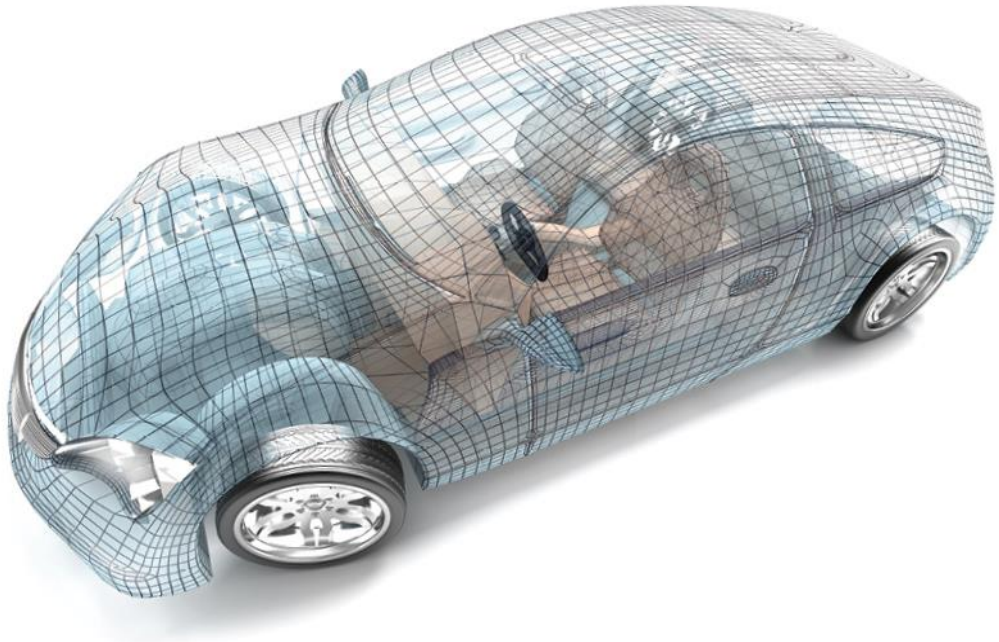
TCC 2020
THERMOPLASTIC COMPOSITES CONFERENCE

A VIRTUAL EVENT
APRIL 29 – MAY 1, 2020



Long Fiber Thermoplastics for Offshore Applications

Presented By: Brian Pillay
Professor, Materials Science and Engineering
MPAD Center, University of Alabama at Birmingham.

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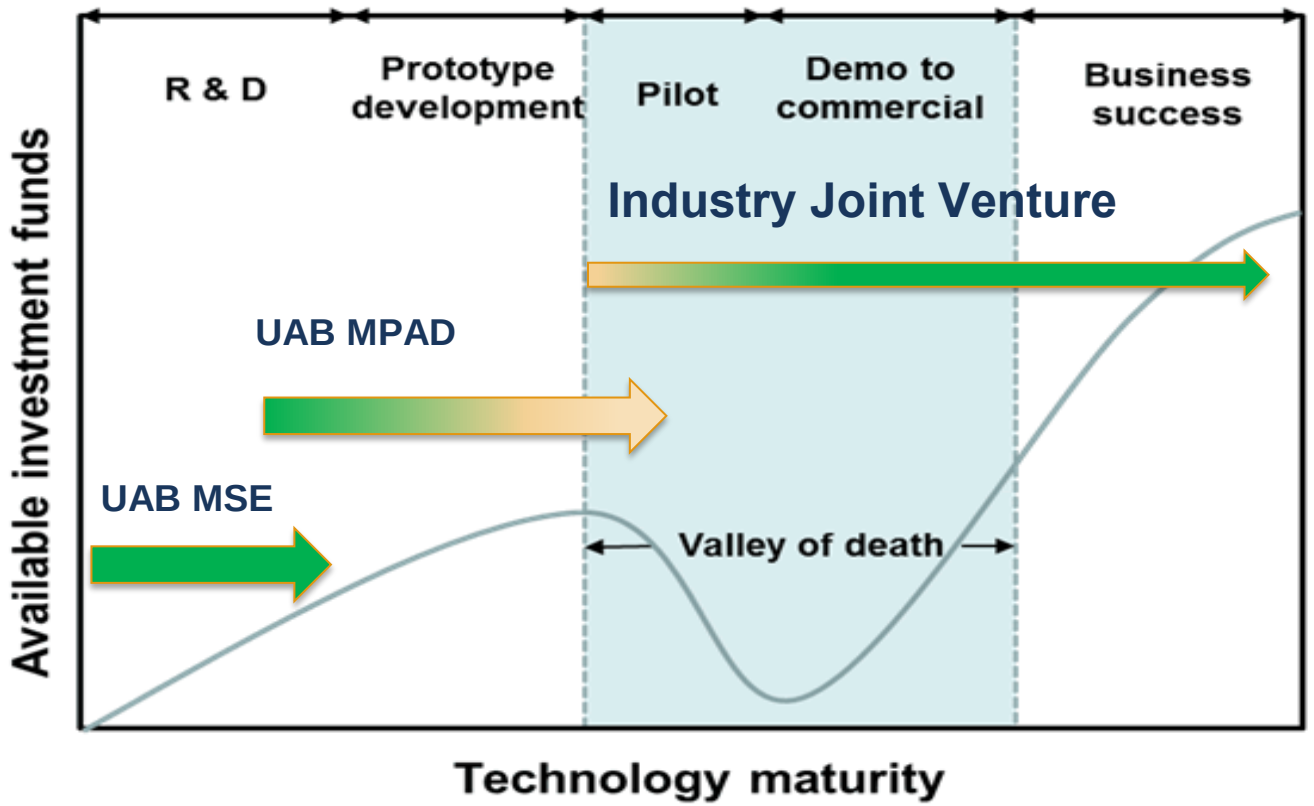
Materials Processing and Applications Development (MPAD) Center



- 20,000 square foot Materials Solutions and Applications R&D Facility
- University-Industry Partnership for translation and commercialization (translation of TRL 6-7 prototype applications to manufacture)
- Stimulate local, regional and national Economic Development by creating opportunities for new companies and expand portfolio of businesses

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Material Forms – TPC Manufacturing

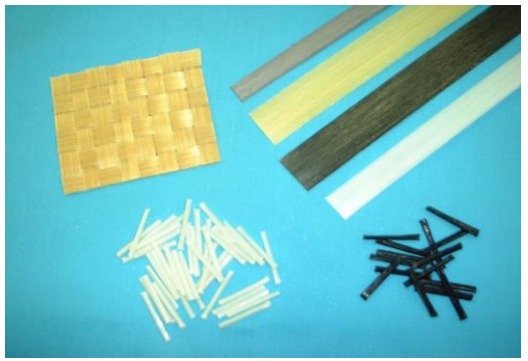
Thermoplastic Matrix Composites

- **Continuous fiber reinforced thermoplastics**
  - **Unidirectional tape**
  - **Woven prepreg**
  - **Other forms (braided prepreg, etc)**
- **Discontinuous fiber reinforced thermoplastics**
  - **Long fiber reinforced thermoplastics (LFT)**
  - **Short fiber filled thermoplastics**

FORMING AND FINISHING OPERATIONS

(INJECTION MOLDING, EXTRUSION, COMPRESSION MOLDING, DIAPHRAGM FORMING, THERMOFORMING, PAINTING, JOINING, ETC…)

