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## ***Creep and relaxation behaviour of SS bolted assemblies***

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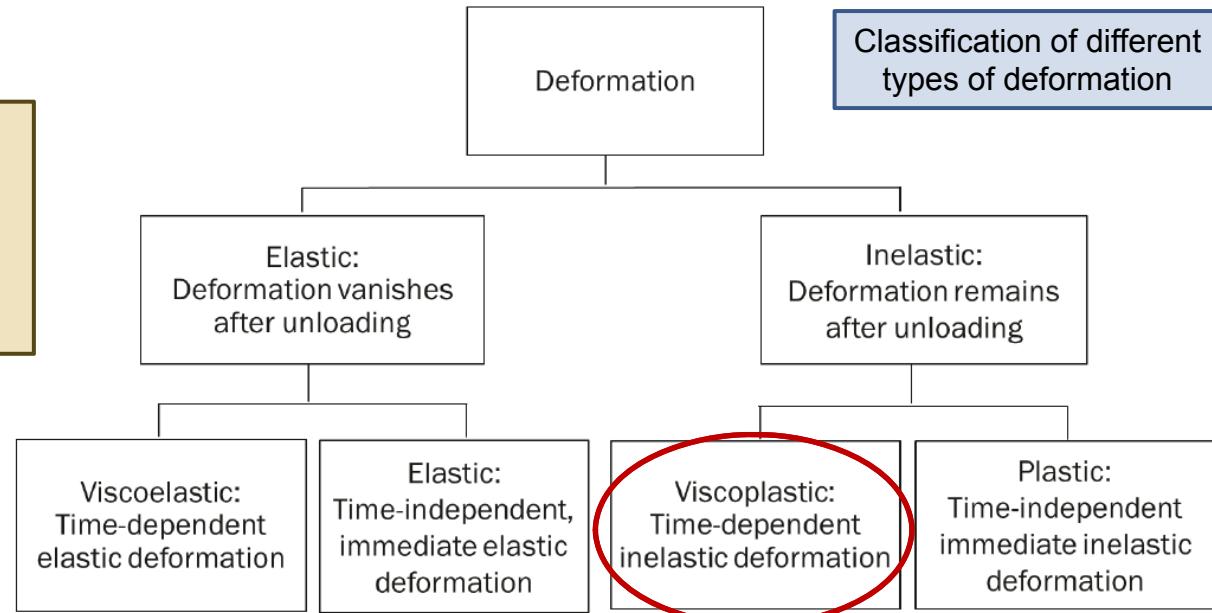
- Introduction
- Creep behaviour of SS plates
- Stress relaxation behaviour of austenitic SS bars
- Relaxation behaviour of preloaded SS bolted assemblies
  - Experimental investigations
  - Results and discussion
- Summary

## RFCS-Project SIROCO

Execution and reliability of slip-resistant connections  
for steel structures using CS and SS



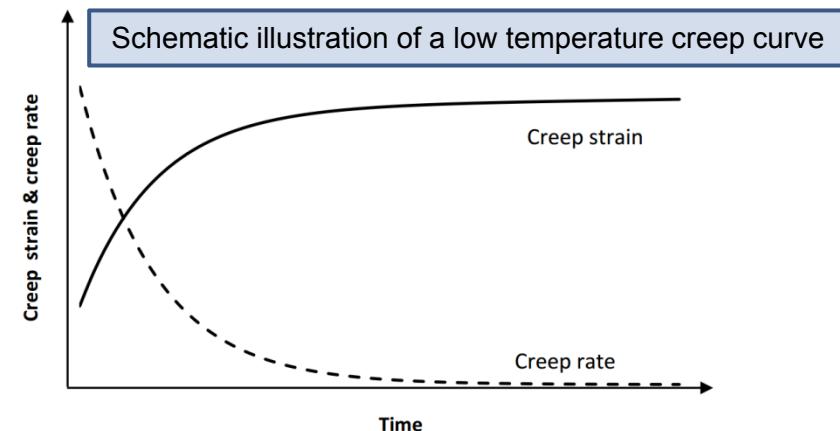
Creep is a **time-dependent** deformation that **becomes more severe with temperature**.



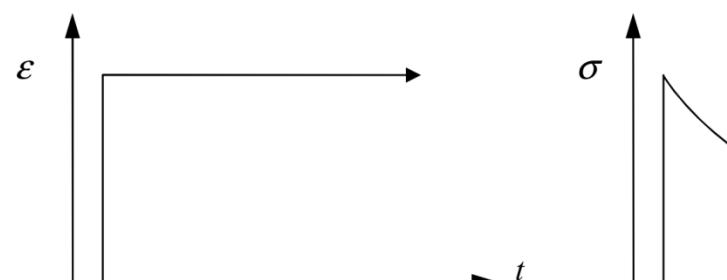
The temperature ranges for creep of metals are conventionally divided into three categories:

- High temperature creep ( $T/T_m > 0.6$ ).
- Intermediate temperature creep ( $0.3 < T/T_m < 0.6$ ).
- Low temperature creep ( $T/T_m < 0.3$ ).

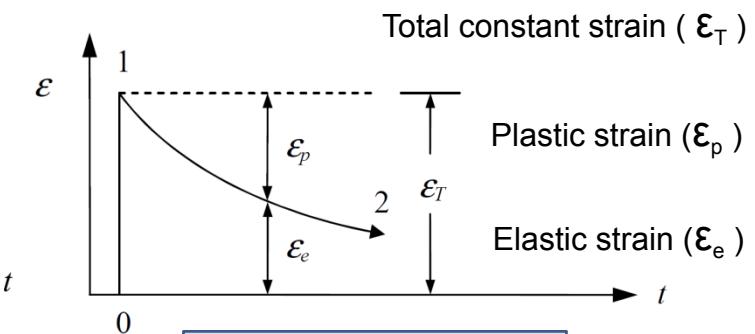
Homologous temperature is defined as the ratio of the material's current temperature to its melting temperature



Stress relaxation can be defined as a **time-dependent** phenomenon when the material is subjected to a constant total strain, **stress in the material gradually decreases as time elapses**.



