Project ID: Mat195

2021 DOE Vehicle Technologies Office Annual Merit Review Presentation

Industrialization of Carbon Fiber Composite Wheels for Automobiles and Trucks

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With Michael Hayes, VP Head of Engineering
ESE Carbon

June 22, 2021
Project ID#mat195

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Overview

Timeline

- May 2020 – May 2022
- Percent Complete:
  - 35% Year 1
  - 75% Year 2

Budget

- Total Funding: $1,000k
  - DOE Share = $500k
  - ESE Share = $500k
- DOE Funding:
  - FY2020 = $125k
  - FY2021 = $250k
  - FY2022 = $125k

Collaboration

- Program Lead Lab
  - Oak Ridge National Lab (ORNL)
- ESE Carbon

Barriers and Technical Targets

- High volume manufacturing
  - Only US carbon composite wheel manufacturer
  - Ability to place and orient fibers as desired
  - OOA (Out-Of-Autoclave)
- Predictive modeling
- Lightweighting
  - Mass Optimization
    - 40% weight savings compared to aluminum wheels
- Pass SAE Testing Requirements for Automotive Wheels

*Light-Duty Vehicles Technical Requirements and Gaps for Lightweight and Propulsion Materials Workshop Report, February 2013

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Relevance

- **Technical Objective:**
  - The primary objective of this project is to couple ESE Carbon's existing passenger car wheel design and manufacturing process with ORNL's expertise in materials characterization, composites processing and computational methods to accelerate the current development phase and the subsequent commercialization phase. Note that both Phases are not sequential but contain overlaps.
- **Achievements:**
  - Moved process out-of-autoclave
  - Testing in month 3
    - Initial testing round completed on first test plaques
      - Processing concerns
    - Second round test bed submitted and recently completed
    - Initiating discussion to perform fatigue tests
  - Design and optimization advanced considerably by ESE Carbon
    - Considered ORNL task for Year 2

Timeline

Phase No.	Task No.	Task Name	Duration (Months) (Start)	(Finish)	Responsible Party
1	1	Baseline Material Characterization	1	4	
	1.a	Fabrication of test panels	1	3	ESE
	1.b	Testing panels	2	4	ORNL
	2	TFP Parametric Study	3	5	Both
	3	Environmental Effects Study	6	7	Both
	4	Damage Tolerance Study	8	9	
2	5	Design Analysis	10	15	Both
	6	Virtual Design Optimization	11	16	Both
	7	Revised Design Analysis	12	17	Both
	8	Fabrication of Optimized Design	15	22	ESE
	9	Testing New Wheels	17	24	ESE

Milestones – Phase/Year 1

Task 1: Baseline Materials Characterization

- Discussion/Description of Work Scope and Approach
  - ESE Carbon manufacturing flat panels for testing
- National Lab(s) Deliverables/Milestone 1
  - ORNL data reports from mechanical testing for static and fatigue properties

Task 2: TFP (Tailored Fiber Placement) Parametric Study

- Discussion/Description of Work Scope and Approach
  - Understand the tradeoffs in performance vs. efficiency.
- National Lab(s) Deliverables/Milestone 2
  - ORNL data reports from mechanical testing for static and fatigue properties
  - ORNL will provide on-site consulting to help optimize the TFP

Milestones – Phase/Year 1

Task 3: Environmental Effects Study

- Discussion/Description of Work Scope and Approach
  - CTD (cold temperature, dry)
  - RTD (room temperature, dry)
  - ETW (elevated temperature, wet)
  - ETD (elevated temperature, dry)
- National Lab(s) Deliverables/Milestone 3
  - Test materials after exposure to provide properties as per Task 1.

Task 4: Damage Tolerance Study

- Discussion/Description of Work Scope and Approach
  - The primary performance and safety concerns for composite wheels are stiffness, fatigue life, thermal stability, and damage tolerance. The above tasks, in conjunction with the SAE wheel tests, will address all but the issue of damage tolerance. ESE Carbon will manufacture flat panels with intentional variabilities that are representative of those found in our prototype wheels.
- National Lab(s) Deliverables/Milestone 4
  - A- and B-allowables for strength parameters
  - S-N curves with confidence bands

Milestones – Phase 2 (original proposal)

Task 5: Design Analysis

- Discussion/Description of Work Scope and Approach
  - Rerun simulations of cornering fatigue, radial fatigue, curb impact, and pothole impact to reassess E2.1 design with new test data for revised TFP plies and process parameters.
- National Lab(s) Deliverables/Milestone 5
  - Provide consulting and computational time at ORNL.

