Determining the Acceptable Ranges of Relative Humidity and Temperature in Museums and Galleries

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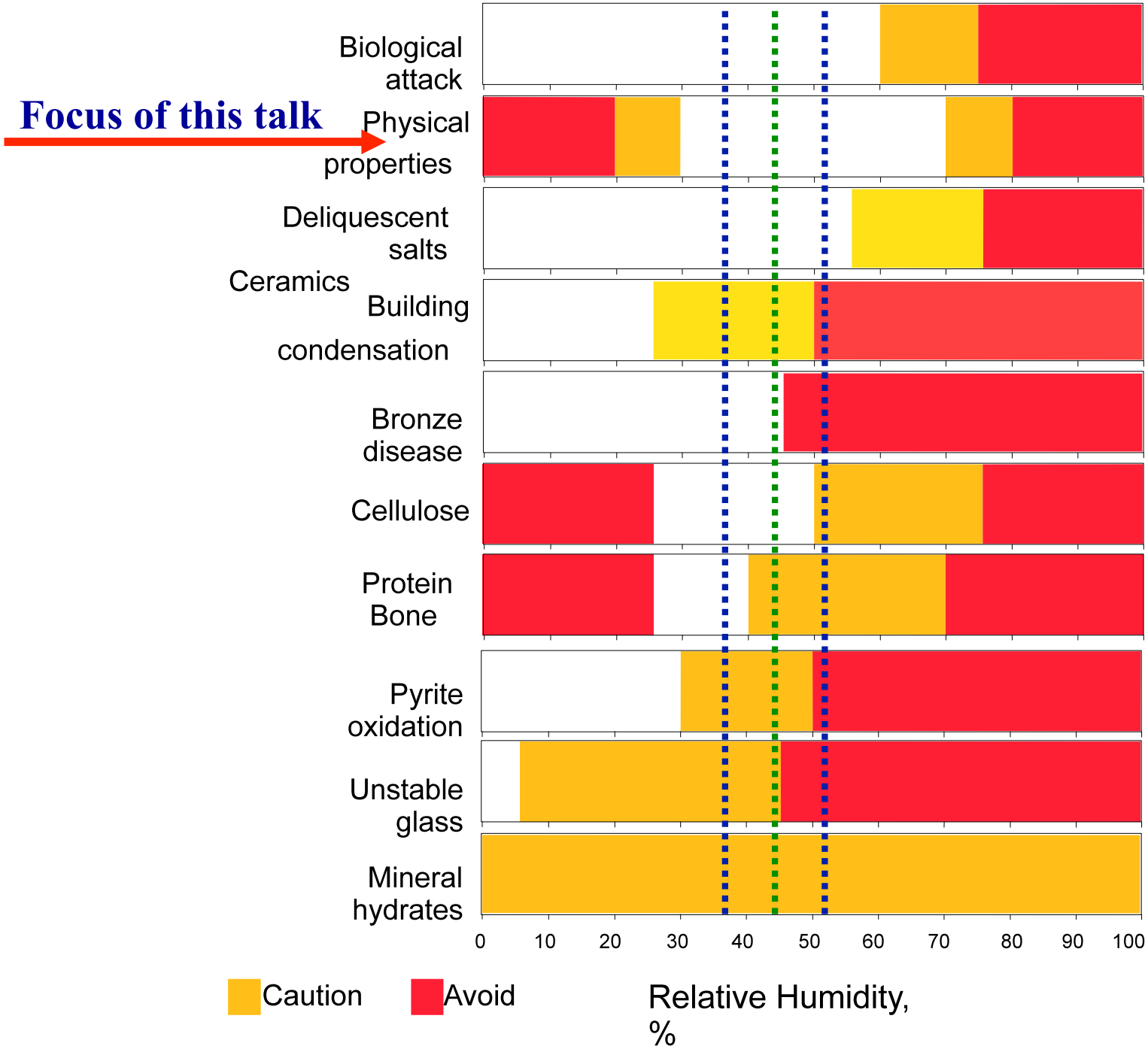
Oslo, Norway, 2010

Looking at the Bigger Picture

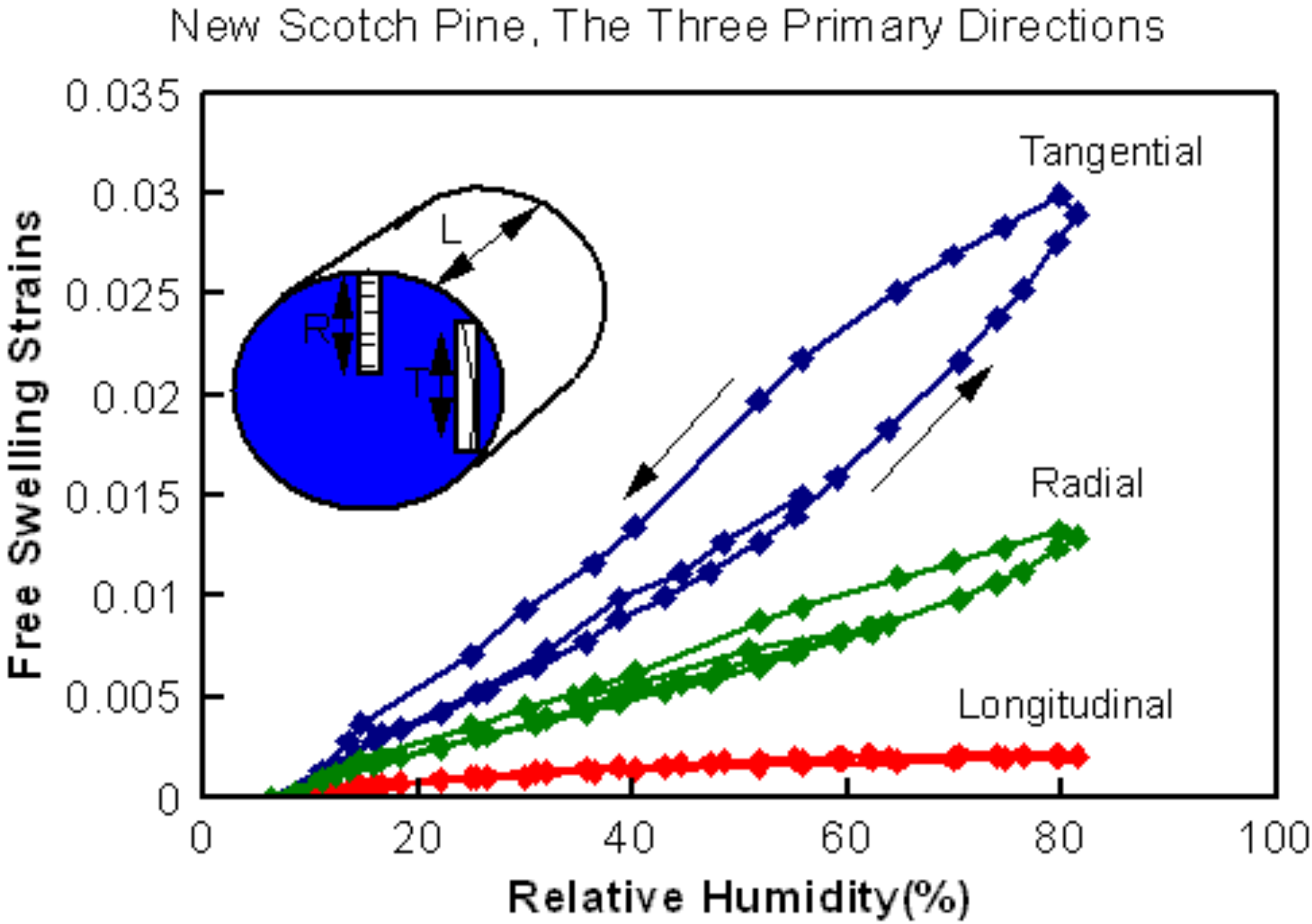
There is no single environment that works for everything in the collections

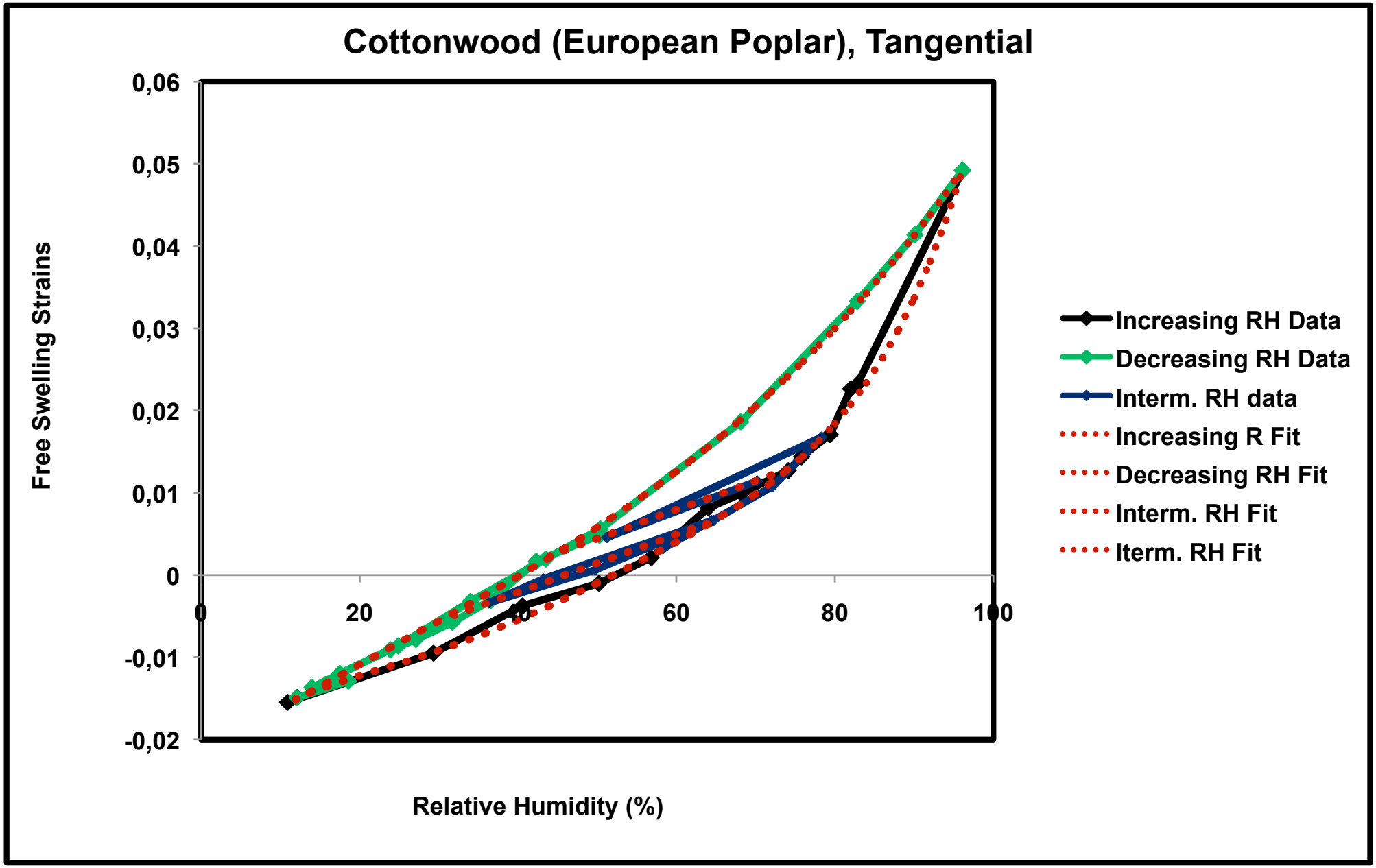
RELATIVE HUMIDITY STABILITY ZONES

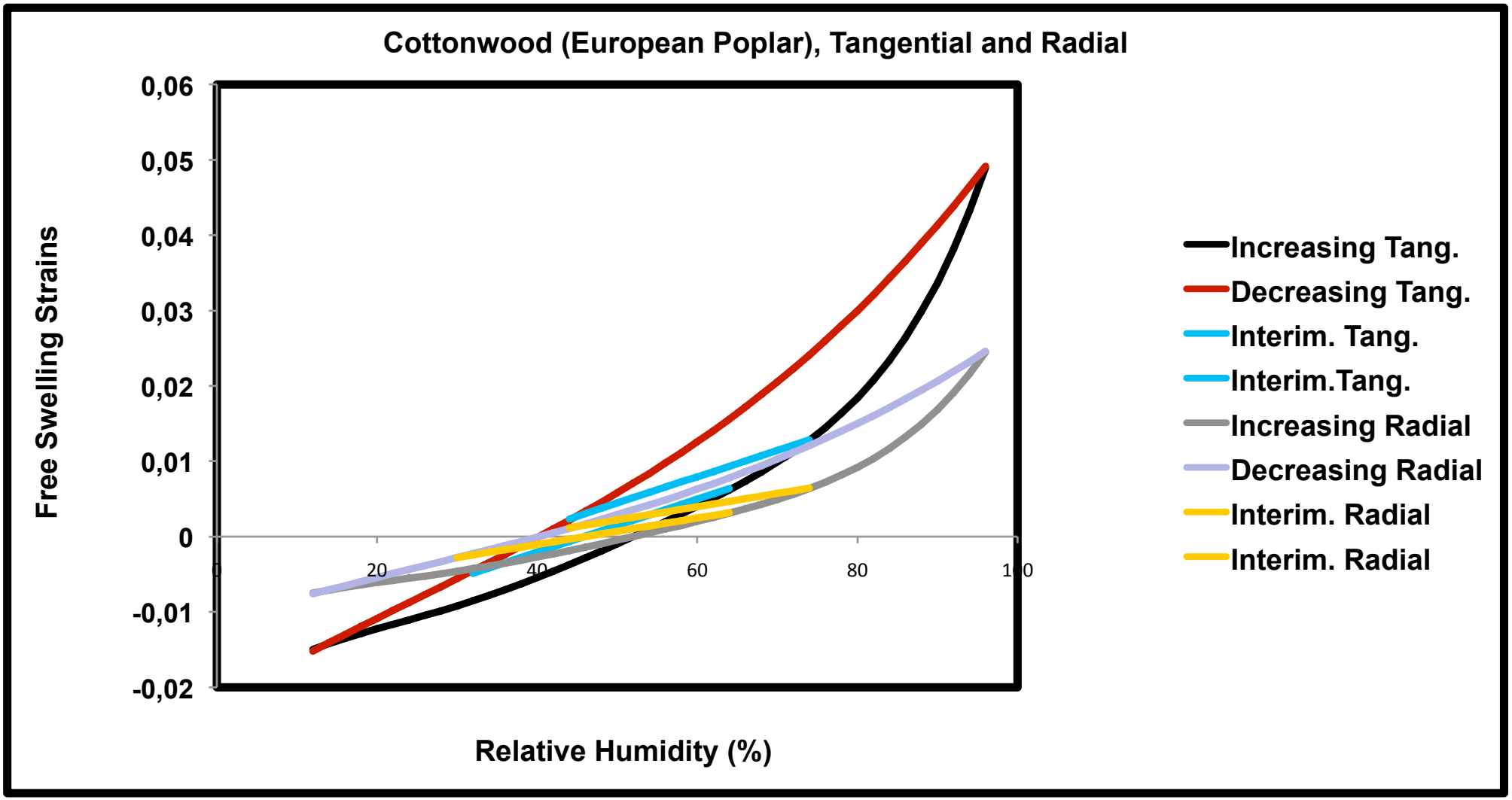


The easiest way to look at the effects of relative humidity on painted wood systems is to look at the dimensional properties and the moisture coefficients.

This approach is only a qualitative first approximation.

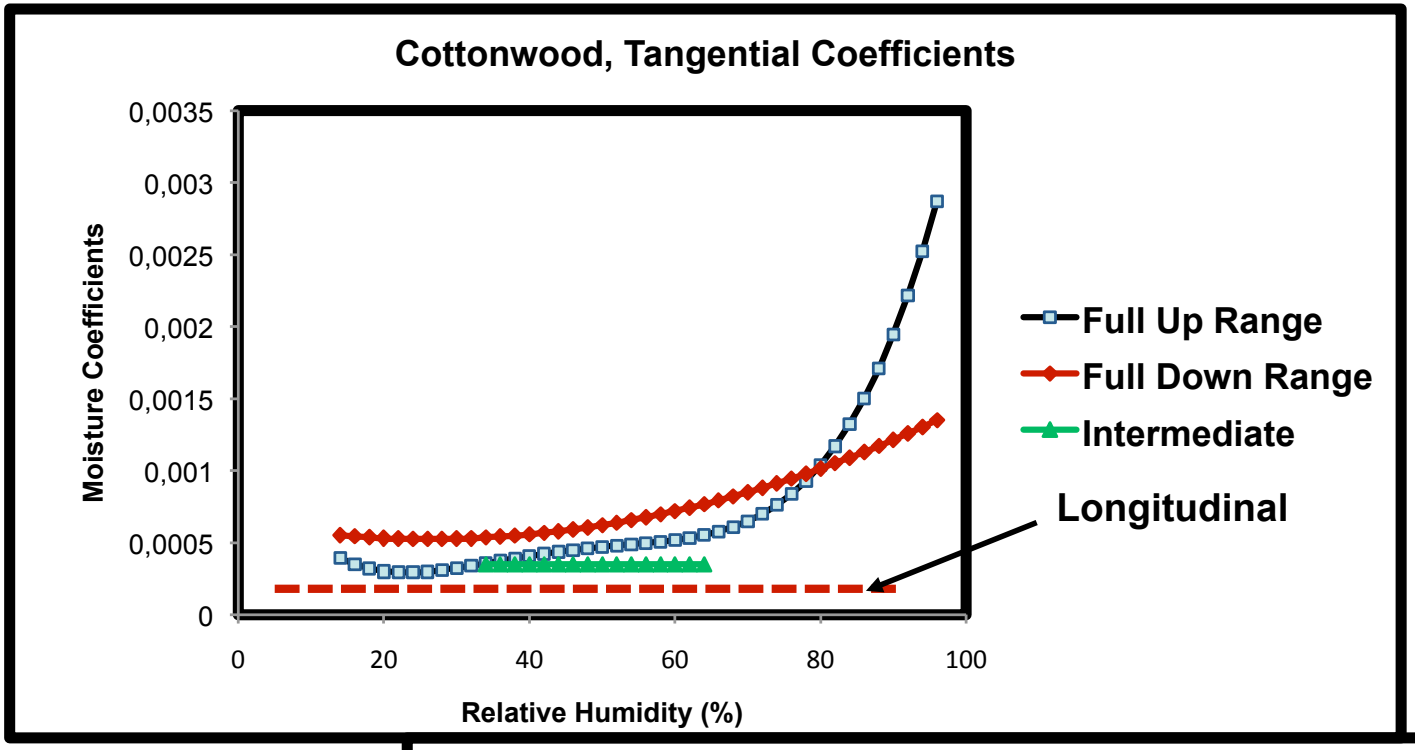

New Scotch Pine, The Three Primary Directions
Free Swelling Strains
Relative Humidity(%)
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0
20
40
60
80
100
Tangential
Radial
Longitudinal
L
R
T

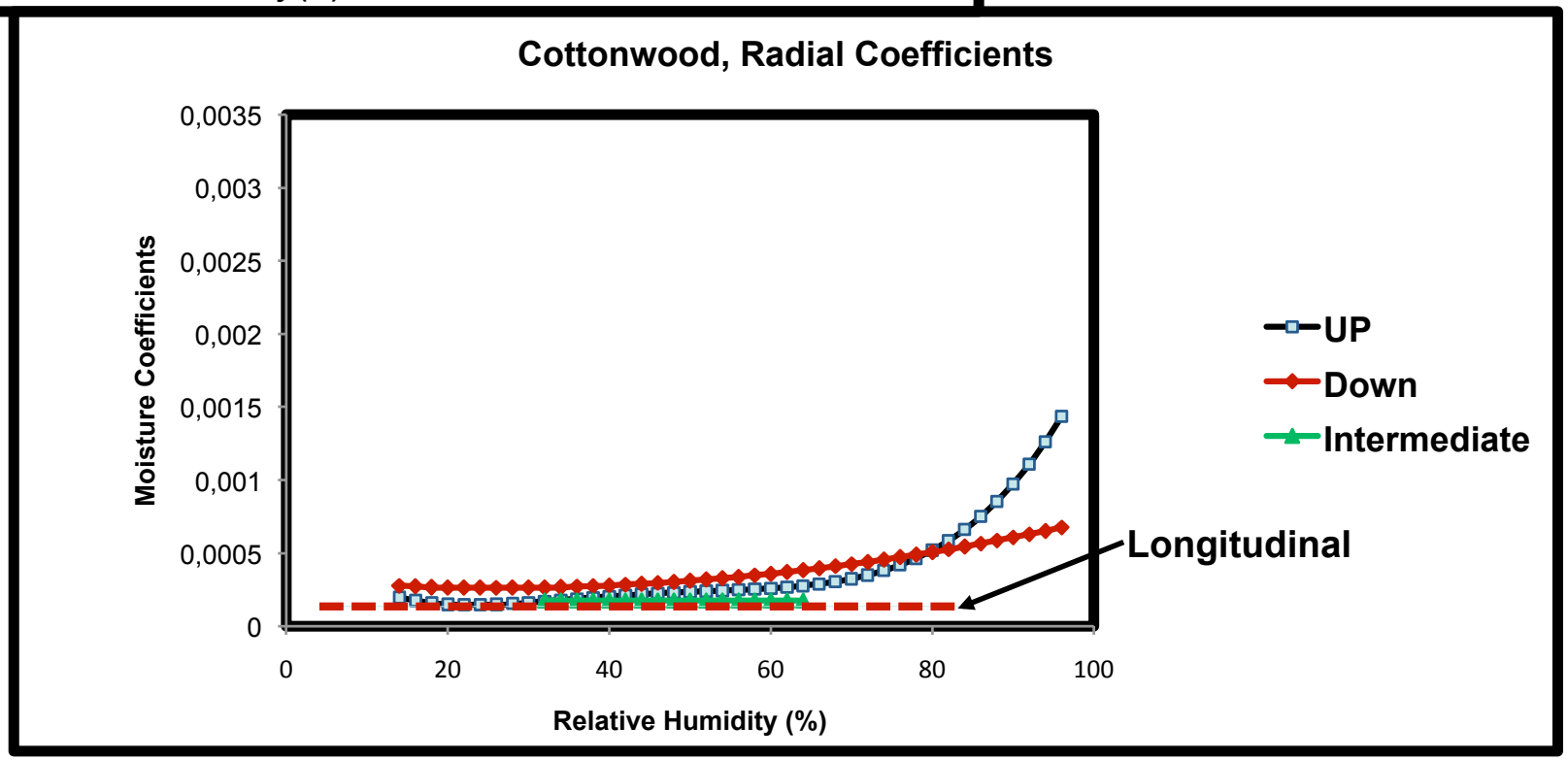

Cottonwood (European Poplar), Tangential
Free Swelling Strains
0,06
0,05
0,04
0,03
0,02
0,01
0
-0,01
-0,02
0
20
40
60
80
100
Relative Humidity (%)
Increasing RH Data
Decreasing RH Data
Interm. RH data
Increasing R Fit
Decreasing RH Fit
Interm. RH Fit
Iterm. RH Fit

