Wire Holding Tests for Liquid Argon TPC's

Hans Jostlein October 27, 2010

Summary

Liquid Argon Time Projection Chambers (TPC's) have typically many sense wires. The wires must be held at a moderate tension and held in a way that minimizes the possibility of breakage. In addition one would like to use a method that is simple, easy to use, does not require much dead area.

We have tested 1243 wires using solder only to hold them.

The test included cold-shocking the boards repeatedly by dunking them abruptly into liquid nitrogen. Cold shocking did not lead to reduced wire tension of wire holding failure.

We find that solder allows the wires to retract (by creep) over a period of a few weeks. When the shear stress on the wire surface is reduced to 170 psi, the creep stops and the wire tension holds steady for 2 years or more. This maximum solder shear stress means that a 6 mil wire under tension of 1 #f needs solder pads that are at least 7 mm long; the same wire under a 2 #f tension needs solder pads that are at least 14 mm long.

Out of the 1243 wires we found only one that pulled out and lost all tension. For now we blame it on poor solder adhesion, but more tests will be needed.

We also tested a combination of solder and epoxy. This combination does not exhibit creep or loss of tension. We made four boards with solder plus epoxy.

Two boards were oven-cured for two days ay 60C. These boards developed frequent electric continuity failure within the epoxy blobs.

Following that we made two more boards that were not oven-cured. These boards had no failures.

Conclusions

We find that cu-Be wires of 6 mil diameter can be held with epoxy solder alone indefinitely if the shear stress on the wire surface is below 170 psi, limited by creep.

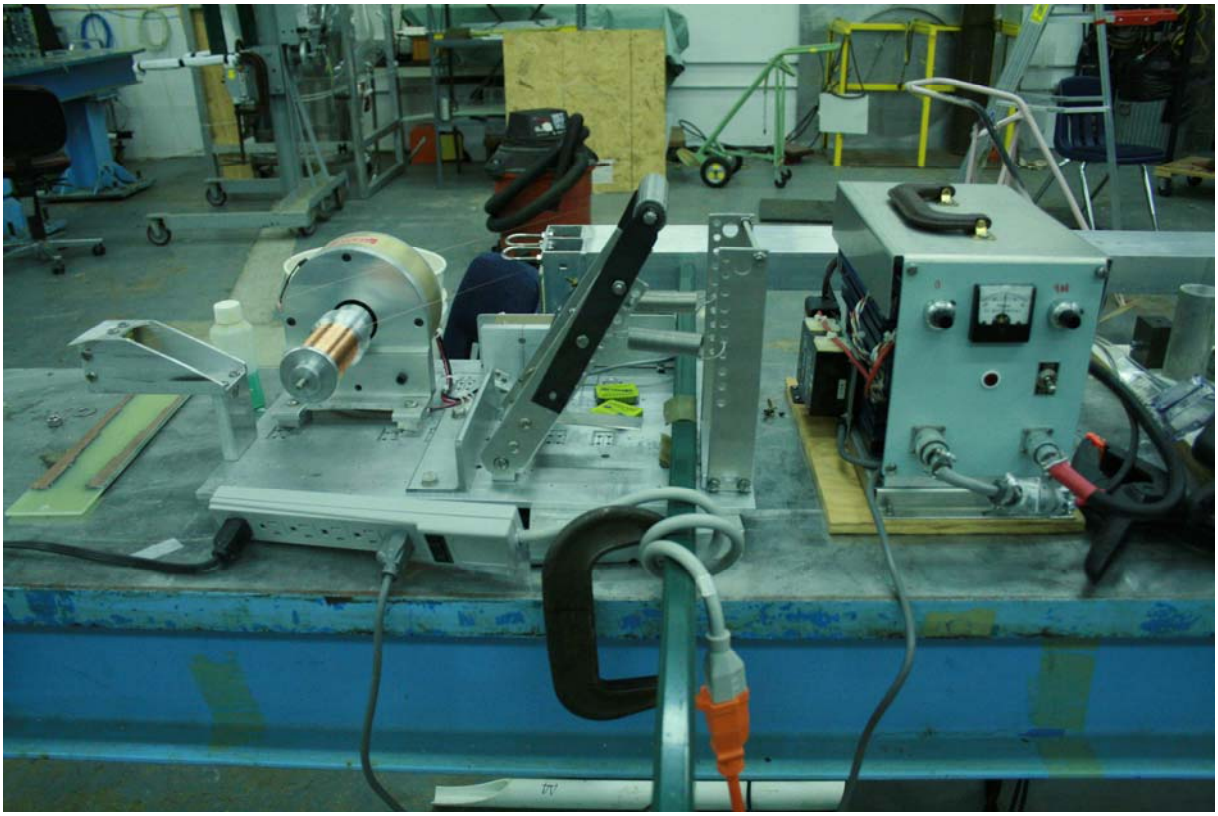
Higher stresses can be supported without significant creep if epoxy blobs are used in addition to the solder. We found, however, a large fraction of electric continuity failures within the epoxy if the boards were oven-cured at 60 C for two days. These failures are not understood.

Study Method

The goal of this study was to terminate large numbers of stretched wires and to measure their tension after cold shocking them and after long observation times.

To that end we produced 20 G10 boards of about 10 cm width and 25 cm length. The boards had raised strips of copper-clad G10 on both faces along both long edges. On of the two strips on each face was continuous, while the other was segmented into electrically separated pads to allow separate measurement of each wire's resonance frequency:

The boards were rotated on a crude manual device about their long axis, while Be-Cu wire of 6 mil diameter was dispensed from a tensioning machine:



and spiral-wound around each board. After soldering the wire to both copper-clad strips on each face, the wire was either cut along the board's edges(solder-only boards) or first epoxy potted and cut later when the epoxy had set.

The resonant frequency was measured by sending a sinusoidal current of adjustable frequency down one wire at a time. The voltage across the wire was displayed on an oscilloscope. The voltage shows an increase (sometimes small and time consuming to detect) when the wire is at resonance. The wire oscillation amplitude is too small to be seen. Repeatability studies show that the frequency of the resonance (which is quite sharp) can be measured reliably to better than 1 Hz (out of 1000 to 3000 Hz).

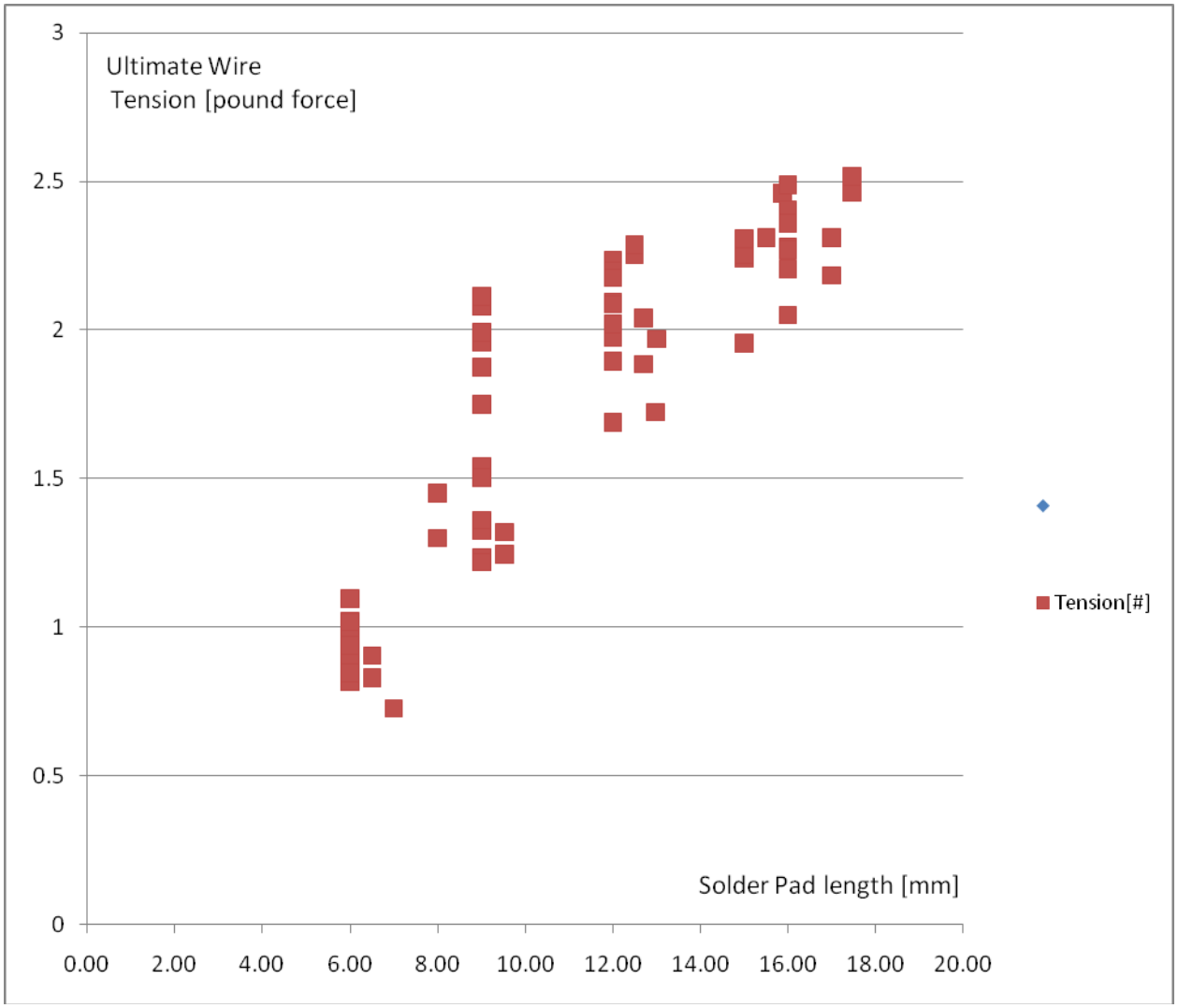
Tests Using Solder Only

In the initial hope of finding no problems, we made 8 boards using ¼" long solder pads, with a total of 929 wires, of which 591 have been re-measured to date; the remainder will be done shortly.

In addition , after discovering the solder creep problem, we made boards 12 through 17, with a total of 525 wires , and each board with solder pads of about 6mm, 9mm, 12.5mm, and 16 mm in length.

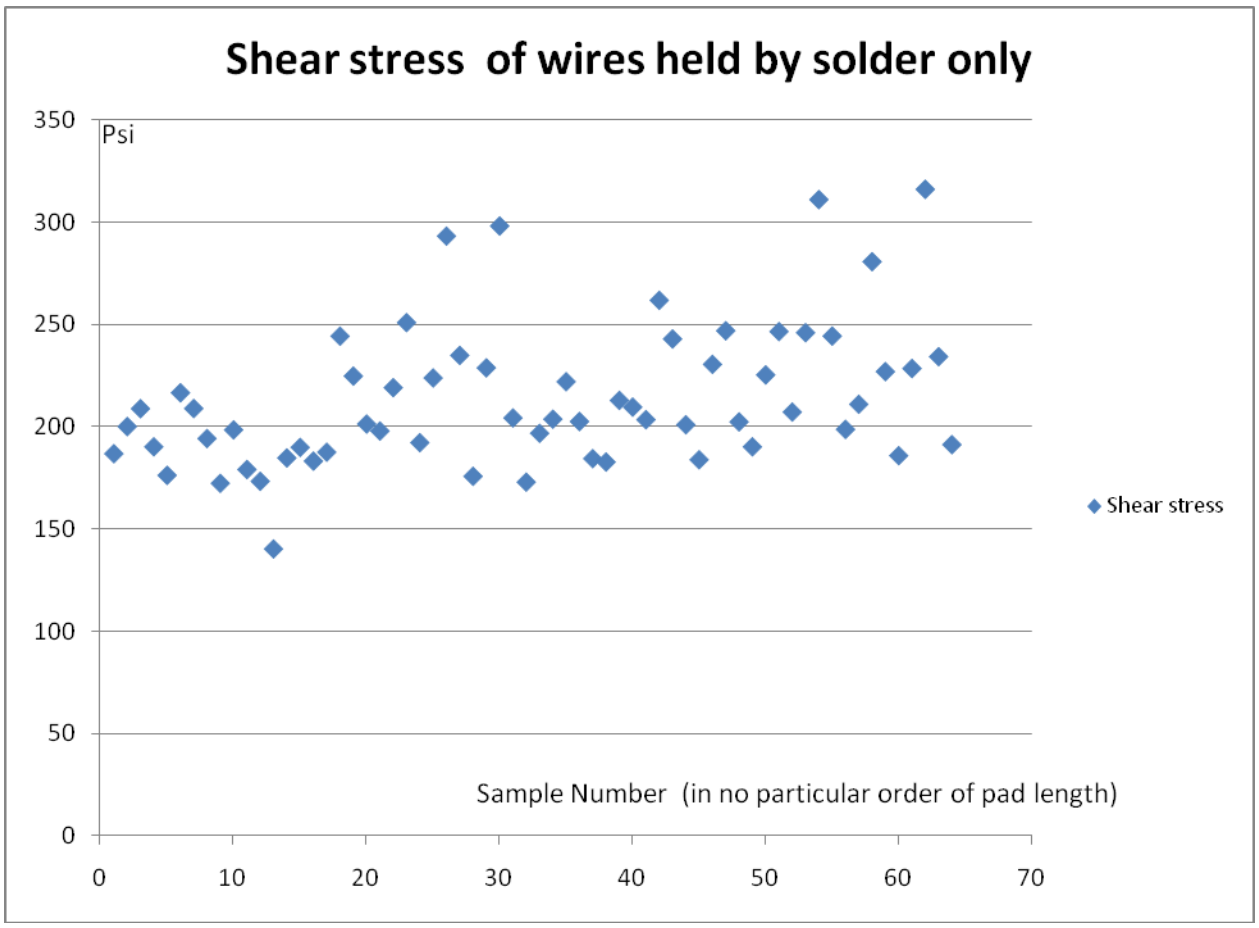
As can be seen from the graphs at the end of the note, wires held by solder only allow the wire to creep and the tension to fall.

The following graph shows the ultimate wire tension (when the creep has stopped) and the creep distance (sum over both ends), as an average over between 10 and 50 wires. The standard deviation is the variation between wires in the group:



We see a clear increase in ultimate tension with wire length.

When we calculate the ultimate shear stress we find it to be independent of the pad length, about 170 psi:



We find that solder allows the wires to retract (by creep) over a period of a few weeks. When the shear stress on the wire surface is reduced to 170 psi, the creep stops and the wire tension holds steady for 2 years or more. This maximum solder shear stress means that a 6 mil wire under tension of 1 #f needs solder pads that are at least 7 mm long; the same wire under a 2 #f tension needs solder pads that are at least 14 mm long.

Out of the 1243 wires we found only one that pulled out and lost all tension. For now we blame it on poor solder adhesion, but more tests will be needed.

Use of Silver Bearing Solder

We attempted to use a solder bearing 2% Silver to combat creep. This was unsuccessful. Please refer to the paper in LArTPC DocDB # 607 for a report by my summer teacher, Juan Solano, on early results on solder holding and on Be-Cu wire damage by high heat.

Tests with solder plus epoxy; post-cured boards

The first two combination boards, # 20 and # 21, had a total of 240 wires.

Here is the information on dimensions and epoxy types :

Solder and Epoxy Boards

Epoxy Types Used:
3M (E Cummins) 2216 Translucent
3M (E Cummins) 2216 Grey
Stycast 2850 FT with Catalyst 9
Epolite FH-5313 with Shell EPI-Cure 3234
Conap CONAP INC. EASYPOXY K-20, CLEAR

Board 20A

Wires 1 to 33	2216 Scotchweld grey
Wires 34 to 60	Scotchweld 2216 translucent

4 mm solder plus 15 mm epoxy

Board 20 B

Wires 1 to 30	2216 Scotchweld grey
	2216 Scotchweld translucent

4 mm solder plus 14 mm epoxy

Board 21A **Oven Postcured**

Wires 1 to 50 Scotchweld 2216 grey
Wires 51 to 60 Conap

Board 21 B **Oven Postcured**

Wires 1 to 31 Conap
Wires 32 to 60 Scotchweld 2216 grey

In an effort to reach a cured-epoxy condition that would be representative of an aged board, the boards were post cured in an oven for 2 days at 60C, while the wires were still under tension.

Disappointingly, on these first two boards, a large fraction of the wires (42 out of 240) failed, in three different modes:

Two of the wires pulled out of the solder / epoxy.

40 of the wires developed an electrical discontinuity within the epoxy blob that was holding them. Note that these wires did not lose tension; they just lost electrical continuity inside the epoxy blob.

The wires broke (i.e. lost electrical continuity) somewhere in the middle of the epoxy pad.

The break distance is tiny and cannot be seen even through the translucent epoxy.

We investigated the distance by measuring the electric breakdown voltage across the gap.

Breakdown Voltage across Wire Gaps inside the Epoxy

Board 20 B	**Wire #**	**Volts**		
	3		450	
	4		550	
	7		950	
	8	<30		Low
	9		770	
	10		420	
	11		520	
	13		580	
	17		500	
	18		620	
	19		560	
	36	600 kOhm		Low
	49	<10		Low
	59		940	

Board 21 A	**Wire #**	**Volts**		
	2		580	
	3		520	
	6		670	
	11		830	
	12		580	
	13		680	
	14		650	
	17		620	
	21		610	
	22		560	
	23	<20		Reconnected after spark
	24		1050	
	25	<20		Reconnected after

			spark
	32	680	
	34	750	
	35	750	
	36	550	
	37	620	
	38	640	
	39	740	
	40	670	
	41	640	
	58	880	

Board 21 B	**Wire #**	**Volts**	
	35	Pulled out; both ends open	
	39	420	
	40	450	
	49	<20	Reconnected after spark
	53	Pulled out	

Average breakdown voltage	647	Volt
STDEV of breakdown voltage	152	Volt

As can be seen from the preceding table, six of the wire gaps broke down at under 20 Volts ; two of them re-connected after the first spark.. The remaining 34 wires showed a consistent breakdown voltage averaging 647 +- 152 volts.

If we use the breakdown electric field strength in air, of 3000 V/ mm, this would correspond to a physical gap of length 0.21 +-0.051 mm.

This can be compared to the wire elongation inside an epoxy blob. For a ½" long blob and 1 #force wire tension, the total elongation within the blob is only 24 microns. We do not understand the cause of these failures.

Clearly this needs more study.

Tests with solder plus epoxy; boards that were not post-cured

After seeing the wire holding failures on the post-cured boards, we made two more boards, # 22 and # 23, without post-curing them. Here are the construction details:

Board 22 A **1/4" epoxy**
Wires 1 to 12 Scotchweld 2216 translucent **No Oven Cure**
wires 13 to 24: Stycast 2850 Ft with Catalyst 9
wires 25 to 37: Epolite FH-5313 with Shell Epicure 32
Wires 38 to 47: Scotchweld 2216 grey

Board 22 B **1/2" epoxy** **No Oven Cure**
Wires 1 to 12 Scotchweld 2216 translucent
wires 13 to 24: Stycast 2850 Ft with Catalyst 9
wires 25 to 36: Epolite FH-5313 with Shell Epicure 32
Wires 37 to 49: Scotchweld 2216 grey

Board 23 A **1/4" epoxy**
Wires 1 to 12 Scotchweld 2216 translucent **No Oven Cure**
wires 13 to 24: Stycast 2850 Ft with Catalyst 9
wires 25 to 36: Epolite FH-5313 with Shell Epicure 32
Wires 37 to 48: Scotchweld 2216 grey

Board 22 B **1/4" epoxy** **No Oven Cure**
Wires 1 to 12 Scotchweld 2216 translucent
wires 13 to 24: Stycast 2850 Ft with Catalyst 9
wires 25 to 37: Epolite FH-5313 with Shell Epicure 32
Wires 38 to 48: Scotchweld 2216 grey

All of the 192 wires on the two boards were held successfully, with no failures.

Furthermore there was essentially no creep and no lessening of wire tension during the 14 months of the test. Almost all the (very small) relaxation occurred in the first two months, as can be seen from the graphs. Here is a wire tension- and creep summary. The +- numbers refer to variations from wire to wire. Most of these are due to variations in the initial tension, blamed mostly on problems with the wire tensioner that was used:

Board 22 A

Initial wire tension [#]	***Jun-09***	0.85	+-	0.06	#
Final wire tension [#]	***Aug-10***	0.82	+-	0.06	#
Wire creep (sum of both ends)		-3.31	+-	2.69	Micron

Board 22 B

Initial wire tension [#]	***Jun-09***	0.96		0.06	#

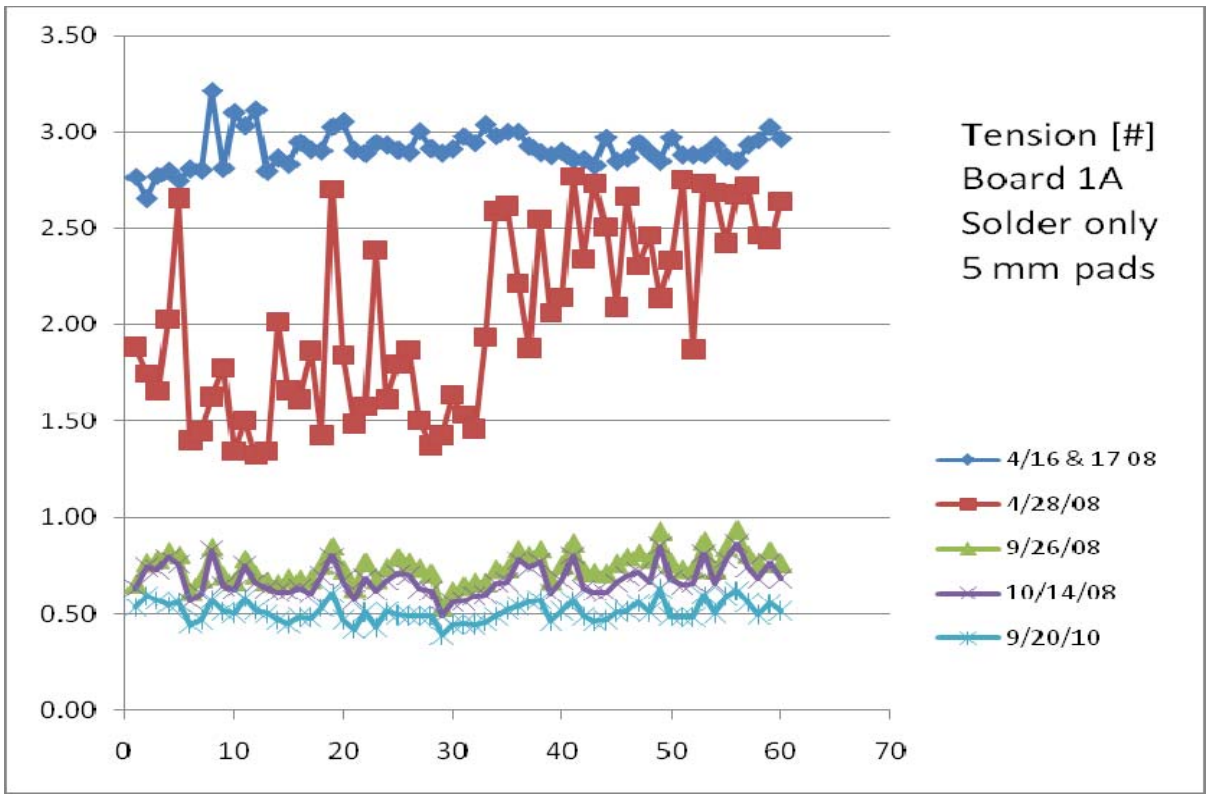
			+-		
Final wire tension [#]	***Aug-10***	0.94	+-	0.06	#
Wire creep (sum of both ends)		-1.72		0.92	Micron

Board 23 A

Initial wire tension [#]	***Jun-09***	0.84	+-	0.09	#
Final wire tension [#]	***Aug-10***	0.81	+-	0.08	#
Wire creep (sum of both ends)		-2.57	+-	2.01	Micron

Board 22 B

Initial wire tension [#]	***Jun-09***	1.04	+-	0.12	#
Final wire tension [#]	***Aug-10***	1.00	+-	0.11	#
Wire creep (sum of both ends)		-4.32	+-	2.07	Micron


Tension [#]
Board 1A
Solder only
5 mm pads
4/16 & 17 08
4/28/08
9/26/08
10/14/08
9/20/10
3.50
3.00
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0.50
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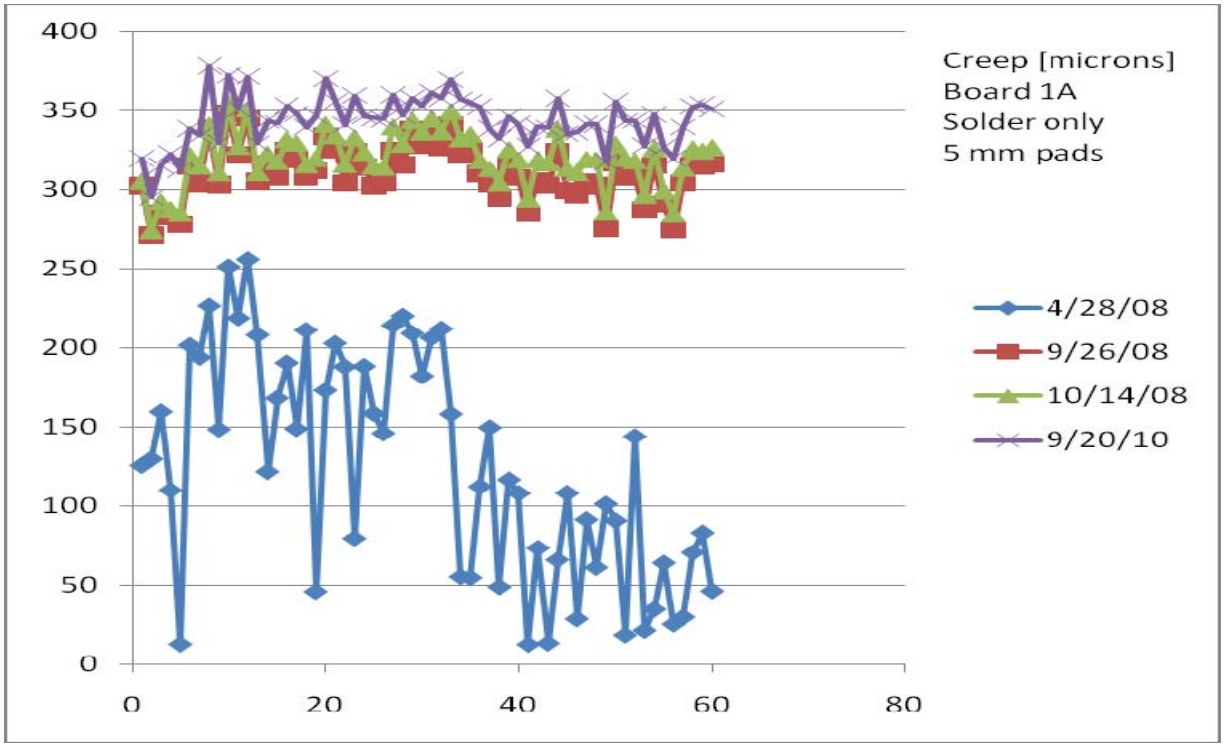
10
20
30
40
50
60
70