Task 6: Virtual Design Optimization

- Discussion/Description of Work Scope and Approach
  - Optimize design with objectives (mass, strain, and cost minimization), design variables (ply thickness, layup, materials) and design constraints (safety factors, strain allowables, stiffness)
- National Lab(s) Deliverables/Milestone 6
  - Determine best software for Design Optimization and write procedures.

Task 7: Revised Design Analysis

- Discussion/Description of Work Scope and Approach
  - Reanalyze new design based on all results accumulated from this project to ensure it passes all necessary testing (including SAE).
- National Lab(s) Deliverables/Milestone 7
  - Assist in analysis and provide report.

Approach

- Testing at ORNL
  - Determine modelling parameters via RT testing
    - 3 months
  - Run environmental testing
    - 4 months
  - Develop S-N curves via fatigue testing
    - 5 months
- AM Tooling (Proposed for Year 2)
  - Develop AM tooling to facilitate prototyping and process optimization
    - Metal definitely
    - Possible AM polymeric inserts
  - Discuss production tooling potential

Technical Accomplishments and Progress

- Fiber test and plaque specimen tensiles and flexures completed

Fiber Properties	
Tensile Strength, ksi	Tensile Modulus, ksi
808	37,000

Plaque Properties – Unidirectional Tensiles			
Tensile Strength, ksi	Tensile Modulus, ksi	Volume Fraction (based on strength)	Volume Fraction (based on modulus)
260	21,000	32%	57%

