COMPOSITES

SPRING / SUMMER 2020

Composites Connection™

Official Newsletter of the SPE Composites Division

Reaching Over 1,000 Composites Professionals
In All Industries

Sponsored by:

SPE COMPOSITES

Sponsor Links:

ABARIS TRAINING

ADDCOMP Polymer Additive Solutions

BYK Additives & Instruments

AsahiKASEI
ASAHI KASEI PLASTICS NORTH AMERICA

BASF We create chemistry

carbon conversions closing the loop - today and tomorrow

DSCCONSUMABLES incorporated

DSM BRIGHT SCIENCE. BRIGHTER LIVING

MITSUBISHI CHEMICAL

Board of Directors

Ian Swentek, Ph.D.

SPE Composites
Director, Chair &
Auditing Committee Chair
Applications
Development Engineer
Hexion
London, ON, Canada
Ian.Swentek@hexion.com

Ray G. Boeman, Ph.D.

SPE Composites
Director, &
Memebership Chair
Director, Vehicle
Technology Area
Michigan State University
Detroit, MI

Antoine Rios, Ph.D.

SPE Composites
Director & Finance Chair
The Madison Group
Madison, WI
Antoine@madisongroup.
com

John P. Busel, F. ACI

SPE Composites Director,
Intersociety Chair
& Chair-Elect
V.P. Composites
Growth Initiative
American Composites
Manufacturers Association
Arlington, VA
busel@armanet.org

Tim Johnson

SPE Composites
Director & Treasurer
Owner, President at
TJohnson LLC
Dayton, OH
TJohnsonLLC@gmail.com

Dale Brosius

SPE Composites Director
& Councilor
Chief Commercialization
Officer, IACMI
Knoxville, TN
dbrosius@iacmi.org

Uday Vaidya, Ph.D.

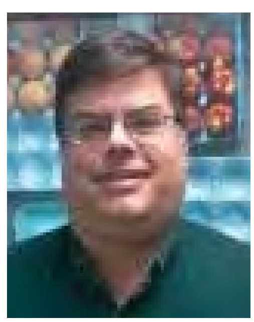
SPE Composites
Director & Education Chair
Professor in Mechanical,
Aerospace & Biomedical
Engineering
Chief Technology Officer
(CTO), IACMI
University of Tennessee
Knoxville, TN
uvaidya@utk.edu

Hicham Ghossein, Ph.D.

SPE Composites Director
& Award Chair
President & Founder
of Endeavor
Hicham.ghossein@
gmail.com

Pritam Das

SPE Composites Director
& Newsletter Chair
Senior Technical Manager
Toray Composites
Materials America (CMA)
Tacoma, WA
pdas@toraytca.com



Dale Grove, Ph.D.

SPE Composites Director
& Award Chair
US Silica
Senior Technology
Product Development
Berkeley Springs, WV
grove.dale@hotmail.com

Andrew Rich

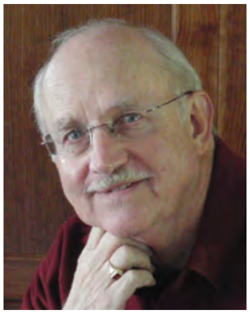
SPE Composites
Director &
Communications Chair
Consultant
elvamk5@comcast.net

Shankar Srinivasan, Ph.D.

SPE Composites Director
& ANTEC Program Chair
Iowa State University
Economic Development
Core Facility
Ames, IA
srigshan@iastate.edu


BASF
We create chemistry
IDEAL
Engineering plastics and polyurethanes by BASF for the automotive industry
We turn your ideas into ideal solutions: BASF plastics for the automotive industry.
Shorter development times, enhanced performance, greater freedom in design. You do not want to settle for anything less than the perfect car. Neither do we. That is why we will stay by your side at every stage of your project - with our comprehensive expertise in plastics and application development, individual parts testing, consultancy in design, simulation and much more - available to you around the world. When your idea turns into the ideal car, it's because at BASF, we create chemistry.
www.performance-materials.basf.com

Board of Directors continued...



Daniel T. Buckley
SPE Composites
Director (Retired)
Emeritus Director

Rich Caruso
SPE Composites Director
CEO Inter/Comp LLC
Falmouth, MA
rpcaruso@gmail.com

Michael Connolly, Ph.D.
SPE Composites Director
Program Manager-Urethane
Composties Huntsman
Polyurethanes
Auburn Hills, MI
michael_connolly@huntsman.com

Frederick S. Deans
SPE Composites Director
Principal
Allied Composite
Technologies, LLC
Rochester Hills, MI
fdeans@alliedcomptech.com

Jack Gillespie, Ph.D.
SPE Composites Director
Director, Center for
Composite Materials
Donald C. Phillips Professor
of Civil and Environmental
Engineering
University of Delaware
Newark, DE
gillespi@udel.edu

Jim Griffing
SPE Composites
Director & SPE
Past President
Boeing (Retired)
Seattle, WA
jsgriff1@gmail.com

Enamul Haque, Ph.D.
SPE Composites
Director
A2H Consulting Group
Enamul.Haque@
a2hconsultinggroup.com

Oleksandr G. Kravchenko, Ph.D.
SPE Composites Director
& Assistant Professor,
Dept. of Mechanical and
Aerospace Engineering
Old Dominion University
Norfolk, VA
okravche@odu.edu

This Issue:

See page 37 for more details

Board of Directors continued...

Christoph Kuhn
SPE Composites Director
Volkswagen
Group Research Materials & Manufacturing Methods
Wolfsburg, Germany
christoph.kuhn@volkswagen.de

Marcos Pantoja, Ph.D.
SPE Composites Director & Next Generation Advisory Board (NGAB) Liaison
Materials and Process Engineer
The Boeing Company
St. Louis, MO
marcos.pantoja@boeing.com

Khaled W. Shahwan, Ph.D.
SPE Composites Director
Sr. Technology Leader - Composites, Methods & Strategies, Fiat Chrysler Automobiles (Innovation & Adv. Engineering)
Auburn Hills, MI
khaled.shahwan@fcagroup.com

Mingfu Zhang, Ph.D.
SPE Composites Director
Johns Manville
Research Manager, Corporate R&D
Littleton, CO
mingfu.zhang@jm.com

Materials. Process. Design.

Building Lighter and Safer Cars for Tomorrow.

Forged Molding Compound
The NEW Look of Carbon Fiber
Carbon Fiber Thermoset Composites

SymaLITE®
Low Weight Reinforced Thermoplastics (LWRT) Composite Materials

KyronMAX™
Advanced Chopped Carbon Fiber Engineering Thermoplastic Compounds: PA, PPA, PPS, PEI, PEAK, PAEK

GMT
Glass Mat Reinforced Thermoplastics

GMTex®
Structural Thermoplastic Composite Materials

FUNCSTER™
Long Glass Fiber Polypropylene Composites

MITSUBISHI CHEMICAL ADVANCED MATERIALS | MITSUBISHI CHEMICAL CARBON FIBER AND COMPOSITES | GEMINI | MYTEX POLYMERS High Performance Polymers Worldwide

Mitsubishi Chemical and our group companies are dedicated to the automotive industry, with R&D and growth in high performance composites aimed at interior, exterior and functional applications. Our focus is on developing and bringing to market lightweight, sustainable, high value and premium asthetic solutions. Look to Mitsubishi Chemical for the ultimate in range, innovation and value.

MITSUBISHI CHEMICAL

mitsubishi-chemical.com

Board Meeting Minutes Dec 3, 2019

By: John P. Busel

SPE Composites Division
Board of Directors Meeting

12:00 PM – 1:00 PM Eastern US
Conference Call

1. Welcome

- Ian Swentek called the meeting to order at 12:01 pm.

- John Busel conducted the Roll Call.

- Due to the number of reports that were late, they will not be discussed during this meeting.

2. Administrative

- Ian Swentek reviewed the last meeting minutes of September 3, 2019. Enamul Haque moved to accept the minutes as written. Hicham Ghossein seconded. Motion passed unanimously.

- Ian Swentek review the action items from the last meeting.
  o Ian Swentek to follow up with Ray Boeman regarding interested volunteers for the Board.

continued on page 8..

Board Meeting Minutes continued...

o Ian Swentek to follow up with Tim Johnson regarding financials and audit.
o Ian Swentek to follow up with Ray Boeman on options for increasing the membership in the Division.

• Ian Swentek requested all reports need to be submitted 1-2 weeks prior to the meeting to be discussed on the agenda and that members can prepare for the meeting.

3. Committee Updates

• Finance:
o Antoine Rios reviewed the report provided to the Board for review regarding the Divisions investments. He made a recommendation to change the investment portfolio to divest the current portfolio. Antoine Rios moved to have the Composites Division divest out of the intermediate bond fund. Seconded by Dale Grove. The group discussed the proposed action. Motion passed.
o Antoine Rios stated that due to changes in the market, he is not prepared to make the second recommendation in the report provided to the Board regarding where to make future investments. It was suggested to move the divested funds to a money market account until the final plan is discussed and approved. The group discussed options offered by Tim Johnson.

• Awards:
o Hicham Ghossein is working with SPE Foundation to identify the opportunities. Hicham Ghossein is asking for more Board members to get involved in the Awards

continued on page 9...

Board Meeting Minutes continued...

committee to help with the activities. Volunteers are Dale Grove, Enamul Haque, Christoph Kuhn.

• Tech Program – ANTEC:

o Shankar Srinivasan reported that 43 submissions were received in October. Currently there are 24 final presentations for ANTEC 2020 that will be 4 sessions of 6 per session.

• Newsletter:

o Pritam Das reported that he is looking for content for the newsletter. Several Board members have provided content for consideration. He did not have an update on sponsorships for the newsletter and will have a report for the next Board meeting. Several Board members volunteered to provide news for the next edition.

4. New Business

• Candidates to be considered for a board position

o Ian Swentek presented several candidates for new position on the Board. The first candidate is Marcos Pantoja, Boeing as representing and serve as the liaison to the NGAB. The seconded nominee is Khaled Swahwan, FCA. Ian Swentek noted this was to address representation from OEMs. Both candidates provided a background for the Board members. Fred Deans moved to approve the candidates as presented. Chris Kuhn seconded. The group suggested to include more diversity to the Board members. Motion passed unanimously. Ian Swentek welcomed the new Board members.

• ANTEC student funding request

o A request was made by ANTEC organizers to the Composites Division to sponsor a support to the student poster competition of $2500. This is not a budgeted item and is a one-time request. The question was raised if the Division supports student travel already. It was pointed out that funds were moved to support NGAB. The group discussed the issue. Michael Connolly moved to support the $2,500 as requested. Hicham Ghossein seconded. The group discussed the merits of the support including receiving contact information of students for future work. Motion passed unanimously.

• Mission Statement review

o Ian Swentek prepared a draft to compare the various versions of the mission and vision of the Composites Division. No vote for today. He asked the Board to review the proposed statements in order to have a unified message on the various platforms and collateral. This item will be discussed at the next meeting.