Creep [microns]
Board 1A
Solder only
5 mm pads
4/28/08
9/26/08
10/14/08
9/20/10
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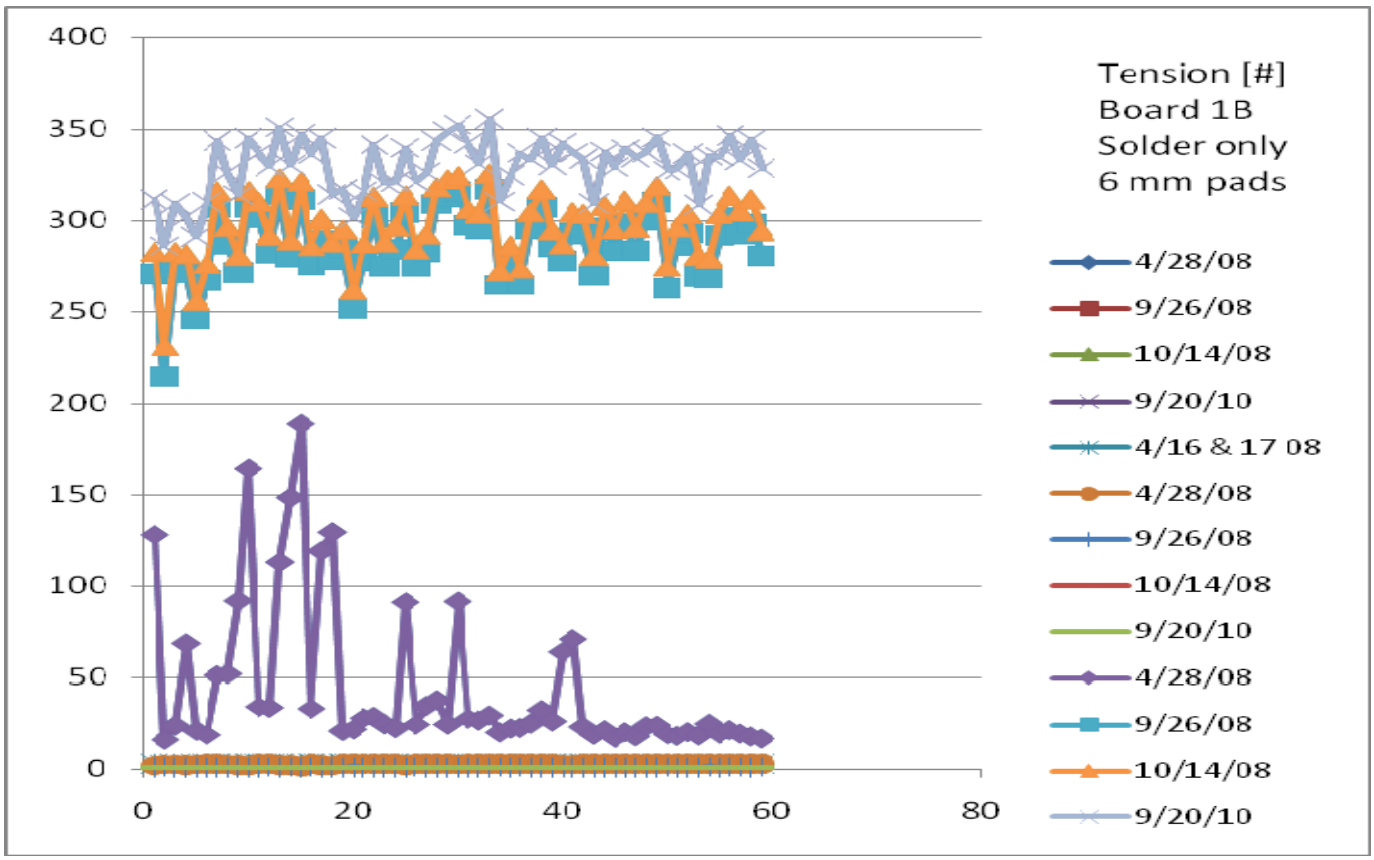
Tension [#]
Board 1B
Solder only
6 mm pads
4/28/08
9/26/08
10/14/08
9/20/10
4/16 & 17 08
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9/26/08
10/14/08
9/20/10
4/28/08
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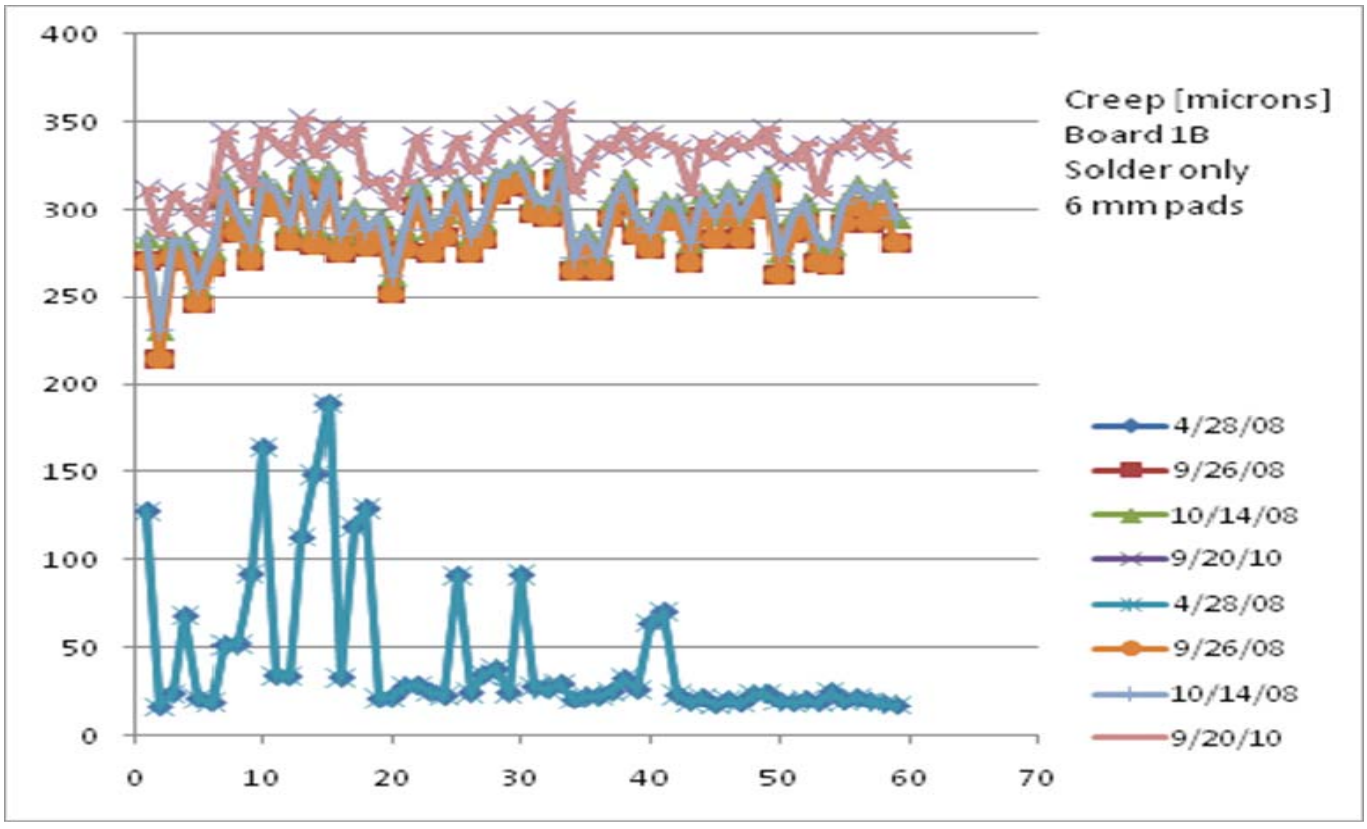
Creep [microns]
Board 1B
Solder only
6 mm pads
4/28/08
9/26/08
10/14/08
9/20/10
4/28/08
9/26/08
10/14/08
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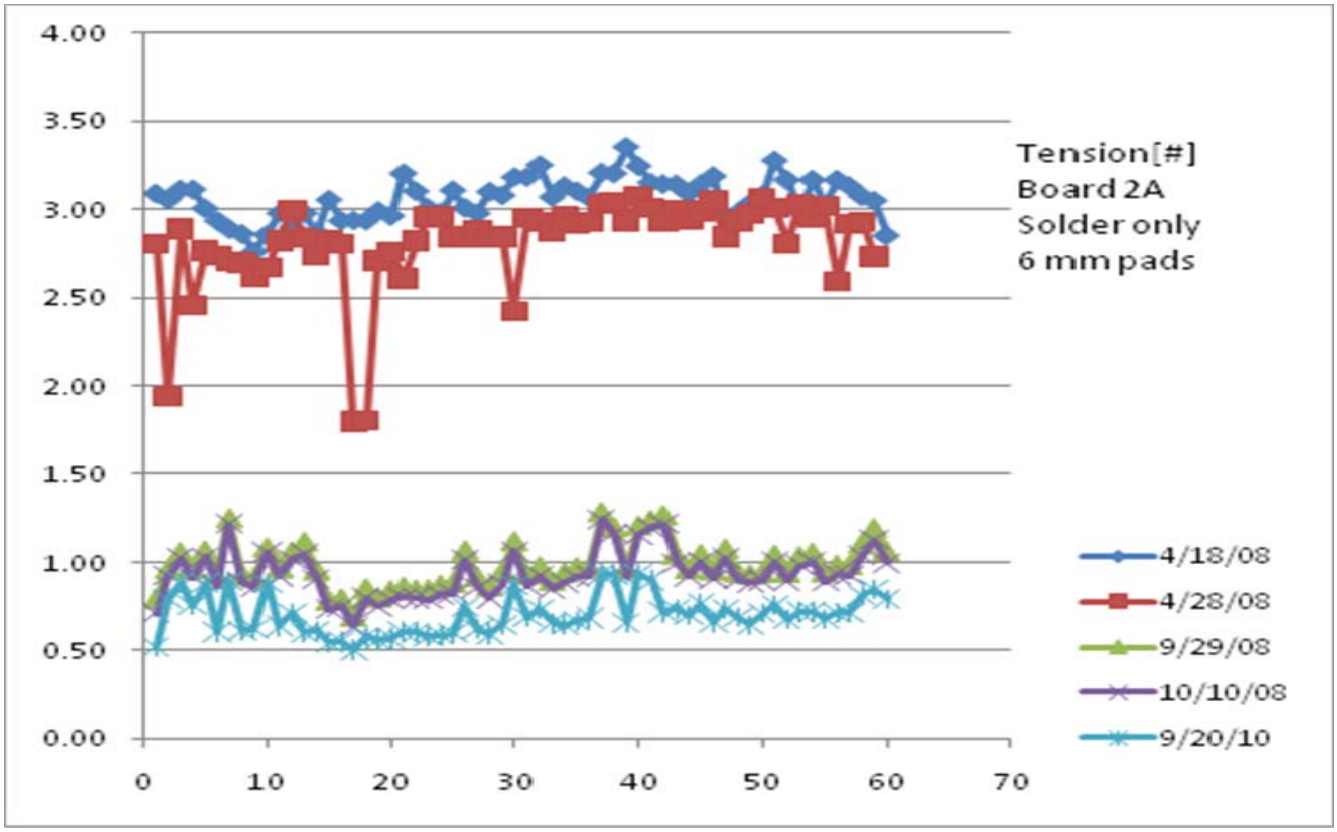
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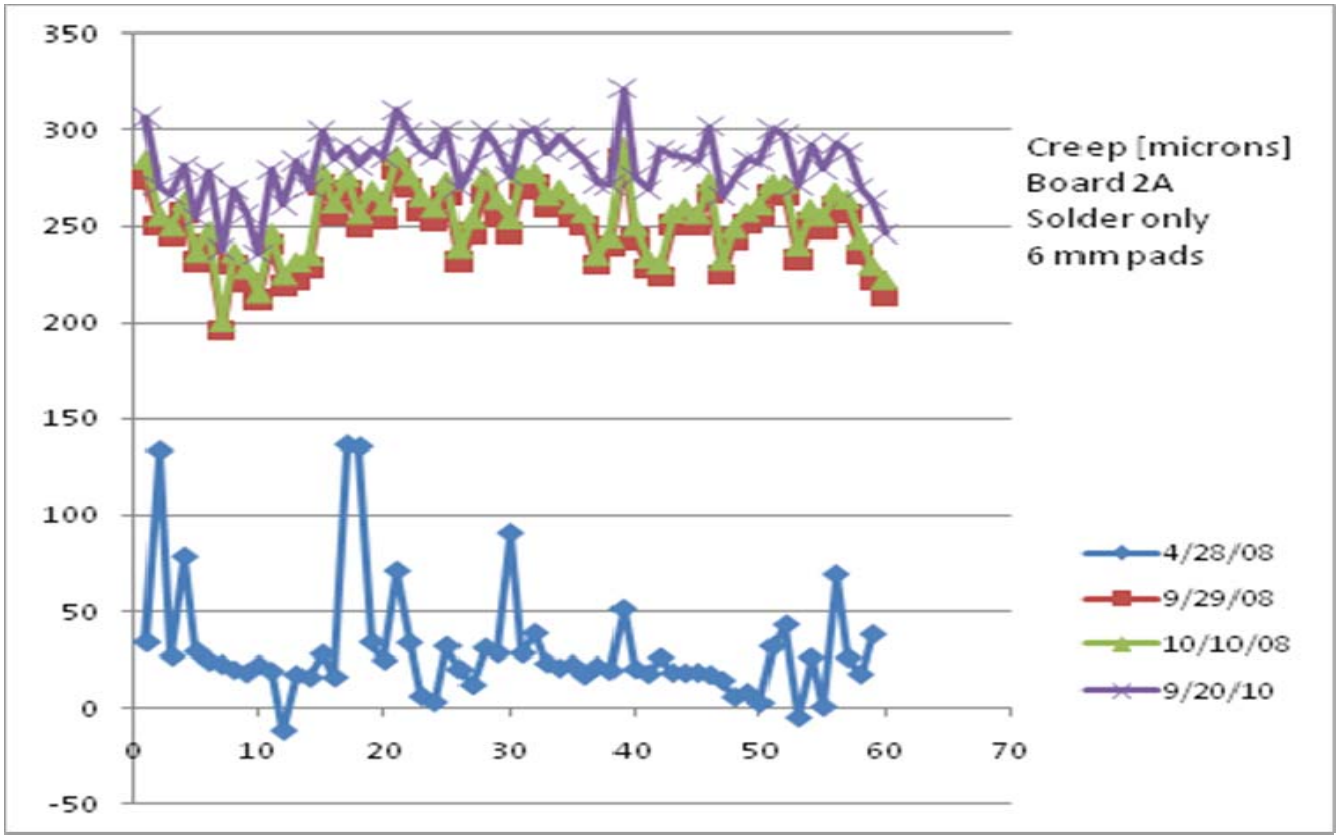
Tension[#]
Board 2A
Solder only
6 mm pads
4/18/08
4/28/08
9/29/08
10/10/08
9/20/10