Stress Relaxation Behavior Caused by a Step Strain



Strain Behavior with Time

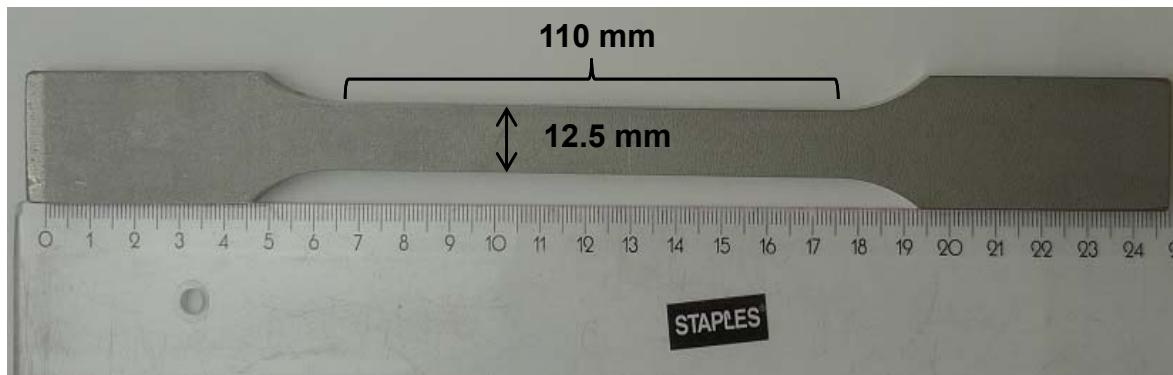
(Dowling, 1993)

(Krapf, 2010)

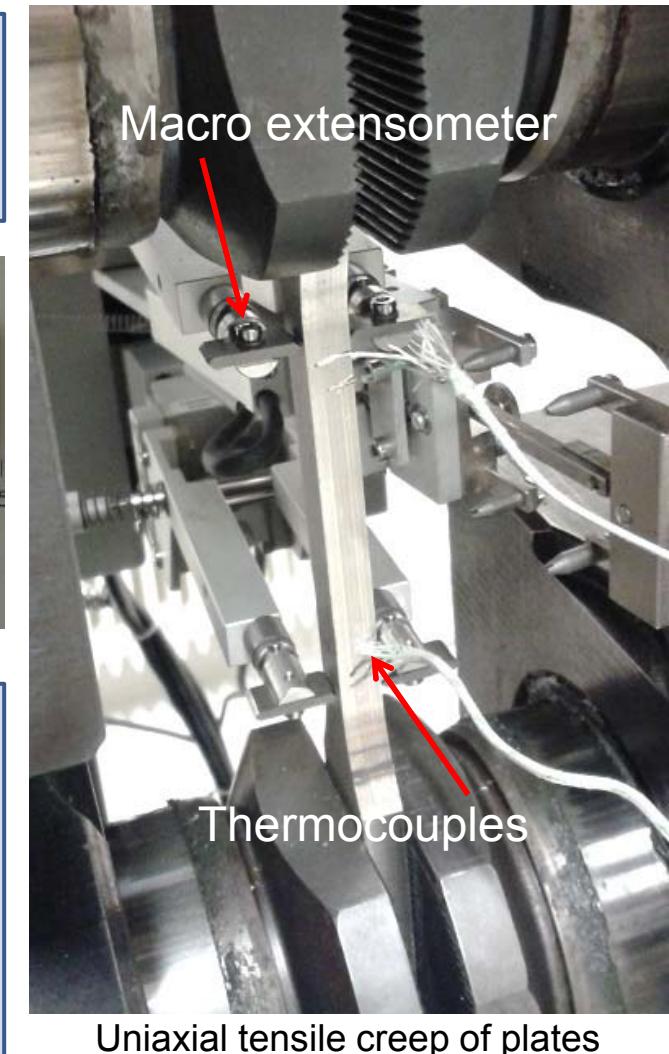
- The main advantage of stress relaxation testing is that a **single stress relaxation** test can often produce data over **a wide range of strain rates**.
- **Analyzing the results is more difficult** since both stress and strain rate are changing simultaneously.

# Creep Test

- Material: Lean Duplex (**EN 1.4162**), Duplex (**EN 1.4462**), Austenitic (**EN 1.4404**) and Ferritic (**EN 1.4003**).
- Flat specimen: full plate thickness of 8.0 and 8.6 mm



- Room temperature conditions
- Initial loading rates:  $10^{-5}$  1/s,  $10^{-4}$  1/s
- Stress levels (for constant stress): 0.5, 0.65, 0.83 and  $1.0 \times R_{p0.2}$
- Test duration: 12 , 20, 100 and 160 h