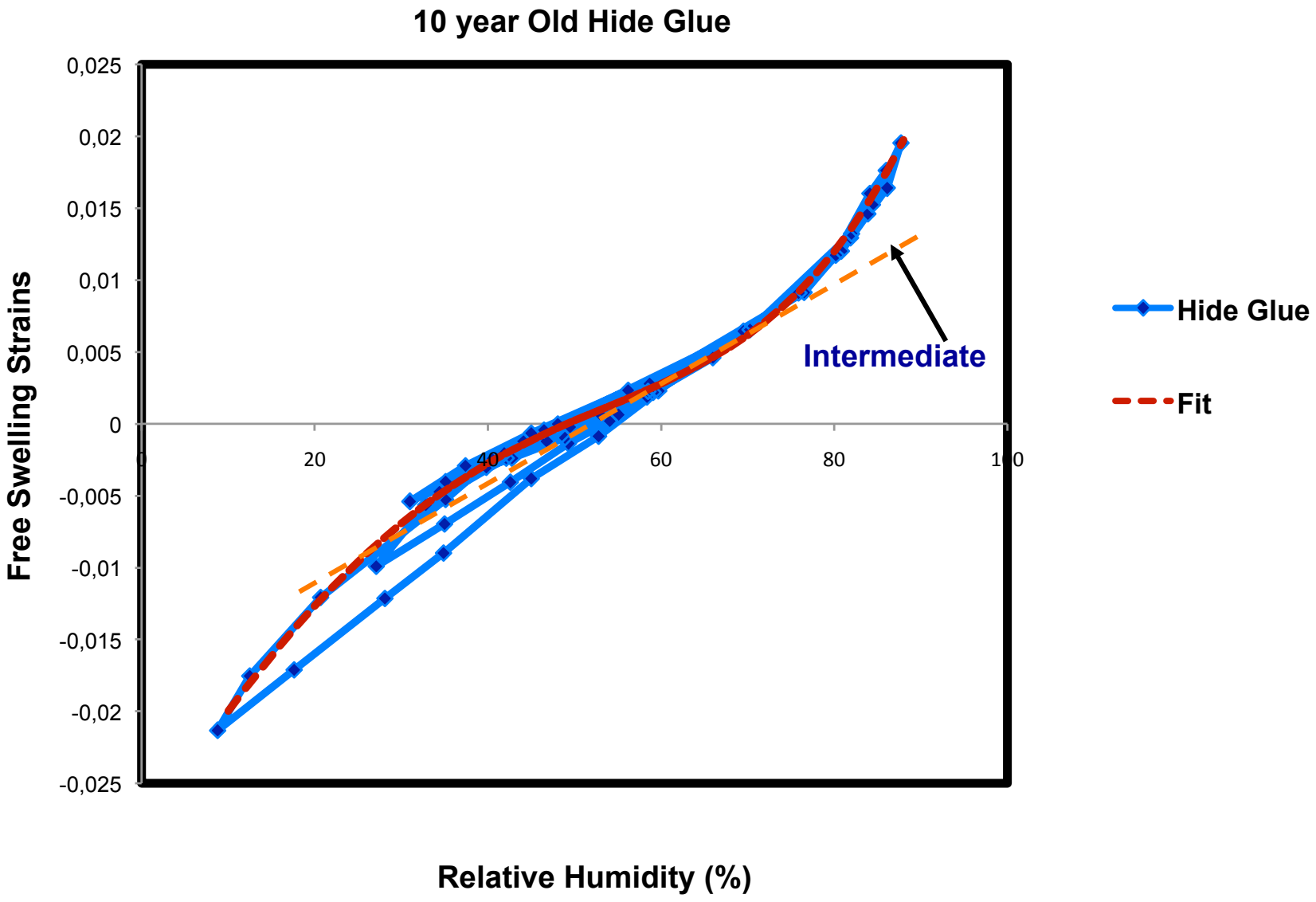


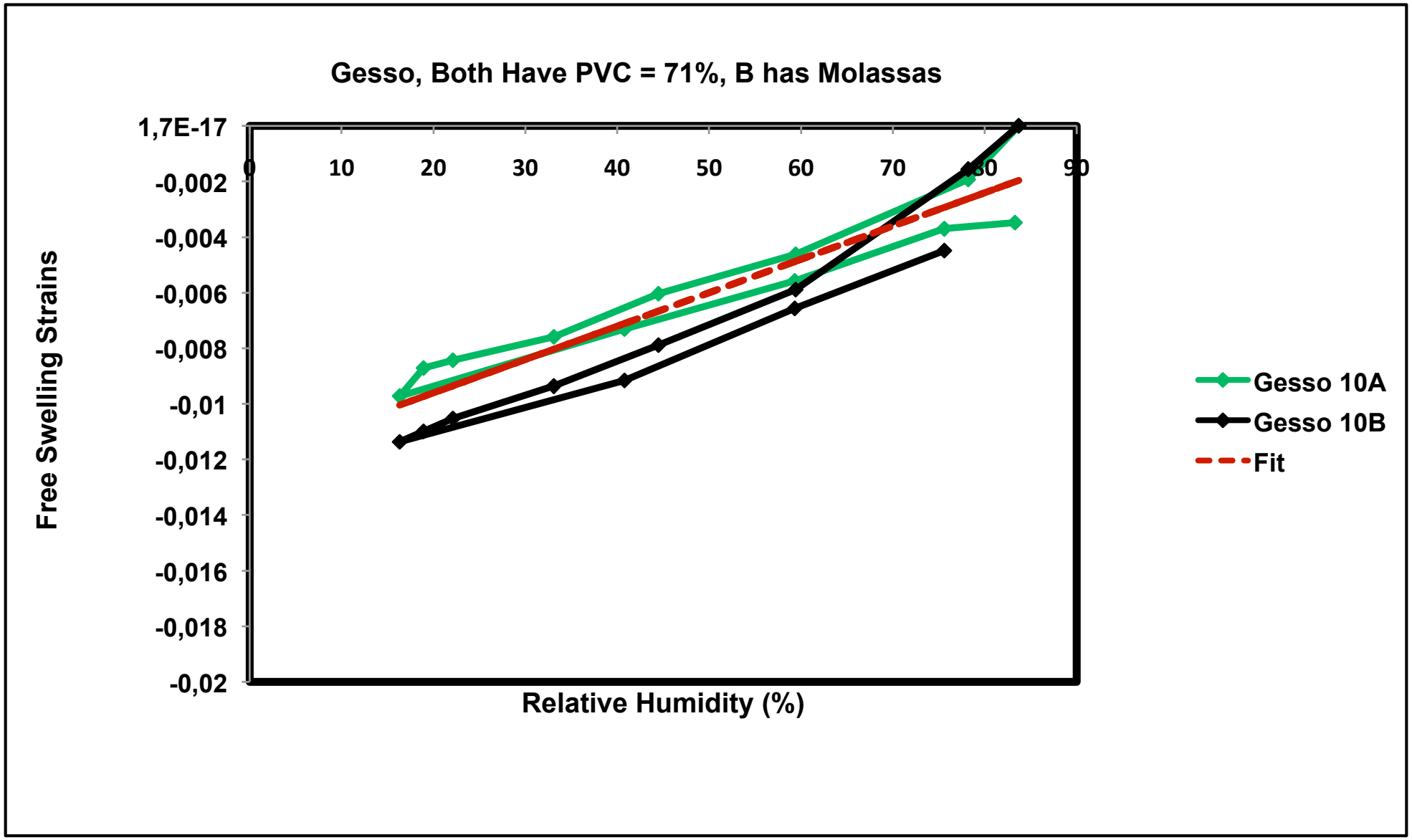
The coefficients of materials are the slopes of these plots or:

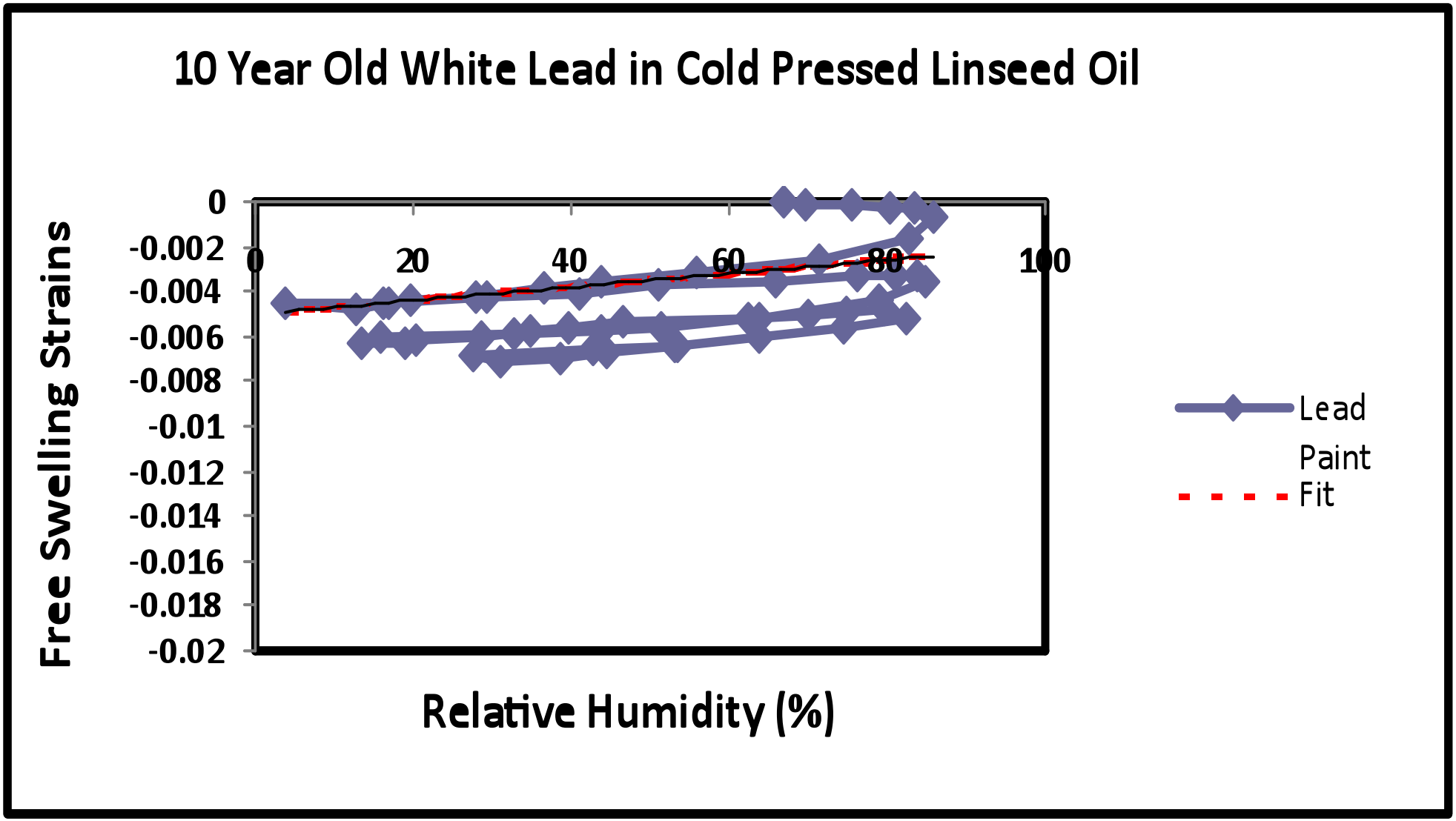
Δ Strains / Δ RH


Cottonwood, Tangential Coefficients
Moisture Coefficients
0,0035
0,003
0,0025
0,002
0,0015
0,001
0,0005
0
0
20
40
60
80
100
Relative Humidity (%)
Full Up Range
Full Down Range
Intermediate
Longitudinal

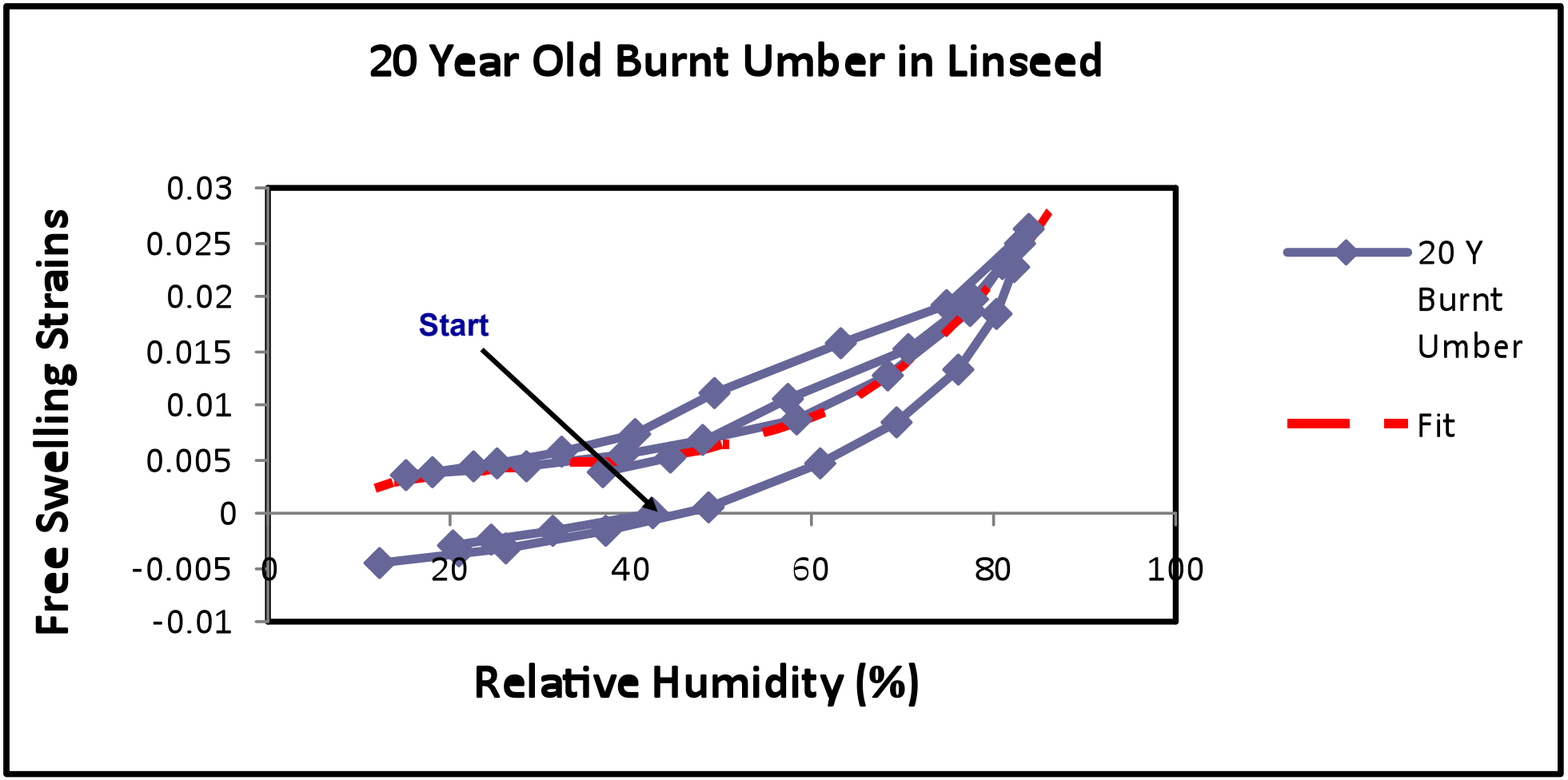

Cottonwood, Radial Coefficients
Moisture Coefficients
0,0035
0,003
0,0025
0,002
0,0015
0,001
0,0005
0
0
20
40
60
80
100
Relative Humidity (%)
UP
Down
Intermediate
Longitudinal


10 year Old Hide Glue
Free Swelling Strains
0,025
0,02
0,015
0,01
0,005
0
-0,005
-0,01
-0,015
-0,02
-0,025
0
20
40
60
80
100
Intermediate
Hide Glue
Fit
Relative Humidity (%)

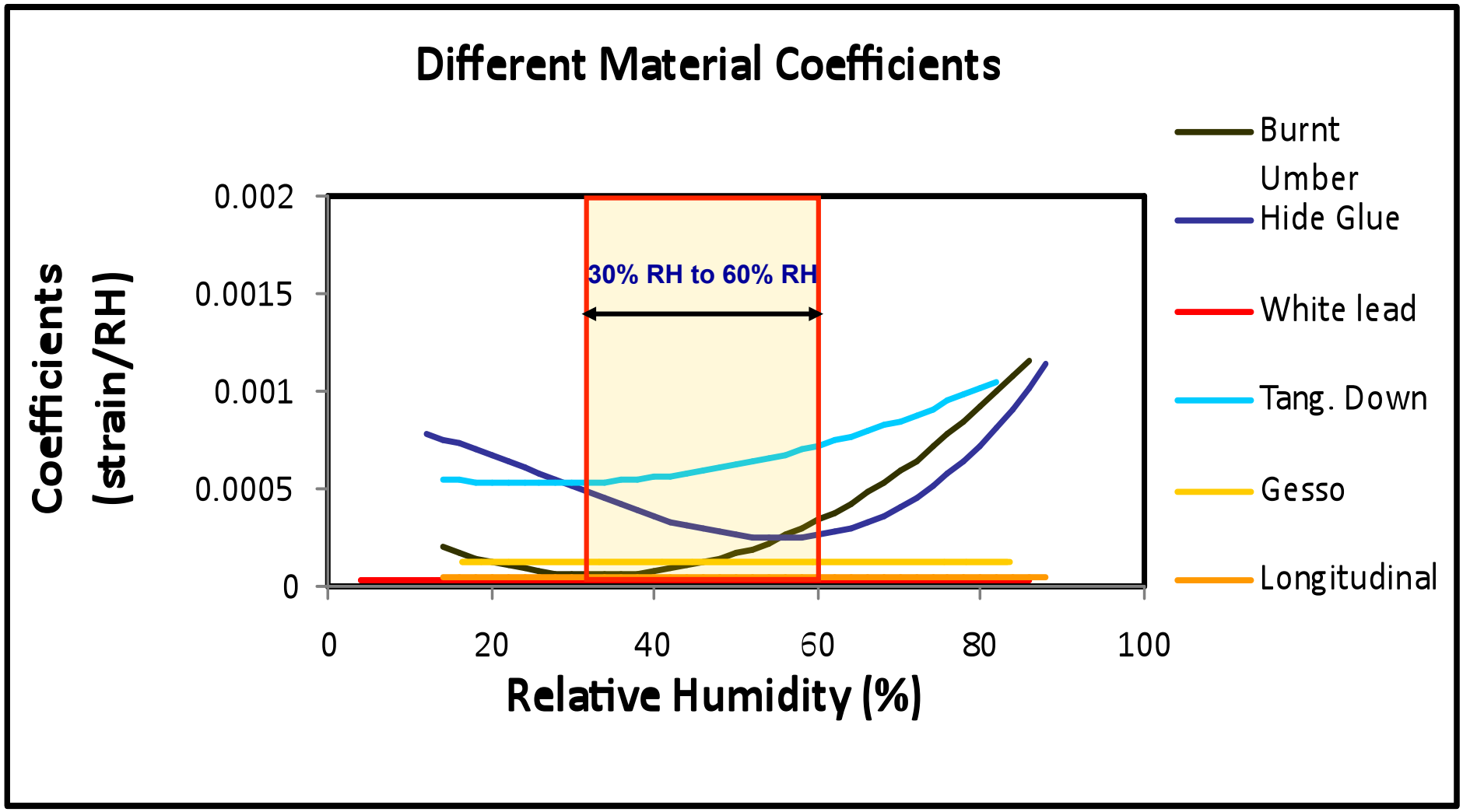

Gesso, Both Have PVC = 71%, B has Molassas
1,7E-17
-0,002
-0,004
-0,006
-0,008
-0,01
-0,012
-0,014
-0,016
-0,018
-0,02
0
10
20
30
40
50
60
70
80
90
Free Swelling Strains
Relative Humidity (%)
Gesso 10A
Gesso 10B
Fit

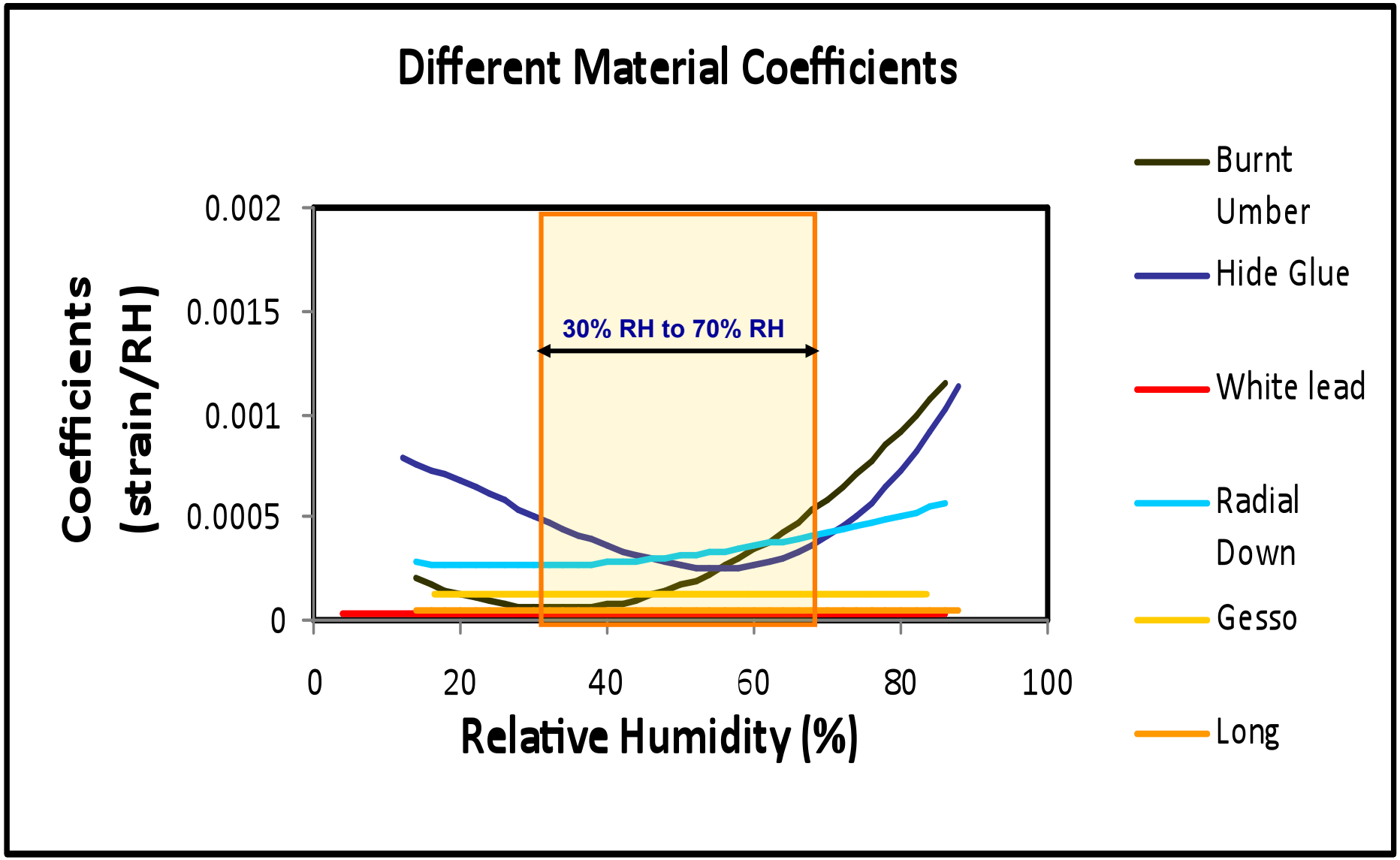


Progressive Shrinkage



Progressive Swelling

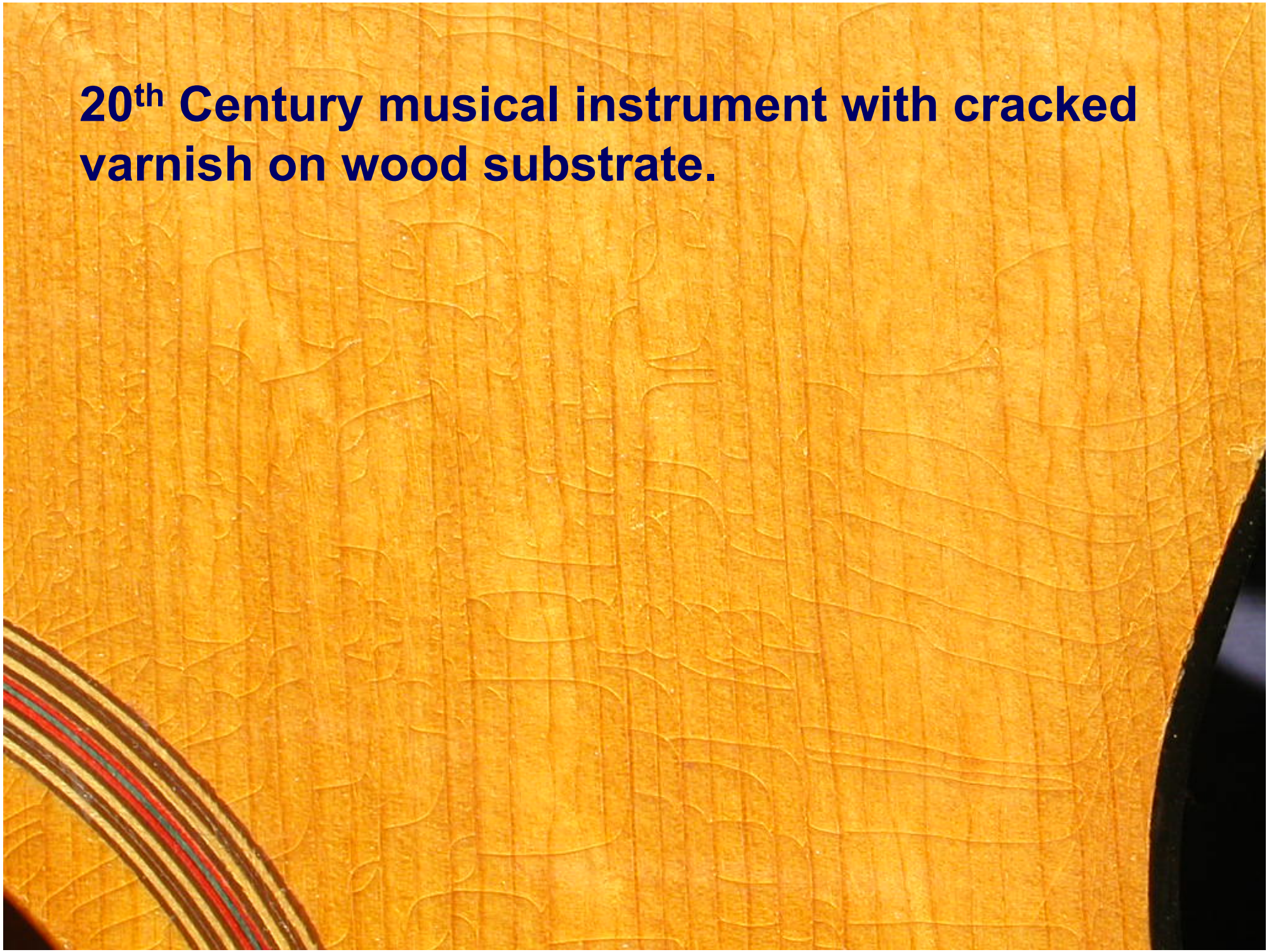

Different Material Coefficients
Coefficients (strain/RH)
0.002
0.0015
0.001
0.0005
0
30% RH to 60% RH
0
20
40
60
80
100
Relative Humidity (%)
Burnt Umber
Hide Glue
White lead
Tang. Down
Gesso
Longitudinal