5. Wrap Up

• Ian Swentek proposed a new meeting in January 2020 to discuss finances of the Division. A survey will be sent to find the best time. The future meetings are as follows:

o Tuesday, March 17, 2020 – 12:00 pm – 1:00 pm EASTERN (conf call)

o Tuesday, June 16, 2020 – 12:00 pm – 1:00 pm EASTERN (conf call)

• Ian Swentek reviewed the meeting action items.

continued on page 10...

This Issue:

Board Meeting Minutes continued...

6. Adjourn

- Ian Swentek adjourned the meeting at 1:04 pm.

Respectfully submitted,
John P. Busel

Attendees

OFFICERS:
Ian Swentek, Chair
Tim Johnson, Treasurer
John P. Busel, Secretary

DIRECTORS:
Dan Buckley
Rich Caruso
Michael Connolly
Pritam Das
Fred Deans
Hicham Ghossein
John Gillespie
Jim Griffing
Dale Grove
Enamul Haque
Alex Kravchenko
Christoph Kuhn
Antoine Rios
Shankar Srinivasan
Uday Vaidya

GUESTS:
Marcos Pantoja
Khaled W. Shahwan

This Issue:

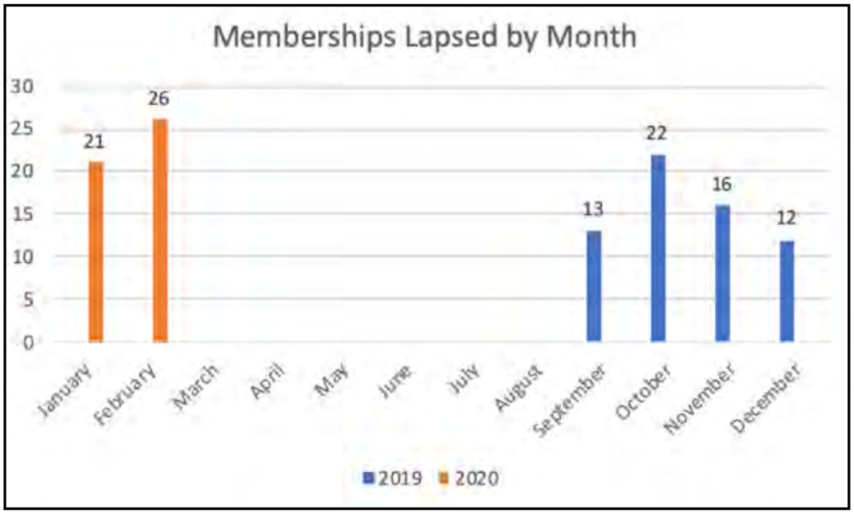
See page 37 for more details

Membership Report

By: Ray Boeman

SPE COMPDIV (D39) Membership Report
Ray Boeman, March 17, 2020 (Data from March 13, 2020)

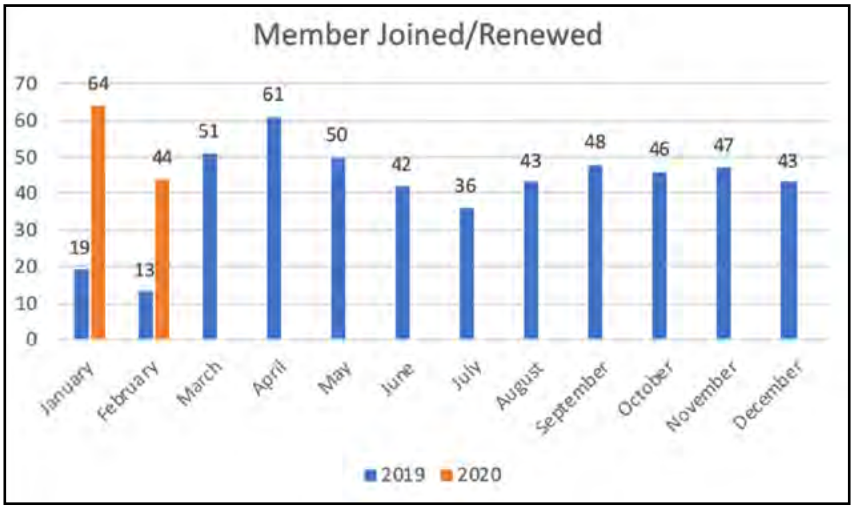
510 Active Members as of March 13, 2020, decrease of 15 from last report (Dec 3, 2019). Memberships lapsed trending up over last quarter



Thirty percent of members are due to renew in the next three months (in addition to those who have lapsed).

Months to Renewal	Number	%
0-3	152	30%
4-6	96	19%
7-9	121	24%
10-12	116	23%
other	25	5%
Total	**510**	**100%**

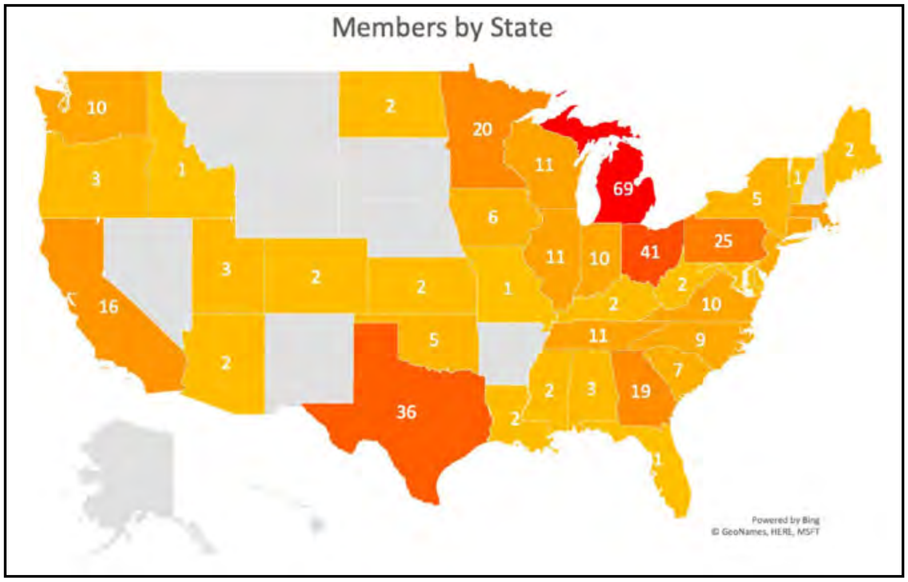
New or renewed memberships trending up over last year.



This Issue:

Membership Report continued...

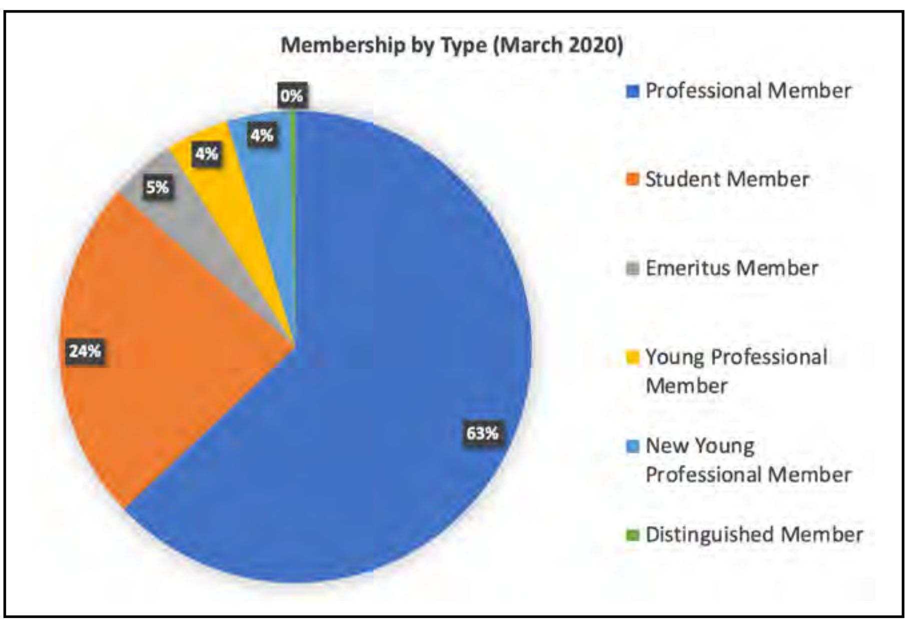
Memberships concentrated in Midwest, Texas, Southeast, Pennsylvania, and West Coast



Although D-39 has members from 32 countries, 88% come from just four countries. Germany, France, South Korea, and the UK contribute 4, 3, 3, and 2 members, respectively.

Country	Number	%
United States	390	76%
Canada	31	6%
India	13	3%
Australia	13	3%

Twenty-four percent of members are Students - critical retention target.



This Issue:

Education Funding Opportunity

By: Uday Vaidya

SPE Composites Division 2018 Grant Update

Polymer Engineering Center
Prof. Tim A. Osswald
December 2, 2019

Purchase and Use of Printer

- Purchased Sinterit Lisa desktop SLS printer
- Currently located in our Polymer Research Lab
- Core equipment for SLS composite research (see below for student use)
- Utilized as main instructional piece in two polymer engineering courses:
  - ME 313 - Polymer Manufacturing; ME/EMA 508 – Composite Materials; ME 514 - Additive Manufacturing
- Exhibited as demonstration piece during Engineering Expo

Publications

- Investigation of Glass Bubbles iM16K Polyamide 12 Composites for Selective Laser Sintering, J. Klett et al., ANTEC 2020
- Validation of Glass Bubble Polyamide 12 Composites for Selective Laser Sintering, Jamie Klett, Master Thesis, UW-Madison
- Glass Bubble Polyamide 12 Composite Structures using Selective Laser Sintering, Simon Cholewa, Master Thesis, University of Erlangen-Nuremberg, LKT, Germany

Dedicated Students Working with Sinterit Lisa		
Student	Standing	Project
Jamie Klett	Graduate	Glass Bubble-PA12 SLS Composites
Simon Cholewa	Graduate	
Sarah Deltour	Undergraduate	

Engineering Expo 2019 - Explaining the SLS Process

This Issue:

Treasury Report

By: Tim Johnson, Treasurer

Currently the Division has cash on the order of $43.8K and $115.2K in investment. This follows reception of our share for the ACCE of $29.3K which was significantly below budgeted forecast. This also reflects a transfer of $30K from cash to investment.

The investment portfolio was also reallocated, moving from Investment Grade Bonds to a split of Treasury Bonds and Money Market, presently $44.2K and $71.0K respectively.

The Division is now accepting the rebates from SPE based upon membership which are distributed quarterly. The Division had historically donated this back to SPE. A portion of those funds had been used to directly pay the liability insurance premium for the Composites Division charged since fall of 2018. The Division will now pay the insurance from our account starting in the fall of 2020. The net benefit to the Division is approximately $2K.

Despite the reduced income from ACCE, several results of COVID-19 have also reduced our expenditures. This includes support for Plastivan events that could not be scheduled for this spring and ANTEC related expenses. The same issue of reduced sponsorship that effected ACCE is also impacting the Division Newsletter. We have determined to reduce the cost of the newsletter by no longer printing the edition for ACCE. Although this cost saving would not impact until next year, current sponsors are advised of this change.