END PRODUCT



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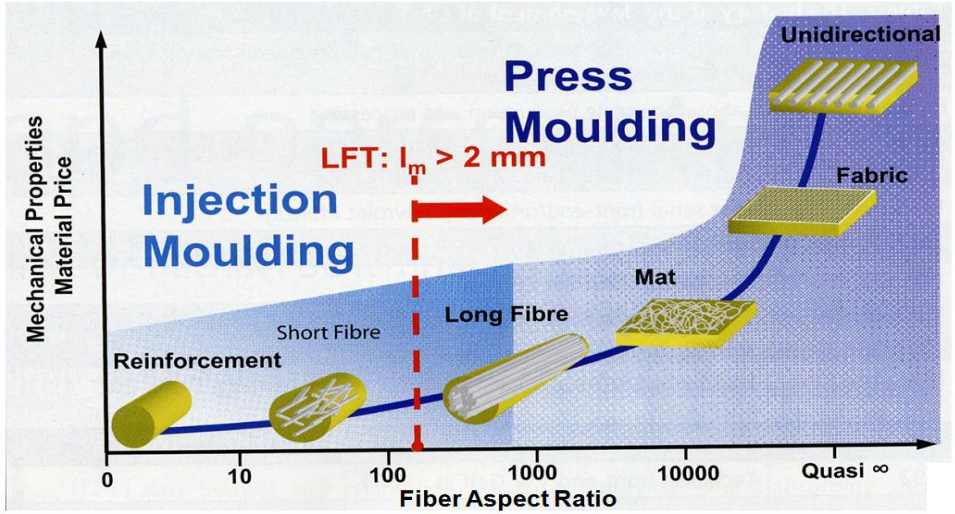
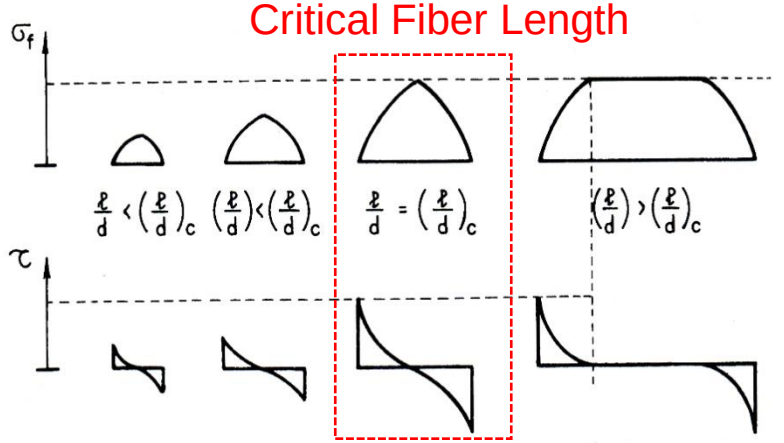
Basics – Critical Fiber Length / Aspect Ratio



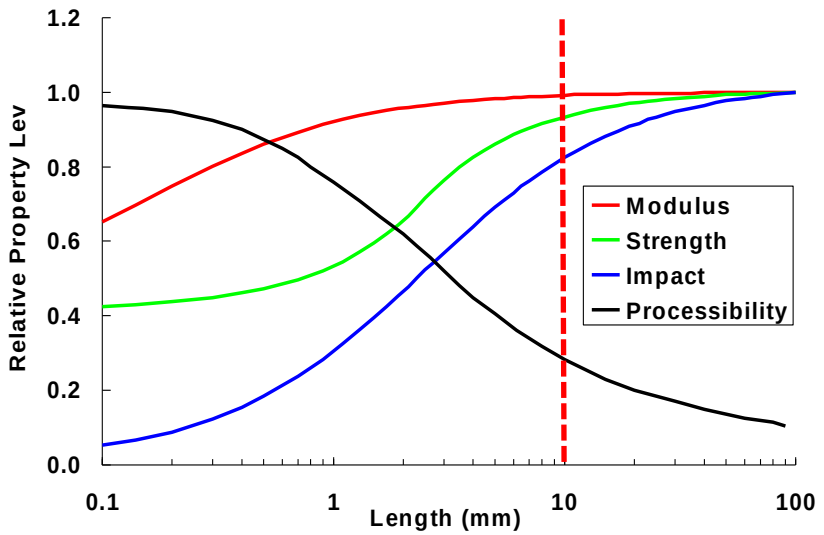
Critical Fiber Length



Critical length to diameter ratio:

Critical Aspect Ratio of Fiber

$$\left(\frac{l}{d}\right)_c = \frac{\sigma_{max}}{2\tau}$$



Chawla KK Mechanical Behavior of Materials, Reinforced Plastics – January 2008

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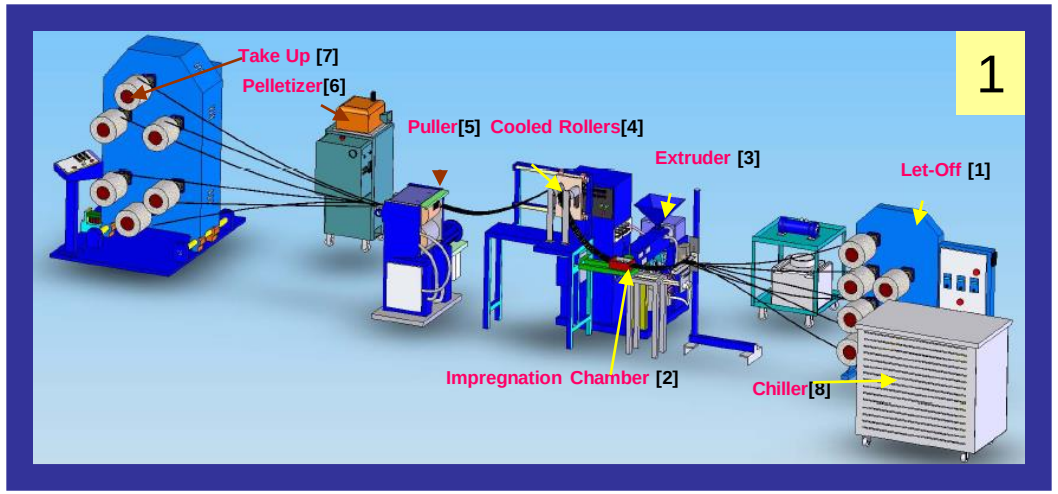
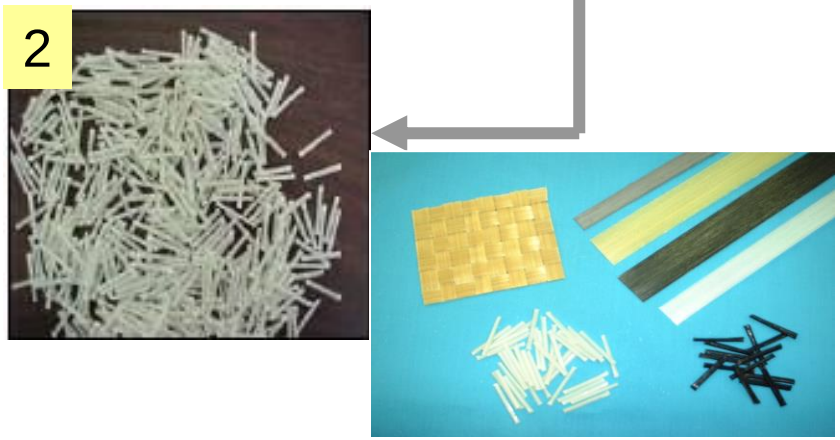
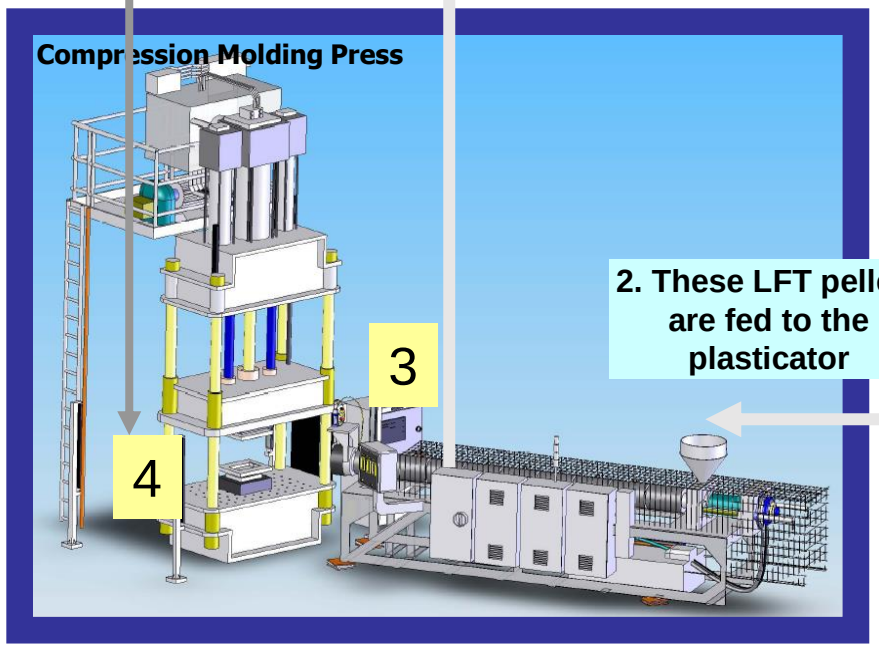
Long Fiber Thermoplastic Composites Technology



1. Hot-Melt Impregnation: Dry fibers are impregnated with extruded thermoplastic polymer in a die. The rod material is chopped into long fiber pellets (of 0.5" to 1" fiber lengths)



2. These LFT pellets are fed to the plasticator



3. The polymer in the LFT pellets melts to produce a molten fiber filled charge that is then compression molded.

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Landing String Stop Collar

ExPert E&P CONSULTANTS LLC
RISER SOLUTIONS LLC
OIL & GAS LLC

Landing String Solutions LLC.