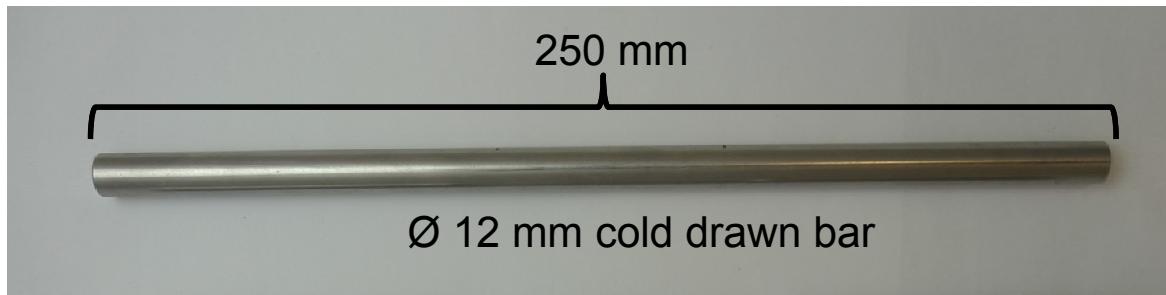


Uniaxial tensile creep of plates

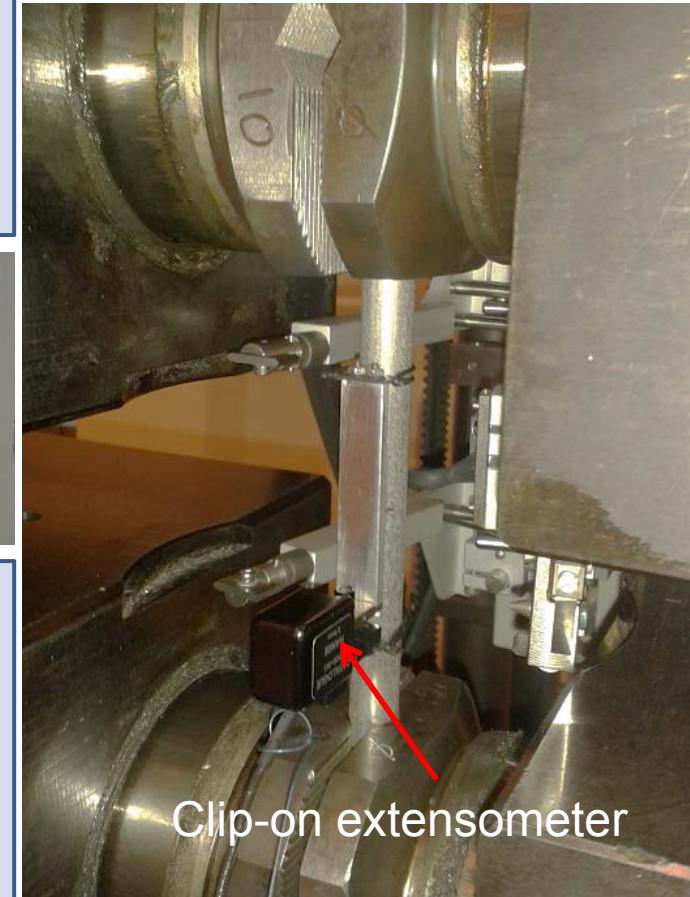
# Stress Relaxation Test

## Test specimen:

- Bars: 12 mm cold drawn, tested as-received,
- Material: EN 1.4436.



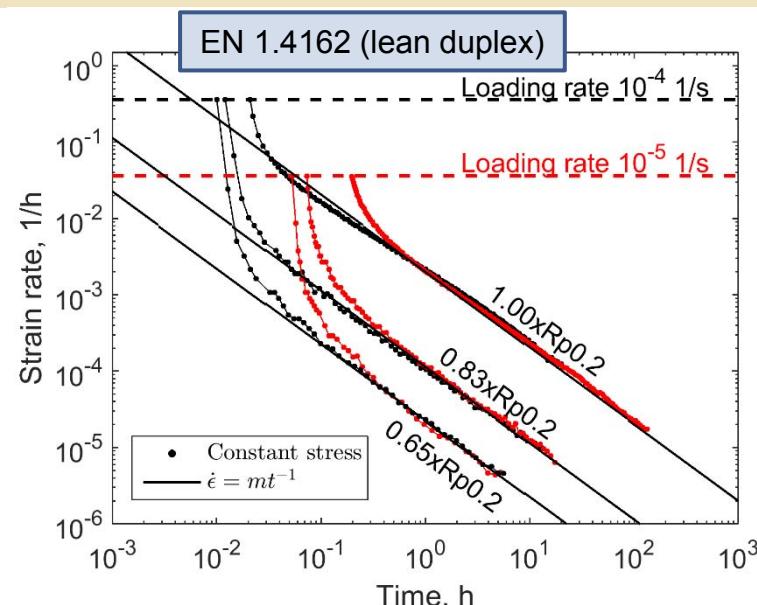
- The sampling rate was initial 25 Hz and then 1 Hz for stress, time and strain.
- Room temperature conditions (no control of temperature).
- Initial loading rate: 10 MPa/s
- Stress levels (for constant strain): 0.6, 0.8 and 1.0 x R<sub>p0.2</sub>
- Test duration: 12 h



