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Room temperature time dependent deformation in small springs

PRESENTED BY

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Is stress relaxation/creep at room temperature really a problem?

Over 144 years, creep of chrome steel to failure at ambient St. Louis temperature has not been an issue.

Eads bridge, St. Louis ca. 1874

Eads bridge, St. Louis 2012

Evidence of room temperature time dependent deformation

Cables – power lines, aerial tramway

Silver braze joints which exhibited delayed failure [Kassner]

Stress relaxation in concrete bridge reinforcement [Krapf]

- From 14% YS to 64% YS and from 11% UTS to 51% UTS (in service)

Creep at moderate temperature in 4320 steel [Neu]

Spring set/spring relaxation

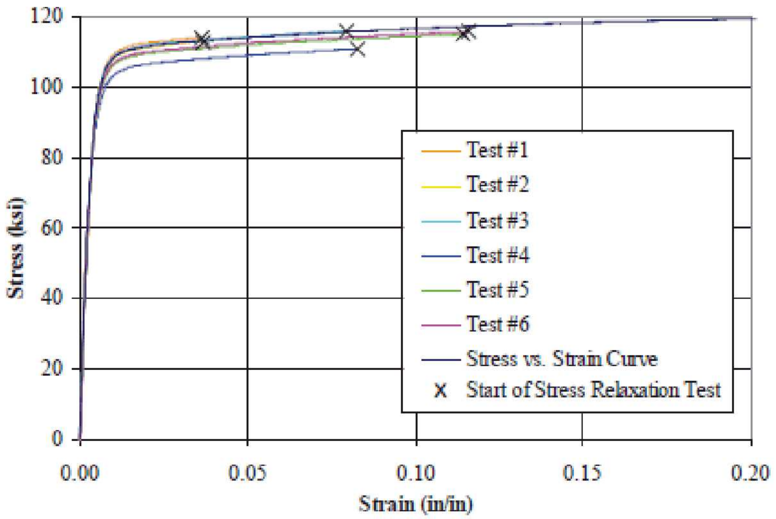
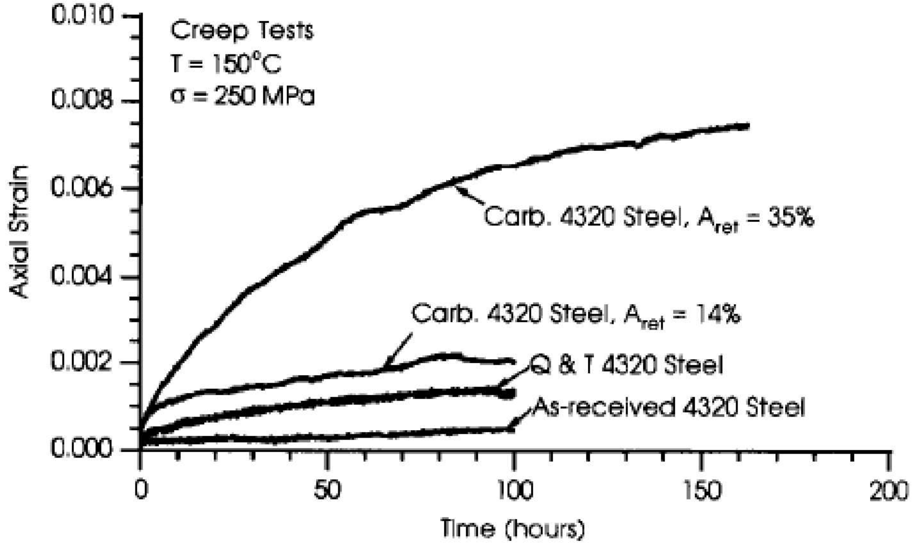


Figure 4.3: Stress *vs* Strain Curves Prior to Relaxation Tests



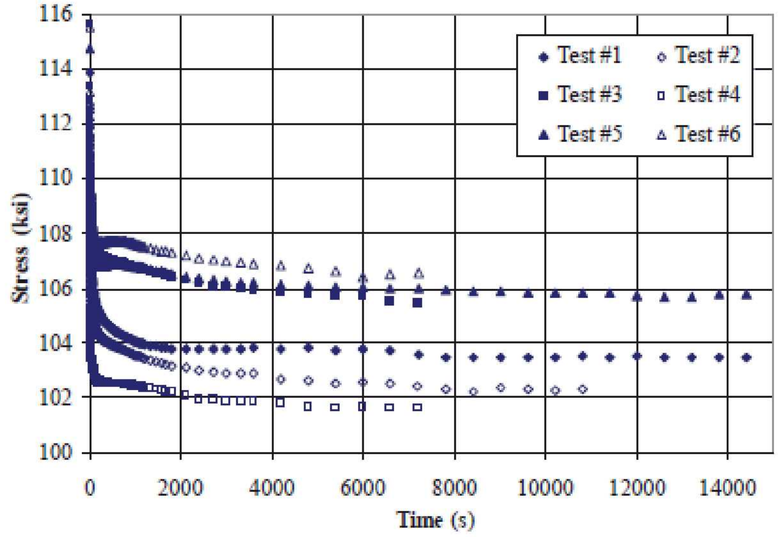


Figure 4.4: Stress Relaxation Results

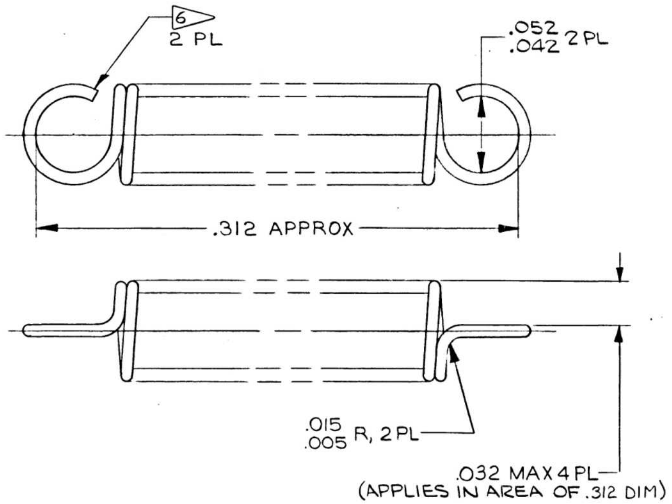
Spring design can be susceptible to room temperature creep

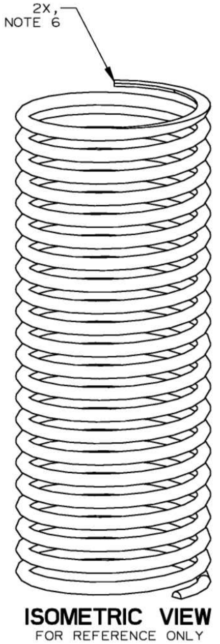
High fraction of yield

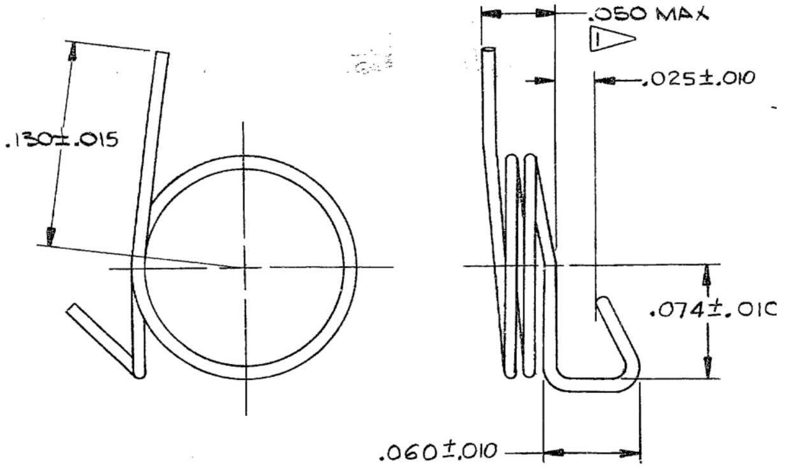
Small changes in spring dimensions can have large effect on force.

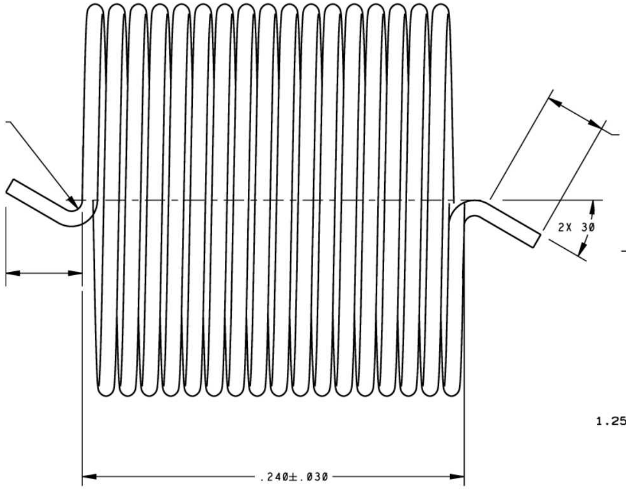
Springs are known to “take a set”.

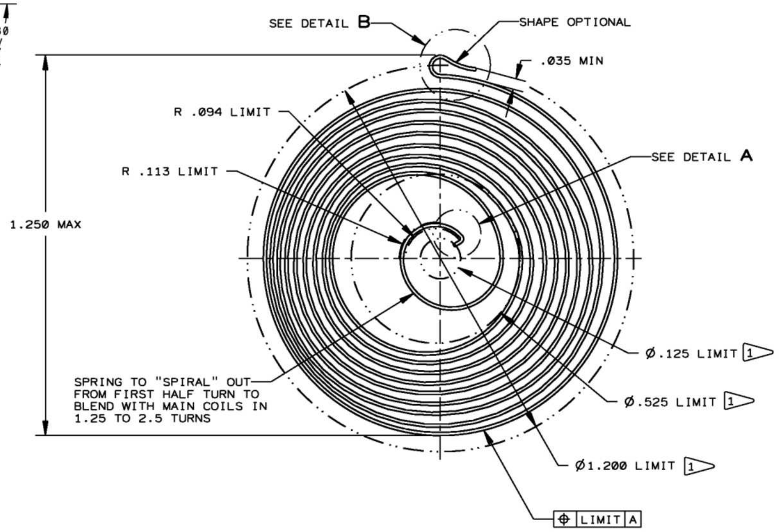
Stress state is complicated – generally torsion, some mixed.