TRELLEBORG

UAB

Partnership for Success

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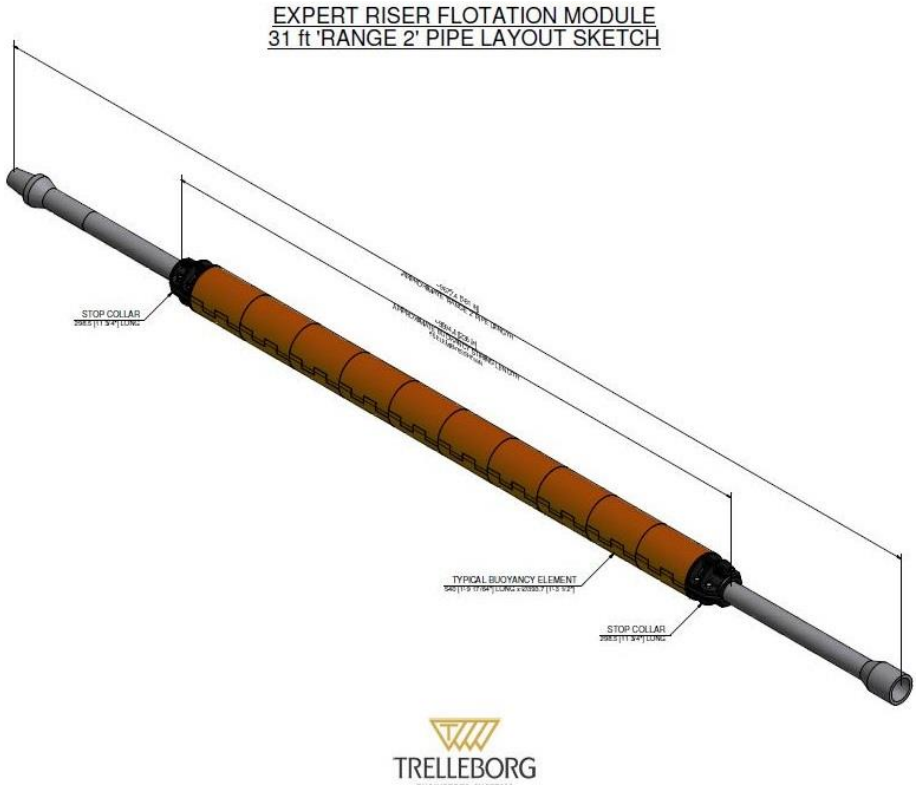
Composite Stop Collar

"Clamp" developed for offshore drilling

Requirements:

- Non-metal
- Stable in drilling environment
- Resist buoyancy force



Composite Stop-Collar and Composite Bolts

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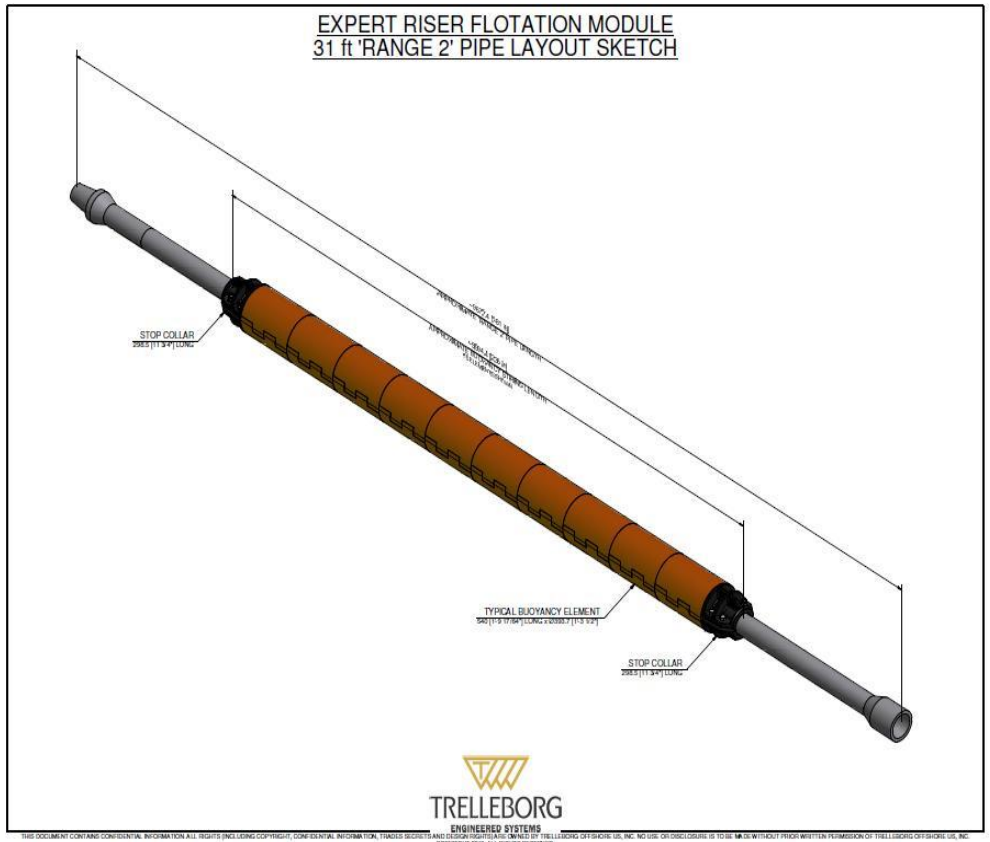
Application



- US Patent 7383885
  - Buoyancy mounted on drill pipe inside drill riser
  - Requires clamp to prevent axial motion of buoyancy
- Environment is drill mud at temperature and pressure
- Objective is reduced load on drill rig during “landing” of casing in new wells

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Application Video

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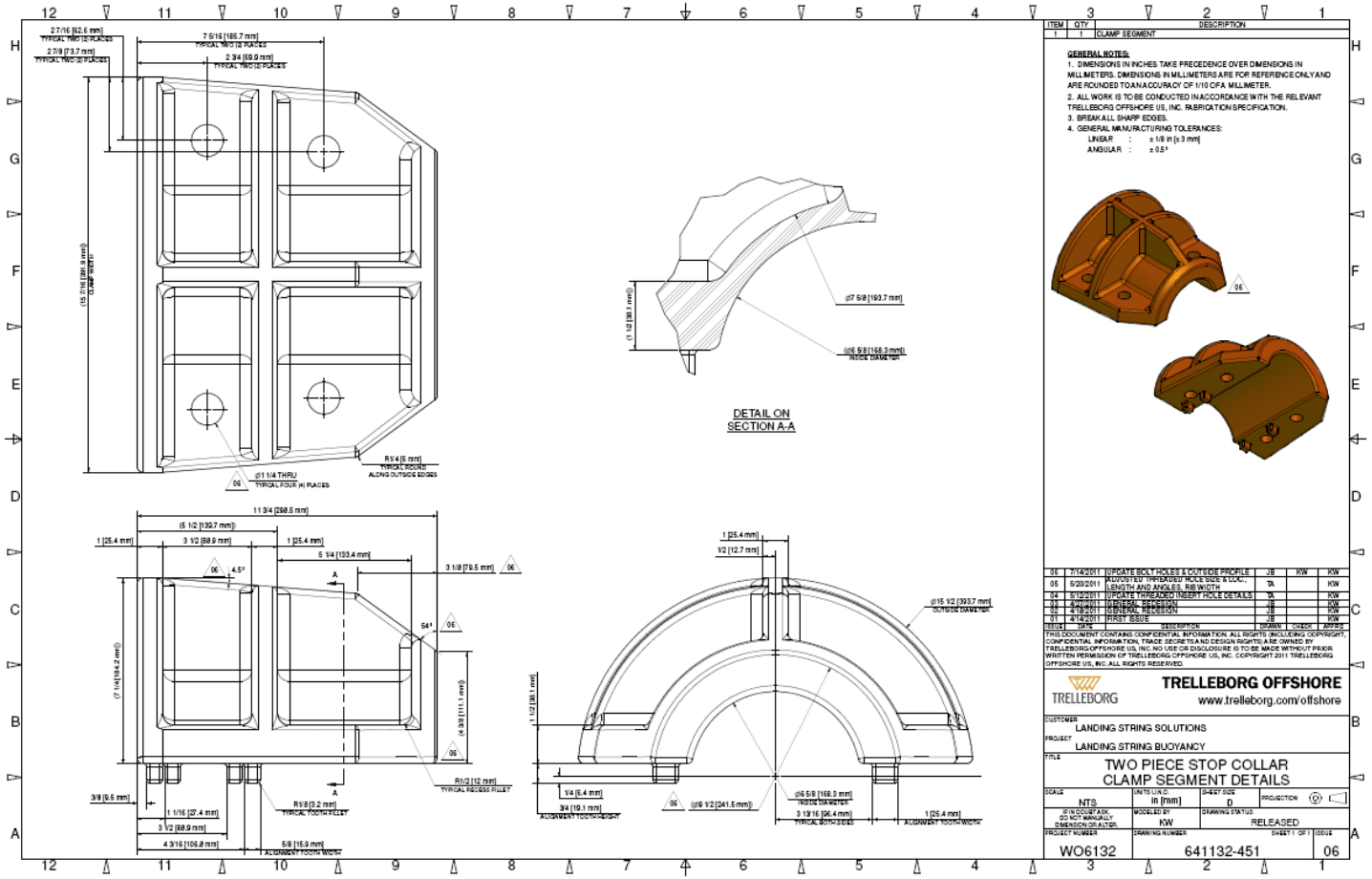
Design Inputs