350
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30
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50
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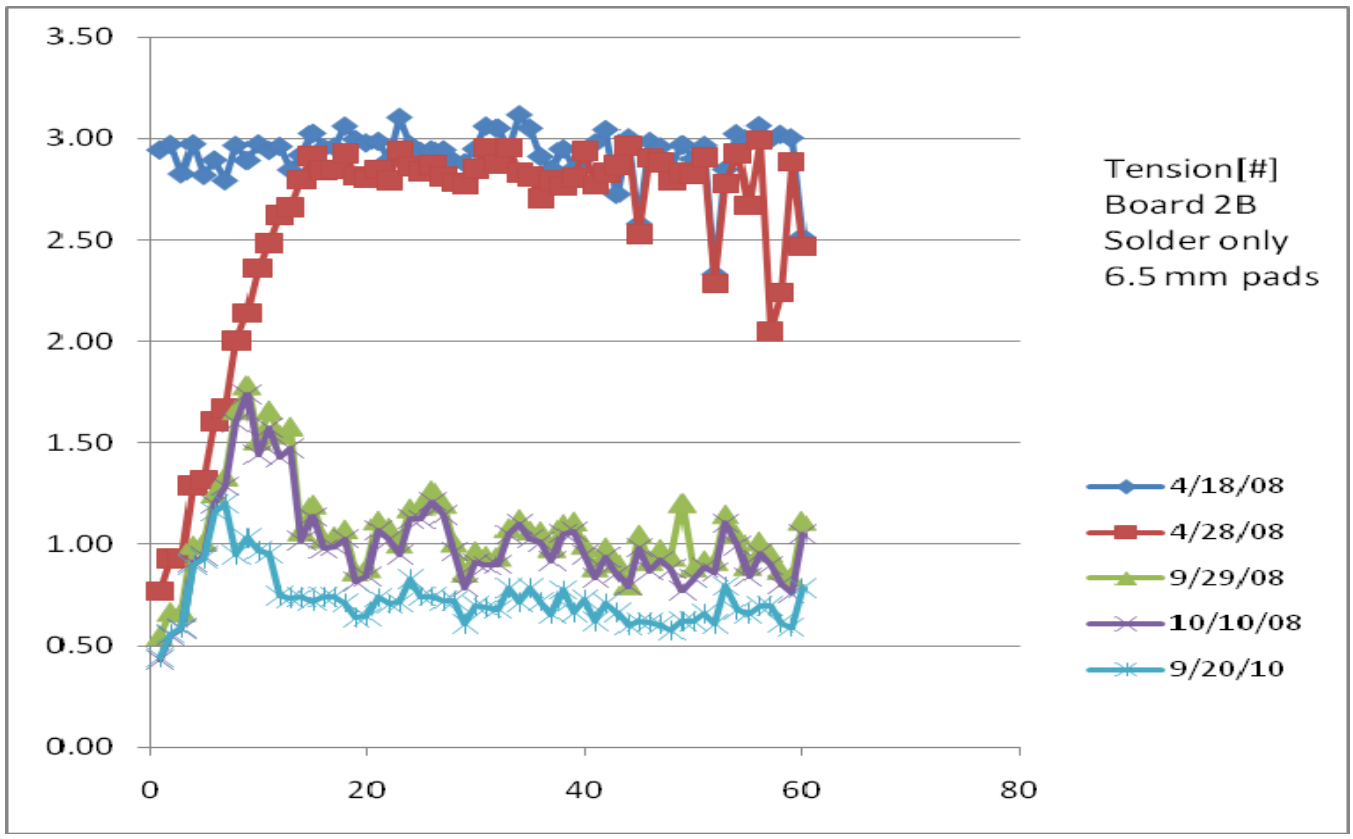
Creep [microns]
Board 2A
Solder only
6 mm pads
4/28/08
9/29/08
10/10/08
9/20/10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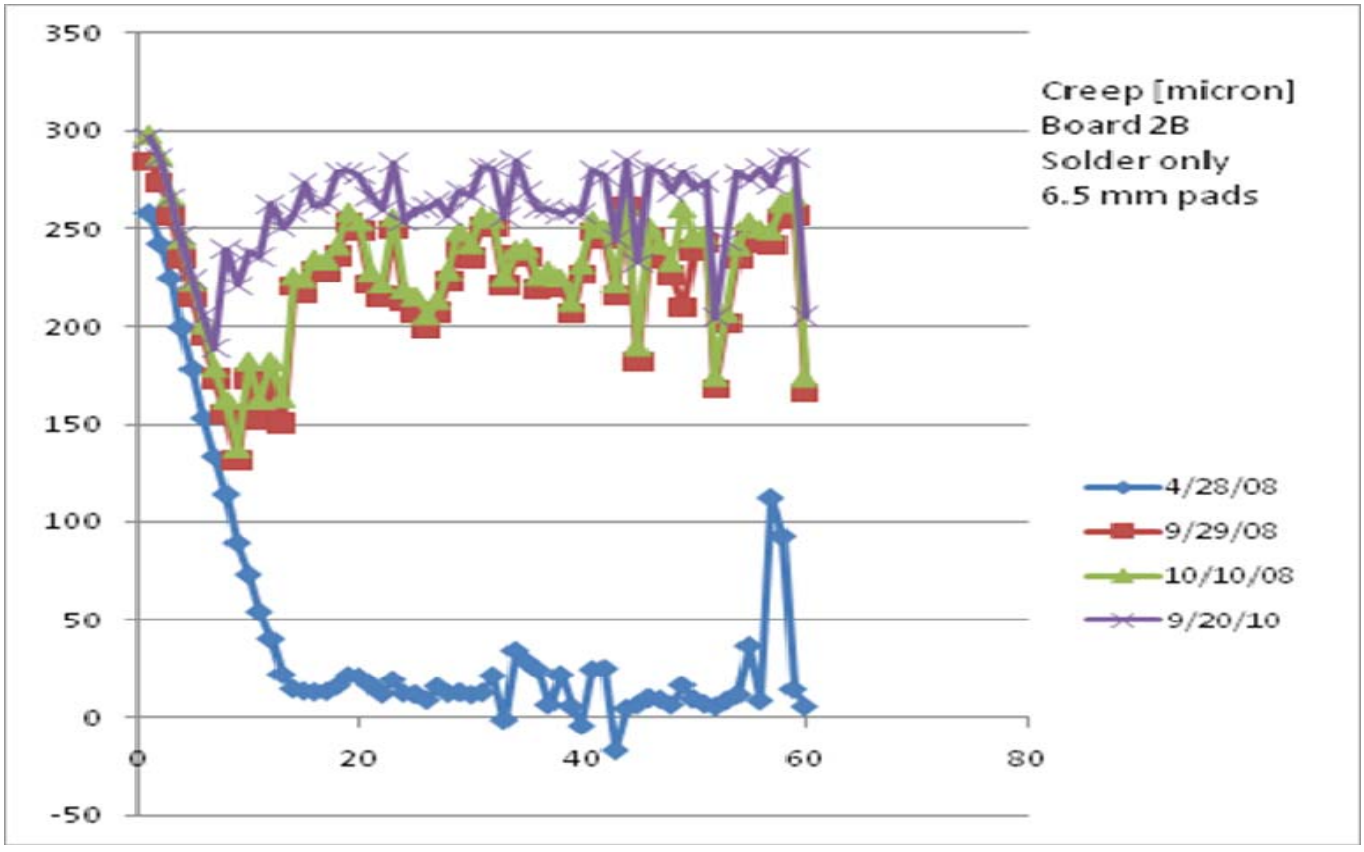
Tension[#]
Board 2B
Solder only
6.5 mm pads
4/18/08
4/28/08
9/29/08
10/10/08
9/20/10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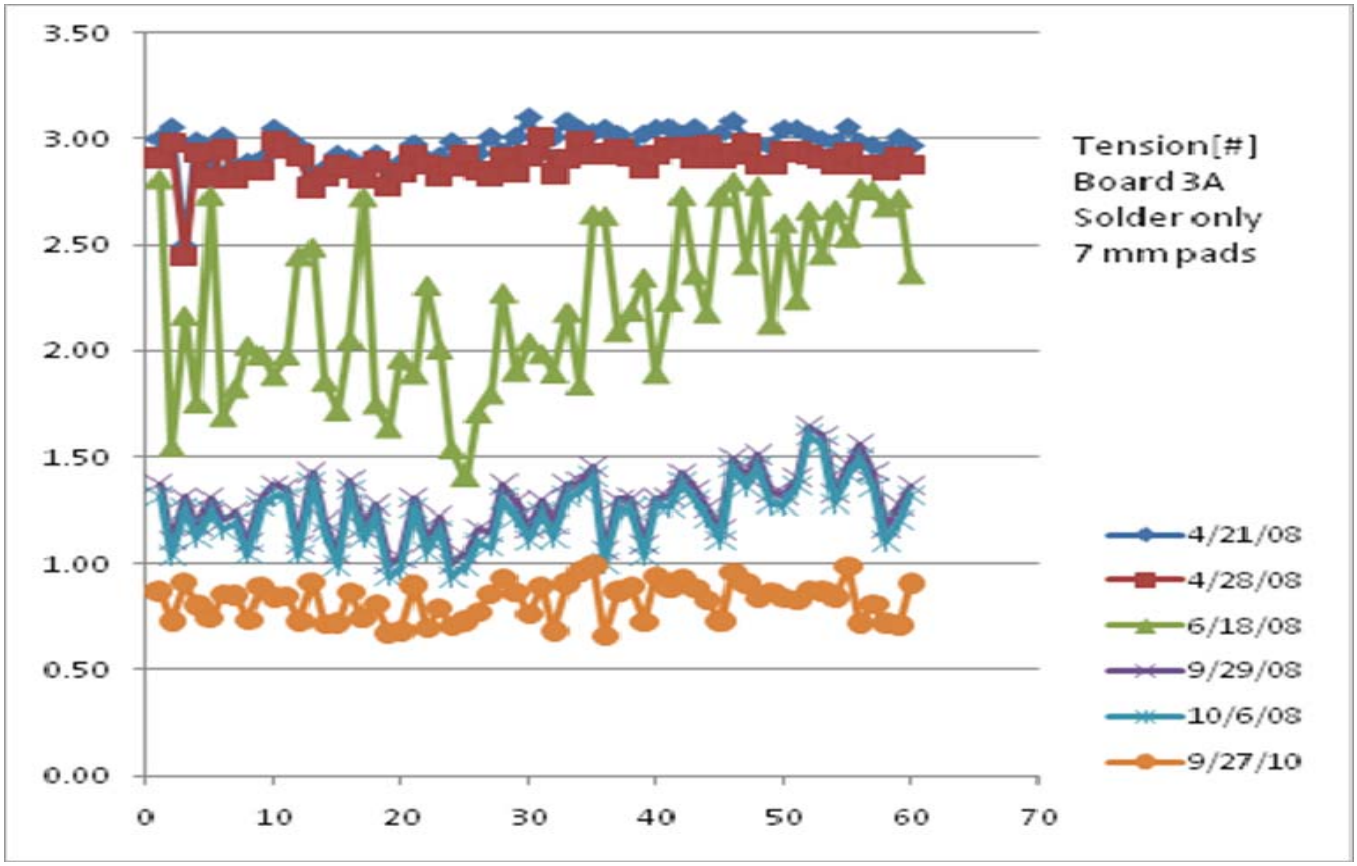
Creep [micron]
Board 2B
Solder only
6.5 mm pads
4/28/08
9/29/08
10/10/08
9/20/10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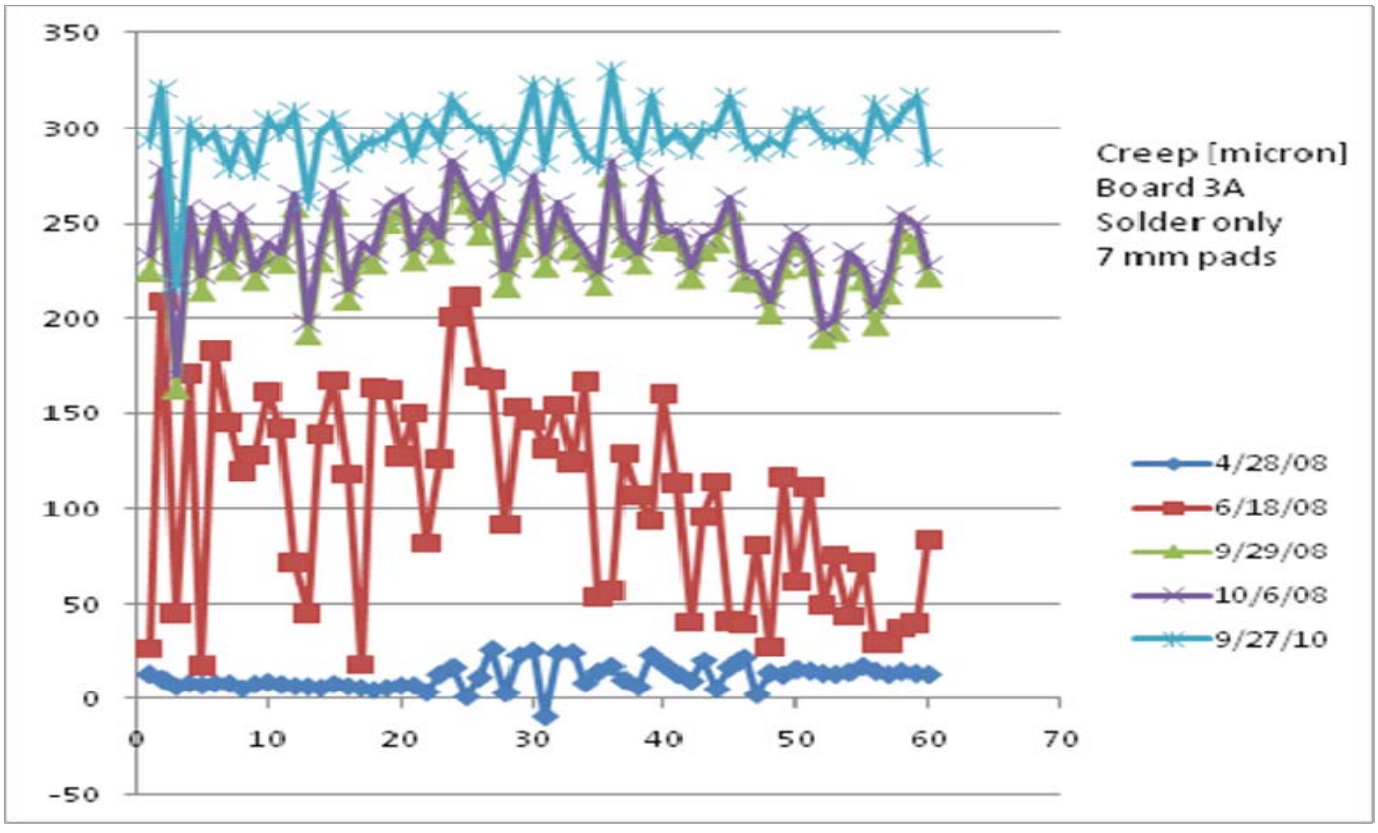
Tension[#]
Board 3A
Solder only
7 mm pads
4/21/08
4/28/08
6/18/08
9/29/08
10/6/08
9/27/10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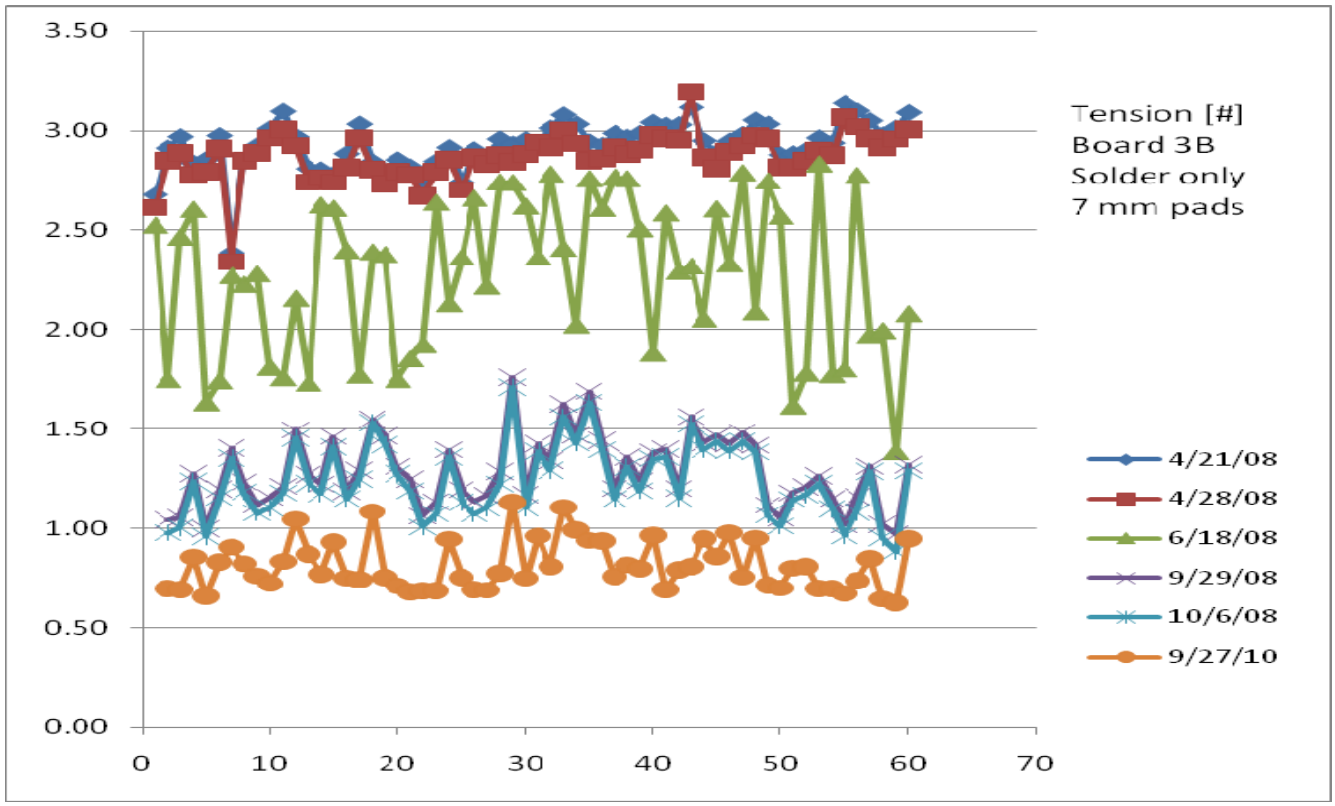
Creep [micron]
Board 3A
Solder only
7 mm pads
4/28/08
6/18/08
9/29/08
10/6/08
9/27/10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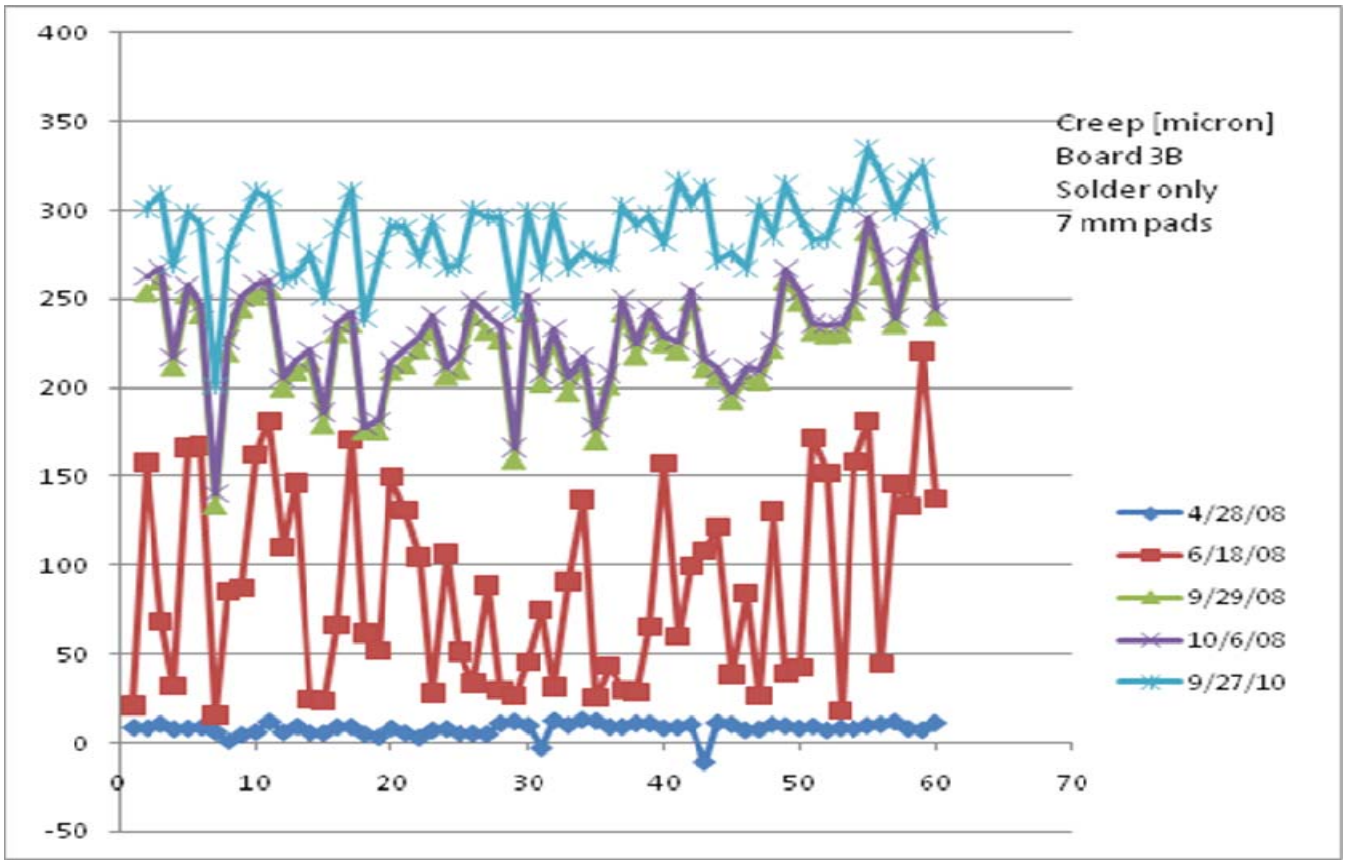
Tension [#]
Board 3B
Solder only
7 mm pads
4/21/08
4/28/08
6/18/08
9/29/08
10/6/08
9/27/10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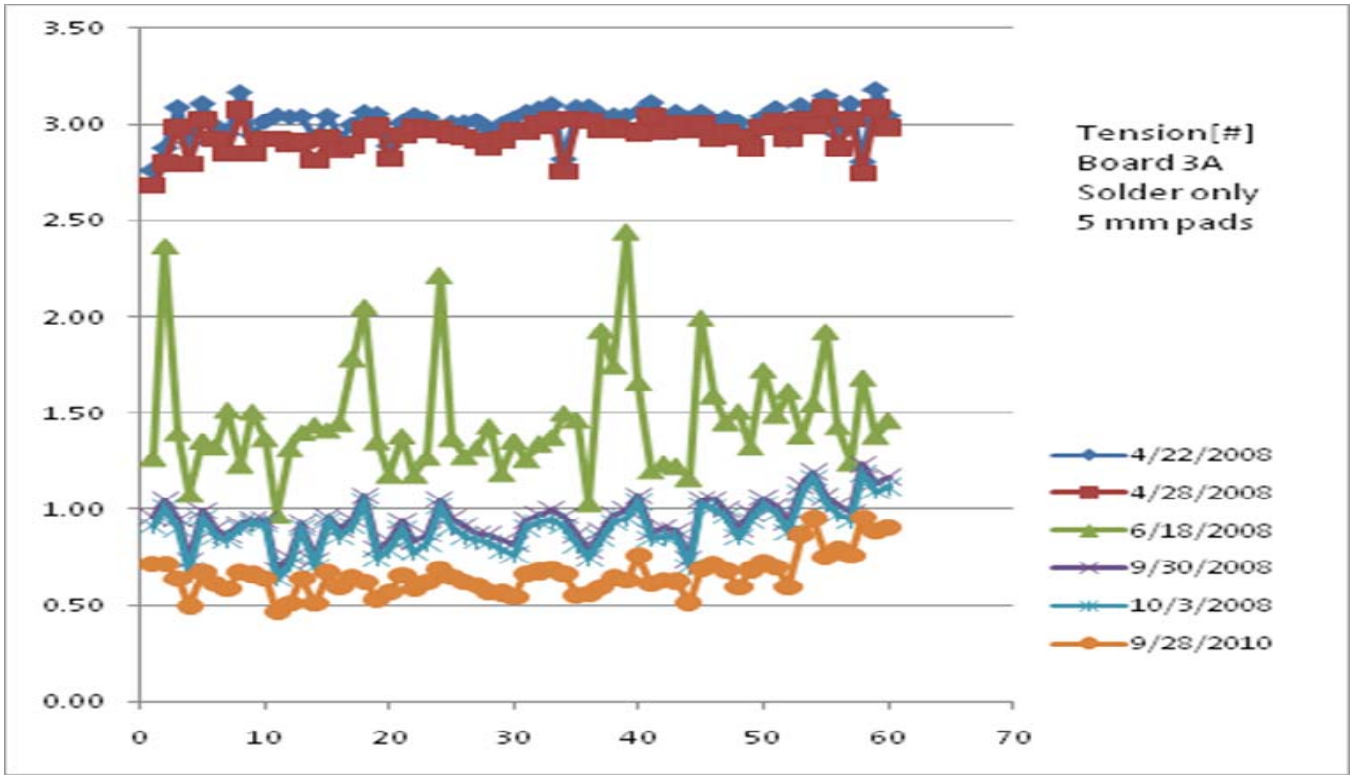
Creep [micron]
Board 3B
Solder only
7 mm pads
4/28/08
6/18/08
9/29/08
10/6/08
9/27/10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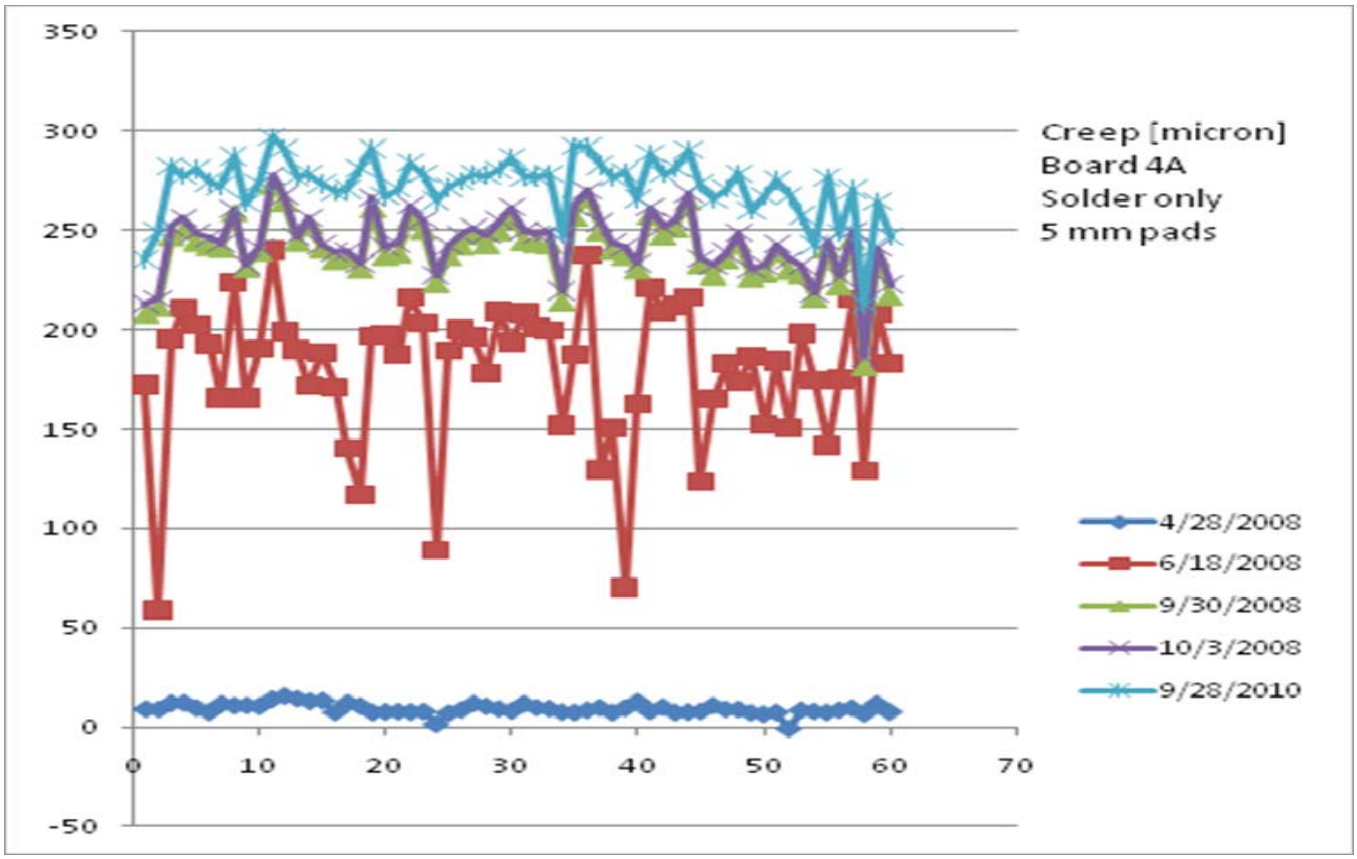
Tension[#]
Board 3A
Solder only
5 mm pads
4/22/2008
4/28/2008
6/18/2008
9/30/2008
10/3/2008
9/28/2010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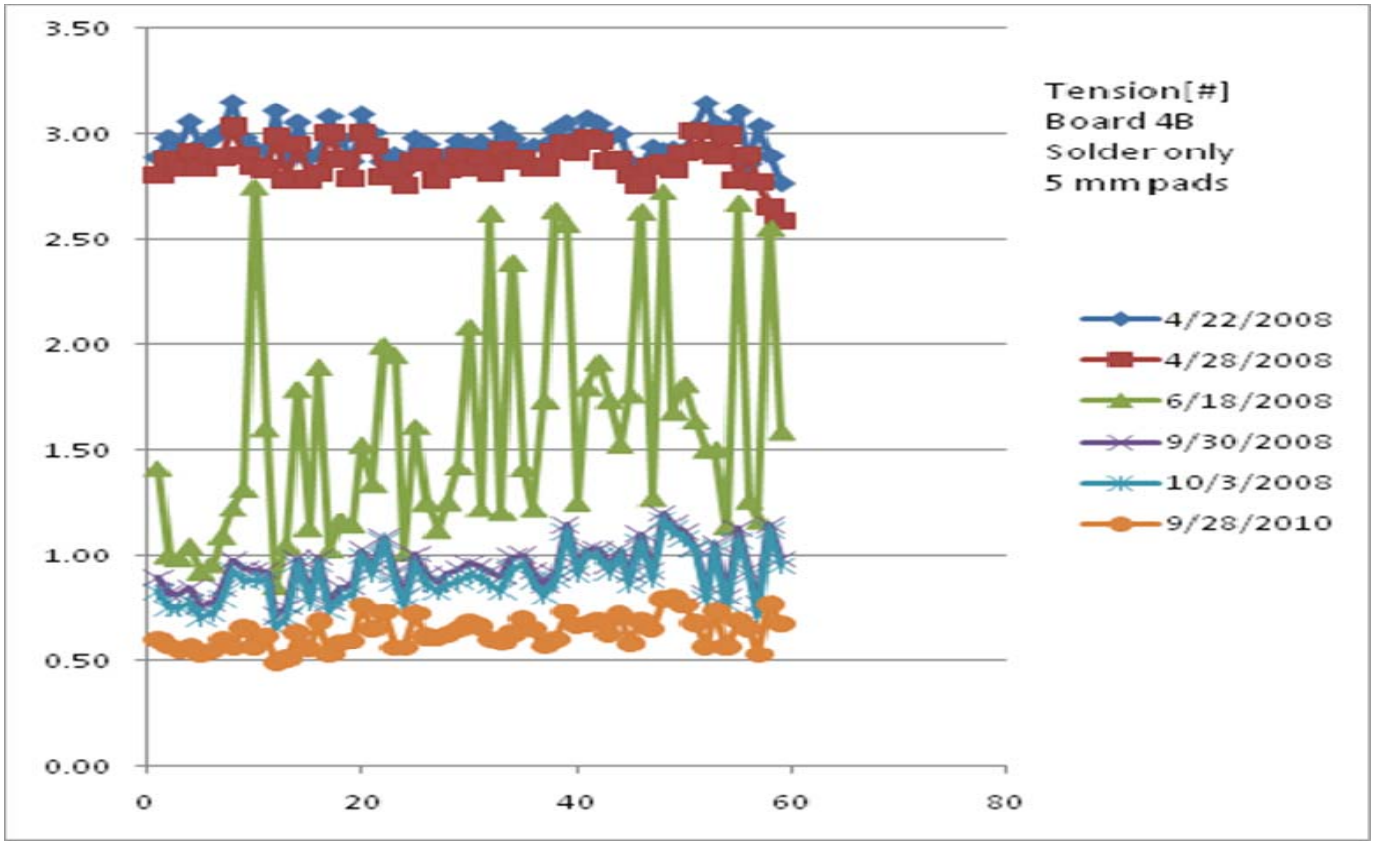
Creep [micron]
Board 4A
Solder only
5 mm pads
4/28/2008
6/18/2008
9/30/2008
10/3/2008
9/28/2010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Solder only
5 mm pads
4/22/2008
4/28/2008
6/18/2008
9/30/2008
10/3/2008
9/28/2010
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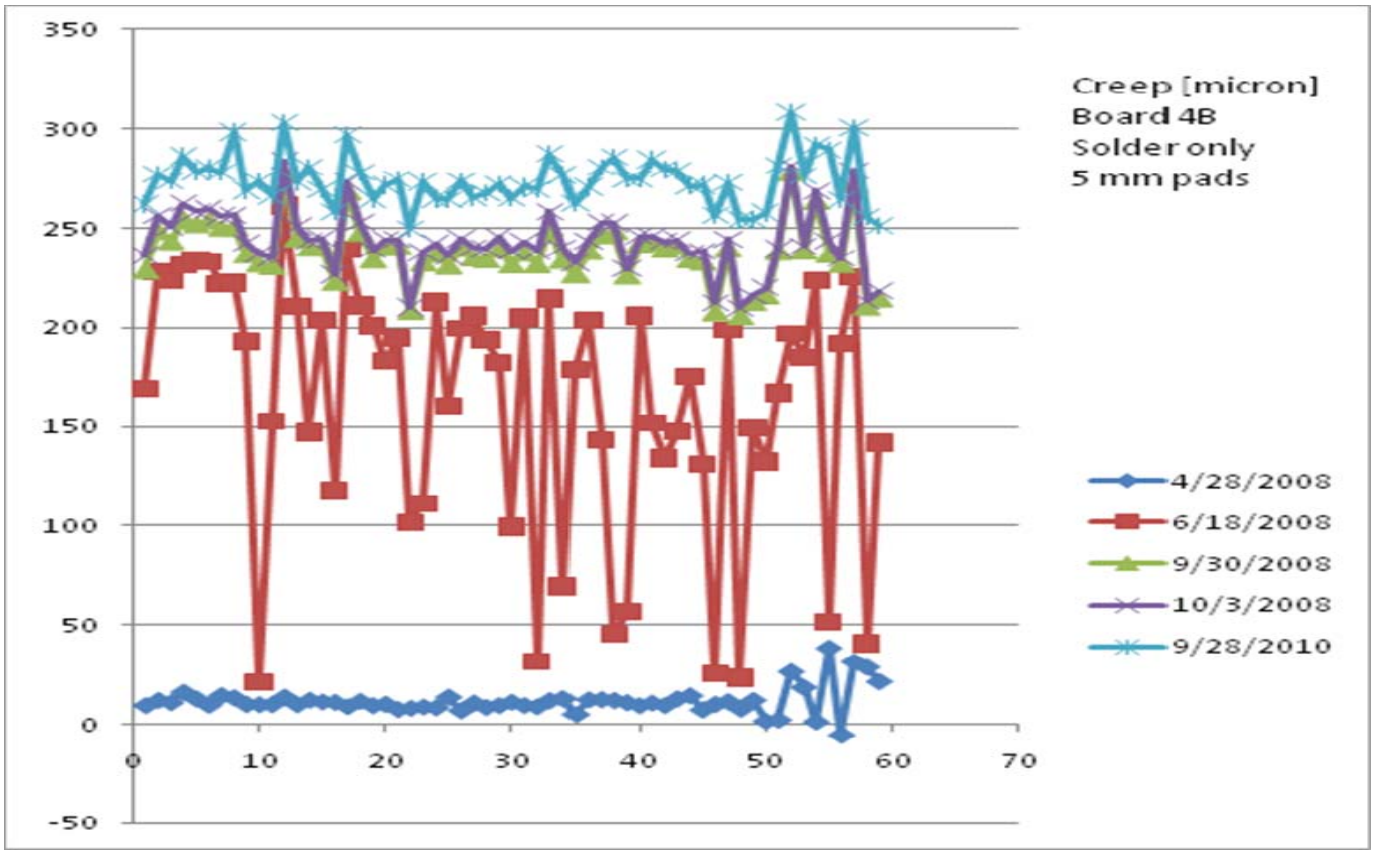
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Board 4B
Solder only
5 mm pads
4/28/2008
6/18/2008
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10/3/2008
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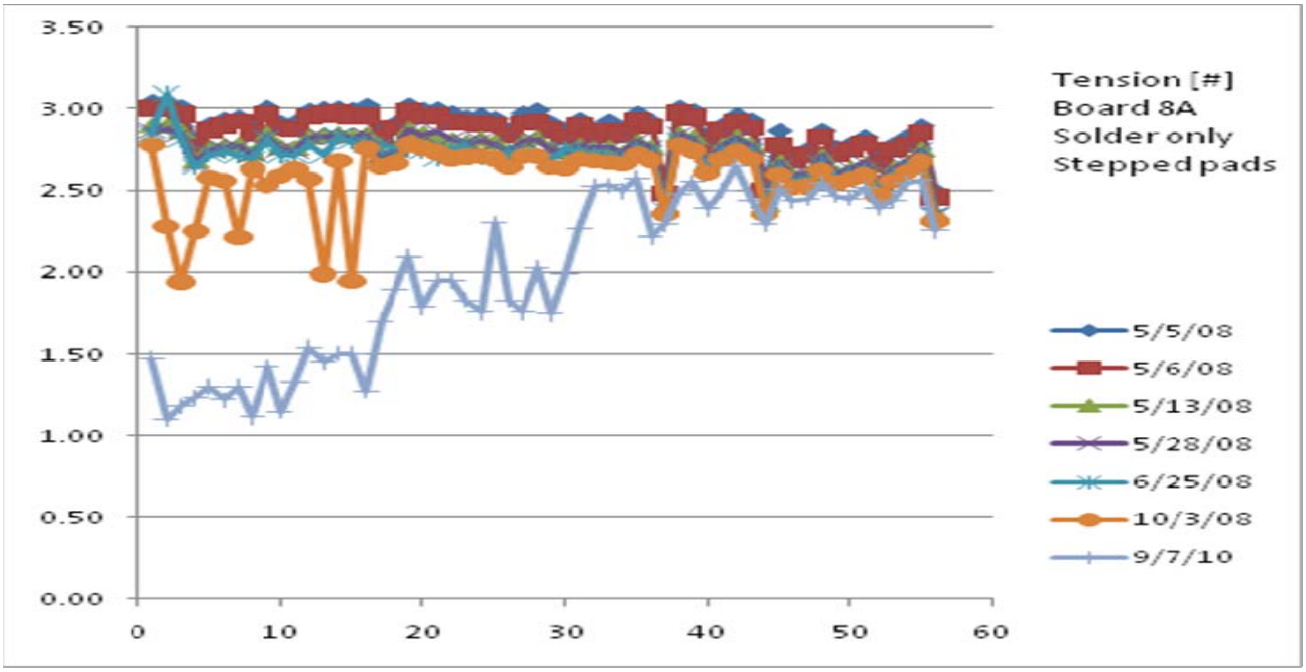
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3.00
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2.00
1.50
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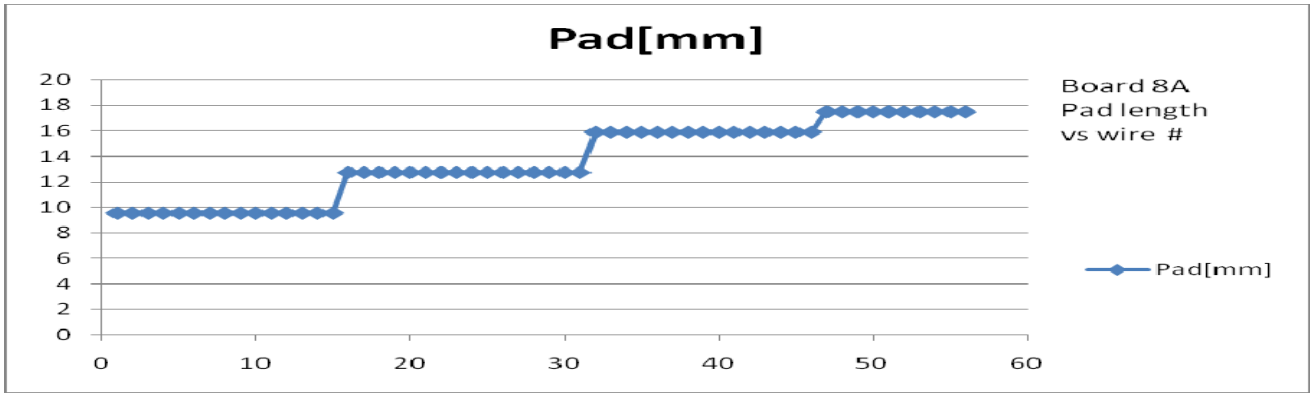
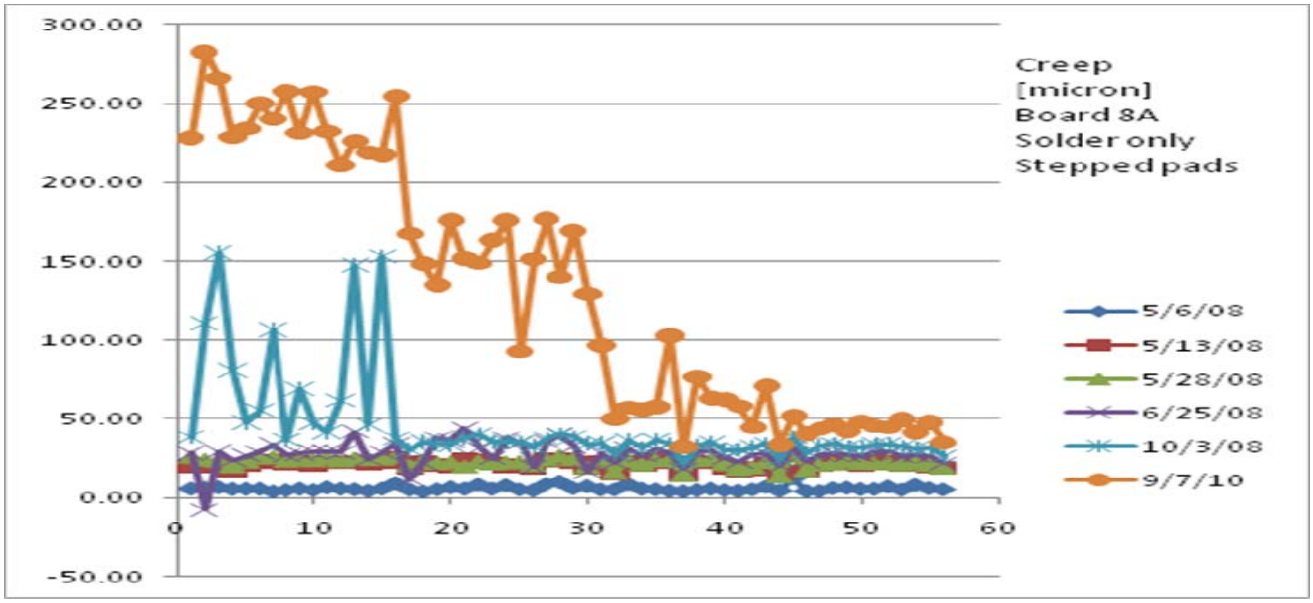
0.50
0.00
0
10
20
30
40
50
60
Tension [#]
Board 8A
Solder only
Stepped pads
5/5/08
5/6/08
5/13/08
5/28/08
6/25/08
10/3/08
9/7/10