Funding of Education Grants is nearly complete, with one school preferring to receive funding per three phased distributions.

A financial summary for the 2019/2020 year to date is provided as a separate file.

Tim Johnson
SPE Composites Division Treasurer

Award Winning Paper

Carbon Fiber Subframe Development
Fatigue and Strength CAE and Test Results

Xiaoming Chen, David A. Wagner and John Uicker • Ford Motor Company
Nikhil Bolar • Magna, Cosma International

Abstract

A research carbon fiber composite front subframe was designed and manufactured for the Ford Fusion to investigate the opportunities and challenges associated with this lightweight material to potentially improve fuel economy. The design process was CAE driven verified with component tests and proving ground vehicle tests. CAE output demonstrated that the carbon fiber composite subframe met performance targets for both high cycle fatigue and critical event strength durability.

Component tests were conducted to verify the subframe's fatigue performance under high cycle loads and strength under quasi static loads. Proving ground vehicle durability test and strength related special event tests were also conducted. The CAE predictions for the component and vehicle tests had various degrees of correlation with the physical test results. Improvements in CAE procedures and material characterization will likely be needed to generate robust CAE predictions of carbon fiber composite structural performance.

Background and Requirements

Carbon fiber composites are alternatives for lightweight materials in automotive component designs. Carbon fiber reinforced plastic components have been used in luxury cars and racecars. The applications of the materials are mostly unidirectional long fiber composites that provide desired mechanical properties with high cost.

continued on page 17...

This Issue:

Award Winning Paper continued...

The subframe in this research project used EpicBlend SMC, compounded by Magna, a chopped 50k industrial-grade carbon fiber with a modified vinyl ester resin. A continuous carbon fiber material, EpicBlend CFS-Z with 0°/90° non crimped fabric (NCF), was co-molded with the chopped EpicBlend SMC material. The SMC allows complex geometries. The NCF patches provide strength at critical areas [1]. This approach is affordable and scalable for high-volume production. In addition to the co-molding of the two carbon fiber composite materials, four stainless steel body mount inserts and two stainless steel steering gear compression limiters are over-molded.

A 2016 Ford Fusion was selected as the baseline vehicle for the development. It has a perimeter subframe shown in Figure 1. It is challenging to design a subframe with carbon fiber composites considering its much lower modulus and tensile strength comparing to steels. This carbon fiber composite (CF) subframe design was CAE driven. The

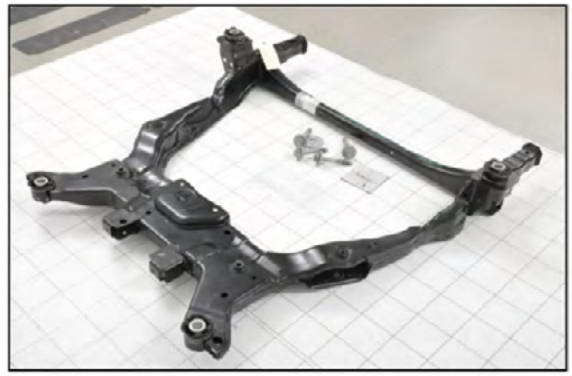


Figure 1: Ford Fusion steel front subframe

continued on page 18...

Award Winning Paper continued...

stiffness and durability performances of the steel subframe were set as reference targets for the CF subframe design. The process started with topology optimization for stiffness followed by durability design. Stress in fastener bearing area was also investigated and washers were introduced to prevent composite damage in fastener bearing areas. CAE results demonstrated that the CF subframe met stiffness, durability and strength targets set for the Fusion steel subframe [2].

To validate the CAE design and prove the quality of the prototype subframe both component and vehicle tests were conducted.

Component tests were conducted to verify the subframe's fatigue performance under high cycle loads and strength under quasi-static loads. There were four loading conditions for fatigue tests and three loading conditions for the strength tests. Under high cycle fatigue loads, the carbon fiber subframes survived the required two accelerated lives. A number of small cracks were observed during the component tests. The majority of cracks did not propagate and the subframes did not lose load carrying capacity. Under quasi-static loads, the subframes exceeded the load carrying capacity requirement for the baseline steel subframe.

Proving ground vehicle durability test and strength related special event tests were also conducted. Numbers of small cracks observed in component fatigue tests did not appear during the vehicle test. There were few cracks in the subframe around the front body mounts and the control arm rear joint. These cracks propagated at certain levels as the test progressed. The cracks did not degrade the subframe's functions on the vehicle. The special event tests included driving over bumps and breaking into potholes. The vehicle passed the Level One test and failed the Level Two test.

The CAE predictions for the component and vehicle tests had various degrees of correlation with the physical test results. Improvements in CAE procedures and material characterization will likely be needed to generate robust CAE predictions of carbon fiber composite structural performance.

Carbon Fiber Subframe Design Highlights

The design of the CF subframe was CAE driven. The CAE design process incorporate the following steps:

Topology Optimization and Design for Stiffness

Topology optimization used the design space to run iterations until the minimal weight was reached and met all stiffness targets set for the optimization. The output of an optimization was a contour plot showing material distribution required to meet all stiffness targets. The topology optimization contour was used to guide the creation of the preliminary subframe design. More CAE iterations were performed to refine the geom-

continued on page 19...

This Issue:

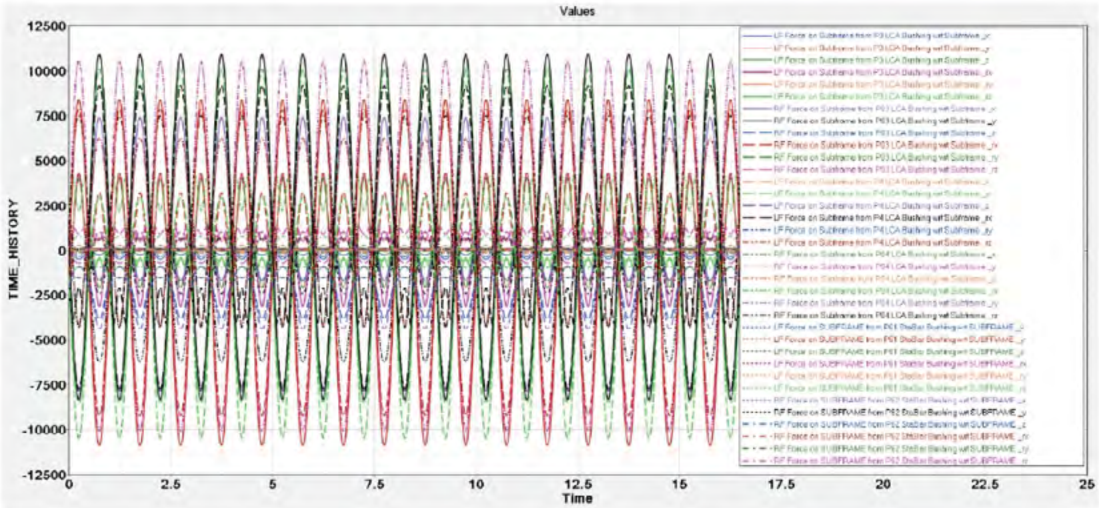


Figure 2: braking event loads applied to joints

etries and gauges. Those simulations led to a mature proposal to start durability design iterations. OptiStruct of HyperWorks [3] was the analysis software for this topology optimization and NASTRAN [4] was used for stiffness design simulations.

Design for Fatigue Life

Design for fatigue simulates the subframe's working condition with high cycle load cases, such as start, brake, turn, etc. The load input for this CF subframe development is the GEDL (Generic Endurance Design Load) load cases of the baseline steel subframe. There are 13 driving events listed for the simulation. For each event, there are three forces and three moments applied to every chassis component attachment joint of the subframe. The load cases represent 150,000 miles or 10 years' service of the vehicle. Figure 2 is the plot of the braking event with 20 cycles.

There were two steps to simulate the subframe's fatigue life with CAE. Step 1 ran NASTRAN analysis with unit loads applied to joints. The output of the analysis was stresses in the structure. Step 2 used nCode [5] combining NASTRAN output and GEDL load cases as input. The minimal CAE-based life prediction required for production subframes is two lives. CAE simulation did not identify any location with fatigue life less than two (2.0 lives) demonstrating that the subframe met GEDL load design targets.

Design for Strength

The strength design of the subframe is for structure integrity under extreme loading conditions. The production subframe's GSS (Global Suspension Strength) load cases were used for the carbon fiber composite subframe's strength design. There are two levels of load inputs for this design process. Level One loads represent moderate abuse such as driving through bumps. Measurements of Level One performance is the structure permanent deformation. Ford's requirement is that the subframe remain completely functional after multiple Level One events. For ductile material subframe, this requirement limits the permanent deformation to less than one or two millimeters depending on location. Level Two loads represent extreme abuse such as braking into potholes. Measurements of Level Two performance is the structure damage. Ford's requirement is

continued on page 20...

This Issue:

that the subframe remain completely functional, though likely in need of repair, after multiple Level Two events. The subframe must maintain function without any separations or loss of integrity. ABAQUS [6] was the analysis software.

Under Level One loading the design criteria for steel subframes are permanent deformations (deformation after unloading) listed as following:

- Permanent deformation < 1 mm at loading points
- Permanent deformation < 2 mm at rest of the subframe

Under Level Two loading the design criterion for steel subframes limits the plastic strain as following:

- Max. plastic strain of the subframe < 50% of the failure strain of the alloy

Since carbon fiber composites have little or no ductility, the failure criteria under both Level One and Level Two loads are defined as following:

- SMC: Max stress > yield stress (187 MPa)
- Laminates: Tsai-Hill criteria predicted failure

$$\frac{\sigma_{11}^2}{S_{11}^2} - \frac{\sigma_{11}\sigma_{22}}{S_{11}^2} + \frac{\sigma_{22}^2}{S_{22}^2} + \frac{\sigma_{12}^2}{S_{12}^2} \geq 1.0$$

CAE simulation results showed stress of SMC is lower than the yield stress. The Max. Failure Index on the control arm front joint laminates is 1.6 indicating concern at that location (Figure 3). It requires verification by tests.

Design for Bolt Load Retention

Subframe joints for the attached chassis components are bolted joints. This CF composite subframe has M14 and M16 bolts (bolts shank diameters are 14mm and 16mm respectively). The proof loads for M14 and M16 bolts are 95.5kN and 130kN. High bolt proof loads could lead to high stresses in fastener bearing area. Yield or any composite damage of fastener bearing area could affect bolt load retention of the joint.

A common practice to reduce the stress level in fastener bearing area is to add washers. Washers create an effective stress bearing area that is larger than the fastener bearing area. Dimensions of washers are decided by bolt proof loads, the size of fastener bearing area and the yield stress of the subframe material [7]. Washers are introduced to all joints of the CF composite subframe except for the control arm rear joint, which has the bushing brackets covering large areas at and around the joints.

