Challenges and Solutions in Developing Ultra-high Pressure Flexibles for Ultra-deep water Applications

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Imagination at work.

confidentiality disclosures.

New Technology – Design, Qualification and Application
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Market Demand and Current Status

- Current Comfort Zone
- Qualified Pipe Structures

- New developments using existing and new technology
- Deep water gas fields
- Deep water oil fields
- Radical new technology and new design concepts
- Demand for Deep water Pipes
- Gulf of Mexico deep water tiebacks 15/20 kpsi
- Current Comfort Zone

Pipe Internal Diameter (mm) vs. Water Depth (m)

Pipe Internal Diameter (inch) vs. Water Depth (ft)
Limitations and Challenges

Four main layers:
- Internal Carcass
- Polymer Barrier
- Pressure Armour
- Tensile Armour

Aimed at qualifying a 4 inch 20kpsi pipe for 3 km water depth (Deepstar Programme)

Key Challenges:
- Integrity of polymer barrier
- Prevent carcass collapse
- Containment of pressure – FAT
- Management of weight
- Development of end fittings
- Satisfy Industry design standards API 17J (ISO 13628-2)
Design of Internal Carcass

Carcass is made of metal - flat strip deformed into a profiled tube

Typical profile shape

Collapse pressure is a function of all above variables, strip material and profile shape

Design Issues

- Carcass material (316L, 22Cr duplex, etc.)
- Collapse pressure (water depth)
- Profile shape (height & width)
- Spiral pitch (bending requirements)
- Strip size (manufacturing capability)

Larger water depth and larger pipe diameter require heavy and stronger carcass which increase the weight of the pipe

Wet collapse:
When the fluid pressure is applied outside of the barrier
Accurate prediction of collapse pressure is difficult and require sound FE model procedures.

Based on the API assessment procedure current GE collapse capacity predicted for 100mm / 4-inch pipe is 3.5 km sea water depth.

Actual qualification test data shows that a 150mm /6-inch GE pipes can withstand 4 km water depth (before safety factors are applied for design purposes).
Integrity of Polymer Barrier

Extruded polymer tube

Barrier is trapped between pressure armour and carcass

Can be single layer or multi-layer extrusions

Barrier stress-strain analyses are performed using FE models of pipe structure

Axisymmetric Models

Considering all layer interactions

Major Issues

- Qualify for API 17J Requirements (ISO 13628-2)
- Material Integrity – failure / damage modes
- Fatigue – stress / strain concentrations
- Low / high temperature effects
- Dynamic interactions between layers
- Development of end fittings with seal integrity
- FAT and offshore field tests
- Integrity of the pipe under rapid depressurization
Challenges in Developing HP & HT Barrier

**Polymer crazing at high pressure**

Crazing will occur in places of high strain if not controlled / prevented

Currently PVDF is used for barrier in all high pressure pipes operating above 70°C service

Pressure limit for using in high pressure pipes is determine by crazing performance

**Rapid gas depressurisation**

Blistering will occur in some materials if depressurisation rates exceed certain limits.

**Creep & ingress in to armour gaps**

Polymer ingress in to gaps
Strain Analysis of Barrier at High Pressure

Critical loading for crazing is during FAT and field pressure tests

FAT performed in Reels

Axial strain and hoop strain in the barrier during FAT

Observation of crazing in barrier of high pressure pipe

Crazing due to axial strain

Crazing due to hoop strain

Prevention of crazing is essential to have barrier integrity at ultra-high pressures
Assessment of Crazing Performance of Polymer

Crazing Test Set-up

Crazing Behaviour of Polymer

Based on crazing performance tests PVDF is not an acceptable barrier material for ultra high pressure pipes.
New Barrier Material CR1404HTP for High Pressure Pipes

CR1404HTP is a TFE + VDF copolymer exclusive to GE

- A fluoropolymer built from the same chemical building blocks as PTFE and PVDF
- Excellent chemical resistance and very low gas permeability at high temperature.
- Contains no plasticiser so no risk of pressure sheath shrinkage.
- No need for impact modifier additives as ductile brittle transition < -40°C.
- Fatigue and creep behaviour better than PVDF
- Temperature performance up to 150°C - better than PVDF
- Excellent resistance to crazing at ultra high pressures

CR1404HTP has not shown crazing at 30kpsi pressure with 18% local plastic strain

Successfully completed FAT at 24 kpsi in a 4.75 inch pipe (15 kpsi design pressure) bent to 2.4 m radius

Plan to build a 4 inch pipe (20 kpsi design pressure) and perform FAT at 30kpsi.
Design of Pressure Armour

Function of the pressure armour is to resist internal pressure.

Based on available carcass design for 3 km water depth maximum pipe internal diameter is limited to 150 mm.

Due to manufacturing limitations the pressure armour wire thickness needs to be below 12 mm.

Single pressure armour (8 mm and 10 mm) is insufficient to achieve design pressure of 15 kpsi.

Dual pressure armour required:
8 (+ 8) mm wires can give 15 kpsi
10 (+10) mm wires can give 20 kpsi
**Weight Management**

**Weight of the pipe**
- Carcass
- Pressure Armour
- Tensile Armour
- Polymer

<table>
<thead>
<tr>
<th>Case</th>
<th>Nominal Diameter (D mm)</th>
<th>Design Pressure (P MPa)</th>
<th>Water Depth (L m)</th>
<th>Carcass</th>
<th>Hoop</th>
<th>Tensile</th>
<th>Pipe Weight</th>
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</table>

**Graphs:**
- **Top Tension** vs. Riser length from top (m)
- **Allowable Tension** (~Installation Limit)
- **Top Tension with stepped buoyancy**
Selection of Tensile Armour

Multiple helically formed wires

Used to support axial load mainly due to weight. Pairs of contra-wound layers to give torsional stability. Lay angle optimised during pipe design to balance axial capacity and hoop strength, giving additional support to the pressure armour layer.

Failure Modes – Fatigue and Buckling

Deep Water 3 km

High Pressure 20 kpsi

Established Materials

New Materials

2 Armour

- Hoop - OK
- Tensile - Not Acceptable

4 Armour

- Hoop - OK
- Tensile - OK

2 Armour

- Hoop - OK
- Tensile - OK

4 Armour

- Hoop - OK
- Tensile - OK

Not ideal, significant buoyancy required

buoyancy or split riser design

Tensile wire buckling resistance is also a consideration. The minimum bend radius of the pipe depends on water depth.
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Project Team
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Any Questions?