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Performance in Composites

Continuous Fiber Composite Electrofusion Coupler

Project ID # MN015

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Automated Dynamics

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Overview

Goal

To advance the state of the art for hydrogen transmission and distribution by improving the joining method.

Barriers

- D. High As-Installed Cost of Pipelines (Delivery)

Timeline and Budget

- Project Start Date: 12/31/15
- Project End Date: 12/31/18
- Total Project Budget: $1,876,865.00
  - Total Recipient Share: $376,865.00
  - Total Federal Share: $1,500,000.00
  - Total DOE Funds Spent*: $38,990.00

* As of 3/31/16 by ADC

Technical Targets	
Transmission Pressure (bar)	100
H_2 Leakage	< 0.5%
Lifetime (years)	50

Partners

- DOE: Project Sponsor
- SRNL: Project Partner
- NOV: Project Partner
- Automated Dynamics: Project Lead

Relevance

- Design and test a continuous fiber reinforced thermoplastic electrofusion coupler (CFRTEC) that will be used to join two sections of reinforced thermoplastic pipe together in the field during pipeline installation.
- The CFRTEC will have a service rating of 100 bar per the technical target.
- The CFRTEC will have a leak rate less than 0.5% of the flow through the pipeline per the technical target.
- The CFRTEC will have a service life of 50 years per the technical target.

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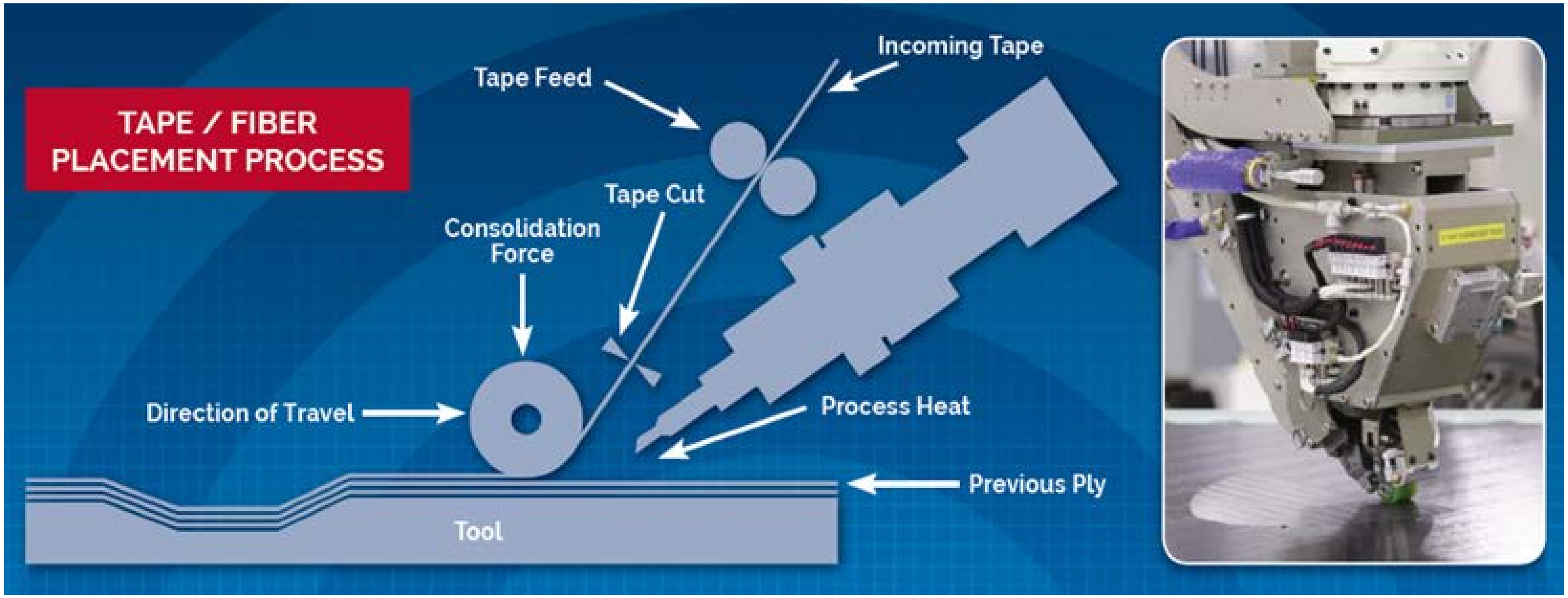
Approach

- The inner surface of the coupler has copper wires that are coated with High Density Polyethylene (HDPE).
- The fiber reinforced composite pre-preg is melt bonded to the wires.
- One end of fiber reinforced pipe is slid into each end of the coupler.
- Electricity flows through the wires heating them and melting the HDPE on the wires and the pipe.