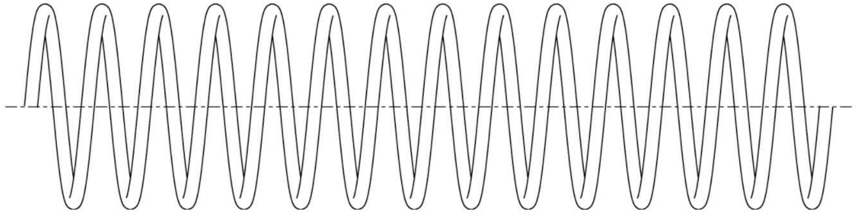






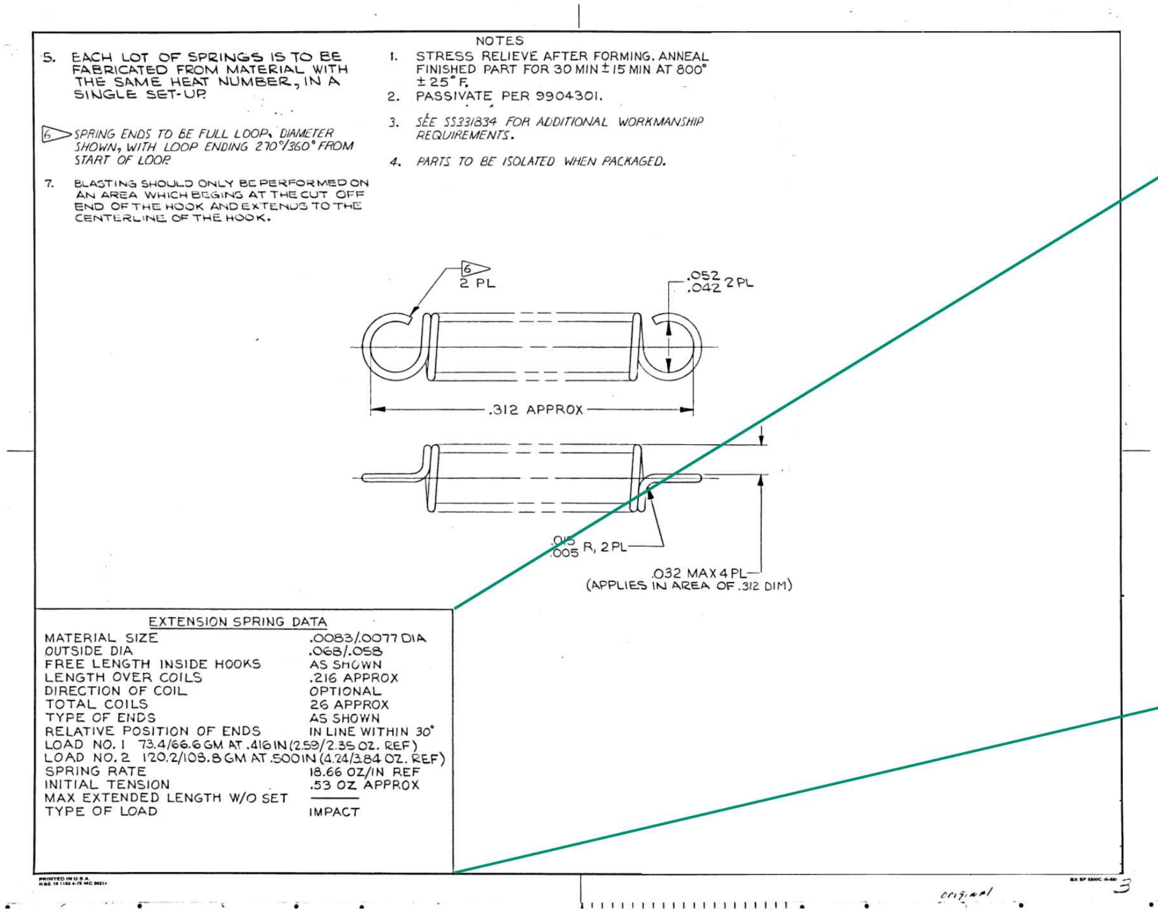


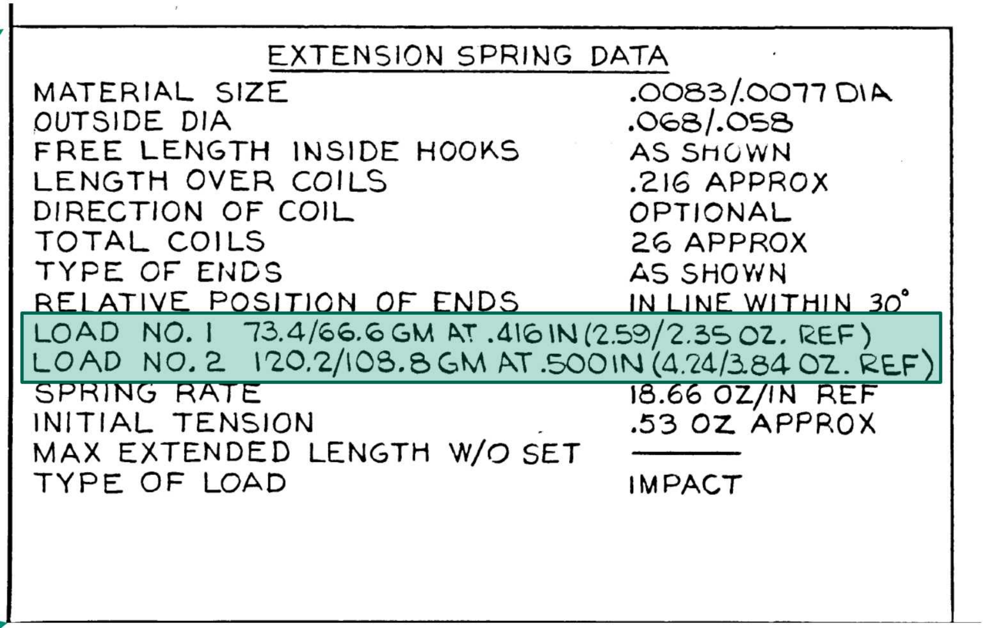




Spring design

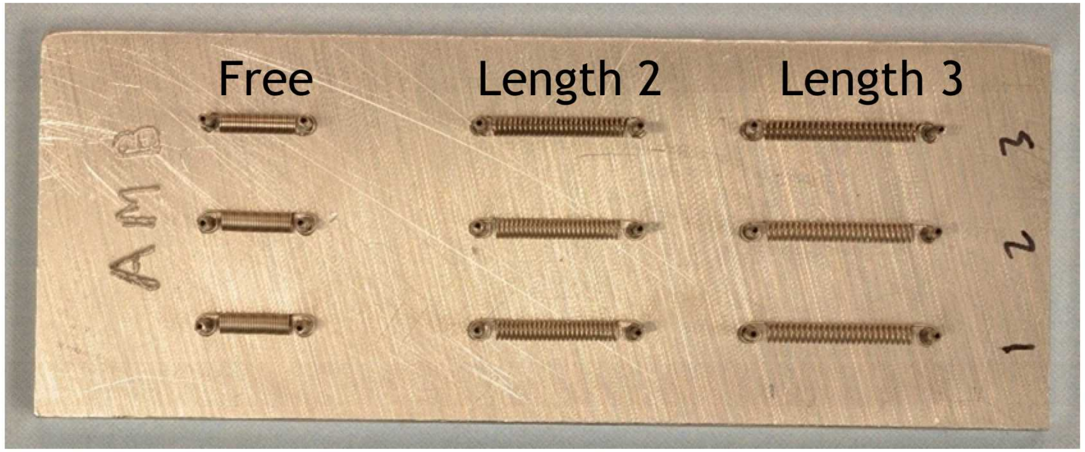
Springs typically sit at one position in the mechanism, then move to a second position to provide force during actuation.

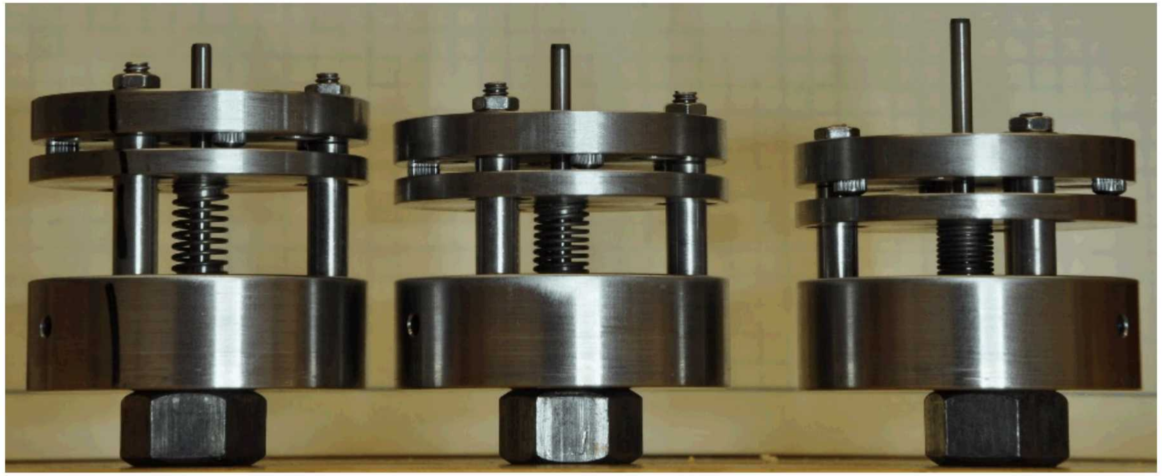




How to accelerate spring aging?

Increase the stress





Increase the temperature < 0.4 melt temperature (Homologous temperature)

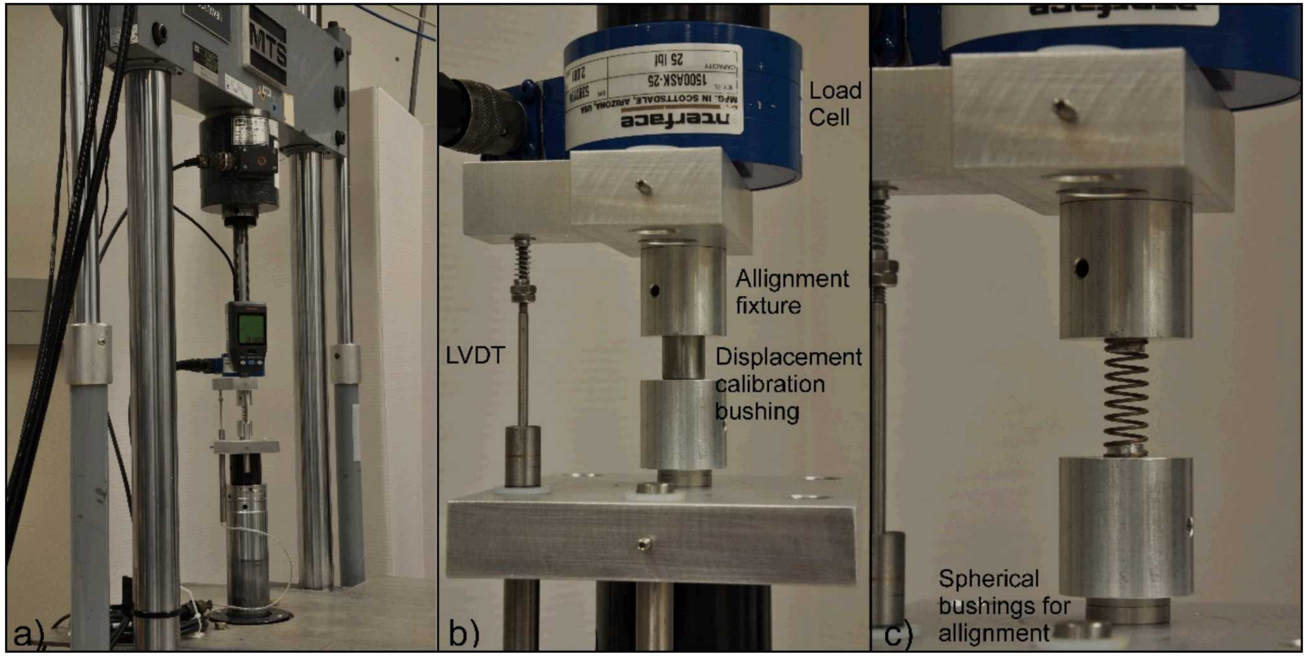
Temperature (°C)	Homologous temperature
Room temperature	0.18
70°C	0.21
100°C	0.22
170°C	0.26
205°C	0.29

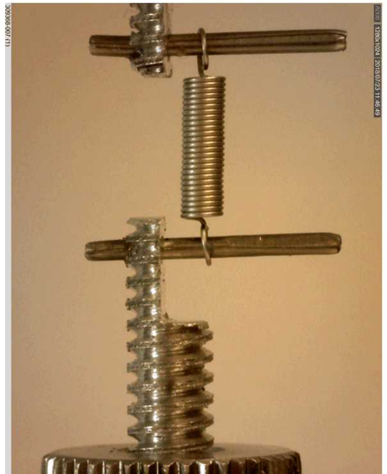
302 tension springs		
Length	Temperature (°C)	Number
Free	Ambient	9
Free	70	1
Free	100	1
Free	170	1
Free	205	1
Length 1	Ambient	2
Length 2	Ambient	4
Length 2	70	2
Length 2	100	2
Solid Height	Ambient	2
Solid Height	70	2
Solid Height	100	3
Solid Height	170	1

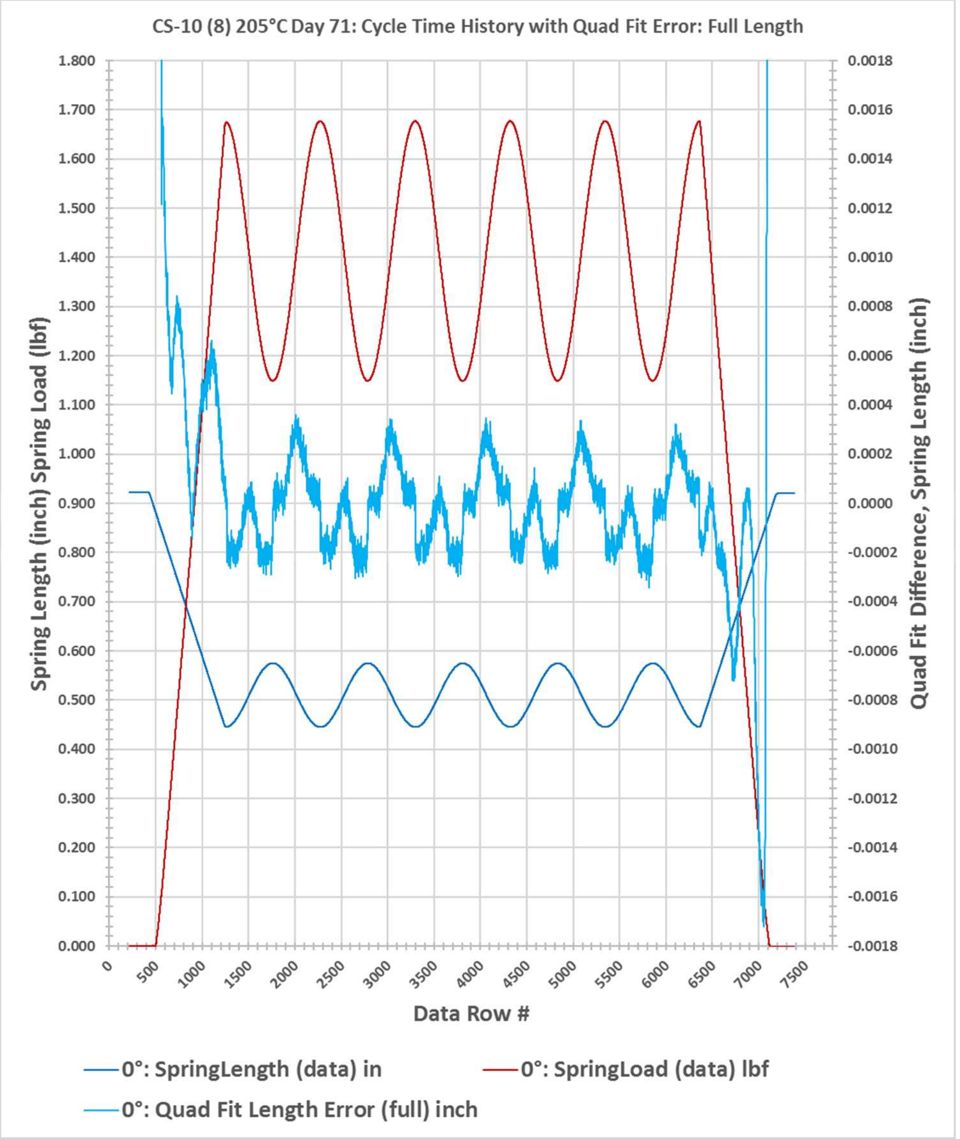
17-7 PH compression springs		
Length	Temperature (°C)	Number
Free	Ambient	3
Free	70	2
Free	100	2
Free	170	2
Free	205	2
Length 2	Ambient	3
Length 2	70	2
Length 2	100	2
Length 2	170	2
Length 2	205	2
Length 3	Ambient	3
Length 3	70	2
Length 3	100	2
Length 3	170	2
Length 3	205	2