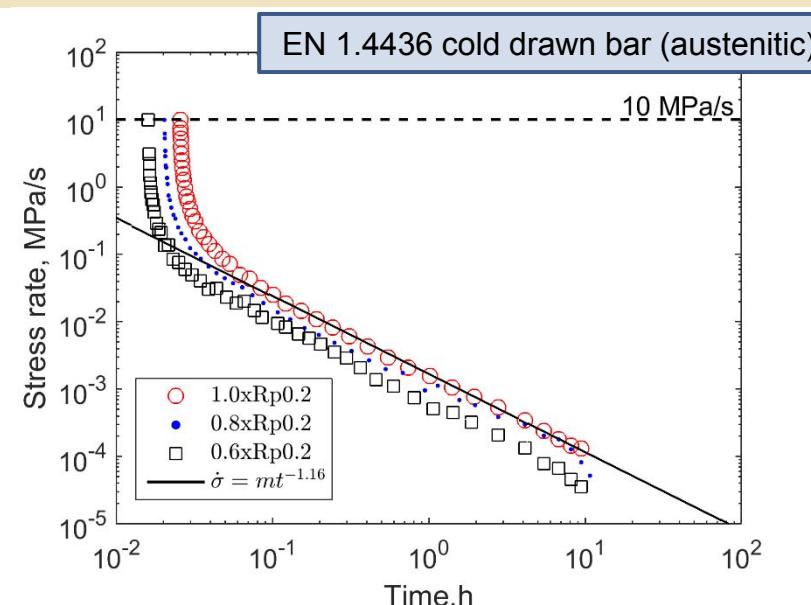
Clip-on extensometer

Uniaxial tensile stress relaxation of bars

# Material Behaviour under Constant Load or Strain Conditions



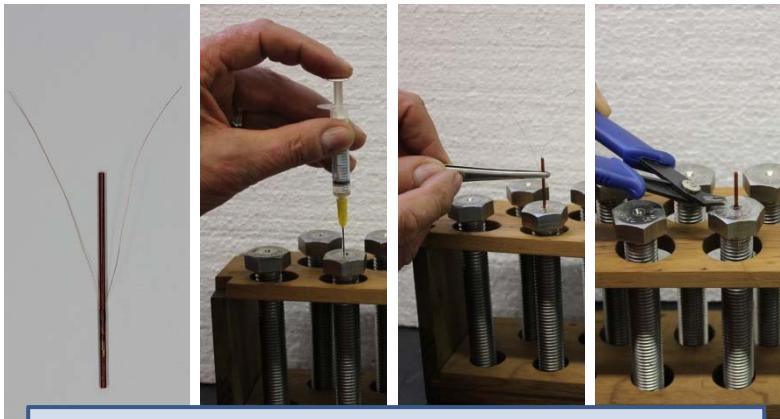
Uniaxial tensile creep of plates (up to 168 h)



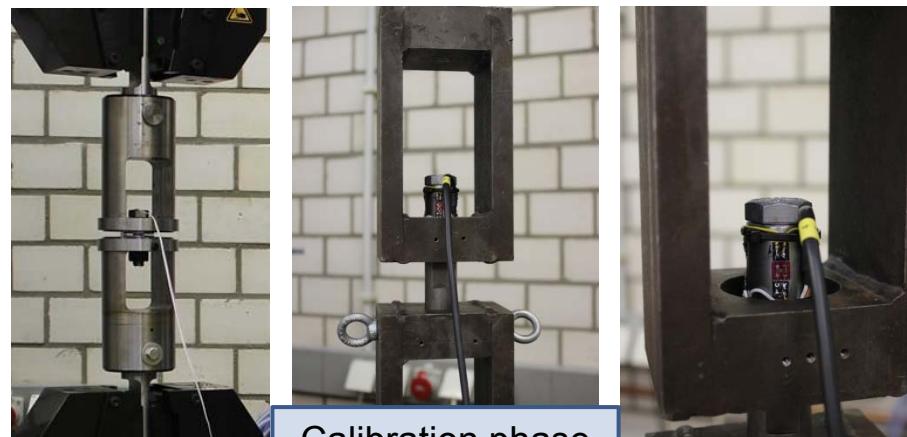
Uniaxial tensile stress relaxation of bars (12 h)

- For both creep and stress relaxation testing the initial rate of change was high but quickly decreased with time.
- After the initial creep, the creep rate could be described by the function:  $\dot{\varepsilon}(t) = mt^{-1}$  where m depends on the stress level.
- For the stress relaxation of bars the stress relaxation could be described by an equation of state (Hart's model):  $\dot{\varepsilon} = K(\sigma - \sigma^*)^m$  where m depends on the stress level.

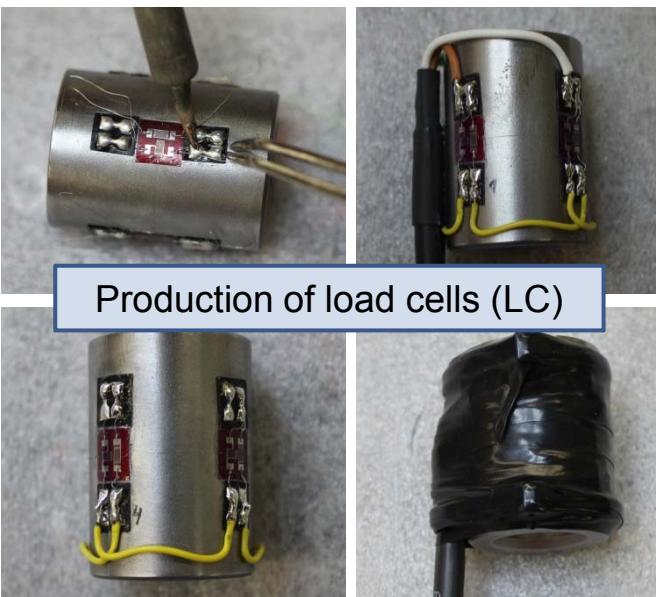
# Production and Calibration Phase



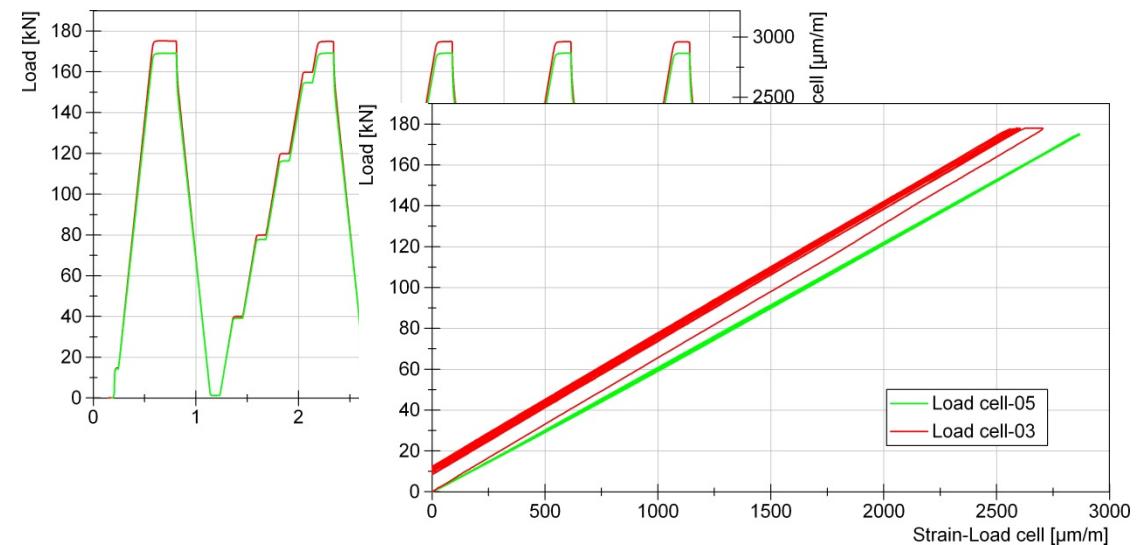
Instrumented bolts with strain gauge (SG)