Pad[mm]
20
18
16
14
12
10
8
6
4
2
0
0
10
20
30
40
50
60
Board 8A
Pad length
vs wire #
Pad[mm]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-50.00
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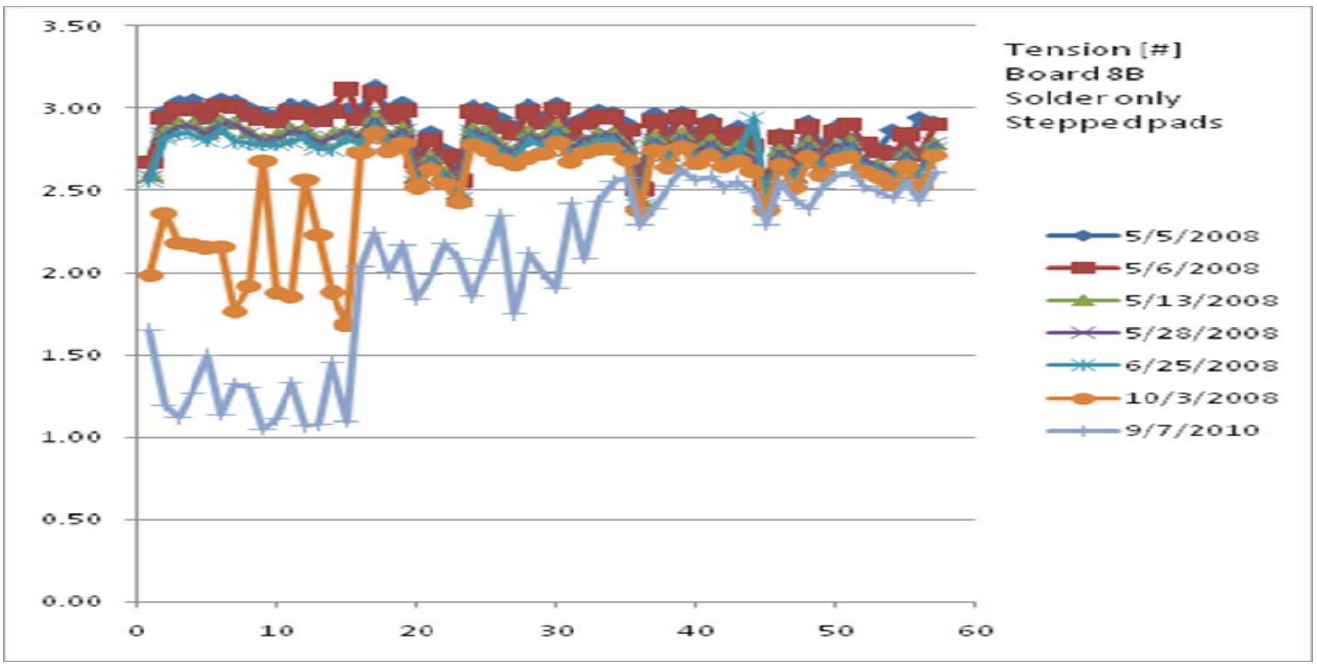
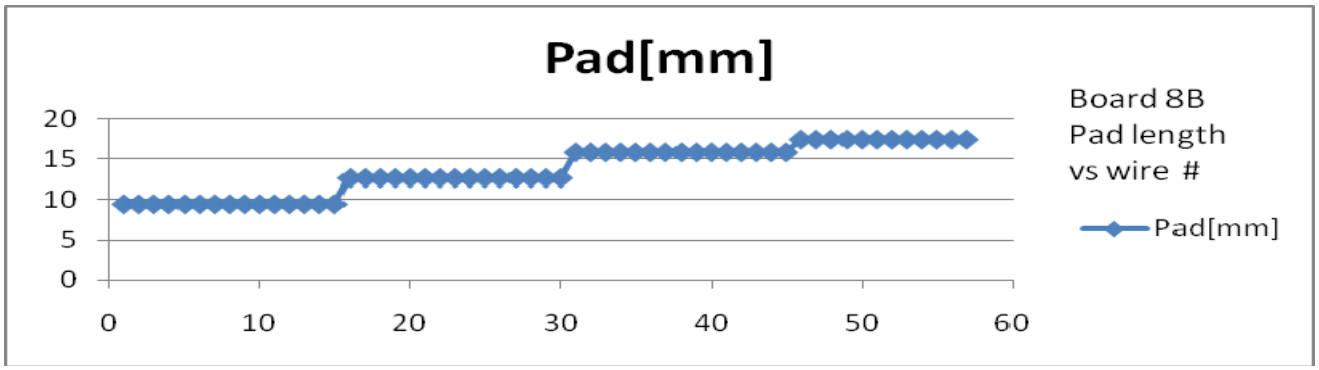
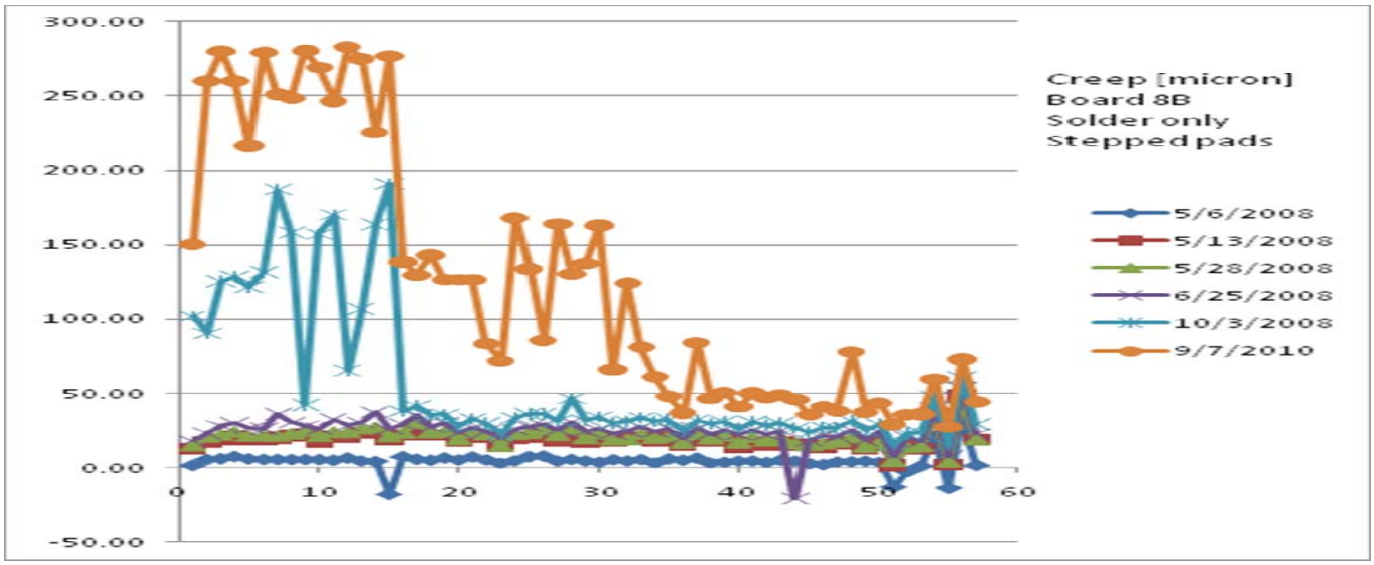
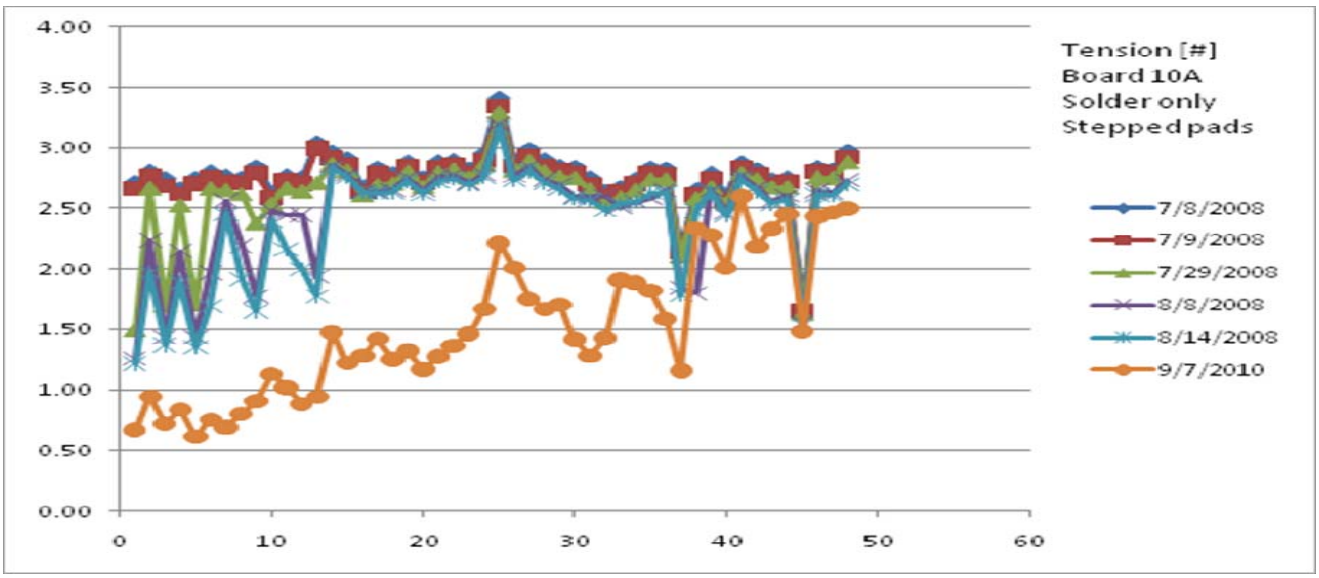
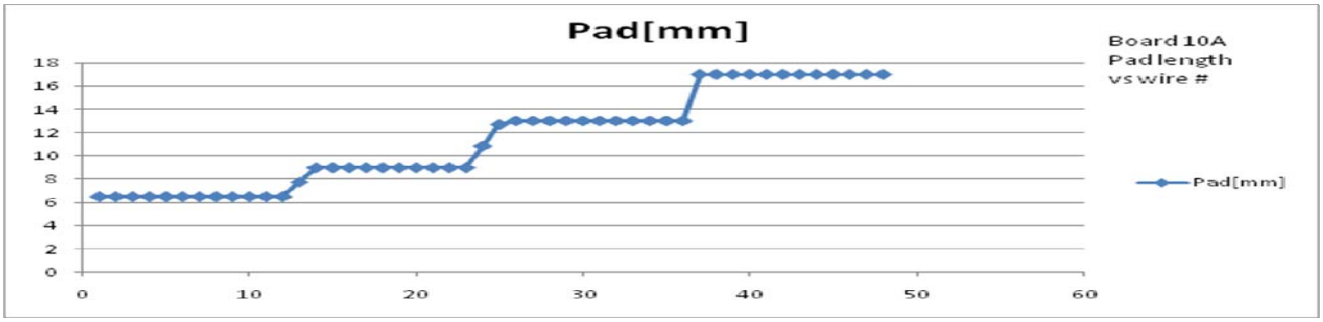
50
60
Creep
[micron]
Board 8A
Solder only
Stepped pads
5/6/08
5/13/08
5/28/08
6/25/08
10/3/08
9/7/10

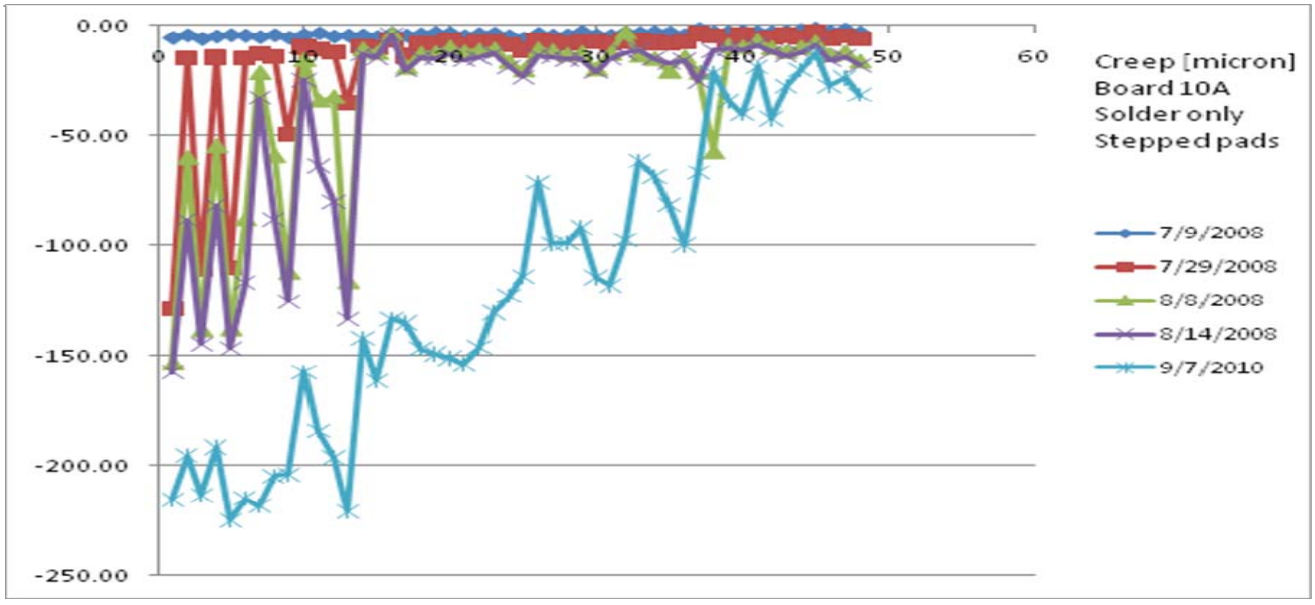

Tension [#]
Board 8B
Solder only
Stepped pads
5/5/2008
5/6/2008
5/13/2008
5/28/2008
6/25/2008
10/3/2008
9/7/2010
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
10
20
30
40
50
60

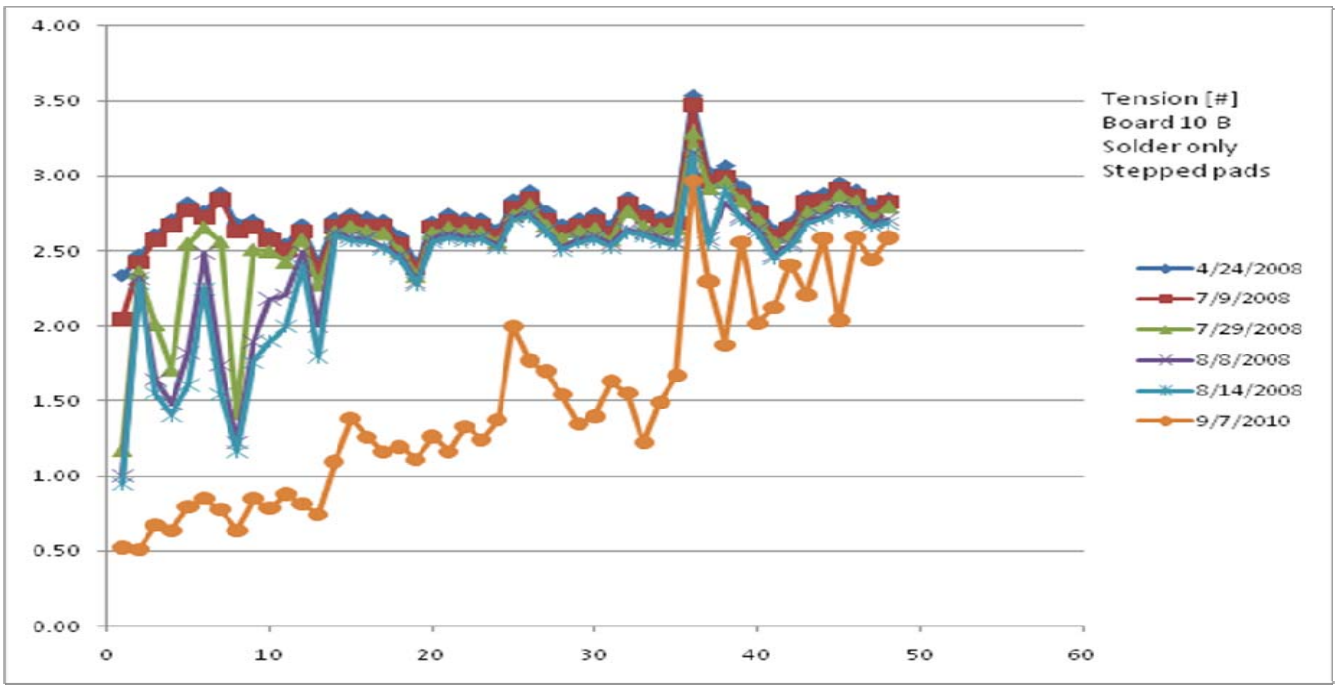

Pad[mm]
Board 8B
Pad length
vs wire #
Pad[mm]
20
15
10
5
0
0
10
20
30
40
50
60

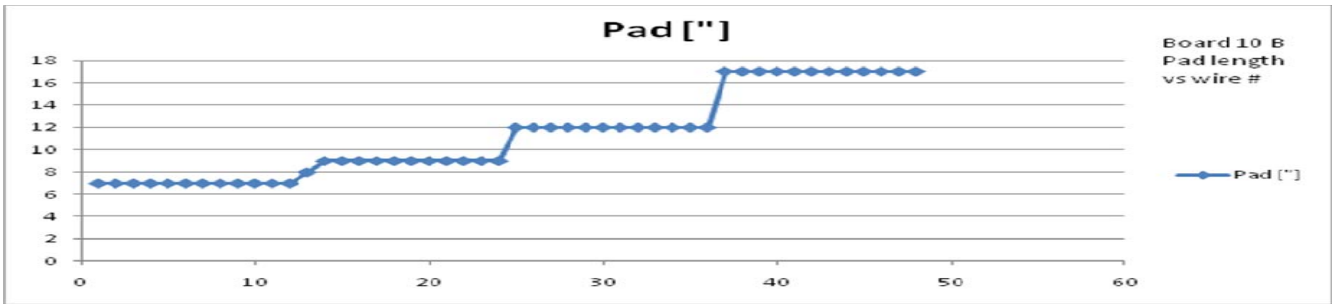

Creep [micron]
Board 8B
Solder only
Stepped pads
5/6/2008
5/13/2008
5/28/2008
6/25/2008
10/3/2008
9/7/2010
300.00
250.00
200.00
150.00
100.00
50.00
0.00
-50.00
0
10
20
30
40
50
60

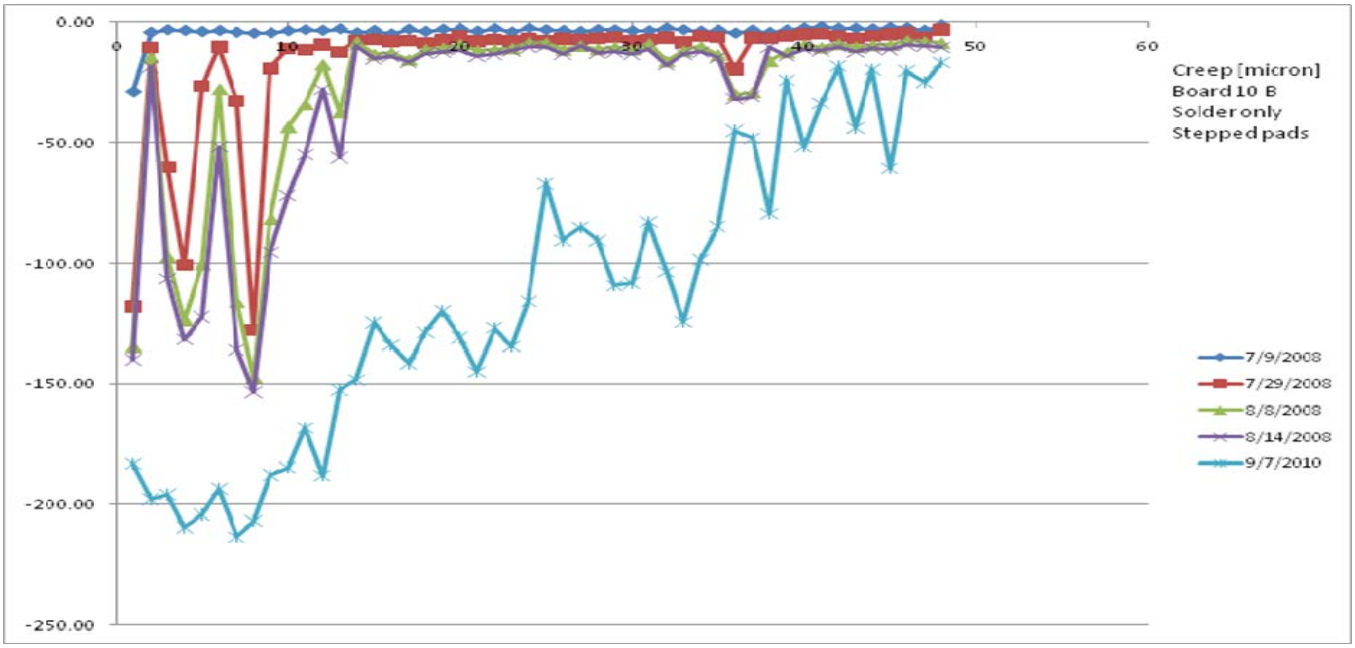

4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
10
20
30
40
50
60
Tension [#]
Board 10A
Solder only
Stepped pads
7/8/2008
7/9/2008
7/29/2008
8/8/2008
8/14/2008
9/7/2010