How to measure tiny displacements

Minimize experimental variation

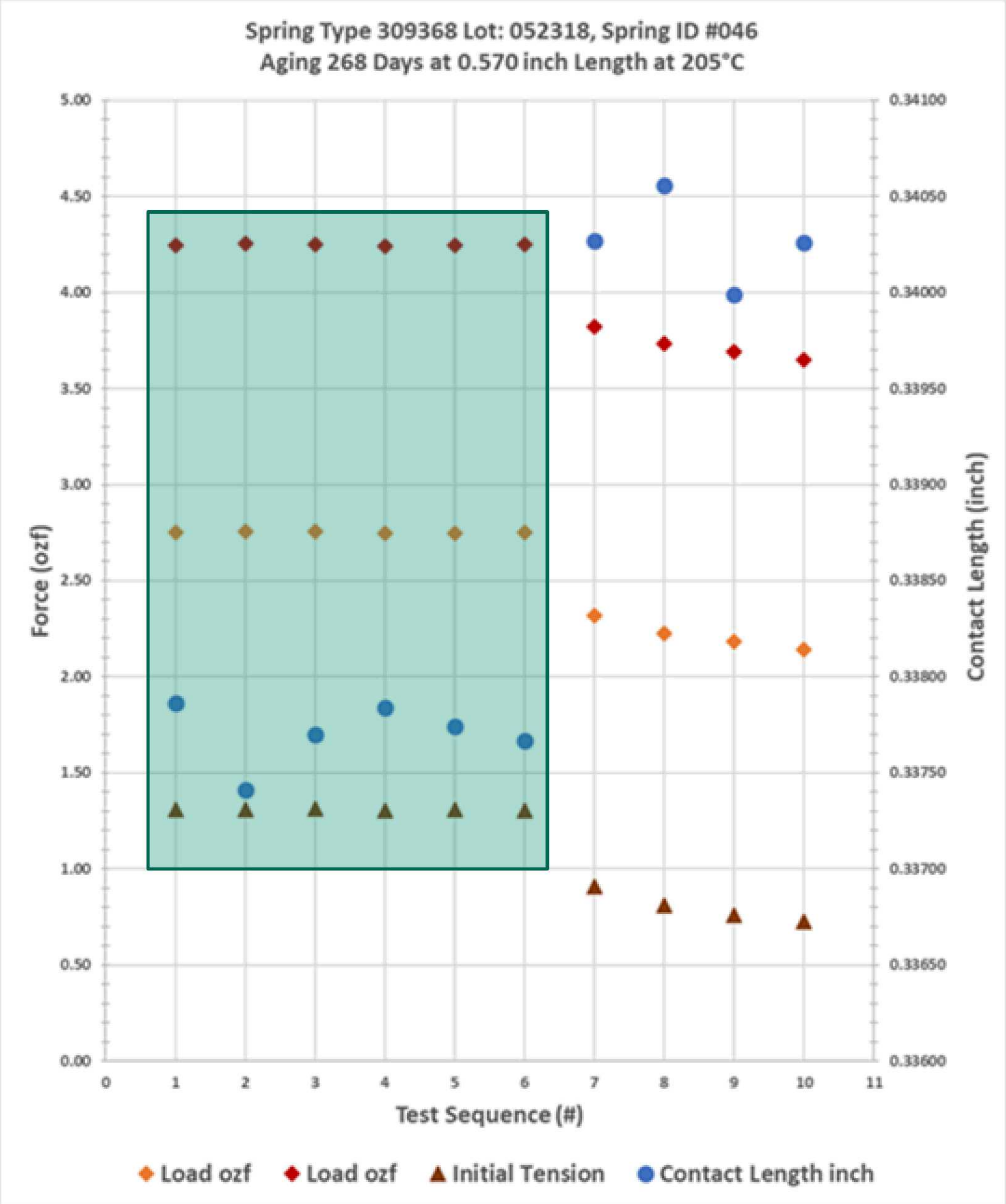






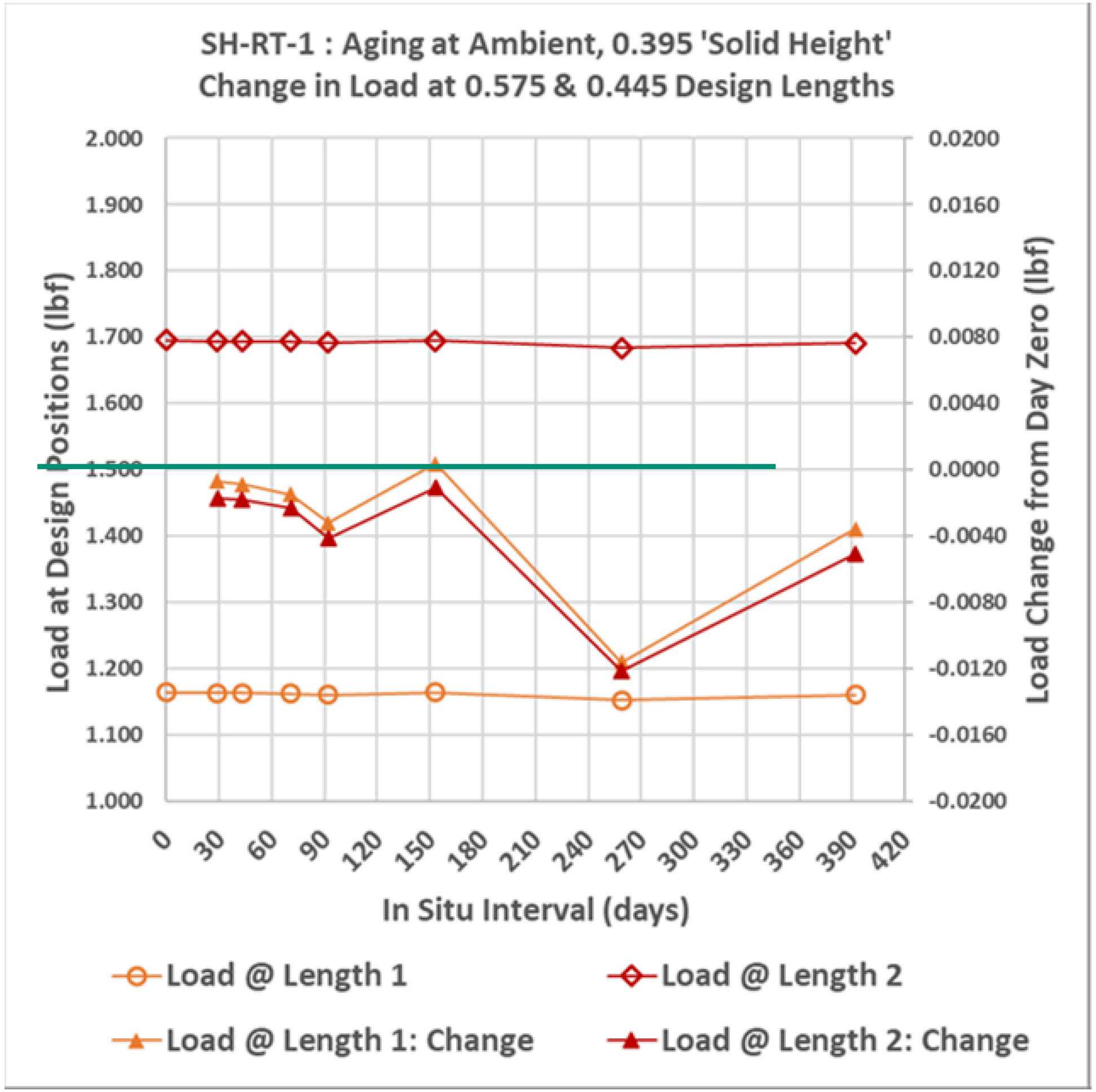
Variability in data – how much property change can we reliably detect?

Shaded area contains the six tests completed prior to aging at 0.57 in and 205ºC

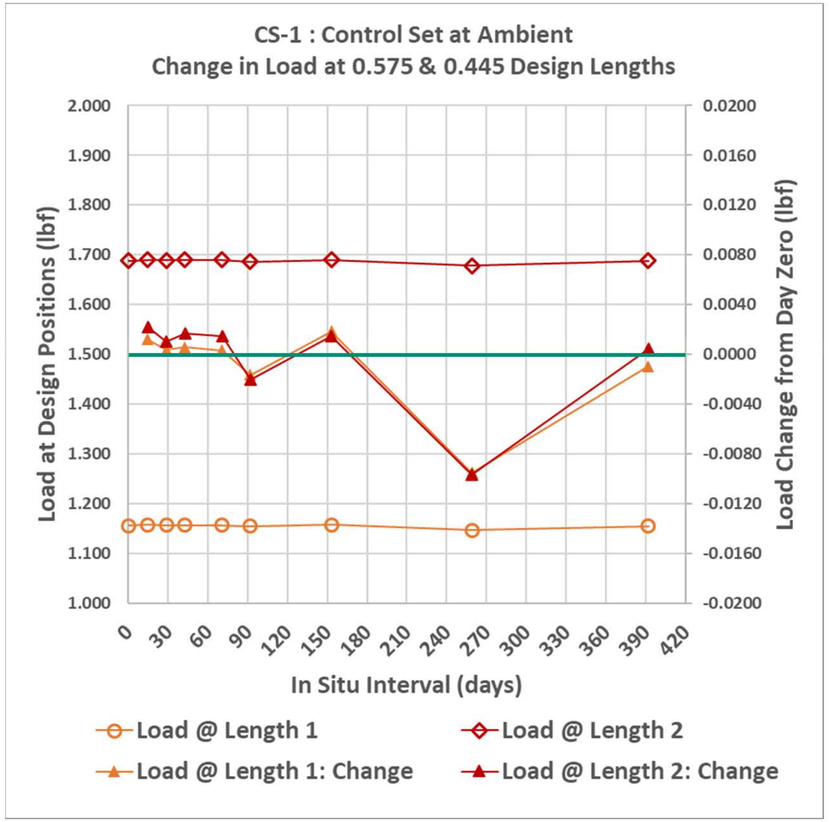


This data demonstrates our ability to observe significant aging behavior.

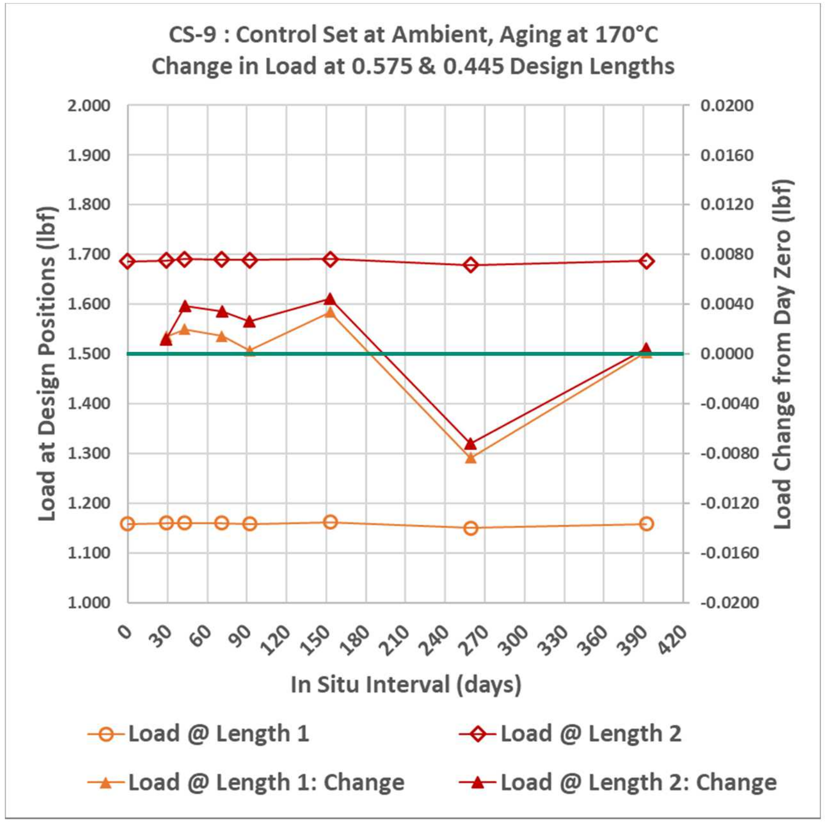
Example of data – 17-7 compression spring at ambient temperature, solid height, 390 days



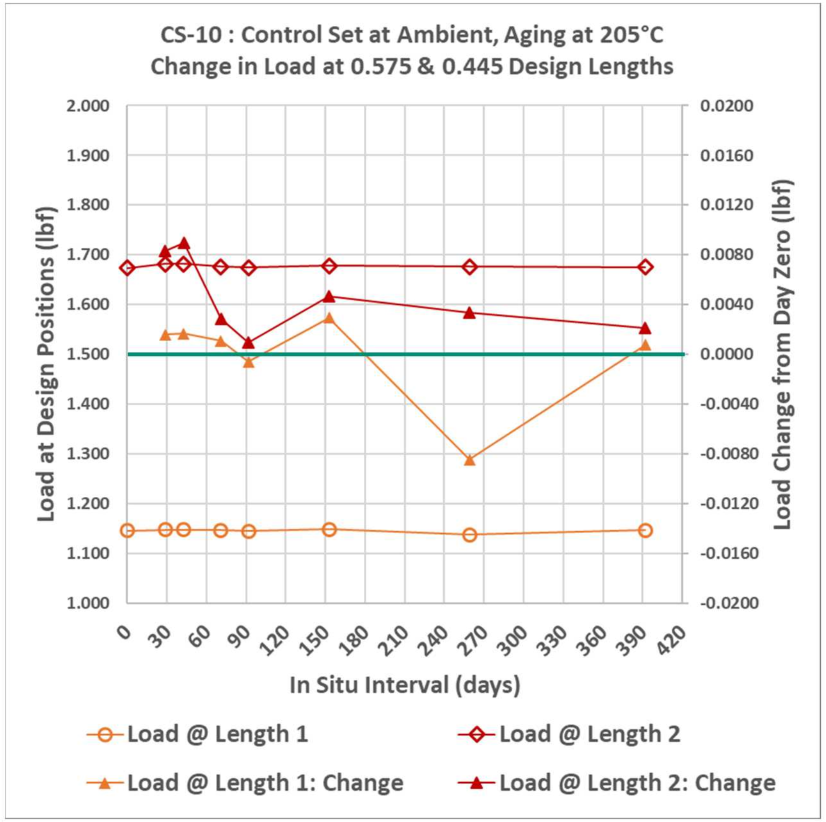
Results from 17-7 PH compression springs – free length at various temperatures



