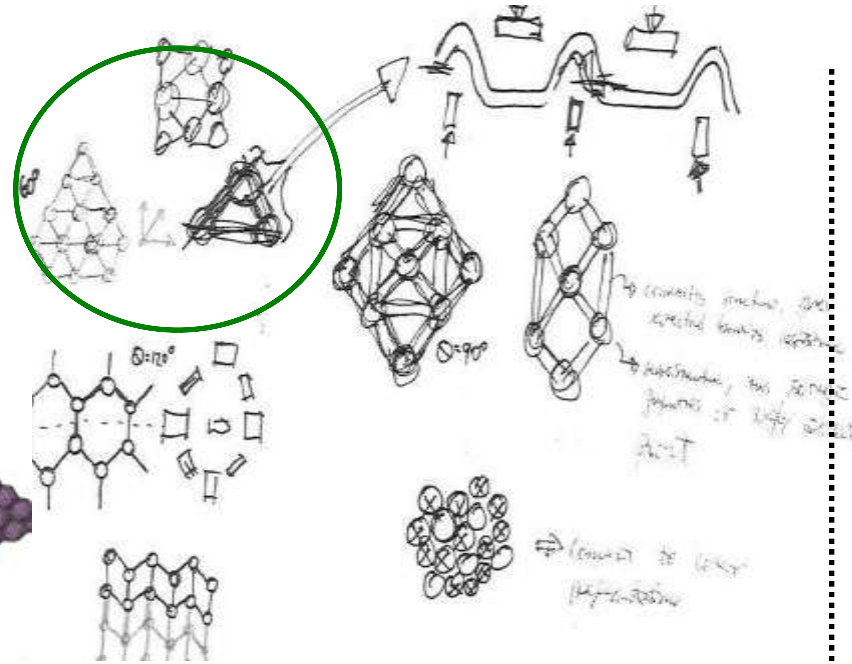
Technical Description

Key Points

- •Bending stiffness ⇧ as emboss height ⇧
- •Tensile stiffness ⇩as emboss height ⇧
- •Ribs determine bending stiffness direction
- •Rib direction influences crack growth







TriForm combines the important features of the Sevelen and Dieppe patterns

Emboss 1

•Uniform distribution, stiffness in two directions

•90 deg property grouping

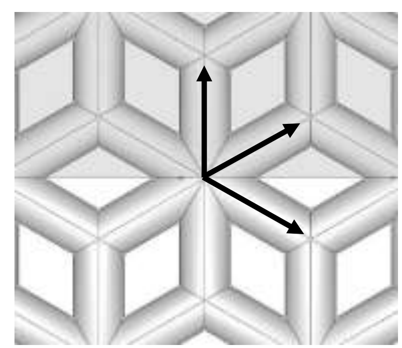
Emboss 2

•High bending stiffness (**90º** pattern)

TriForm

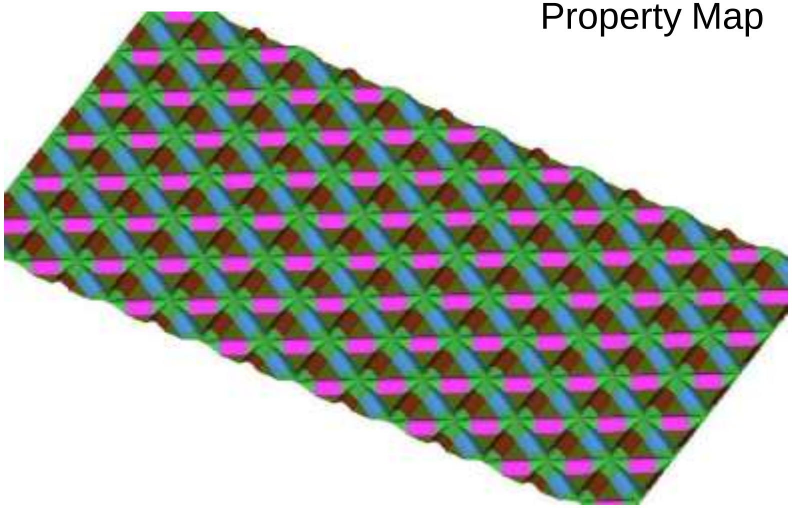
•Maintain bending stiffness in **three directions**