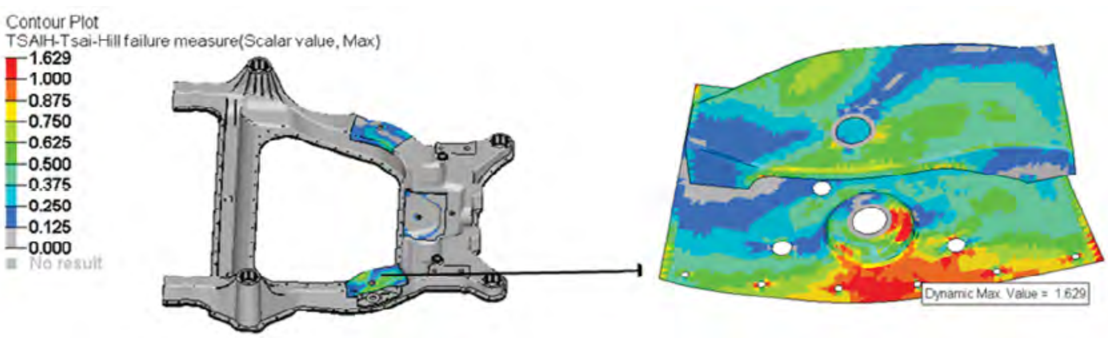


Figure 3: CAE predicted failure on control arm front joint laminate

continued on page 21...

This Issue:

Award Winning Paper continued...

Most washers in the CF composite subframe are “Hat” washers. “Hat” washers cover the top surfaces of bolt holes and small portion of the side wall of bolt holes. “Hat” washers are made of the same steel and have the same finish as for bolts, which is one of the corrosion mitigation strategies in addition to its bolt load retention function. Figure 4 is the control arm front joint with four “Hat” washers.

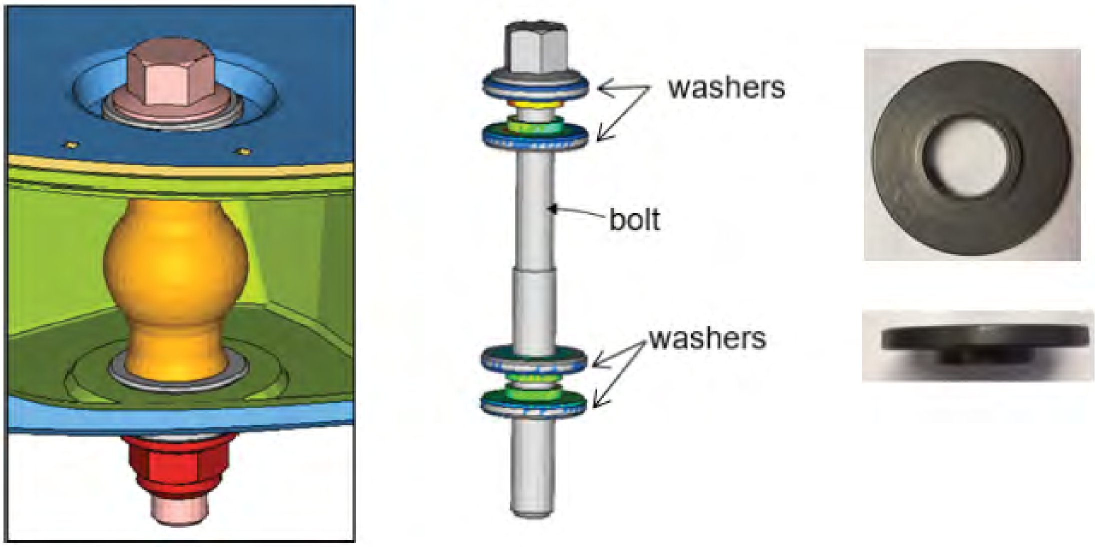


Figure 4: control arm front joint with “Hat” washers

ABAQUS was used to run the fastener bearing area stress analyses. The failure criteria are the same as those for strength design iterations. The control arm front joint surfaces were identified by CAE simulations as areas of concern (Figure 5). The high stress were on laminates. It needs to be verified by tests.

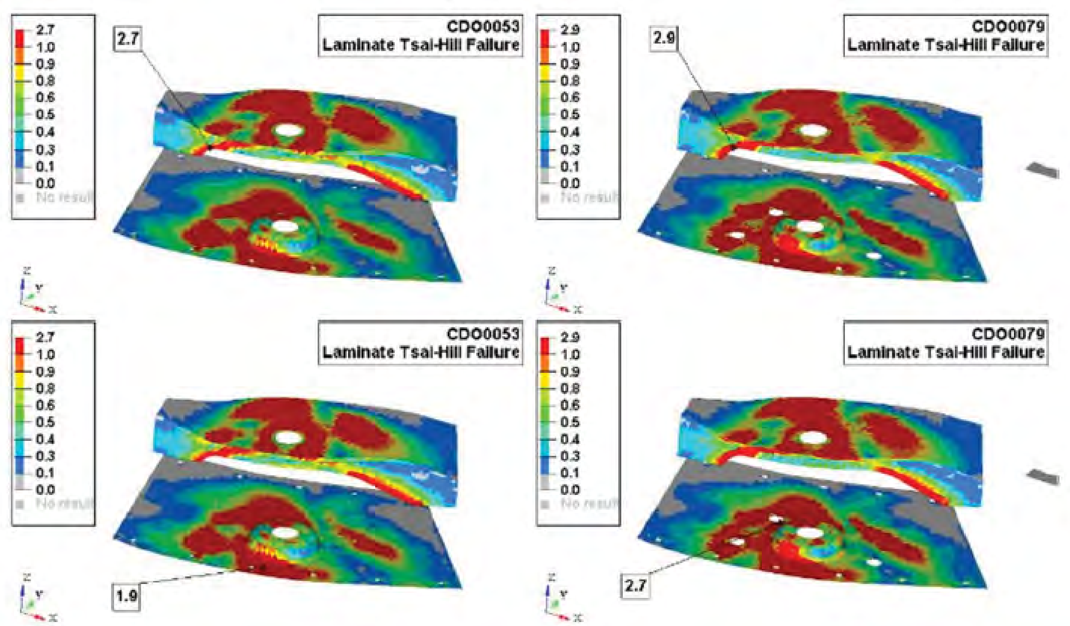


Figure 5: control arm front joint laminate surfaces

continued on page 22...

This Issue:

Award Winning Paper continued...

CF Subframe Prototype

The CF composite subframe prototypes are produced by Magna International. The subframe utilizes an industrial carbon fiber compounded with a modified vinyl ester resin system in EpicBlendTM CFS-Z SMC that is approximately 50% by weight chopped carbon fiber. The second carbon fiber composite material that is co-molded with the SMC is a prepreg material that utilizes continuous 0°/90° non crimped fabric that is approximately 56% by weight continuous oriented carbon fiber. The design and combination of materials achieves a 7.3 kg (28%) mass reduction over a stamped steel subframe. The subframe achieves an 82% part reduction by replacing the 45 steel parts with two molded parts that incorporate six over molded steel parts. The two moldings, an upper clamshell and a lower close out panel, are joined be adhesive bonding and structure rivets. Details of the subframe components are shown in Figure 6.

The finished part is shown in Figure 7.

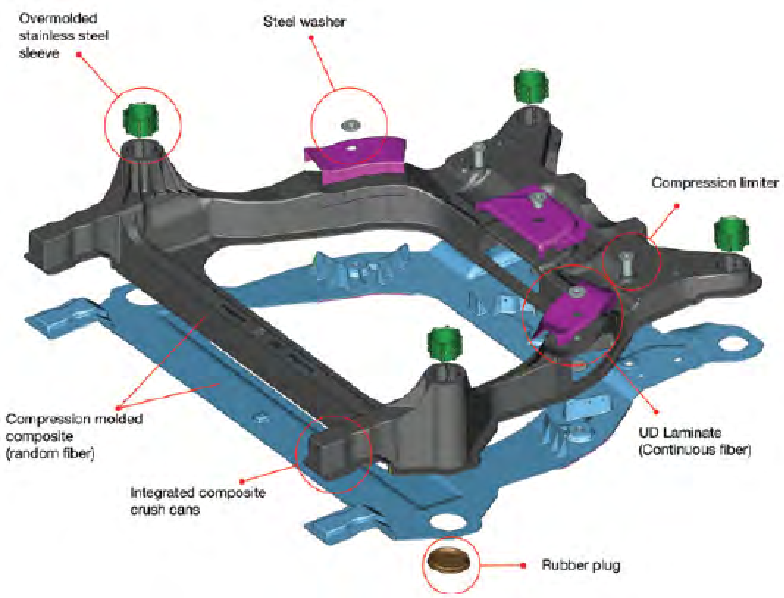


Figure 6: CF composite subframe components

Figure 7: CF composite subframe prototype part

continued on page 23...

This Issue:

Carbon Fiber Composite Subframe Component Fatigue Tests

Subframes were tested to validate the CAE design and prove the quality of the CF composite prototype. Tests included component durability under fatigue loads and strength under static loads. The fatigue tests were conducted for all four joints of the subframe. A steel subframe was also tested for each setup. The load cases were developed based on the GEDL loads (Generic Endurance Design Loads) of the surrogate part. CAE were conducted to simulate the tests. The outputs were compared with test results. The CAE predictions did not correlate with test results.

Roll Restrictor Fatigue Test

Test Procedure

The subframe was mounted to the bedplate in vehicle position utilizing the body mounts as shown in Figure 8. Horizontal longitudinal block cycle loads were applied 90 degrees to the roll restrictor bushing fastener through a solid loader. The height of the loader was equal to that of the roll restrictor. Lower arm bushings were bolted in the lower arm pockets on all samples.

Horizontal sinusoidal loads of two baseline lives and eight over stress loading blocks were generated from production Fusions' GEDL roll restrictor load events.

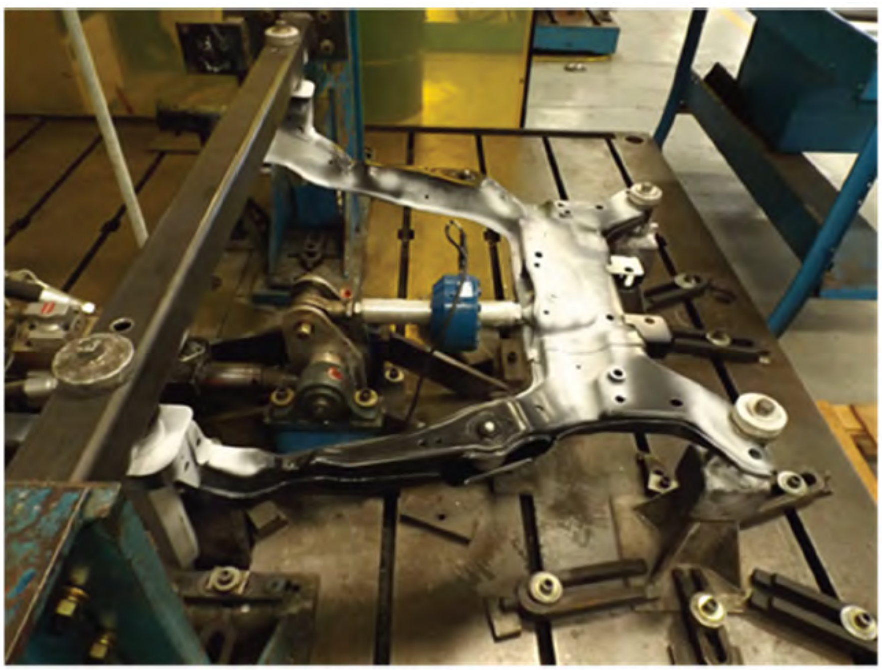


Figure 8: roll restrictor test setup

continued on page 24...