Different Material Coefficients
Coefficients (strain/RH)
0.002
0.0015
0.001
0.0005
0
30% RH to 70% RH
0
20
40
60
80
100
Relative Humidity (%)
Burnt Umber
Hide Glue
White lead
Radial Down
Gesso
Long

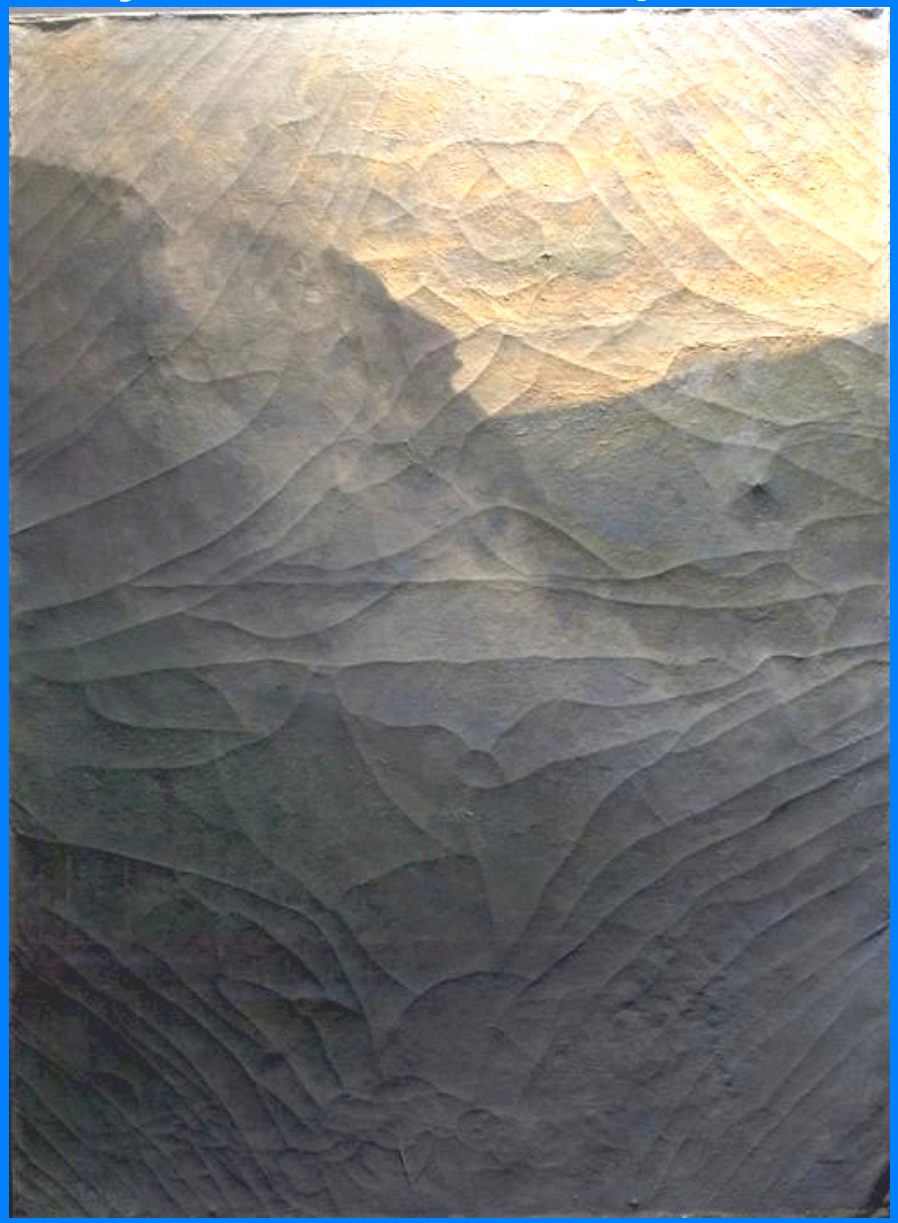
Historically there has been considerable confusion and controversy with regards to determining the correct temperature and relative humidity settings for museums and galleries.

Few were able to say with any certainty what caused damages in any specific object. There has certainly been anecdotal reports but rarely were specific details available.

For example, let's look at a few damaged objects.


20th Century musical instrument with cracked varnish on wood substrate.

20th century American landscape, oil on canvas.



George Parker, Untitled, (Lower Ausable Lake at Indian Head), American, 1911, 48in. x 35.5in. . (Photo by James Hamm and courtesy of the Adirondack Museum in Blue Mountain Lake, N.Y.)


19th century American landscape, oil on canvas.

20th century American abstract, oil and acrylic on canvas.

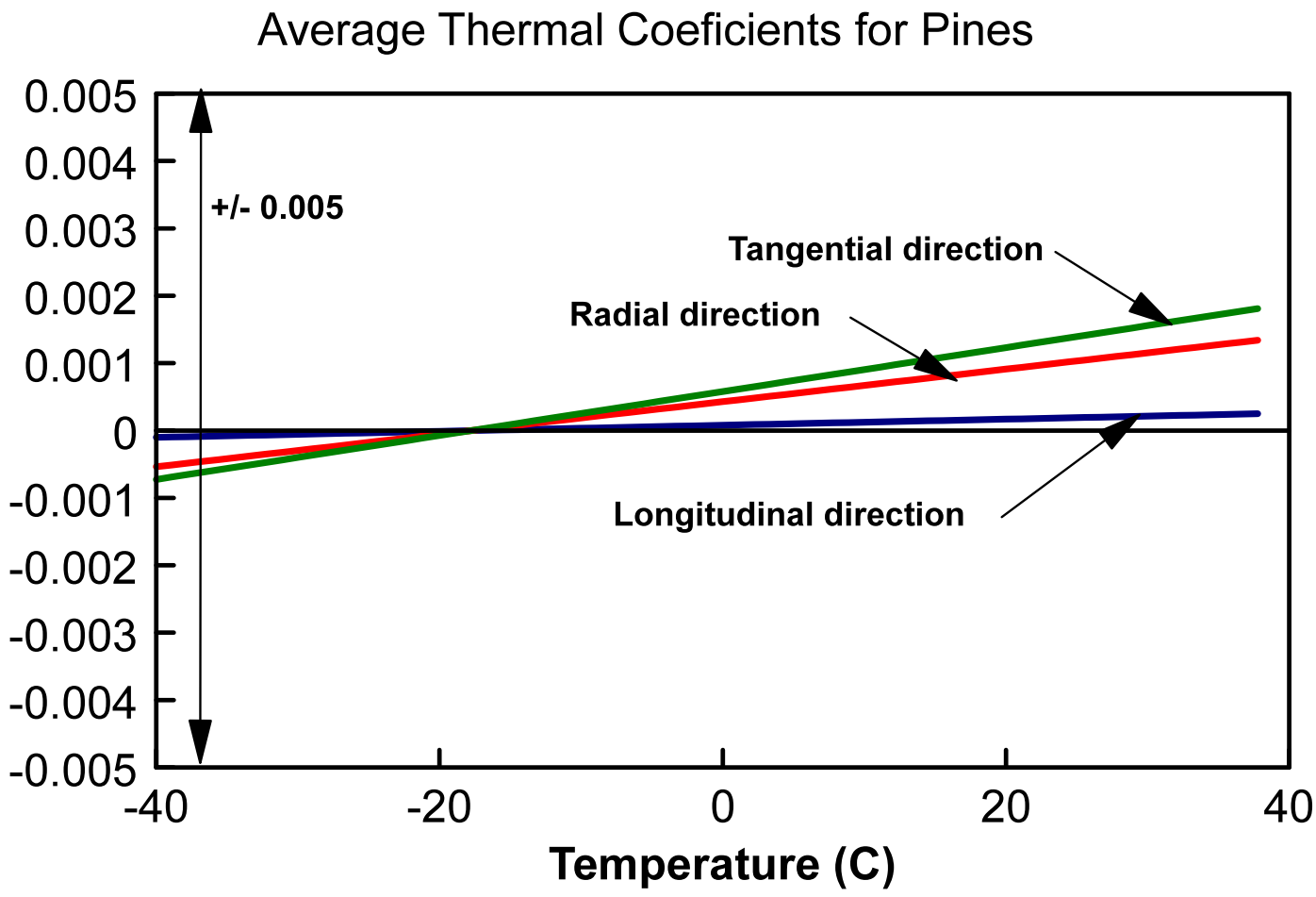
20th century American abstract, oil and acrylic on canvas.
(Photo by James Hamm and courtesy of the owner)

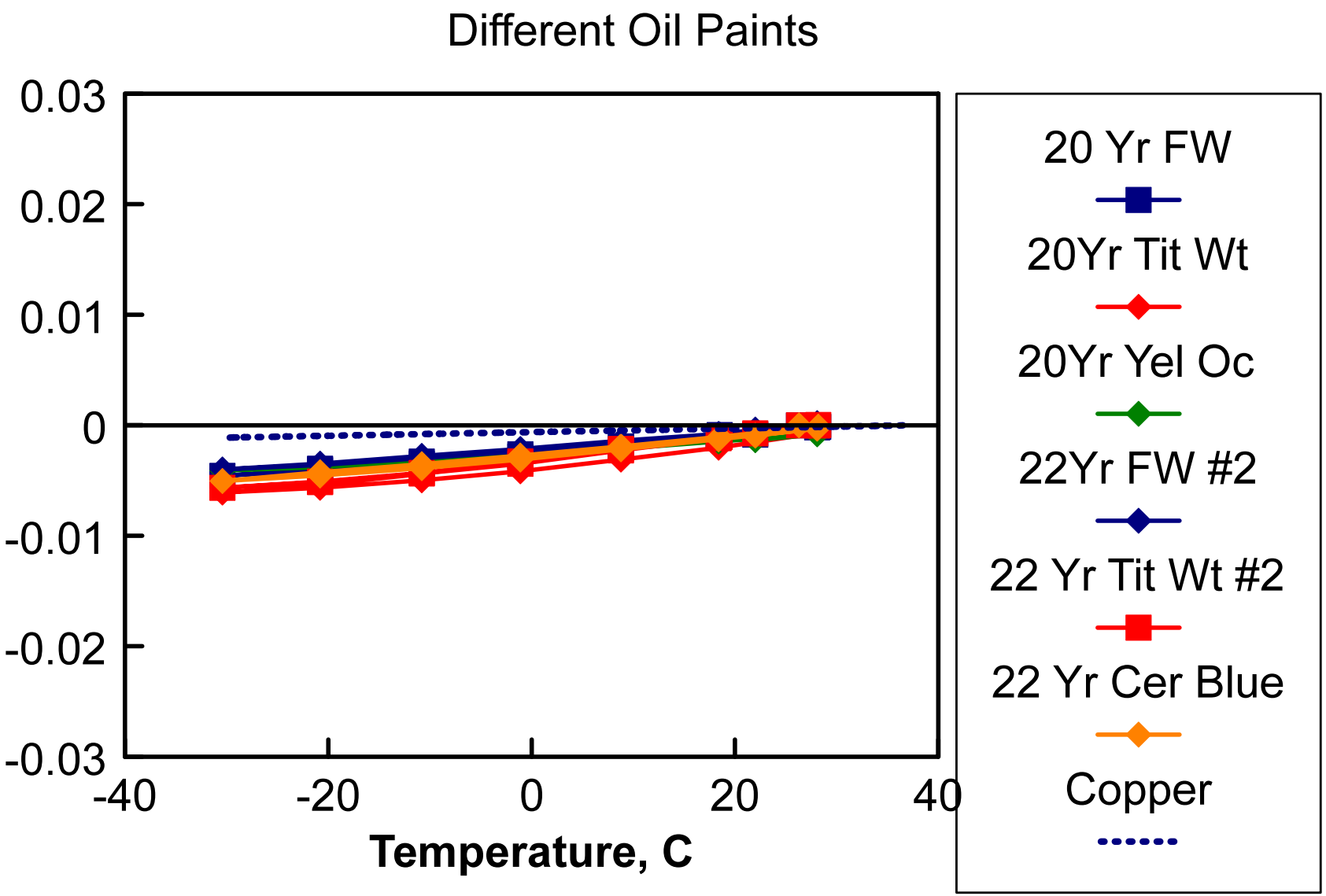
All of the objects just seen were damaged by exposure to low temperatures and RH played no role at all.

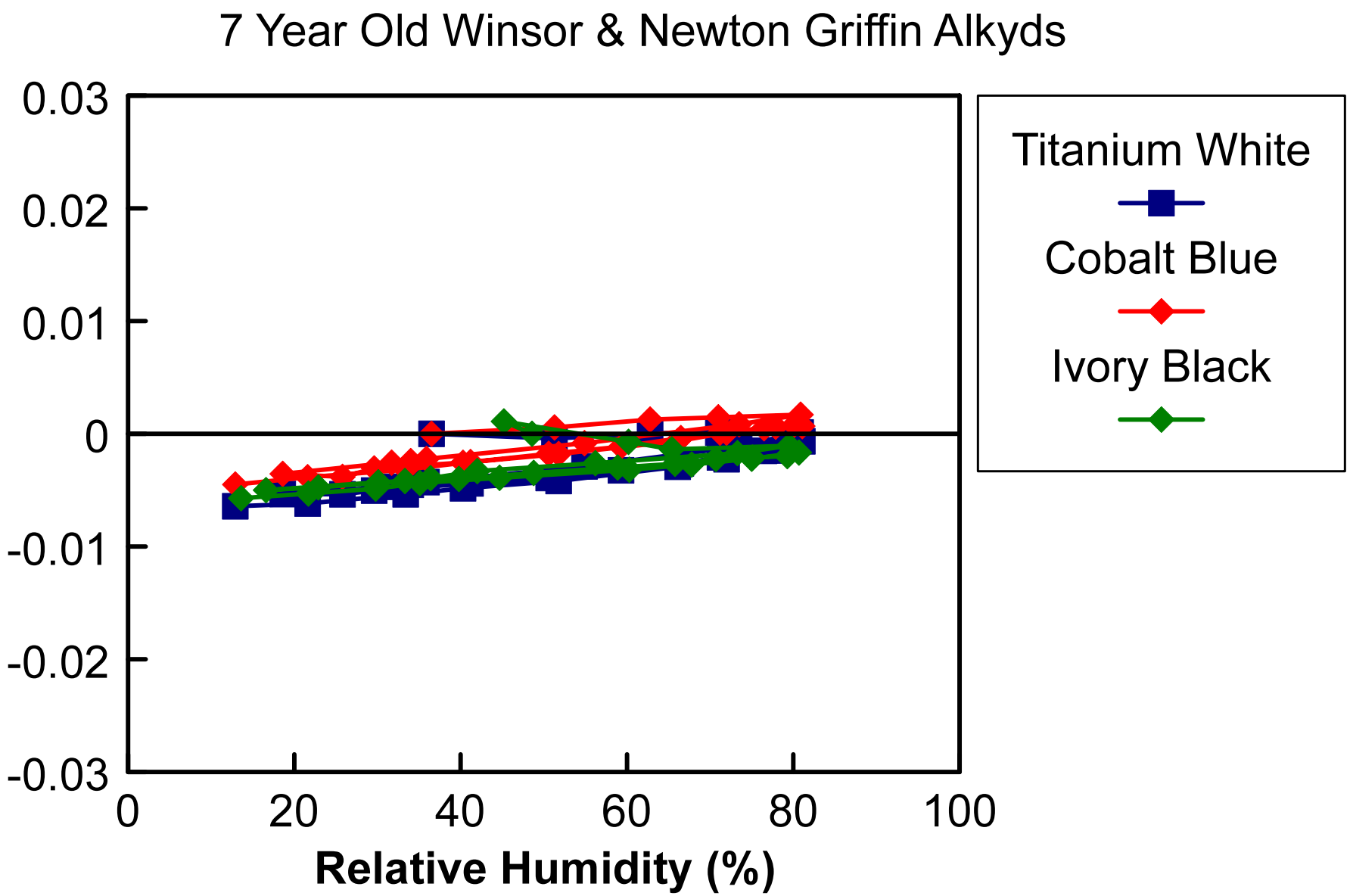
The reason these object were damaged by low temperature is because all oil, alkyd and acrylic paints have low glass transition temperatures. If the ambient temperature falls enough below the glass transition temperature, the paint layers will crack.

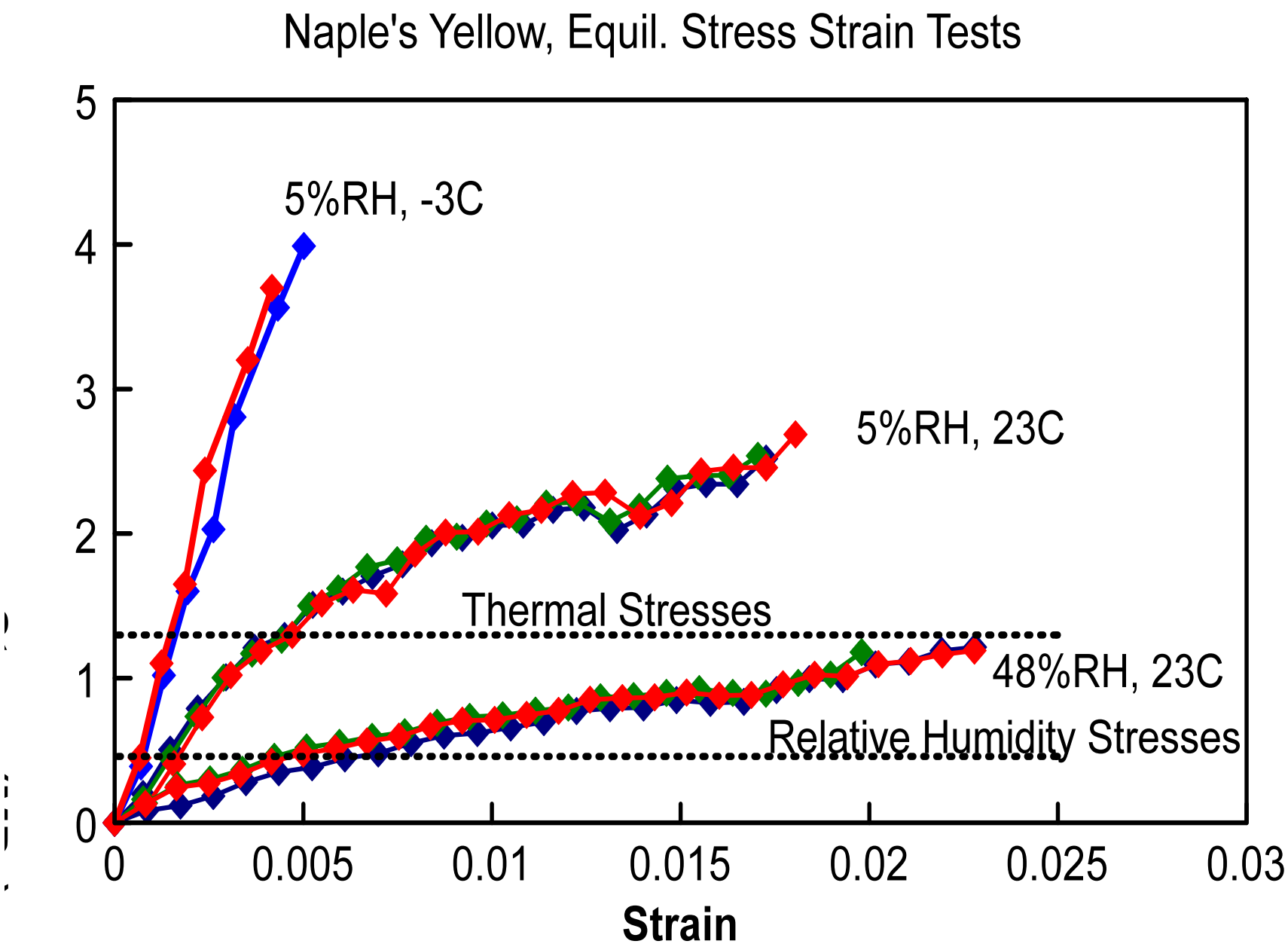
Temperature Behavior

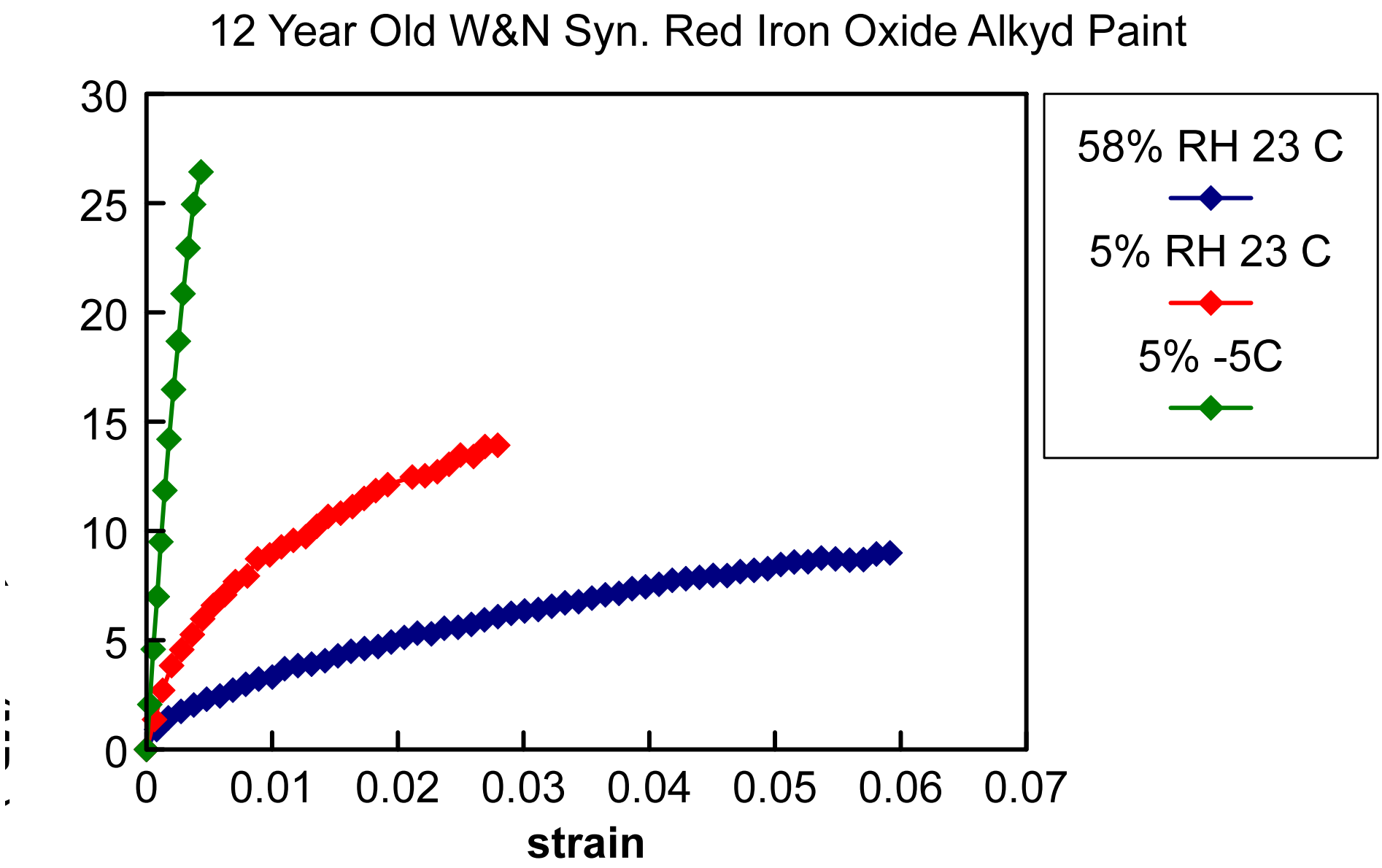
In general the thermal coefficients for woods are very low. The Wood Handbook defines thermal coefficients in the radial and tangential directions as functions of their density. Higher densities Mean higher thermal coefficients.