Approach: Electrofusion Coupler

- The most notable aspects of this pipe coupler technology are its design, manufacturability, and installation procedure. The objective of this project is to advance from TRL 3 to 5, ultimately yielding results of field-condition tested prototypes. Over three years, the project will deliver iterations of designs, prototypes, manufacturing process refinements, and test results. The installation procedure will be addressed emphasizing the simplicity of the procedure with the ability to automate the fusion process and record bond quality data. The end goal of this technology beyond this project is to provide a simple, robust, cost-effective method of joining pipes, allowing a reliable network of high-pressure hydrogen delivery lines.
- This project is building off of work SRNL did with DOE funding for developing FRP pipes.

Approach



- These coupler will be made using an in situ automated fiber placement process.
- The wires will be placed with this process in addition to the pre-preg.

Approach: Year 2016 Milestones

Milestone Summary Table				
Recipient Name:		Automated Dynamics		
Project Title:		Continuous Fiber Composite Electrofusion Couplers		
#	Task Title	Milestone #	Milestone Description	Anticipated Qtr of Completion
1	Develop specification for composite coupler	1.1	Create a specification for the electrofusion coupler and submit a report.	1^{st}
2	Determine ideal wire	2.1	Submit verification calculations that predict how different wire type, sizes and coating thickness will affect bonding the coupler to the pipe. Demonstrate that the wire can melt a PE pipe when current is applied.	2^{nd}
3	Surface treatment and surface area of coupler and pipe	3.1	Make coupons with different surface treatments and perform tensile testing. Make coupons with different surface areas and perform tensile testing. Tensile strength of the bond region must be at least 3,000 lbs. along the pipes longitudinal axis. Submit report of results and conclusions.	2^{nd}
4	Determine composite layup	4.1	Submit report that shows the methodology followed to determine the ideal ply layup for the coupler. Perform Burst test to verify strength of layup. Must be at least 100 bar.	3^{rd}
5	Make part to be tested	5.1	Automated Dynamics will build prototypes based on results to date & have them tested for leak rate. Must be less than 10×10^{-4} cm^3 H_2/s	4^{th}
NA	Go/No-Go	Go/No-Go	Review the results from the first year of the project. If prototypes pass the 100 bar burst test, 3,000 lb. tensile test, and have a leak rate equal to or less than 10×10^{-4} cm^3 H_2/s then the project will continue.	4th

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Approach: Year 2017 Milestones

Milestone Summary Table				
Recipient Name:		Automated Dynamics		
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#	Task Title	Milestone #	Milestone Description	Anticipated Qtr of Completion
6	Make 4 parts for Bond Strength	6.1	Conduct bond test on 4 electrofusion couplers that are bonded to pipe. Bond strength must be at least 7,500 lbs.	5^{th}
7	Make parts for statistics of Burst Strength	7.1	Test and perform statistical analysis for burst strength. Burst strength must be at least 225 bar.	6^{th}
8	Make parts and test them to validate parameters	8.1	Conduct tests to validate leak rate is less than 5 x 10^{-4} cm^3 H_2/s.	7^{th}
9	Report final design of Coupler	9.1	Finalize design of the coupler and submit the final design to DOE.	8^{th}
NA	Go/No-Go	Go/No-Go	Prototype must show 1) leakage rate less than 5 x 10^{-4} cm^3 H_2/s, 2) hydrostatic standards set by ASTM D2992 over 28,500 cycles at an R ratio of 0.5 and maximum burst pressure of approximately 225 bar (or pipe burst before the joint), and 3) tensile strength meets standards set by ASTM D3517 and approximately 7,500 lbs. axial load.	8th

Accomplishments and Progress

- Completed the Coupler's technical specification. This is the first milestone of this project.
- Determined melt bond to liner would not be sufficient to hold required axial load.
- Need to bond the fiber reinforced thermoplastic coupler to the fiber reinforced thermoset layer of the pipe.

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Technical Specification

- **Dimensions**
- Pipe Name: FS LP 2" 1,500 (E)
- Pipe ID: 1.89 inches nominal
- Pipe OD: 2.43 inches nominal
- Coupler OD: TBD
- Coupler Length: TBD

- **Nominal Ultimate Specifications (@26°C)**
- Burst Pressure: 406.8 bar (5,900 psi)
- Tensile Load: 10,000 lbs.
- Compressive Load: -10,900 lbs.
- Collapse Pressure: 48.3 bar (700 psi)
- Fatigue Life: 91,250 cycles with a 0.5R ratio for 100 bar

- **Service Specification**
- Fluid: Hydrogen gas
- Pressure: 103.4 bar (1450 psi)
- Maximum Leak Rate: 5×10^{-4} cm^3 H_2/sec
- Service Life: 50 years
- Tensile Load: 4,000 lbs.
- Fatigue Life: 36,500 cycles with a 0.5R ratio

- **Environmental Specifications**
- Operating Temperature: -34˚C (-29˚F) to 60˚C (140˚F)

- **Installation Specifications:**
- *Electrofusion Power Supply*
- Voltage: 110 to 120 VAC 60 Hz
- Current: 20A maximum
- Electrofusion cycle time: TBD

Axial loading calculation

Problem - Calculate the tensile load of a pressurized pipe with unconstrained ends.