•Use new pattern distribution of **60º to 120º**

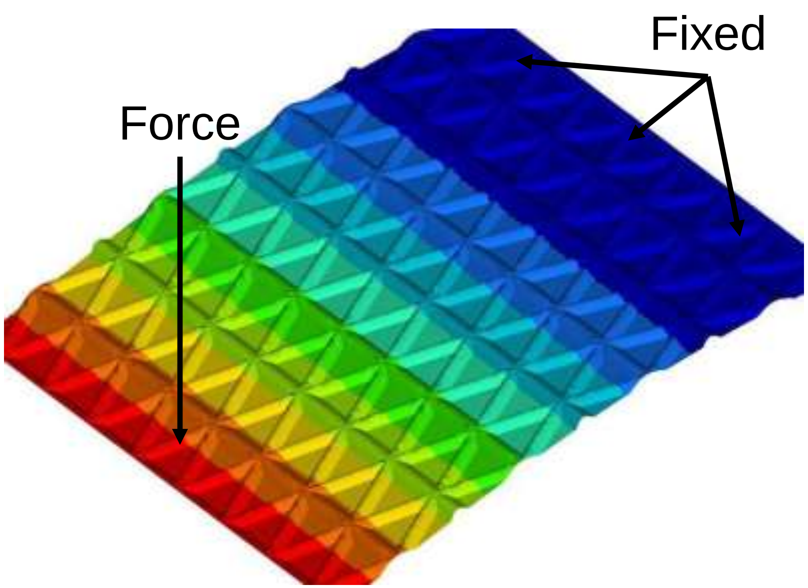


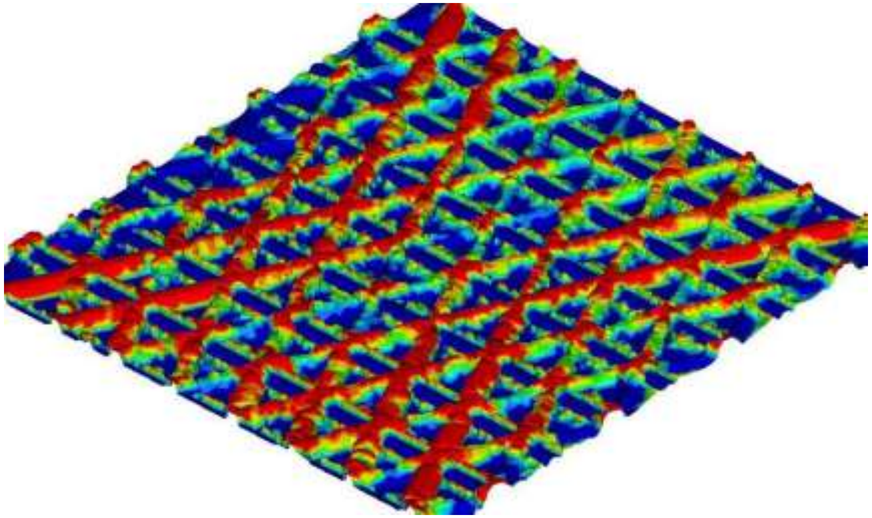
TriForm

Design Case III – Emboss Structure Design

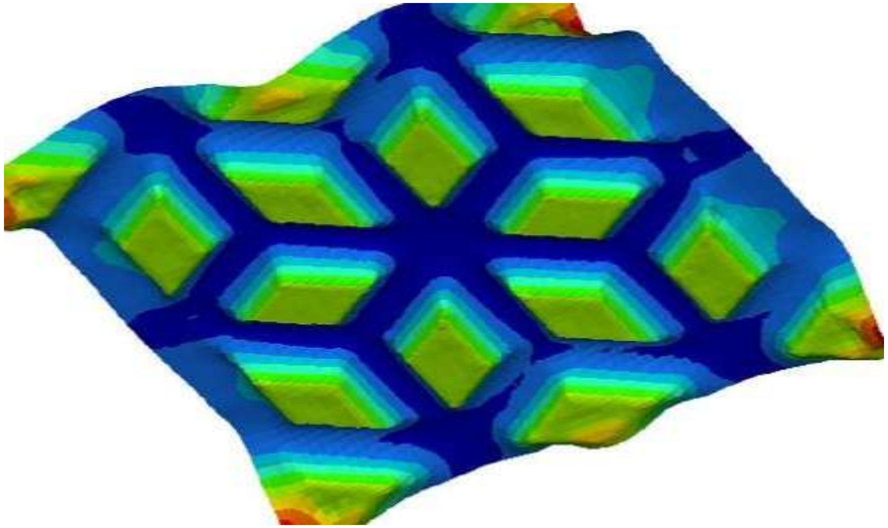


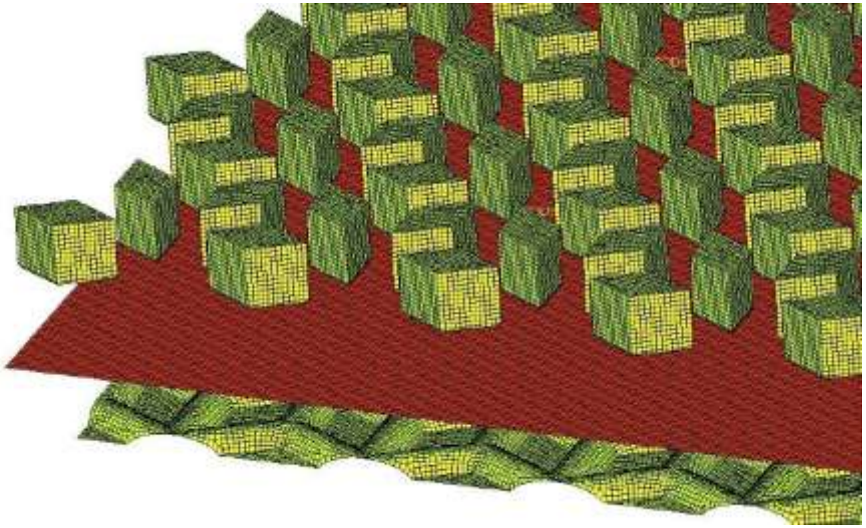
- Linear behavior predicted via beam theory
- Model show trends in geometry response to applied bending load
- Rib areas broken up into different properties to control symmetry
- Ribs along loading direction increase in height

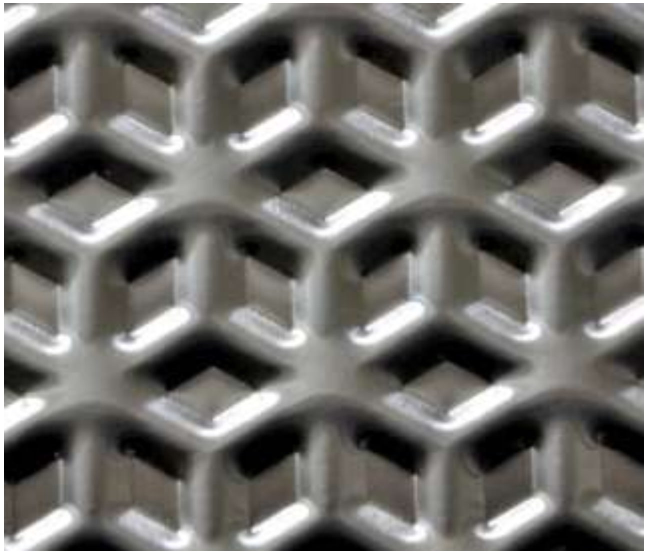




Design Case IV: TriForm Shape Forming

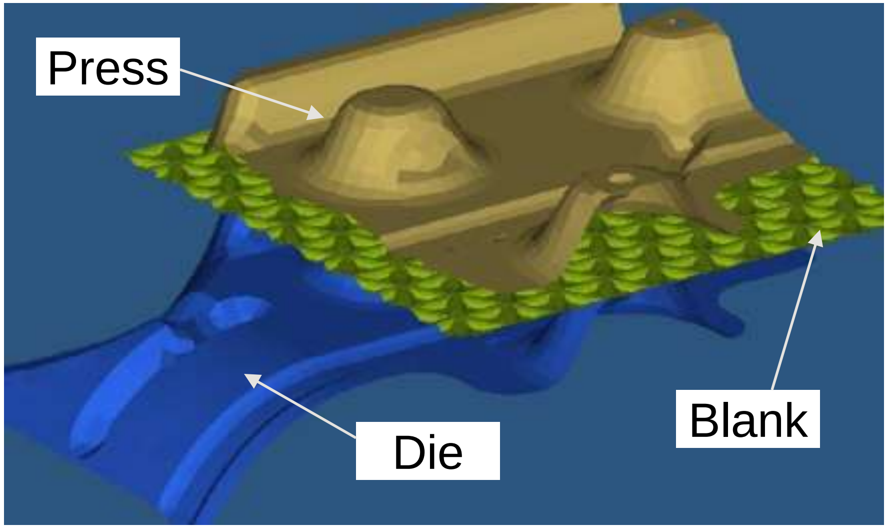




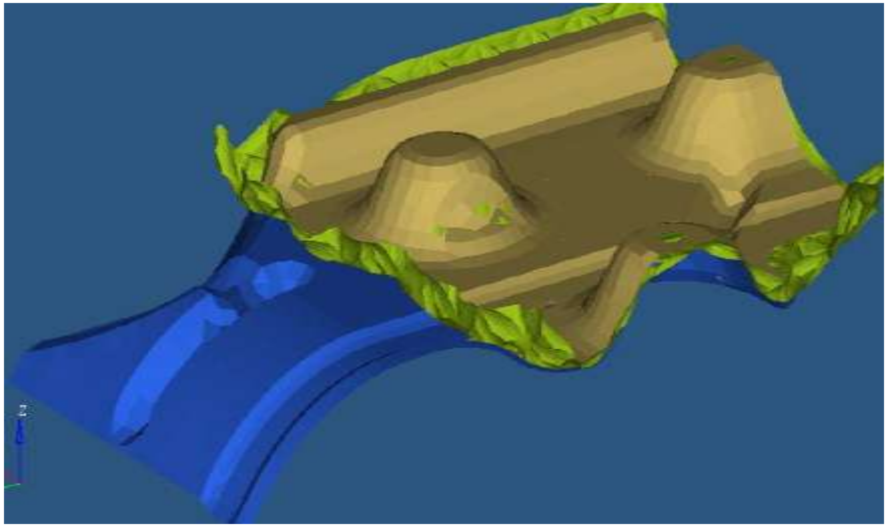


- Forming behavior simulated using HyperForm Incremental solver
- High stress areas identified in mold design
- Design refinements made to improve forming of embossment

Design Case IV: Sheet Metal Forming Simulation



- Embossed sheet metal blank with specific embossing pattern
- Simple crush simulation with fixed Die and closes the Press – deforming the Blank
- Non-linear material model assigned to the blank

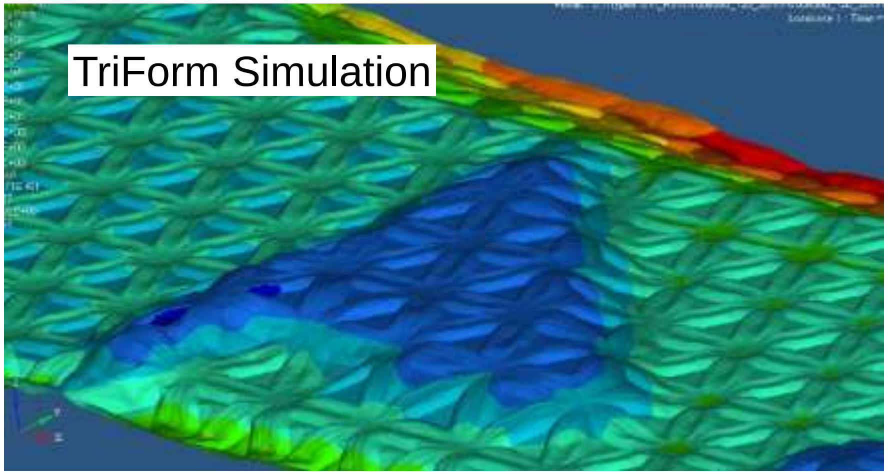


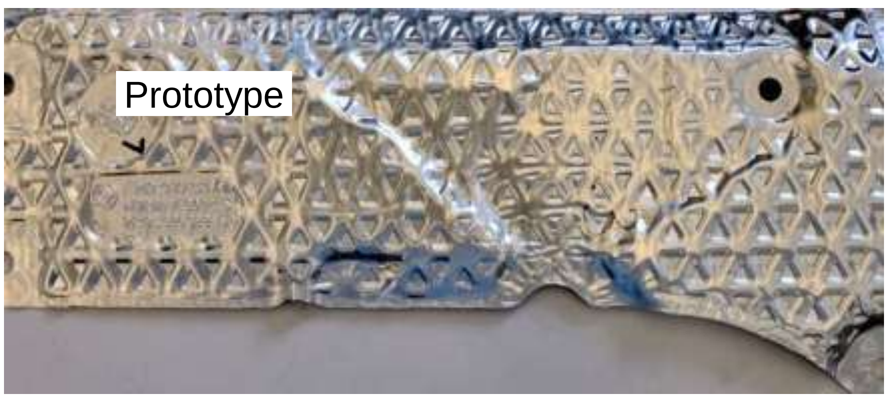
Deformation of aluminum sheet can be evaluated for different embossing patterns

Small blank sections used to reduce computation time

Focus on geometric area with high forming potential

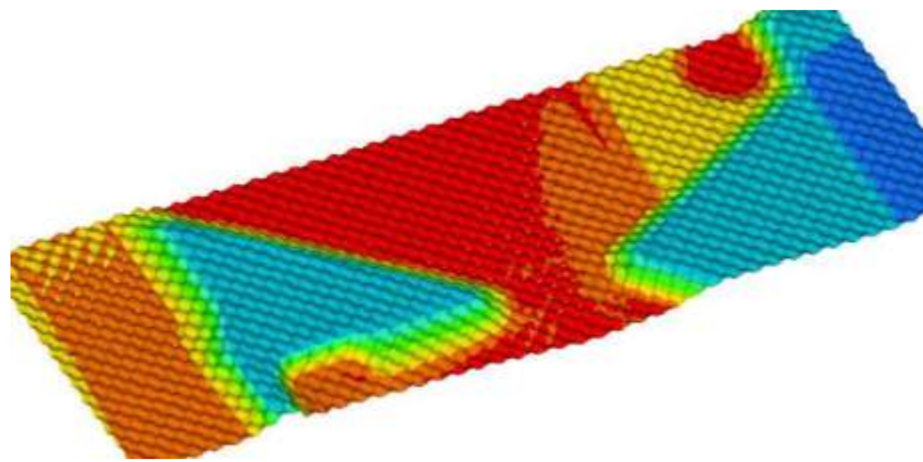
HyperForm Incremental Forming Simulations





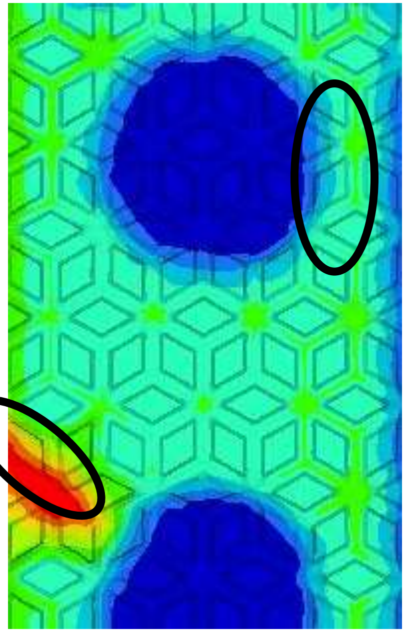
- Full forming model of embossed aluminum on heat shield geometry
- Contours over difficult forming areas can be represented correctly
- Final emboss shape and crushing degree can be predicted
- Very long simulation time (2-3 days)

Standard Pattern

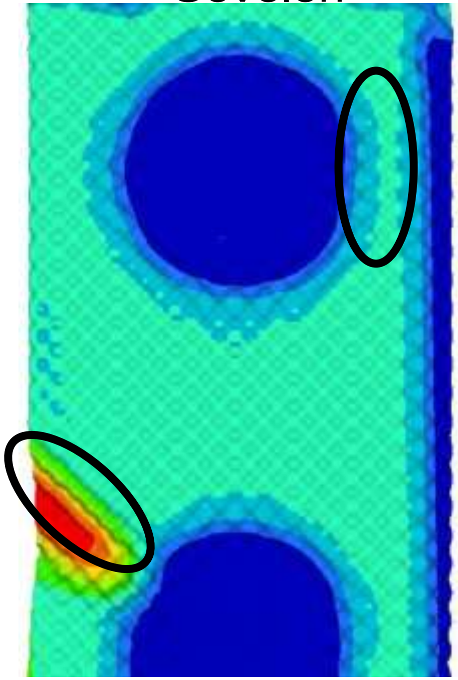


Displacement Deformation of TriForm vs Standard

TriForm



Sevelen



- Displacement contours show difference in forming ability over identical topography
- Sevelen displays smoother transition ability between flat and high aspect ratio structures
- TriForm 120 reproduces forming areas similar to Sevelen

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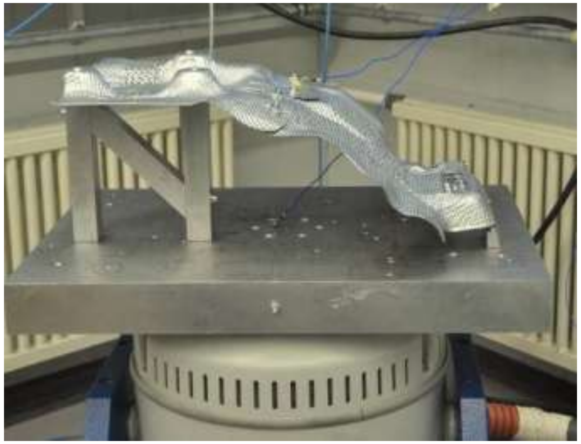
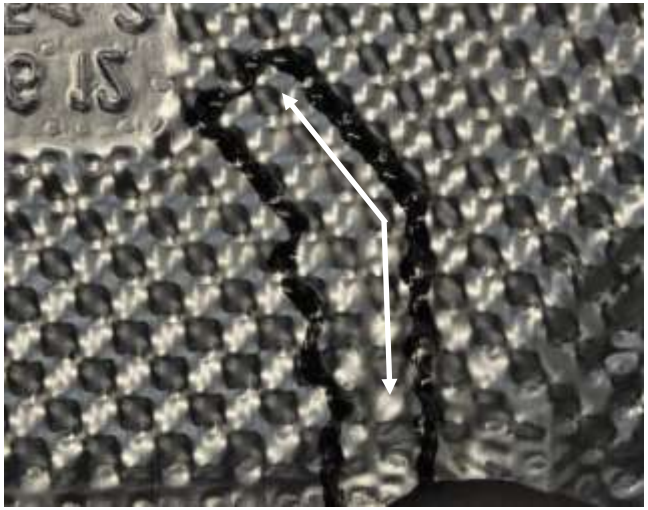
Fatigue results – TriForm vs. Standard

More fatigue resistant if more on the right

- Dynamic similar to Standard
- Fatigue life improved with TriForm
- TriForm rib pattern reduces crack propagation ability



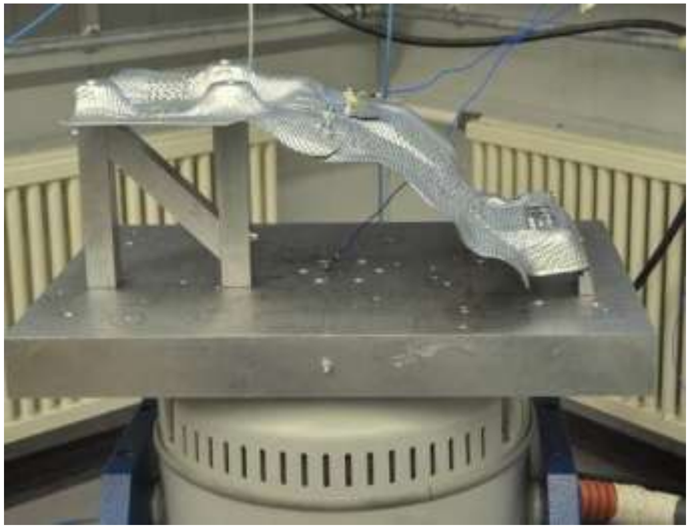
Fatigue Crack Behavior – Durability



1.5G 600k Cycles

- Worse case scenario presented, TF120 rib aligned with natural stress line of part
- TF120 blunts and retards crack growth at comparable cycle count w/Standard
- Reflected in the improved mode degradation results of TF120
- TF120 reduces crack propagation ability as compared with Standard pattern

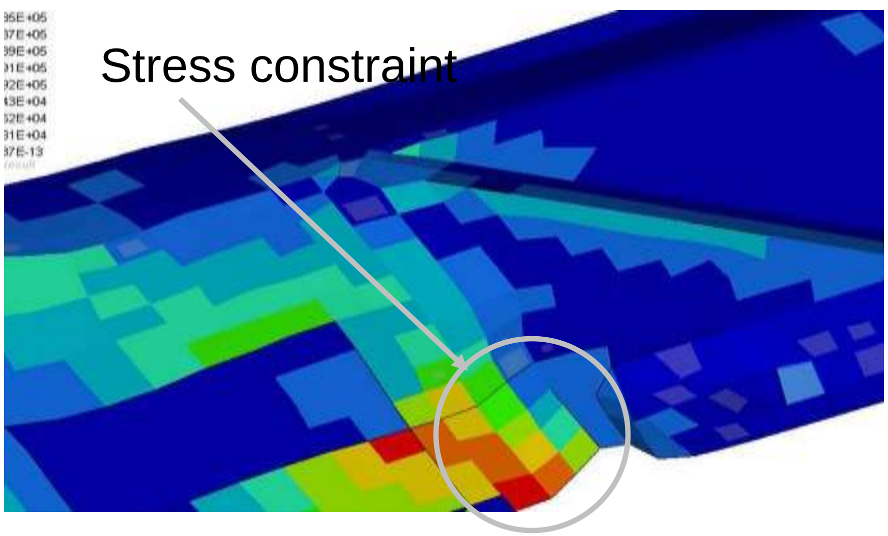
Future Directions



Expand analysis into fatigue simulation domain

Include fatigue limit as a design constraint

Optimize heat shield geometry in combination with embossed structure



Shaker test simulation

- Forced frequency response
- Composite material fatigue description

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