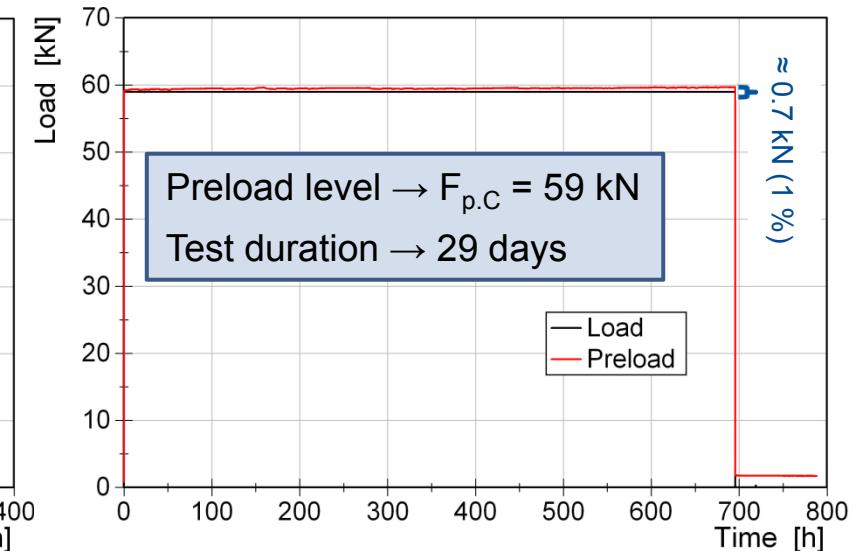
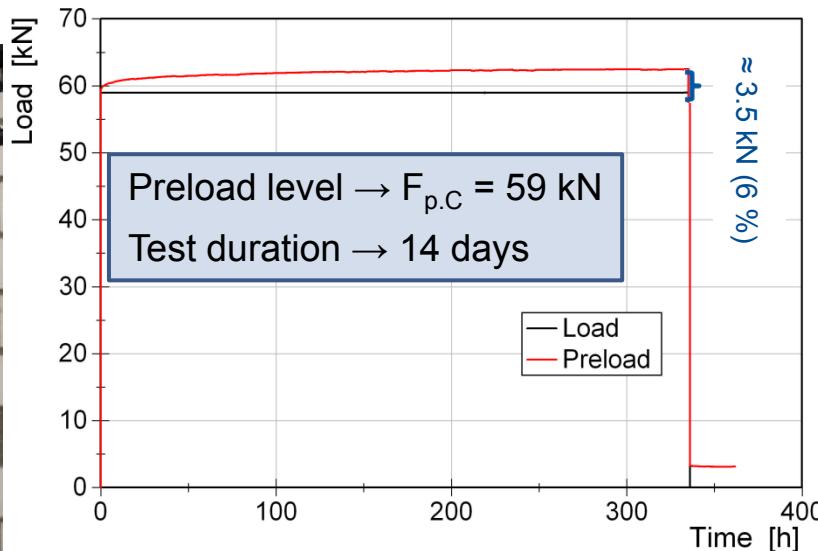
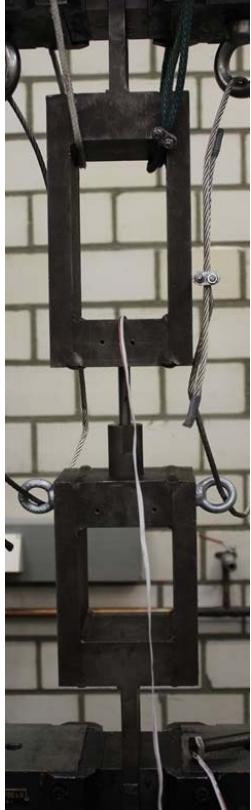
Calibration phase



Production of load cells (LC)



## M12 x 80 Super Duplex bolt (1.4410), Class 10.9



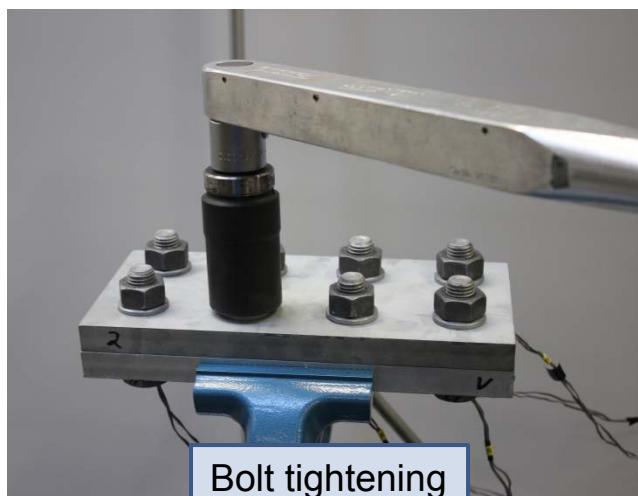
- Viscoplasticity occurs already during the preloading process of the stainless steel.
- These changes in the strain were measured by the strain gauges as well.
- This yielded to deviating values in comparison to the real preload level.

# Relaxation tests

Preliminary tests → to proof the accuracy of the load cells



## Relaxation tests



# Test specimens and geometries



**Test specimen M16/20 | 8 bolts**  
300x150x8/16 mm

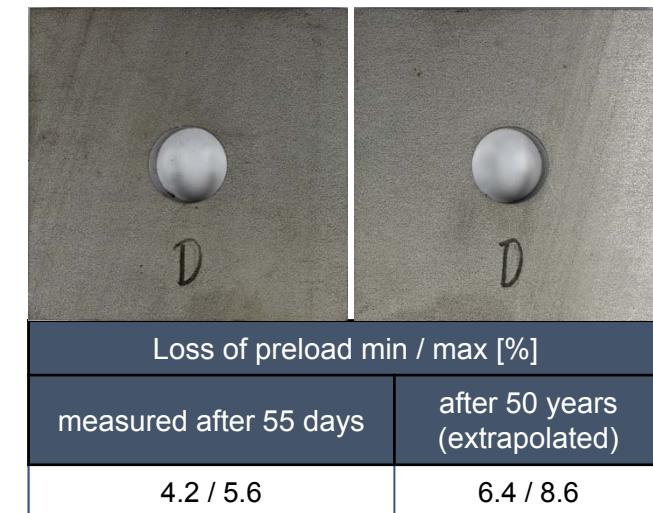
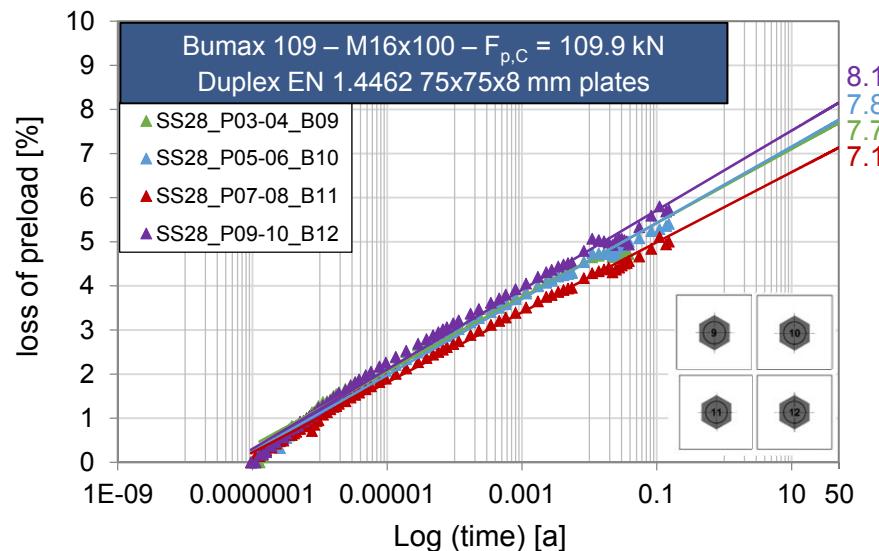
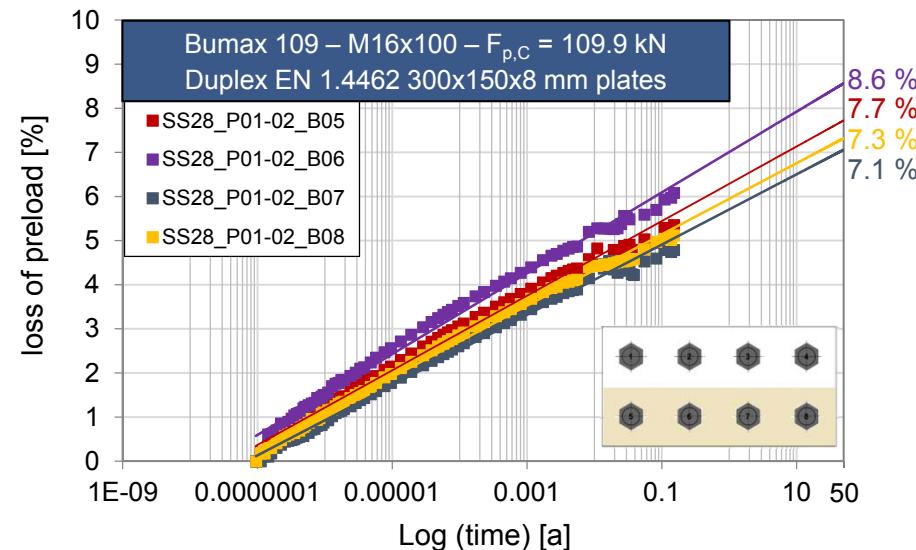
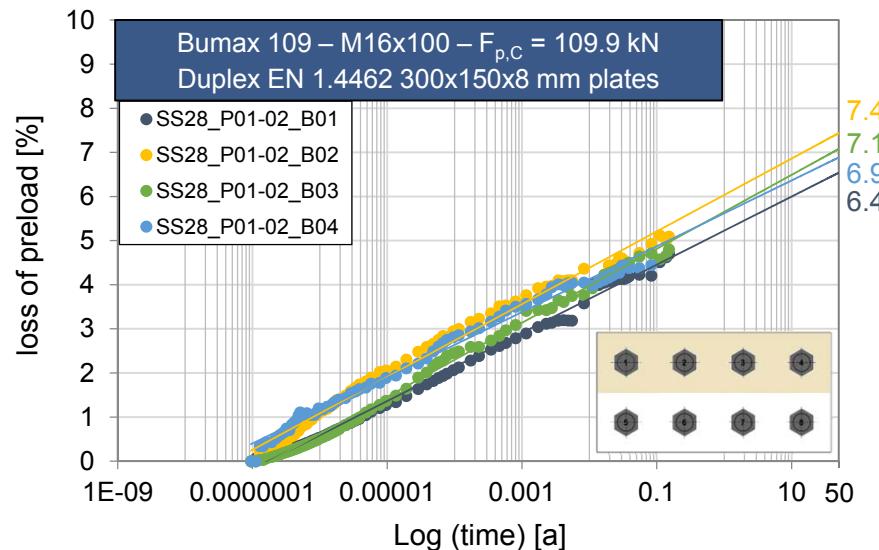