This Issue:

Award Winning Paper continued...

Test Results

A single steel subframe was tested through two baseline-loading cycles (two lives) and seven over stress cycles. There was no damage detected.

The CF subframe was also tested for two baseline cycles and seven over stress loading cycles. There was visible damage, i.e., small cracks, but without loss of function or load carrying capacity.

For the carbon composite subframe samples, several small cracks were observes through the loading process. Most of the cracks were on the front body mount surfaces. Few were near the loading location and the control arm rear joint (Figure 9). Some cracks were detected before the end of the second baseline cycle. All cracks were stabilized as the loading progressed. The subframe structure maintained its integrity and load carrying capacity through the test. This component test result proved that the CF subframe met the fatigue requirements at the roll restrictor joint.

Front Lower Control Arm Fatigue Test

Test Procedure

The subframes were secured to a fixture which was rigidly bolted to the bedplate. A longitudinal and a lateral actuator were connected to the ball joint stud of the left and right lower control arms shown in Figure 10. Loads were applied into the subframe by block cycles. Inspections were made periodically throughout the test to look for cracks in the subframe.

A calibrated Flextest controller was used to control the load of all four hydraulic actuators. Loads were applied in a sinusoidal wave based on the block cycles generated from production Fusions' GEDL control arm load events.

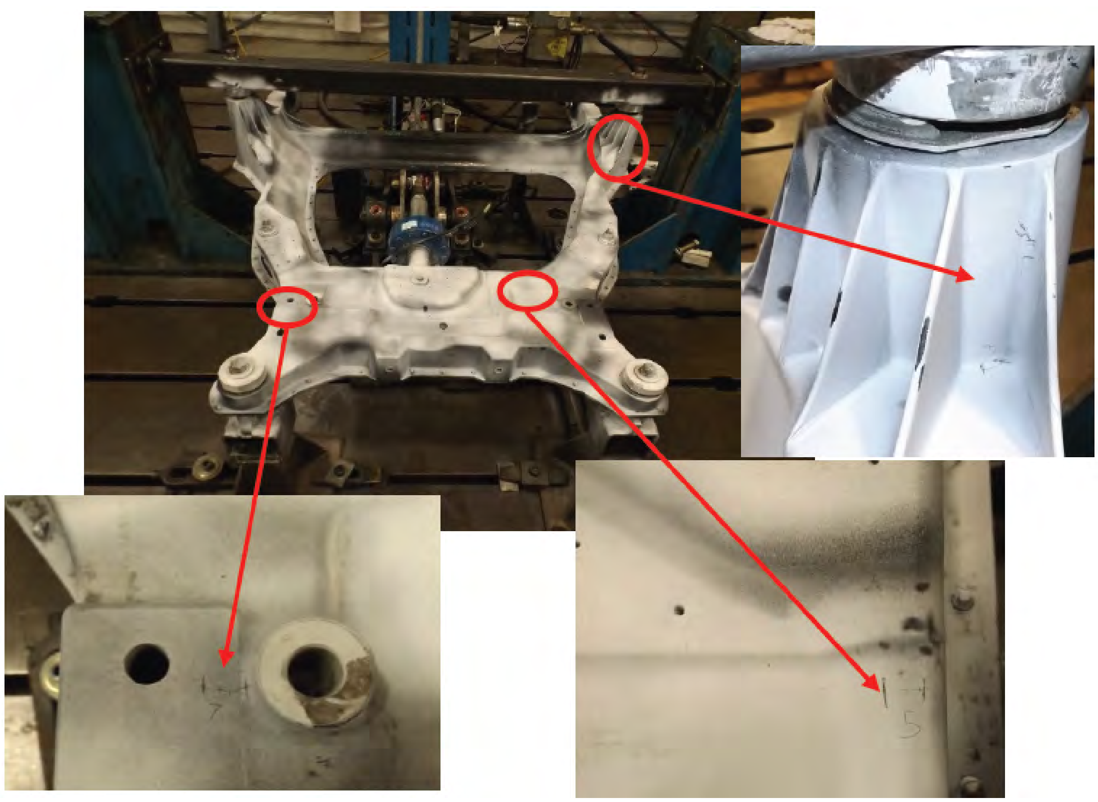


Figure 9: roll restrictor test cracks - CF subframes

continued on page 25...

This Issue:

Award Winning Paper continued...

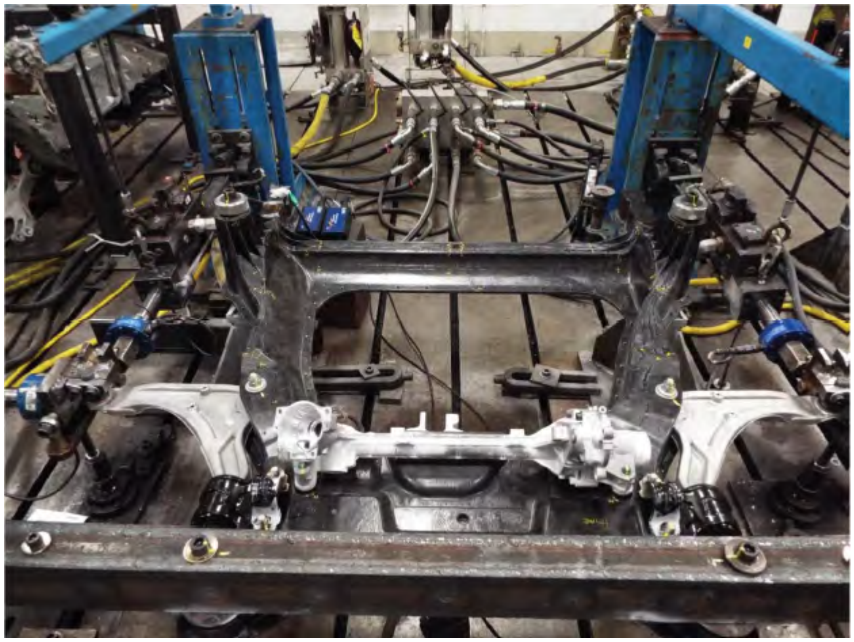


Figure 10: control arm test setup

Figure 11: control arm test cracks – steel subframe

Test Results

The steel subframe was tested through two baseline-loading cycles (two lives). Cracks were detected before completing the second baseline loading cycles (Figure 11)

The CF subframe was also tested for two baseline cycles.

For the three carbon fiber composite subframe samples, multiple small cracks were detected. Some initiated at the early loading blocks. Most of the cracks were around the front body mounts. Propagations were observed as the test progressed. Selected cracks are shown in Figure 12. The subframes survived the two baseline loading cycles without losing its load carrying capacity.

continued on page 26...

Award Winning Paper continued...

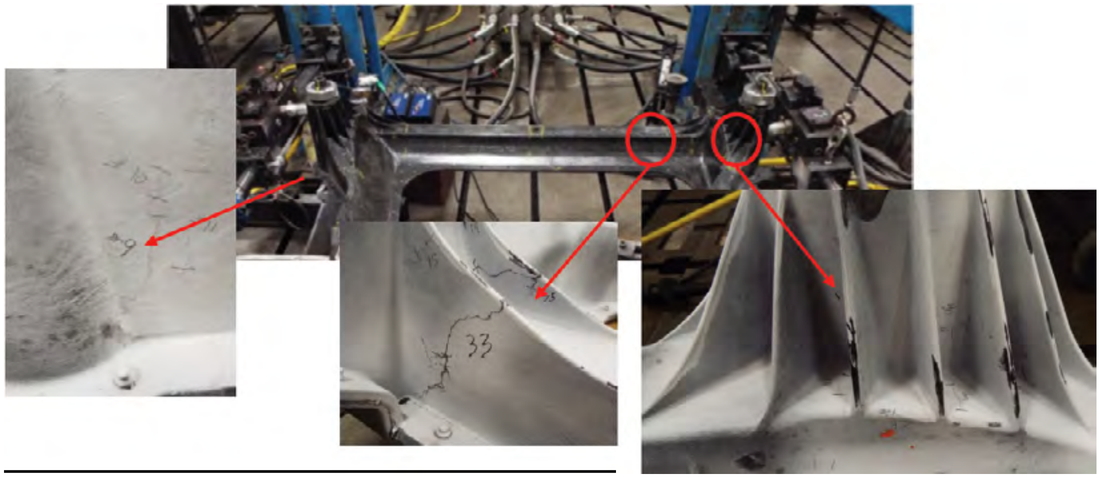


Figure 12: *control arm test cracks* –CF *subframe*

Stabilizer Bar Fatigue Test

Test Procedure

The CF subframe was mounted level to the bedplate as shown in Figure 13. The subframe was loaded through the stabilizer bar brackets and bushings. The test load was applied 90 degrees to level using a production stabilizer bar. Lower control arm bushings and a roll restrictor were bolted in place, and a steering gear was mounted to each frame tested.

Sinusoidal Block cycle test loads were applied. The two actuators were run 180 degrees out of phase at 2.0 Hz with the two baseline lives and four over stress loading blocks generated from production Fusions' GEDL stabilizer bar load events.

continued on page 27...

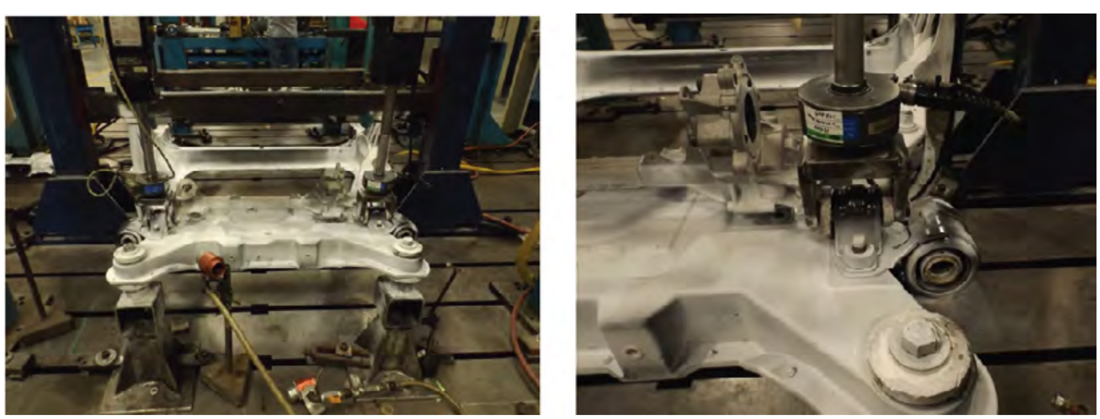


Figure 13: *stabilizer bar test setup*

This Issue:

This Issue:

Test Results

One steel subframe was tested through two baseline-loading cycles (two lives) and four over stress cycles. There was no damage detected.