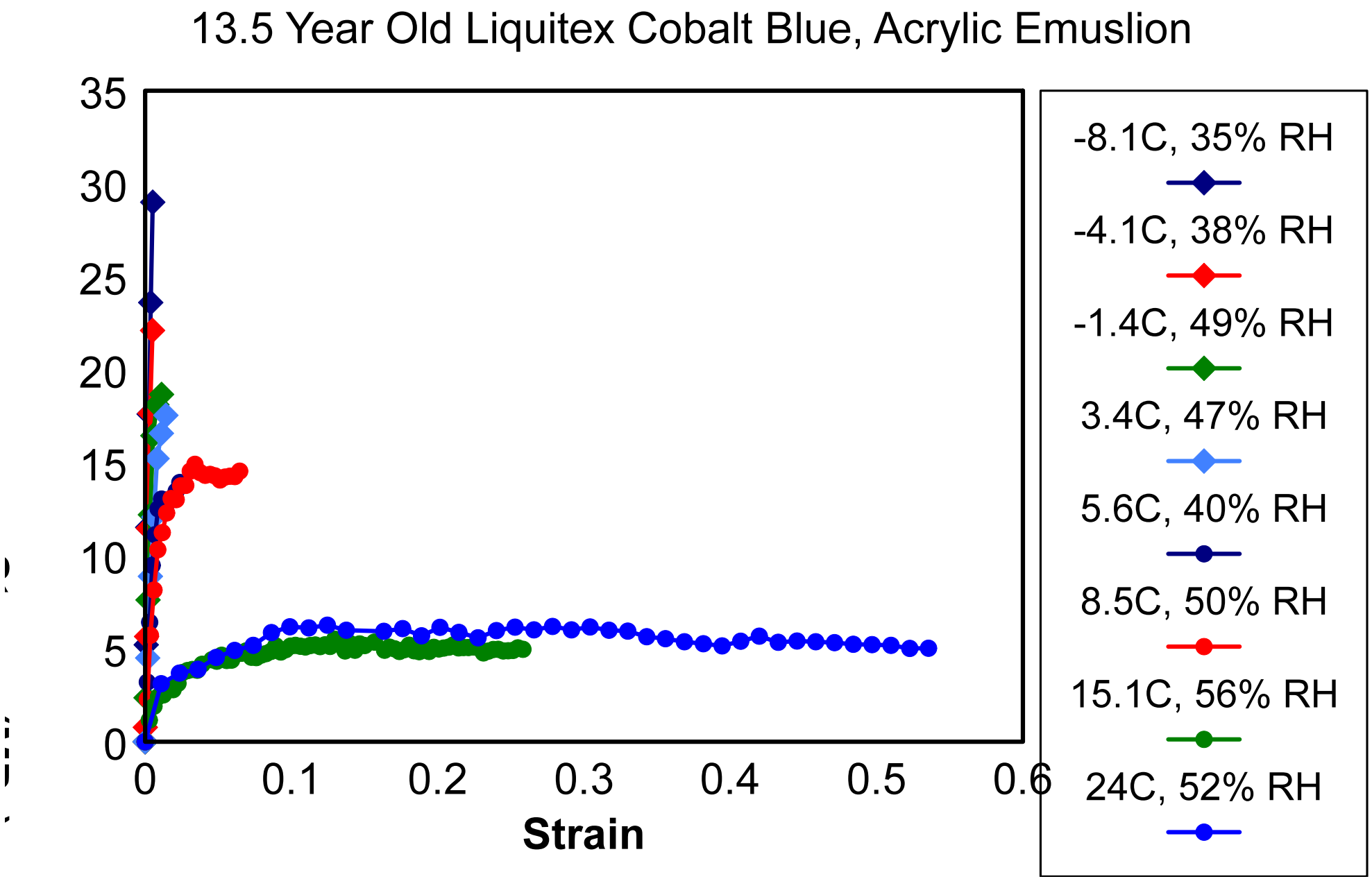



Different Oil Paints
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-40
-20
0
20
40
Temperature, C
20 Yr FW
20Yr Tit Wt
20Yr Yel Oc
22Yr FW #2
22 Yr Tit Wt #2
22 Yr Cer Blue
Copper


7 Year Old Winsor & Newton Griffin Alkyds
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
0
20
40
60
80
100
Relative Humidity (%)
Titanium White
Cobalt Blue
Ivory Black


Naple's Yellow, Equil. Stress Strain Tests
5%RH, -3C
5%RH, 23C
Thermal Stresses
48%RH, 23C
Relative Humidity Stresses
0
1
2
3
4
5
0
0.005
0.01
0.015
0.02
0.025
0.03
Strain


12 Year Old W&N Syn. Red Iron Oxide Alkyd Paint
30
25
20
15
10
5
0
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
strain
58% RH 23 C
5% RH 23 C
5% -5C


13.5 Year Old Liquitex Cobalt Blue, Acrylic Emuslion
35
30
25
20
15
10
5
0
0
0.1
0.2
0.3
0.4
0.5
0.6
Strain
-8.1C, 35% RH
-4.1C, 38% RH
-1.4C, 49% RH
3.4C, 47% RH
5.6C, 40% RH
8.5C, 50% RH
15.1C, 56% RH
24C, 52% RH

Detail, 20th century English Abstract, oil on canvas.

(Photograph courtesy of Richard Saltoun and taken by Steve Gayler)

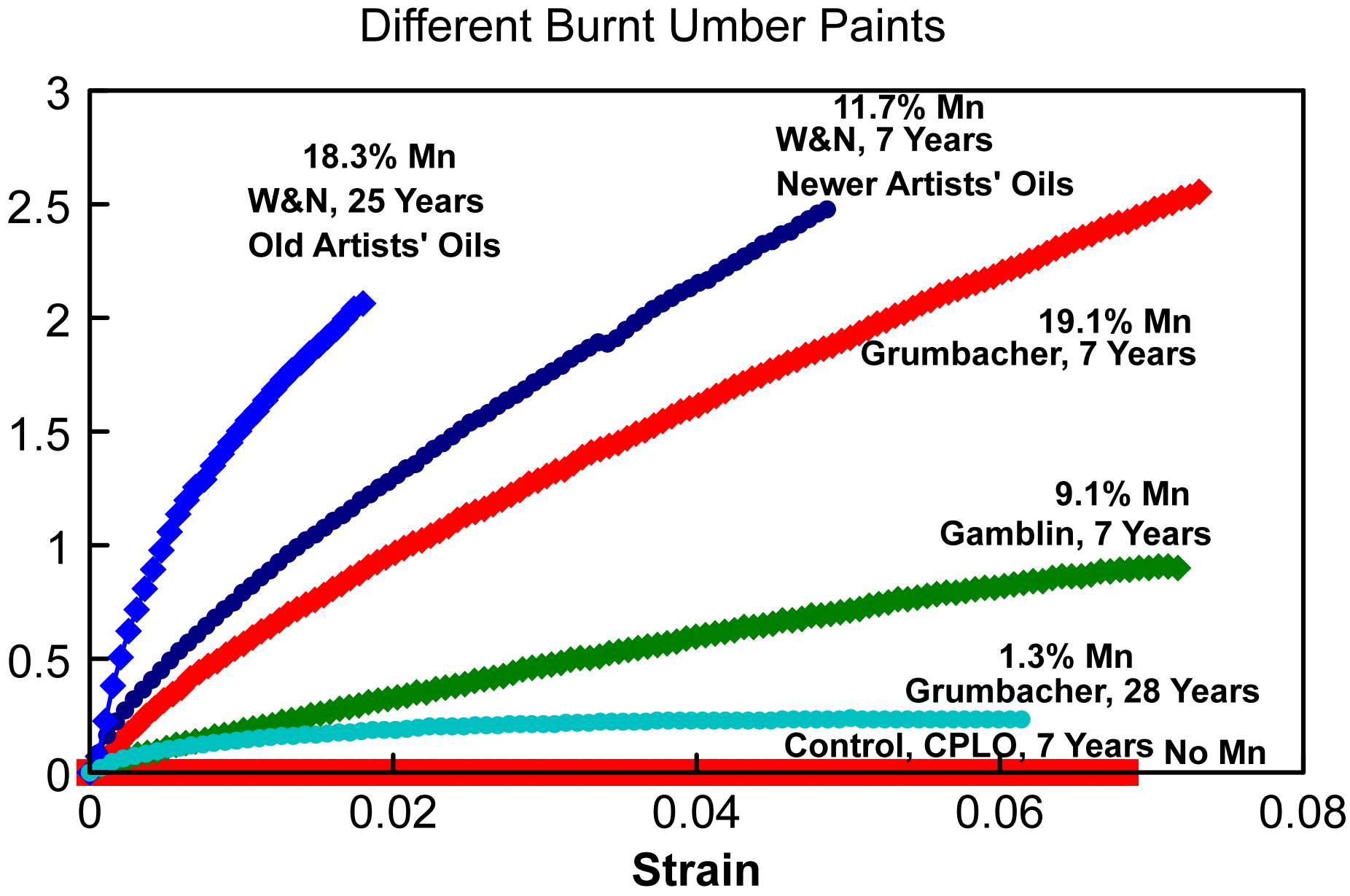
The prior painting was damaged by rolling and neither temperature or relative humidity played any role in the damage.

The reason the damage was so extensive with interlayer cleavage was that zinc oxide was mixed with the lead carbonate in the oil. Zinc is notorious for cracking and delaminating.

(Research on the mechanical properties of artists paints at the SI, MCI)

Other factors

The effects of naturally occurring manganese



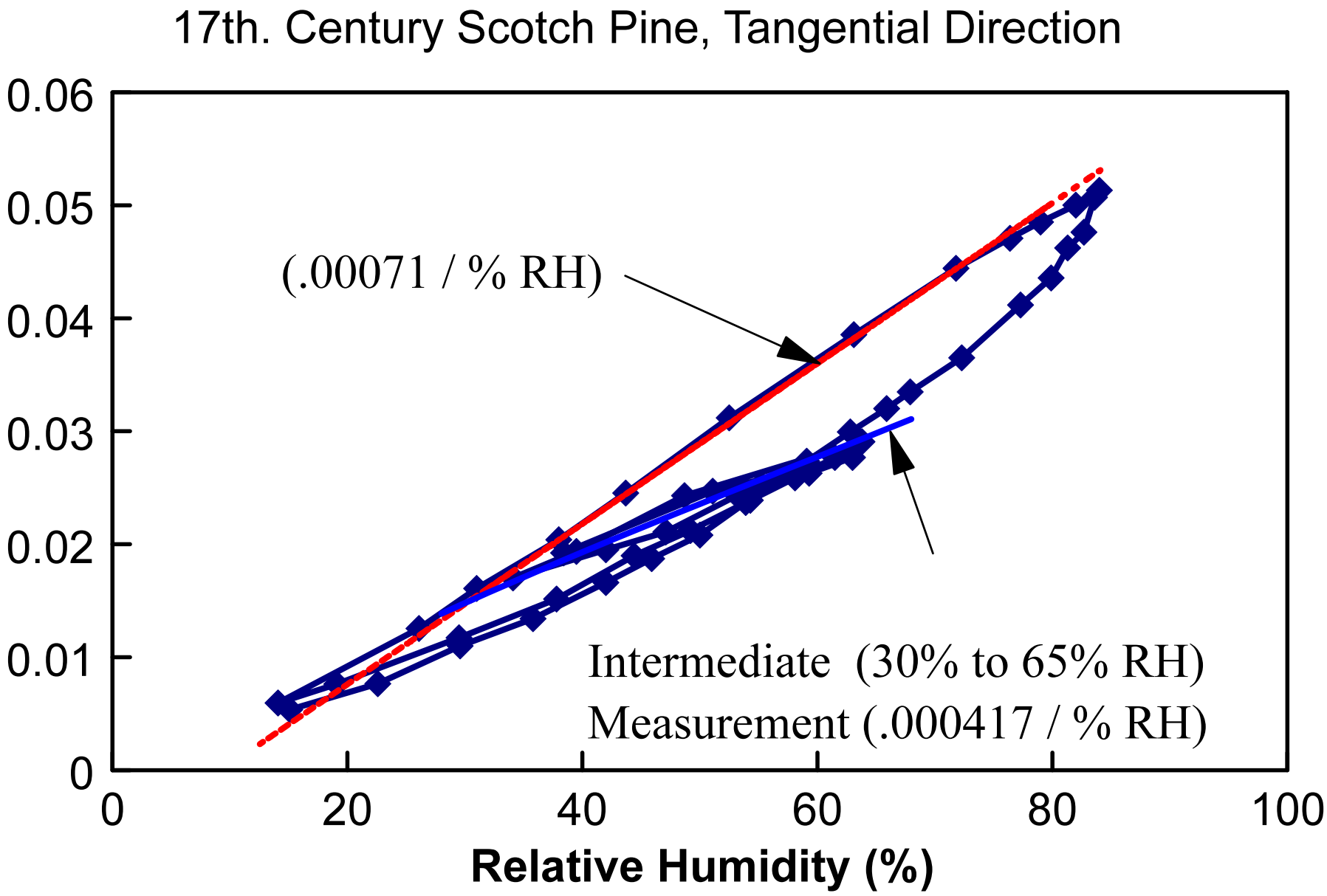
In order to show exactly how objects respond mechanically to different environmental changes, it is necessary to first look at the individual materials used in their construction.

There are three types of tests needed to define The materials:

1. **The dimensional response to changes in RH and temperature.**
2. **The stress-strain test.**
3. **The restrain and desiccate (or cool) test.**

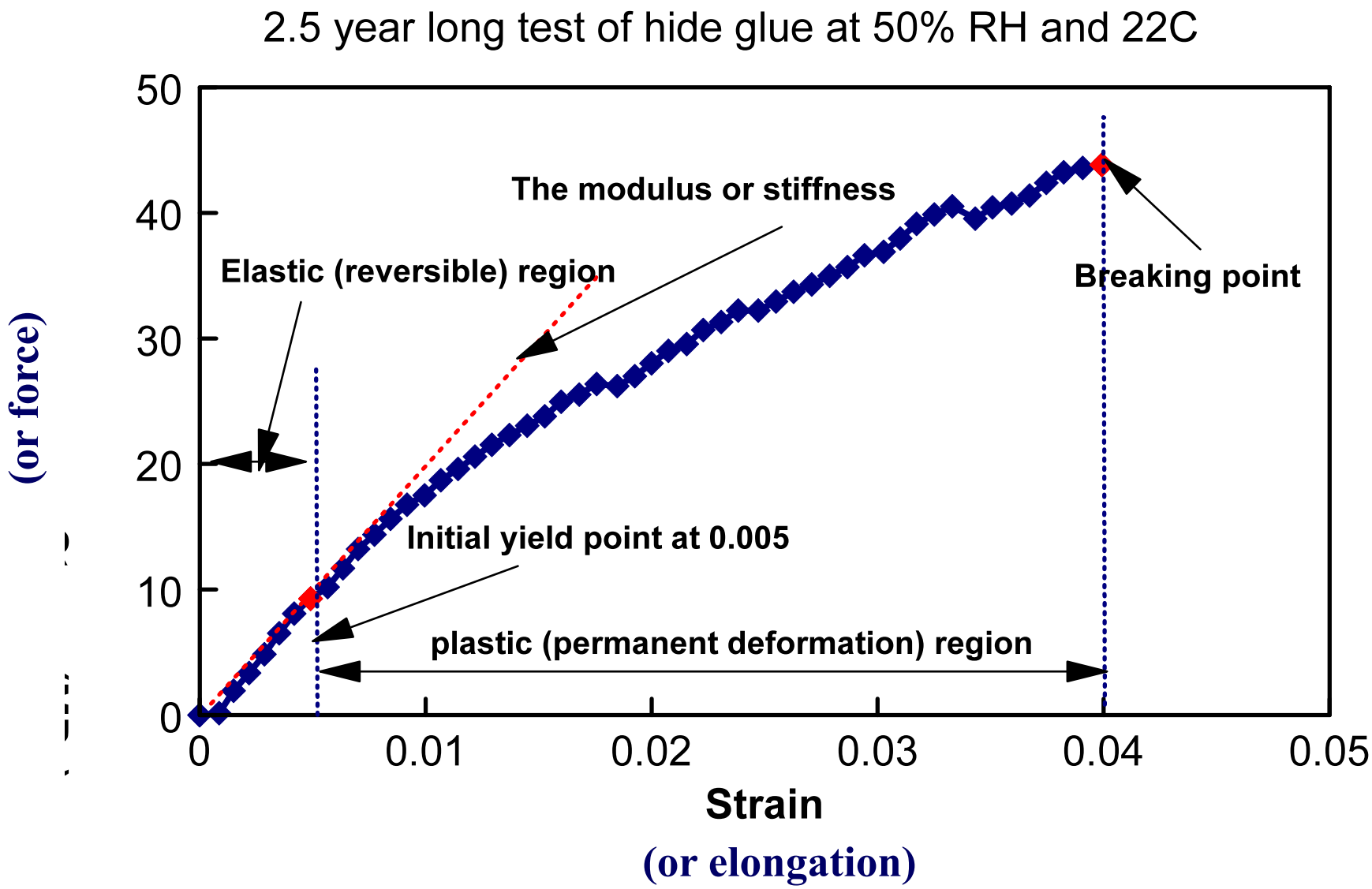
Testing the dimensional response of materials to changes in RH.

Wood's dimensional response to moisture.

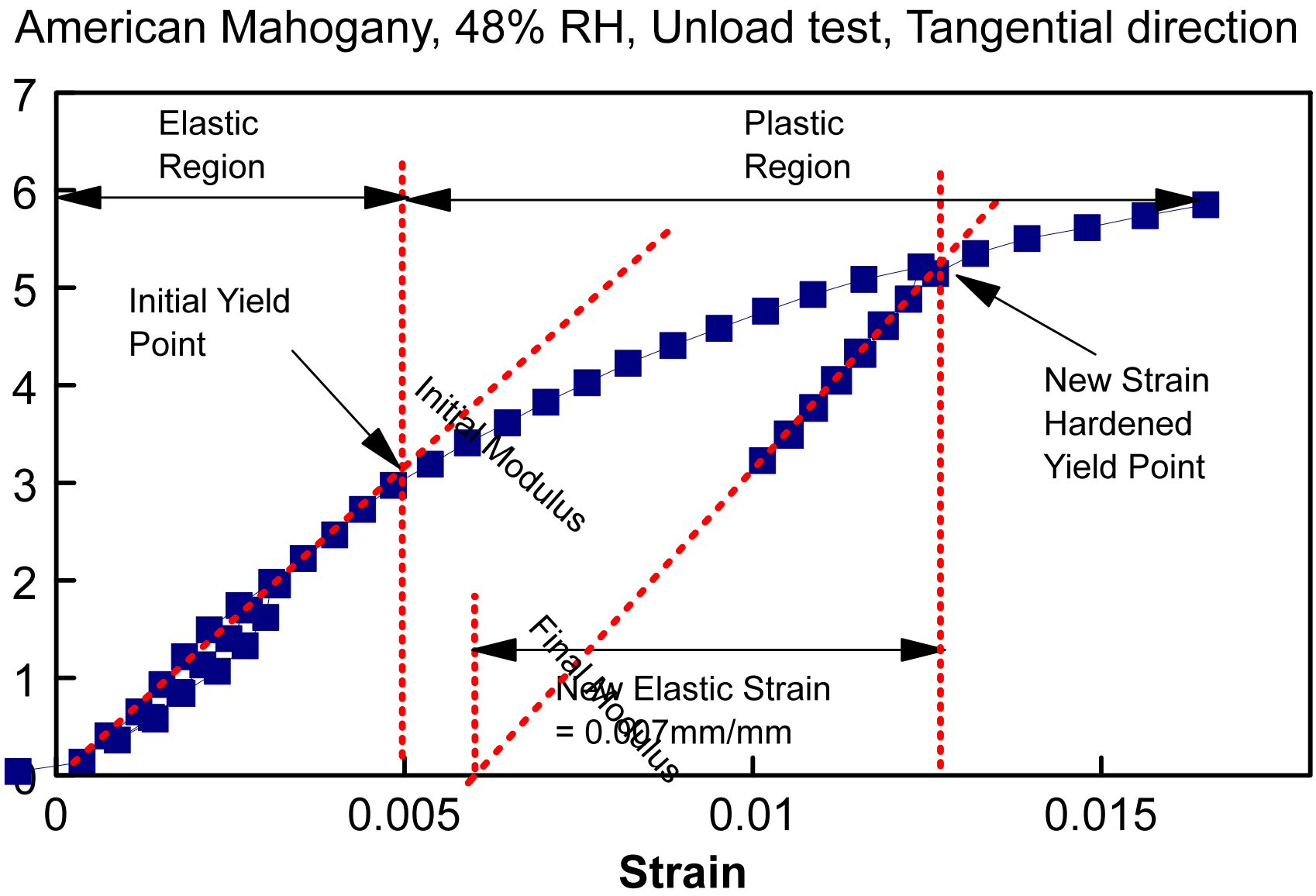


Measuring the mechanical properties of materials; the stress strain test.