**Test specimen M16/M20 | 1 bolt**  
75x75x8/16 mm

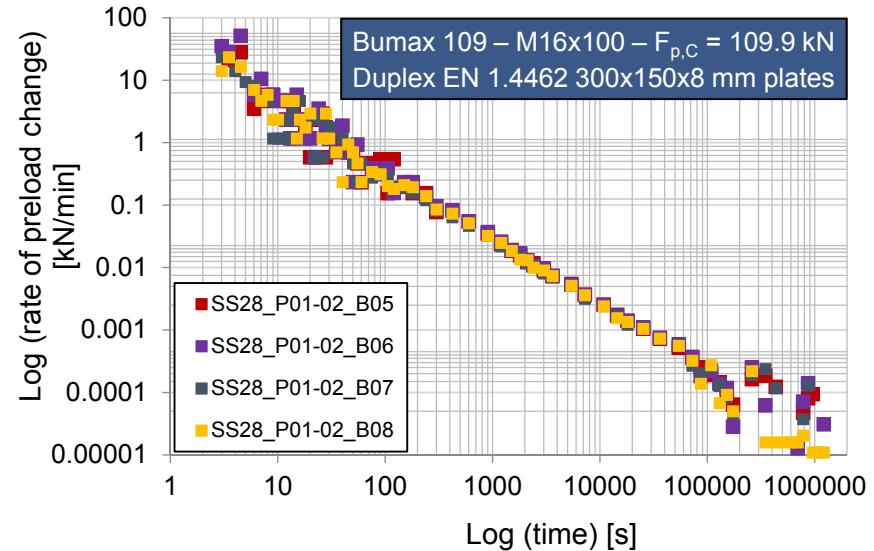
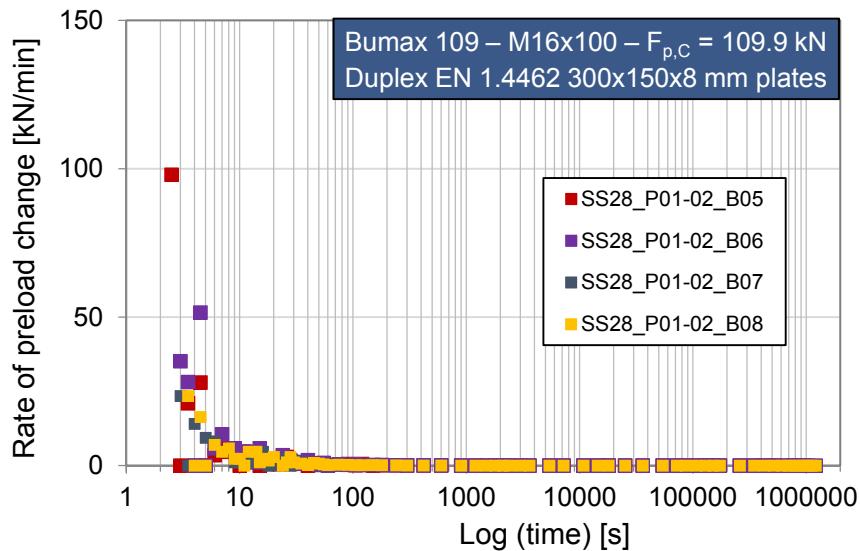


- Plates:
  - Carbon steel (CS)
  - Austenitic - EN 1.4404
  - Ferritic - EN 1.4003
  - Duplex - EN 1.4462
  - Lean Duplex - EN 1.4162
- Bolts:
  - Carbon steel - HV - 10.9
  - Austenitic - 1.4436
    - Bumax 88
    - Bumax 109
- Test duration: 14- 68 days
- Preload levels:  $F_{p,C}$

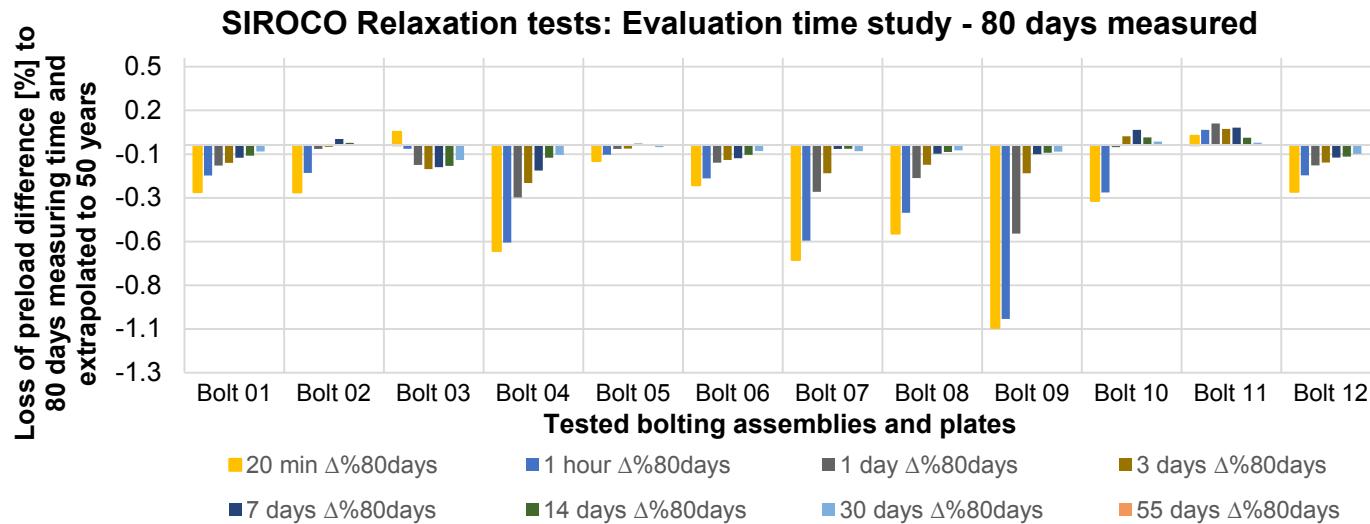
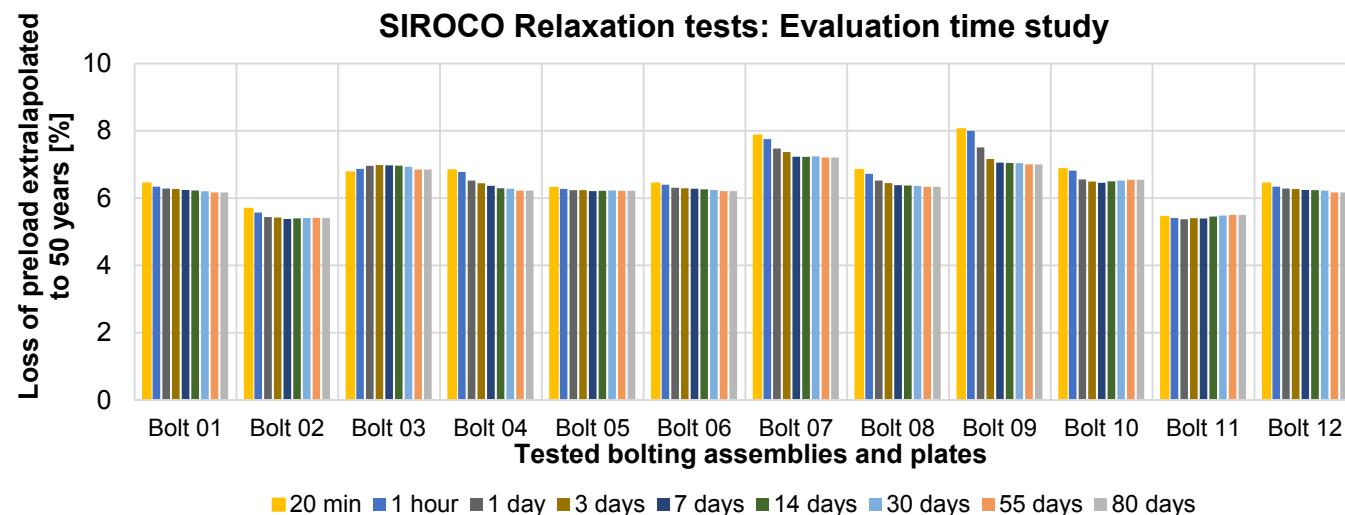
# Relaxation Tests