25°C



170°C



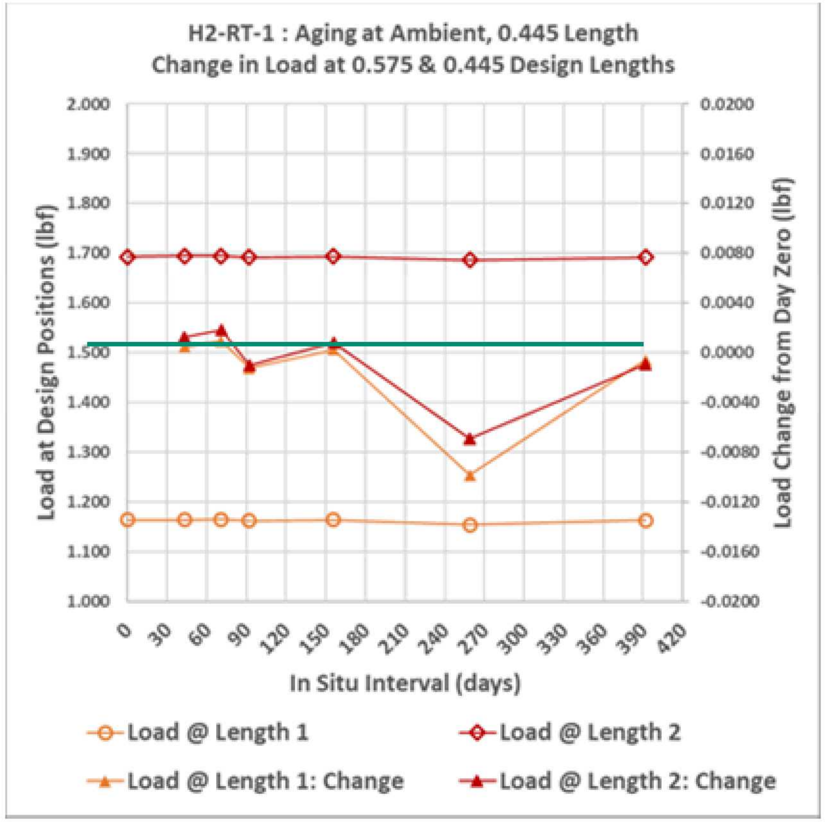
205°C

Shows variation of measurement – some deviation at the 260 day measurement

Essentially no change

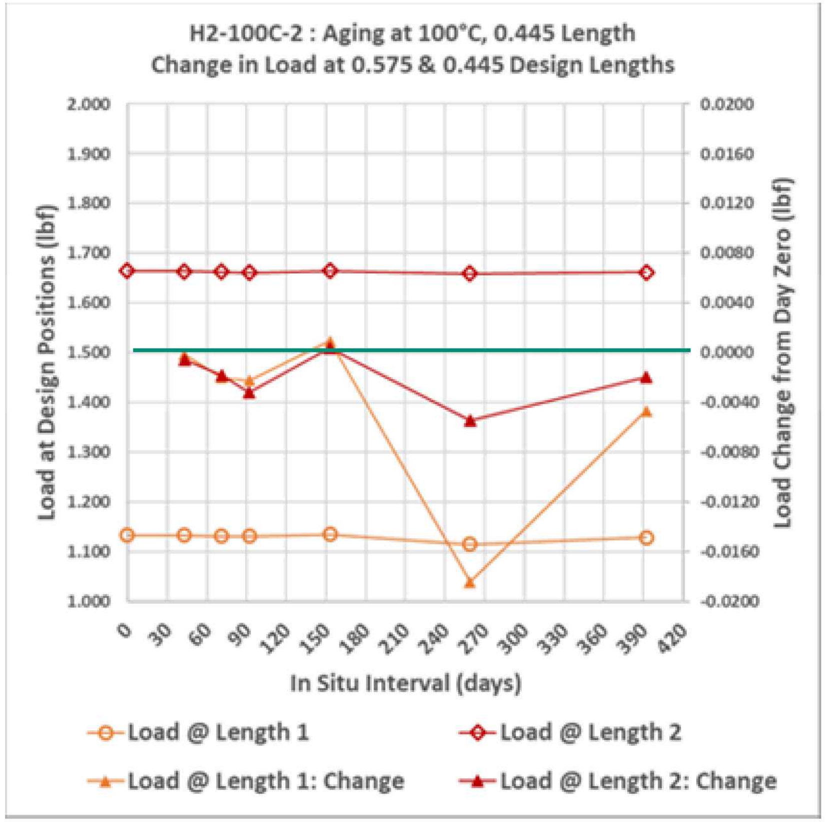
The springs got longer?!

Results from 17-7 PH compression springs – Height 2 at various temperatures



25°C

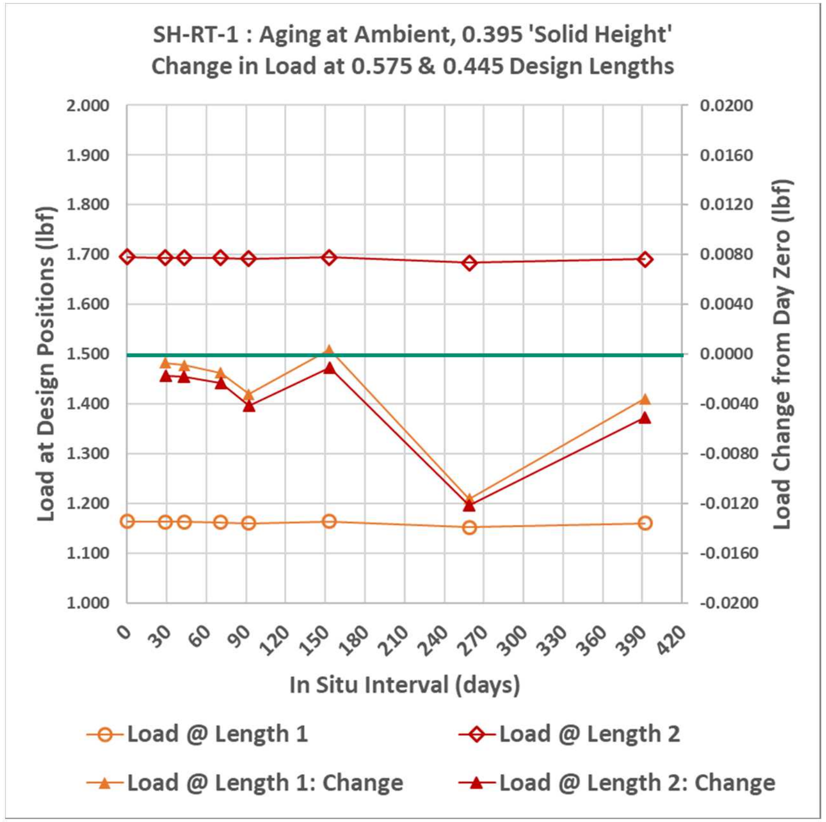
Essentially no change

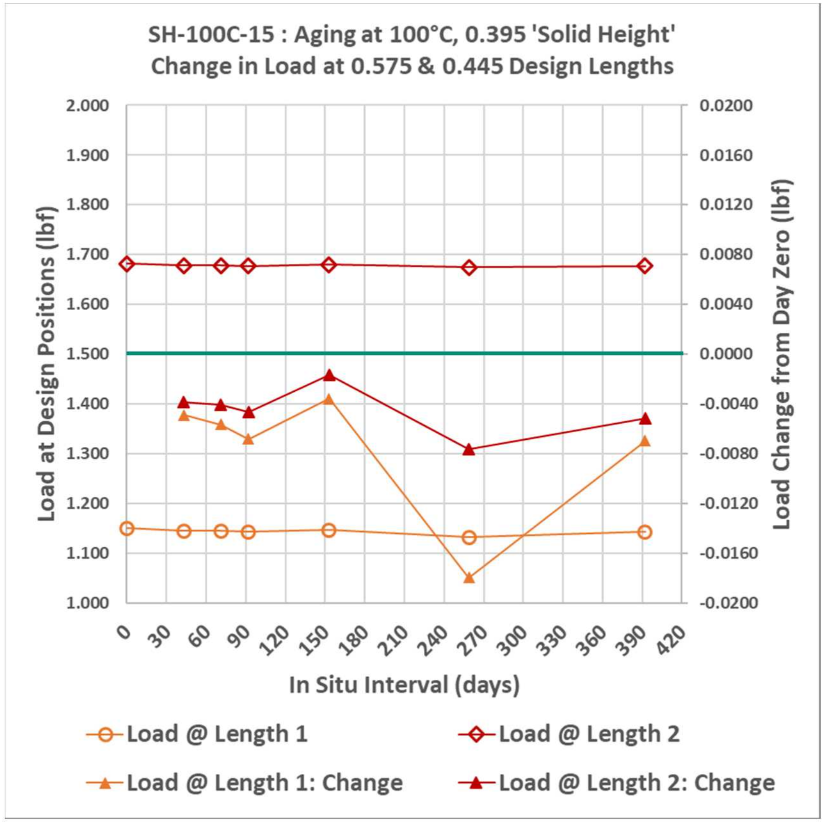


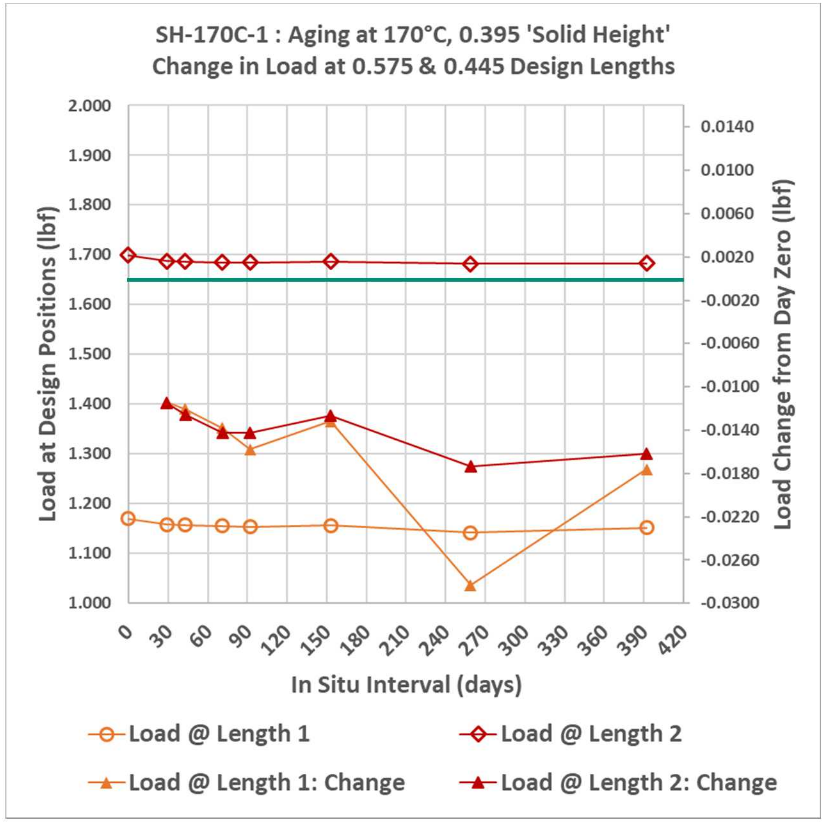
100°C

Decrease in spring height

Results from 17-7 PH compression springs – Solid height at various temperatures



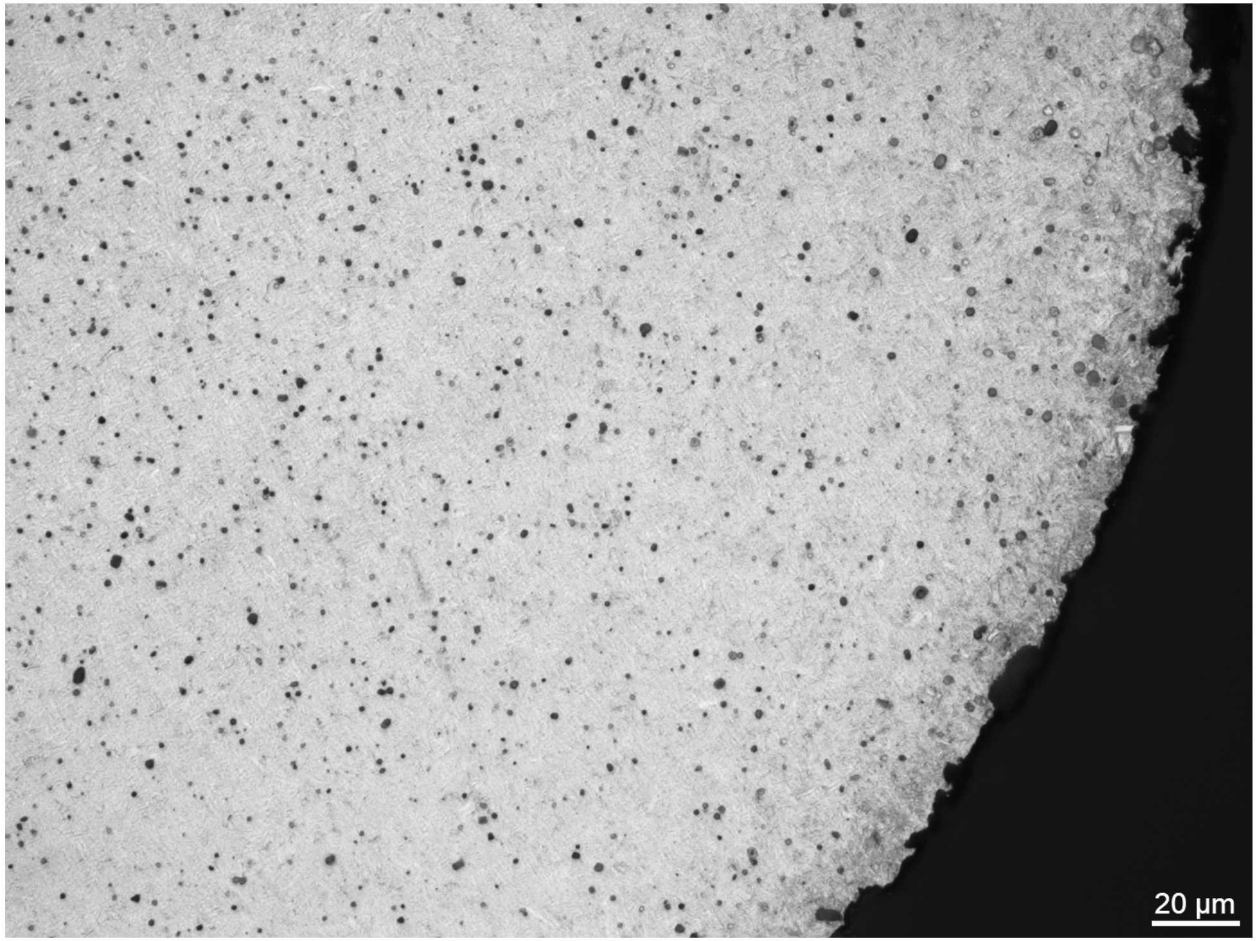


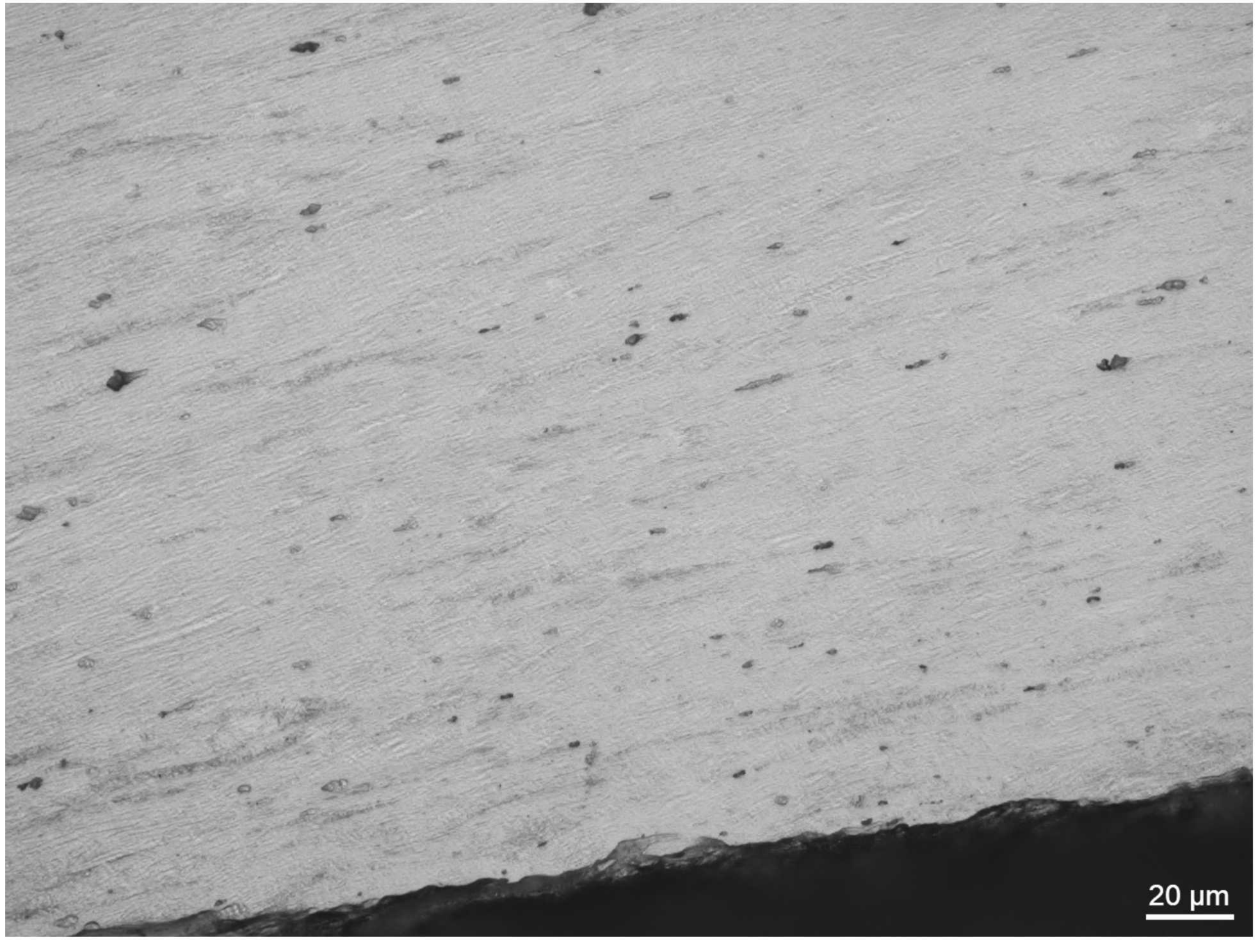


25°C	100°C	170°C
Springs got shorter	Springs got shorter	Springs got shorter

17-7 cold worked spring microstructure

17-7 CH 900 – cold worked, followed by precipitation hardening. Martensitic microstructure.



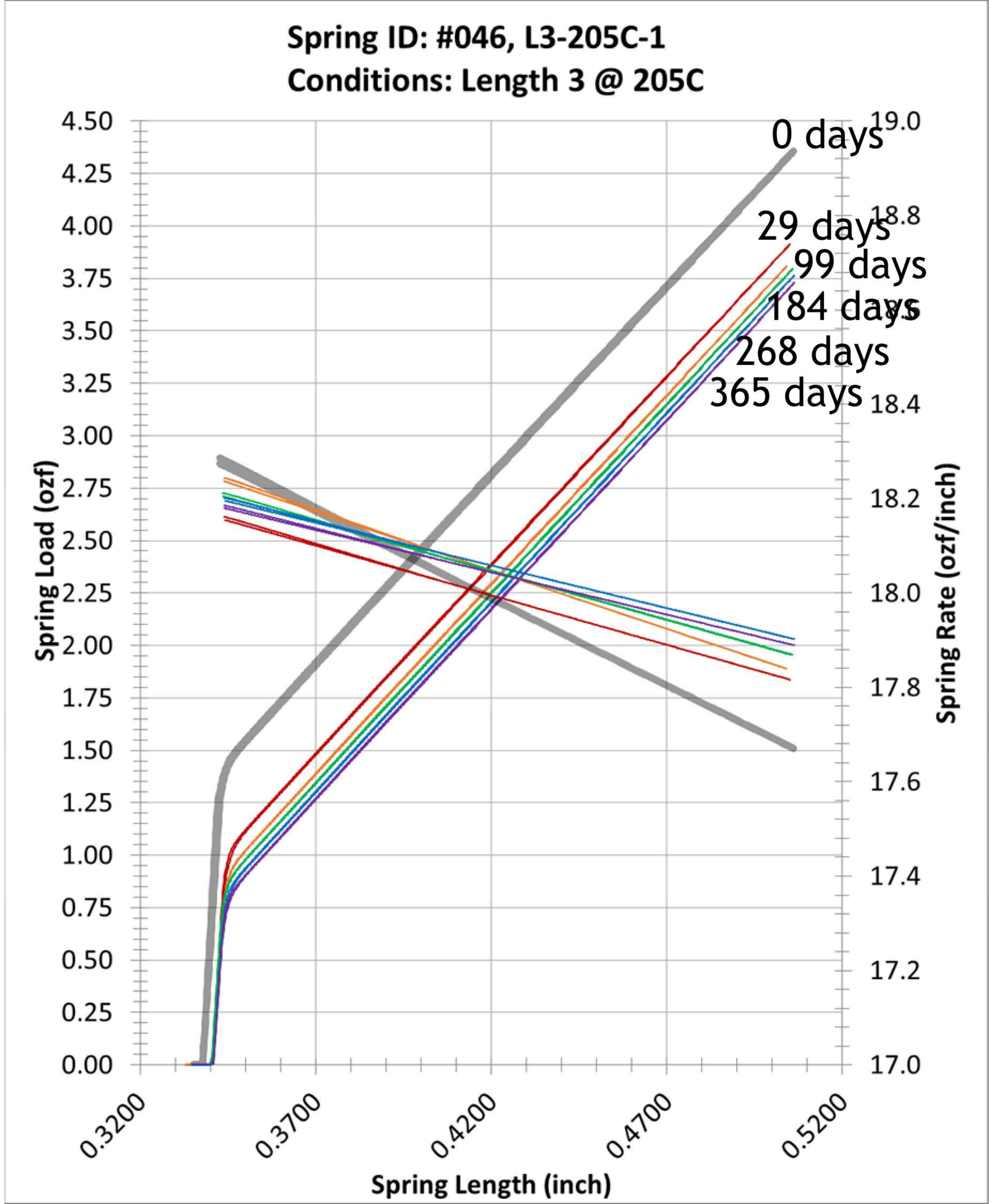


302 stainless steel tension spring

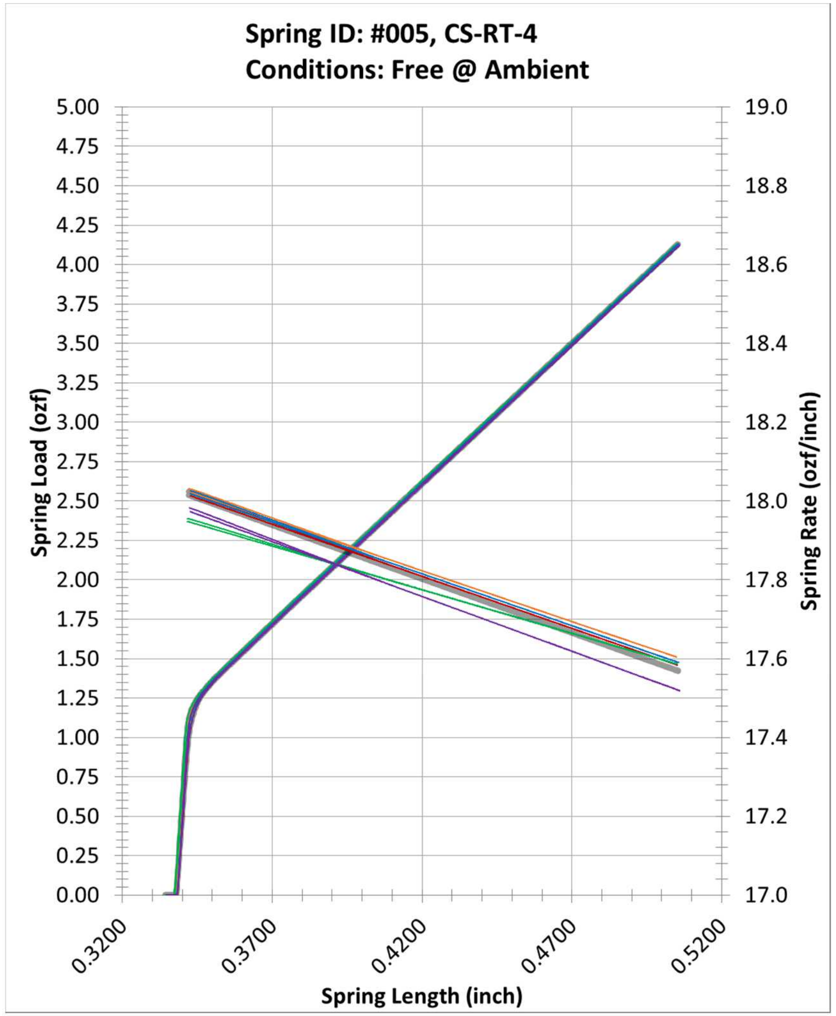
Multiple tests plotted in each data set.

Clear change in the initial tension with aging.

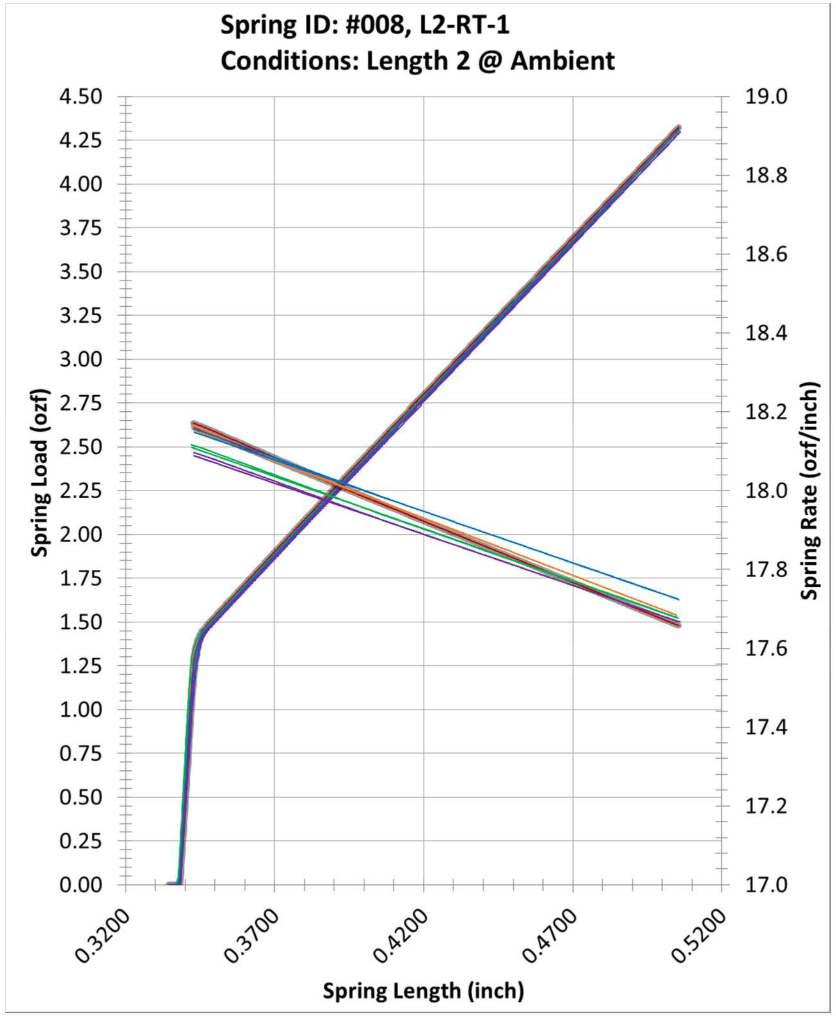
Spring rate decreases with spring extension.



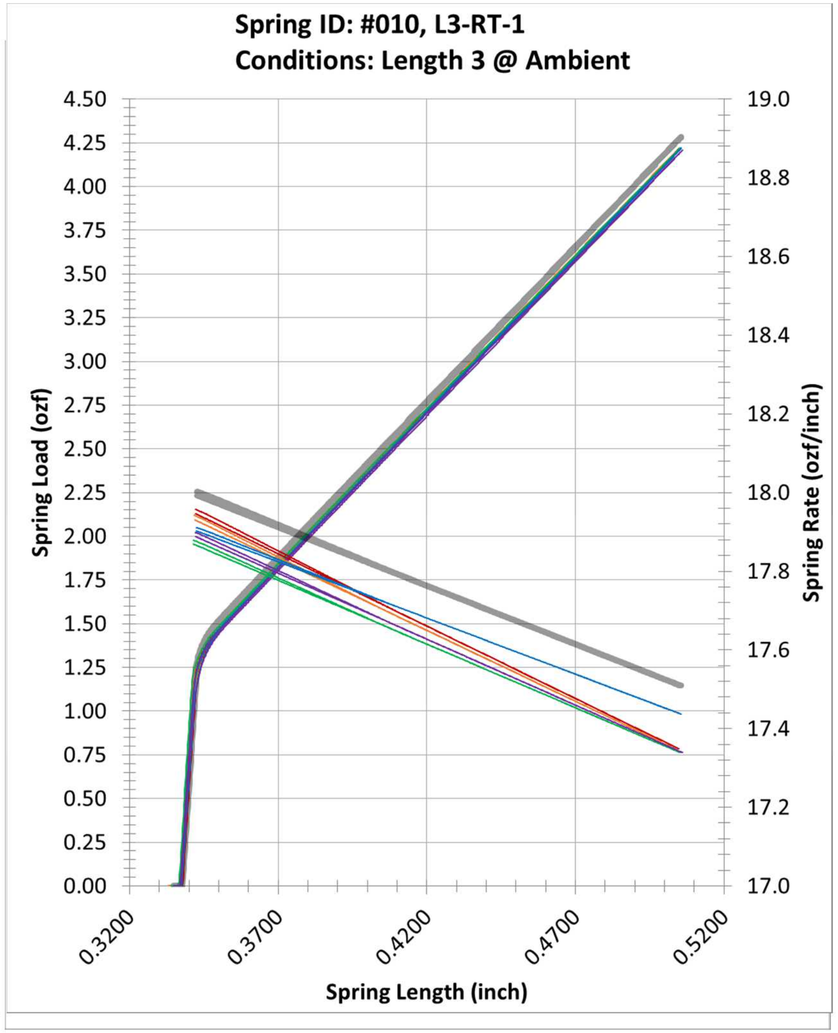
302 stainless steel 365 days aging results – ambient temperature



Free length

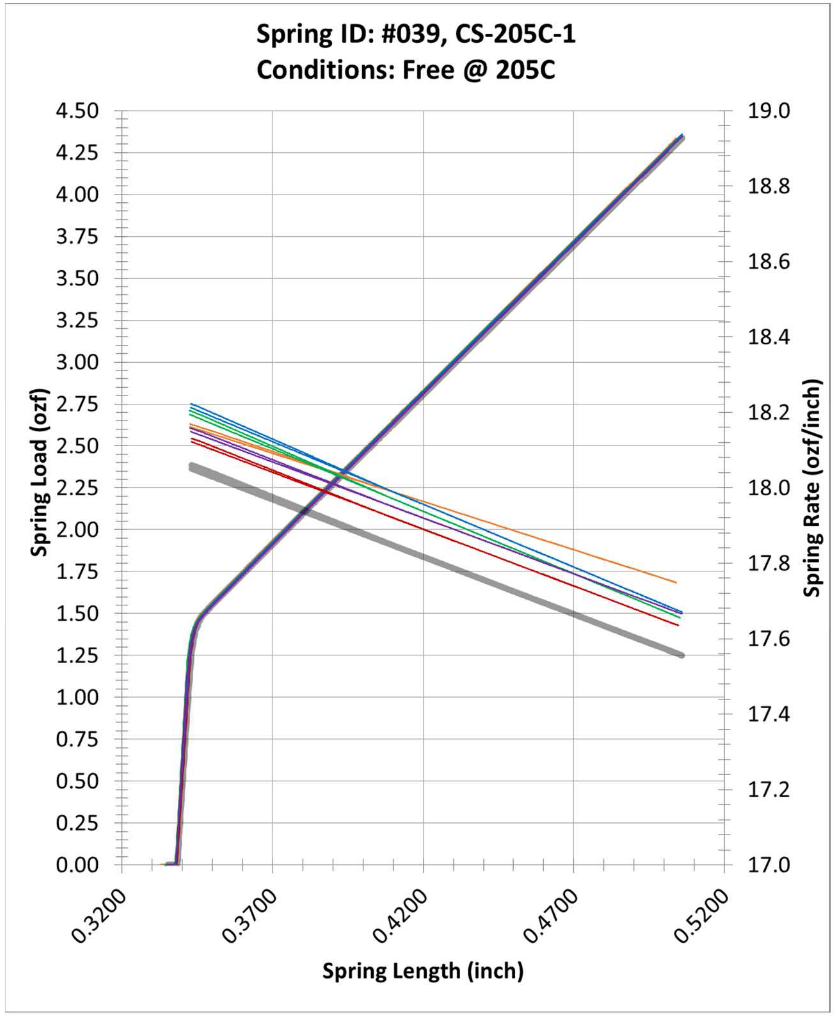


Length 2

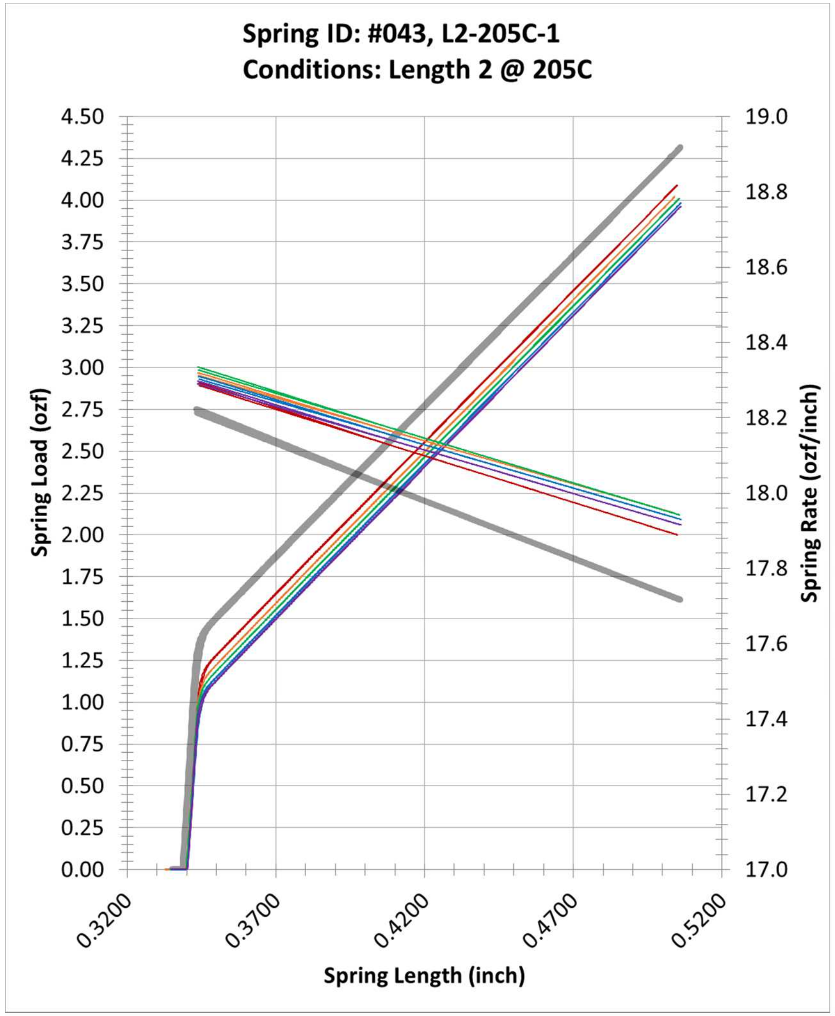


Length 3

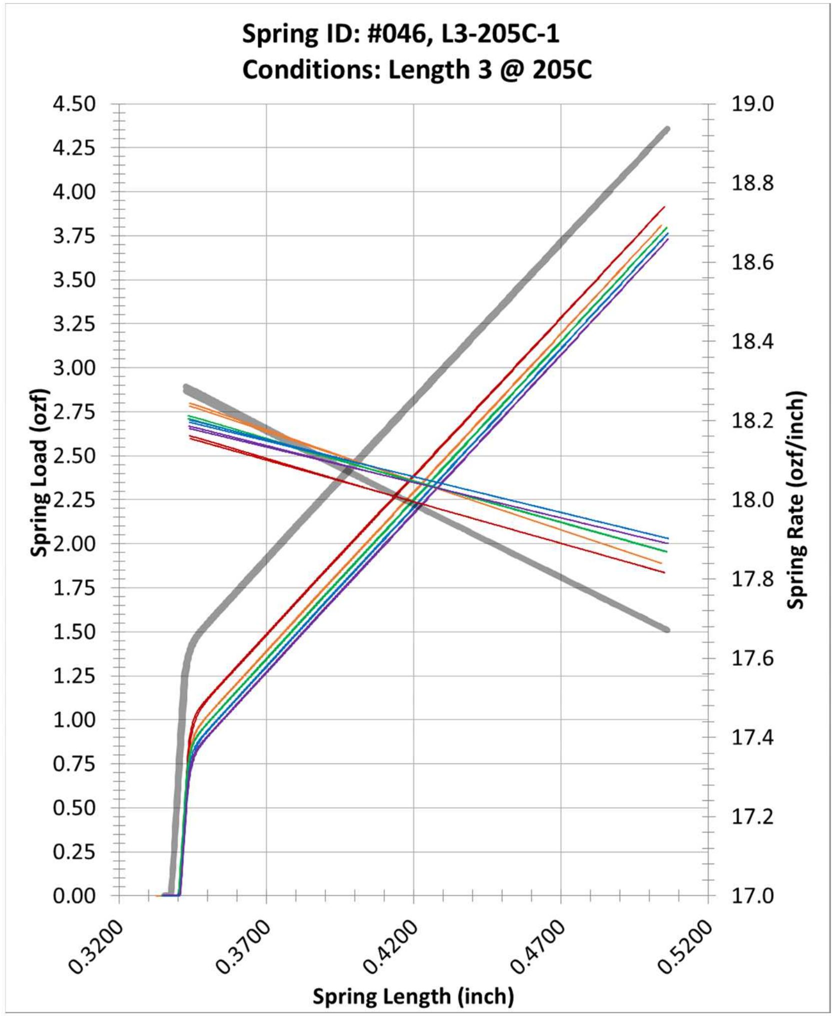
302 stainless steel 365 days aging results – 205°C



Free length

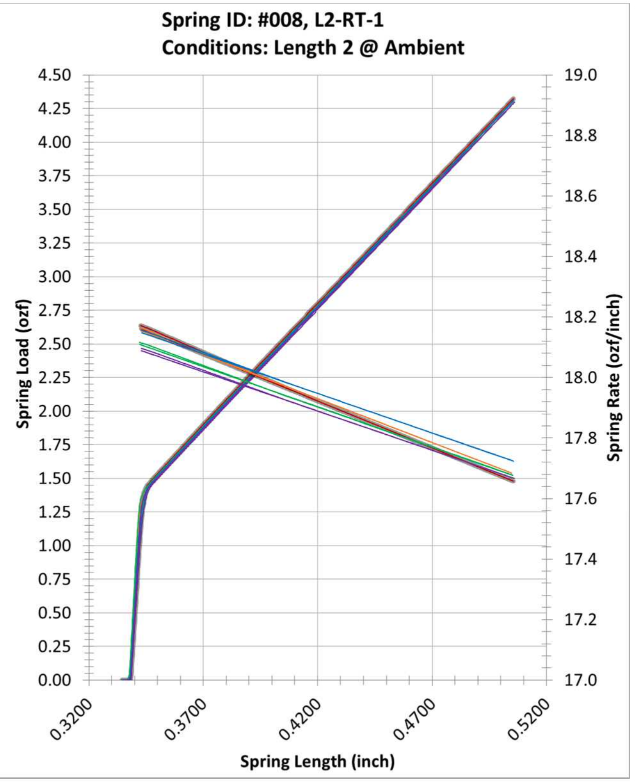


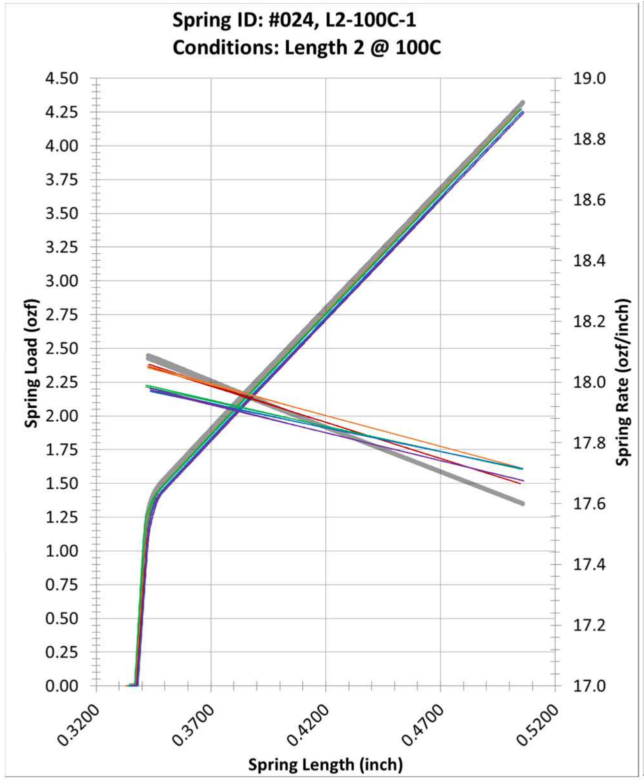
Length 2

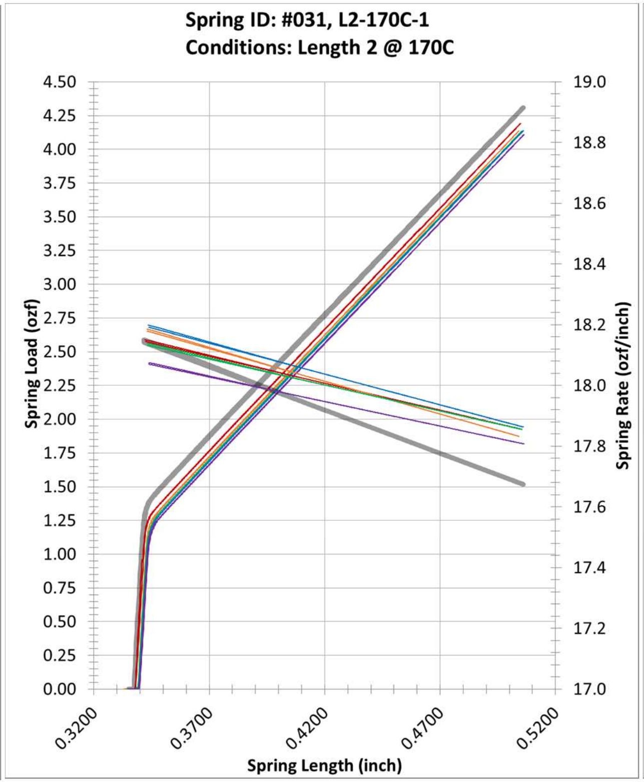


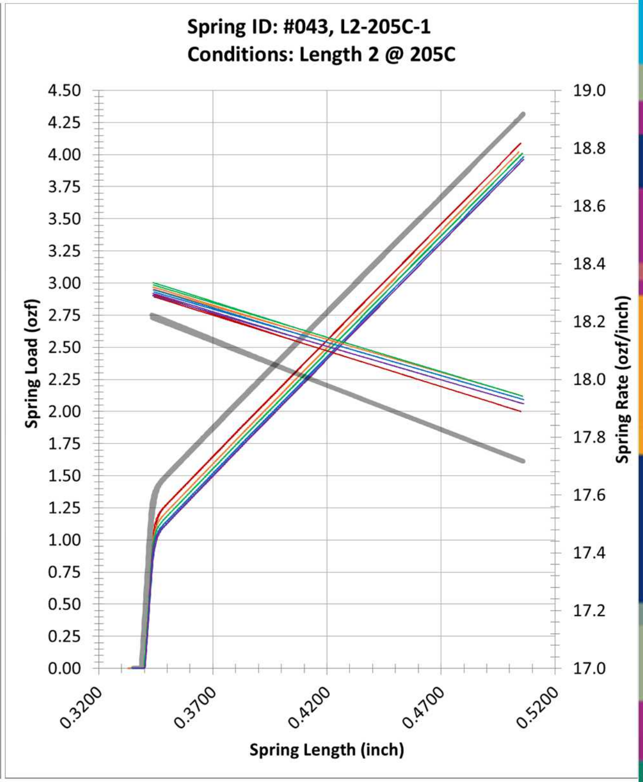
Length 3

302 stainless steel 365 days aging results – Position 2









Ambient

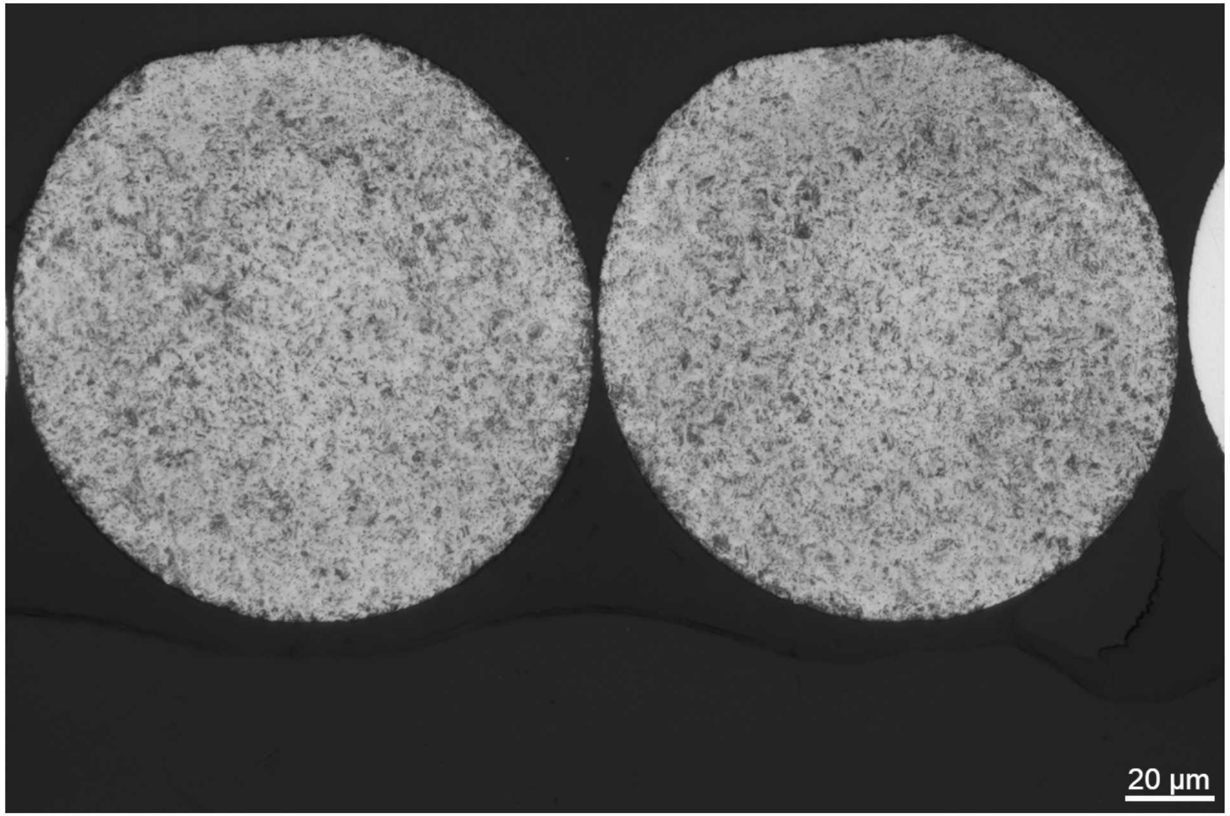
100ºC

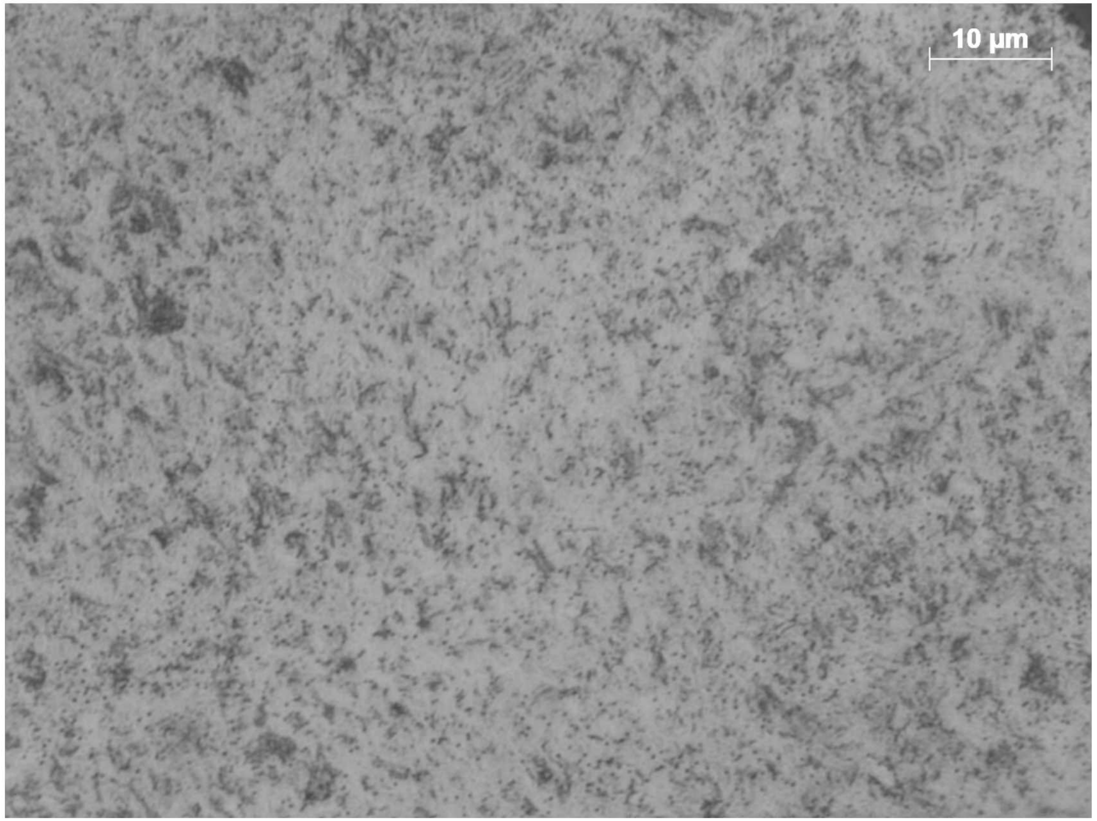
170ºC

205ºC

302 cold worked microstructure

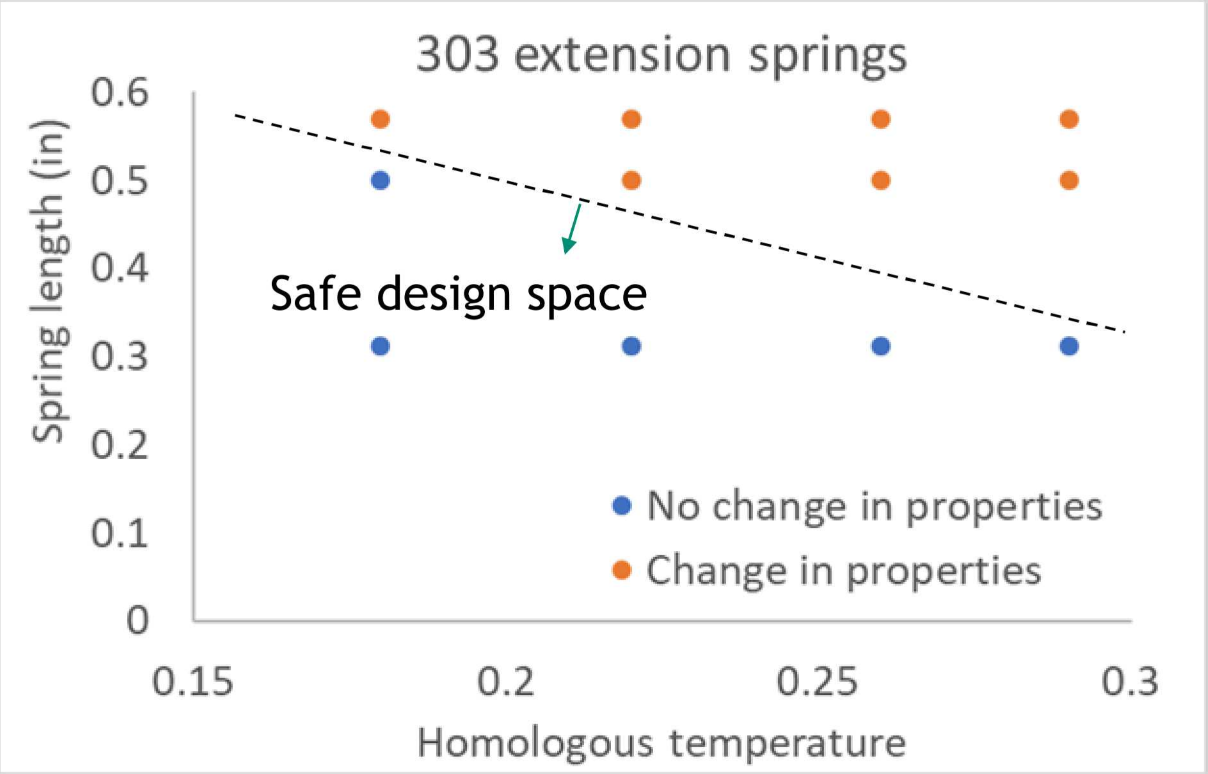
Martensitic, hard to etch well or image with channeling contrast.