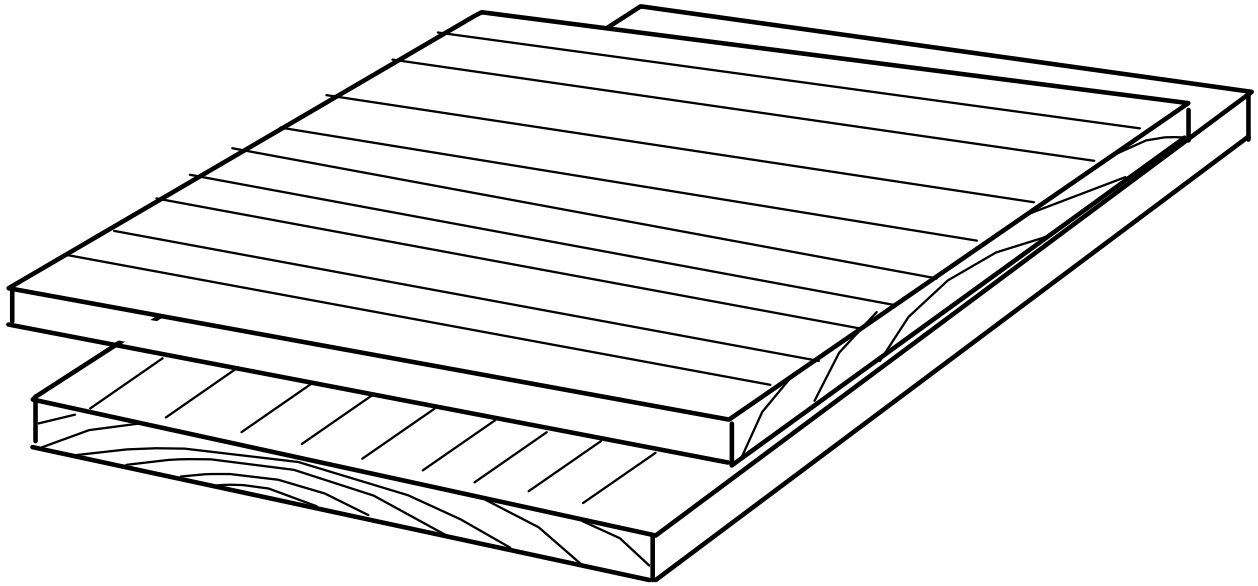
The stress strain test: Stress is force divided by the cross-sectional area of the sample and Strain is the change in the sample length divided by it original length.



Review of the definitions of the mechanical properties

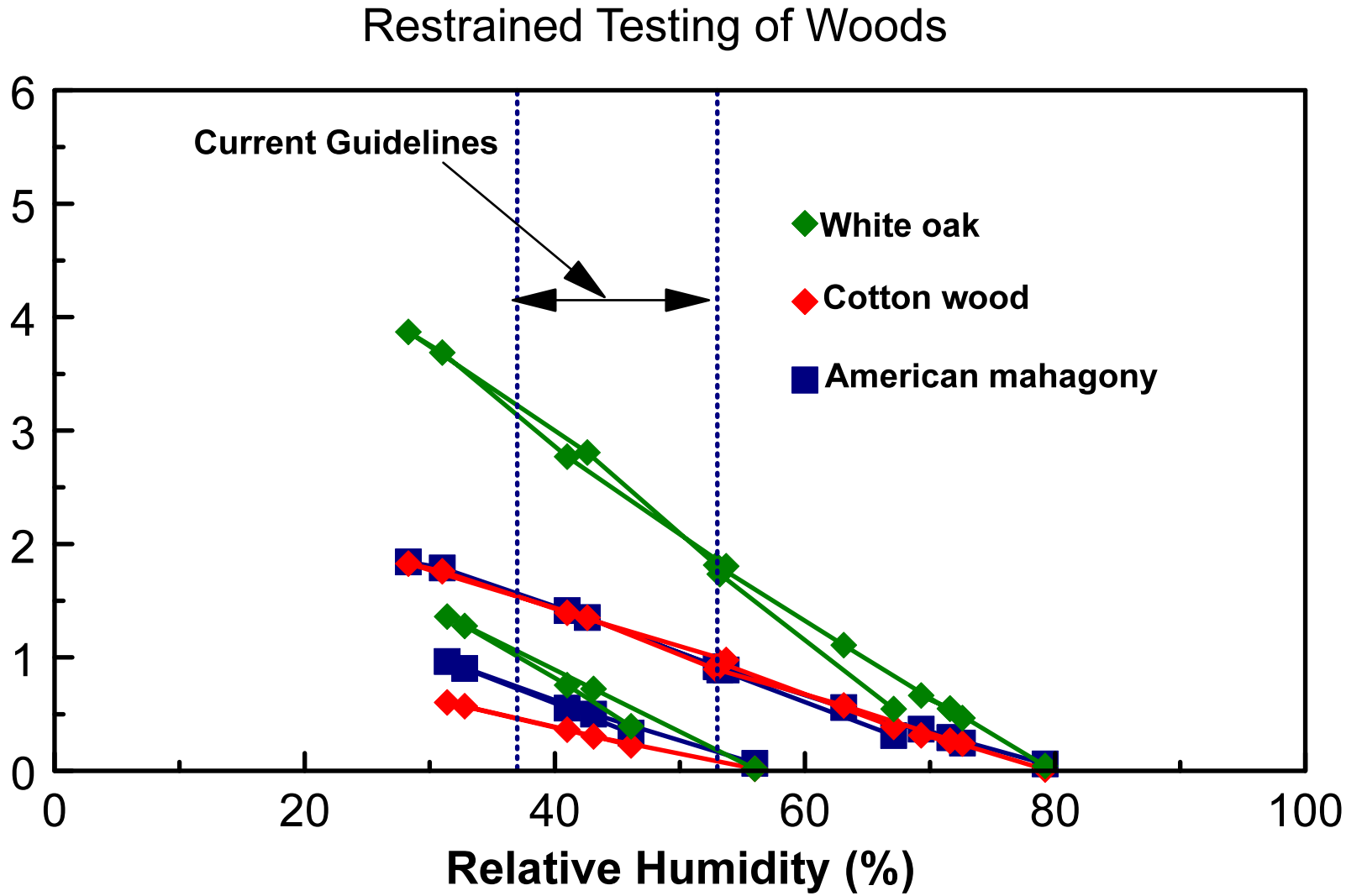


Measuring the stresses (or forces) when materials are under restraint and the environment is changing

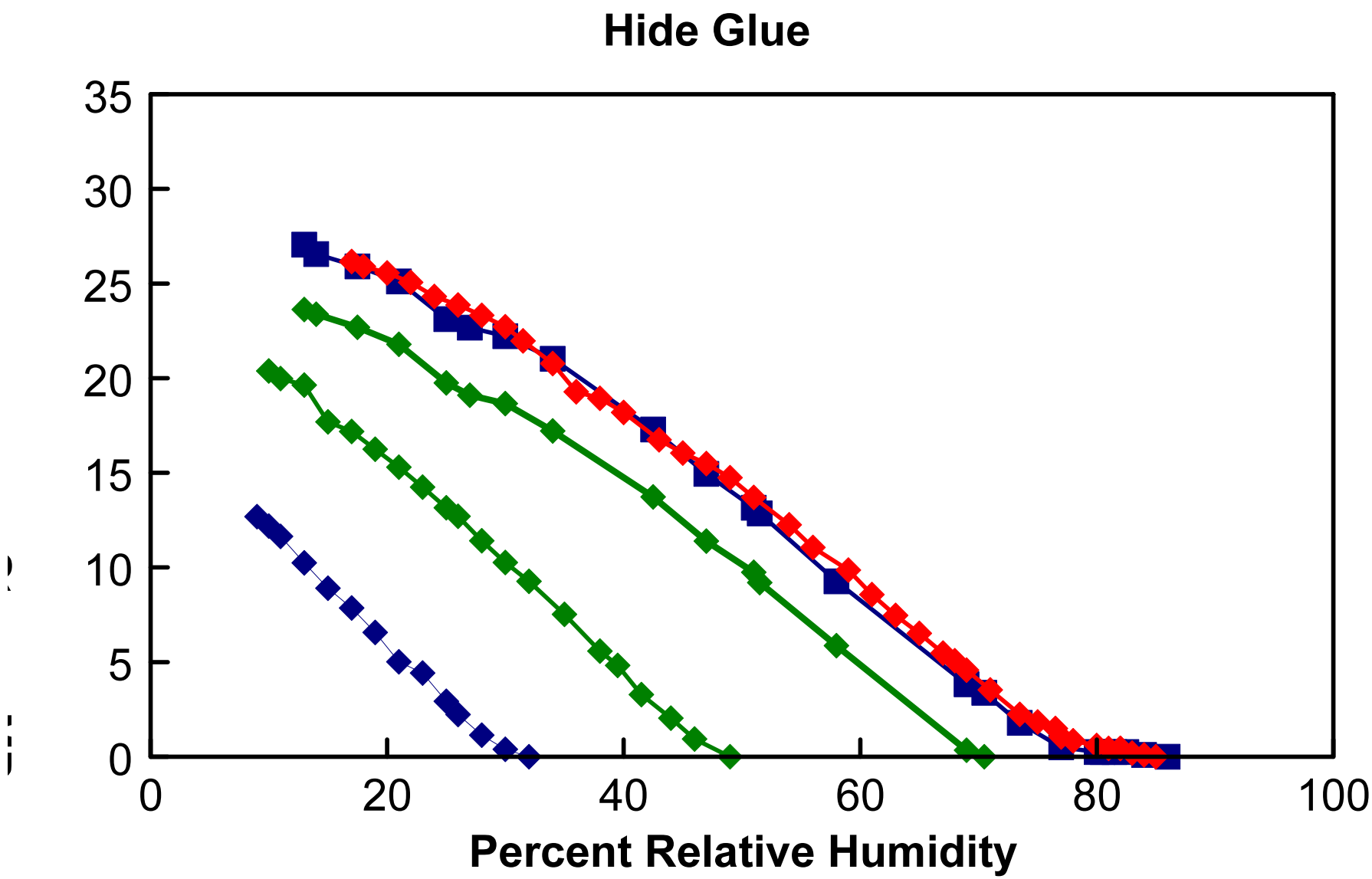


Woods glued cross-grained develop mutual restraint to dimensional response with changes in either temperature or RH.

Wood samples restrained in a changing environment.



Samples of hide glue restrained and desiccated.



Connecting the Three Tests

Relating the tests is required. For example: How are the strains in the stress strain test related to the strains in the dimensional response test?

From an environmental perspective The magnitude of the strains in the stress strain test are identical to the magnitude of the strains in the dimensional response test.*

*1996, Mecklenburg, M. F. and C. S. Tumosa, "The Relationship of Externally Applied Stresses to Environmentally Induced Stresses", in Fiber Composites in Infrastructure, H. Saadatmanesh and M. R. Ehsani Eds., Proceedings of the First International Conference on Composites in Infrastructure, NSF and University of Arizona, 956-971.

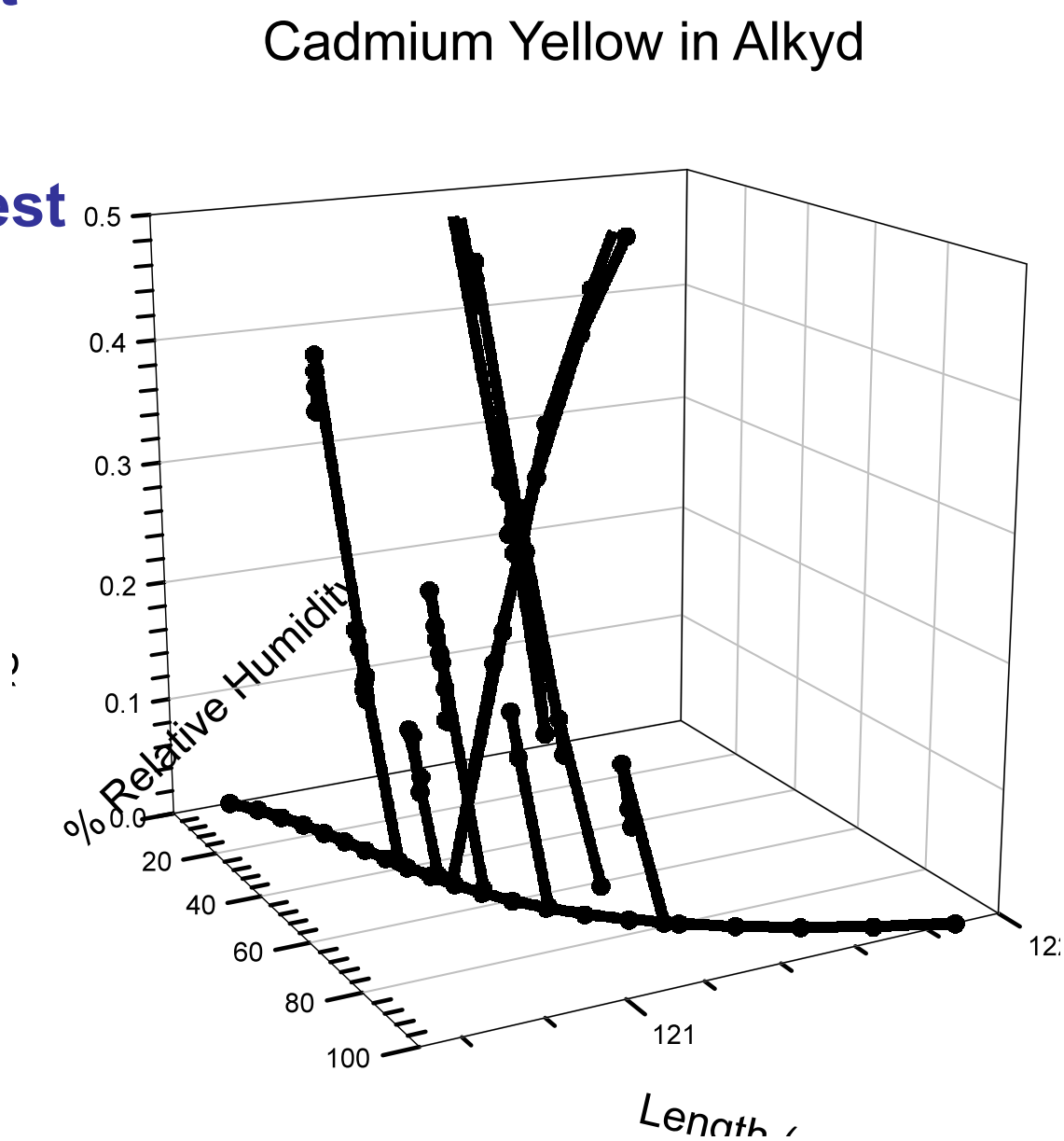
Under true equilibrium conditions, all three tests:

1. The stress-strain test

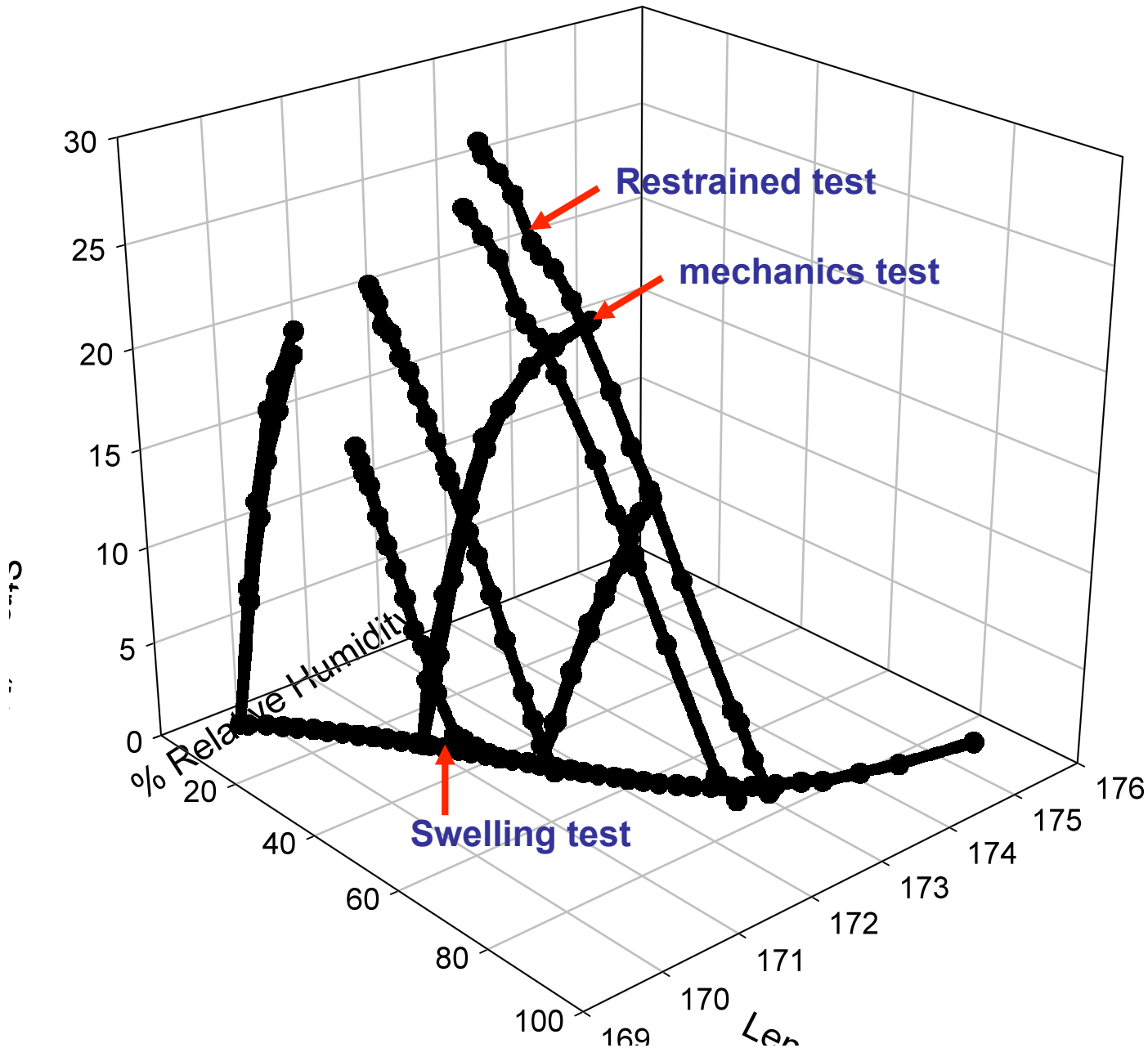
2. The swelling test

3. And the restrained test

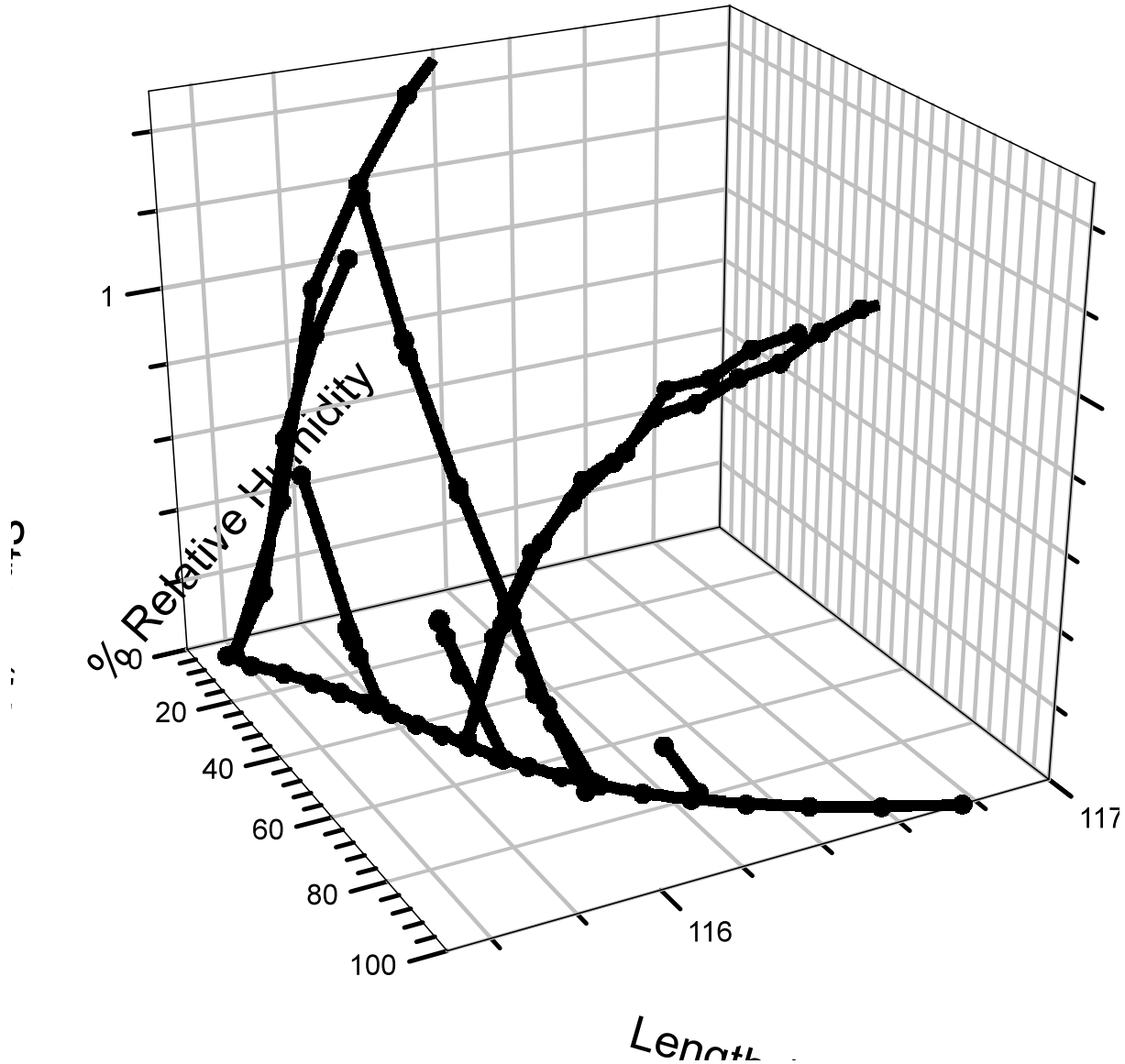
can be related.



Hide Glue


Restrained test
mechanics test
Swelling test
30
25
20
15
10
5
0
% Relative Humidity
20
40
60
80
100
169
170
171
172
173
174
175
176

Titanium Dioxide in Oil



Establishing Criteria for Determining RH Boundaries

Setting initial assumptions and criteria for determining the allowable RH for rigid objects, this includes furniture, ivory, panel paintings, painted wood, etc.

