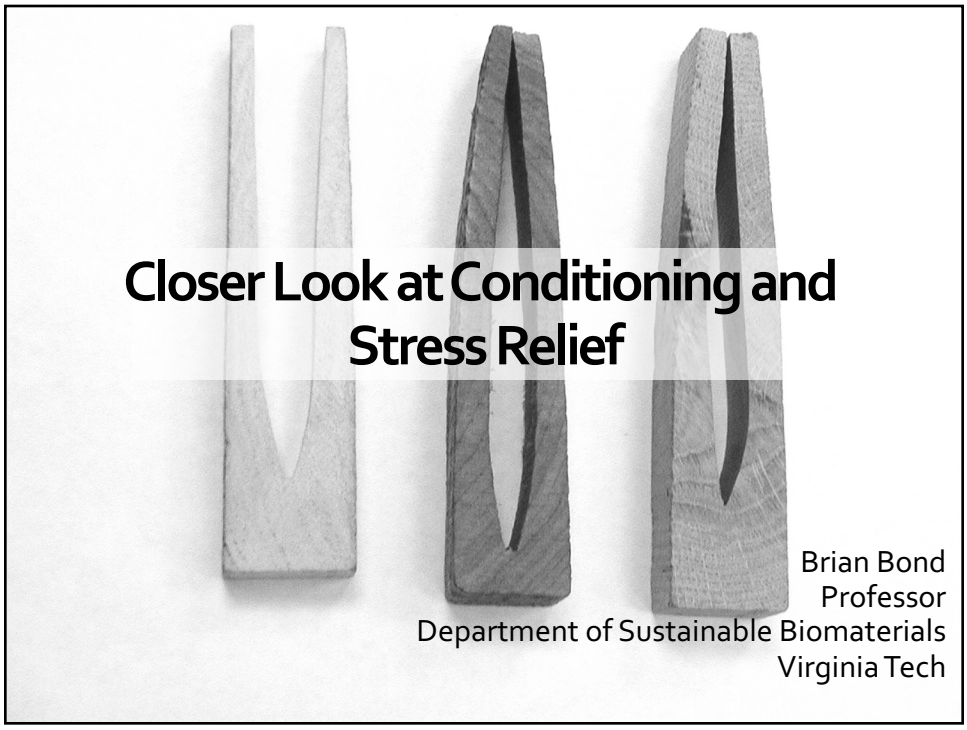
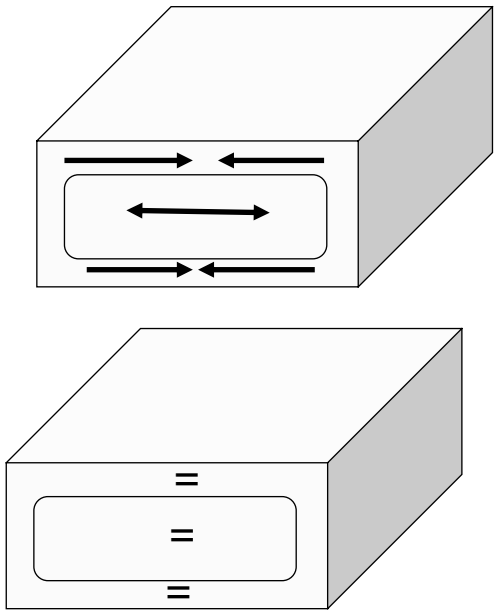