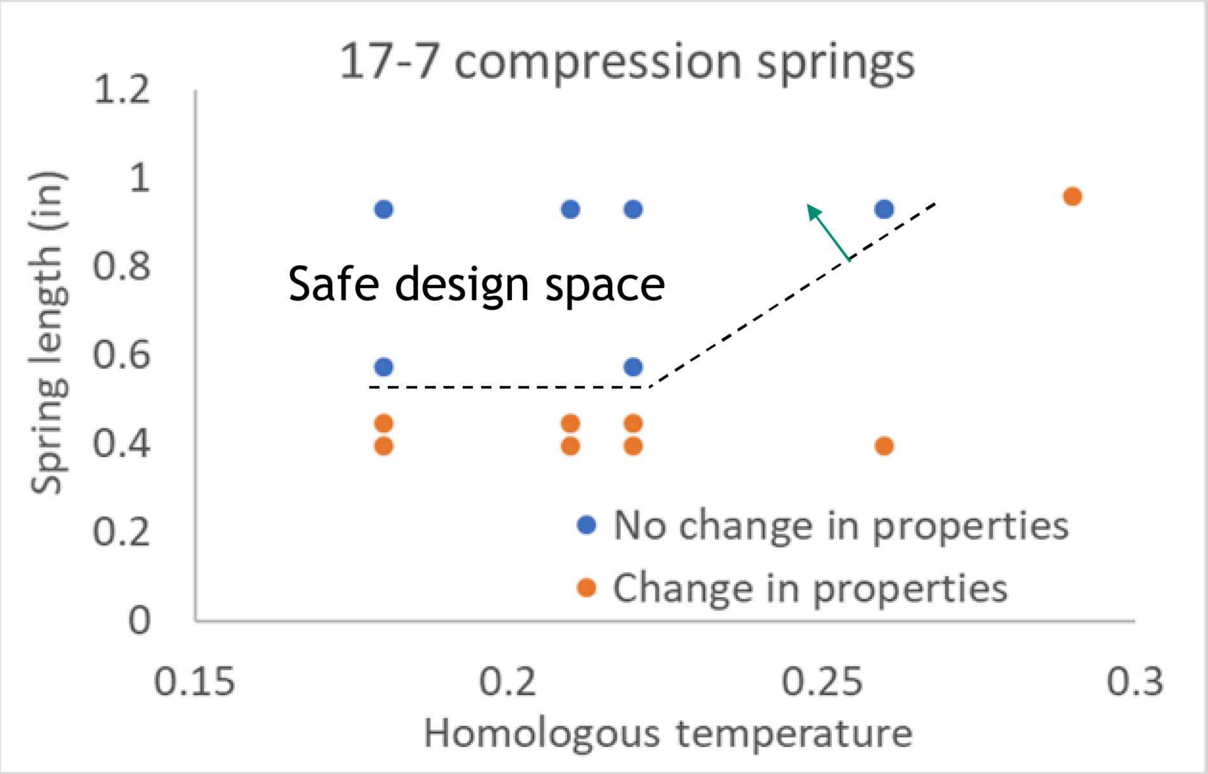




Overall summary

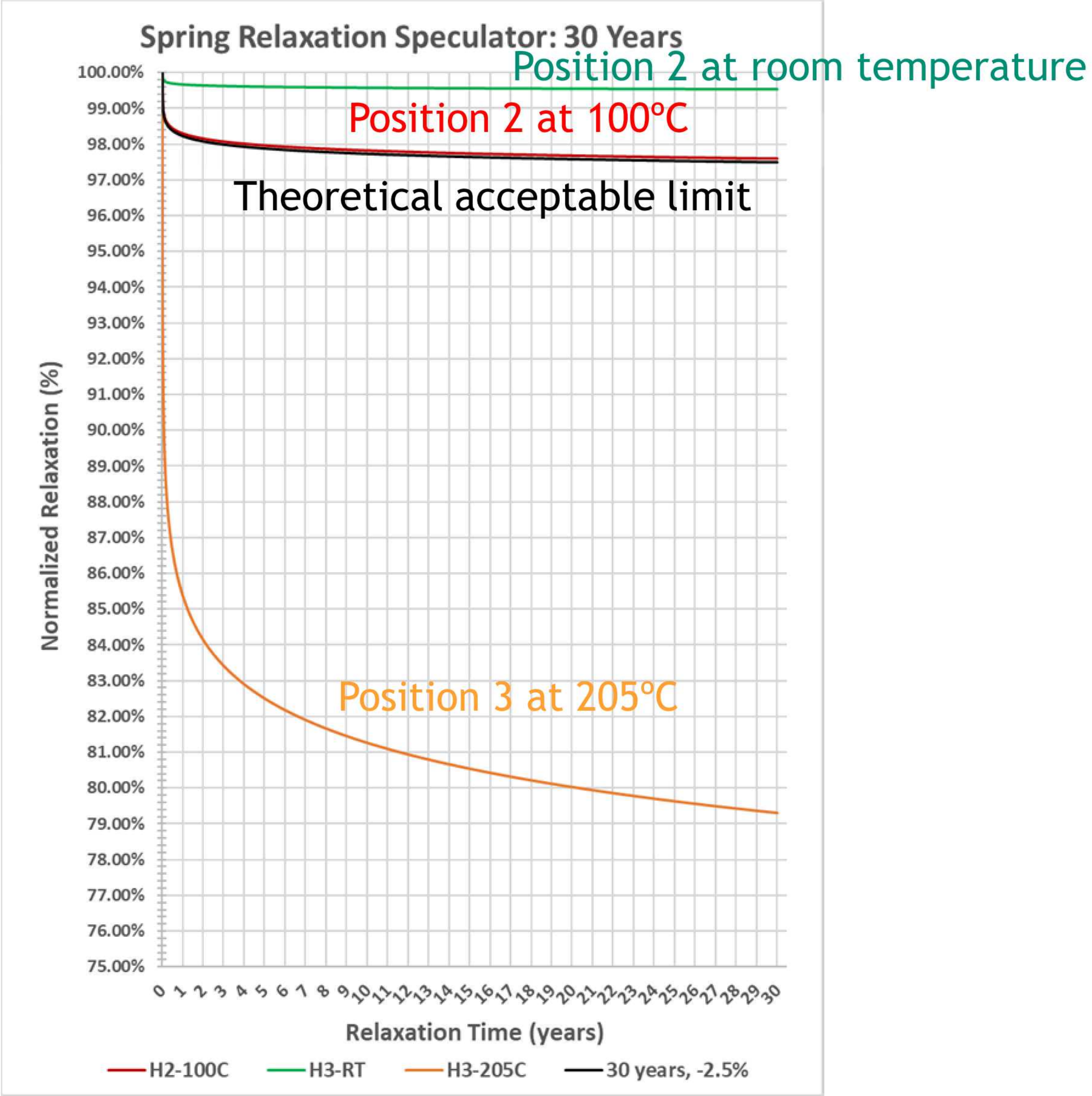
We have determined stress and temperature boundaries for onset of low temperature creep in 302 and 17-7 springs.



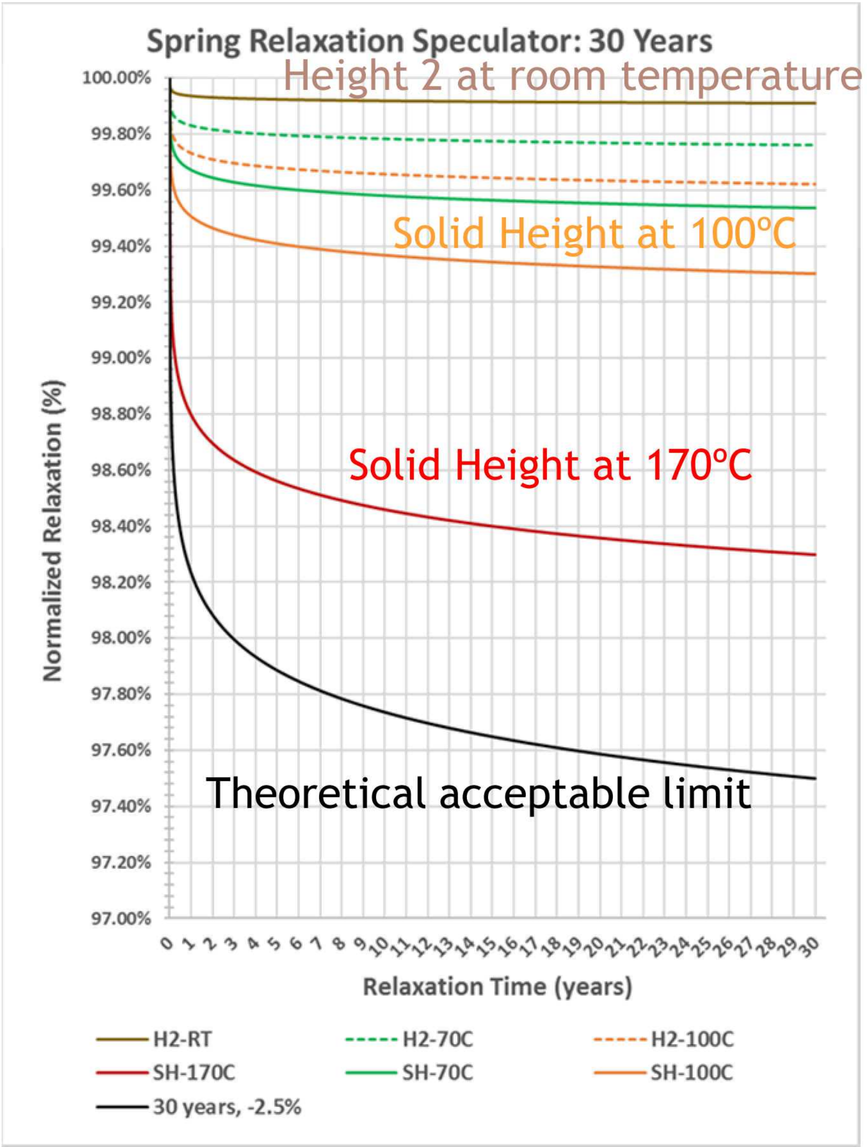


Life prediction

302 tension spring



17-7 PH compression spring



17-7 compression springs results summary

Springs at elevated temperatures of 170°C and 205°C do change shape – at 205°C they get longer if unconstrained – evidence of residual stress relaxation.

Springs at 100°C and room temperature only change shape if they're held at solid height.

Conclusion: It is not expected that the compression springs will experience any significant stress relaxation over a period of 30 years if kept below 100ºC and in either height 1 or height 2 position.

302 results summary

Springs under stress appear to change spring constant at room temperature, even at Length 2.

Springs at high temperature appear to change spring constant even at free length.

Initial tension does not change in springs at free length at any temperature.

Initial tension changes some at 0.57 inches at ambient and at 100ºC and 0.5 inch.

Conclusion: For normal aging conditions (Position 1 and Ambient temperature) we do not observe any changes.

Mechanisms of creep and stress relaxation

Diffusion (vacancy) based
- Nabarro-Herring – through grains
- Coble – along grain boundaries

Definitely high temperature mechanisms

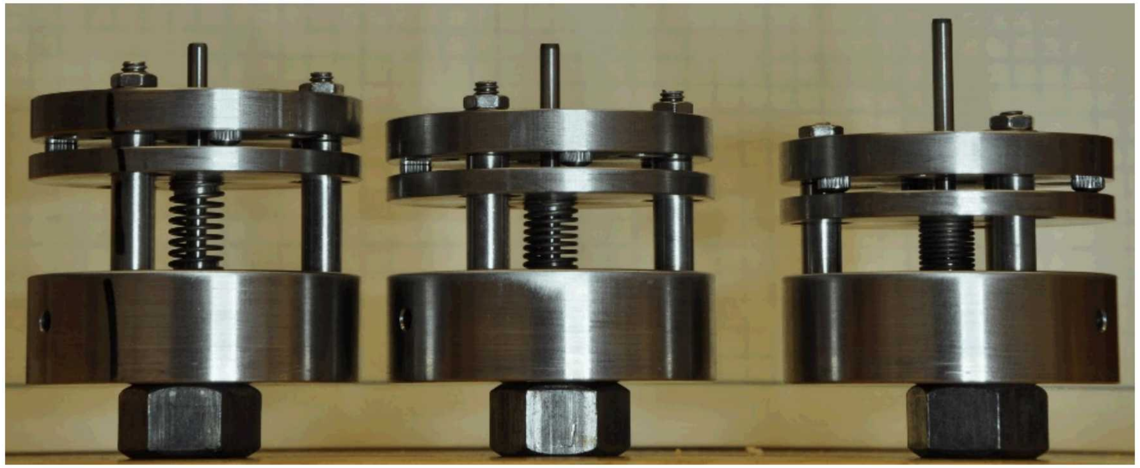
Dislocation creep – at high stresses
- Dislocation Climb

Harper-Dorn – low stresses, large grain sizes - ???

Solute drag – dislocation and diffusional flow

High temperature mechanisms, but maybe low too?

Particular springs tested and motivation



Piston springs
- Potential spring performance degradation concern
- 17-7 PH compression spring

Timing springs
- In many systems, and potential for spring performance degradation
- 302 stainless steel tension spring