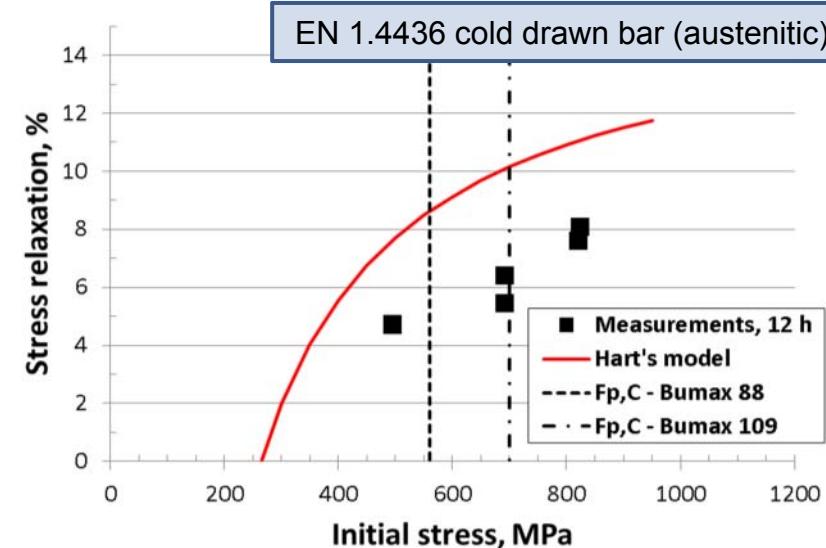
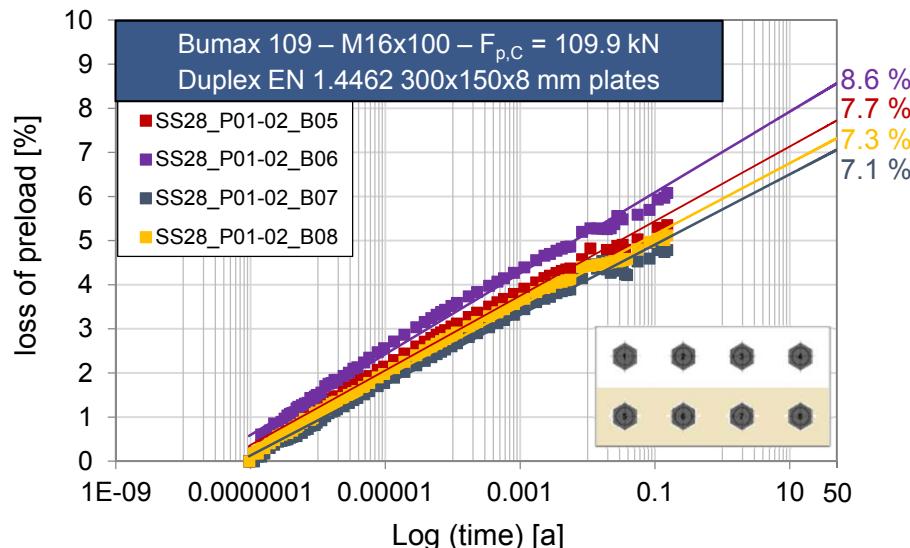
# Rate of Preload Losses



- The loss of preload  $\Rightarrow$  starts immediately after tightening of the bolts.
- The highest rate of loss of preload  $\Rightarrow$  is at beginning of the test.
- The rate of loss of preload  $\Rightarrow$  has been decreased during the time.



# Summary



- Room temperature creep  $\Rightarrow$  for austenitic, ferritic and duplex plates
  - $\Rightarrow$  The resulting stress was too low to cause significant creep deformation for the preload used.
- Extrapolated loss of preload to 50 years was in agreement with the asymptotic stress relaxation by Hart's model found from the stress relaxation testing of cold drawn bar.
- The high concern about the loss of preload due to relaxation and creep seems to be unreasonable.

# Thank you very much for your attention!



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