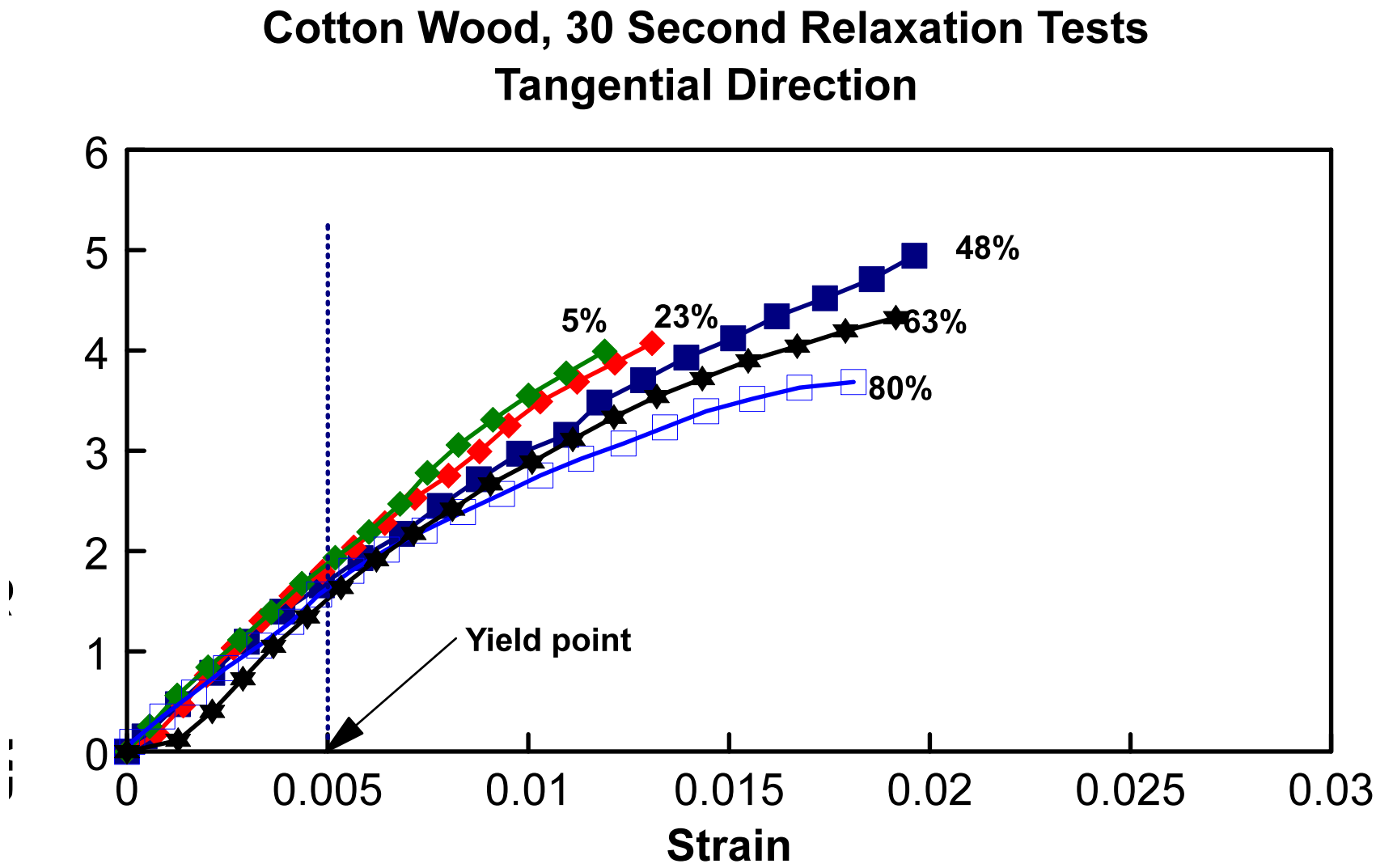
1. **All materials in the objects in the collections are assumed to be fully restrained from any movement.**

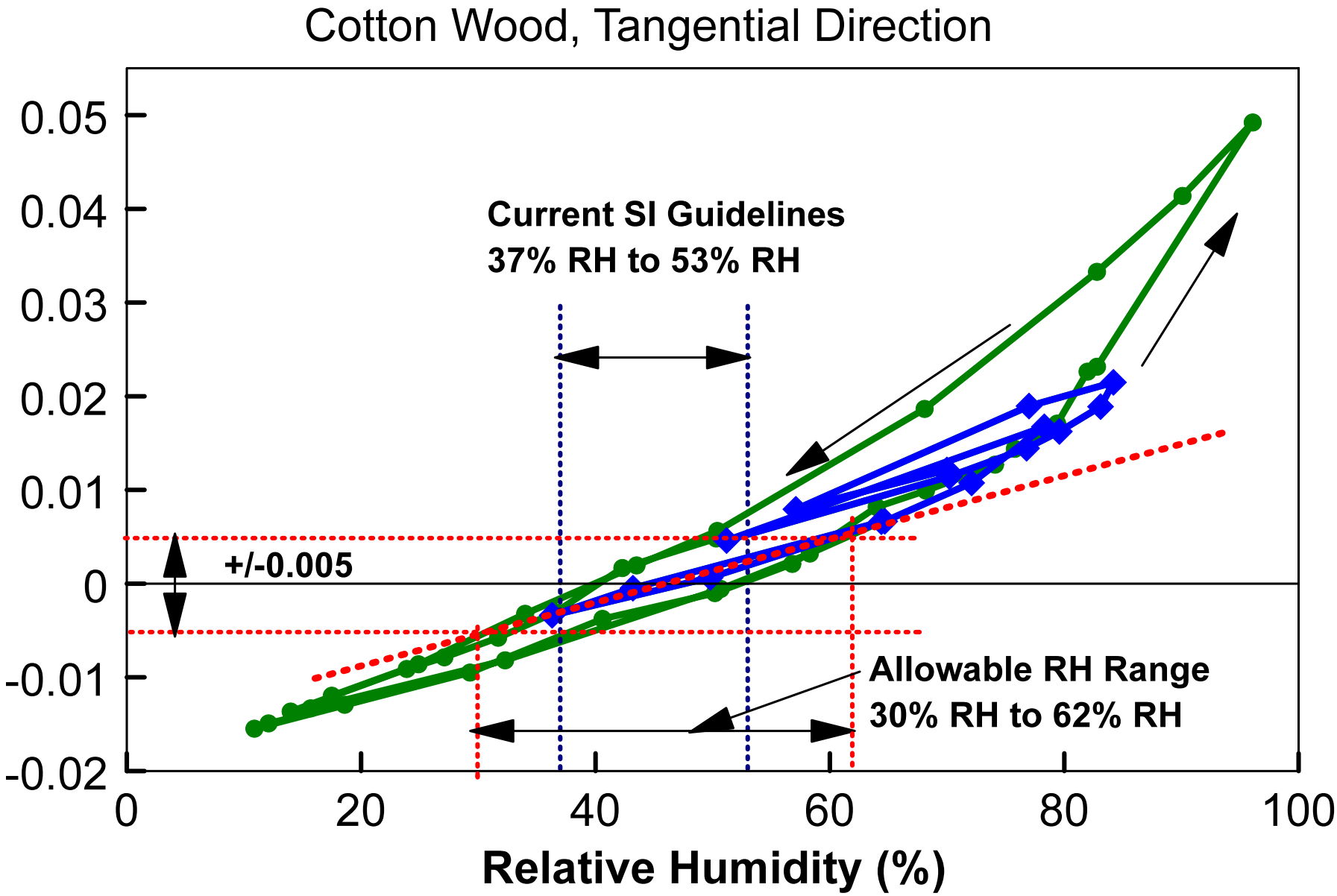
2. **The strain in any material in any object is not to exceed the yield strain in either tension or compression.**

3. **There can be initial stresses in the materials in the object.**

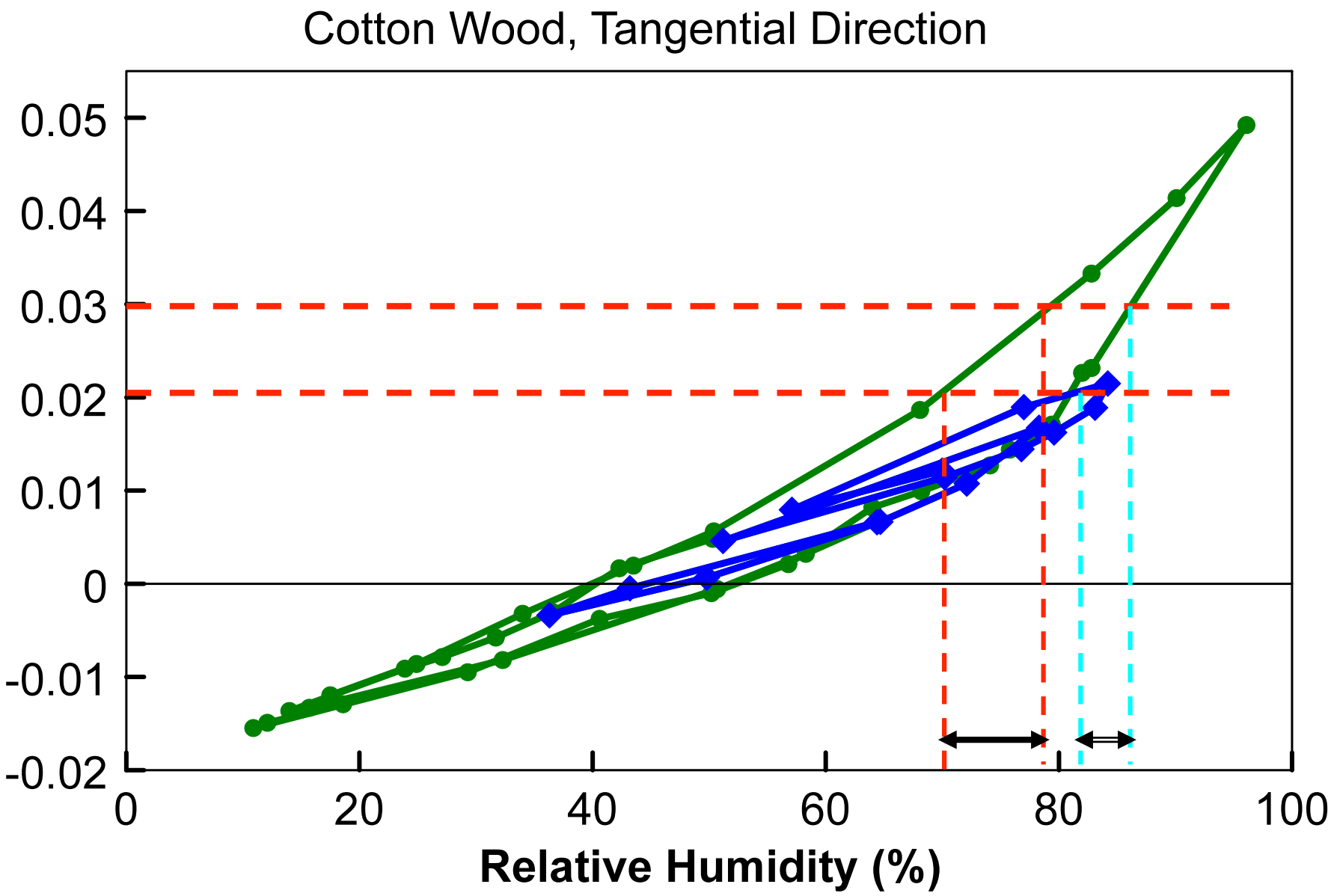
4. **There are no cracks in the objects**

Determining the allowable RH using the established criteria.



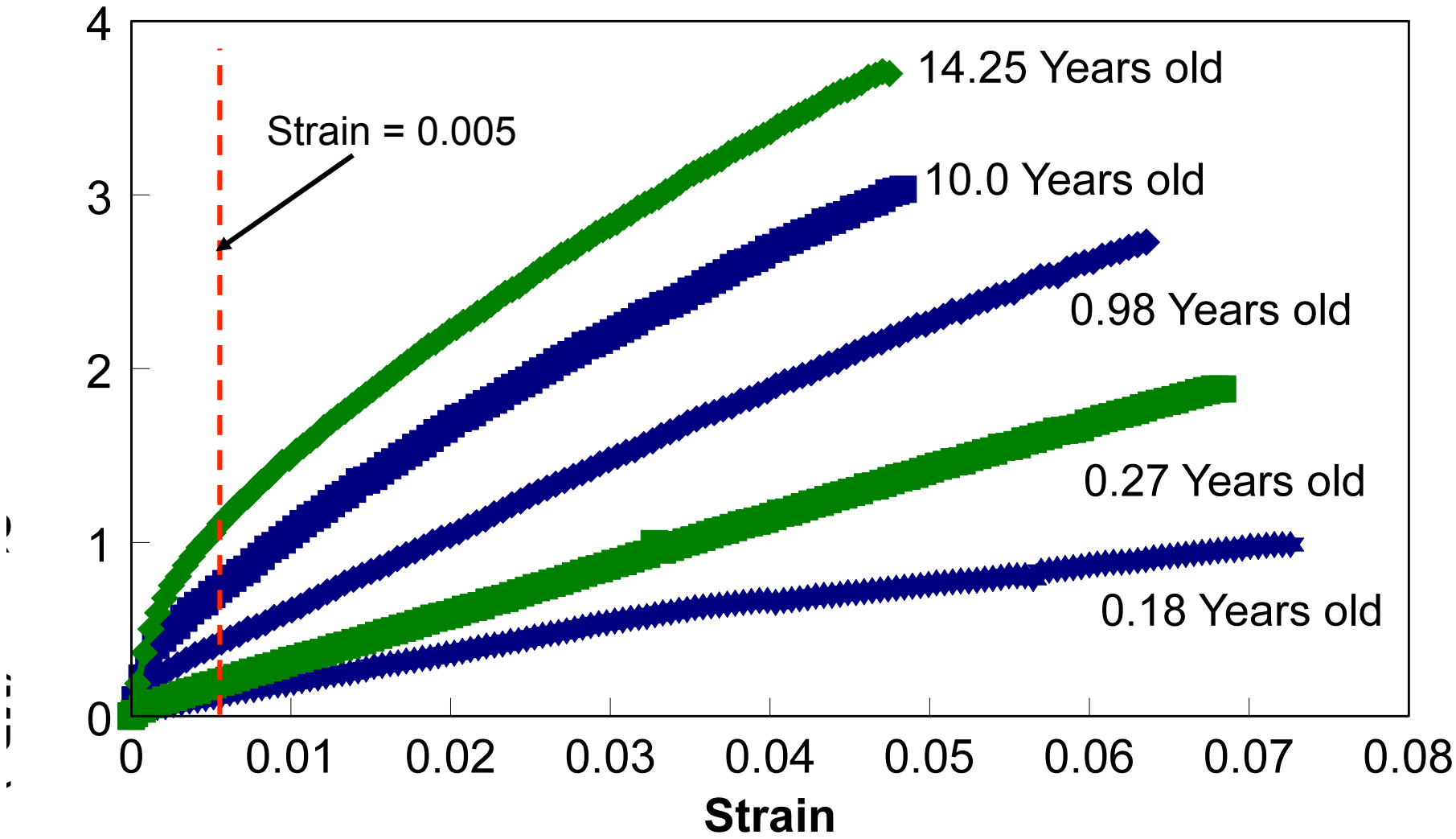

Cotton Wood, Tangential Direction
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
0
20
40
60
80
100
Relative Humidity (%)
Current SI Guidelines
37% RH to 53% RH
+/-0.005
Allowable RH Range
30% RH to 62% RH

Effects of conditioning to very high Relative Humidity

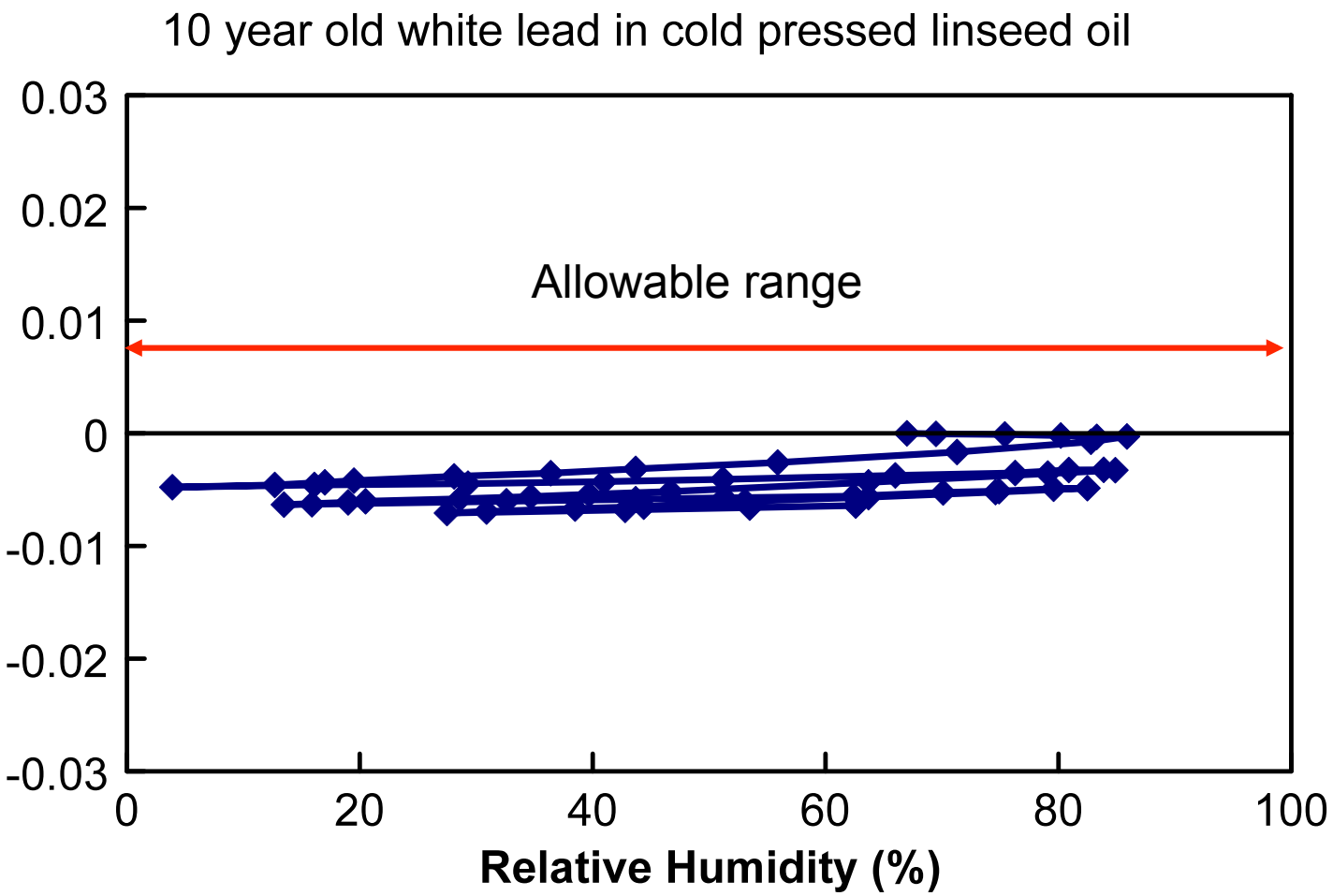


It would be expected that all oil paints get stiffer and stronger as time goes on.

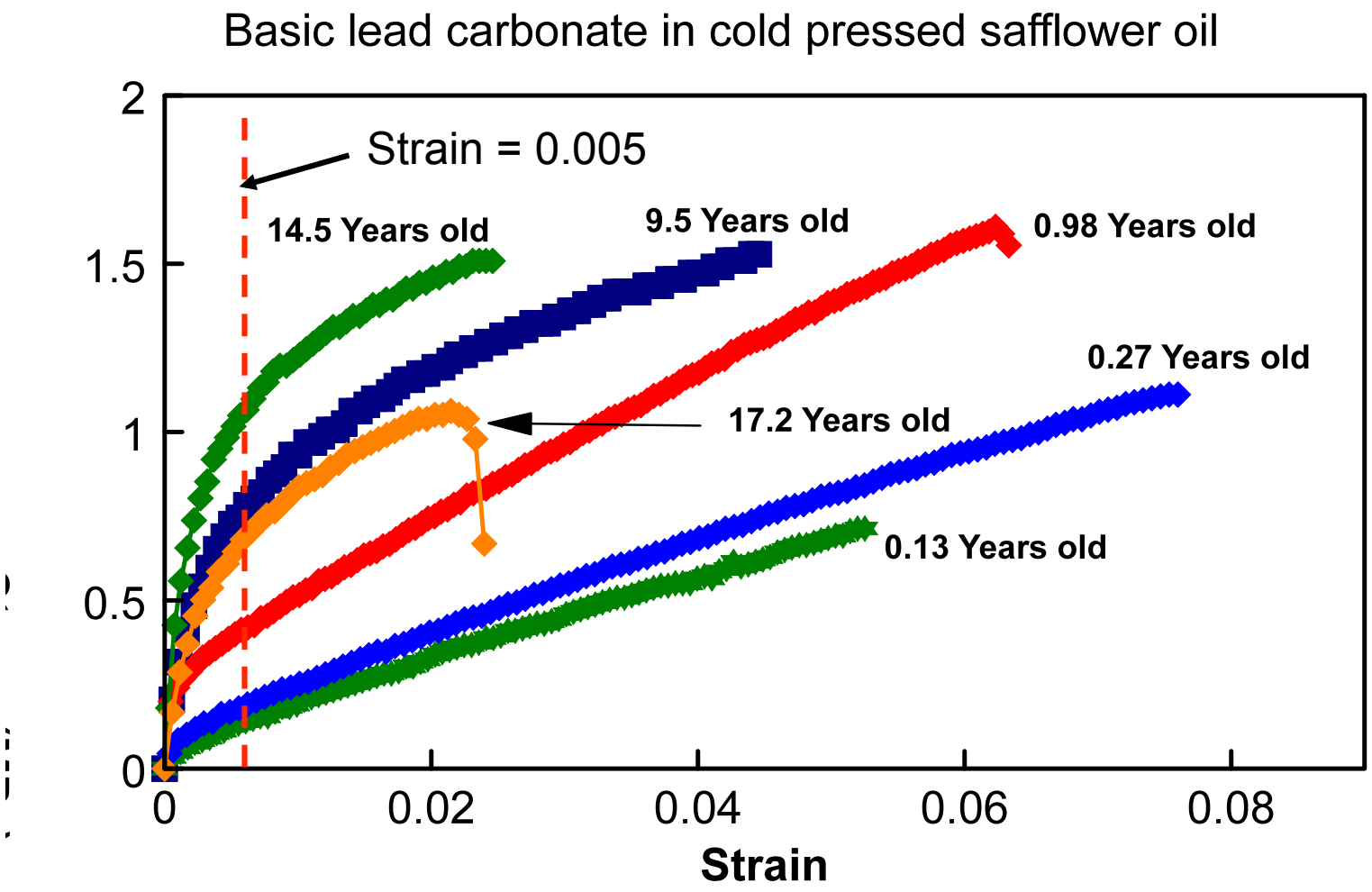
Basic lead carbonate in cold pressed linseed oil