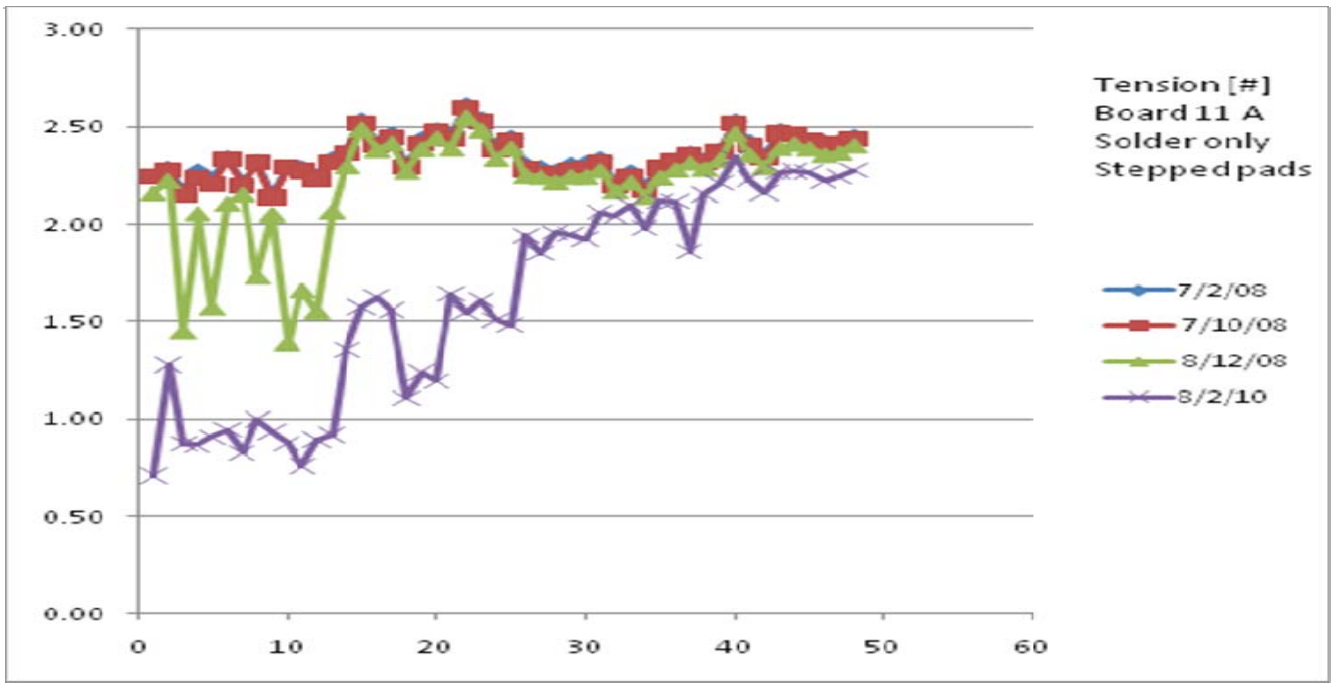

Pad[mm]
18
16
14
12
10
8
6
4
2
0
0
10
20
30
40
50
60
Board 10A
Pad length
vs wire #
Pad[mm]

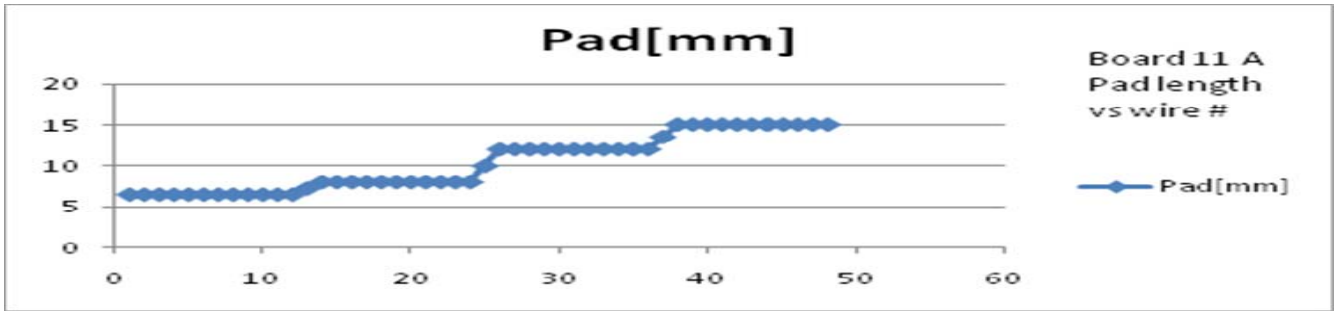

0.00
-50.00
-100.00
-150.00
-200.00
-250.00
0
10
20
30
40
50
60
Creep [micron]
Board 10A
Solder only
Stepped pads
7/9/2008
7/29/2008
8/8/2008
8/14/2008
9/7/2010

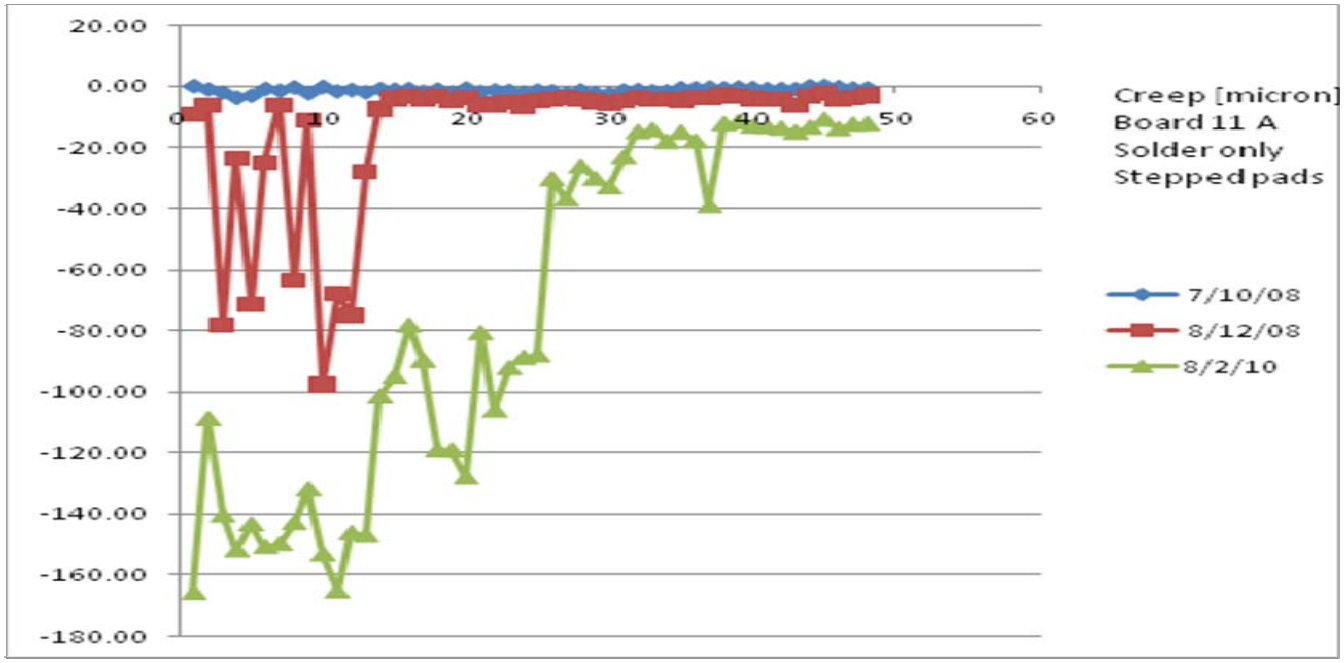

Tension [#]
Board 10 B
Solder only
Stepped pads
4/24/2008
7/9/2008
7/29/2008
8/8/2008
8/14/2008
9/7/2010

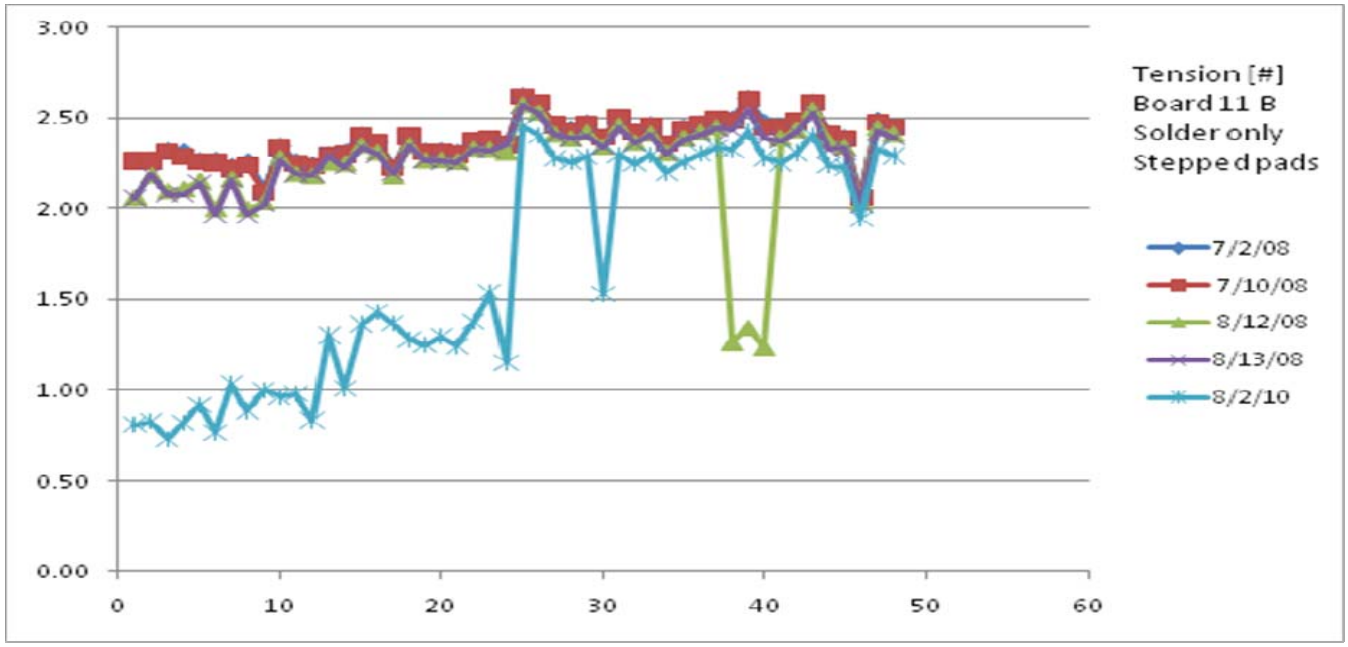

Pad ["]
Board 10 B
Pad length
vs wire #
Pad ["]

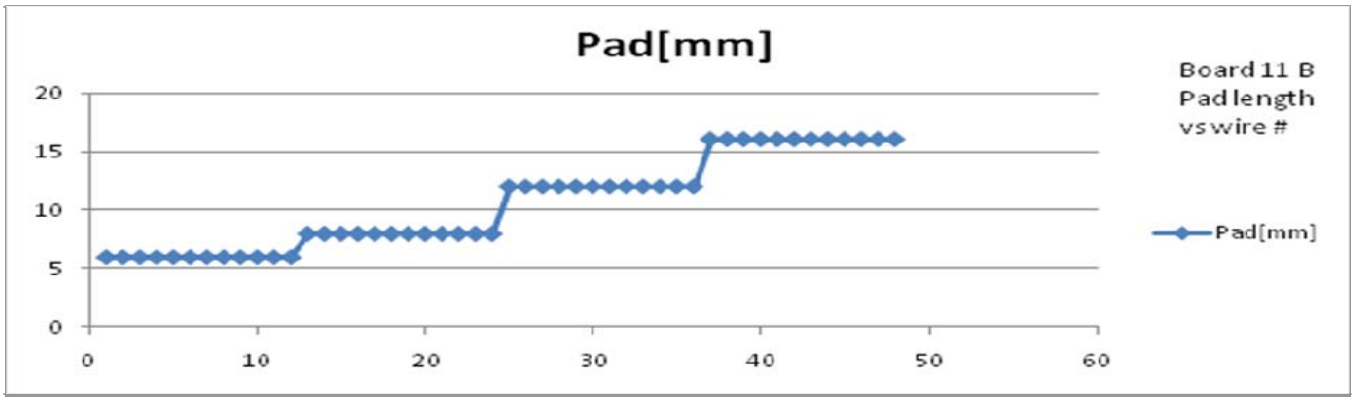

Creep [micron]
Board 10 B
Solder only
Stepped pads
7/9/2008
7/29/2008
8/8/2008
8/14/2008
9/7/2010

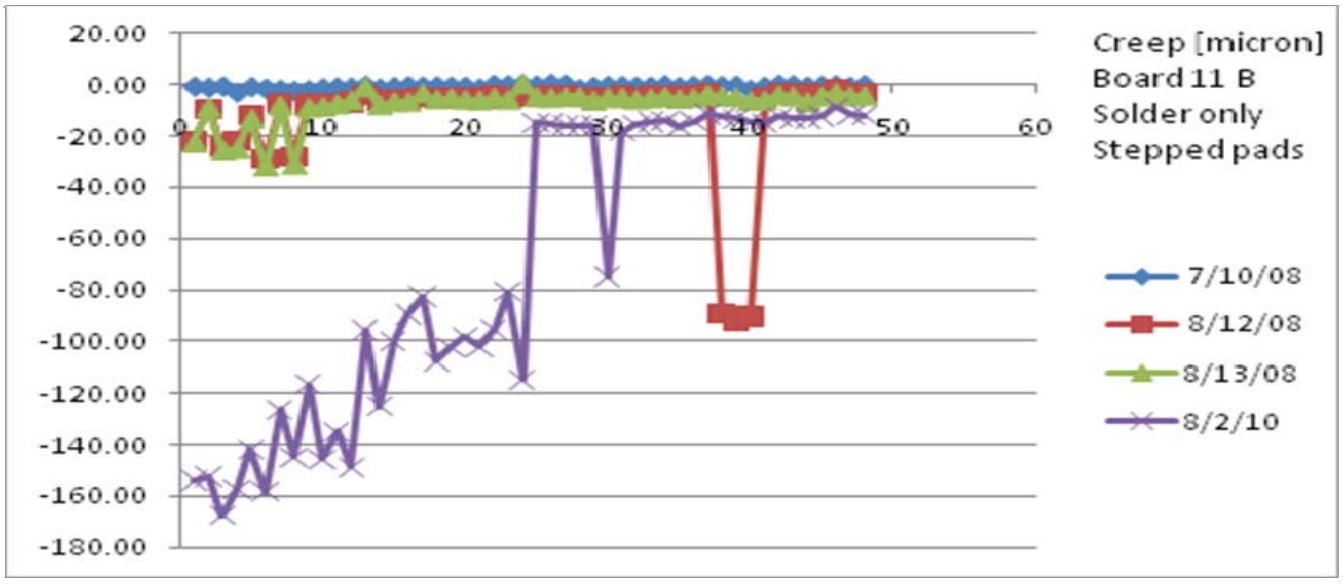

3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
10
20
30
40
50
60
Tension [#]
Board 11 A
Solder only
Stepped pads
7/2/08
7/10/08
8/12/08
8/2/10


Pad[mm]
20
15
10
5
0
0
10
20
30
40
50
60
Board 11 A
Pad length
vs wire #
Pad[mm]


20.00
0.00
-20.00
-40.00
-60.00
-80.00
-100.00
-120.00
-140.00
-160.00
-180.00
0
10
20
30
40
50
60
Creep [micron]
Board 11 A
Solder only
Stepped pads
7/10/08
8/12/08
8/2/10


3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
10
20
30
40
50
60
Tension [#]
Board 11 B
Solder only
Stepped pads
7/2/08
7/10/08
8/12/08
8/13/08
8/2/10


Pad[mm]
20
15
10
5
0
0
10
20
30
40
50
60
Board 11 B
Pad length
vs wire #
Pad[mm]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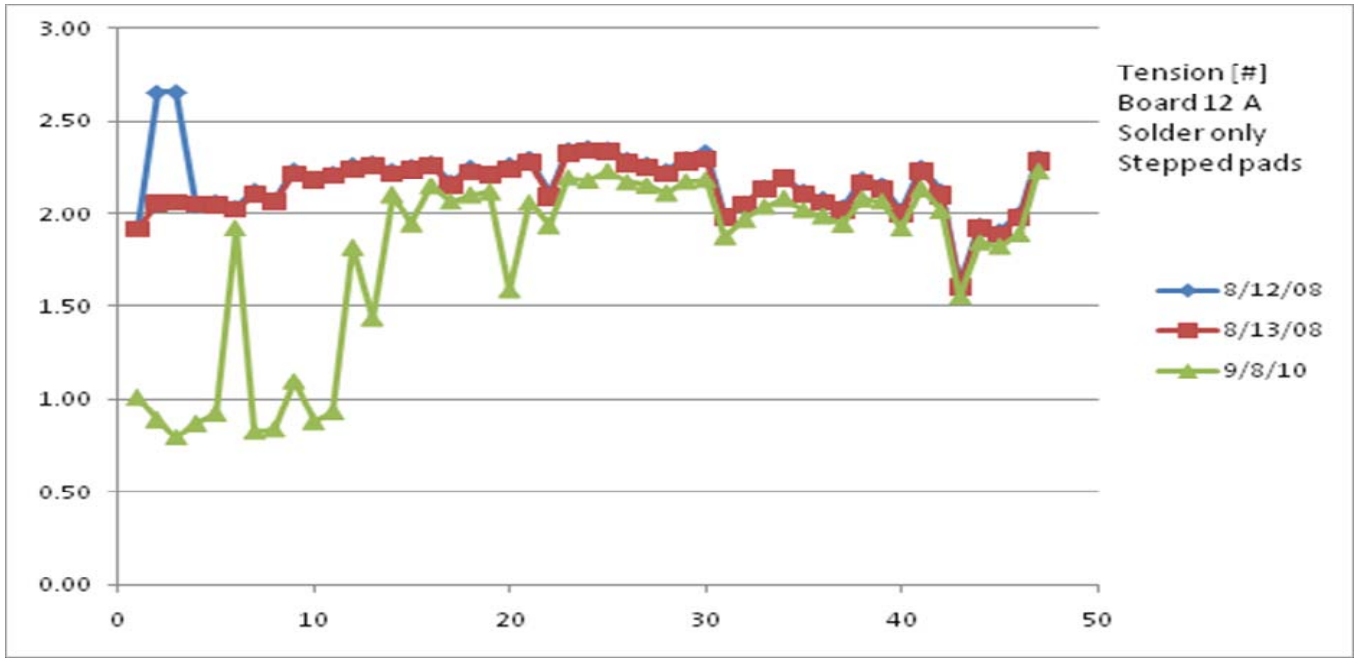
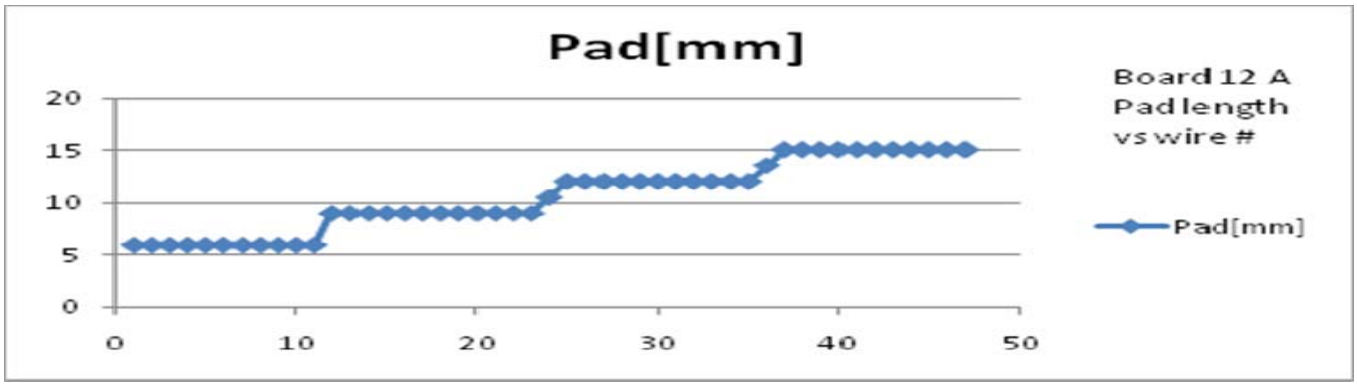
0.00
-20.00
-40.00
-60.00
-80.00
-100.00
-120.00
-140.00
-160.00
-180.00
0
10
20
30
40
50
60
Creep [micron]
Board 11 B
Solder only
Stepped pads
7/10/08
8/12/08
8/13/08
8/2/10


3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
10
20
30
40
50
Tension [#]
Board 12 A
Solder only
Stepped pads
8/12/08
8/13/08
9/8/10