For the three CF subframe samples, cracks initiations were detected close to the finish of second baseline cycles. More small cracks were observed through over stress loading. Several cracks were around the front body mounts and other cracks were scattered throughout the subframe. Most cracks did not propagate. Selected cracks are shown in Figure 14. The subframes successfully passed the two baseline loading cycles and four over stress cycles without losing its load carrying capacity.

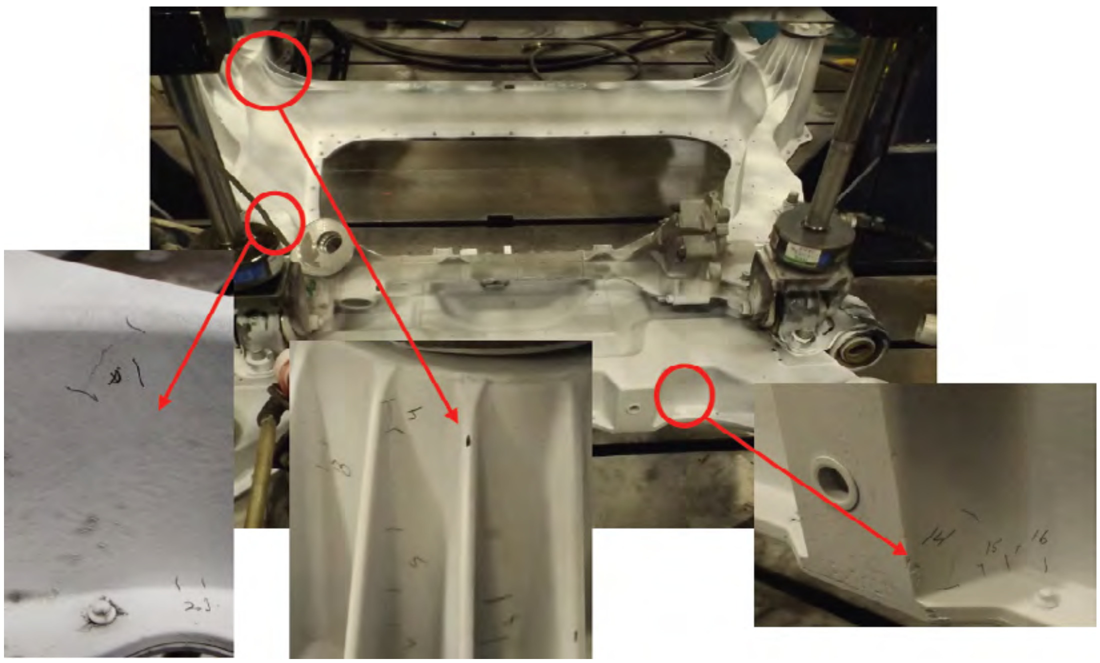


Figure 14: stabilizer bar test cracks –CF subframe

See page 37 for more details

Award Winning Paper continued...

Steering Gear Fatigue Test

Test Procedure

The CF subframe was mounted level to the bedplate as shown in Figures 15. The subframe was loaded through a steering gear housing using simulated tie rod ends. The load axis was 6 degrees forward and 6 degrees down at outer tie rod ball joints, 26 mm from the ends of the housing. Lower arm bushings and a roll restrictor were placed in their respective locations and bolted into place.

The two actuators were run 180 degrees out of phase such that when the Left Hand load cell was in tension, the Right Hand load cell was in compression. Block cycle loads were applied with two baseline lives and eleven over stress generated from production Fusions' GEDL steering load events.

Test Results

One steel subframe was tested through two baseline-loading cycles (two lives) and eleven over stress cycles. There was no damage detected.

Multiple crack initiations were detected on each of the three CF subframe samples before the completion of second baseline cycles. Cracks were at or close to the steering gear attachment joint. The cracks did not propagate much. Selected cracks are shown in Figure 16. The subframes passed the two baseline loading cycles and eleven over stress cycles without losing its load carrying capacity.

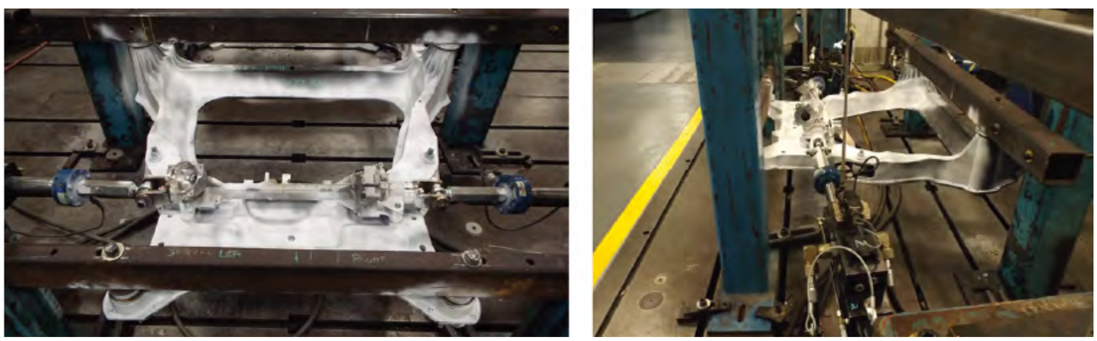


Figure 15: steering gear test setup

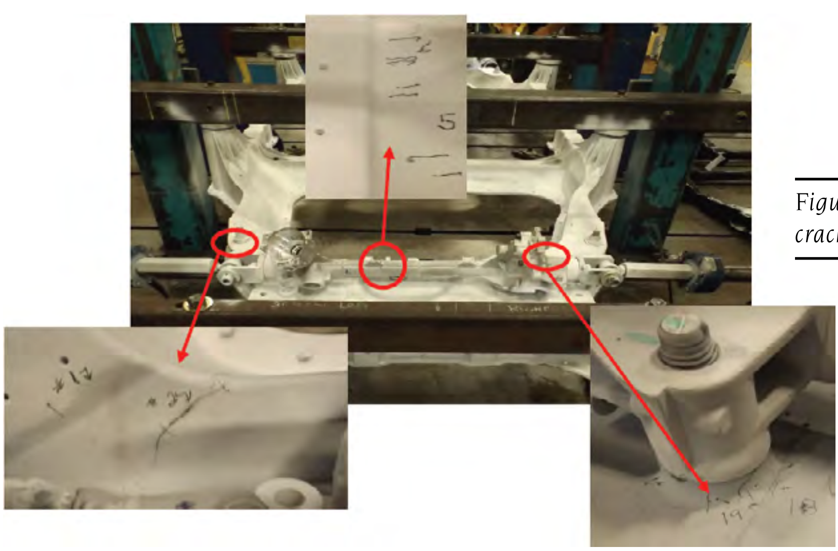


Figure 16: steering test cracks – CF subframe

continued on page 29...

This Issue:

Award Winning Paper continued...

Vehicle High Cycle Durability Test

A carbon fiber composite subframe was installed in a production Fusion and tested at Ford Michigan Proving Ground. The test followed the Ford procedure which is one of several tests required for passenger cars, crossovers and utility vehicles. The test emphasizes accelerated vehicle body and chassis systems and component durability based on customer correlated public road usage [8].

The vehicle was inspected daily through the three month test duration. The inspections evaluated part condition and visually inspected the paint marks on the subframe joints to detect possible bolted fastener movements.

The vehicle durability test results were contrary to the component fatigue tests. Scattered small cracks were not observed through the test. Few cracks were detected. The crack on the front body mount was found at the very early stage of the test. It propagated and stabilized at about 25% of the test duration. Other cracks were recorded at about 50% of the test duration. They remain the same lengths until the end of the test. The cracks are shown in Figure 17.

continued on page 30...

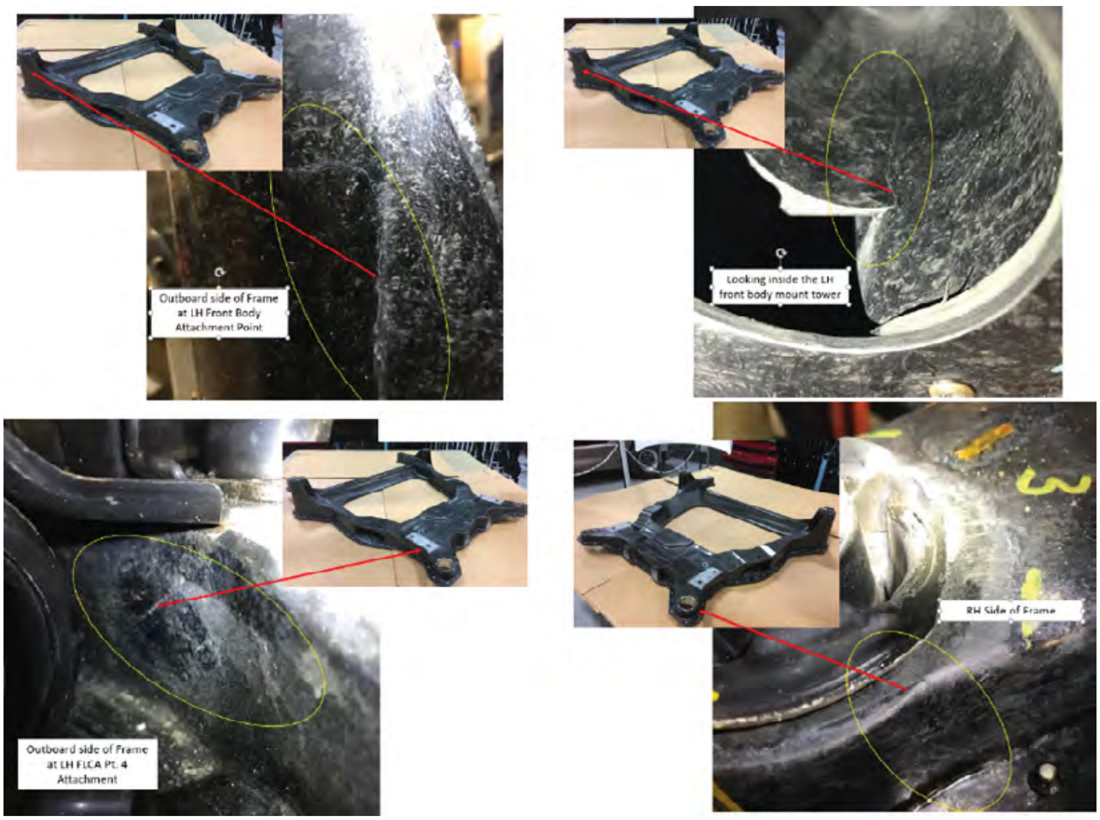


Figure 17: cracks – vehicle durability test

This Issue:

Award Winning Paper continued...