- Stitching from the TFP may be reducing the tensile strength

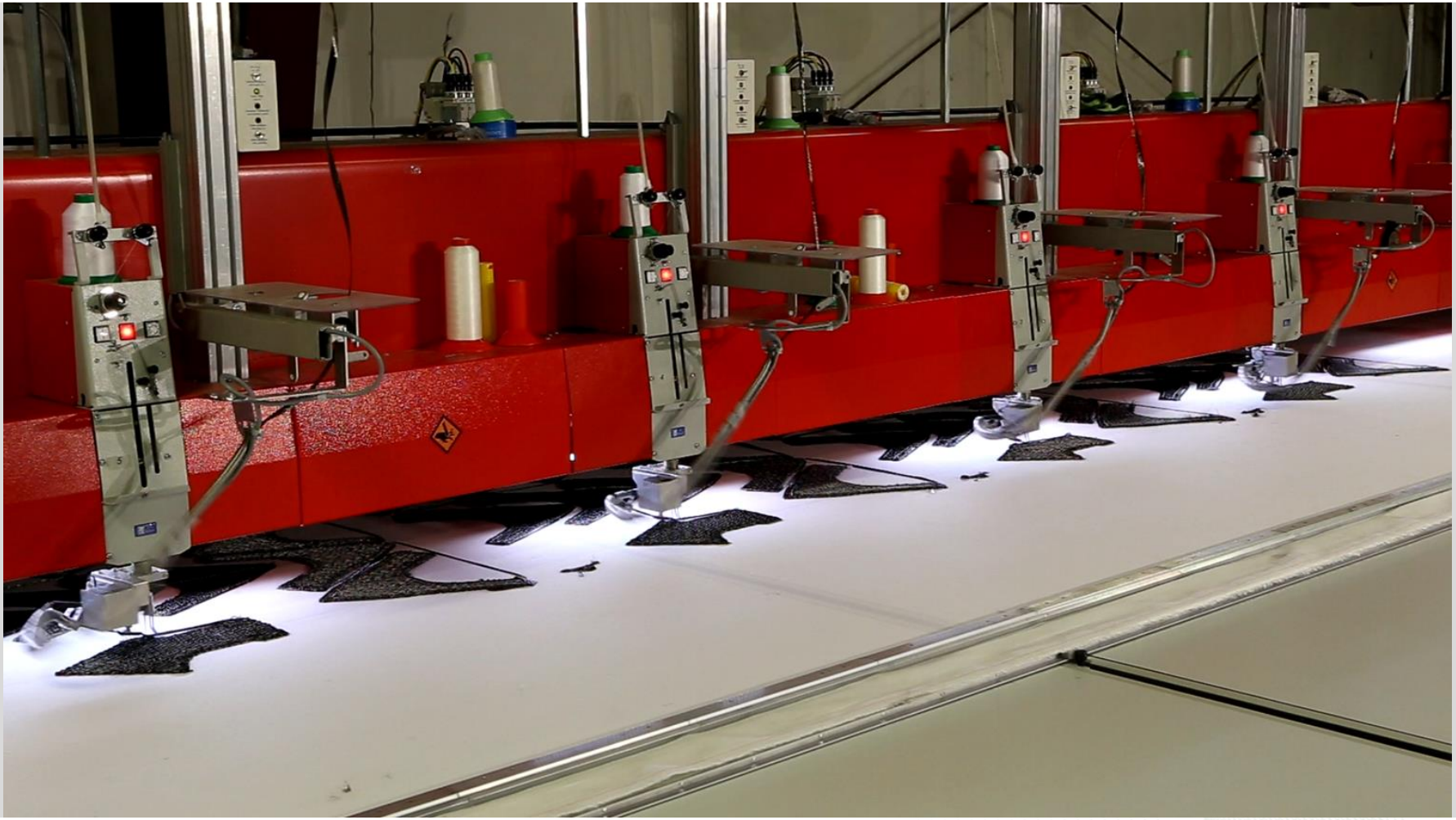
Technical Accomplishments and Progress

- Flexure tests completed

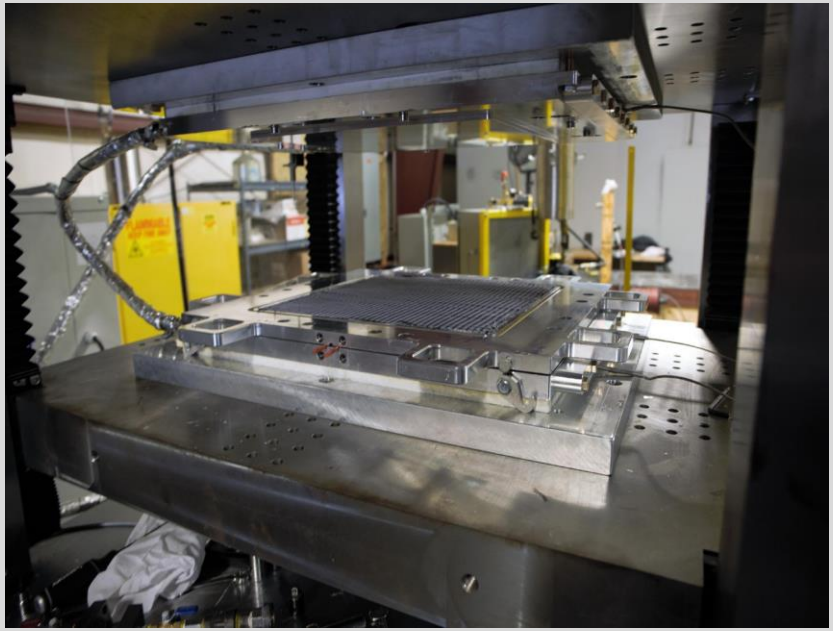
Flex Strength, ksi	Shear Strength, ksi	Flexural Modulus, ksi
221	10	19,000

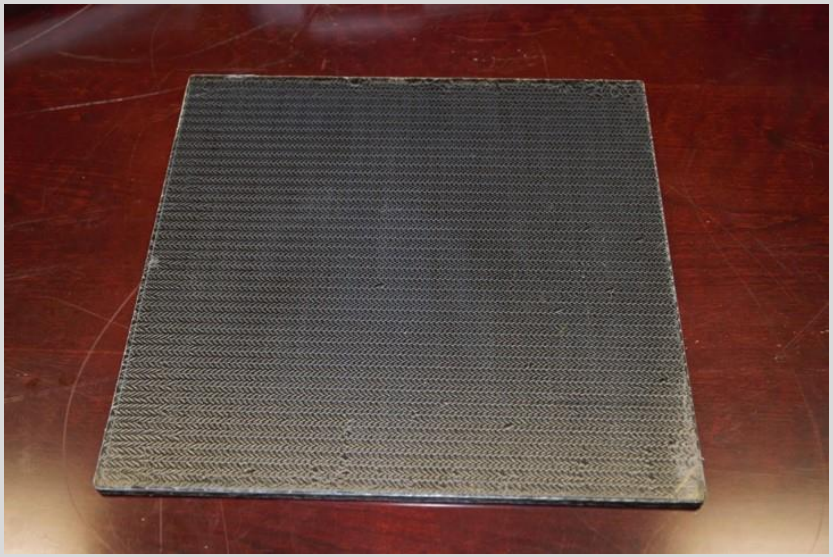
- Design and Optimization of wheel completed ahead of schedule

Tailored Fiber Placement (TFP) at ESE Carbon



Flat Panel Production at ESE Carbon





Collaborator - ESE Carbon

- Improved Braking, Handling and Ride
- Improved Fuel Efficiency / Extended Range
- Added value for premium carbon fiber options
- Developed for SUVs, Performance and Luxury Sedans
- Optional finishes – Colors, embroidered patterns under development
- Cost competitive with premium forged wheels

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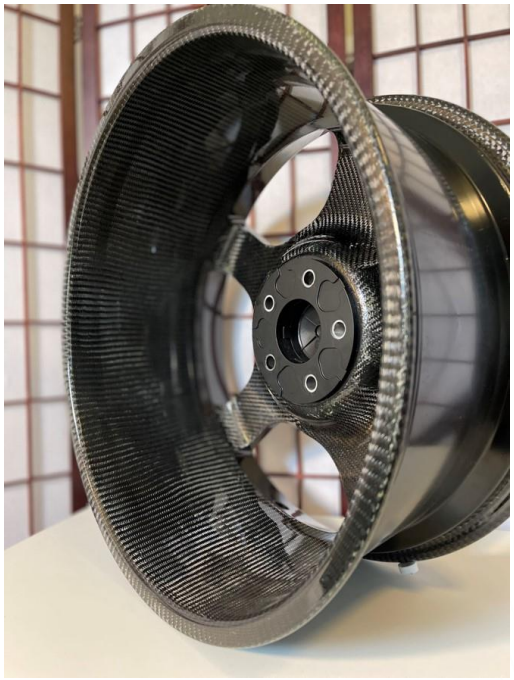
Collaborator - ESE Carbon



Collaborator -ESE Wheel Technology

- Demonstrated ~40% weight reduction versus aluminum wheels
- Continuous carbon fiber composite
- Tailored Fiber Placement
- One infusion with one cure*
- High Temperature Resin System (200C Tg)

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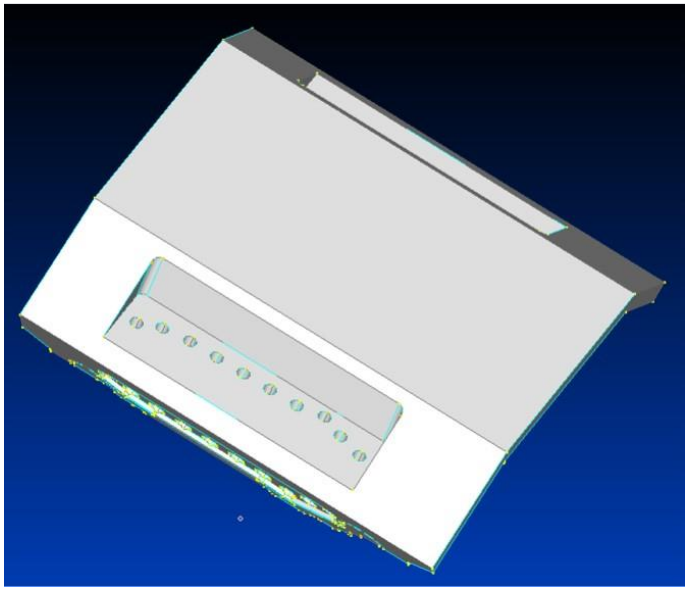
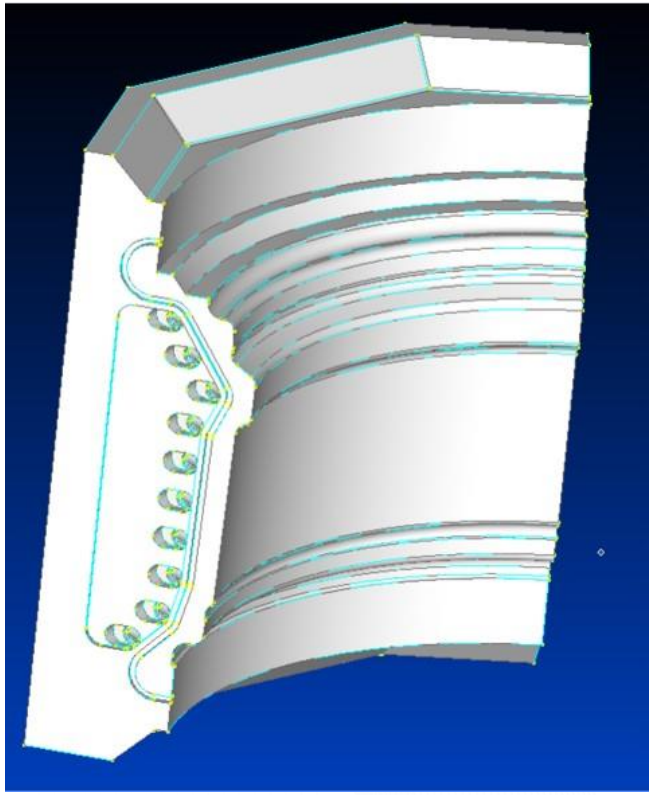
Remaining Challenges and Barriers

- ORNL testing is 6 months behind schedule due to shutdown, reduced staff in testing lab, and personal leave for PI due to surgery.
  - May perform part of the testing at University of Tennessee Knoxville to accelerate fatigue testing
- Decrease in strength of composite due to stitching may affect wheel testing
- ESE Carbon needs assistance in production tooling
  - Proposing ORNL assist with Additive Manufactured tooling for Phase/Year 2

Proposed Future Research -Advantages of AM Tooling

- Allow fluid channels
- Eliminate CNC roughing step
- Eliminate hole drilling step
- Reduce parts by 50%
  - Time savings of 50%





*Any proposed future work is subject to change based on funding levels

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Summary

- Completed year 1 of 2-year program with ESE Carbon
- In material testing phase which will need to continue into year 2 for ~6 months
- Year 2 virtual modelling tasks for ORNL completed and would like to develop AM tooling instead

Technical Back-Up Slides

- Performance specifications
- Wheel development process
- Virtual prototyping
- Stress analysis
- Cornering fatigue
- Curb impact
- Radial (pothole) impact
- Tool development

Performance Specifications

- Initially, in the absence of an OEM contract, ESE Carbon designed to SAE J2530 “Aftermarket Wheels – Passenger Cars and Light Truck - Performance Requirements and Test Procedures”
  - Then increased a few requirements to be more conservative (essentially adopted McLaren’s OEM specification)
  - Also adopted the European AK-LH 08 Radial (Pothole) Impact Test
- SAE J3204 “Aftermarket Composite Wheels - Passenger Car Test Procedures and Performance Requirements” was published in 2020 with new requirements, incl. increasing fatigue test loads to accommodate the “strength reduction factor” (SRF)
  - SRF is addressed by Task 3
- ESE Carbon now has 3 development contracts with 3 different customers

Wheel Development Process

Concept development (style, # of spokes, AM vs OEM)