Closer Look at Conditioning and Stress Relief

Brian Bond
Professor
Department of Sustainable Biomaterials
Virginia Tech

1

Stress Relief



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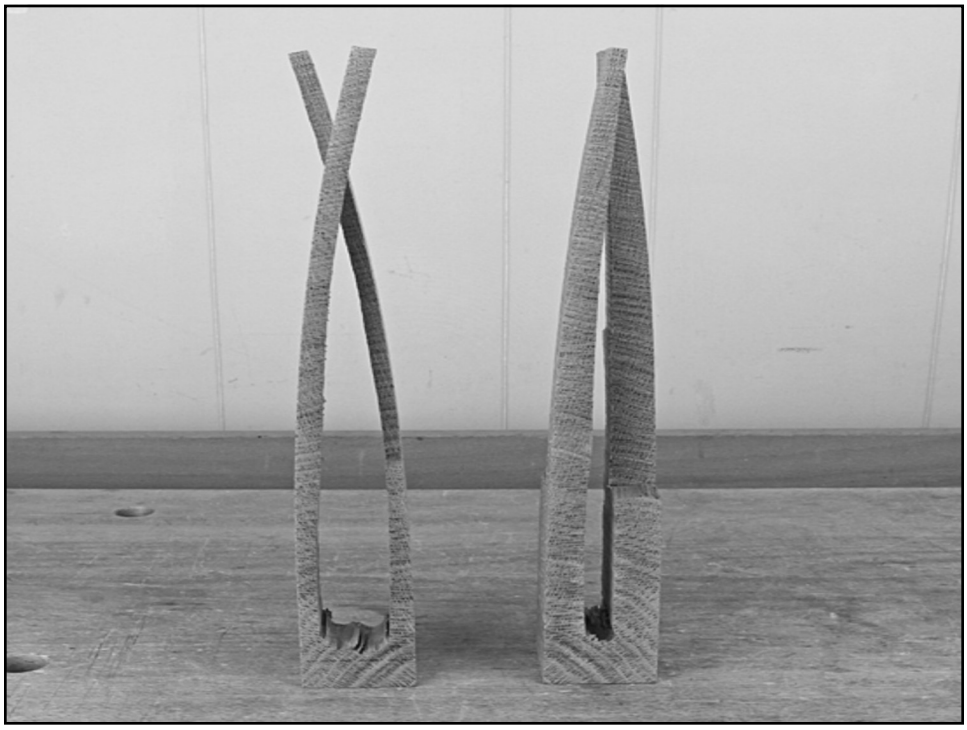
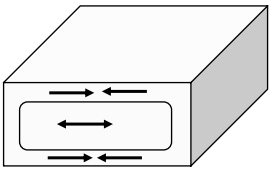
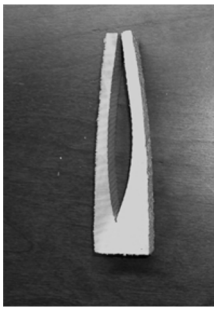


3

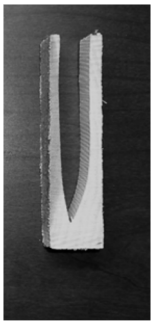
Stress Relief





"Conditioning"

- Stress removal
- MC uniformity within



4

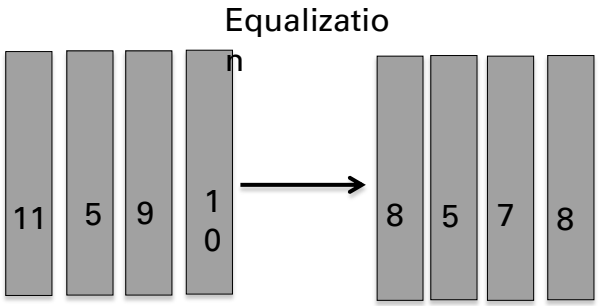
T3-D2

Step	% Moisture Content	Dry-bulb	Wet-bulb	Depression
1	Above 50	110	106	4
2	50 to 40	110	105	5
3	40 to 35	110	102	8
4	35 to 30	110	96	14
5	30 to 25	120	90	30
6	25 to 20	130	90	40
7	20 to 15	140	95	45
8	15 to Final	160	115	45
Equalize and Condition as necessary				

5

EQUALIZATION

Br ngs about mo sture un form ty bet ween boards



6

Equalization "By the book!"

1. Begin when the driest sample is 2% below the target moisture content
2. Set wet bulb and dry bulb temperatures known to give an EMC in kiln that is 2% below target
3. Continue until the wettest sample reaches the target moisture content

Why are we talking about Equalization? Conditioning?

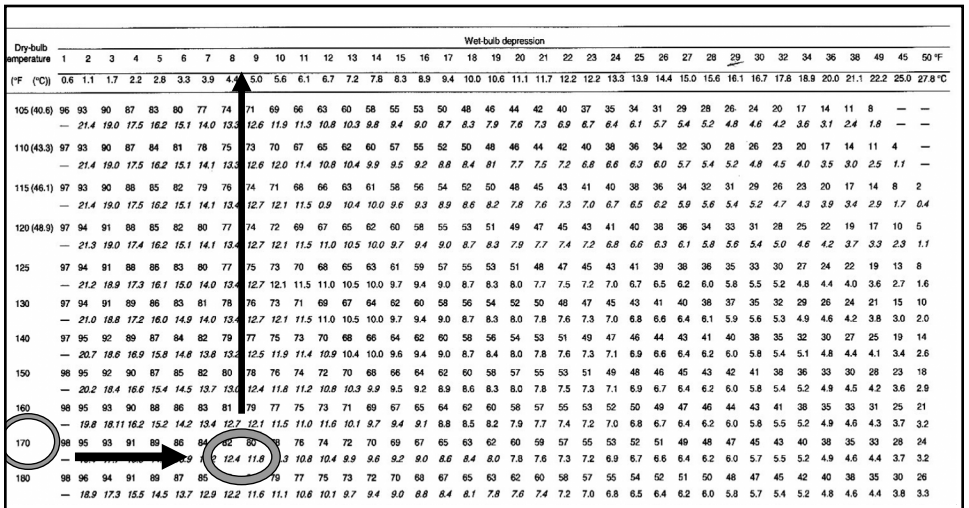
7

Conditioning: "By the book"

1. Begin when the wettest sample reaches the target MC
2. Set the kiln to an EMC of 4% above target MC
   - Hardwoods
3. Dry bulb temperature the highest allowed in the schedule

8% target
EMC = 12%
Highest Temperature used 170 F

8

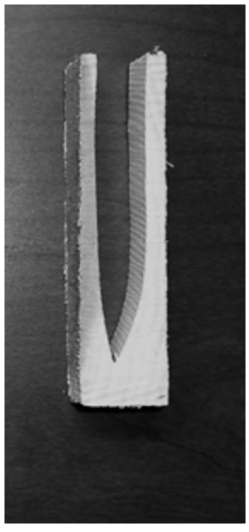


Dry-bulb temperature	Wet-bulb depression																																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	32	34	36	38	49	45	50 °F
(°F (°C))	0.6	1.1	1.7	2.2	2.8	3.3	3.9	4.4	5.0	5.6	6.1	6.7	7.2	7.8	8.3	8.9	9.4	10.0	10.6	11.1	11.7	12.2	12.2	13.3	13.9	14.4	15.0	15.6	16.1	16.7	17.8	18.9	20.0	21.1	22.2	25.0	27.8 °C
105 (40.6)	96	93	90	87	83	80	77	74	71	69	66	63	60	58	55	53	50	48	46	44	42	40	37	35	34	31	29	28	26	24	20	17	14	11	8	—	—
	—	*21.4*	*19.0*	*17.5*	*16.2*	*15.1*	*14.0*	*13.3*	*12.6*	*11.9*	*11.3*	*10.8*	*10.3*	*9.8*	*9.4*	*9.0*	*8.7*	*8.3*	*7.9*	*7.6*	*7.3*	*6.9*	*6.7*	*6.4*	*6.1*	*5.7*	*5.4*	*5.2*	*4.8*	*4.6*	*4.2*	*3.6*	*3.1*	*2.4*	*1.8*	—	—
110 (43.3)	97	93	90	87	84	81	78	75	73	70	67	65	62	60	57	55	52	50	48	46	44	42	40	38	36	34	32	30	28	26	23	20	17	14	11	4	—
	—	*21.4*	*19.0*	*17.5*	*16.2*	*15.1*	*14.1*	*13.3*	*12.6*	*12.0*	*11.4*	*10.8*	*10.4*	*9.9*	*9.5*	*9.2*	*8.8*	*8.4*	*81*	*7.7*	*7.5*	*7.2*	*6.8*	*6.6*	*6.3*	*6.0*	*5.7*	*5.4*	*5.2*	*4.8*	*4.5*	*4.0*	*3.5*	*3.0*	*2.5*	*1.1*	—
115 (46.1)	97	93	90	88	85	82	79	76	74	71	68	66	63	61	58	56	54	52	50	48	45	43	41	40	38	36	34	32	31	29	26	23	20	17	14	8	2
	—	*21.4*	*19.0*	*17.5*	*16.2*	*15.1*	*14.1*	*13.4*	*12.7*	*12.1*	*11.5*	*0.9*	*10.4*	*10.0*	*9.6*	*9.3*	*8.9*	*8.6*	*8.2*	*7.8*	*7.6*	*7.3*	*7.0*	*6.7*	*6.5*	*6.2*	*5.9*	*5.6*	*5.4*	*5.2*	*4.7*	*4.3*	*3.9*	*3.4*	*2.9*	*1.7*	*0.4*
120 (48.9)	97	94	91	88	85	82	80	77	74	72	69	67	65	62	60	58	55	53	51	49	47	45	43	41	40	38	36	34	33	31	28	25	22	19	17	10	5
	—	*21.3*	*19.0*	*17.4*	*16.2*	*15.1*	*14.1*	*13.4*	*12.7*	*12.1*	*11.5*	*11.0*	*10.5*	*10.0*	*9.7*	*9.4*	*9.0*	*8.7*	*8.3*	*7.9*	*7.7*	*7.4*	*7.2*	*6.8*	*6.6*	*6.3*	*6.1*	*5.8*	*5.6*	*5.4*	*5.0*	*4.6*	*4.2*	*3.7*	*3.3*	*2.3*	*1.1*
125	97	94	91	88	86	83	80	77	75	73	70	68	65	63	61	59	57	55	53	51	48	47	45	43	41	39	38	36	35	33	30	27	24	22	19	13	8
	—	*21.2*	*18.9*	*17.3*	*16.1*	*15.0*	*14.0*	*13.4*	*12.7*	12.1	11.5	11.0	10.5	10.0	9.7	9.4	9.0	8.7	8.3	8.0	7.7	7.5	7.2	7.0	6.7	6.5	6.2	6.0	5.8	5.5	5.2	4.8	4.4	4.0	3.6	2.7	1.6
130	97	94	91	89	86	83	81	78	76	73	71	69	67	64	62	60	58	56	54	52	50	48	47	45	43	41	40	38	37	35	32	29	26	24	21	15	10
	—	*21.0*	*18.8*	*17.2*	*16.0*	*14.9*	*14.0*	*13.4*	*12.7*	*12.1*	*11.5*	11.0	10.5	10.0	9.7	9.4	9.0	8.7	8.3	8.0	7.8	7.6	7.3	7.0	6.8	6.6	6.4	6.1	5.9	5.6	5.3	4.9	4.6	4.2	3.8	3.0	2.0
140	97	95	92	89	87	84	82	79	77	75	73	70	68	66	64	62	60	58	56	54	53	51	49	47	46	44	43	41	40	38	35	32	30	27	25	19	14
	—	*20.7*	*18.6*	*16.9*	*15.8*	*14.8*	*13.8*	*13.2*	*12.5*	*11.9*	*11.4*	*10.9*	10.4	10.0	9.6	9.4	9.0	8.7	8.4	8.0	7.8	7.6	7.3	7.1	6.9	6.6	6.4	6.2	6.0	5.8	5.4	5.1	4.8	4.4	4.1	3.4	2.6
150	98	95	92	90	87	85	82	80	78	76	74	72	70	68	66	64	62	60	58	57	55	53	51	49	48	46	45	43	42	41	38	36	33	30	28	23	18
	—	*20.2*	*18.4*	*16.6*	*15.4*	*14.5*	*13.7*	*13.0*	*12.4*	*11.8*	*11.2*	*10.8*	*10.3*	*9.9*	9.5	9.2	8.9	8.6	8.3	8.0	7.8	7.5	7.3	7.1	6.9	6.7	6.4	6.2	6.0	5.8	5.4	5.2	4.9	4.5	4.2	3.6	2.9
160	98	95	93	90	88	86	83	81	79	77	75	73	71	69	67	65	64	62	60	58	57	55	53	52	50	49	47	46	44	43	41	38	35	33	31	25	21
	—	*19.8*	*18.11*	*16.2*	*15.2*	*14.2*	*13.4*	*12.7*	*12.1*	*11.5*	*11.0*	*11.6*	*10.1*	*9.7*	*9.4*	*9.1*	8.8	8.5	8.2	7.9	7.7	7.4	7.2	7.0	6.8	6.7	6.4	6.2	6.0	5.8	5.5	5.2	4.9	4.6	4.3	3.7	3.2
170	98	95	93	91	89	86	84	82	80	[illegible]	76	74	72	70	69	67	65	63	62	60	59	57	55	53	52	51	49	48	47	45	43	40	38	35	33	28	24
	—	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*12.4*	*11.8*	[illegible]	*10.8*	*10.4*	*9.9*	*9.6*	*9.2*	*9.0*	*8.6*	*8.4*	*8.0*	7.8	7.6	7.3	7.2	6.9	6.7	6.6	6.4	6.2	6.0	5.7	5.5	5.2	4.9	4.6	4.4	3.7	3.2
180	98	96	94	91	89	87	85	[illegible]	[illegible]	77	75	73	72	70	68	67	65	63	62	60	58	57	55	54	52	51	50	48	47	45	42	40	38	35	30	26
	—	*18.9*	*17.3*	*15.5*	*14.5*	*13.7*	*12.9*	*12.2*	*11.6*	*11.1*	*10.6*	*10.1*	*9.7*	*9.4*	*9.0*	*8.8*	*8.4*	*8.1*	*7.8*	*7.6*	*7.4*	7.2	7.0	6.8	6.5	6.4	6.2	6.0	5.8	5.7	5.4	5.2	4.8	4.6	4.4	3.8	3.3

8% target
EMC = 12%
Highest Temperature used 170 F
Wet-bulb should be 161-162 F

9

Continue conditioning until the stresses are relieved as shown by the stress test (prong test)



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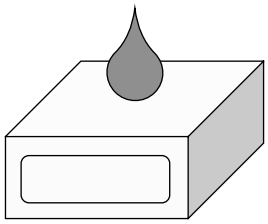
How does this it work?