Pad[mm]
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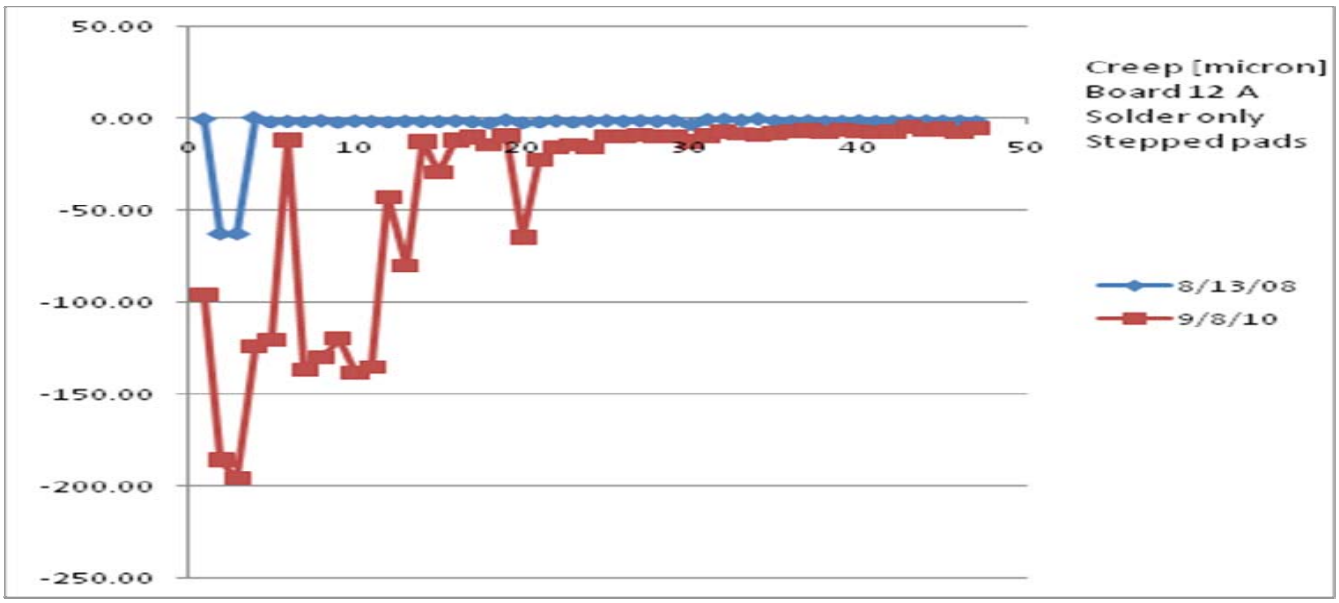
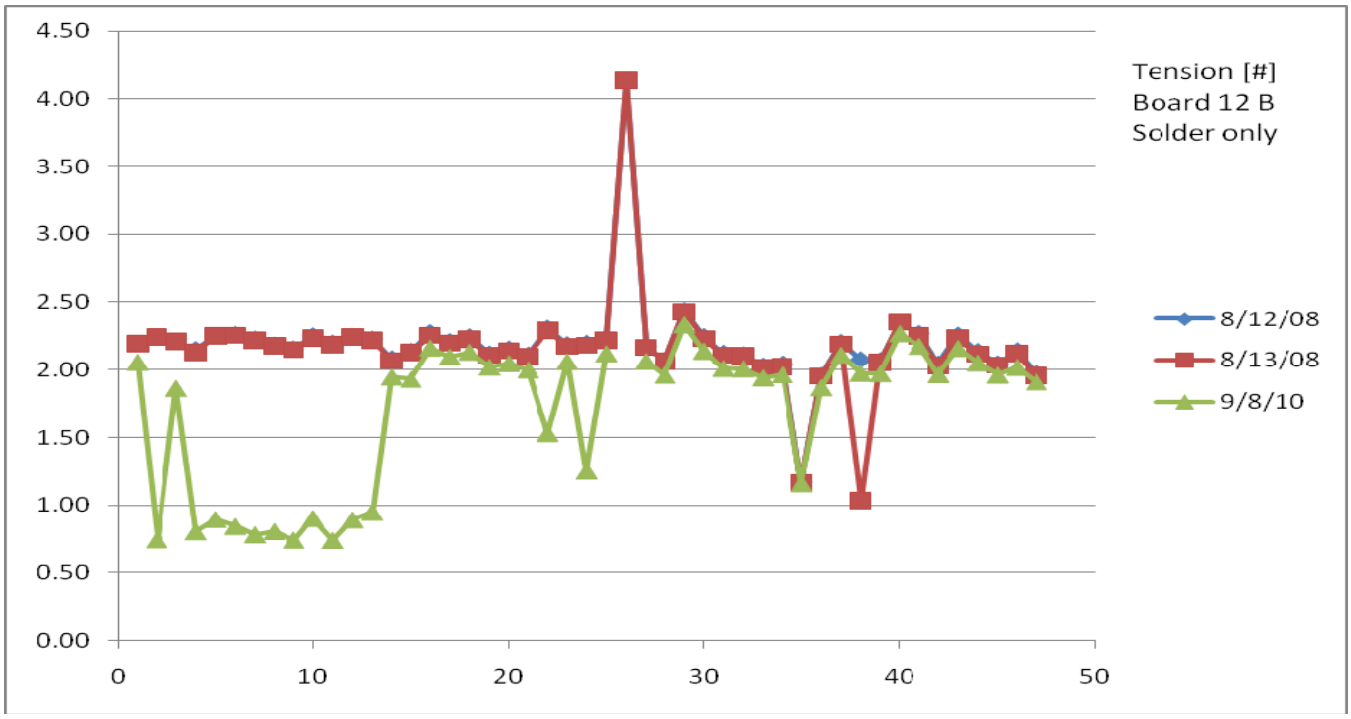
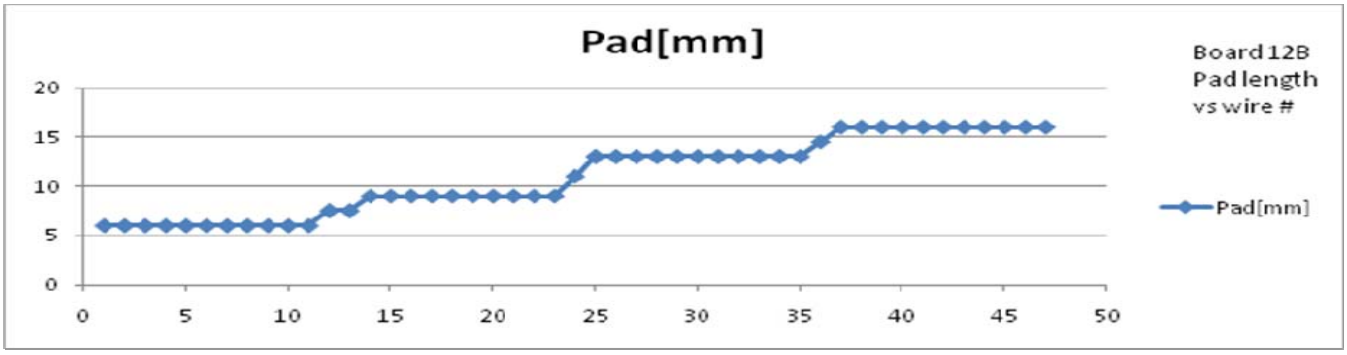
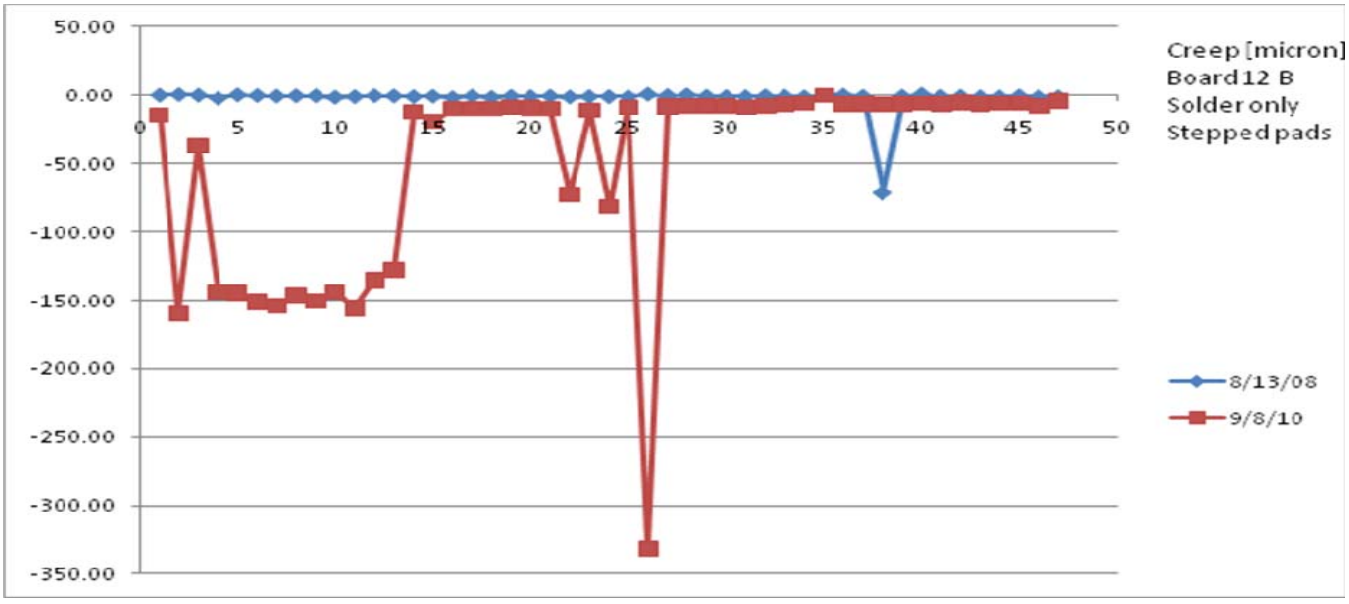
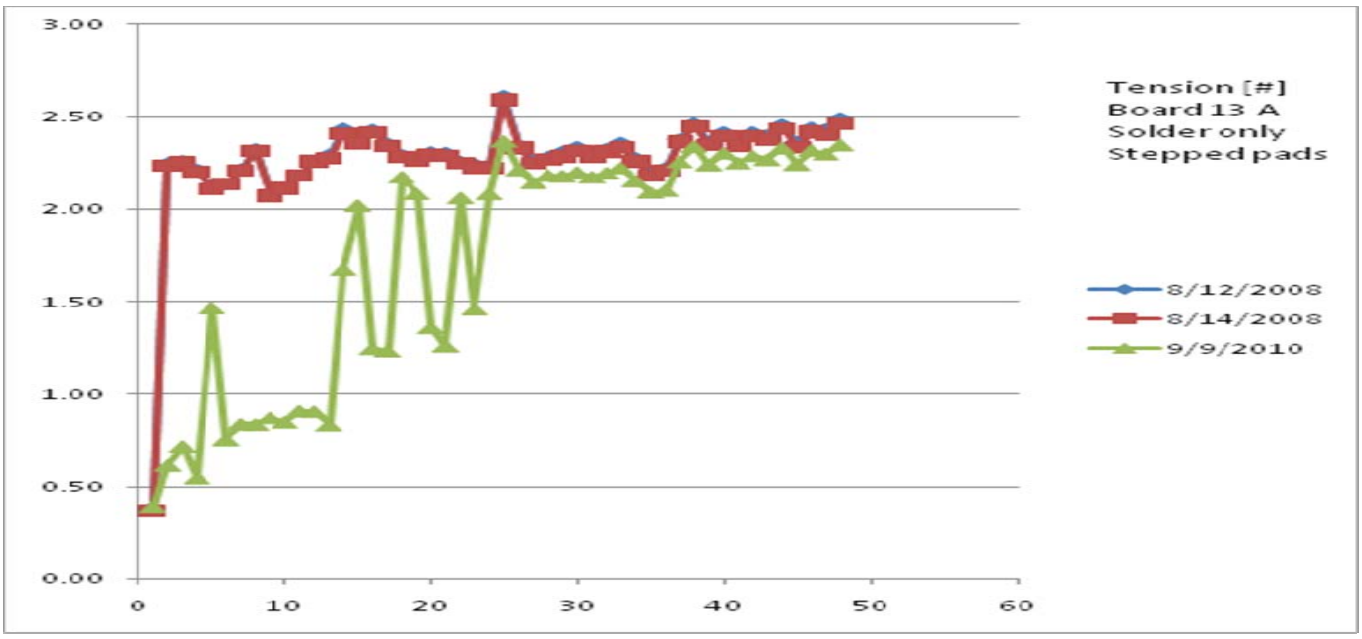
15
10
5
0
0
10
20
30
40
50
Board 12 A
Pad length
vs wire #
Pad[mm]

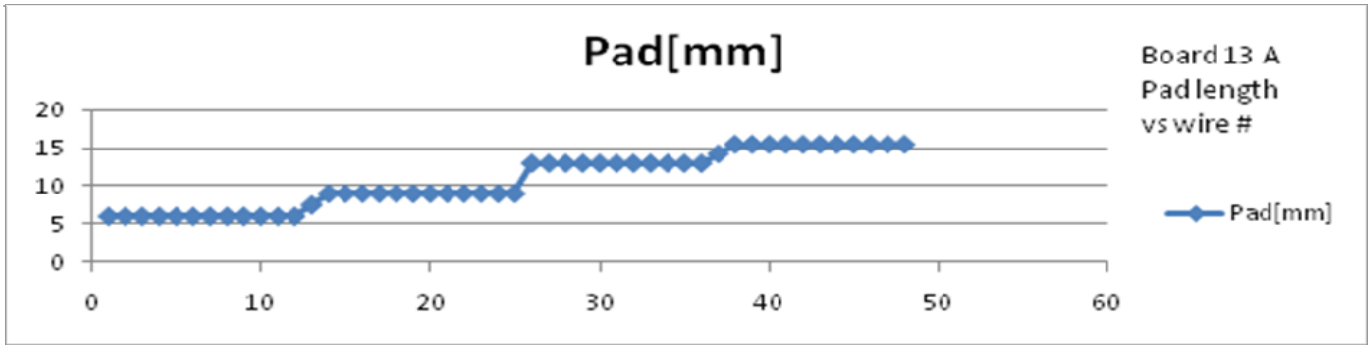

50.00
0.00
-50.00
-100.00
-150.00
-200.00
-250.00
0
10
20
30
40
50
Creep [micron]
Board 12 A
Solder only
Stepped pads
8/13/08
9/8/10

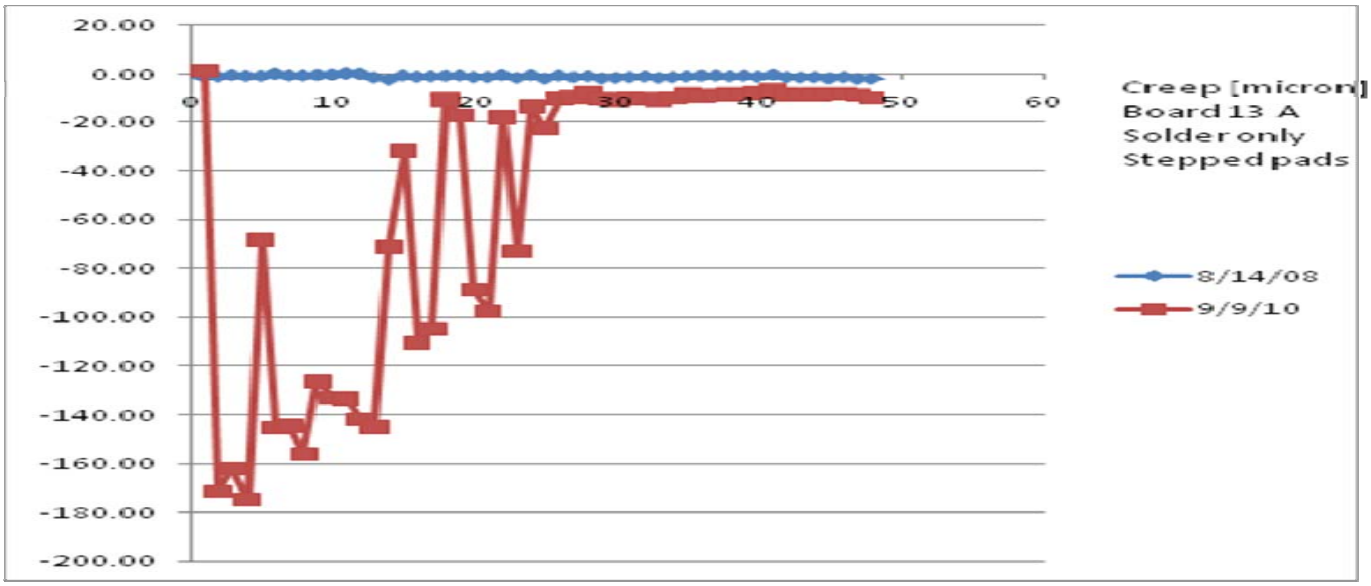

4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
10
20
30
40
50
Tension [#]
Board 12 B
Solder only
8/12/08
8/13/08
9/8/10


Pad[mm]
20
15
10
5
0
0
5
10
15
20
25
30
35
40
45
50
Board 12B
Pad length
vs wire #
Pad[mm]


50.00
0.00
-50.00
-100.00
-150.00
-200.00
-250.00
-300.00
-350.00
0
5
10
15
20
25
30
35
40
45
50
Creep [micron]
Board 12 B
Solder only
Stepped pads
8/13/08
9/8/10


3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
10
20
30
40
50
60
Tension [#]
Board 13 A
Solder only
Stepped pads
8/12/2008
8/14/2008
9/9/2010


Pad[mm]
20
15
10
5
0
0
10
20
30
40
50
60
Board 13 A
Pad length
vs wire #
Pad[mm]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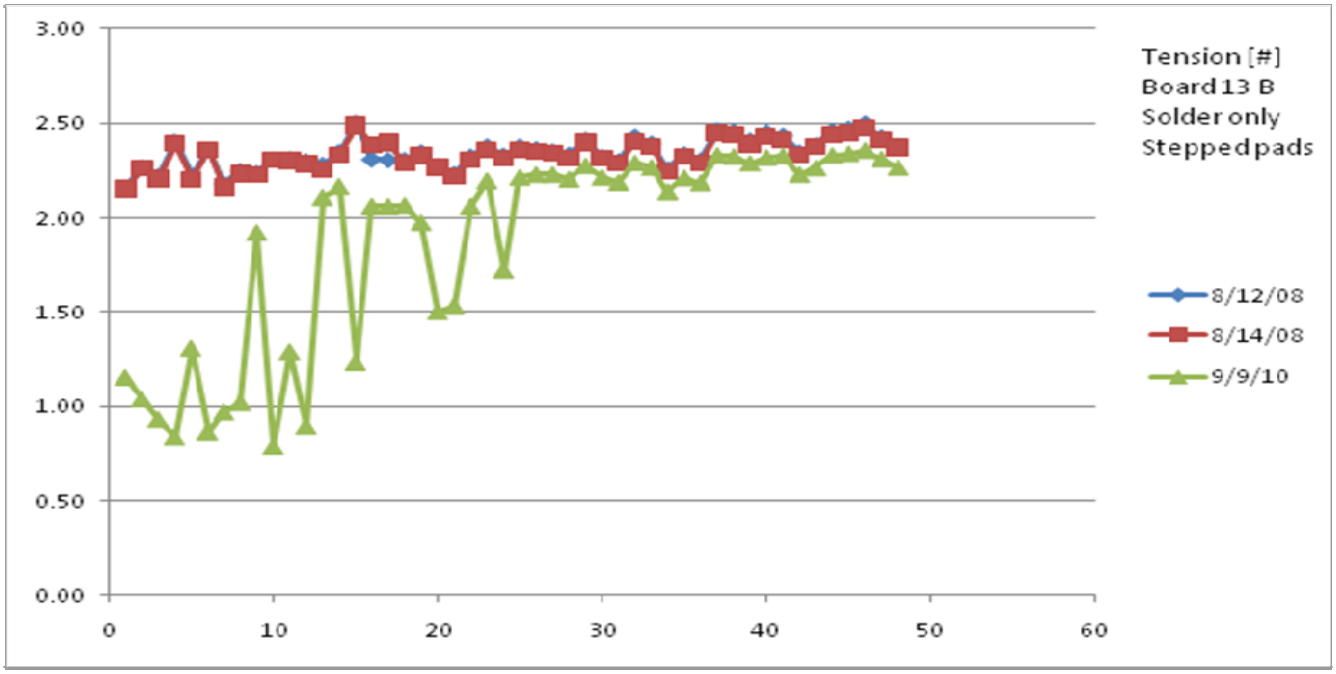
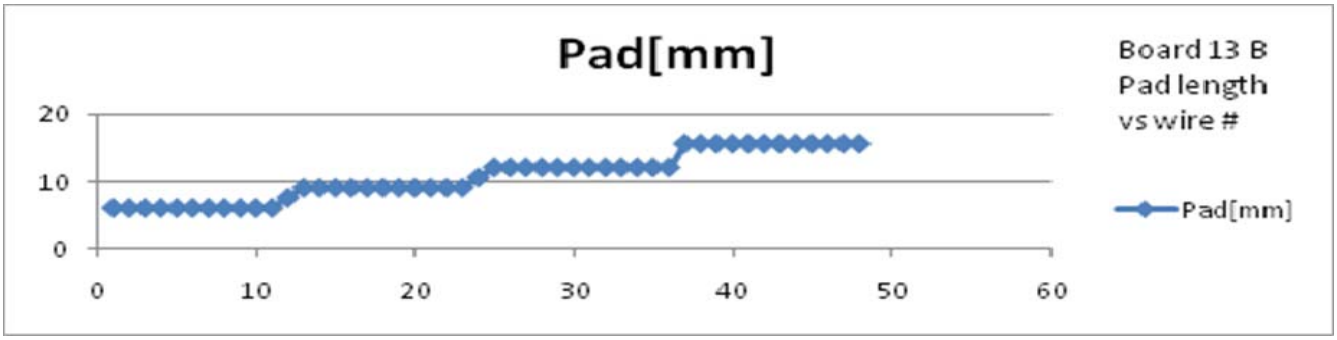
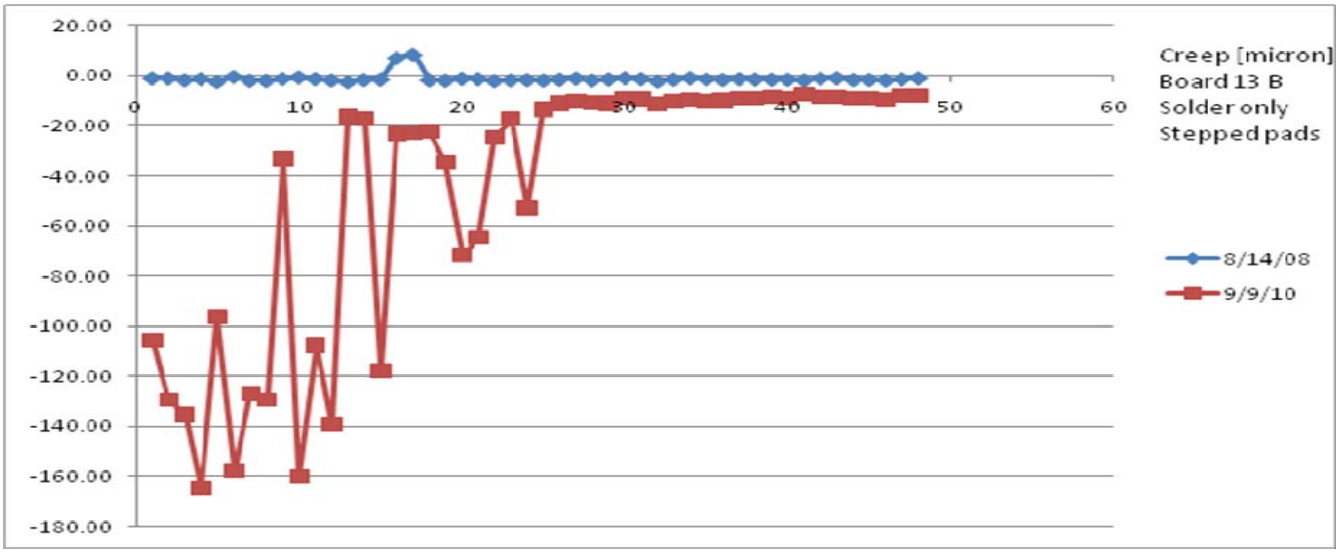
0.00
-20.00
-40.00
-60.00
-80.00
-100.00
-120.00
-140.00
-160.00
-180.00
-200.00
0
10
20
30
40
50
60
Creep [micron]
Board 13 A
Solder only
Stepped pads
8/14/08
9/9/10


3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
10
20
30
40
50
60
Tension [#]
Board 13 B
Solder only
Stepped pads
8/12/08
8/14/08
9/9/10


Pad[mm]
20
10
0
0
10
20
30
40
50
60
Board 13 B
Pad length
vs wire #
Pad[mm]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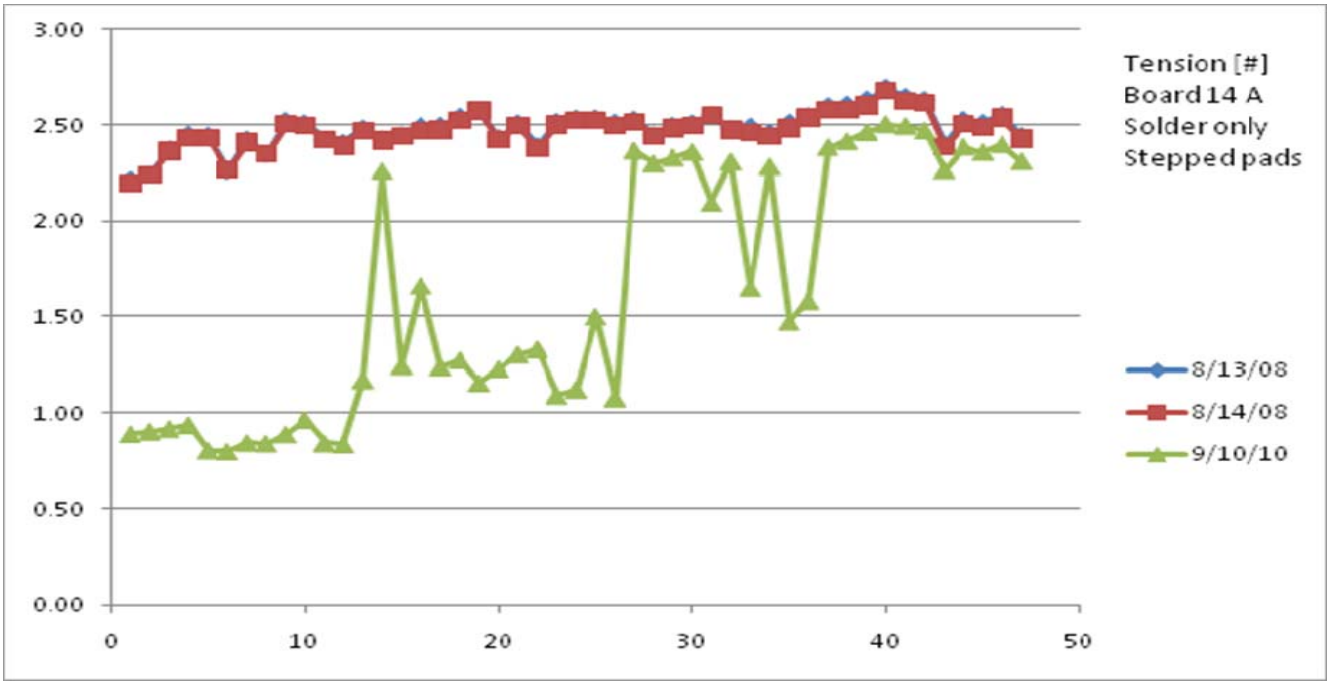
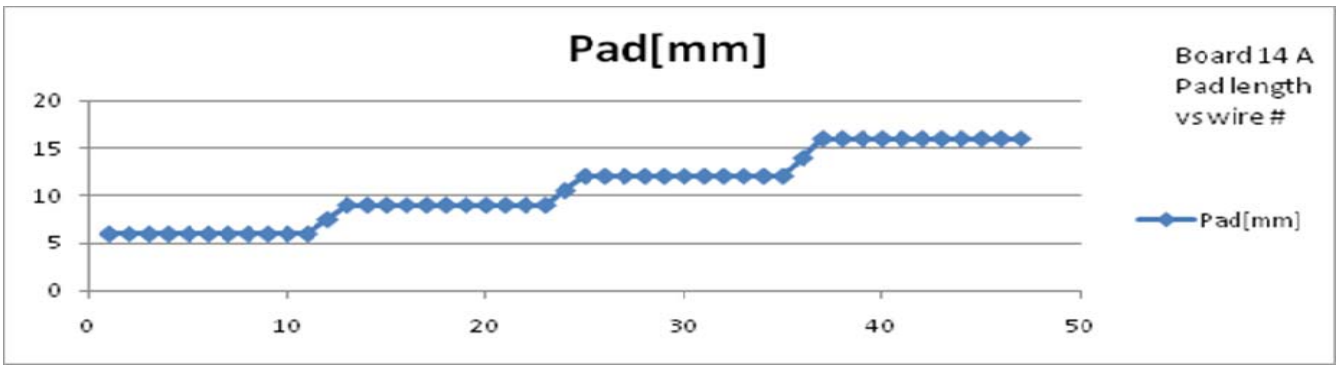
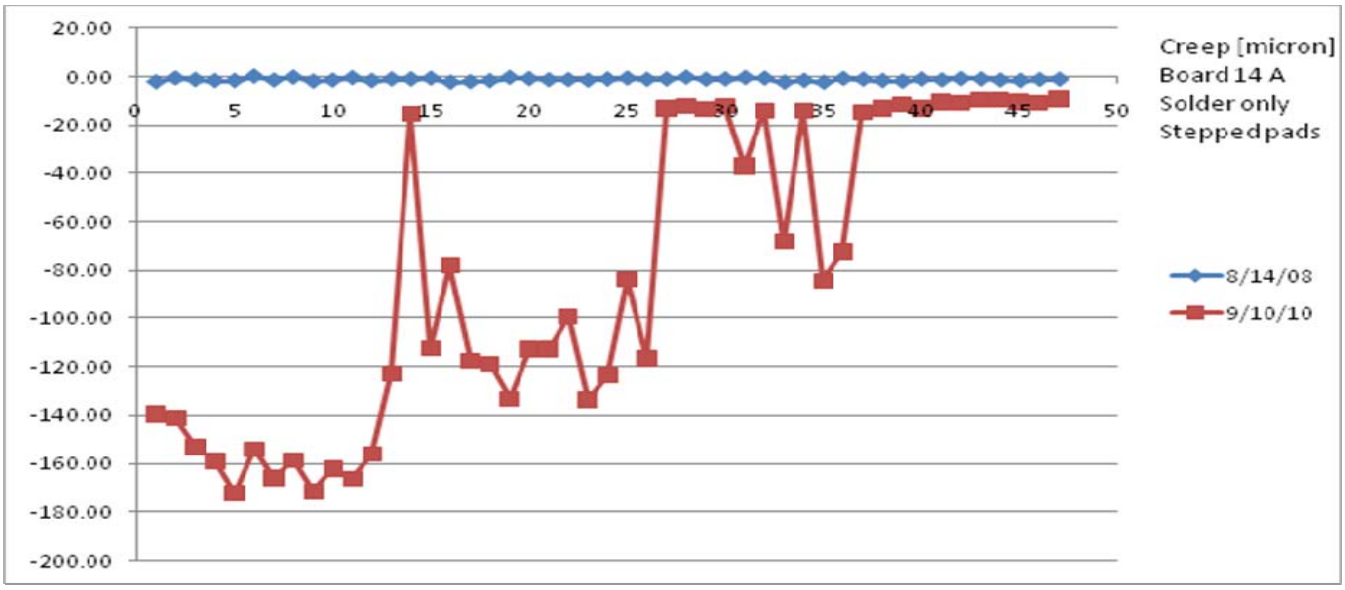
0.00
-20.00
-40.00
-60.00
-80.00
-100.00
-120.00
-140.00
-160.00
-180.00
0
10
20
30
40
50
60
Creep [micron]
Board 13 B
Solder only
Stepped pads
8/14/08
9/9/10


3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
10
20
30
40
50
Tension [#]
Board 14 A
Solder only
Stepped pads
8/13/08
8/14/08
9/10/10


Pad[mm]
20
15
10
5
0
0
10
20
30
40
50
Board 14 A
Pad length
vs wire #
Pad[mm]