Define performance specifications

"Virtual prototyping" via CAE and refine design

Design & manufacture tooling

Design ply schedule

Manufacture TFP plies

Design & manufacture preform tools

Initial layup trials

Design & 3D print layup tools

Refine layup and infusion/cure

Testing: laboratory, road, & proving grounds

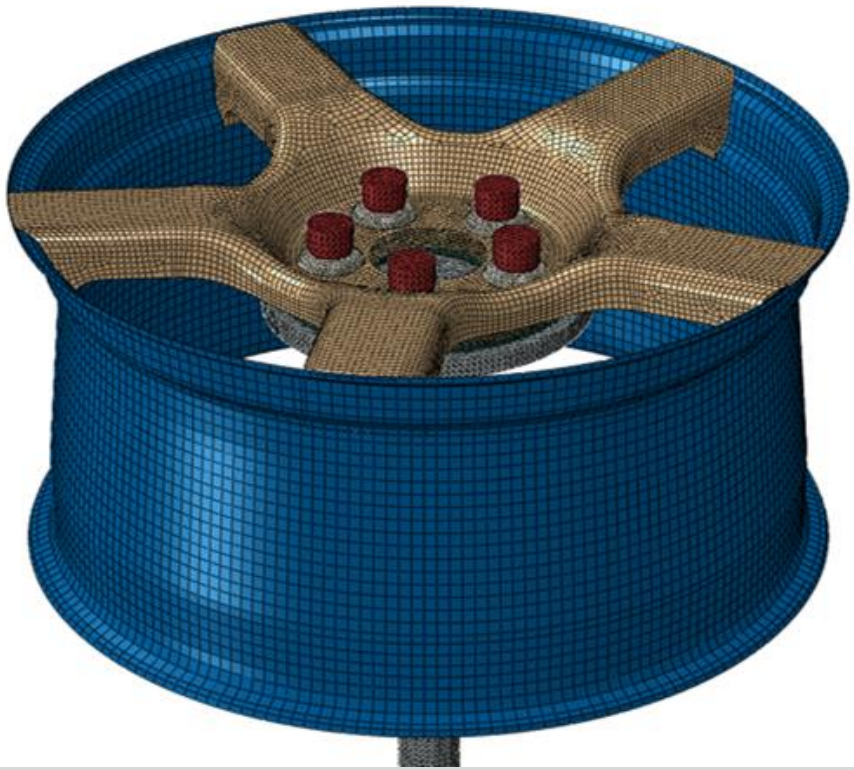
Virtual Prototyping

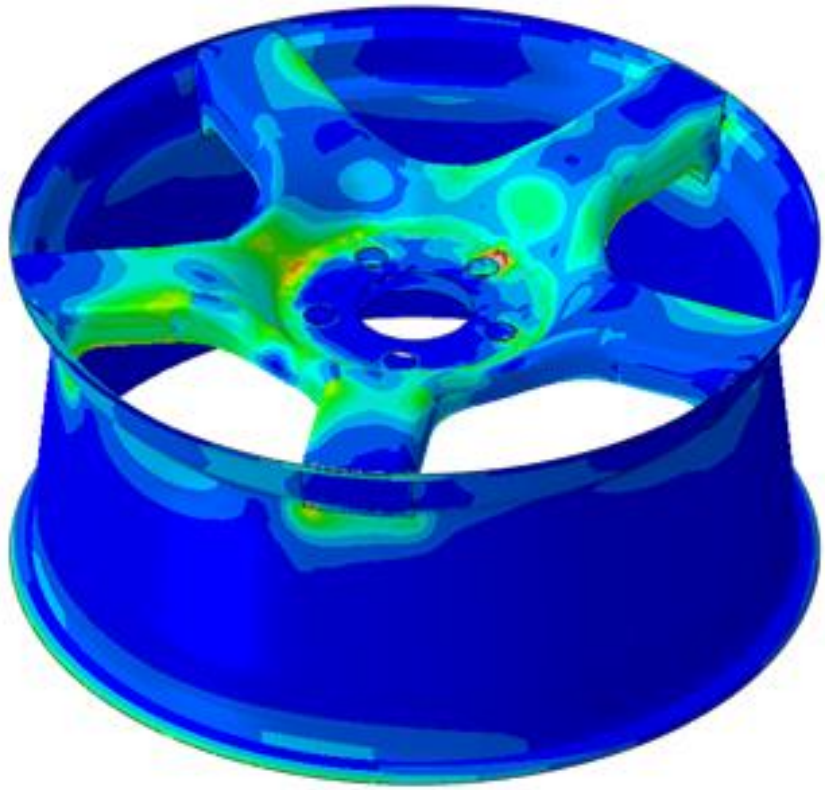
- Our Product Development team utilizes Finite Element Analysis (FEA) to develop wheel designs.
- Ability to analyze the four primary wheel tests of SAE/OEMs:
  - Cornering fatigue
  - Radial fatigue
  - Lateral, 13-degree (curb) impact
  - Radial (pothole) impact

Stress Analysis

- Performed using Finite Element Analysis (FEA) in Abaqus
- We are currently transitioning to 3DExperience (CATIA + Abaqus):
  - CATIA-to-Abaqus link provides more rapid virtual prototyping tool
  - The manufacturing aids within 3DX allow for easier translation to our TFP design software
- Static and dynamic models currently built using composite laminated shell elements using handbook material data (AGATE) for inputs
- Damage mechanics can be utilized to predict fracture during impact events