↑ WBT = ↑ % RH

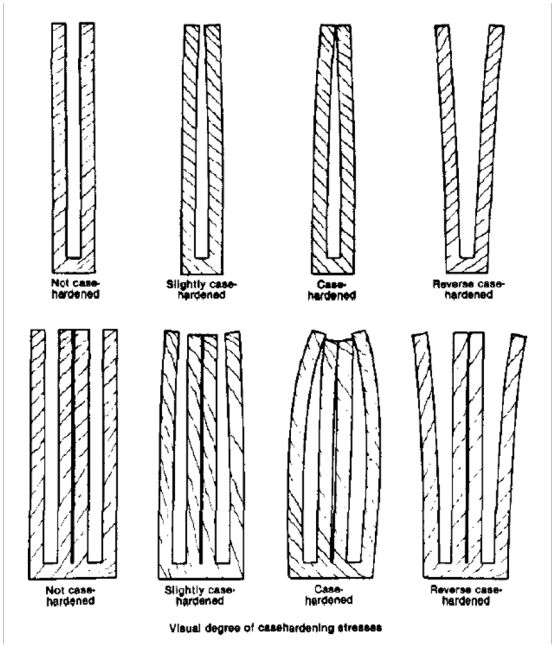


↑ temperature & ↑ increased moisture = plasticization

Stress Relaxation

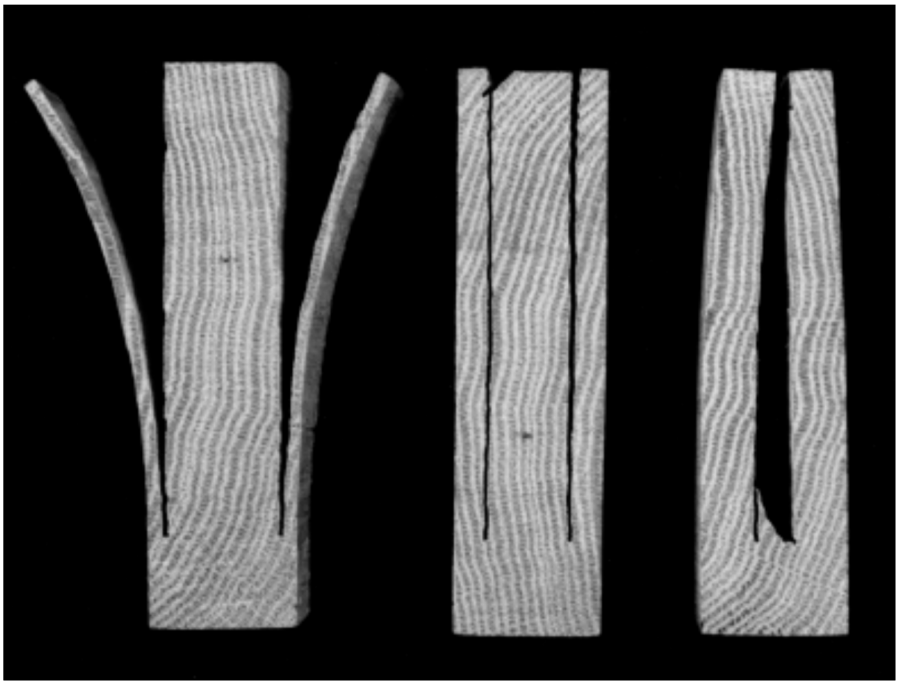
the loss in stress when it is held at a constant strain over a period of time

11



4/4 and 5/4 lumber cut the prongs *one-fourth* the thickness of the lumber

12



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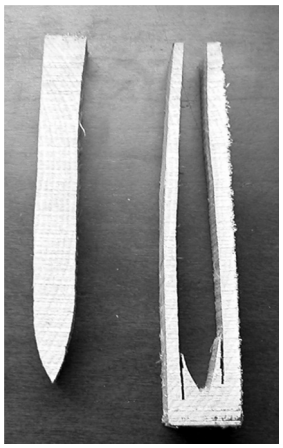
Interpreting Stresses



How many of you:

Cut stress test and read immediately?

Cut stress test and let cool before interpreting?

Cut prong test and microwave 15-20 seconds?

Look for moisture content increase of 1-1.5%?

"The time of cutting the prongs, whether immediately following removal from the kiln or delayed for 1 week, had no substantial effect on prong response" -Fuller and Hart 1994

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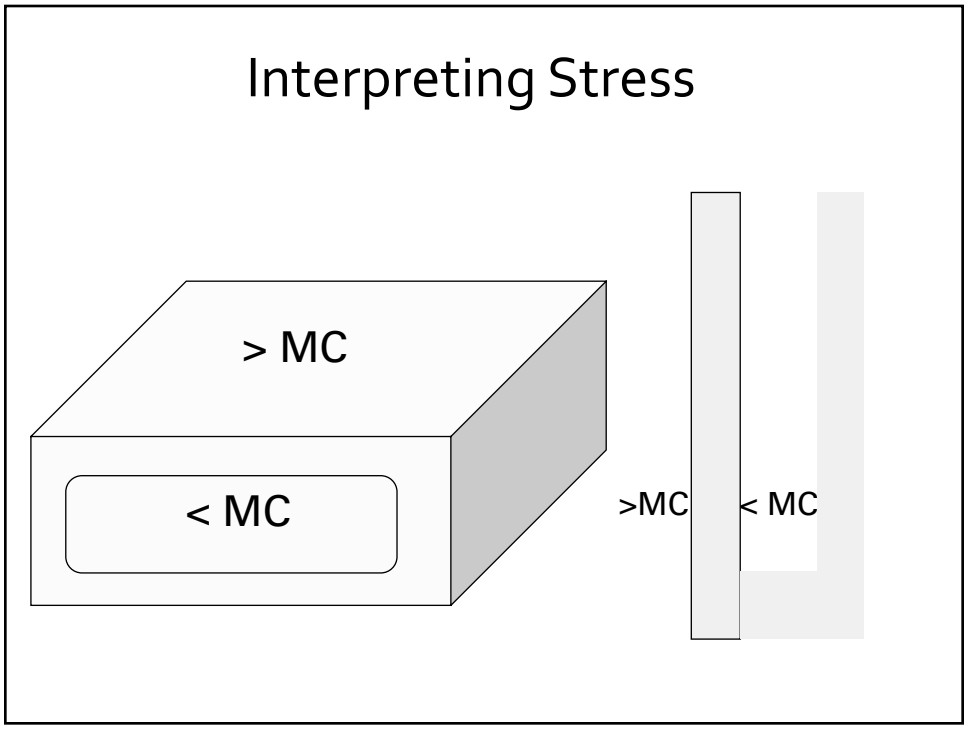
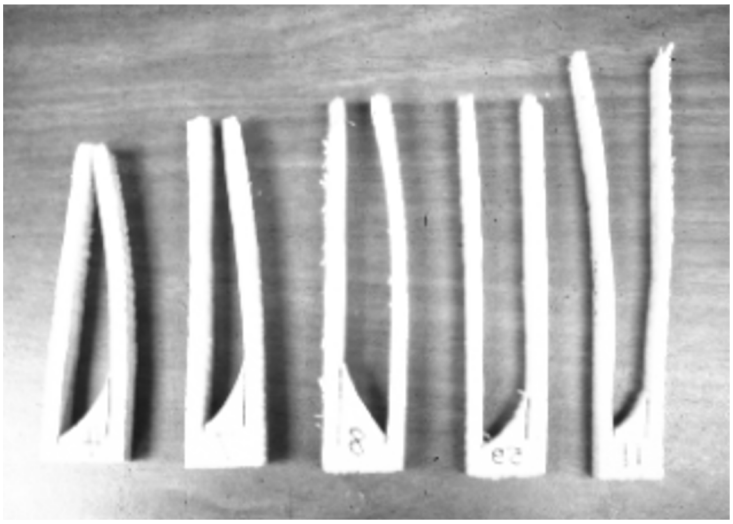


15



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Factors Influencing Conditioning Time

4 hours or 2 days?

- Drying stress
- Density
- Thickness
- Properly equalized
- Temperature
- Relative humidity

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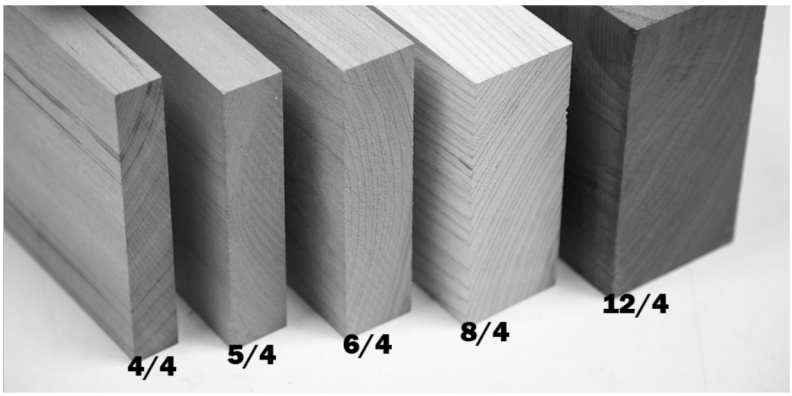
Lumber Thickness

Thicker lumber =
- longer conditioning times
- longer subsequent cooling times
  - to eliminate moisture gradients



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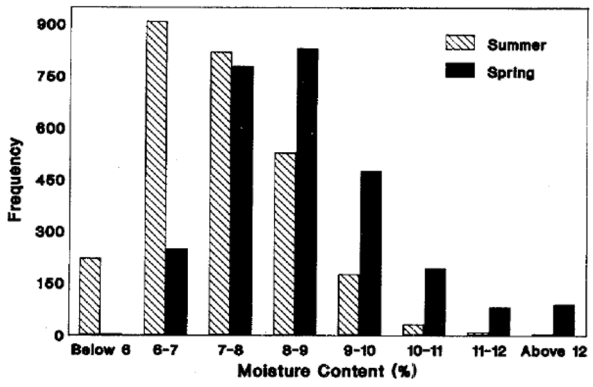
Equalization

Properly equalized?

MC uniformity within charge = Better/Uniform Conditioning



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Relative Humidity

Alone RH will not reduce case hardening!

- Time to reach proper depression
  - Influences overall time!
- Too low
  - Poor conditioning
- Too severe
  - Reverse case hardening

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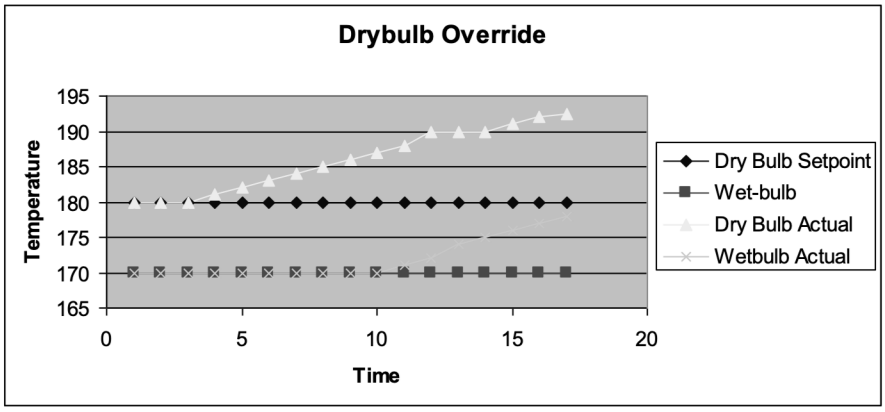
Conditioning



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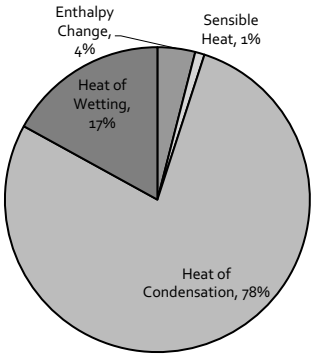
Why override?

- Enthalpy Change
  - Live steam injected into kiln pressure drops to atmospheric pressure and steam temperature goes to 212.
- Sensible Heat
  - When live steam at 212 cools to the kiln temperature
- Heat of Condensation
  - When steam condenses on wood, vapor to liquid
- Heat of wetting
  - Chemical bonding of water molecules to molecules in wood



Hart, 1990

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Avoiding Dry-bulb Over-ride 1

- Turn off heating coils
- Raise the wet-bulb temperature to set point
- The steam spray will raise the wet-bulb temperature and the heat in the steam will raise the dry-bulb
- Raise the dry-bulb temperature to set point and open one heating coil
- Open additional coils *only if needed* to hold heat

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Avoiding Dry-bulb Over-ride 2

- After equalizing, cool the kiln for several hours
  - Open the doors/vents
  - Leave fans on
- Close kiln
- Turn on steam spray to reach set-point
  - Leave dry-bulb off
  - Moisture will condense of surface more easily
- Watch closely to avoid stress-reversal

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Avoiding Dry-bulb Over-ride 3

Use high pressure water vapor

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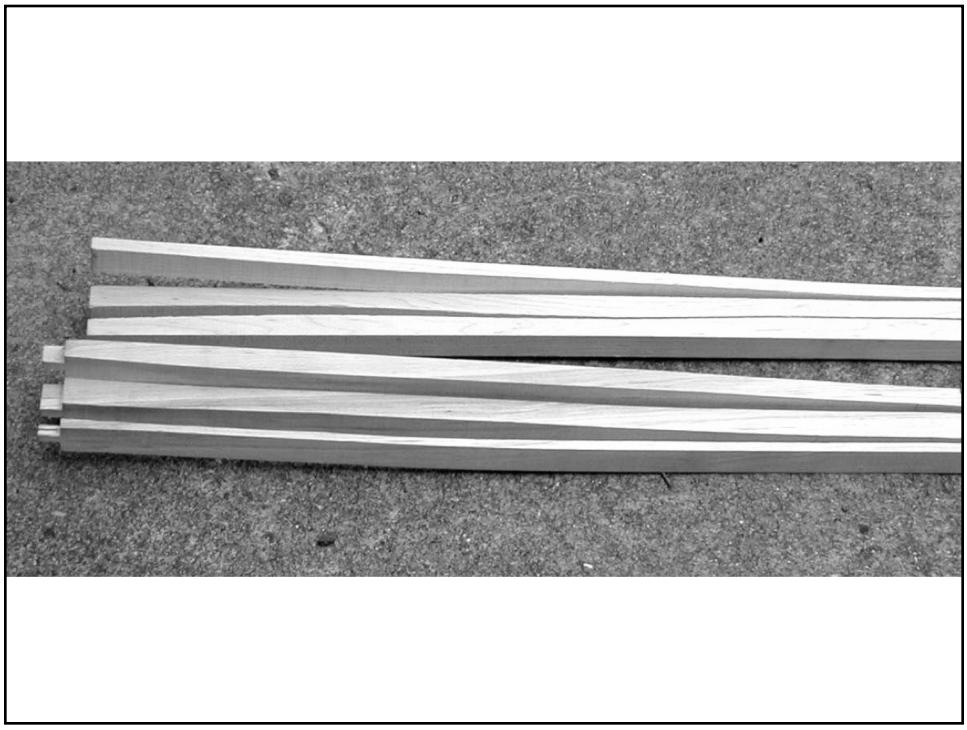

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Longitudinal Stress

- Use higher temperatures (over 160 F)
- Reaching setpoint quickly
- Proper conditioning time

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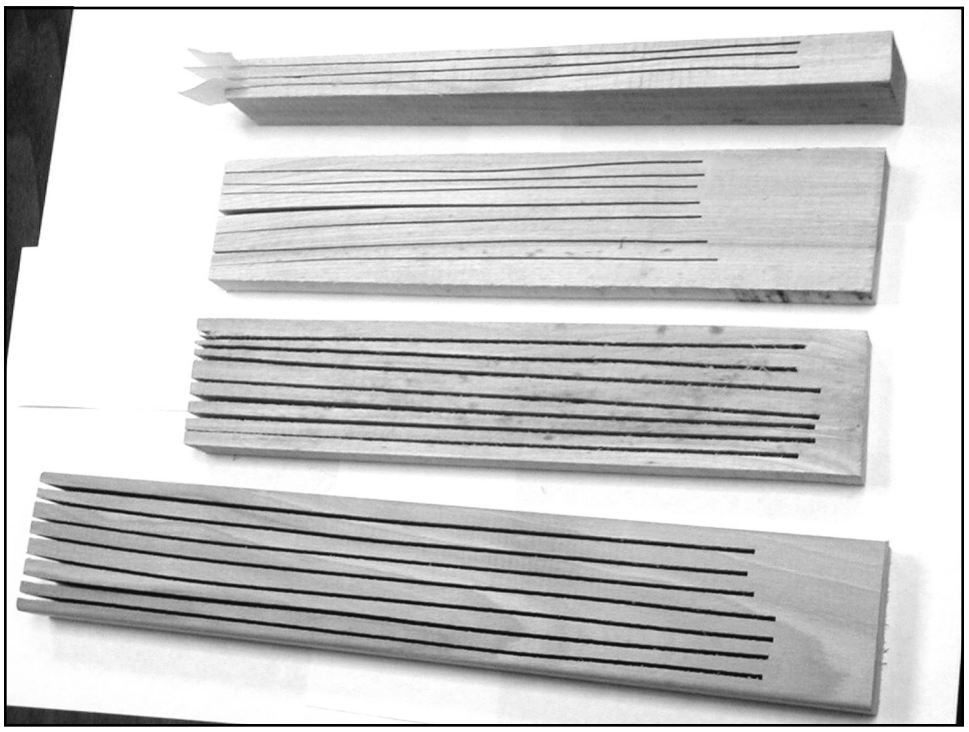

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Summary

Variables:

- Temperature (higher better)
- Relative Humidity (increase and get there quickly)
- Also influenced by thickness, density, prior stress, equalization

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