The vehicle completed required test conditions and cycles. No degradation of functions was detected. The post-test inspection, Figure 18, did not find visible movement of fasteners. The Fusion vehicle with a CF composite subframe successfully passed the proving ground durability test.

Figure 18: CF subframe – post vehicle durability test

Carbon Fiber Subframe Component Strength Tests

The strength tests were conducted to evaluate the load carrying capacity of the CF subframe. Three loading conditions were designed. Fixtures were built for each of the tests. The subframe was secured at the four body mounts shown in Figure 19. The subframes were loaded under quasi-static loads up to failure occurred and compared with the surrogate vehicle's GSS loads (Global Suspension Strength) at the loading joints.

CAE simulations were done before the tests to predict failure locations and peak loads. CAE simulation results also helped to choose load cells for the tests. ABAQUS was used for CAE simulations.

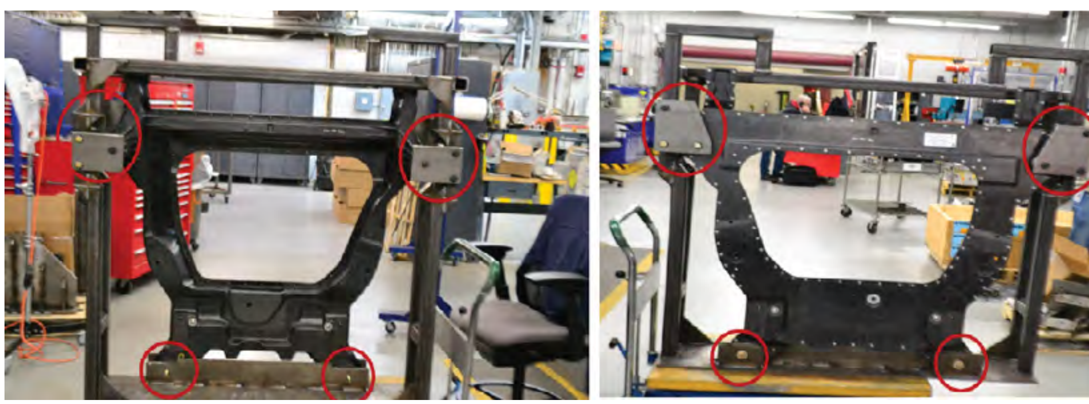


Figure 19: CF subframe – Strength test fixture

Figure 20: Strength test – roll restrictor loading

Roll Restrictor Strength Test

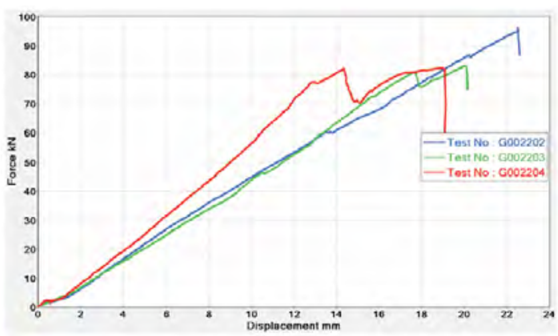
Test Setup

For the roll restrictor test, a steel tube was used to represent the roll restrictor bushing. The load was applied in the vehicle's longitudinal direction shown in Figure 20.

continued on page 31...

This Issue:

Figure 21: *strength test – roll restrictor loading damage*



Test Results

The failure started at the loading location. The bolt hole of the roll restrictor was damaged. The bolt was bent and the nut was broken shown in Figure 21. The force curve is shown in Figure 22. The peak load is about 80 kN.

Figure 22: *Strength test – roll restrictor loading force deflection plot*

Test and CAE Comparison

The test results were compared with CAE predictions. The ABAQUS simulation predicted high stress area at the edge of the bolt hole that is the same location showing failure in the tests (Figure 23). The peak load predicted by the simulation is higher than the failure load of the test.

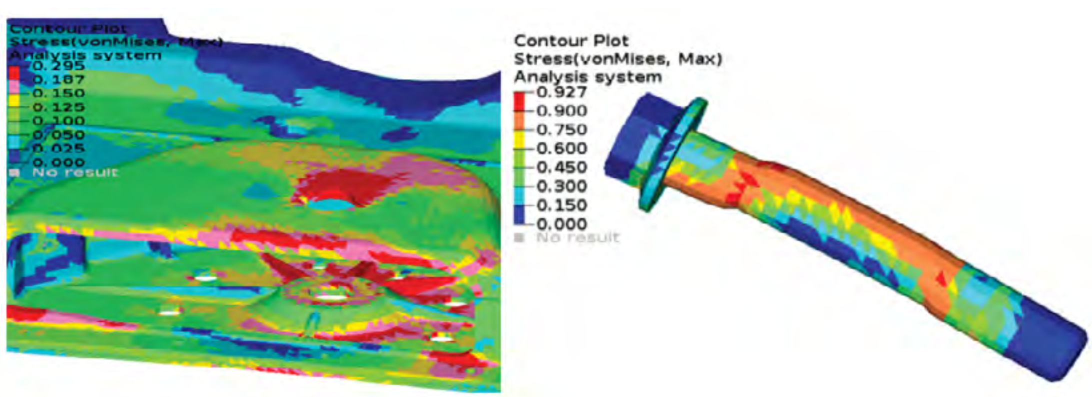


Figure 23: *Strength test – roll restrictor loading CAE failure locations*

continued on page 32...

This Issue:

Award Winning Paper continued...

Control Arm Front Joint Strength Test

Test Setup

For the control arm front joint test, a steel tube was used to represent the control arm bushing. The load was applied in the vehicle's lateral direction shown in Figure 24.

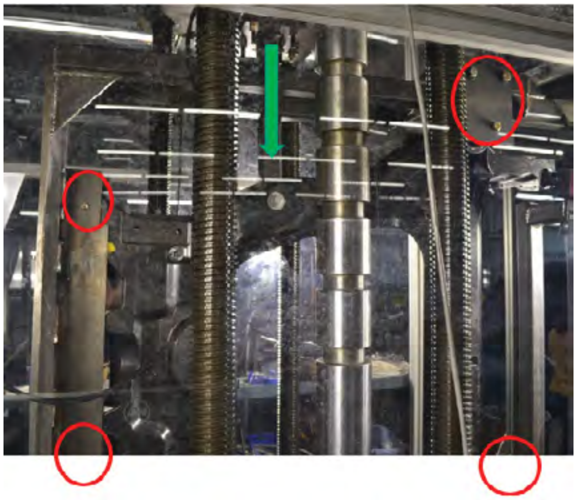


Figure 24: Strength test – control arm front joint loading

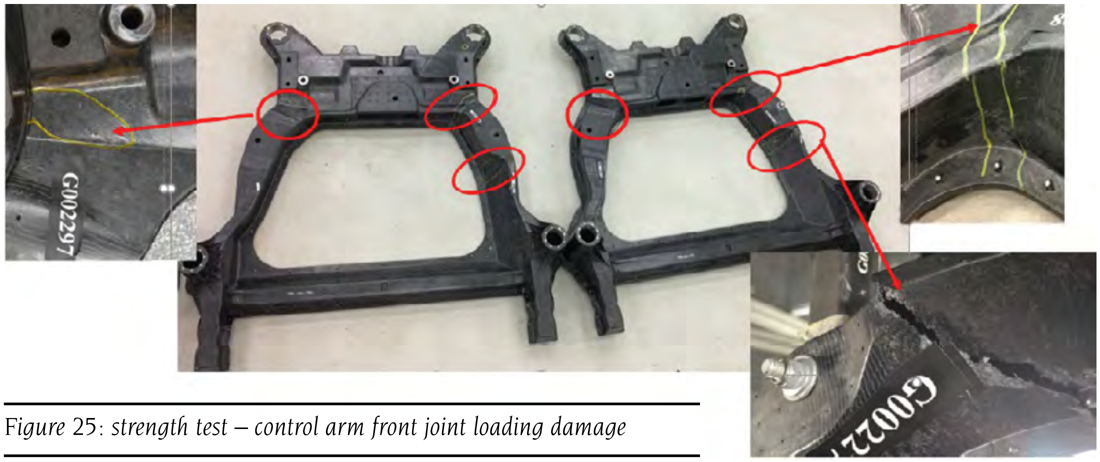


Figure 25: strength test – control arm front joint loading damage

Test Results

The damage started near the loading location. There was a crack on the opposite side of the loading point. Figure 25 shows cracks on the subframe. The force curve is shown in Figure 26. The peak loads of the test are higher than 58 kN, the GSS resultant load at this hard point.

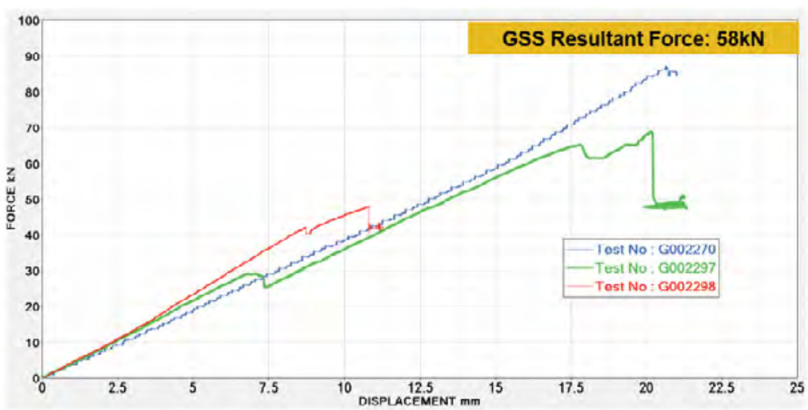


Figure 26: strength test – control arm front joint force deflection plot

continued on page 33...

This Issue:

Test and CAE Comparison

The test results were compared with CAE predictions. The ABAQUS simulation predicted high stress areas near the loading point that are the same locations showing failures in the tests (Figure 27). The CAE simulation did not catch the crack on the opposite side of the loading point. The peak load predicted by the simulation is higher than the failure load of the test.