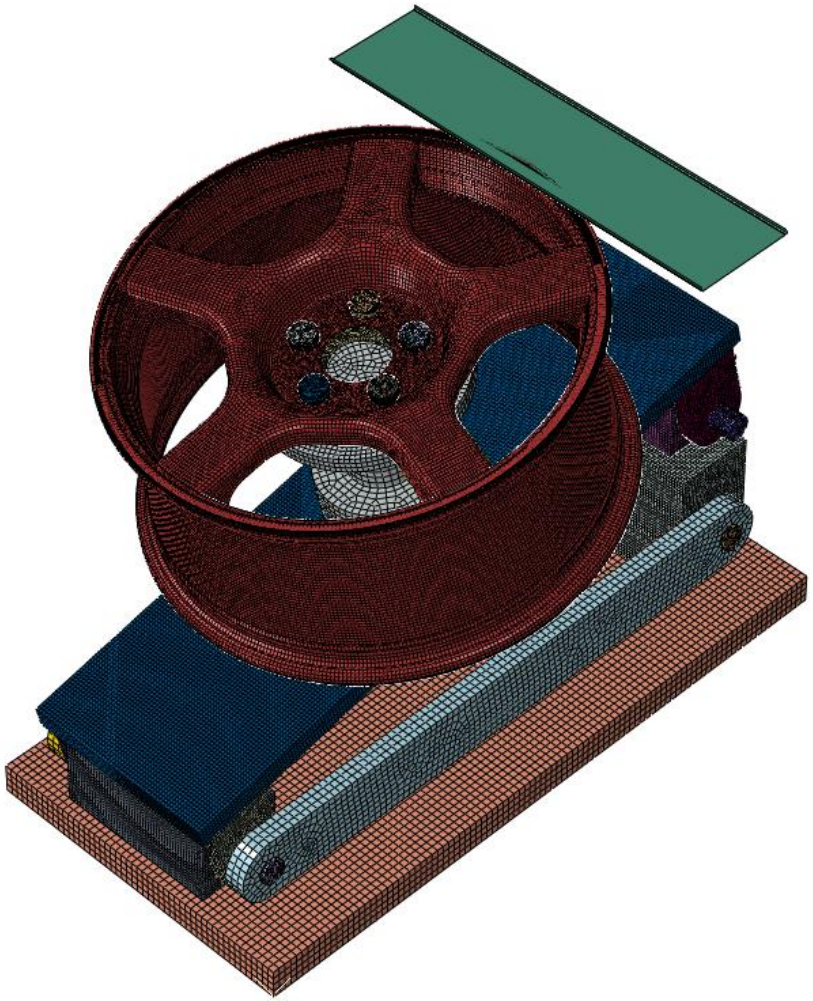
Cornering Fatigue (Static Analysis)



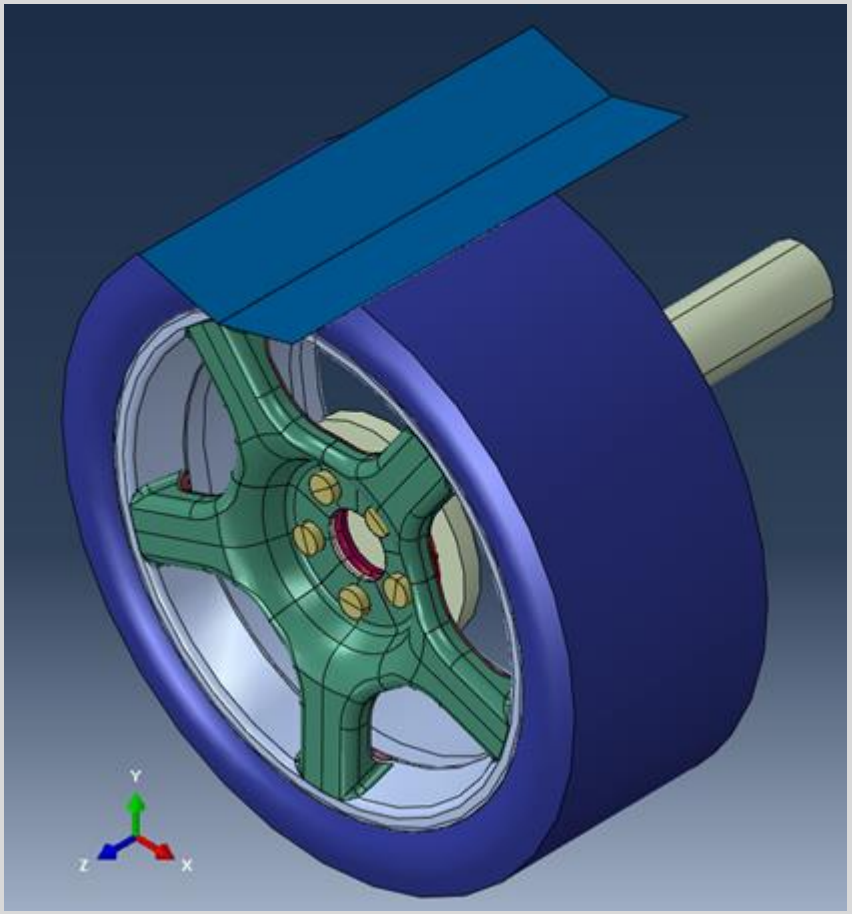


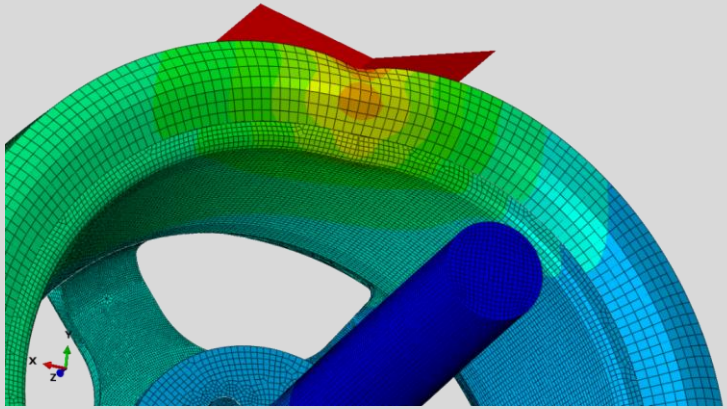
Curb Impact

- Full Dynamic analysis run using the Explicit solver in Abaqus
- SAE J175 support fixture modeled in full detail
- For simplicity and to be conservative, we omit the tire and allow direct impact to the outboard flange.



Radial (Pothole) Impact





Current challenges include:

- Tire model
- Establishing criterion for target energies and acceptable damage.

Tool Development

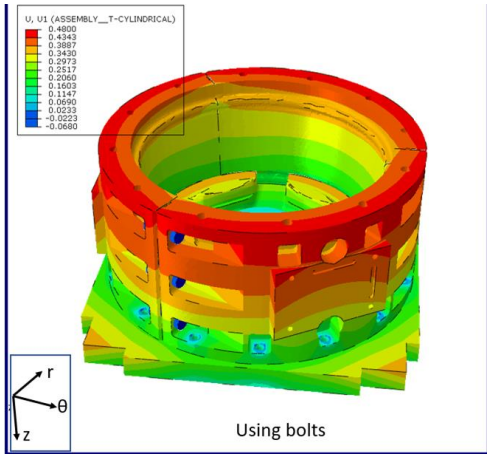
We manufacture and build our tools in-house.

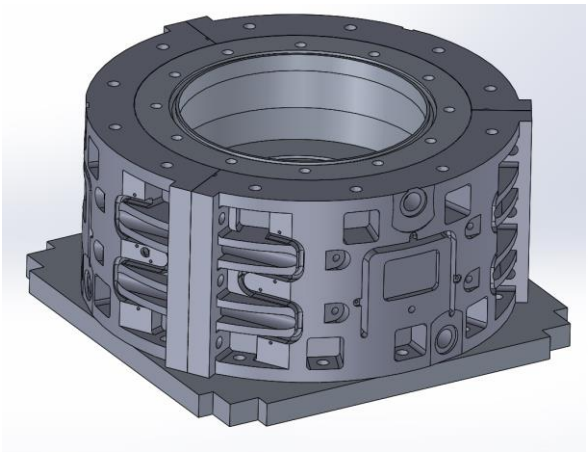
We have consulted with two major tool makers.

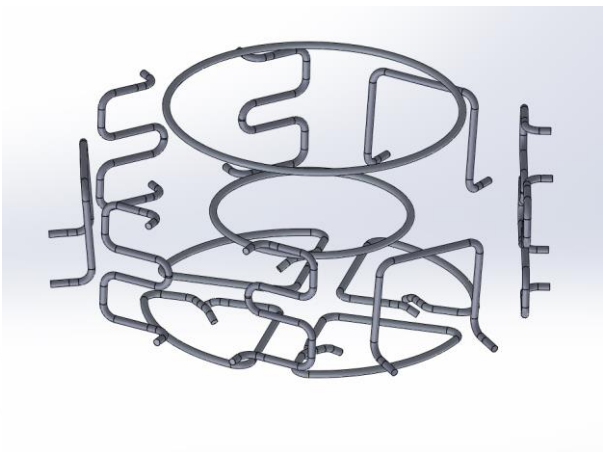
Structural analysis is performed in-house.

Limited thermal analysis is also performed in-house.

We are also working with a vendor to perform thermal-fluid analysis







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