Type 316L (N-controlled) Strain Hardening Simulation

Gleeble™ Thermocycle Modeling

Shutong Zhang, Engineer/Scientist IV, M&R
Steve McCracken, Senior Technical Executive, WRTC

Presented by Heather Malikowski, EPRI MRP

February 21, 2024

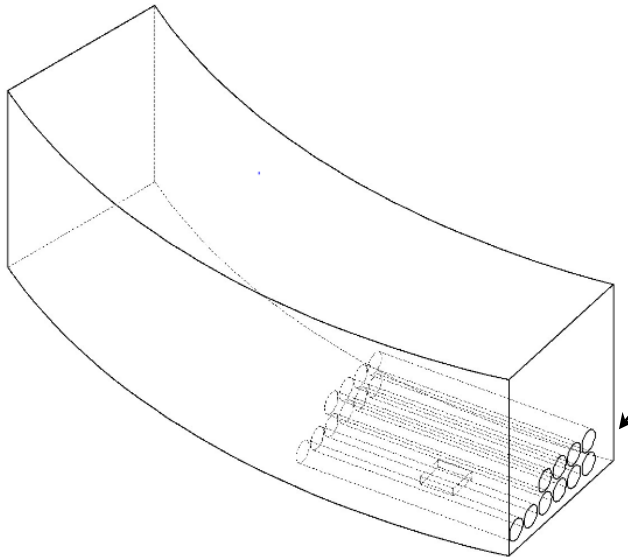
Gleeble™-based Thermo-mechanical Test Development

- Hypothesis
  - The SCC observed in the root region of the EDF SI piping is potentially associated with welding induced strain hardening
- Objectives
  - Simulate the weld thermal cycle in the heat affected zone (HAZ) of Type 316L (N-controlled) safety injection piping
  - Investigate the strain hardening behavior of Type 316L (N-controlled) during pipe welding

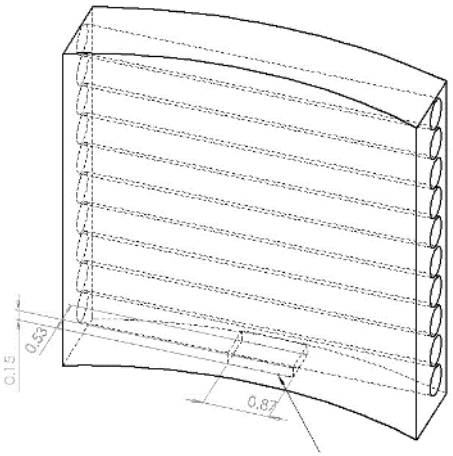
AFNOR Gr. Z2 CND 18-12 N-controlled Material

EDF Safety Injection Pipe

EDF Pipe for Comparison



Gleeble Samples



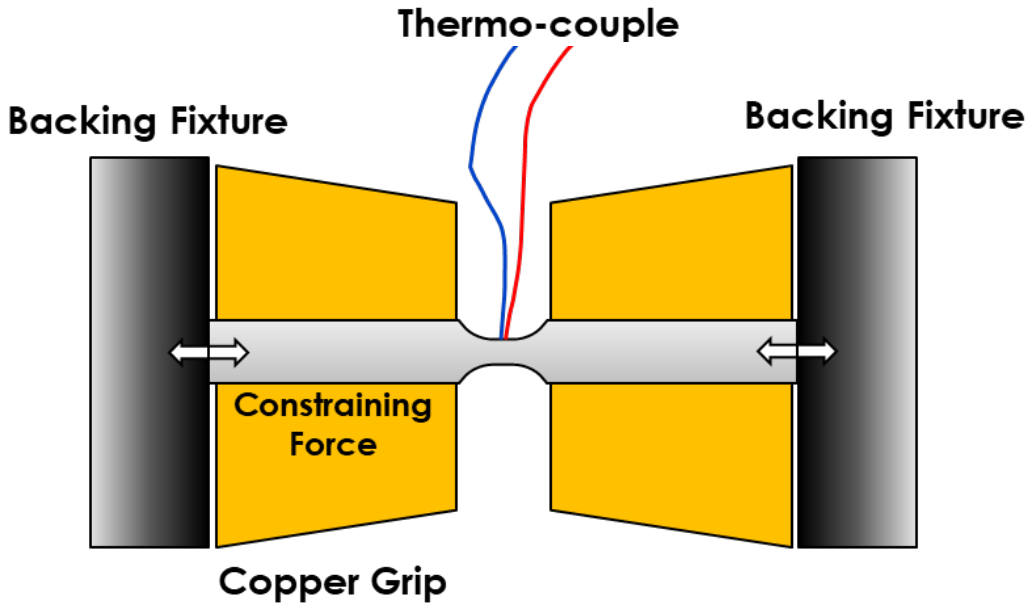
Chemical Compositions Comparison

	C	Mn	Si	P	S	Cr	Ni	Mo	N	Co	Cu
Spec[1]	0.03	2	0.75	0.04	0.015	16.5 -18	11-13	2-2.5	0.1	NA	NA
SI Pipe	0.026	1.84	0.55	0.024	0.003	17.26	12.06	2.36	0.069	0.07	0.22
Comparison Pipe	0.0009	1.69	0.36	0.03	0.0008	16.74	11.4	2.19	0.061	0.103	NA
ASME SA-182 Gr. F316LN	0.03	2	0.75	0.045	0.030	16 -18	11-14	2-3	0.1-0.16	NA	NA