Data

$ID := 1.89 \cdot in$

$Wall\_thickness := 0.1 \cdot in$

$Ultimate\_burst\_pressure := 225 \cdot bar$ $\qquad Ultimate\_burst\_pressure = 3.263 \times 10^{3}\, psi$

$Normal\_ultimate\_tensile\_load := 4000 \cdot lbf$

$Length := 3 \cdot in$

$\sigma := 3000 \cdot psi$ conservate value for yield strength of HDPE from Matweb

Calculations

First calculate the Liner Maximum Tensile Load

$OD := ID + Wall\_thickness \cdot 2$

$$Liner\_area := \frac{\pi}{4} \cdot \left(OD^{2} - ID^{2}\right) \qquad Liner\_area = 0.625 \cdot in^{2}$$

$Liner\_max\_tensile\_load := \sigma \cdot Liner\_area$

$$Liner\_max\_tensile\_load = 1.876 \times 10^{3} \cdot lbf$$

Now calculate the tensile load due to internal pressure.

$$Axial\_pressure\_load := Ultimate\_burst\_pressure \cdot \pi \cdot \left(\frac{OD}{2}\right)^{2}$$

$$Axial\_pressure\_load = 1.12 \times 10^{4} \cdot lbf$$

$$\frac{Liner\_max\_tensile\_load}{Axial\_pressure\_load} = 0.168$$

Responses to Previous Year Reviewers' Comments

- This is a new project and was not available for review last year.

Collaborations

Partner	Relationship	Type	Extent of collaboration
SRNL	Sub	Federal Laboratory	High
NOV	Sub	Industry	Medium

- Collaborating with SRNL has been productive. They are very knowledgeable and responsive. They are very important to the success of this project. SRNL provides guidance on technical aspects related to Hydrogen delivery. SRNL will also be completing the mechanical testing for this project.
- Collaborating with NOV has been productive. They have provide sections of FRP pipe for evaluation which is critical for completing the project objectives. They have and will continue to provide information about the industrial requirements for the couplers.

Remaining Challengers and Barriers

- Complete the design of the electrofusion coupler
- Manufacture prototype couplers for initial mechanical testing
- Prototypes must meet the requirements outlined in the Milestone table.
- Progress coupler from a TRL 3 to TRL 5.

Proposed Future Work 2016

- In this quarter, the ideal wire for the coupler will be determined, along with the ideal surface treatment for the bond area between the coupler and FRP pipe. This will help archive the goal of leak rate less than 0.5% and the service pressure of 100bar.
- In the third quarter, the layup of the coupler will be determined. This will help achieve the objective of a 100 bar service rating and the 50 year service life.
- In the fourth quarter, electrofusion coupler prototypes will be fabricated and tested for leak rate.

Proposed Future Work 2017

Quarter	Task	Purpose
1st of 2017	Prototypes of the couplers will be fabricated and tested for tensile strength 7,500 lbs.	Validate that the coupler can withstand the axial load required to safely contain 100 bar of service pressure
2nd of 2017	Prototypes will be fabricated and tested for burst strength of 225 bar	This is the factor of safety for the service pressure of 100 bar
3rd of 2017	Prototypes will be fabricated and tested for a leak rate of less than 0.5%	This is required by the technical target.
4th of 2017	Prototypes will be tested for fatigue life. The final design of the electrofusion coupler will be submitted to the DOE	This design will be tested to show that it meets the technical requirements for service pressure and leak rate

- The 50 year service life will be tested in 2018.

Technology Transfer Activities

- Automated Dynamics will seek out and hold discussions with potential partners in Year 1 of the project and will finalize relationships for commercialization by the end of Year 2. In Year 3 of the project, the team envisions engaging the partners as advisors for the commercialization of the coupler.
- Partners include material suppliers, end-users, and of course, pipe manufacturers who will help qualify the couplers and associated pipe.
- The strategy for protecting the developed IP will begin with all investigators agreeing to monitor the research and contact the appropriate office when such property has been discovered.

Summary

- The Continuous Fiber Reinforced Thermoplastic Electrofusion Coupler will have a lifetime of 50 years, a service rating of 100 bar and a leak rate less than 0.5% of the flow rate.
- This CFRTEC will be scalable to large diameter pipes.