20.00
0.00
-20.00
-40.00
-60.00
-80.00
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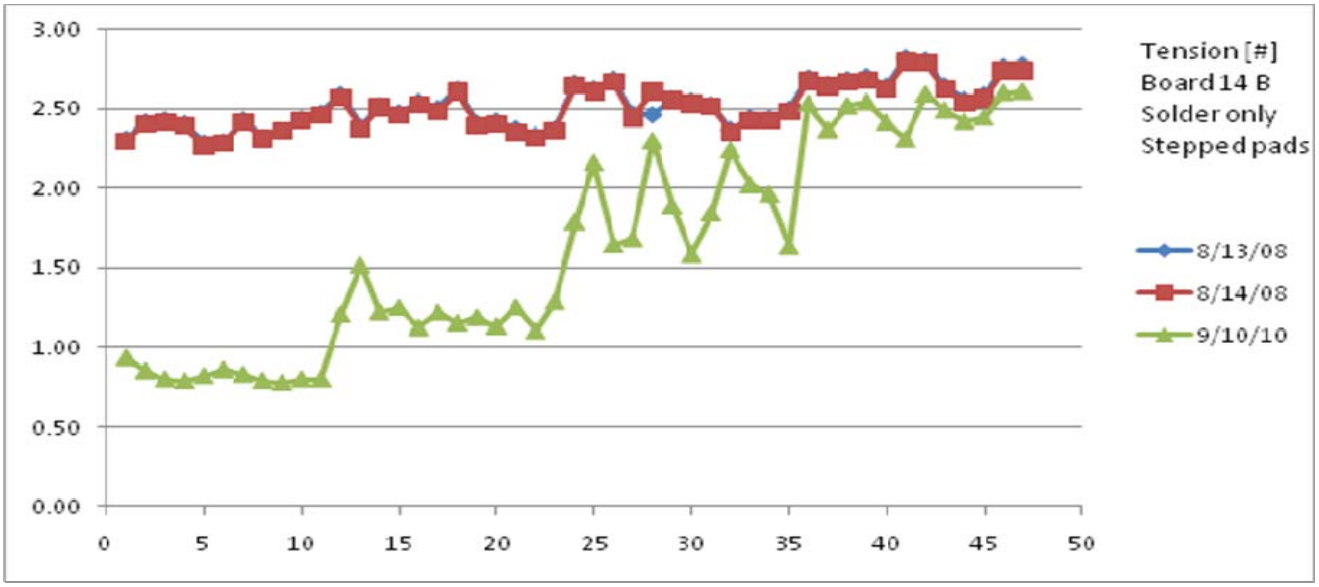
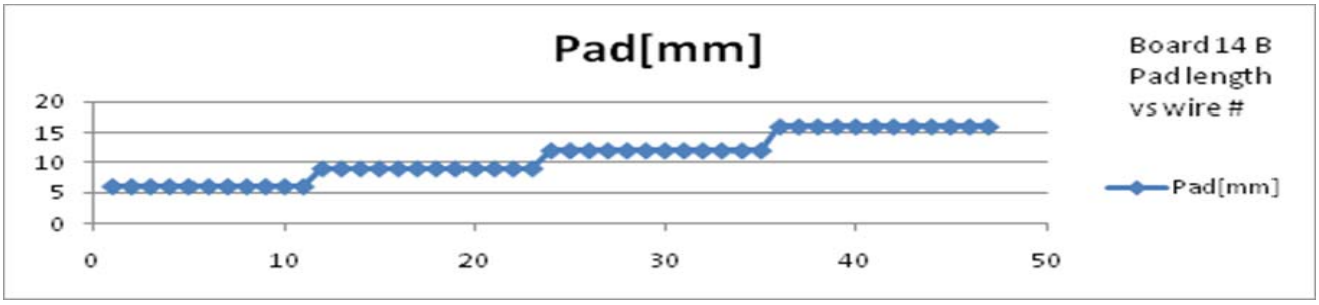
-120.00
-140.00
-160.00
-180.00
-200.00
0
5
10
15
20
25
30
35
40
45
50
Creep [micron]
Board 14 A
Solder only
Stepped pads
8/14/08
9/10/10


3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
5
10
15
20
25
30
35
40
45
50
Tension [#]
Board 14 B
Solder only
Stepped pads
8/13/08
8/14/08
9/10/10


Pad[mm]
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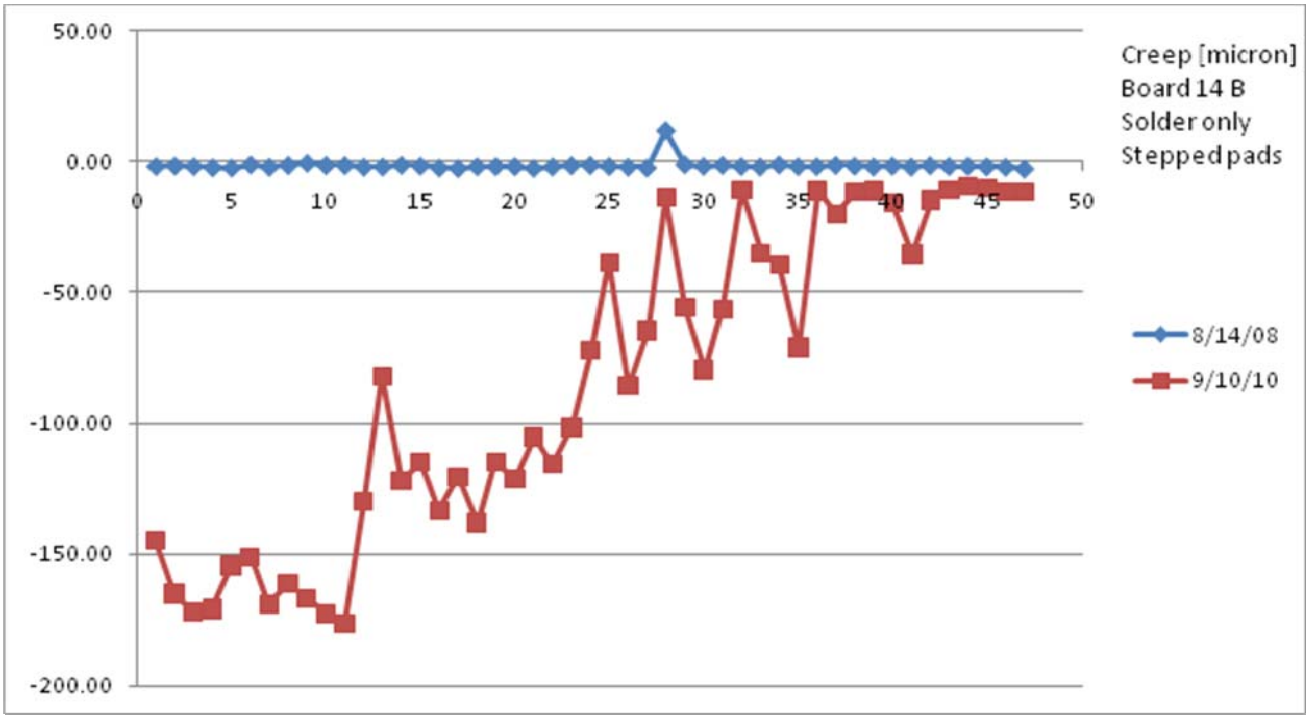
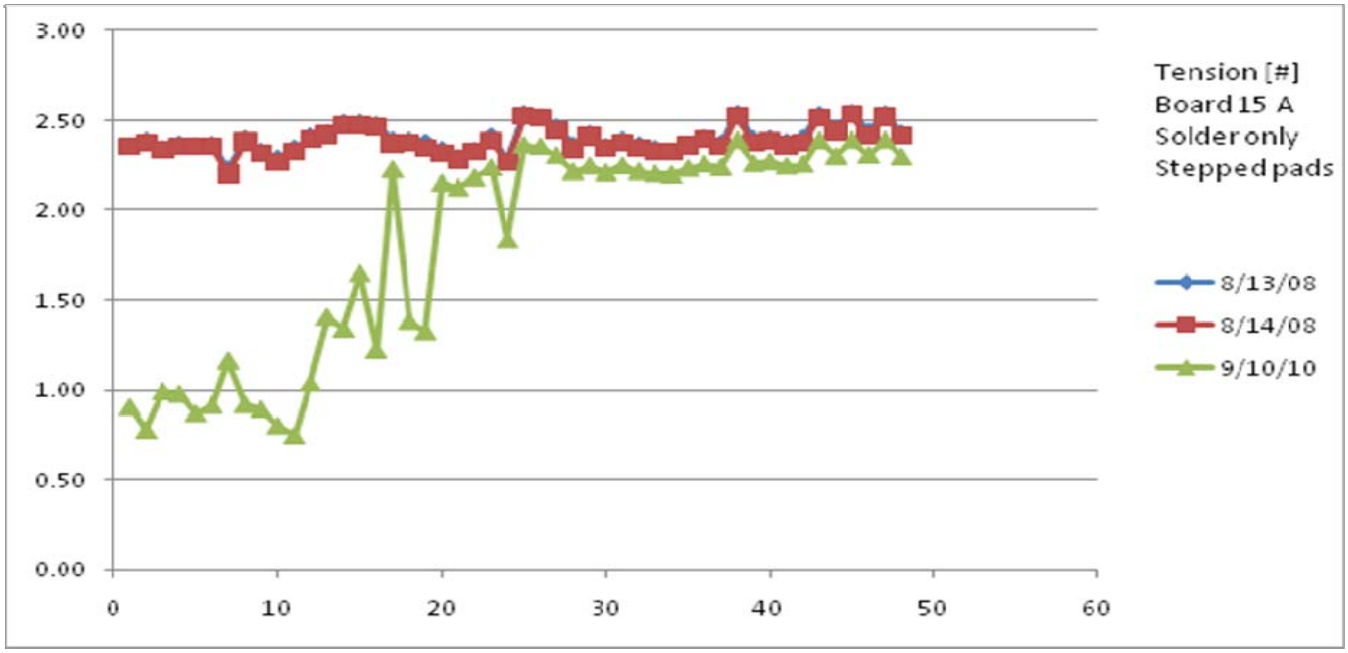
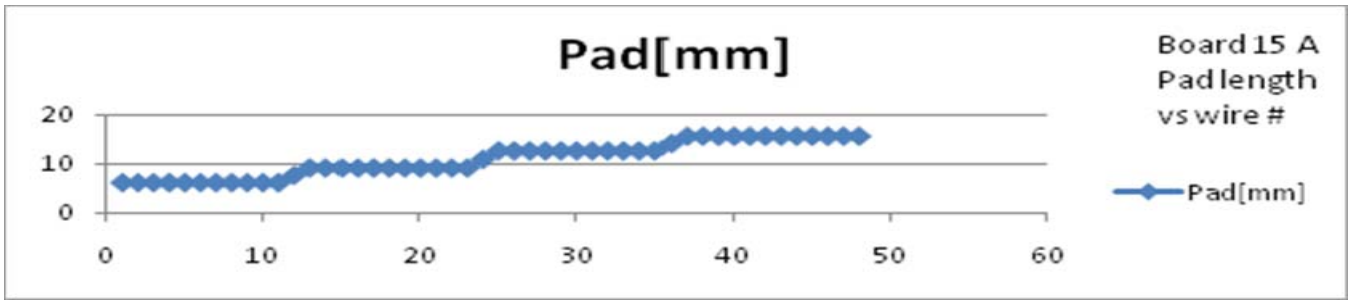
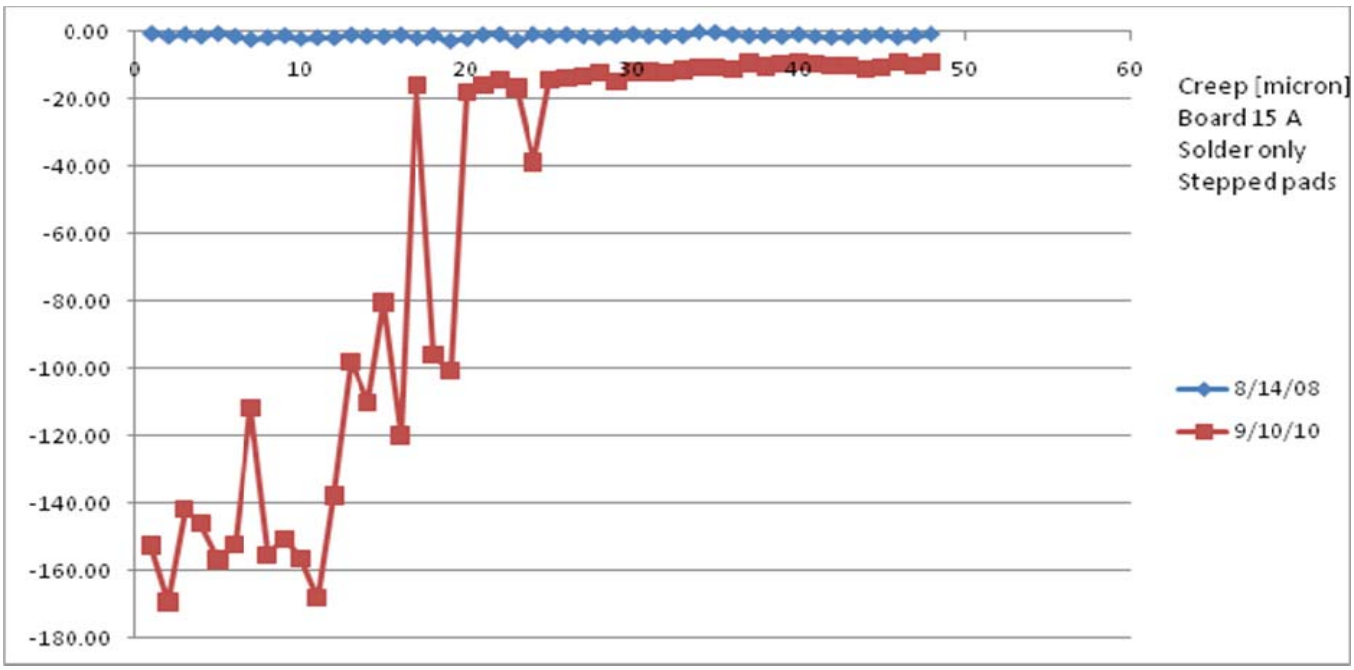
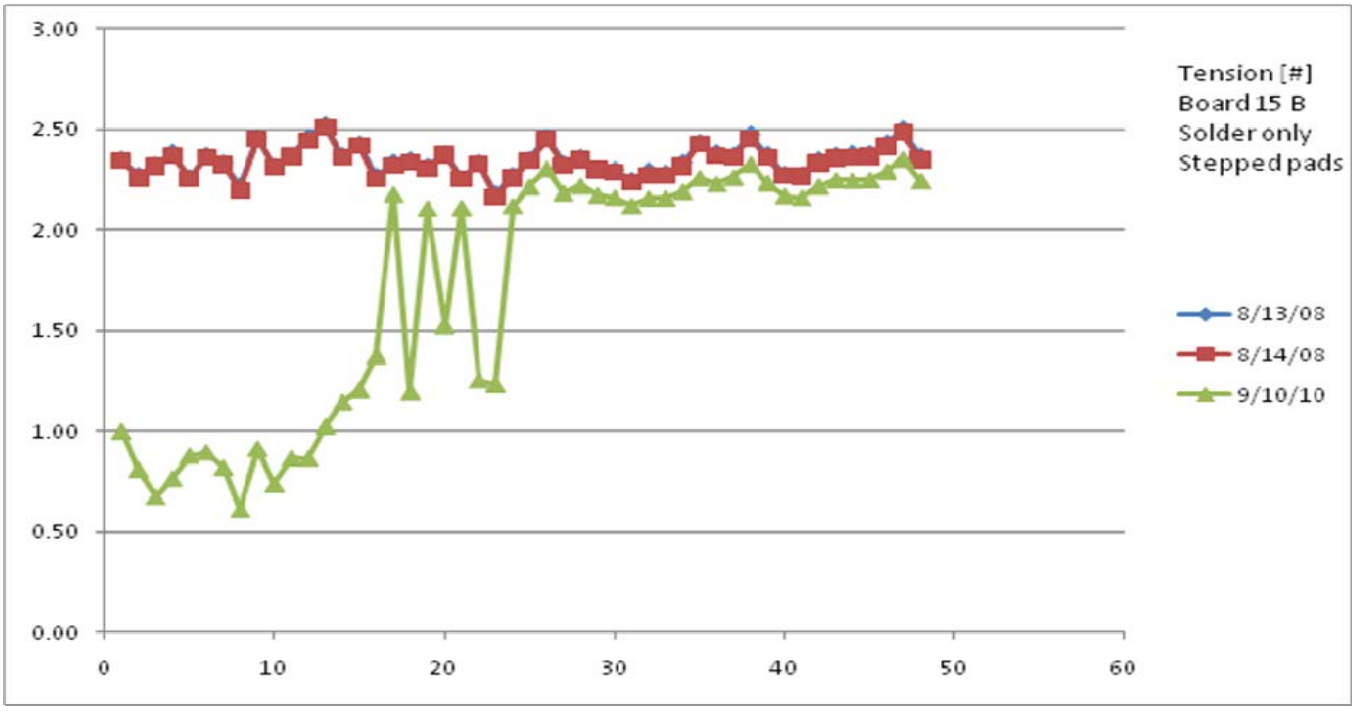
15
10
5
0
0
10
20
30
40
50
Board 14 B
Pad length
vs wire #
Pad[mm]

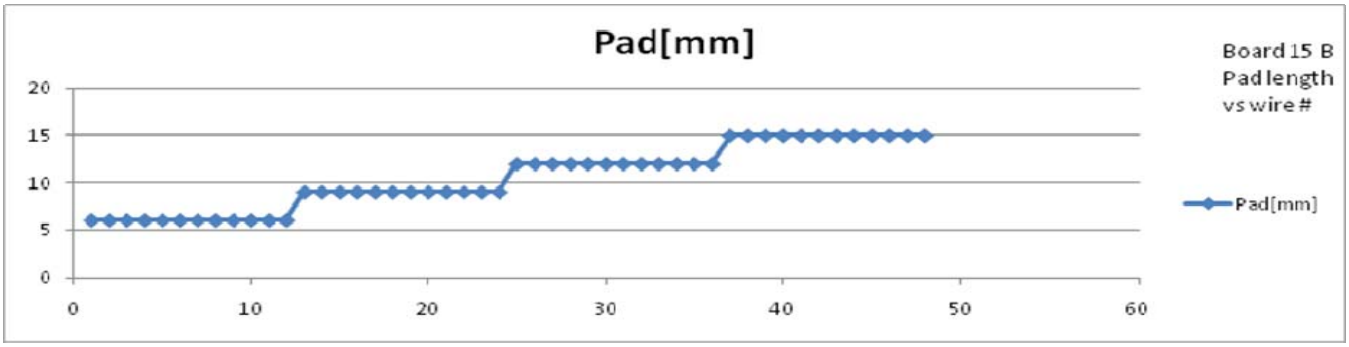

50.00
0.00
-50.00
-100.00
-150.00
-200.00
0
5
10
15
20
25
30
35
40
45
50
Creep [micron]
Board 14 B
Solder only
Stepped pads
8/14/08
9/10/10

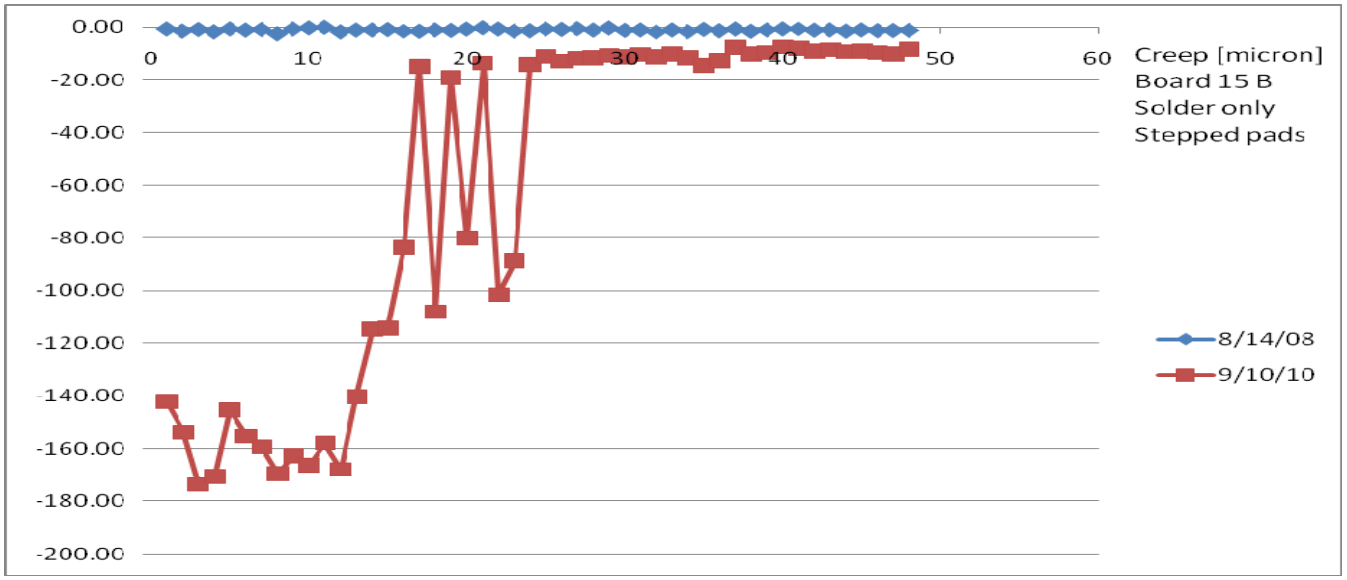

3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
10
20
30
40
50
60
Tension [#]
Board 15 A
Solder only
Stepped pads
8/13/08
8/14/08
9/10/10

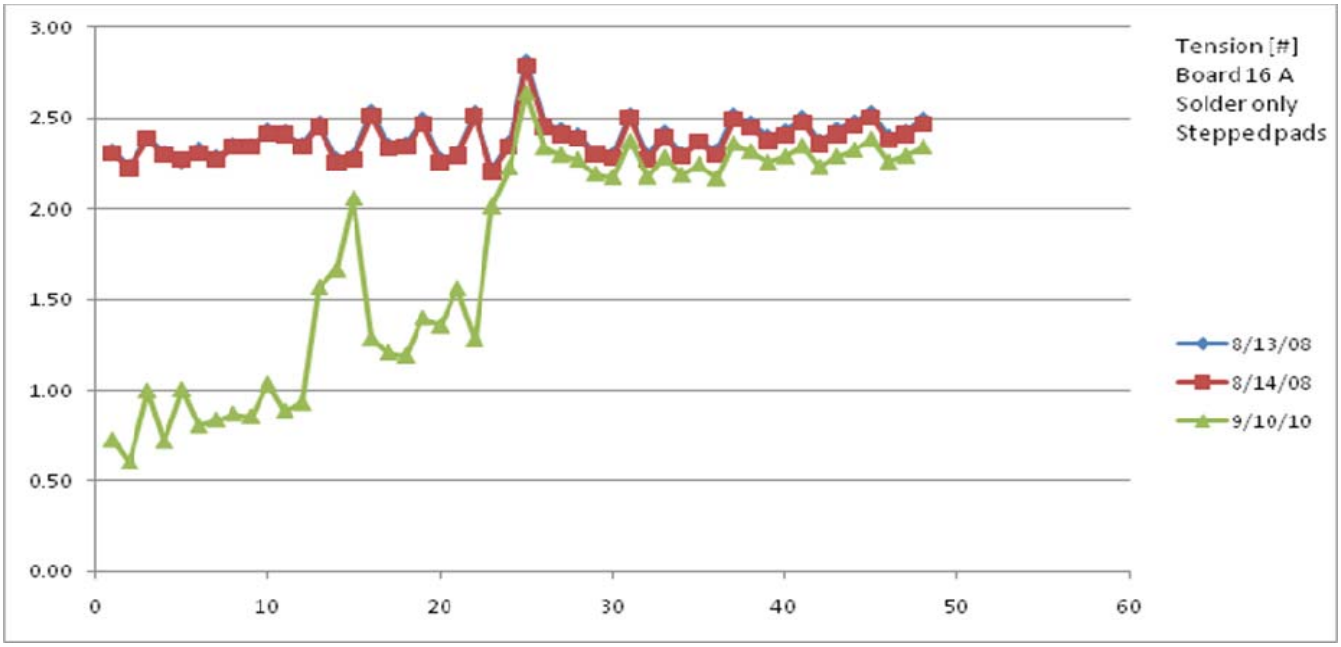

Pad[mm]
20
10
0
0
10
20
30
40
50
60
Board 15 A
Pad length
vs wire #
Pad[mm]

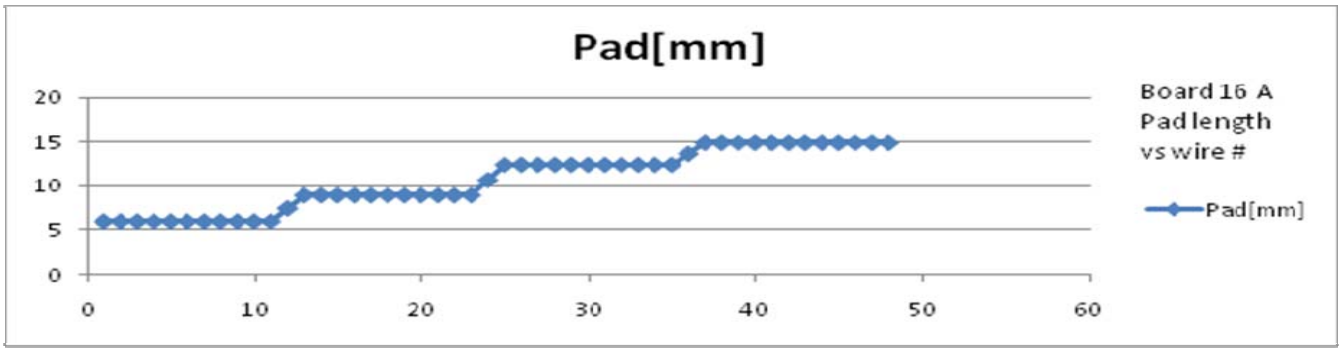

0.00
-20.00
-40.00
-60.00
-80.00
-100.00
-120.00
-140.00
-160.00
-180.00
0
10
20
30
40
50
60
Creep [micron]
Board 15 A
Solder only
Stepped pads
8/14/08
9/10/10