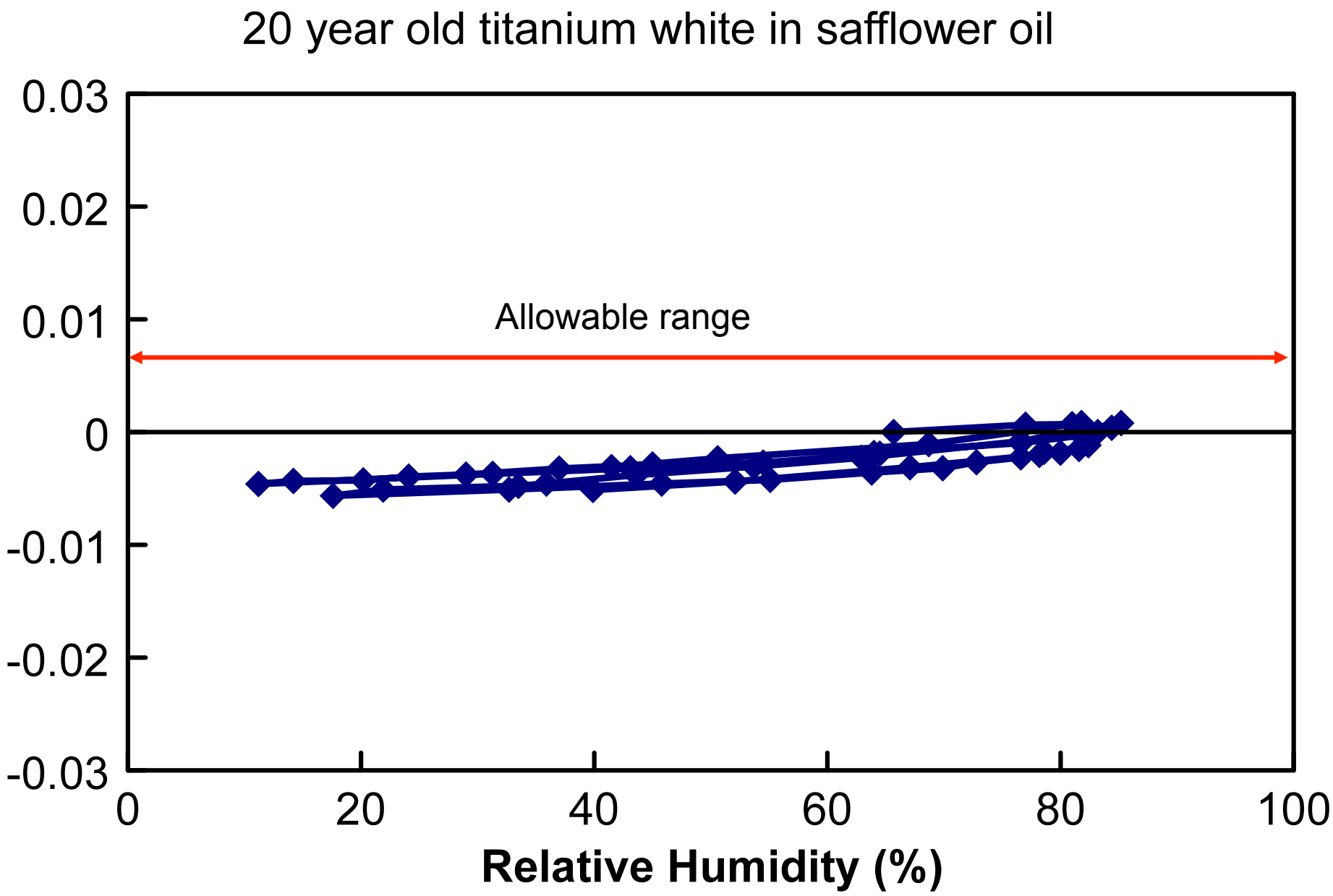


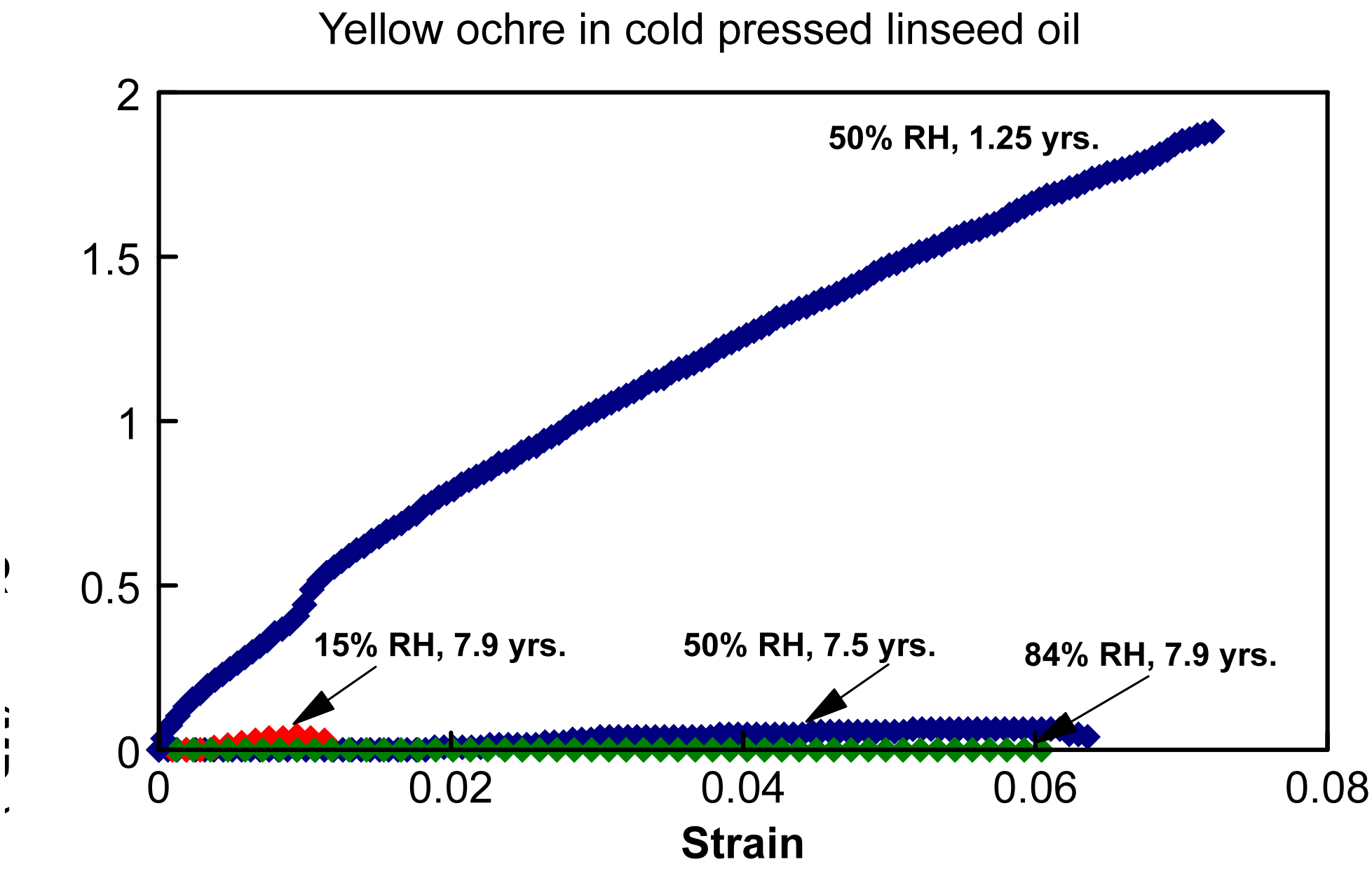
Oil paints made with white pigments such as basic lead carbonate, titanium dioxide and zinc oxide remain fairly stable in changing relative humidity



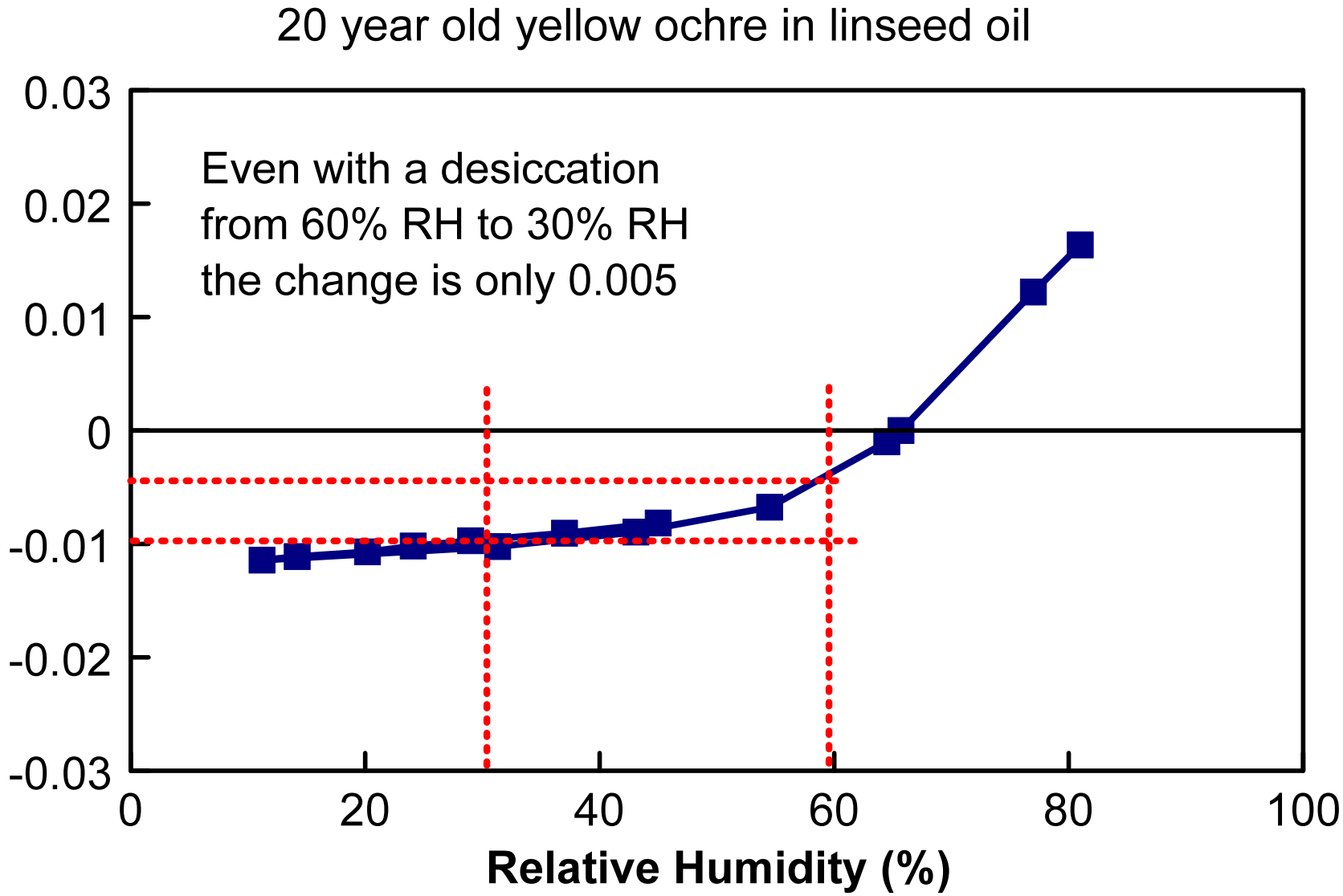
The use of safflower oil ultimately demonstrates adverse effects. The strength is decreasing and the strain to failure is decreasing. Safflower oil makes a weaker paint than when using cold pressed or alkali refined linseed oil.




20 year old titanium white in safflower oil
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
Allowable range
0
20
40
60
80
100
Relative Humidity (%)

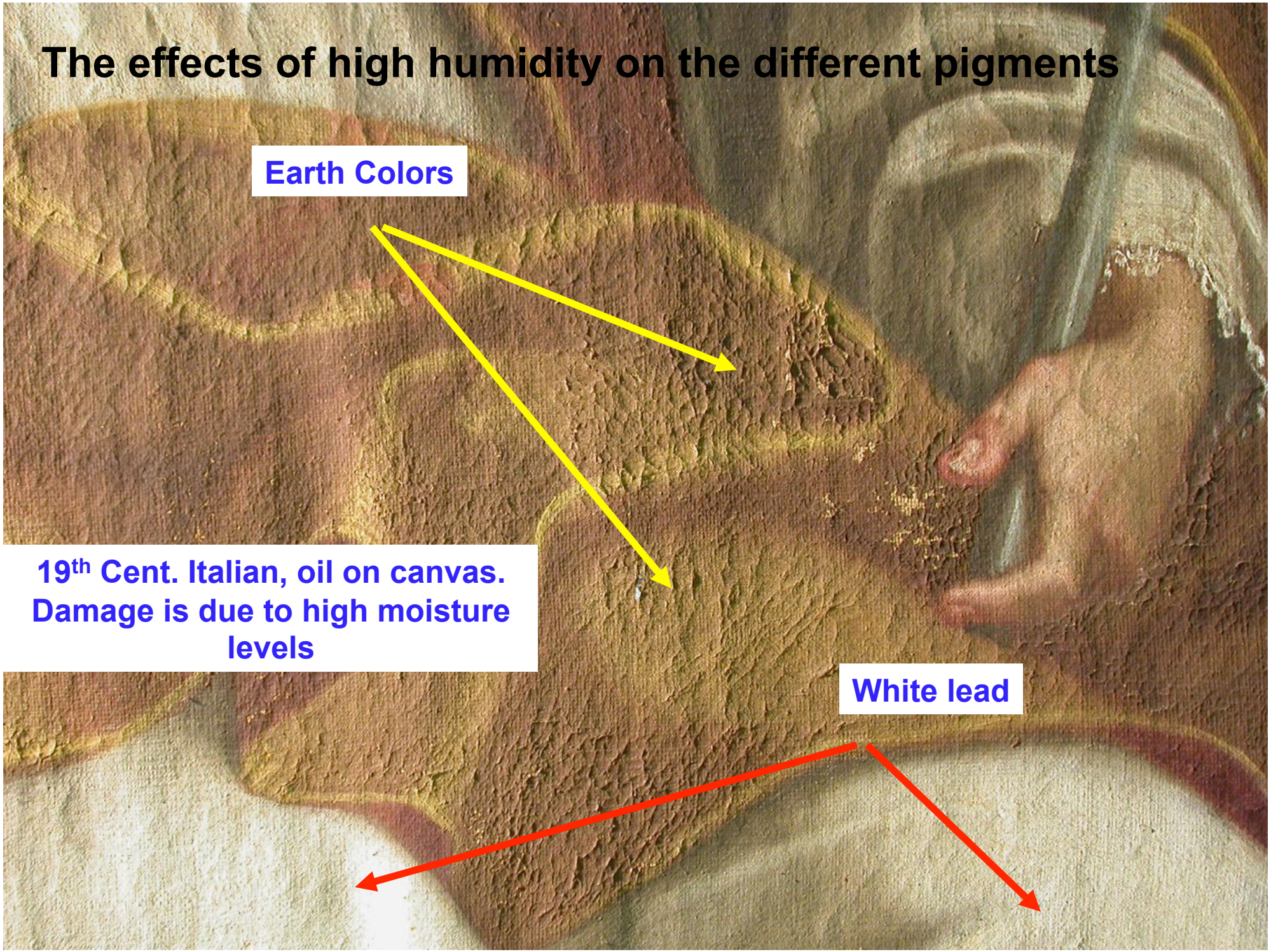

Yellow ochre in cold pressed linseed oil
50% RH, 1.25 yrs.
15% RH, 7.9 yrs.
50% RH, 7.5 yrs.
84% RH, 7.9 yrs.
2
1.5
1
0.5
0
0
0.02
0.04
0.06
0.08
Strain

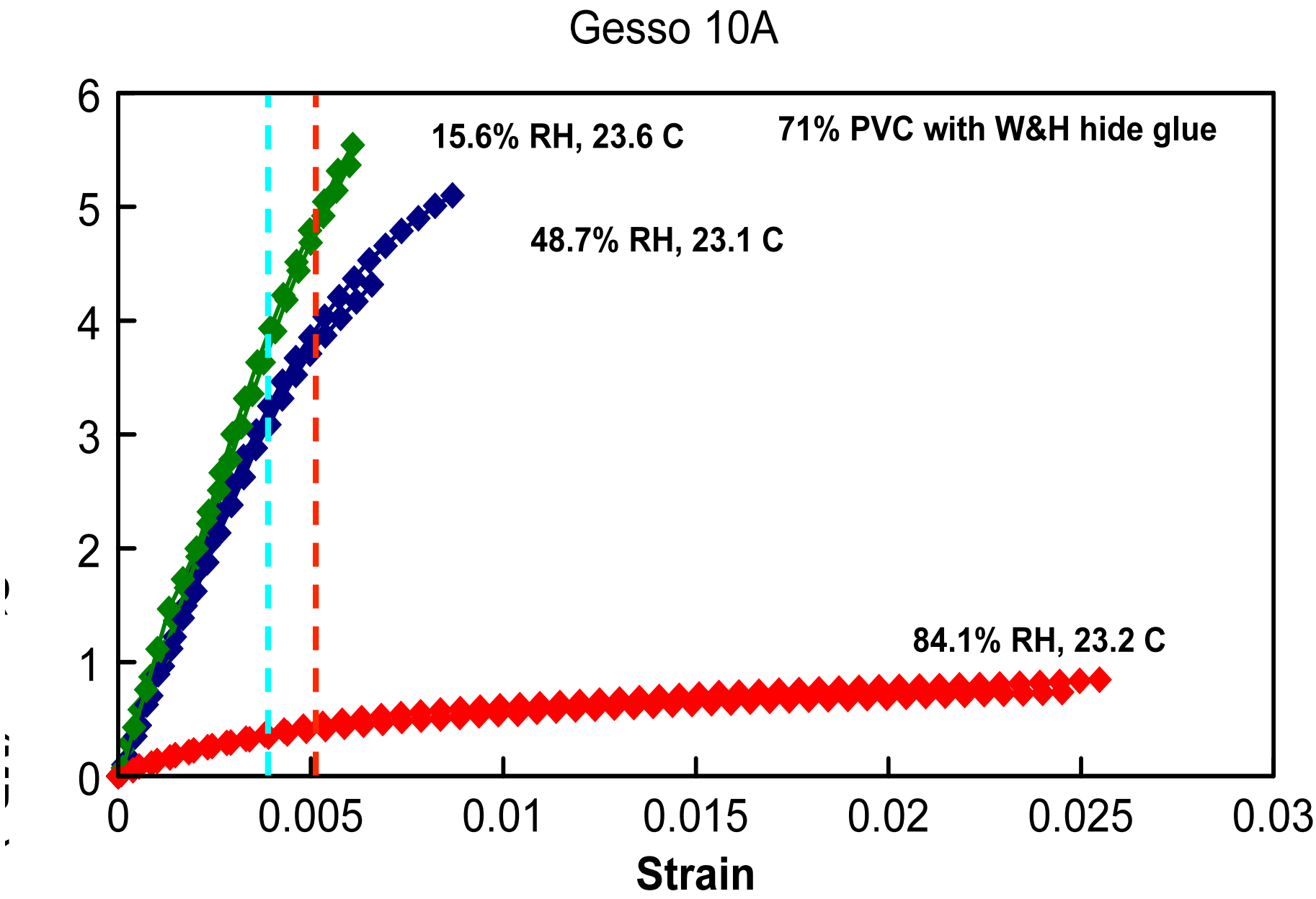
Clay in the natural earth colors causes significant swelling from relative humidity