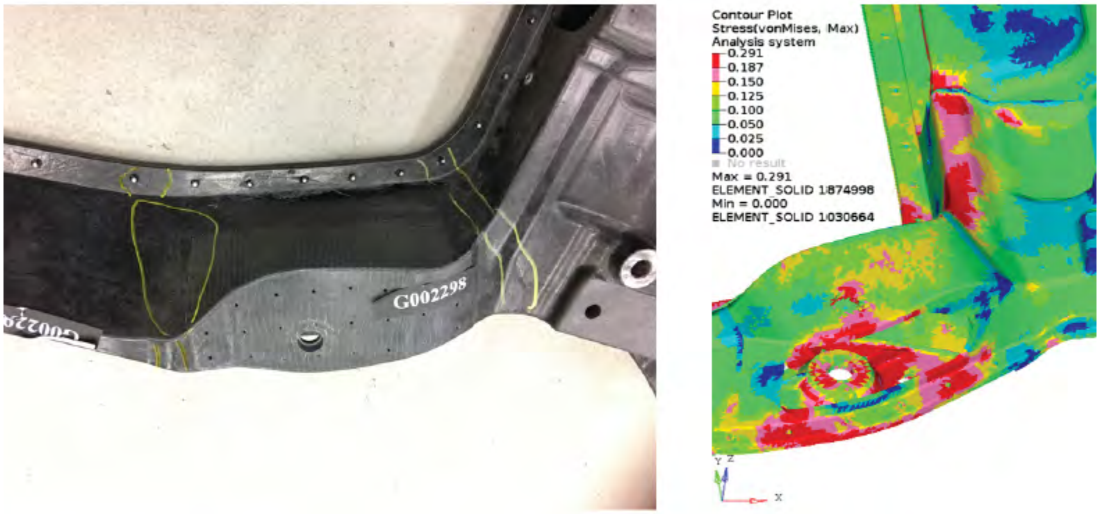


Figure 27: Strength test – control arm front joint loading CAE failure locations

Figure 28: Strength test – control arm rear joint loading

Control Arm Rear Joint Strength Test

Test Setup

For the control arm rear joint test, A "U" bracket was used to represent the control arm bushing bracket. The load was applied to the lateral direction of the vehicle shown in Figure 28.

continued on page 34...

This Issue:

Test Results

The damage started near the loading location. Figure 29 shows cracks on the subframe. The force curve is shown in Figure 30.

The peak loads of the test are much higher than 35 kN, the GSS resultant load at this hard point.

Figure 29: strength test – control arm rear joint loading damage

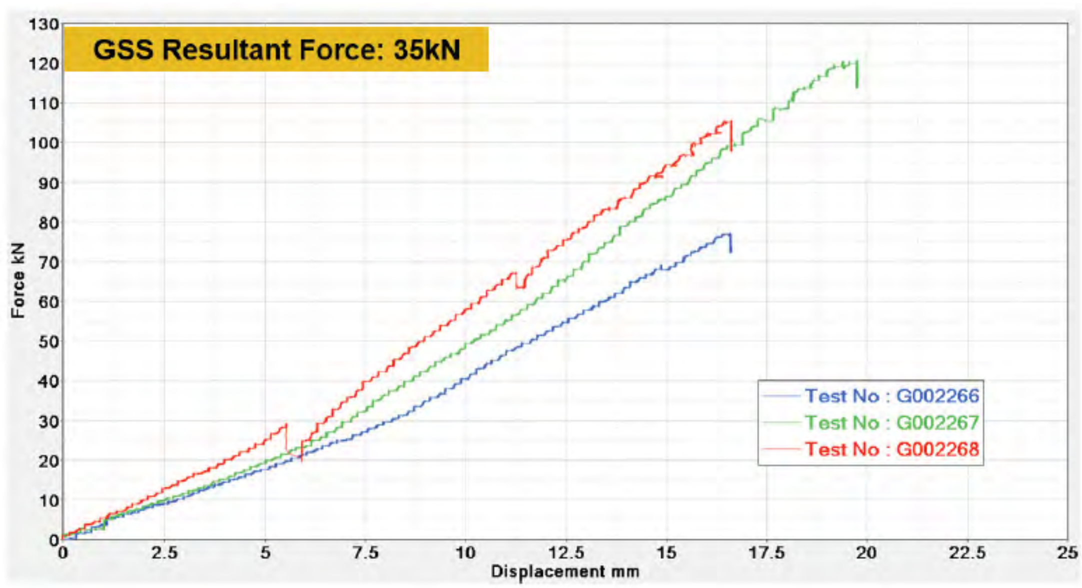


Figure 30: strength test – control arm rear joint force deflection plot

This Issue:

Test and CAE Comparison

The test results were compared with CAE predictions. The ABAQUS simulation predicted the high stress area near the rear body mount that is the same location showing a crack in the tests (Figure 31). The CAE simulation did not catch the crack between the control arm front and rear joints. The peak load predicted by the simulation is higher than the failure load of the test.

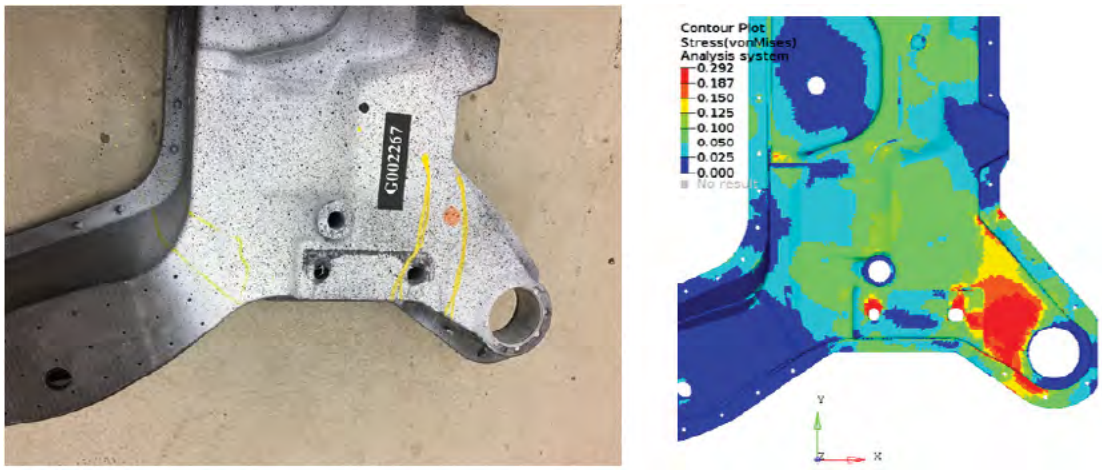
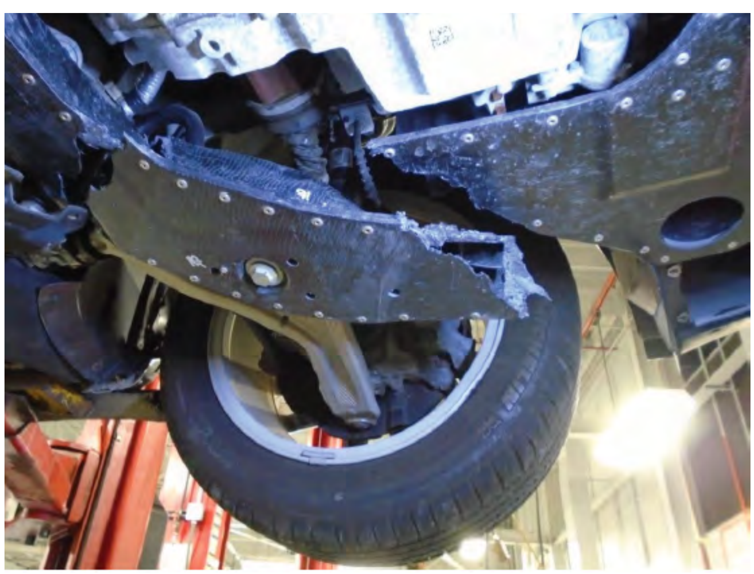


Figure 31: *Strength test – control arm rear joint loading* CAE *failure location*

Vehicle Special Event Tests

The proving ground special event test is intended to examine the effect on suspension, steering and affected body components, when subjected to shock loading as experienced when driving over curbs and braking into potholes. This procedure is part of a set of tests which evaluate the effect of severe driving maneuvers to a worldwide passenger cars, CUV's, Mustang, police cars and small sport utility vehicles [9].



The test results stated that the Fusion with a CF subframe passed the Level One test. No damage was observed at the completion of the Level One test. The vehicle did not pass the Level Two test. The subframe was damaged at one of the braking into pothole runs. The post-test photo is shown in Figure 32.

continued on page 36...

Figure 32: CF *subframe – post vehicle special event test*

This Issue:

The CAE driven design process did not simulate this dynamic loading event. This damage was not anticipated based on our knowledge with steel subframes and early development of other lightweight research subframes. We learned from this incident that a CAE procedure is necessary to analyze the response of CF chassis components under underbody impact loading.

Summary

A carbon fiber composite research subframe was developed based on Ford Fusion's package space. The prototype subframe was compression molded with EpicBlend SMC, a chopped 50k industrial-grade carbon fiber with a modified vinyl ester resin. EpicBlend CFS-Z with 0˚/90˚ NCF, was co-molded with the chopped EpicBlend SMC material. The design was CAE driven. CAE design iterations demonstrated that the CF subframe met stiffness, durability and bolt load retention performance requirements.

Both component and vehicle tests were conducted to verify the design and build of this industry first CF composite subframe.

Component fatigue tests produced multiple cracks on the subframe. Most of the cracks are small. The cracks stabilized at certain points of the tests. All tests passed the required two lives loading cycles without losing load carrying capacity. CAE simulations did not correlate with test results.

The vehicle high cycle durability test was successful. It produces less than five cracks. The cracks propagated and stabilized as the test progressed. The vehicle maintain all functions through the test. No fastener torque loss was observed after the test. CAE simulations did not correlate with test results.

Component strength tests were completed with satisfied results. The peak loads exceeded the GSS loads at all tested hard points. CAE predictions captured most failure locations. CAE predicted peak loads were higher than test loads.

The Vehicle special event Level one test was completed. The vehicle did not pass the Level Two tests.

One of the challenges of the CF subframe design was the material input for CAE simulations. More efforts are needed to create material models for CF composite analyses.

Acknowledgements

The CF subframe prototypes were built at Magna International. We acknowledge Armando Perez and Vijay Gabbita for their contribution on design and CAE analyses, Rudy Schrempf for developing the molding process. The fatigue tests were conducted at Ford Building #4 test lab. We acknowledge the contributions of our Ford colleagues Jonathan McDonalds and Tom Miller for conducting the tests. We also received support from Ford Chassis Engineering team, Hasan Kabir helped to develop test load cases, and Sukhwinder Dhindsa shared his test documents. The strength tests were conducted at Ford Safety Innovation Lab. We appreciate the help from Stephen Stewart and Joe Chou for developing and conducting the tests. We also want to thank Jeff Wallace for his support on fixture design and builds.

continued on page 37...

This Issue:

Award Winning Paper continued...

Bibliography

1. Wagner, D., Chen, X., Uicker, J., Weiler, J., Swikoski, A., Bolar, N., Ford Lightweight Subframe Research and Development, Automotive Engineering Digital Edition, May 2019
2. Bolar, N., Chen, X., and Wagner, D., "Carbon Fiber Subframe Design and CAE," SPE ACCE, September 2019.
3. OptiStruct, HyperWorks version 2017.2.2, Altair Engineering, 2017
4. Nastran, 2018.2.1.0 Production, MSC Software 2018
5. nCode , HMB-nCode
6. ABAQUS, 6122 Production, Dassault System
7. Ford fastener Handbook
8. Ford Global Structural Durability Test for Passenger Cars, CUV and Small SUV Vehicles
9. Ford Suspension System Vehicle Strength

Sponsor the Newsletter

This Issue: