USE OF COMPOSITE BRACKETS AND REINFORCEMENTS IN A VEHICLE STRUCTURE MODEL FOR A LIGHTWEIGHT DESIGN

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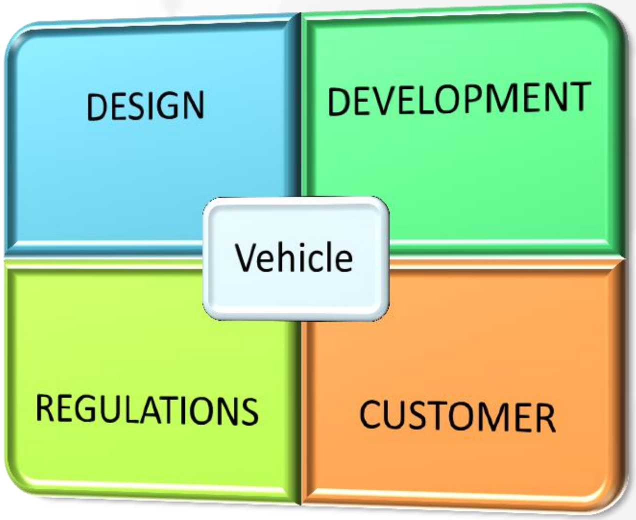
INTRODUCTION

Motor Vehicles

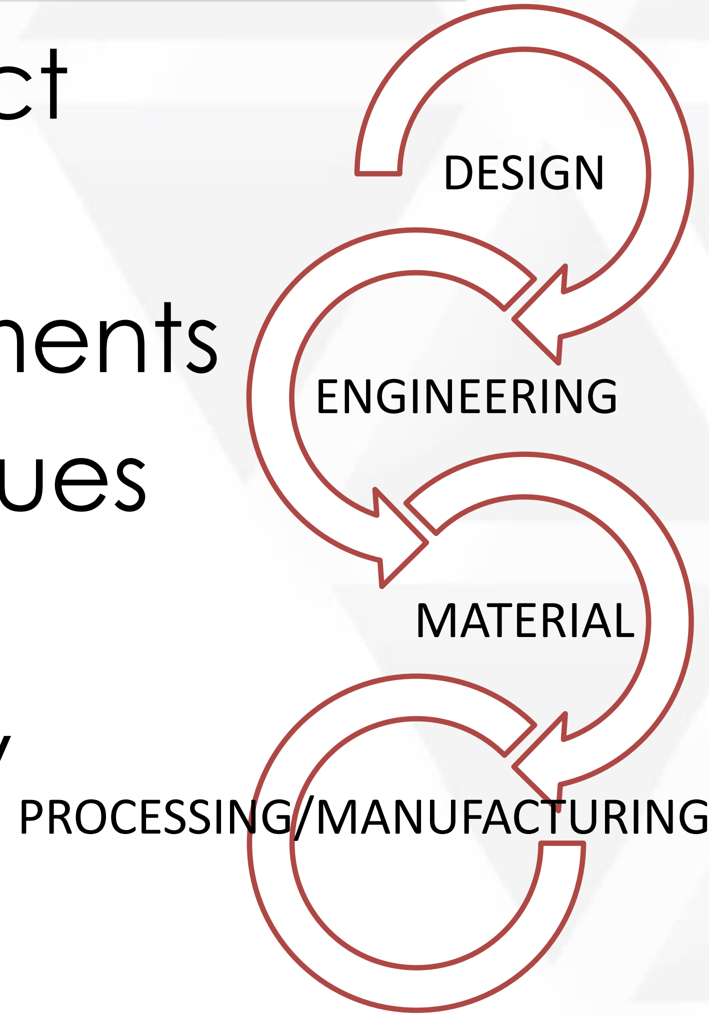
- More Elegant Design and Development
  - Customer Centric
    - » Optimized in Shape/Size
    - » Quality/Quantity/Affordable
- Stringent and Complex Safety Targets
  - New Regulations: NHTSA, IIHS
    - » Excellent Structure
    - » Good Occupant Response
- Fuel Efficient
  - Great Mileage
    - » Mass Reduction
    - » Low Cost



Introduction Cont'd – Current Trend

<u>OPPORTUNITIES FOR WEIGHT REDUCTION</u>

- New Designs and Product Developments
- New Material Developments
- CAE Processing Techniques
- Environment protection
- Increased Fuel Economy



Introduction Cont'd – Efficiency & Effectiveness

- Safety Benefits of lightweight Plastics and Composite Intensive Vehicles (PCIVs) (Park et al 2012)
- NHTSA directed various research centers to develop a future road map for PCIVs
- In order to facilitate their use by 2020
- (1) material database, (2)crashworthiness test method development, and (3) crash modeling (Barnes, 2010)

MATERIAL SIGNIFICANCE

- Energy Absorption/Dissipation by Vehicle Structures
- Under high velocity impact loadings
- Their ability to absorb/dissipate energy differs from one component to another
- Depending upon the material used, geometry and mode of deformation
- Selection of suitable material in designing of a vehicle structure
- Maximum amount of energy should dissipate while the material surrounding the passenger compartment is deformed to protect the people inside

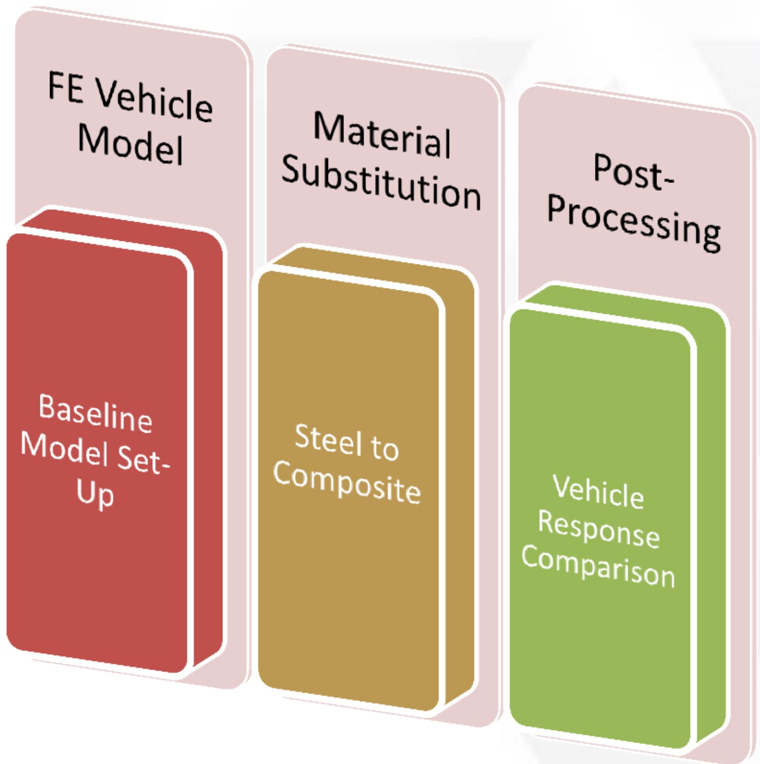
(Mamalis et al 2003)

COMPOSITES

- Combination of two or more materials
- Higher stiffness/weight and strength/weight ratio
- Widely used in many structural applications
- More and more metal parts are being replaced by composites
- Usage of Plastic/Composites grown up by 15% since 2010 (National Research Council Committee on Fuel Economy of Light-Duty Vehicles, Phase 2 Exploring Options for Lighter-Weight Vehicles February 13, 2012 – Ann Arbor, MI)

OBJECTIVE

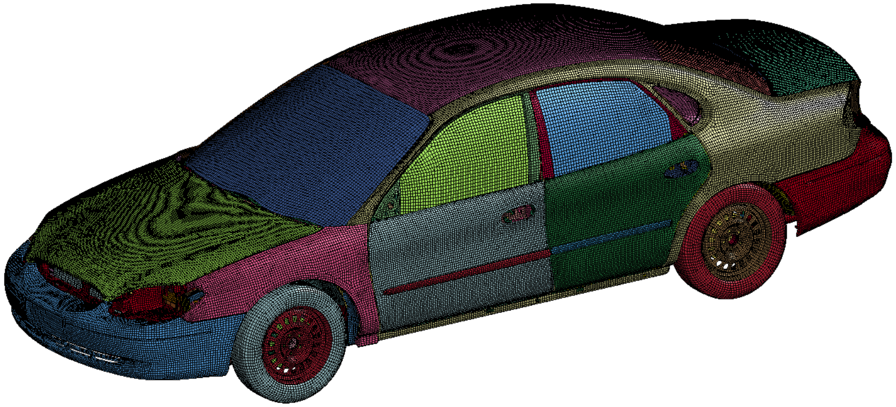
- To evaluate impact response of composite materials
- Comparison between conventional steel structures against composites
- Subjected to a High speed impact
- With the help of Computer Aided Engineering (CAE) techniques
- Investigate vehicle weight reduction opportunities



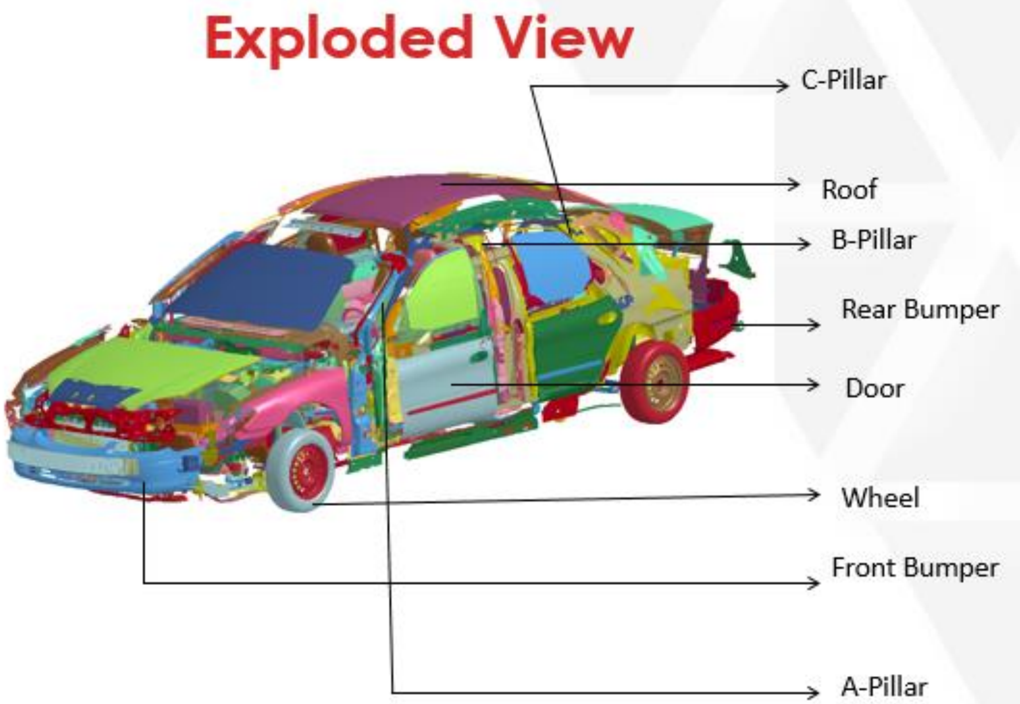
METHODOLOGY

- A Finite Element Analysis (FEA) study
- FE Model of a Sedan
- Identify components for weight reduction opportunities
- Replacement of steel materials with set of composite materials
- Compare vehicle crash performance between the steel and composite
- Frontal Crash Mode (NCAP) – 35MPH

METHODOLOGY - FORD TAURUS 2001



Vehicle Mass	
No. of elements	>1 million
No. of nodes	936237
Total Mass (kg)	1634.5 (~3605 lb)

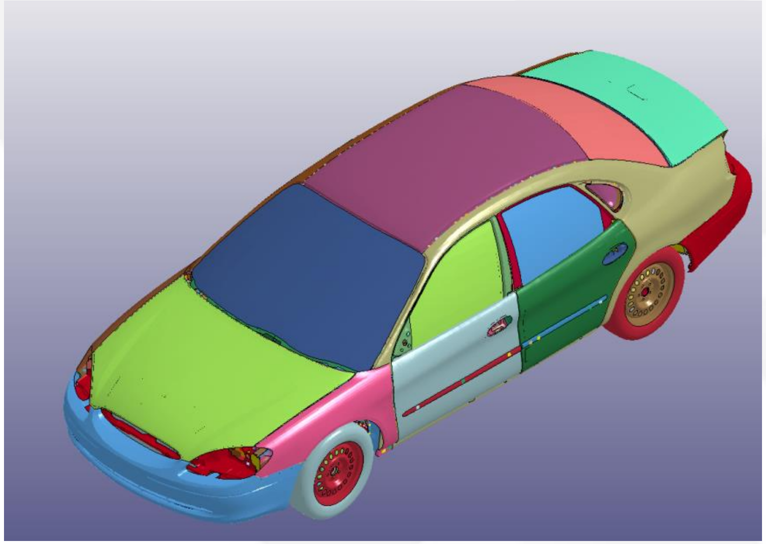


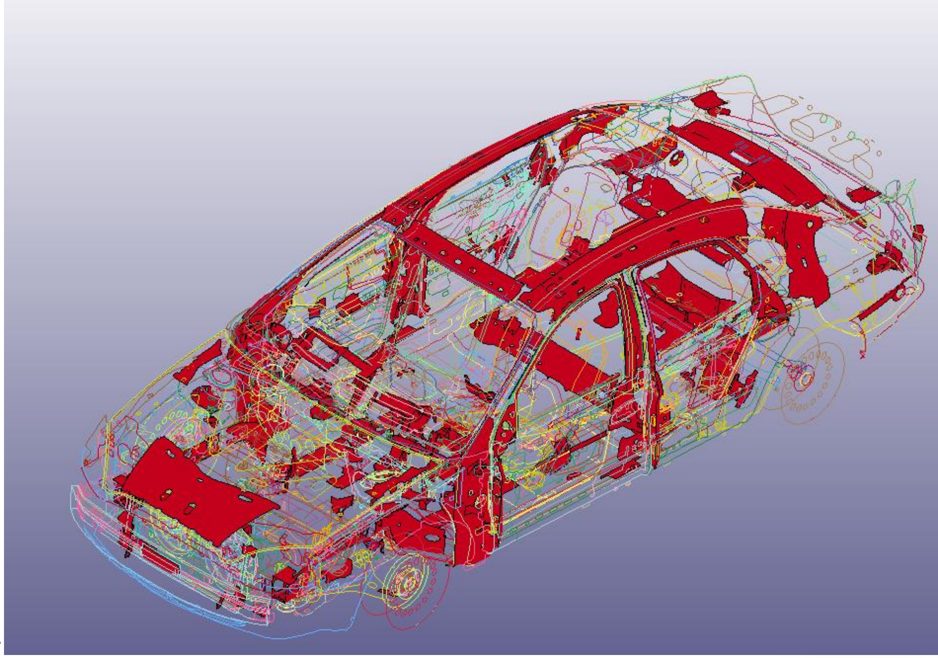
Reference: https://www.nhtsa.gov/crash-simulation-vehicle-models#12101

METHODOLOGY – Cont'd

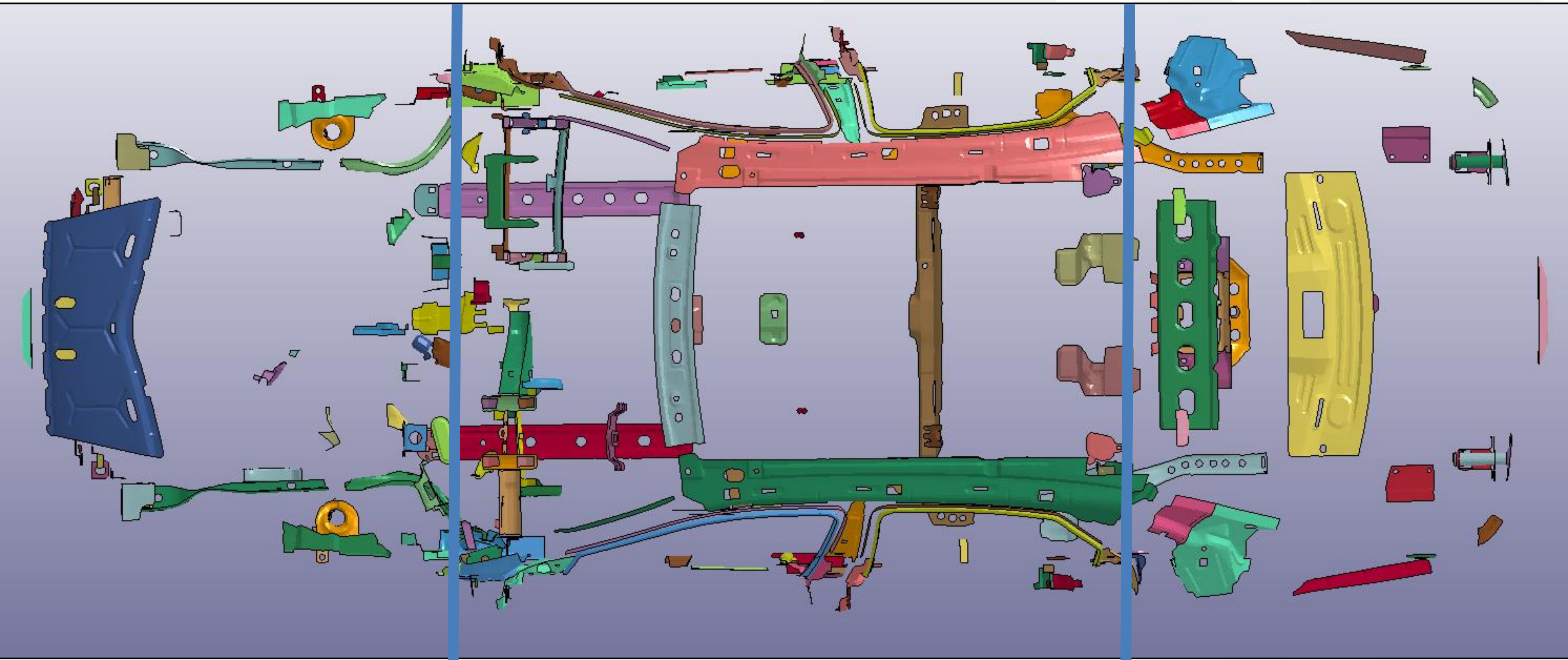
- Selection of Parts
- Brackets/Reinforcement/ Attachments
- Spanning from front bumper frame to the rear bumper
- Over 200 components out of ~795 components
- Varying mass/gauge from 8 g to 3 kg

  0.5 mm to 7 mm
- Varying steel material property data





METHODOLOGY – Cont'd



Bumper frame reinforcements
Hood reinforcements
Radiator mount brackets
Rail reinforcements
Engine mount brackets

Pillar Reinforcements
CCB reinforcements
Knee bolster/Glove box reinforcements
Seat mounting brackets
Door outer/inner reinforcements
Roof reinforcements

C- Pillar Reinforcements
Rear Seat frame
Trunk reinforcements
Rear bumper reinforcements

Composite Materials Used for the FE analysis

- **CFRTP (Carbon Fiber Reinforced Thermoplastics):** Similar properties to thermosetting resins but with higher ductile fracture properties

Reference: Goto, T., Matsuo, T., Uzawa, K., Ohsawa, I., & Takahashi, J. (2011). Study on optimal automotive structure made by CFRTP. In Proceedings of the 18th International Conference of Composite Materials, TH32, 1-4.

- **CFS003:** 2x2 twill fabric using Amoco T300 fiber and impregnated with LTM25 epoxy resin

Reference: Jindong, Ji. Lightweight Design of Vehicle Side Door. Diss. Politecnico di Torino, 2015.

- **E-Glass/Epoxy:** Manufactured in a fabric way but lower strength/modulus with higher material density

Reference: Jindong, Ji. Lightweight Design of Vehicle Side Door. Diss. Politecnico di Torino, 2015.

- **CTBC (Carbon Thermoset Braided Composite):** It is well-suited for components that are of simple geometry and need to provide off-axis as well as unidirectional strength

Reference: Park, C-K., Kan, C-D., Hollowell, W., & Hill, S.I. (2012, December). Investigation of opportunities for lightweight vehicles using advanced plastics and composites. (Report No. DOT HS 811 692). Washington, DC: National Highway Traffic Safety Administration

Material Parameters for the Composites

	Density (g/cm^3)	Ea (GPa)	Eb (GPa)	PR	GAB (GPa)	GAC (GPa)	GBC (GPa)	XT (MPa)	XC (MPa)	YT (MPa)	YC (MPa)
CFS003	1.45	53.6	55.2	0.042	2.85	2.85	1.42	618	642	652	556
E-Glass/Epoxy	1.85	29.7	29.7	0.17	5.3	5.3	5.3	369	549	369	549
CTBC	1.50	80	80	0.35	30	30	30	800	300	1000	300
CFRTP	1.36	34	N/A	0.21	ELASTIC-PLASTIC MATERIAL						

RHO— density of composite material;

EA— Young's modulus of longitudinal direction, a direction;

EB— Young's modulus of transverse direction, b direction;

PR— Main Poisson's ratio, related to a direction and b direction;

GAB— Shear modulus of a direction and b direction;

GAC— Shear modulus of a direction and c direction, direction c is perpendicular to the plane of ab;

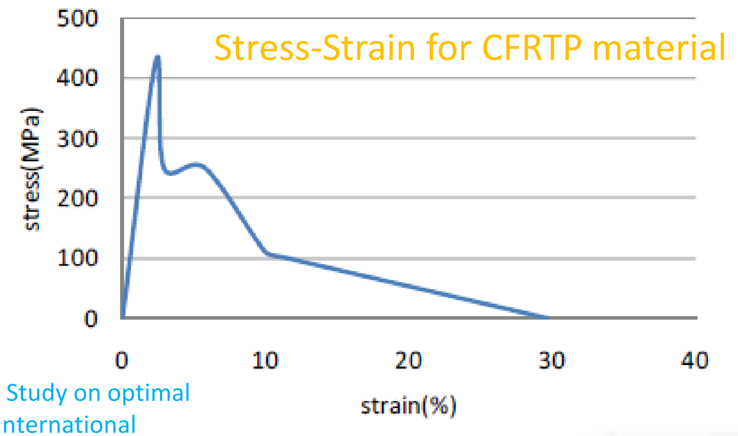
GBC— Shear modulus of b direction and c direction;

XT— Longitudinal tensile strength;

XC— Longitudinal compressive strength;

YT— Transverse tensile strength;

YC— Transverse compressive strength;

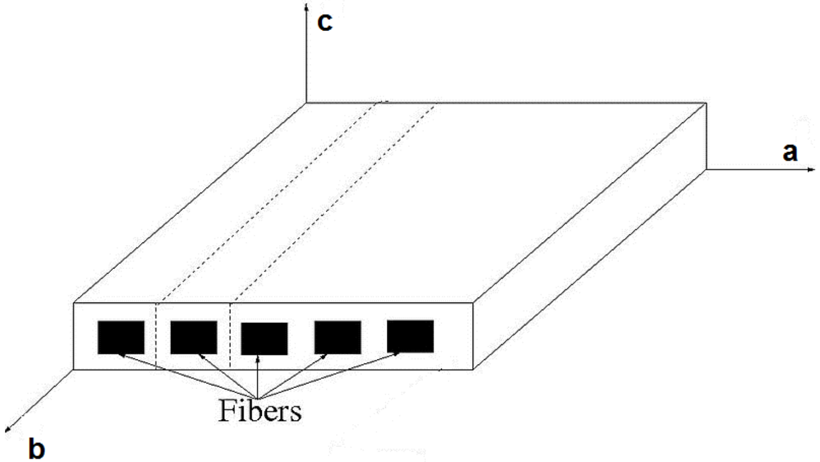


Reference: LSDYNA KEYWORD USERS MANUAL
http://lstc.com/pdf/ls-yna_971_manual_k.pdf
Goto, T., Matsuo, T., Uzawa, K., Ohsawa, I., & Takahashi, J. (2011). Study on optimal automotive structure made by CFRTP. In Proceedings of the 18th International Conference of Composite Materials, TH32, 1-4.

LSDYNA Material Model for the Composites

- **MAT54/55 -MAT_ENHANCED_COMPOSITE_DAMAGE**

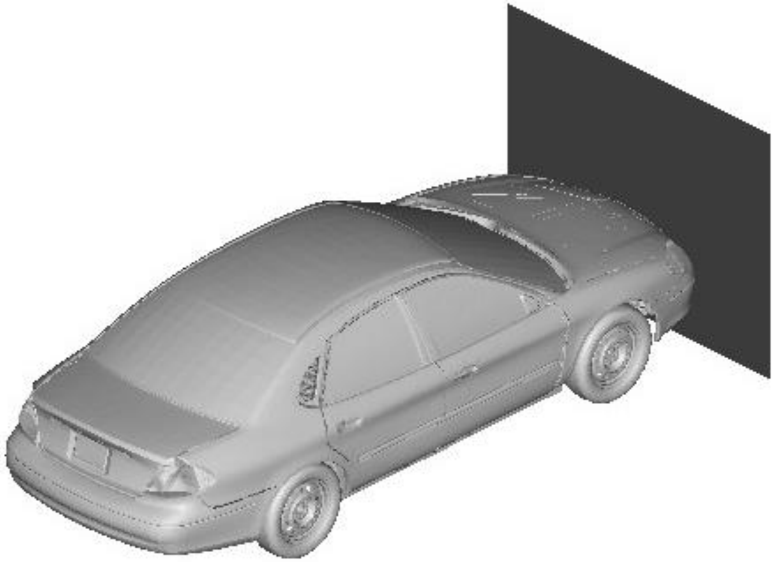
- A composite failure material model available in the material databases of a non-linear large deformation FE solver LS-DYNA (LSTC, Livermore, CA).
- This material model allows assignment of different material properties to the fibers in three orthogonal directions (a, b, and c).
- According to literature, two directions in fabric reinforced aramid laminates of shell had similar material behaviors.
- Therefore, a transversely isotropic material would be sufficient to define the material behavior.
- where one set of moduli and strengths were for the radial directions (a and b) while other ones for the tangential directions (c).



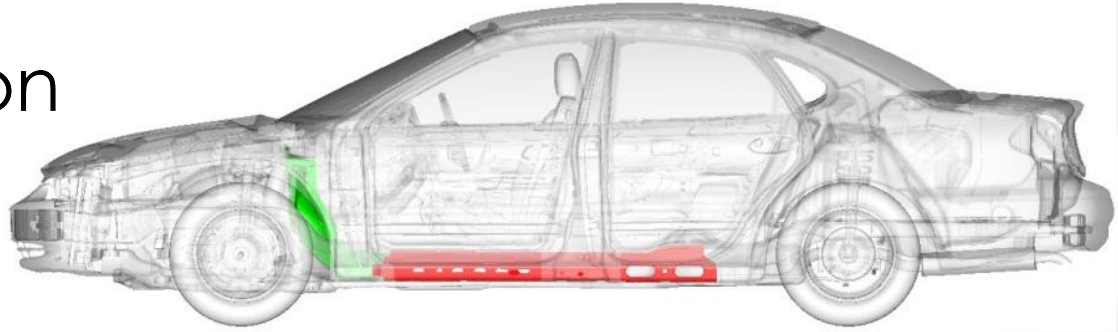
Reference: LSDYNA KEYWORD USERS MANUAL
http://lstc.com/pdf/ls-yna_971_manual_k.pdf

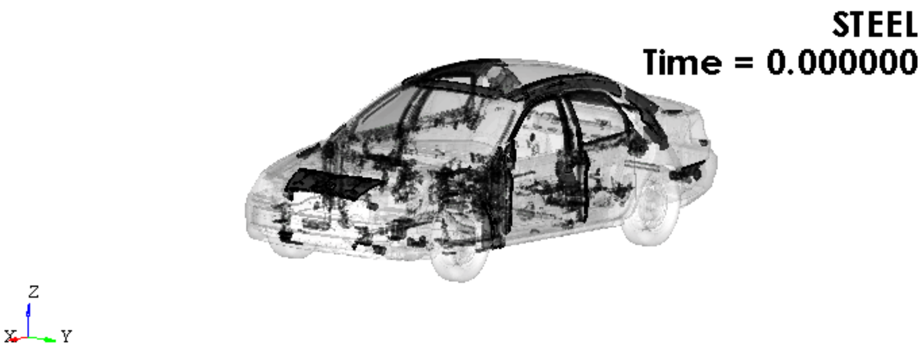
METHODOLGY - Crash Load Case and Vehicle Structure Responses

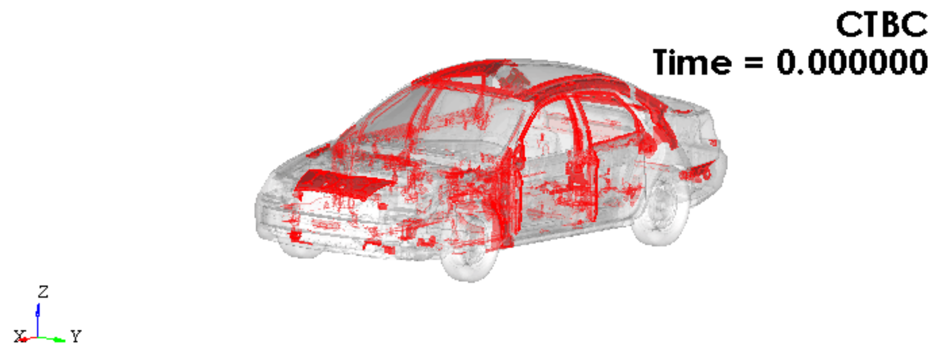
- FRONTAL (NCAP) IMPACT
  - 35 MPH
  - Rigid Wall

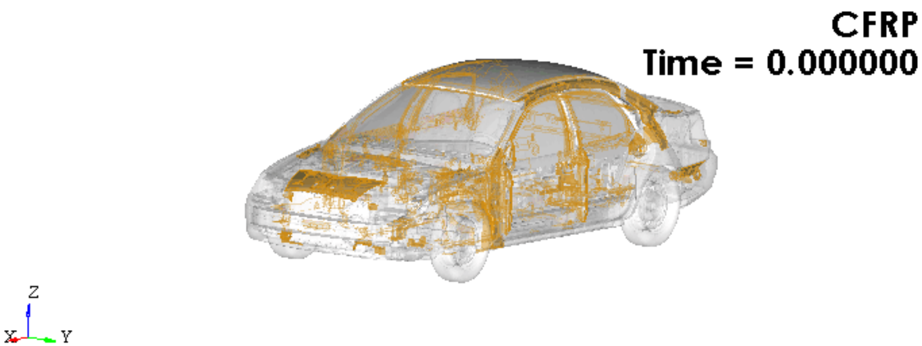


- FRONTAL (NCAP) IMPACT
  - Vehicle Acceleration at L Rocker Inner
  - Vehicle Crush
  - Energy Absorption




STEEL
Time = 0.000000
Z
X
Y


CTBC
Time = 0.000000
Z
X
Y


CFRP
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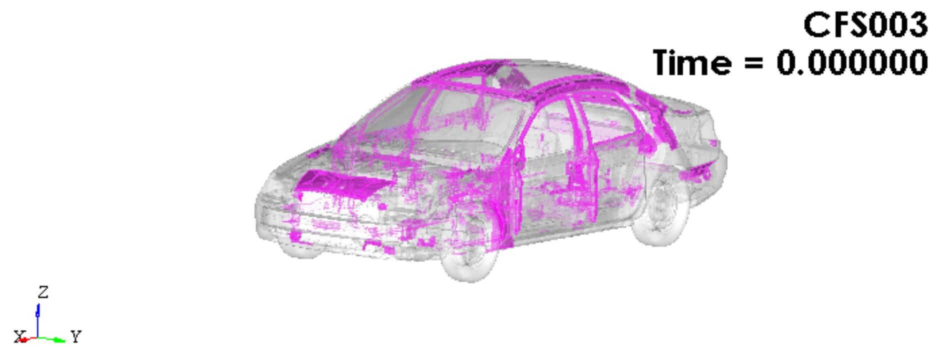
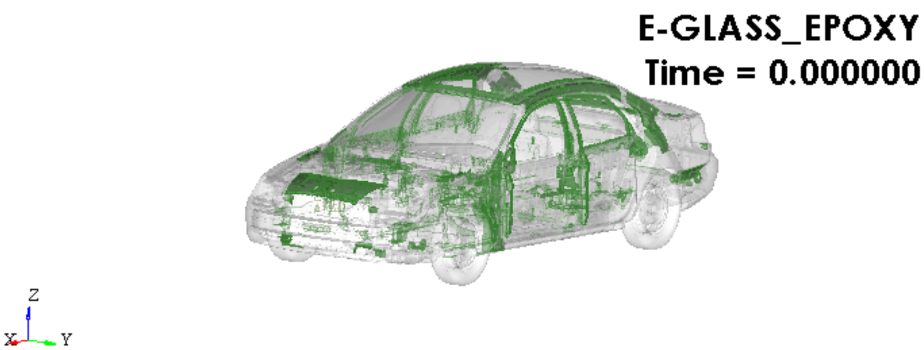
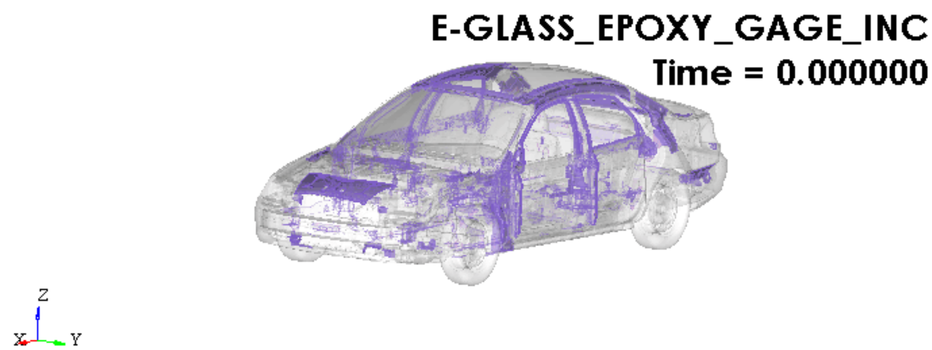
Z
X
Y


CFS003
Time = 0.000000
Z
X
Y


E-GLASS_EPOXY
Time = 0.000000
Z
X
Y


E-GLASS_EPOXY_GAGE_INC
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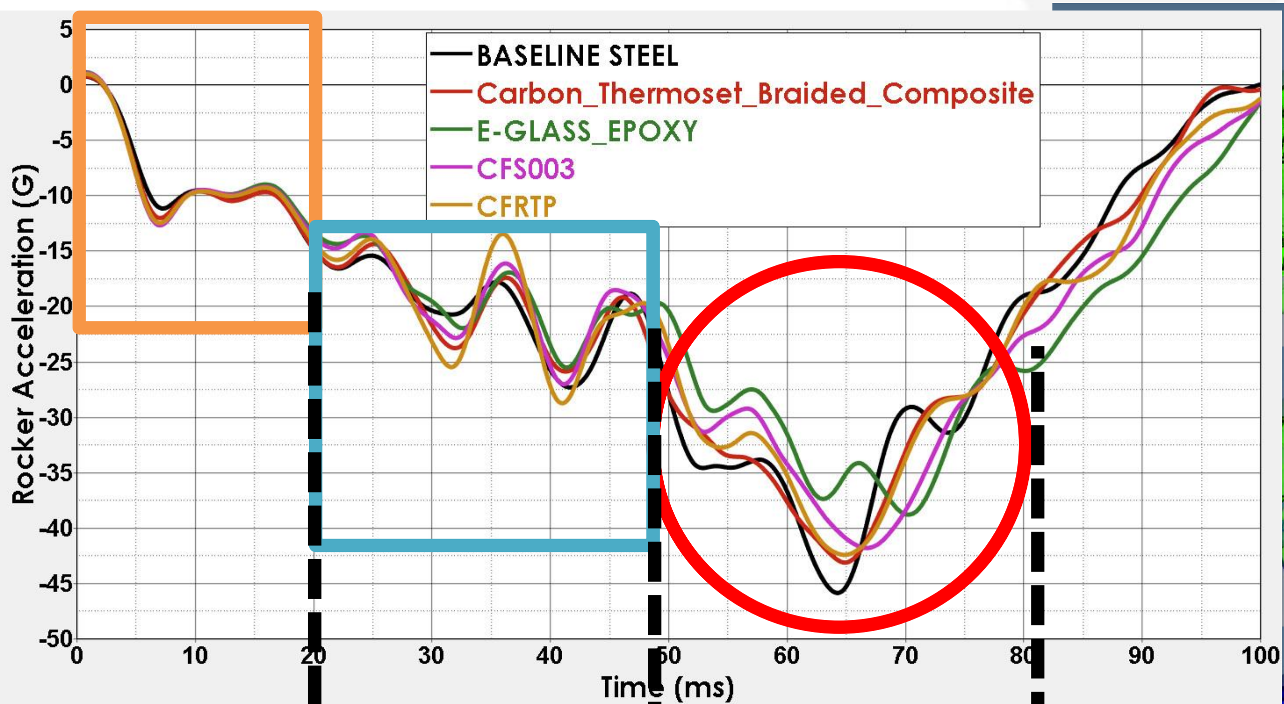
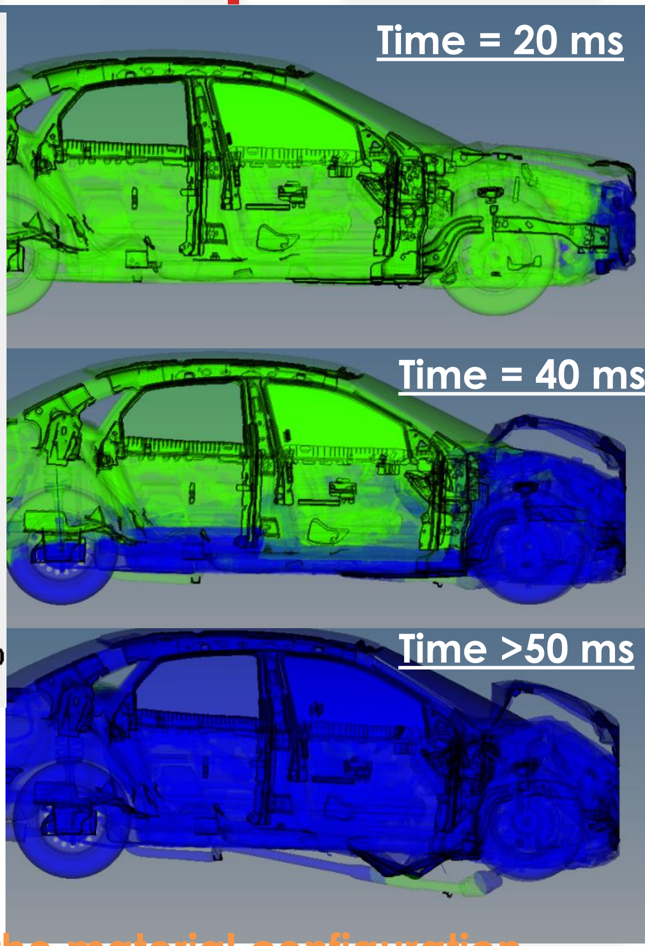
Z
X
Y

RESULTS – Rocker Acceleration Comparison





- Bumper collapse
- Engine Subframe deformation
- crash load transmitted to the rails

- Structure fwd. of the engine fully deformed
- Rail deformation
- Load transferred to the dash, cowl, floorplans and rockers

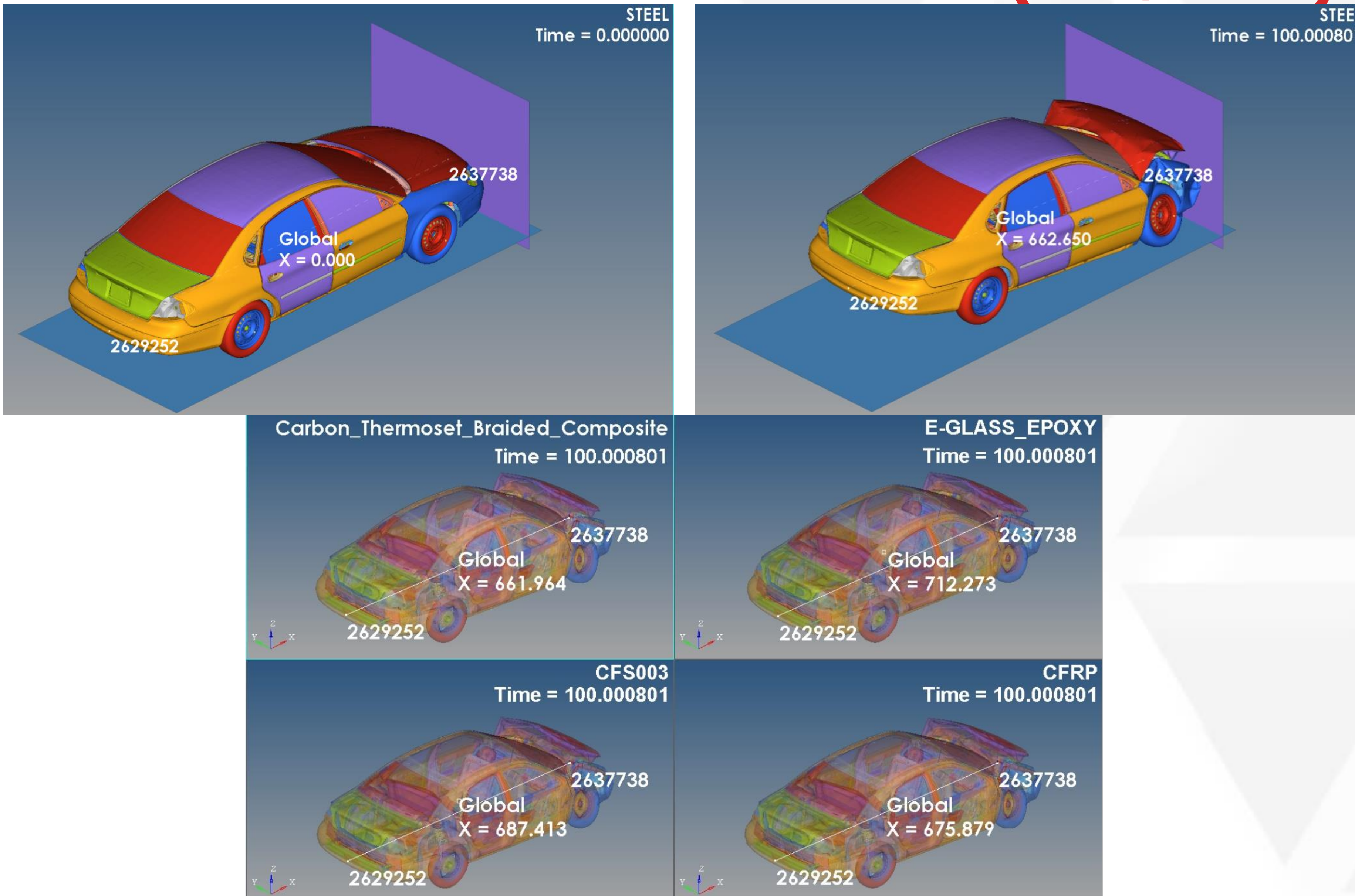
- Load transferred to the back-up structure
- Maximum deformation of the passenger compartment

❖ Until 20 ms the acceleration patterns are similar across all the material configuration

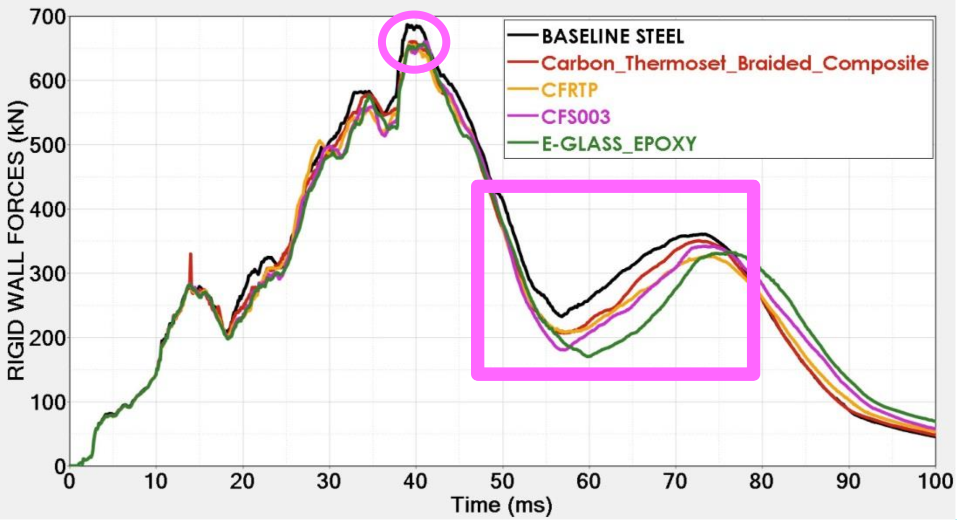
❖ Between 21 to 50 ms a variable pattern is observed between the material configurations which shows the vehicle structure engagement with the wall

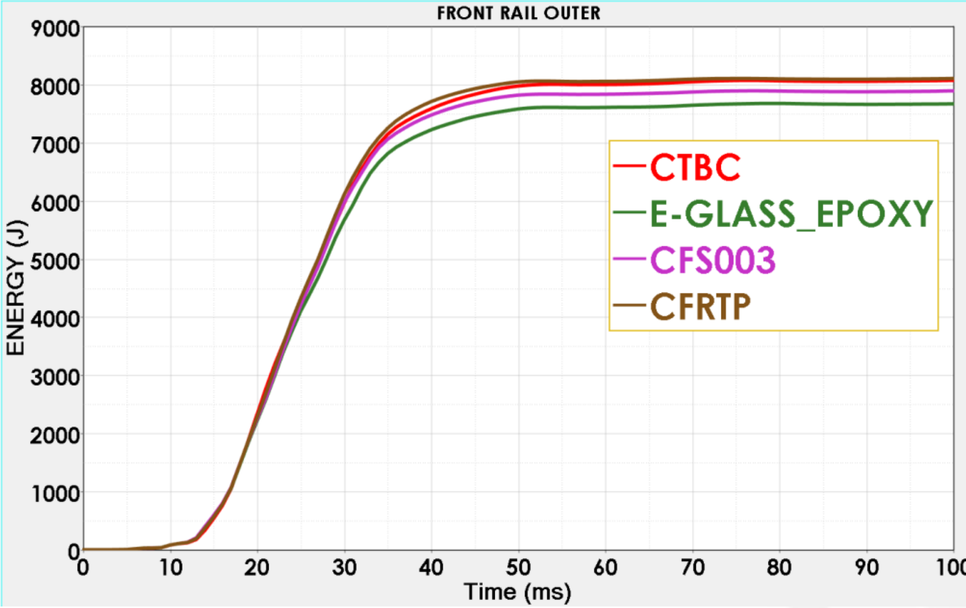
❖ After 50 ms and before the re-bounding phase the peak acceleration magnitudes show a reasonable comparison between CFRTP,CTBC. However comparing the baseline with the CFS003 and E-Glass a considerable amount of difference is observed (~10G)

RESULTS – Total Vehicle Crush (Pre/Post)



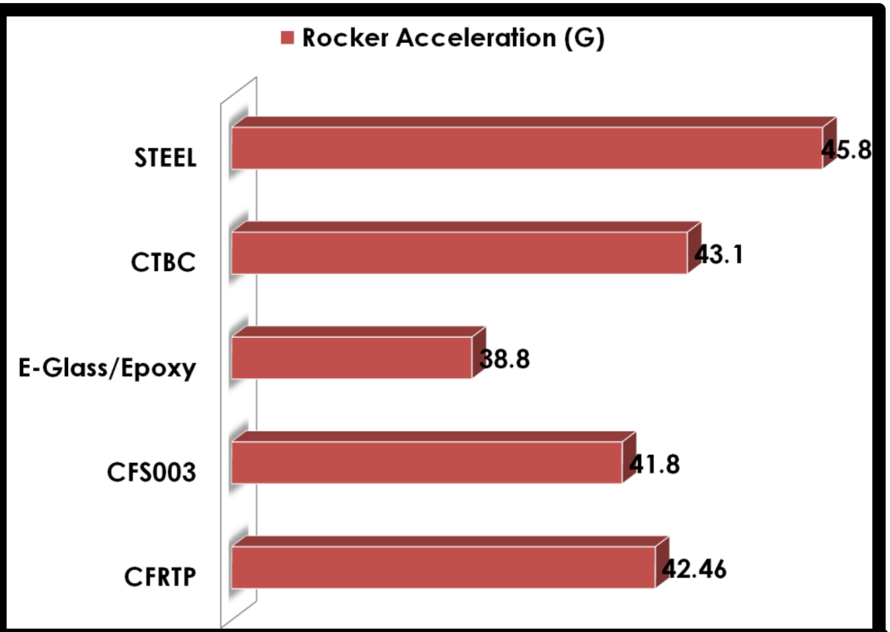
RESULTS – Wall Forces/Internal Energy



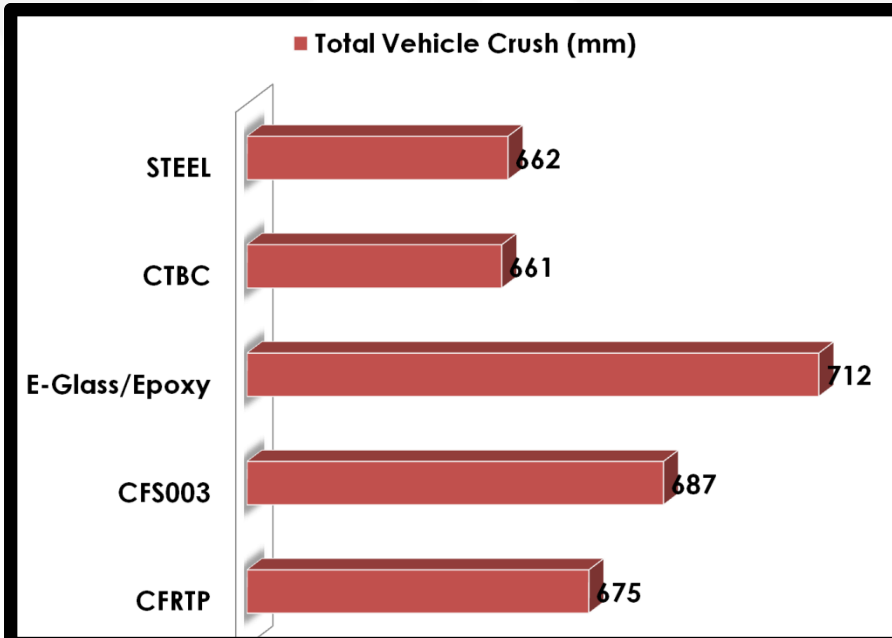


- ❑ **Baseline has five peaks with a certain force range**
- ❑ **All the four composite materials show reduction in the peak forces than the baseline – Vehicle mass reduced**
- ❑ **No excessive peak forces are observed before the re-bounding phase**
- ❑ **Not variable forces are observed until 50 ms**
- ❑ **Energy absorbed by E-GLASS is minimum**
- ❑ **CTBC/CFRTP performance is quite similar**

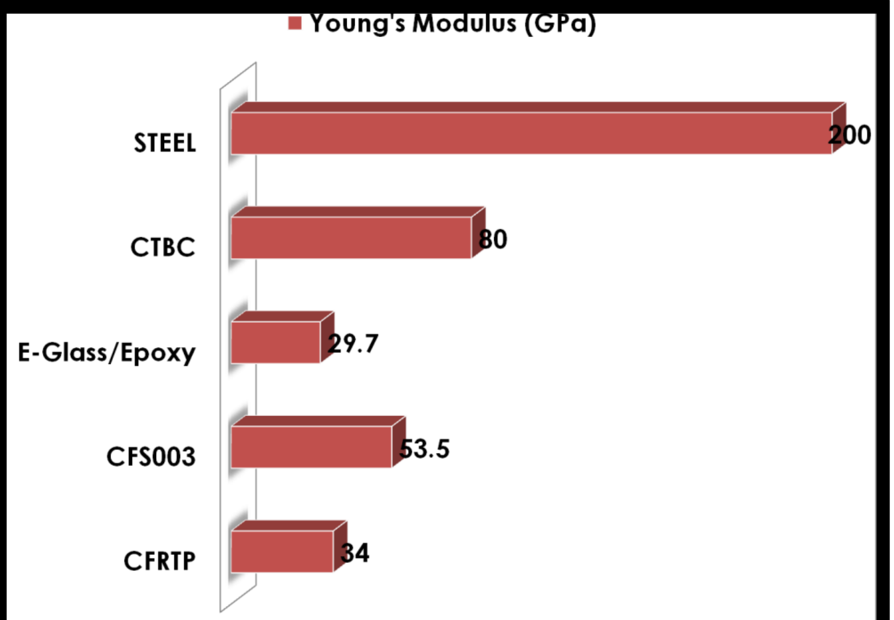
DISCUSSION



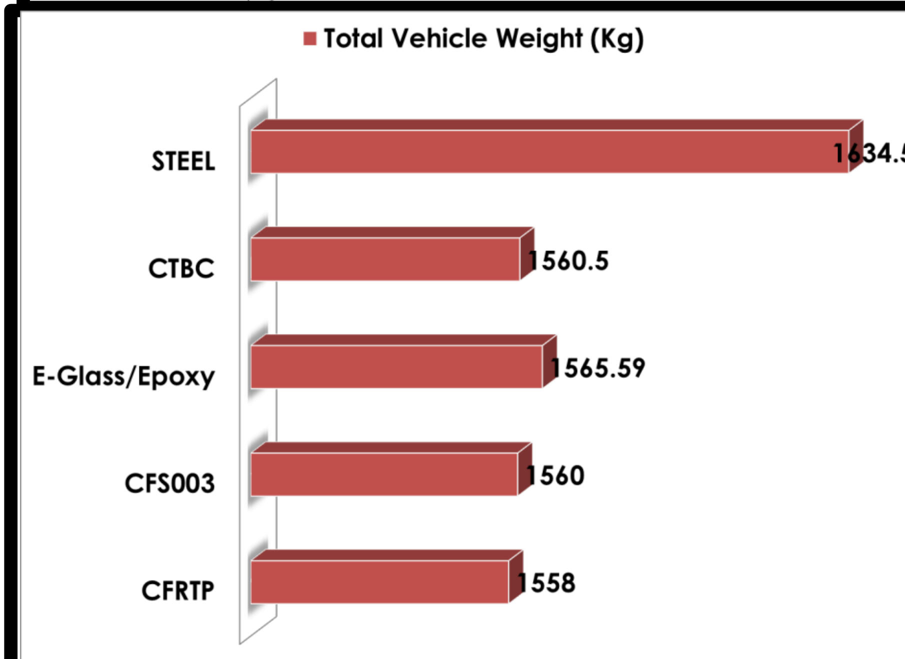
Rocker Acceleration (G)
STEEL
CTBC
E-Glass/Epoxy
CFS003
CFRTP
45.8
43.1
38.8
41.8
42.46



Total Vehicle Crush (mm)
STEEL
CTBC
E-Glass/Epoxy
CFS003
CFRTP
662
661
712
687
675



Young's Modulus (GPa)
STEEL
CTBC
E-Glass/Epoxy
CFS003
CFRTP
200
80
29.7
53.5
34



Total Vehicle Weight (Kg)
STEEL
CTBC
E-Glass/Epoxy
CFS003
CFRTP
1634.5
1560.5
1565.59
1560
1558

CONCLUSION

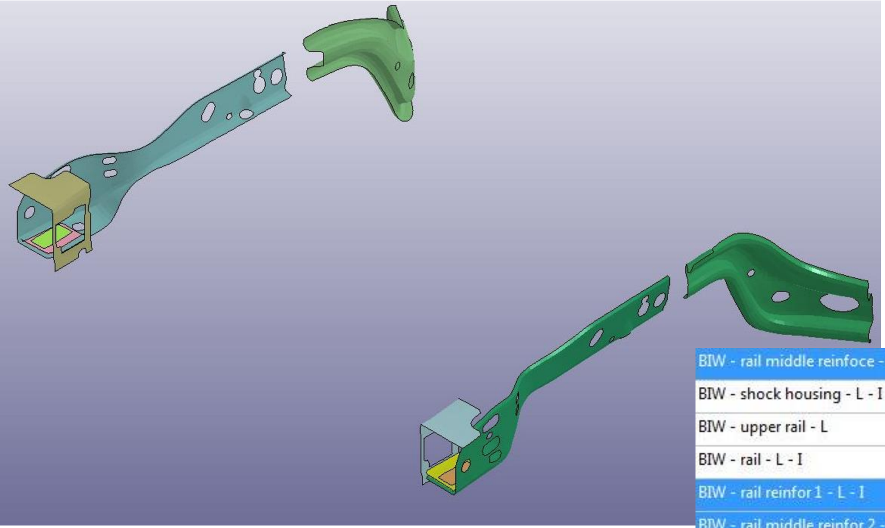
- A preliminary FE crash analysis
- Highlighting use of composite materials
- Based on different composite material grade
- Interesting vehicle responses and structure energy attenuation characteristics were found

LIMITATIONS and FUTURE WORK

- Only material substitution study
- Attachment (bonding/joining) methodology between composite/steel structures is not studied
- Validation Studies
- Further Scope identification and Optimization studies -
- Other Crash modes
- NVH
- Manufacturing/Packaging
- Robust vehicle consisting of Composite materials

Additional Study

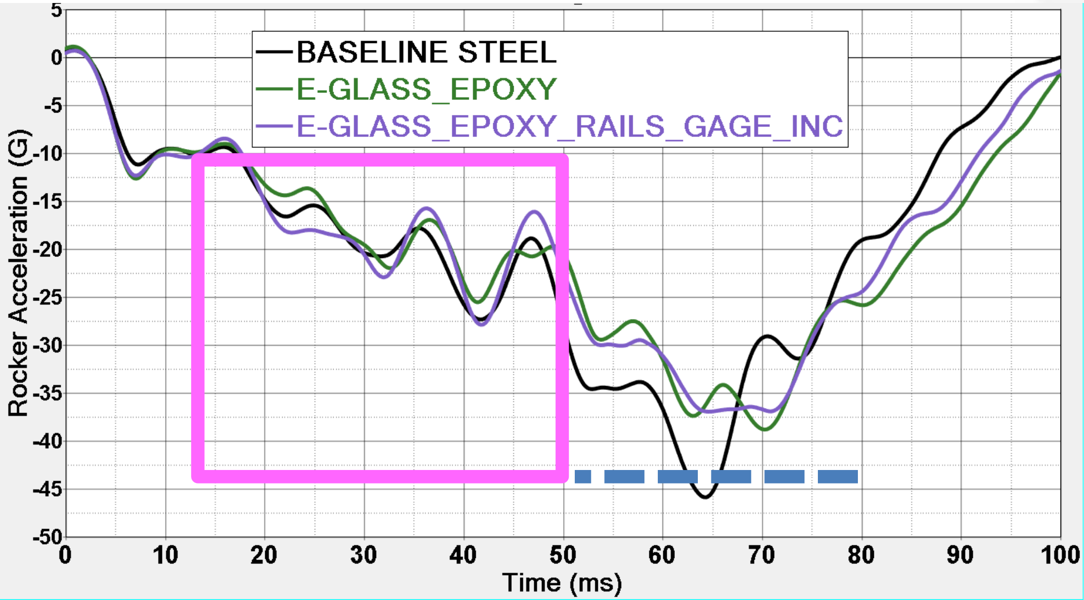
- E-Glass Case
- Up gage the Front Rail Reinforcements

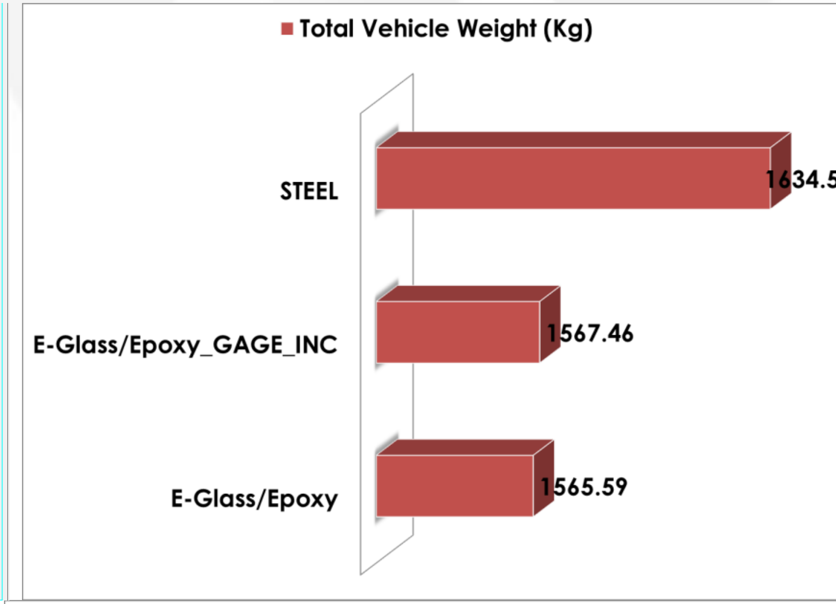


- Changed the gage to 5 mm
- Compare responses between original E-glass and the upgaged one

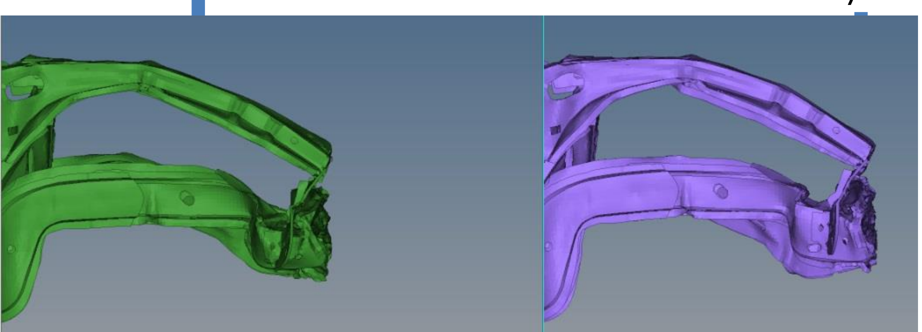
BIW - rail middle reinfoce - L	054/055 ENHANCED_COMPOSITE_DAMAGE	2.55
BIW - shock housing - L - I	024 PIECEWISE_LINEAR_PLASTICITY	2.48
BIW - upper rail - L	024 PIECEWISE_LINEAR_PLASTICITY	1.5
BIW - rail - L - I	024 PIECEWISE_LINEAR_PLASTICITY	1.9
BIW - rail reinfor 1 - L - I	054/055 ENHANCED_COMPOSITE_DAMAGE	2.07
BIW - rail middle reinfor 2 - L	054/055 ENHANCED_COMPOSITE_DAMAGE	2.4
BIW - rail reinforcement 2 - L-I	054/055 ENHANCED_COMPOSITE_DAMAGE	3.4
BIW - rail middle bracket 1 - L	054/055 ENHANCED_COMPOSITE_DAMAGE	2
BIW - upper wheel well - R - I	024 PIECEWISE_LINEAR_PLASTICITY	1.28
BIW - rail plate 1 - R	024 PIECEWISE_LINEAR_PLASTICITY	2.51
BIW - rail plate 2 - R	024 PIECEWISE_LINEAR_PLASTICITY	1.52
BIW - rail - R - O	024 PIECEWISE_LINEAR_PLASTICITY	1.91
BIW - rail middle reinfoce - R	054/055 ENHANCED_COMPOSITE_DAMAGE	2.55
BIW - upper rail - R	024 PIECEWISE_LINEAR_PLASTICITY	1.5
BIW - rail - R - I	024 PIECEWISE_LINEAR_PLASTICITY	1.9
BIW - rail reinfor 1 - R - I	054/055 ENHANCED_COMPOSITE_DAMAGE	2.07
BIW - rail middle reinfor R - L	054/055 ENHANCED_COMPOSITE_DAMAGE	2.4
BIW - rail reinforcement 2 - R-I	054/055 ENHANCED_COMPOSITE_DAMAGE	3.4
BIW - rail middle bracket 1 - R	054/055 ENHANCED_COMPOSITE_DAMAGE	2

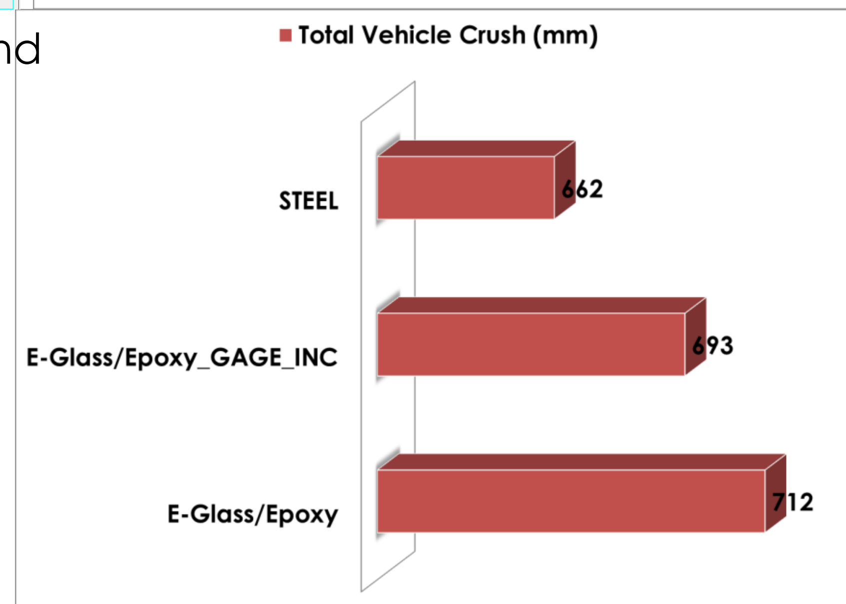
Additional Study





- The structure shows more stiffness early and around 40 ms similar performance is observed as that of steel
- Increase of 2kg weight with the upgage
- Overall the vehicle crush is reduced by ~ 20 mm





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- (National Research Council Committee on Fuel Economy of Light-Duty Vehicles, Phase 2 Exploring Options for Lighter-Weight Vehicles February 13, 2012 – Ann Arbor, MI)
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- Mamalis A.G., Manolakos D.E., Ioannidis M.B., Kostazos P.K. et al., "Static and dynamic axial collapse of fibreglass composite thin-walled tubes: finite element modelling of the crush zone", International Journal of Crashworthiness, 8(3):247-254, 2003.
- LSDYNA (LIVERMORE SOFTWARE, CA)
- LS-PREPOST

Thank You!