Operating Environment	Maximum Temperature (°C)	Minimum Temperature (°C)	Maximum Pressure (MPa)
Olefin-based Drilling Mud	65.5	2.2	41.37
Atmospheric	65.5	-5	0
Minimum axial slip load for stop collar (kN)[1]			39.03
Bolt torque per bolt (N-m)[2]			162.7
Bolt tension per bolt (kN) [3]			38.5

- Operating environment is synthetic-based drill fluid, 8 – 15 lb/gal
  - Up to 30% water, remainder short-chain polyols and fillers
- High temperature and pressure
  - Fluid column in riser
- Collar must resist buoyancy weight in air during lifting/handling and buoyancy upthrust during service
  - Safety factors
  - Calculated using 15 lowest density modules in 15 lb/gal olefin-based drill mud.
  - Measured torque at which slip load requirement was met.
  - Calculated upper bound of possible tension generated by 120 lbf-ft torque.
- Design constraints:
  - No metallic components
  - Minimize the amount of ‘trap points’ for the drilling mud

TOUS composite stop collar clamp – original design



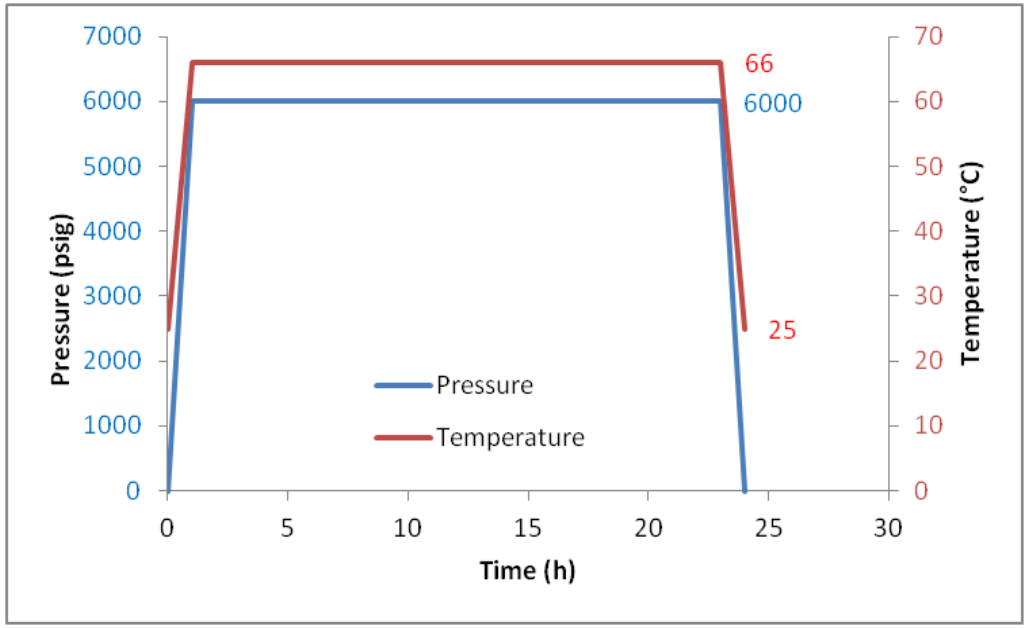
Qualification requirements

- Mechanical testing
  - Lab samples
    - As-produced
    - Aged
      - 14 cycles to max. service conditions
    - Fiber flow considerations
- Finite element analysis
  - Majority – ANSYS
    - TOUS validation – ABAQUS
  - Average inputs from both conditions
  - Two simulation steps
    - Torque-up
    - Slip
- Product
  - Material utilization no greater than 40%
  - Fit-up
  - Slip load testing
    - Ambient
    - Hot
  - Torque – Clamping force correlation
    - Ambient
    - Hot
  - Friction characterization

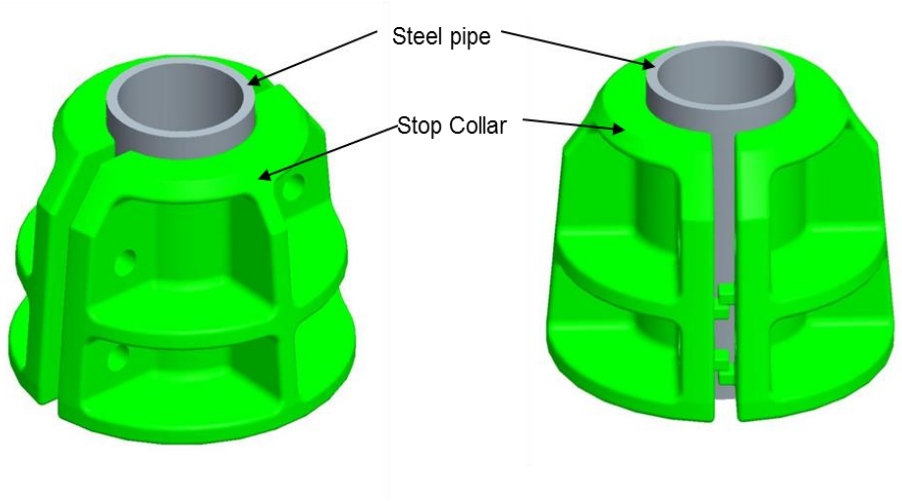
Material aging plan

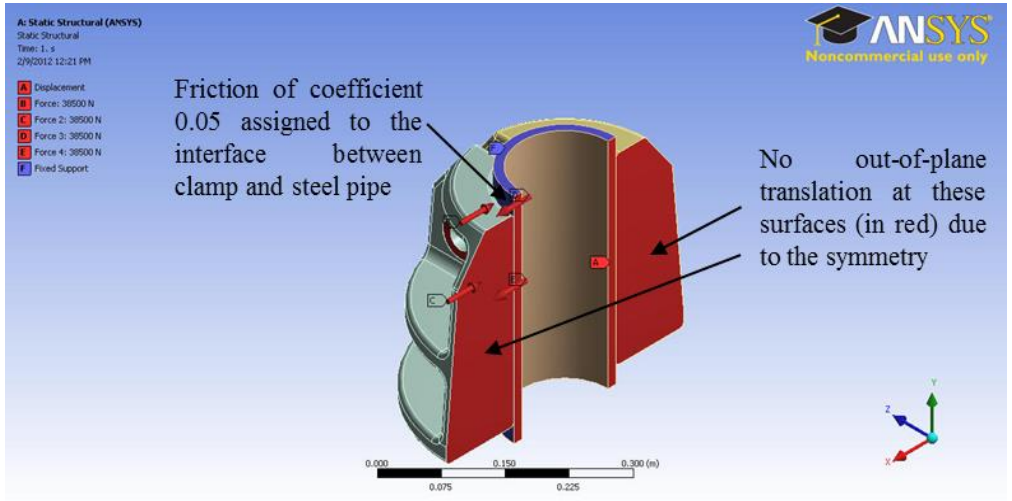
- Sample lots of various composite materials were submitted for cyclic aging
  - Intertek Westport Laboratories, Houston, TX
- Heated, pressurized, olefin-based drill mud
- Densities ranging from 8.0 to 14.0 lb/gal
  - MI Swaco under the Rheliant System moniker
- Conditions for 1 cycle at right

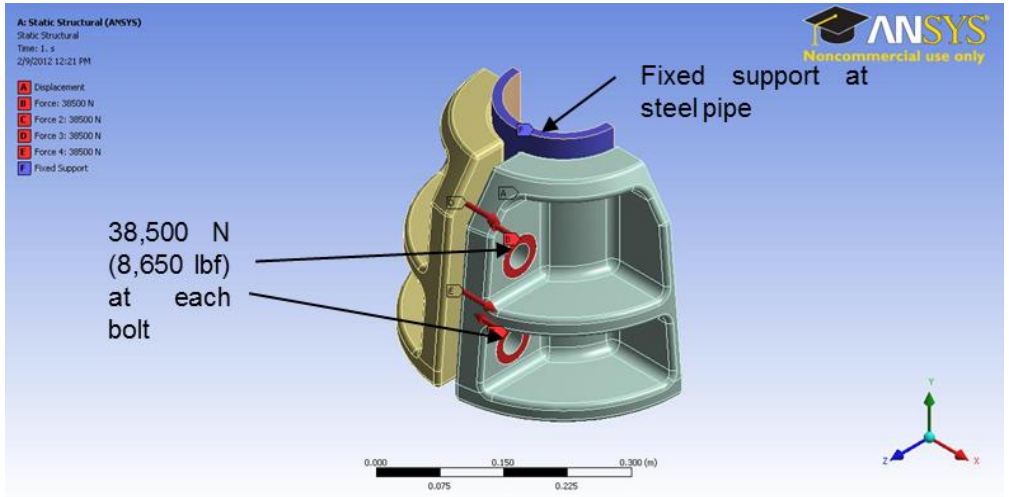
Number of Cycles	Temperature (°C)		Pressure (psi)		Total Time per cycle (h)	Pressurization Rate (psi/min)
	Initial	Hold	Initial	Hold		
14	25	66	0	6000	24	100



FEA: Setup, boundary conditions, load cases







- Material data from testing
- Design geometry
- Load cases
  - Bolt tension from initial trials – 38.5 kN
  - Apply temperature – 65.5 °C
  - Axial load on bottom flange – 39.03 kN

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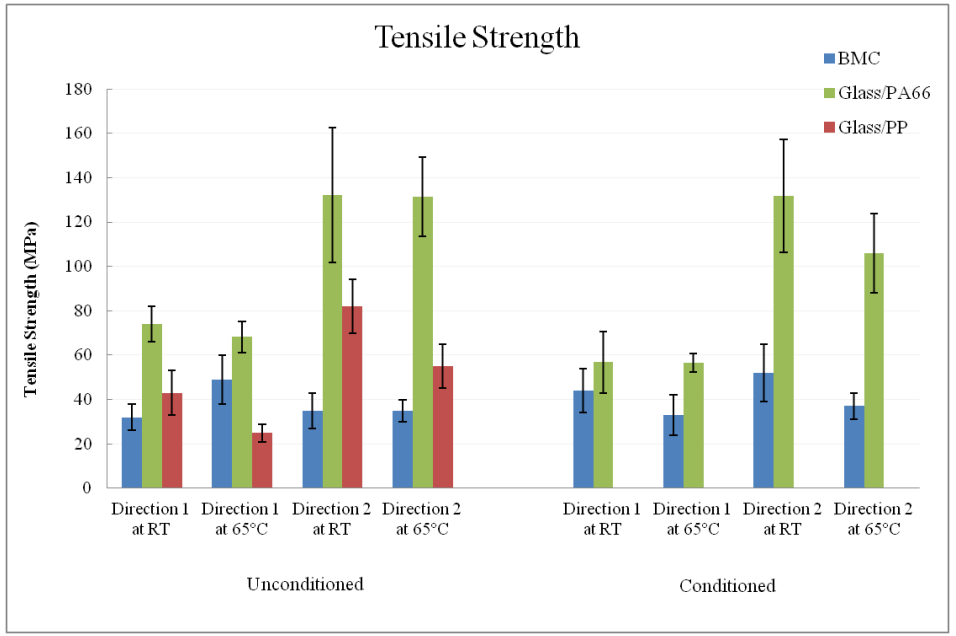
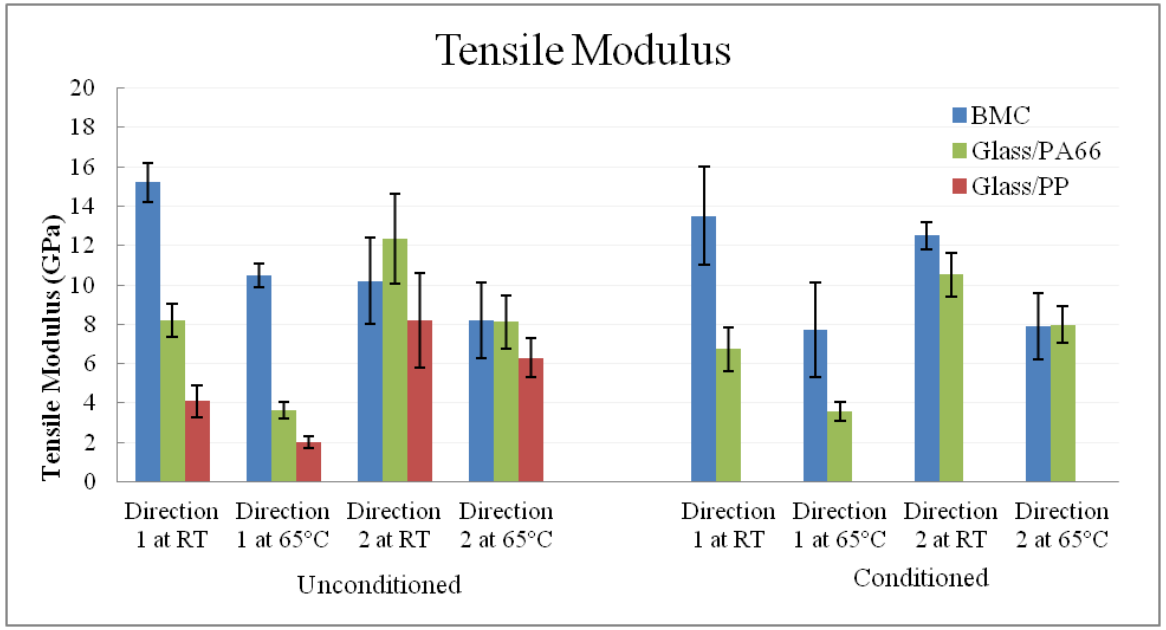
Materials considered

- Particulate-filled, cast, thermosetting polyurethane
- Reactive glass fiber reinforced thermoplastic PBT
- Polyester-based, glass fiber reinforced bulk molding compound(s)
- Long fiber thermoplastics
  - Glass fiber reinforced
  - Matrices
    - PP
    - PA 66
    - PBT
    - TPU
    - POM
- Testing
  - RT and 65.5 °C
  - Both conditions

Material testing results - tensile





- Glass fiber PP eliminated after initial testing
- Glass fiber reinforced PA66 and a BMC evaluated in both un-aged and aged condition
- BMC stiffest, but PA66 had higher tensile strength
- Average performance used as FEA inputs