[1] *AFNOR Gr. Z2 CND 18-12 N-controlled specification values from SI Pipe CMTR*

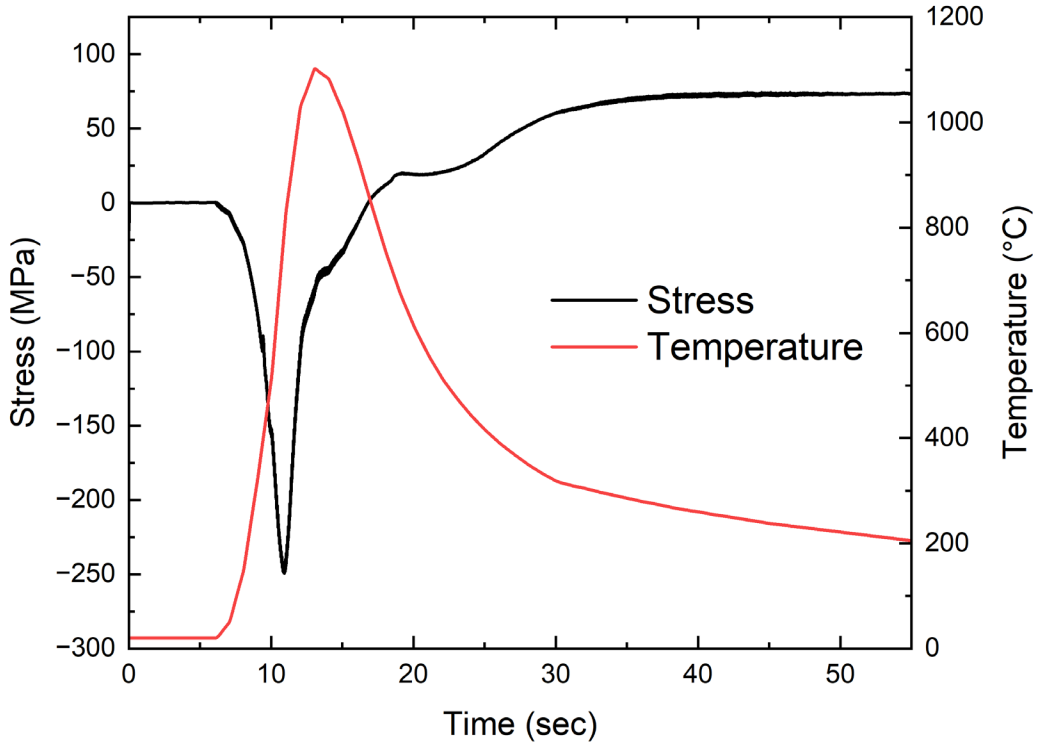
Experimental Methodology – Test Design

Experimental Design



- The reduced gauge section of the sample is designed to minimize the thermal gradient
- Includes a copper grip to allow fast cooling
- The backing fixture provides restraining force
- The Gleeble jaws are set to a stroke of 0 mm during the thermal cycle for complete restraint

Thermal Cycle from Welding Simulation



- The Gleeble thermal cycle setting replicates the welding thermal histories received from EDF
- The restraint results in a compressive / tensile force during heating / cooling

Summary of the Gleeble Simulation Setup and Results

A Gleeble™ based thermo-mechanical test has been developed to simulate the plastic strain (deformation) in the heat affected zone of the Safety Injection pipe during welding. The key findings are summarized below.

Test development

- On-heating plastic deformation occurs in the time-period between the peak compression and the maximum temperature, which was confirmed by the dilatometer measurement
- Under complete restraint (fixed jaws), plastic deformation occurs in the first and second thermal cycle, which contribute to the strain hardening of the 316L specimen verified by hardness measurement (As received average 142 HV0.5 vs. 162 HV0.5 after 2 thermal cycles)
- On-cooling plastic deformation due to tension cannot be reproduced in the tests due to sample design limitations

Summary of the tested EDF material results

- The safety injection pipe shows less plastic strain than the comparison pipe under complete-restraint thermal cycle simulation
- Did not observe expected significant increase in micro-hardness after thermal cycle simulations

Test Matrix and Status of Work

Experiment		Gleeble Thermal Cycle Simulation	Microhardness Map	EBSD Strain Analysis
Safety Injection Pipe	1 cycle	Complete	Complete	---
	2 cycles			---
	3 cycles			---
	4 cycles			---
Comparison Pipe	1 cycle	Complete	Complete	Complete
	2 cycles			---
	3 cycles			---
	4 cycles			---

Additional work scope:

- Improve Gleeble sample design and fixturing to better simulate tensile strain cycles
- Repeat 2 and 3 cycle simulations and hardness mapping for SI pipe and comparison pipe
- Perform 2 and 3 cycle simulations and hardness mapping with ASME SA-182 Gr F316LN pipe material from an AP1000 hot leg DMW mockup

www.epri.com