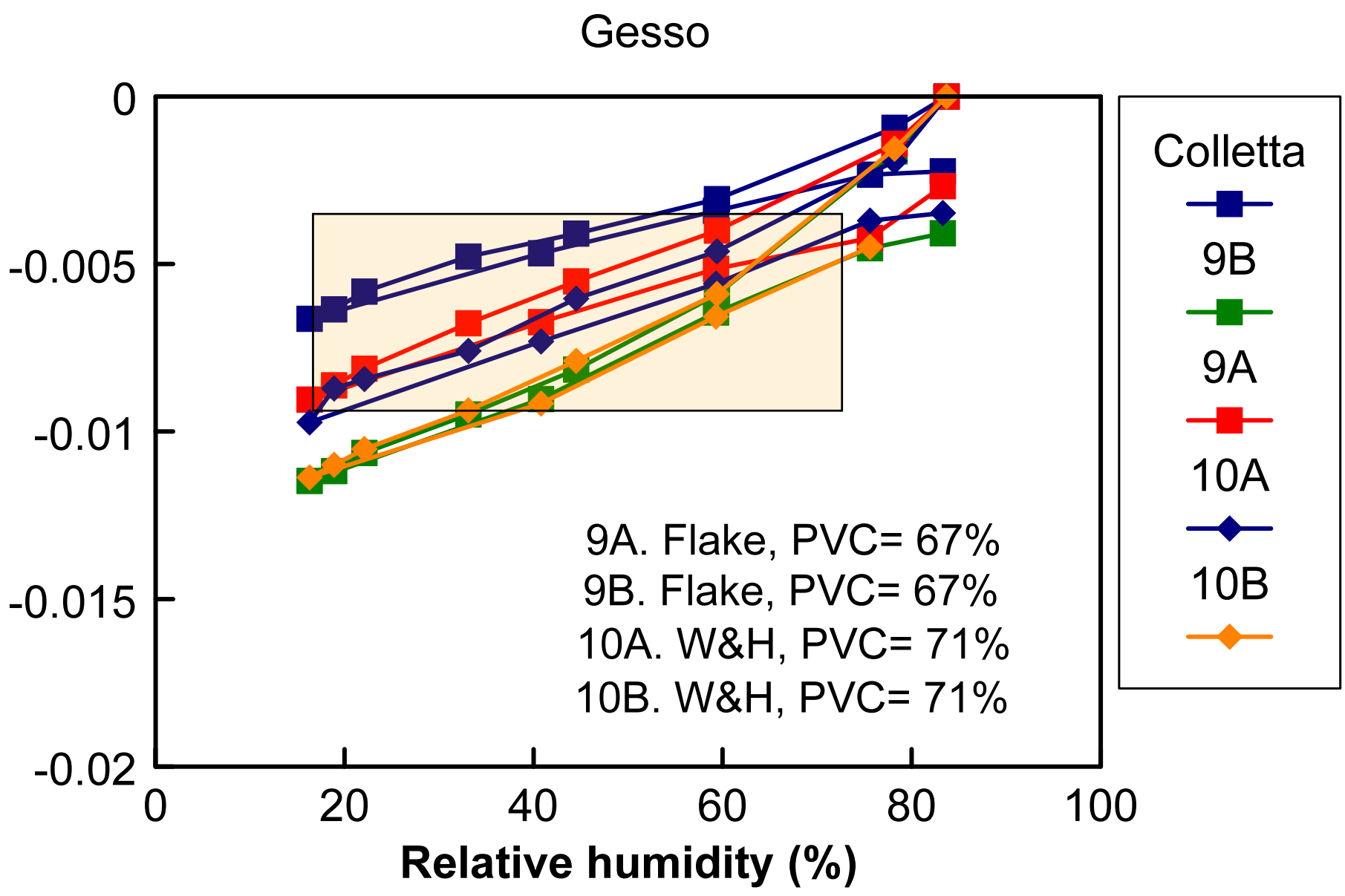


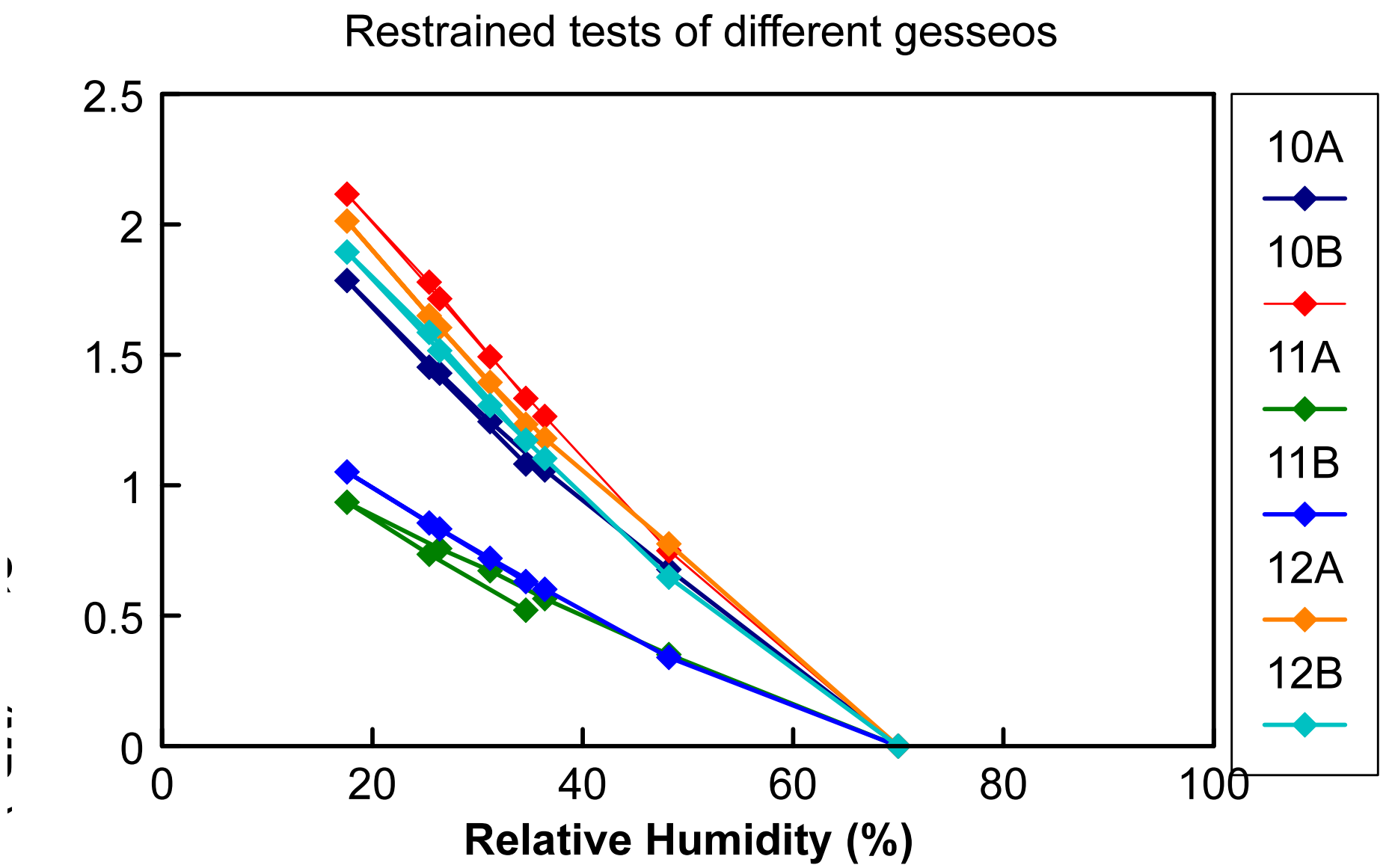
a

The effects of high humidity on the different pigments



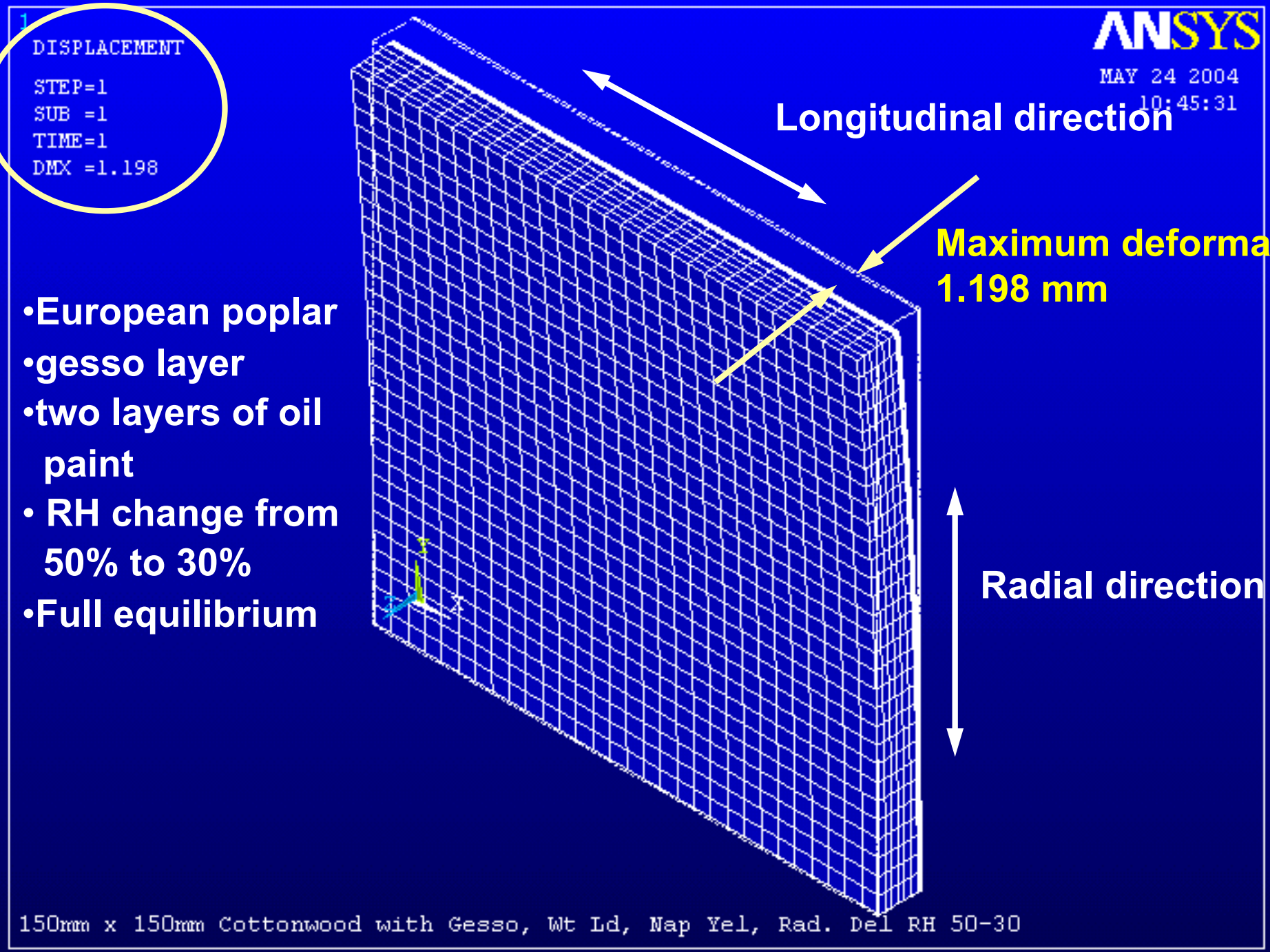

Gesso 10A
15.6% RH, 23.6 C
71% PVC with W&H hide glue
48.7% RH, 23.1 C
84.1% RH, 23.2 C
0
1
2
3
4
5
6
0
0.005
0.01
0.015
0.02
0.025
0.03
Strain


Gesso
0
-0.005
-0.01
-0.015
-0.02
0
20
40
60
80
100
Relative humidity (%)
9A. Flake, PVC= 67%
9B. Flake, PVC= 67%
10A. W&H, PVC= 71%
10B. W&H, PVC= 71%
Colletta
9B
9A
10A
10B

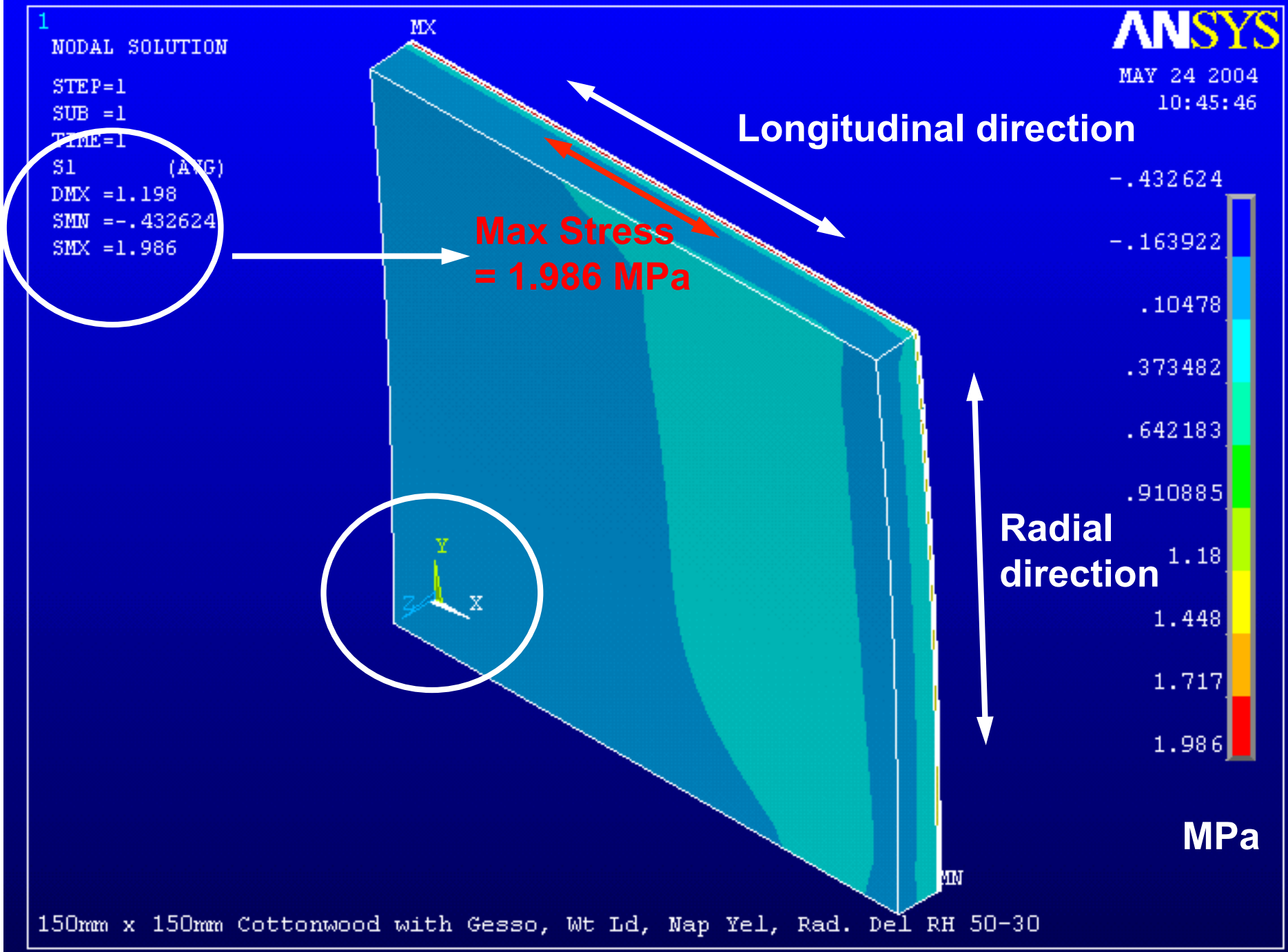

Restrained tests of different gesseos
2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
Relative Humidity (%)
10A
10B
11A
11B
12A
12B

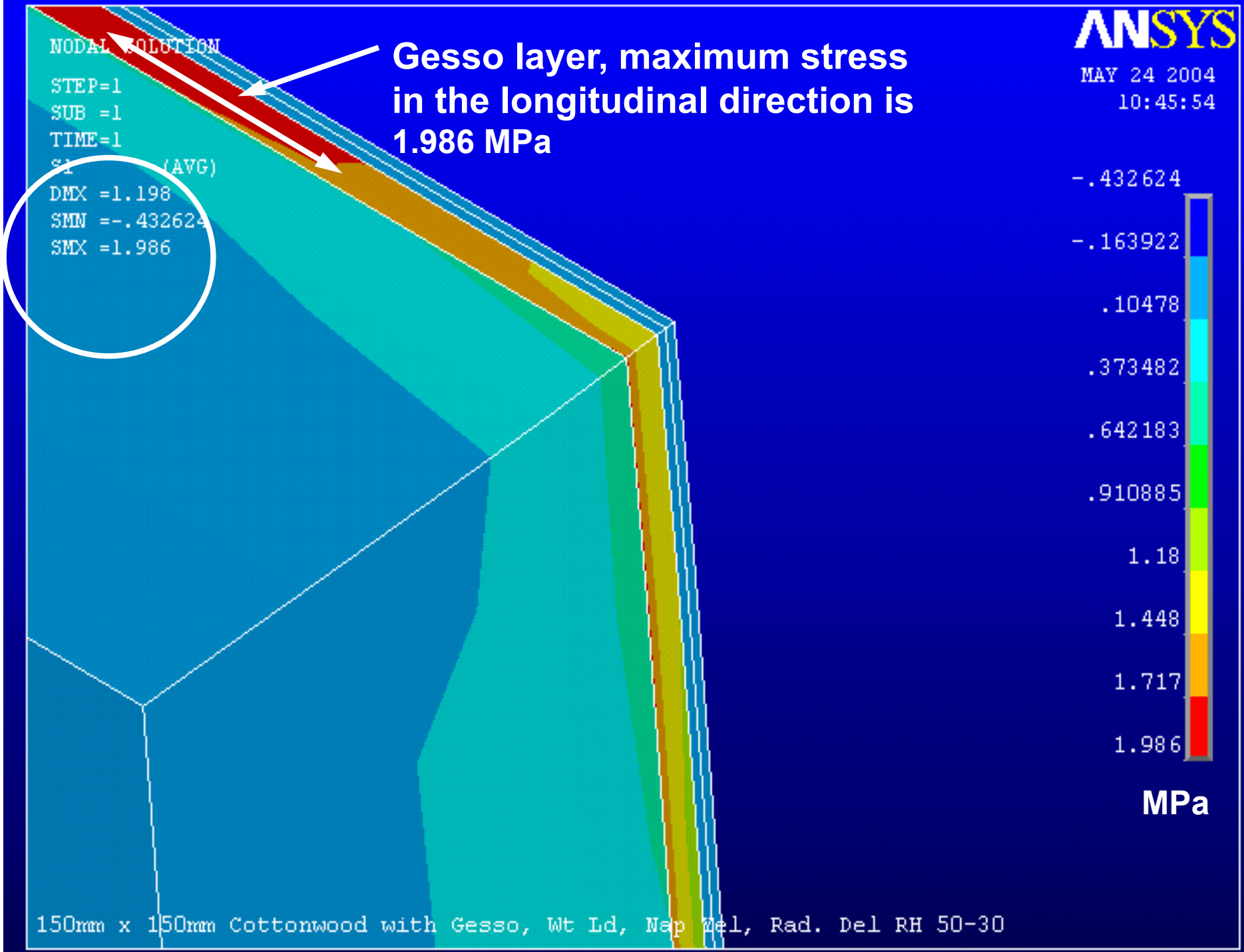
Analytical tools

Computer modeling



- European poplar
- gesso layer
- two layers of oil paint
- RH change from 50% to 30%
- Full equilibrium

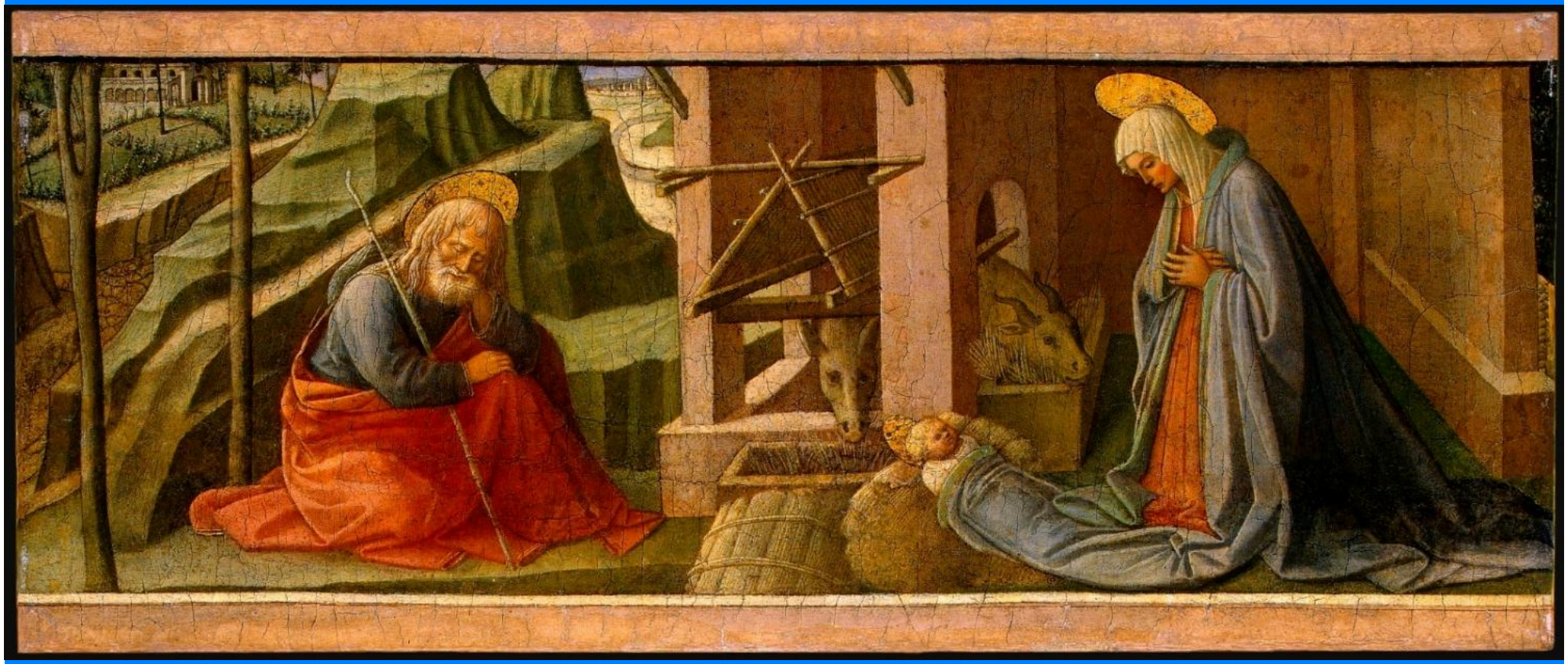

1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
S1 (AVG)
DMX =1.198
SMN =-.432624
SMX =1.986
MX
MN
ANSYS
MAY 24 2004
10:45:46
Longitudinal direction
Max Stress
= 1.986 MPa
Radial
direction
-.432624
-.163922
.10478
.373482
.642183
.910885
1.18
1.448
1.717
1.986
MPa
Y
X
Z
150mm x 150mm Cottonwood with Gesso, Wt Ld, Nap Yel, Rad. Del RH 50-30


Gesso layer, maximum stress in the longitudinal direction is 1.986 MPa
ANSYS
MAY 24 2004
10:45:54
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
(AVG)
DMX =1.198
SMN =-.432624
SMX =1.986
-.432624
-.163922
.10478
.373482
.642183
.910885
1.18
1.448
1.717
1.986
MPa
150mm x 150mm Cottonwood with Gesso, Wt Ld, Nap Del, Rad. Del RH 50-30

It is now possible to compare actual material test data to the computer model results.

Gentile da Fabriano, Marchigian, c. 1370-1427, Madonna and Child Enthroned, c 1420, Tempera on panel, 37 11/16 in. x 22 ¼ in. (95.7 x 56.5 cm), Samuel H. Kress Collection, 1939.1.255.
(Courtesy of the National Gallery of Art, Washington, D.C.)

All of the cracks originated in the gesso layer and are perpendicular To the grain of the wood. The environmental ranges in RH had to have exceeded 70% to 20% for this damage to occur. The wood is acting as a restraint to the gesso layer.



Fra Lippo Lippi and workshop, Florentine, c. 1406-1469, The Nativity, probably c 1445, oil and tempera (?) on panel, 9 1/8 in. x 21 ¾ in. (23.2 x 55.3 cm), Samuel H. Kress Collection, 1939.1.279. (courtesy of the National Gallery of Art, Washington, D.C.)

All of the cracks originated in the gesso layer and are perpendicular To the grain of the wood. The environmental ranges in RH had to have exceeded 70% to 20% for this damage to occur. The wood is acting as a restraint to the gesso layer.

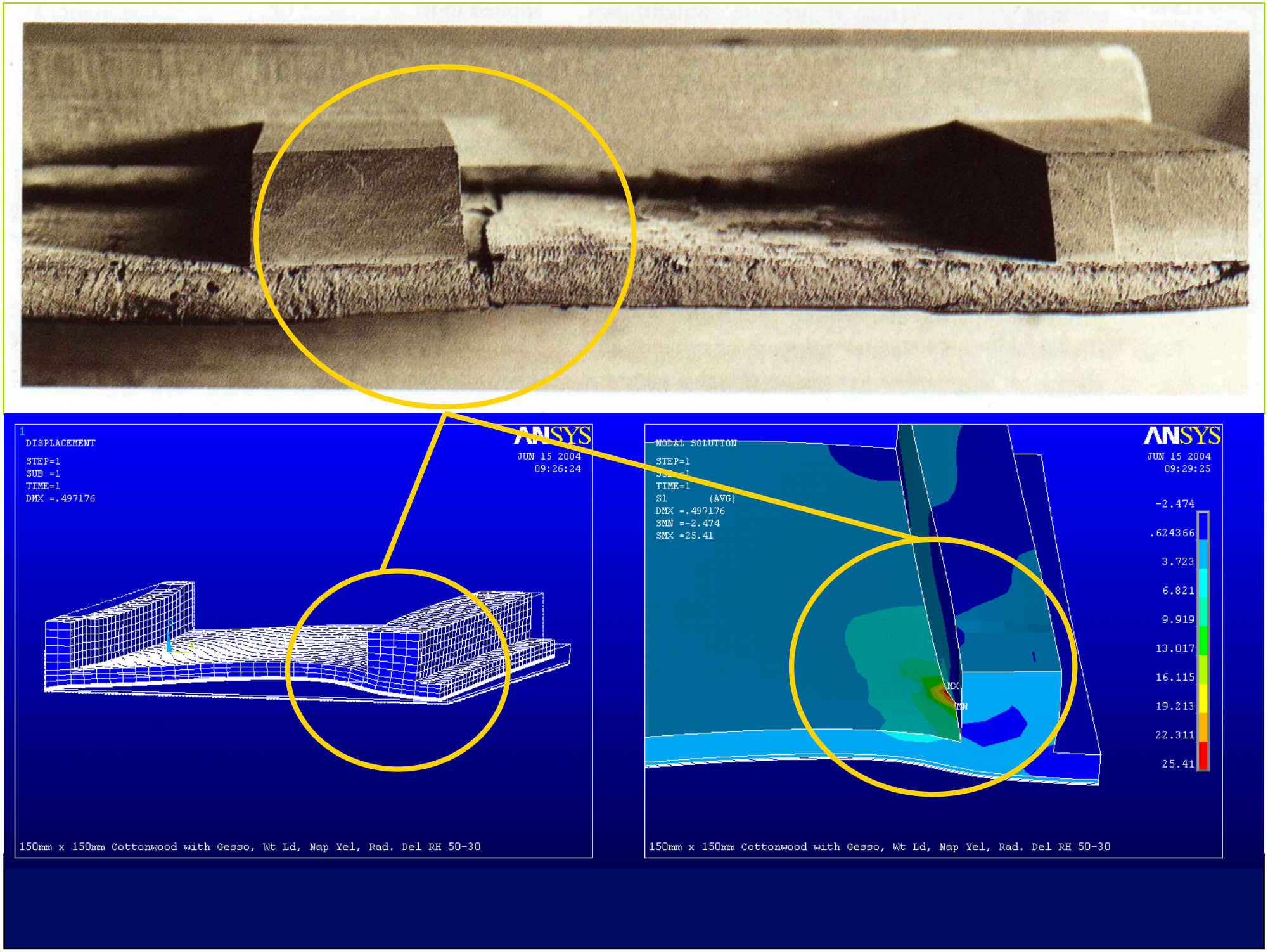
For those materials that are fully restrained and are allowed a strain variation of +/- 0.005, with an initial stress of zero, the RH range results are as follows.

Material	From	To
Woods in general	30-32%	62%
Hide glue	30%	60%
Ivory	26%	67%
Gesso	18%	72%
White Lead Paint	0%	100%
Titanium White Paint	28%	66%
Zinc White Paint	16%	63%
Earth Color Paints	30%	64%

For those materials fully restrained and already under stress:

Woods	30%	80%
Gesso	20%	70%
Linen	10%	90%
Hide glue	30%	70%
White lead Paint	20%	75%
Naples Yellow Paint	20%	75%

If constraint of materials and large humidity swings occur together then damage will result.


1
DISPLACEMENT
STEP=1
SUB =1
TIME=1
DMX =.497176
ANSYS
JUN 15 2004
09:26:24
150mm x 150mm Cottonwood with Gesso, Wt Ld, Nap Yel, Rad. Del RH 50-30
NODAL SOLUTION
STEP=1
TIME=1
S1 (AVG)
DMX =.497176
SMN =-2.474
SMX =25.41
ANSYS
JUN 15 2004
09:29:25
-2.474
.624366
3.723
6.821
9.919
13.017
16.115
19.213
22.311
25.41
MX
MN
150mm x 150mm Cottonwood with Gesso, Wt Ld, Nap Yel, Rad. Del RH 50-30

If you have any questions contact me at mecklenburgm@si.edu

For additional information see the following links.

http://www.si.edu/mci/downloads/reports/Mecklenburg-Part1-RH.pdf
http://www.si.edu/mci/downloads/reports/Mecklenburg-Part2-Temp.pdf