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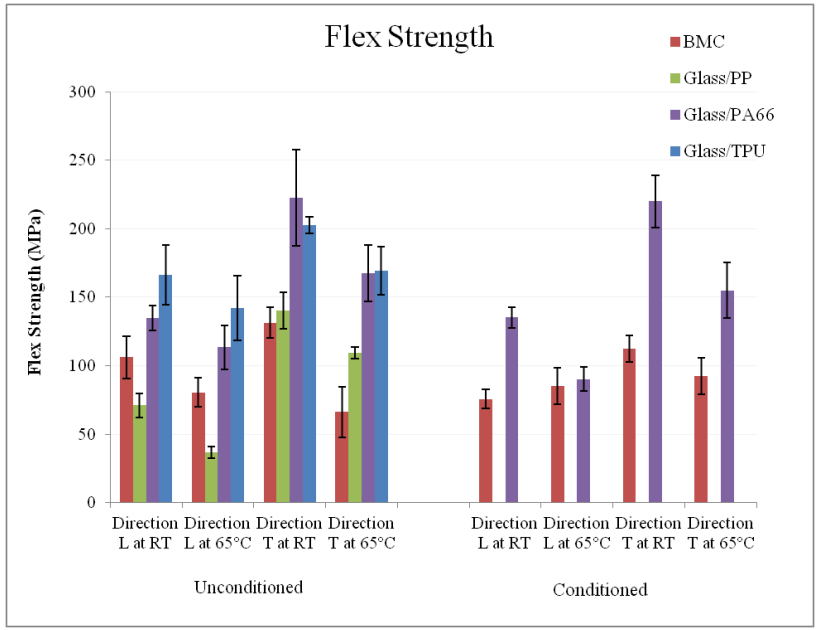
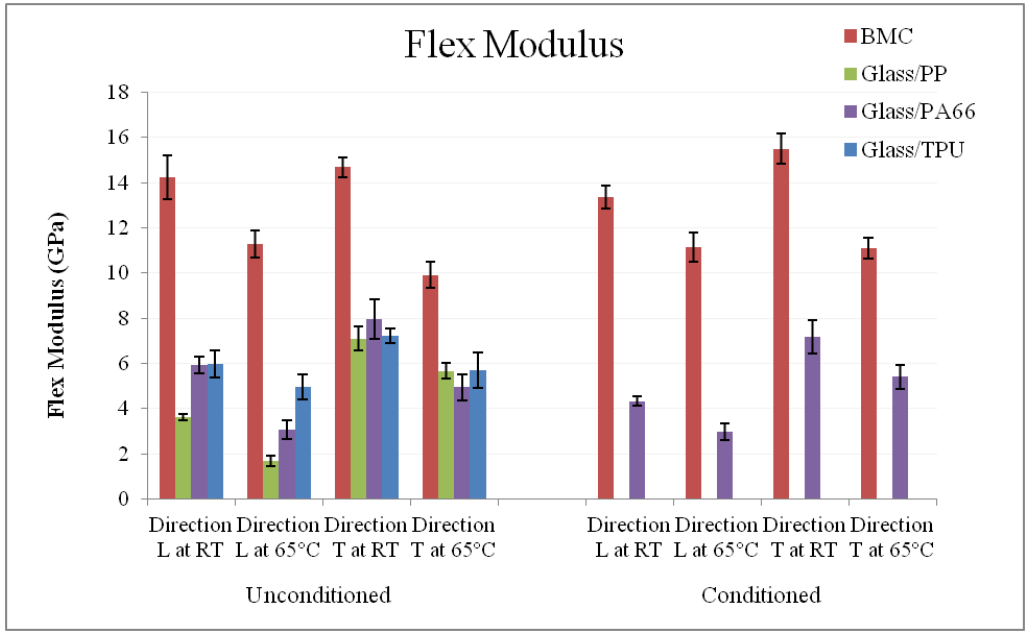
Material testing results - flexural





- Glass fiber PP eliminated after initial testing
- Glass fiber reinforced PA66 and a BMC evaluated in both un-aged and aged conditions
- BMC was stiffest but PA66 had the best flexural strength
- TPU material performed very well but was not aged due to raw material cost

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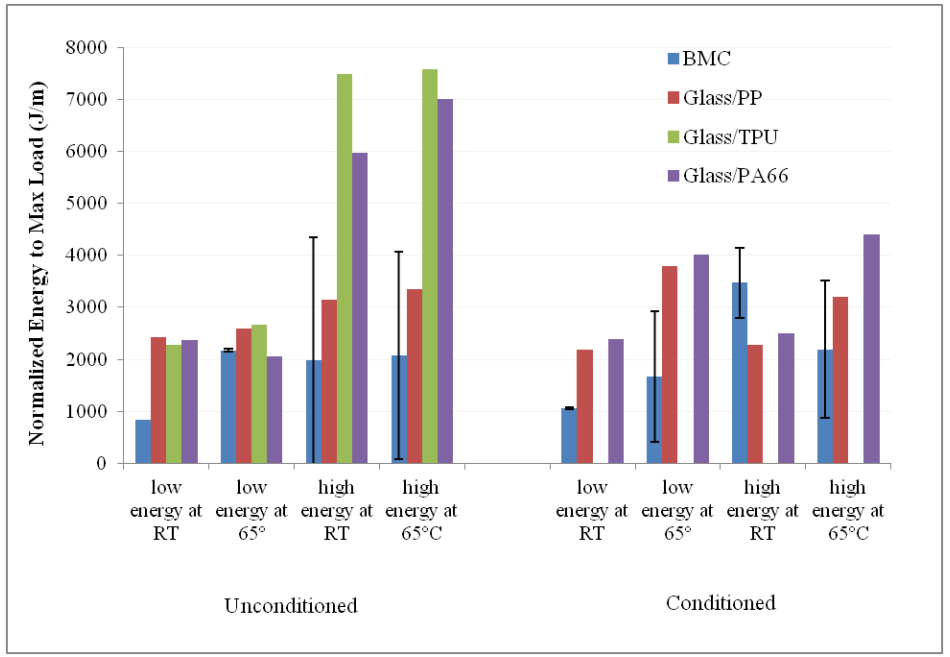
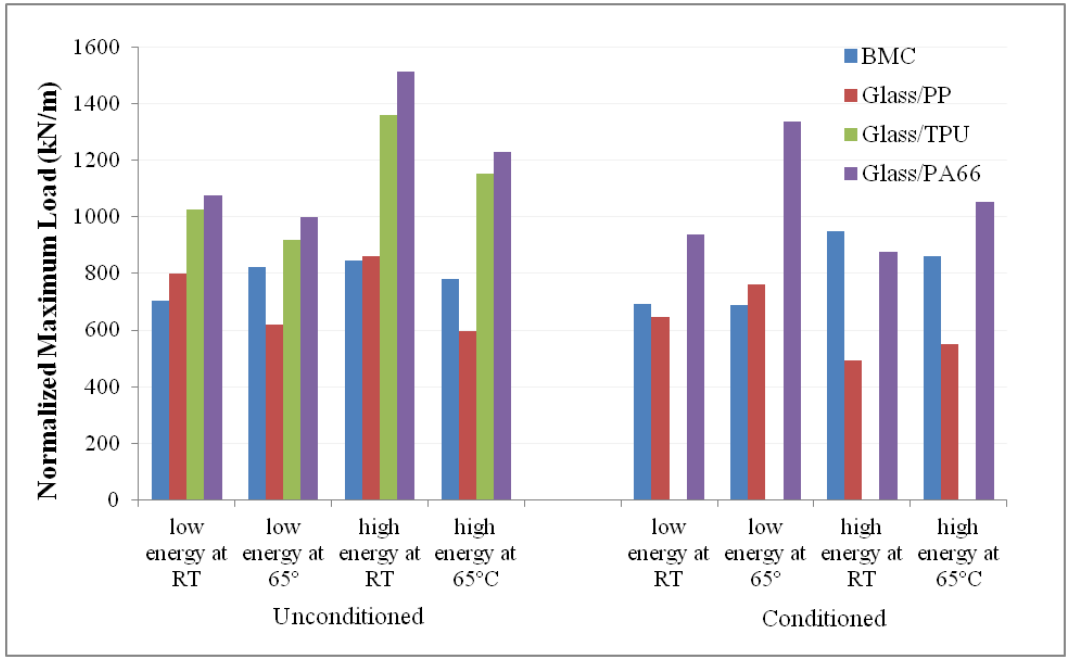
Material testing results – low velocity impact





- LFT materials outperform BMC
- Useful design information due to potential impact conditions of collar with spider rollers
  - NOT an analysis design criteria

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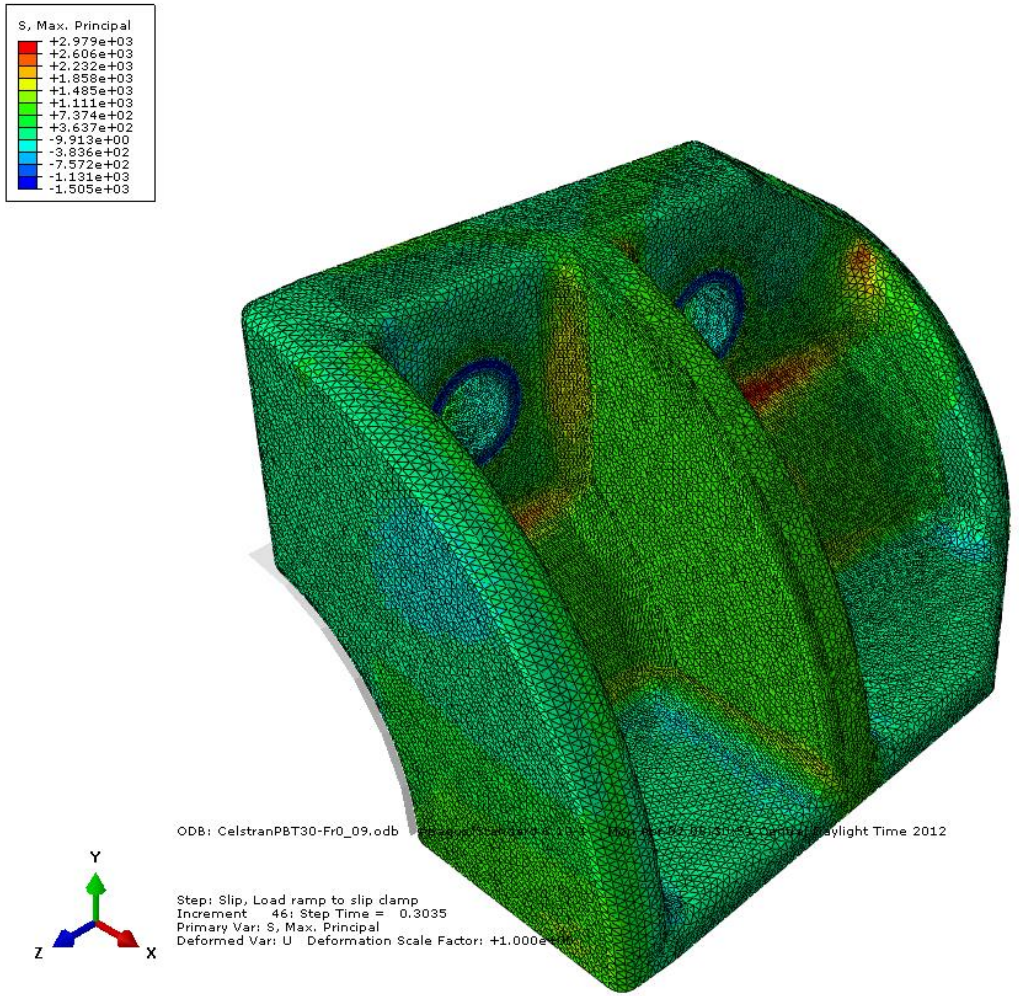
Finite Element Analysis

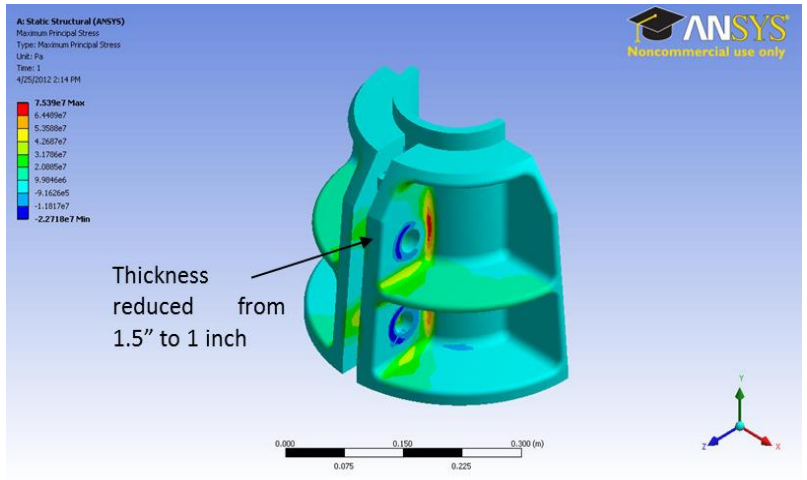
- FEA Workflow
  - Evaluation of maximum stresses in the three load cases
    - Torque
    - Temperature
    - Slip
  - Bolt torque-up is the critical case for part design
- Select material
  - SF >= 2.5?
  - Design optimization
    - Geometry “tweaks”
    - Subsequent runs examine this case exclusively during optimization
- Re-evaluate all load cases at final design point

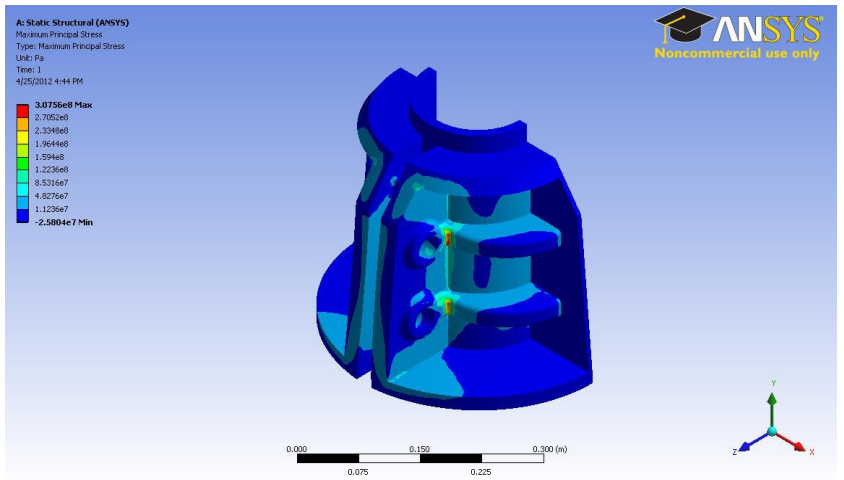


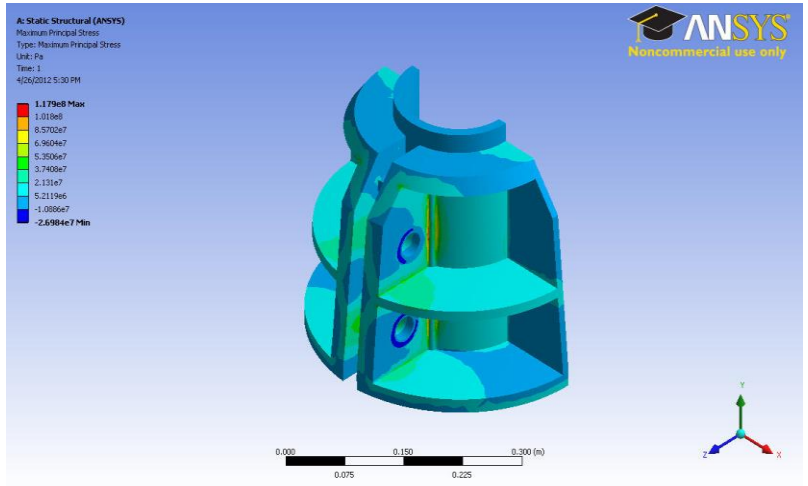
Design optimization

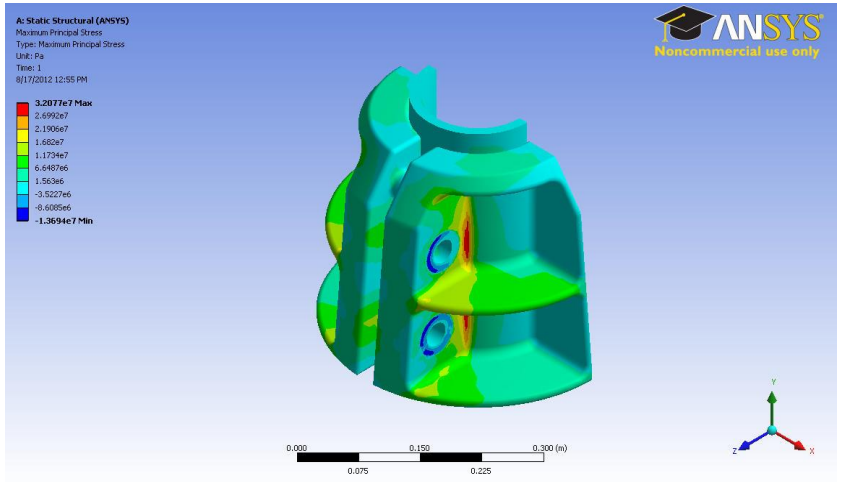
- None of the initial FEA analysis showed a material utilization of under 40%
- PA66 LFT
  - Utilization of 46 – 53% with initial design
  - Selected for design
- FEA to optimize collar design
  - Minimize stress during torque-up
  - Variables:
    - Fillet sizes
    - Rib placement
    - Rib geometry
    - Bolt facing
    - Flange thickness
    - Flange geometry

Optimization - Intermediate designs









- Clockwise FTL – reduced thickness, modified ribs, fillet radius, flange increased thickness
- None produced a material utilization less than 40% for the worst case loading

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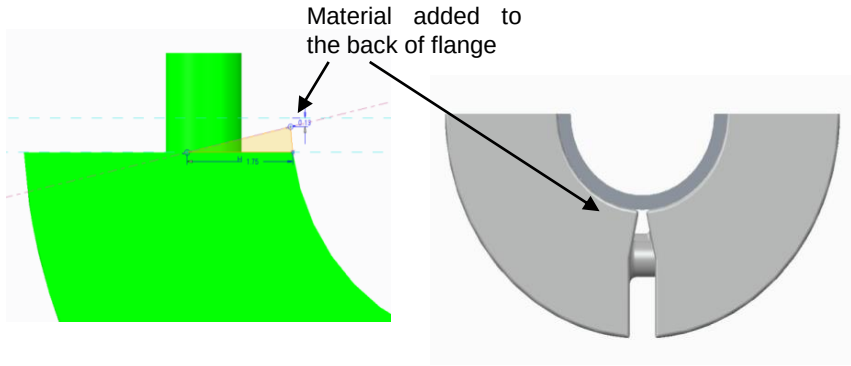
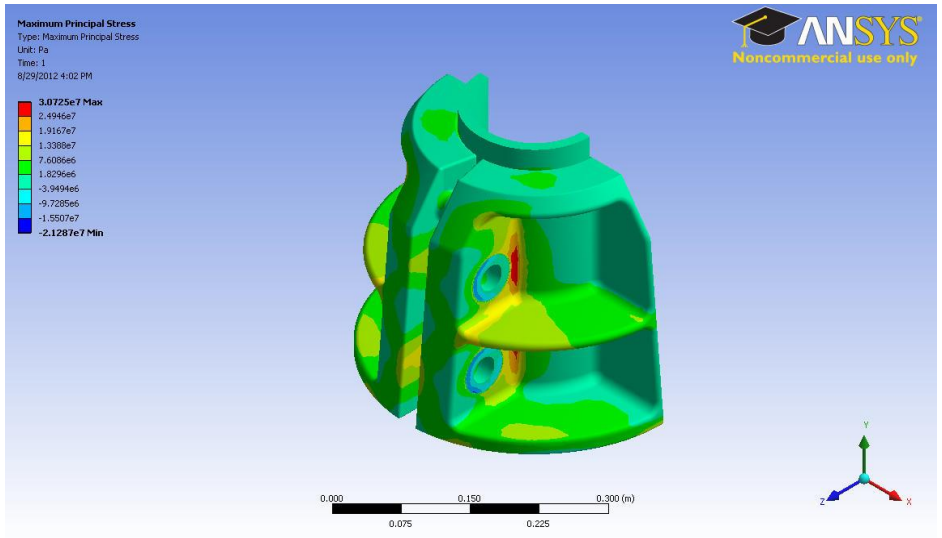
Optimized design

- Flange thickness is increased
  - 3.81 cm to 4.45 cm
- A slope is added at the back side of the flange
- 3.16 % material usage reduction from original design
- Highest material utilization in any load case
  - 38 % (i.e, FS =2.61)





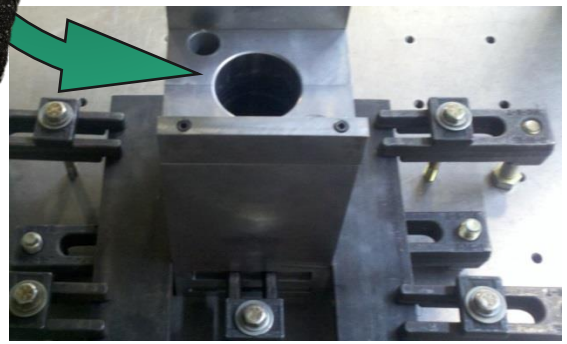
Processing

LFT Pellets or
Recycled Regrind

Plastication

LFT Charge

Extrusion/ Compression Molding



Performance Tests

Clamp Slip/Friction

Bolt/Nut Strength

Torque & Preload

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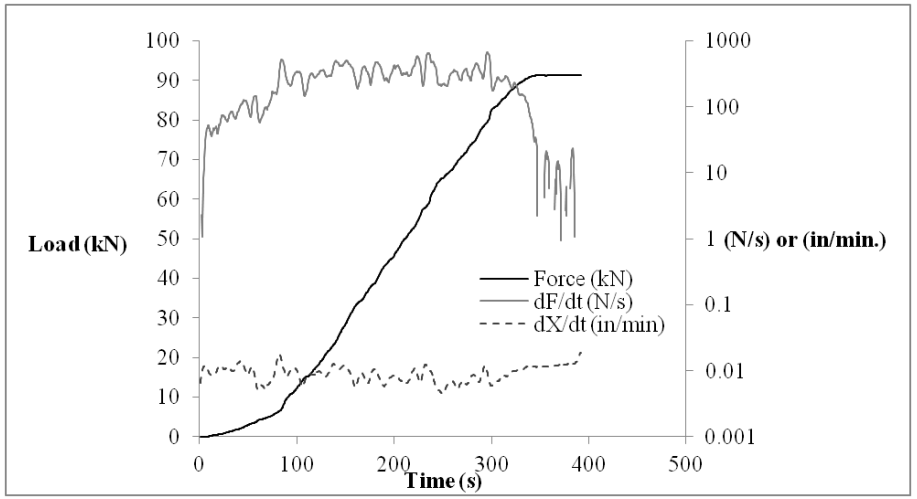
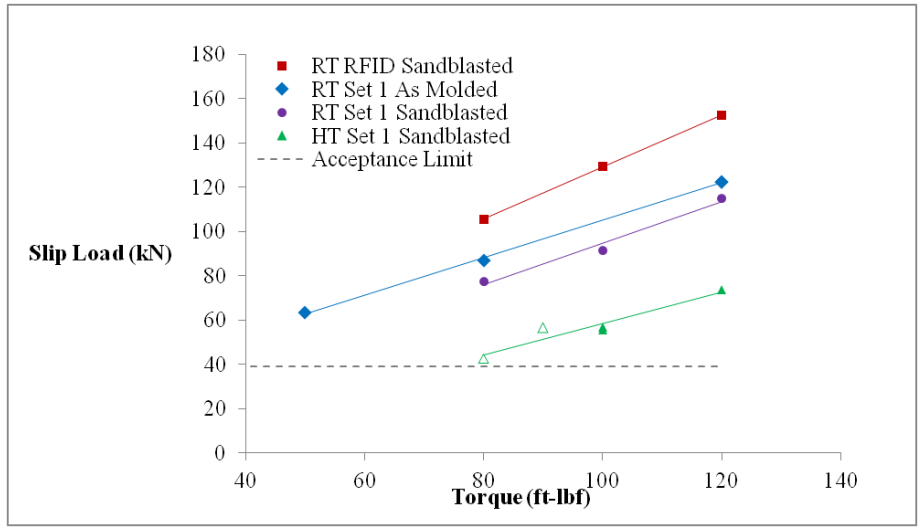
First article evaluation

- Initial samples were extrusion-compression molded at MPAD facilities
- Subjected to bolt-torque and slip testing at room and elevated temperatures
- Successful design
  - Slip loads of up to 140 kN realized at initial design bolt torque
  - 33% bolt torque reduction achieved while still meeting minimum slip load criteria of 39.03 kN





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Results

- Industry/University partnership successfully developed first composite stop collar application for offshore oil and gas
- Combination of materials and design
  - Glass fiber, PA66 LFT material
  - Extrusion compression molding
  - Iterative FEA design optimization
- Composite LFT design passed all qualification tests
- Composite Hardware performed better than alternative commercial options.
- Prototype to final product in **10** months.

Actual Drill String Unit and Drill Pipe

Full Drill String Test

- UAB MPAD was contracted to manufacture 750 Clamps and 1500 sets (1 bolt with integrated washer, 1 flange nut and 1 jam nut) of hardware.
- Final delivery of all components and complete buy off from end customer in 9 months

Assembly of Clamp and Buoyancy Module on Drill String

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Fully Assembled Drill String

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Results of Full String Test

- The trial was successfully conducted
- There were some issues with handling of the string, jaws grabbed onto clamp (operator error); however clamp and hardware, even in damaged condition, successfully maintained buoyancy in position.
- The use of the string resulted in $42 million saving

Thank You for Your Attention

Contact Information

Brian Pillay: Professor and MPAD Director, Department of Materials Science and Engineering, UAB
Phone: 205 9965797 /205 9348450
Email: pillay@uab.edu