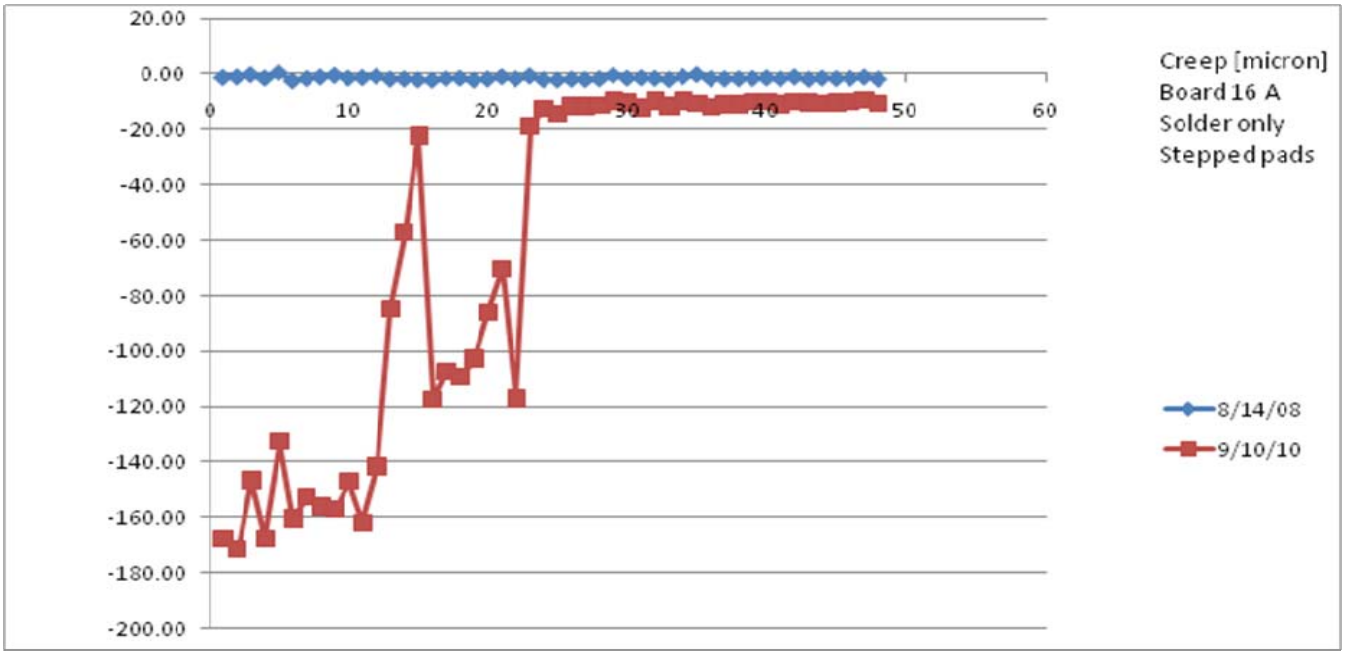

3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
10
20
30
40
50
60
Tension [#]
Board 15 B
Solder only
Stepped pads
8/13/08
8/14/08
9/10/10

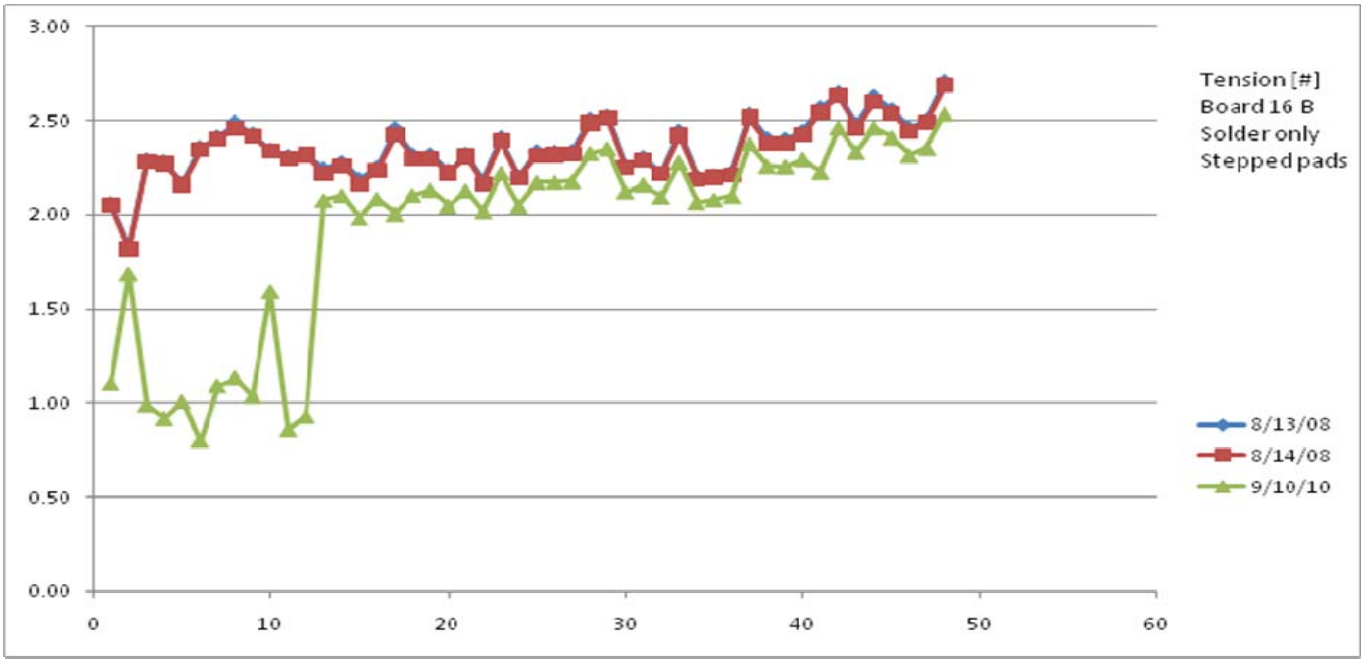

Pad[mm]
20
15
10
5
0
0
10
20
30
40
50
60
Board 15 B
Pad length
vs wire #
Pad[mm]

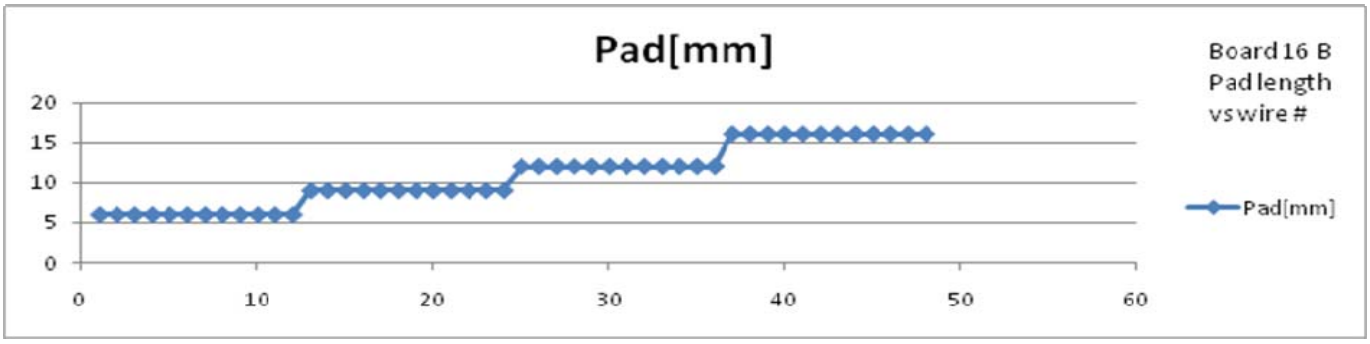

0.00
-20.00
-40.00
-60.00
-80.00
-100.00
-120.00
-140.00
-160.00
-180.00
-200.00
0
10
20
30
40
50
60
Creep [micron]
Board 15 B
Solder only
Stepped pads
8/14/08
9/10/10

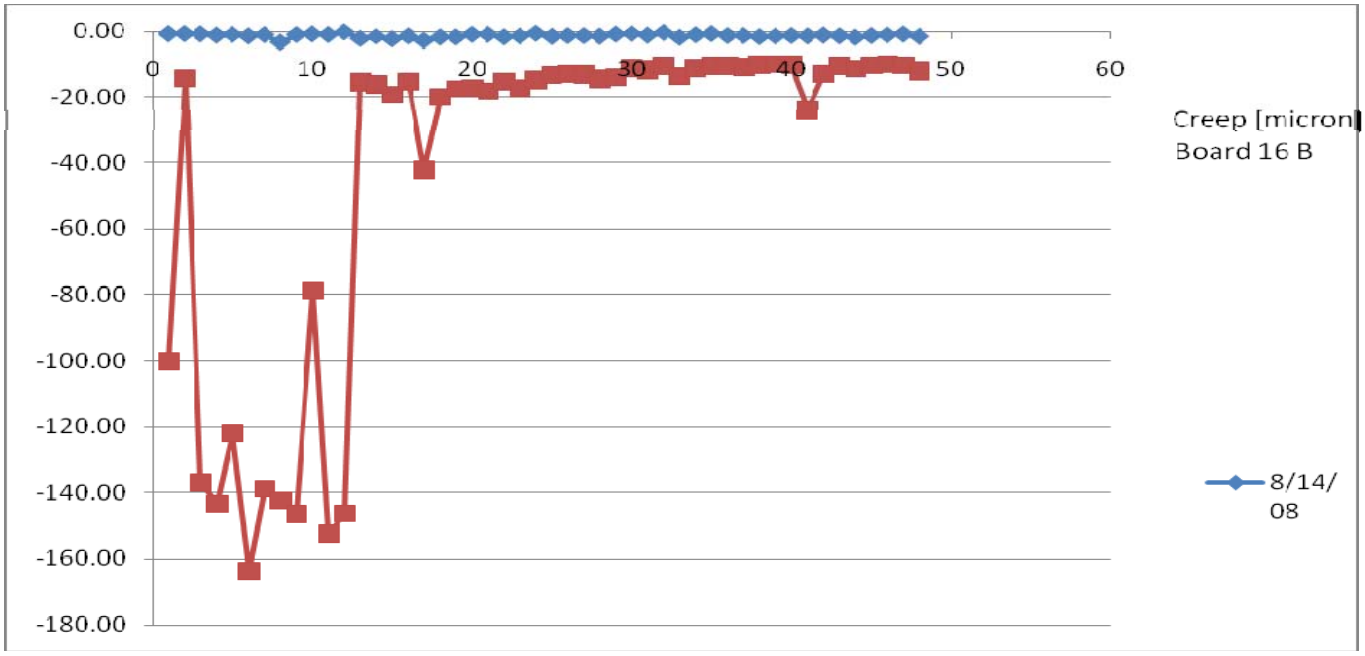

3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
10
20
30
40
50
60
Tension [#]
Board 16 A
Solder only
Stepped pads
8/13/08
8/14/08
9/10/10

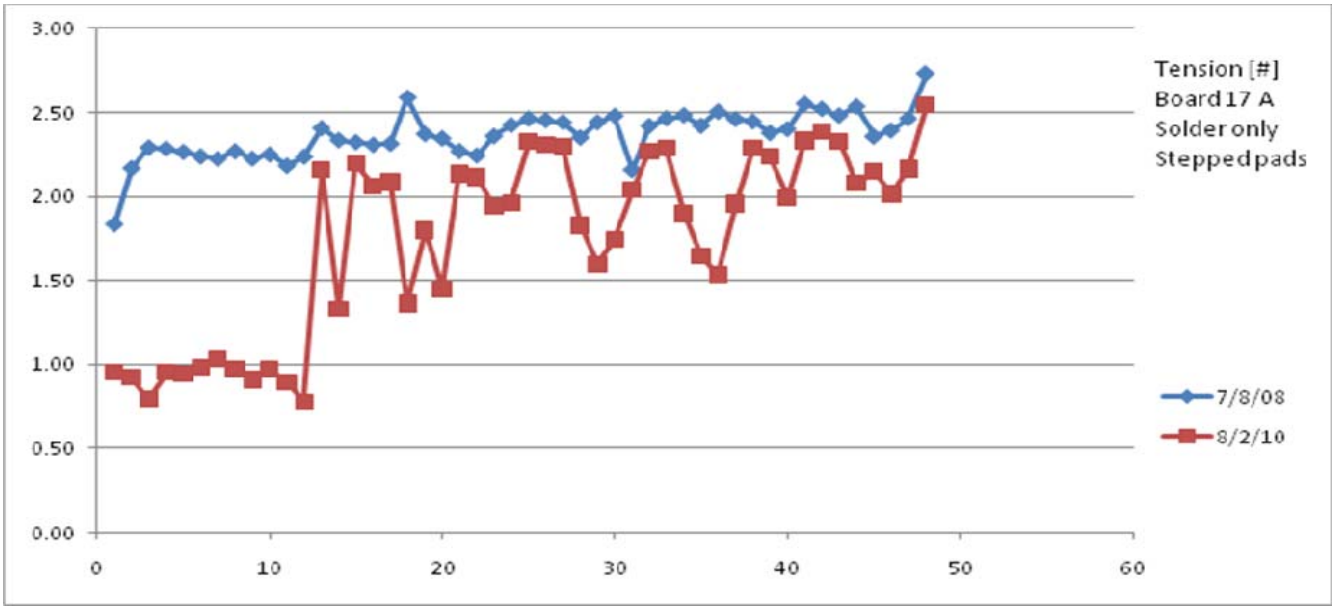

Pad[mm]
20
15
10
5
0
0
10
20
30
40
50
60
Board 16 A
Pad length
vs wire #
Pad[mm]

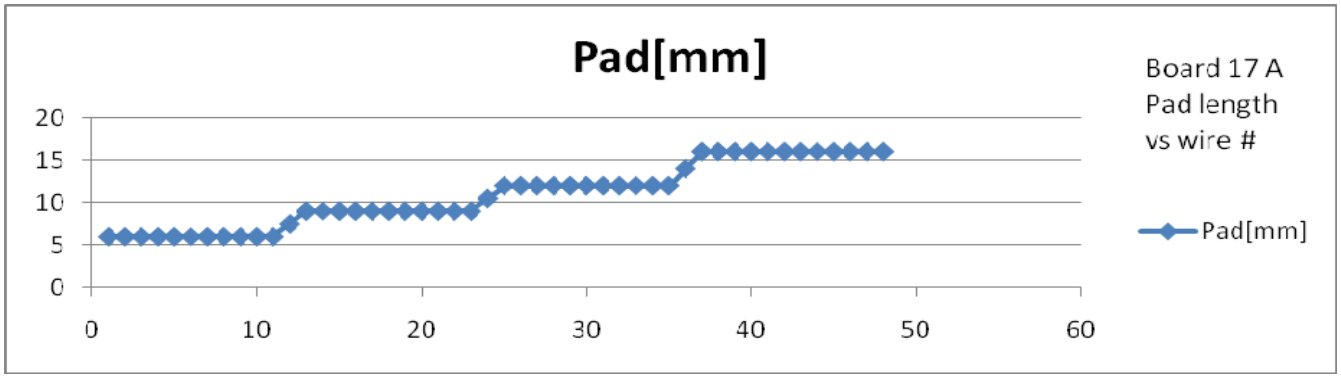

20.00
0.00
-20.00
-40.00
-60.00
-80.00
-100.00
-120.00
-140.00
-160.00
-180.00
-200.00
0
10
20
30
40
50
60
Creep [micron]
Board 16 A
Solder only
Stepped pads
8/14/08
9/10/10

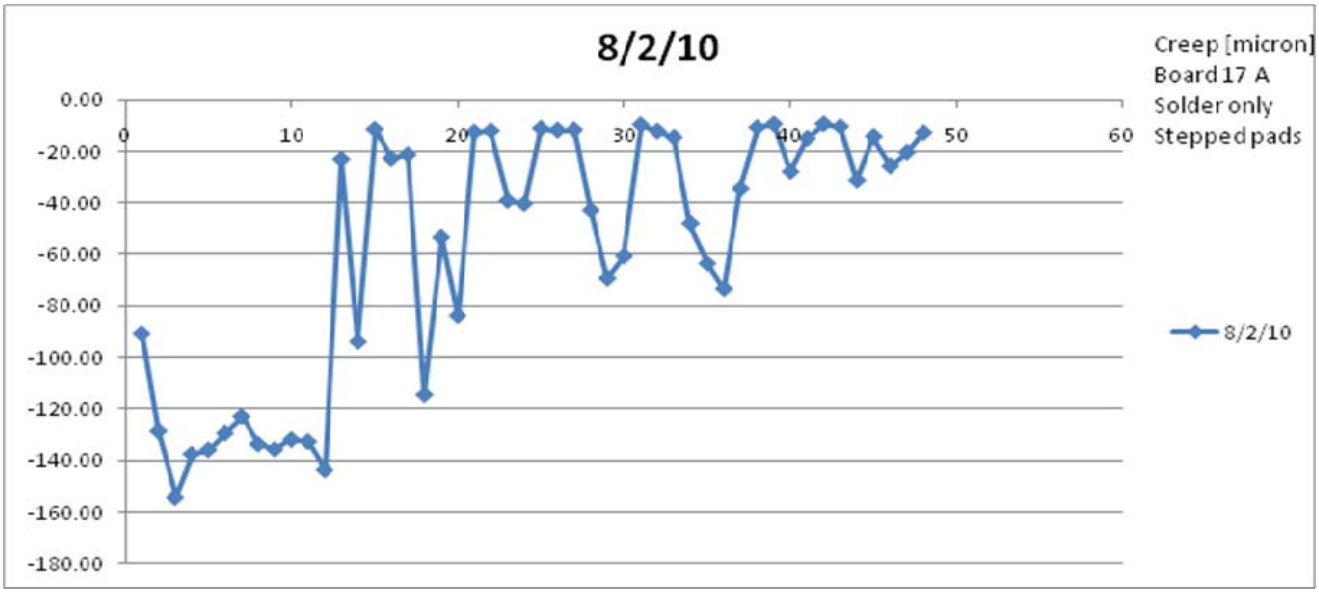

3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
10
20
30
40
50
60
Tension [#]
Board 16 B
Solder only
Stepped pads
8/13/08
8/14/08
9/10/10

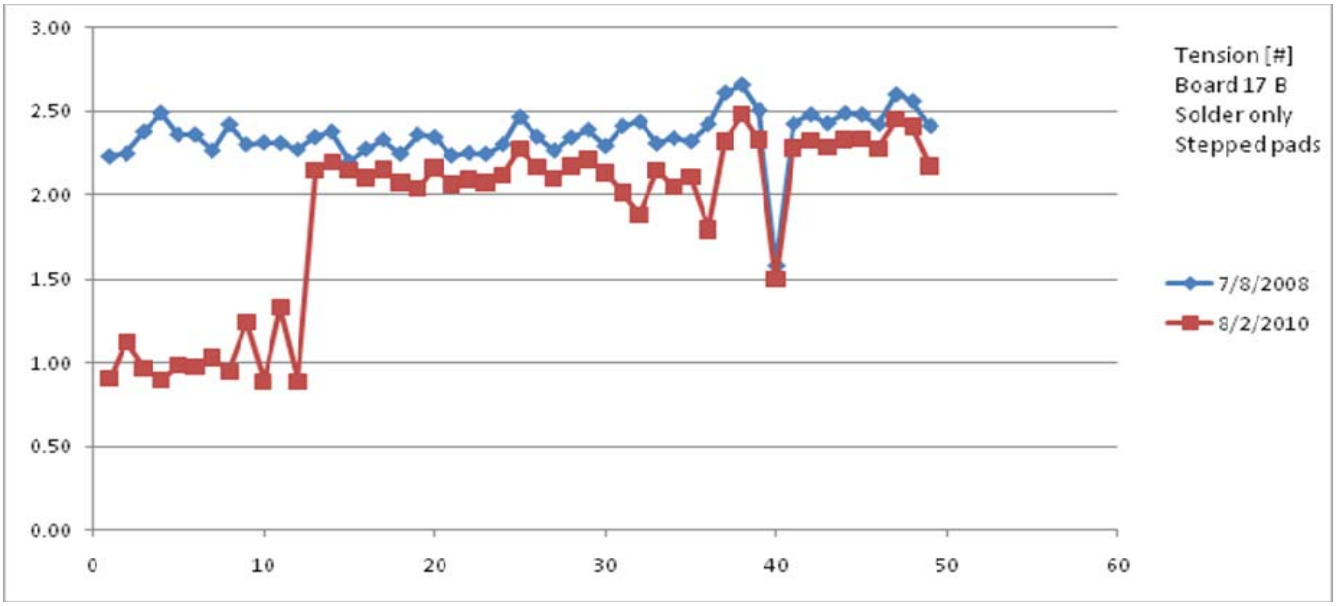

Pad[mm]
20
15
10
5
0
0
10
20
30
40
50
60
Board 16 B
Pad length
vs wire #
Pad[mm]

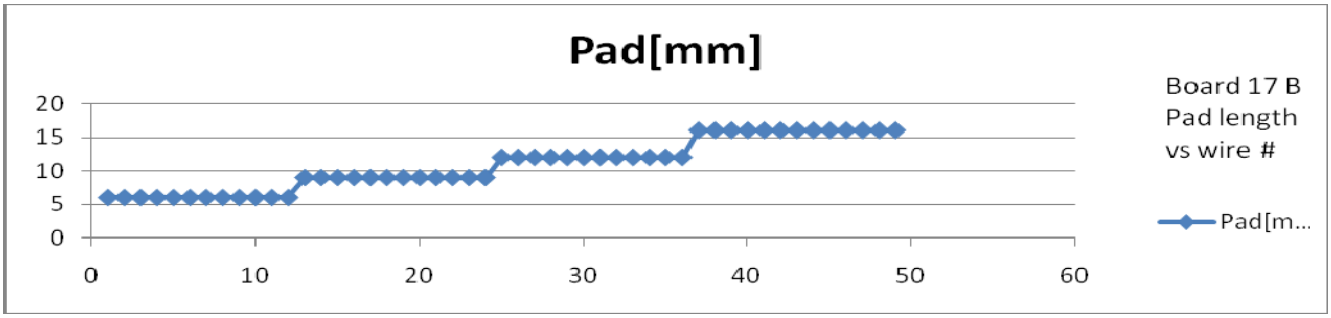

0.00
-20.00
-40.00
-60.00
-80.00
-100.00
-120.00
-140.00
-160.00
-180.00
0
10
20
30
40
50
60
Creep [micron]
Board 16 B
8/14/
08

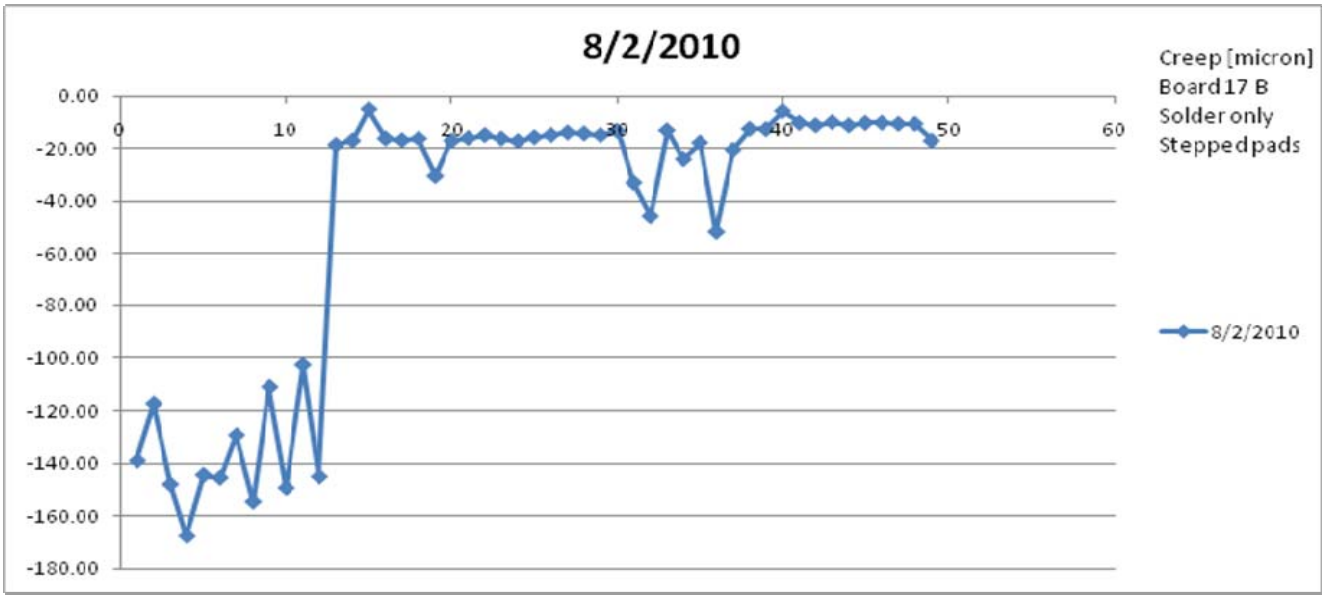

3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
10
20
30
40
50
60
Tension [#]
Board 17 A
Solder only
Stepped pads
7/8/08
8/2/10

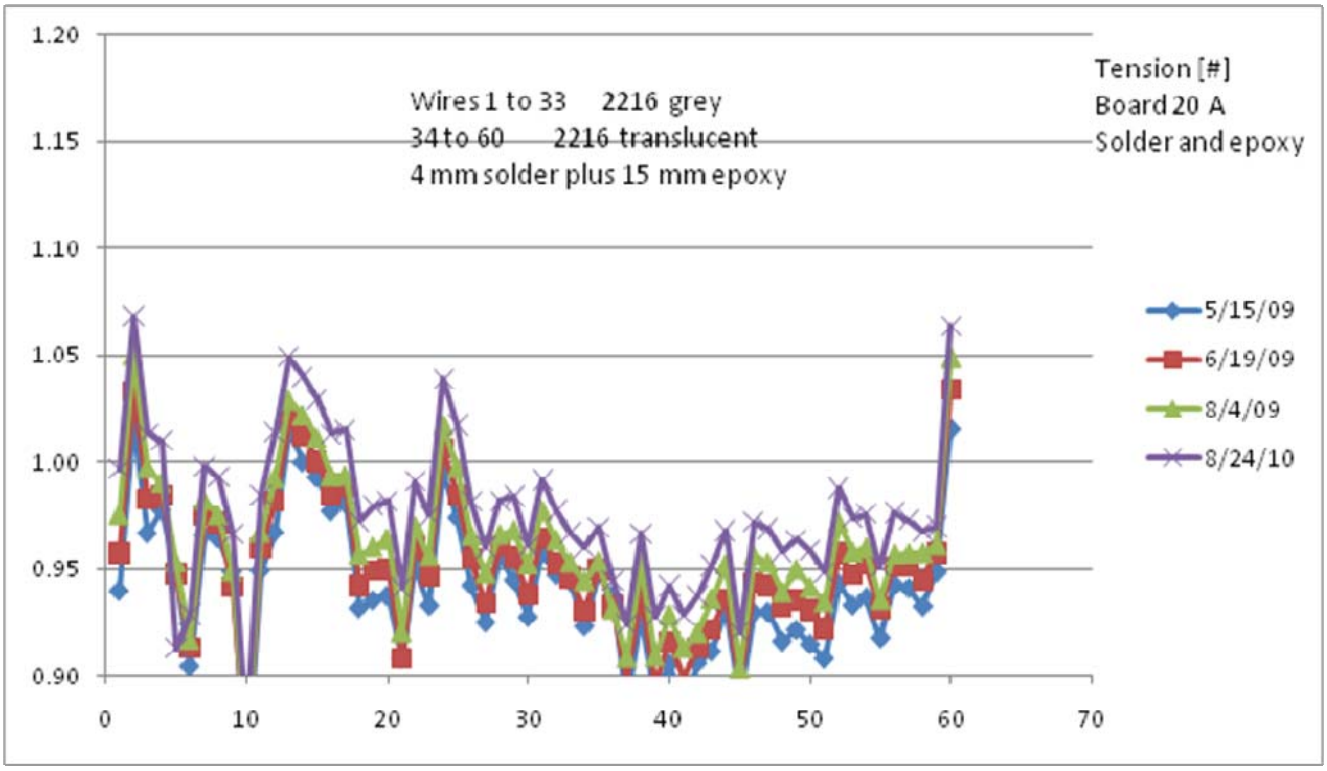

Pad[mm]
20
15
10
5
0
0
10
20
30
40
50
60
Board 17 A
Pad length
vs wire #
Pad[mm]

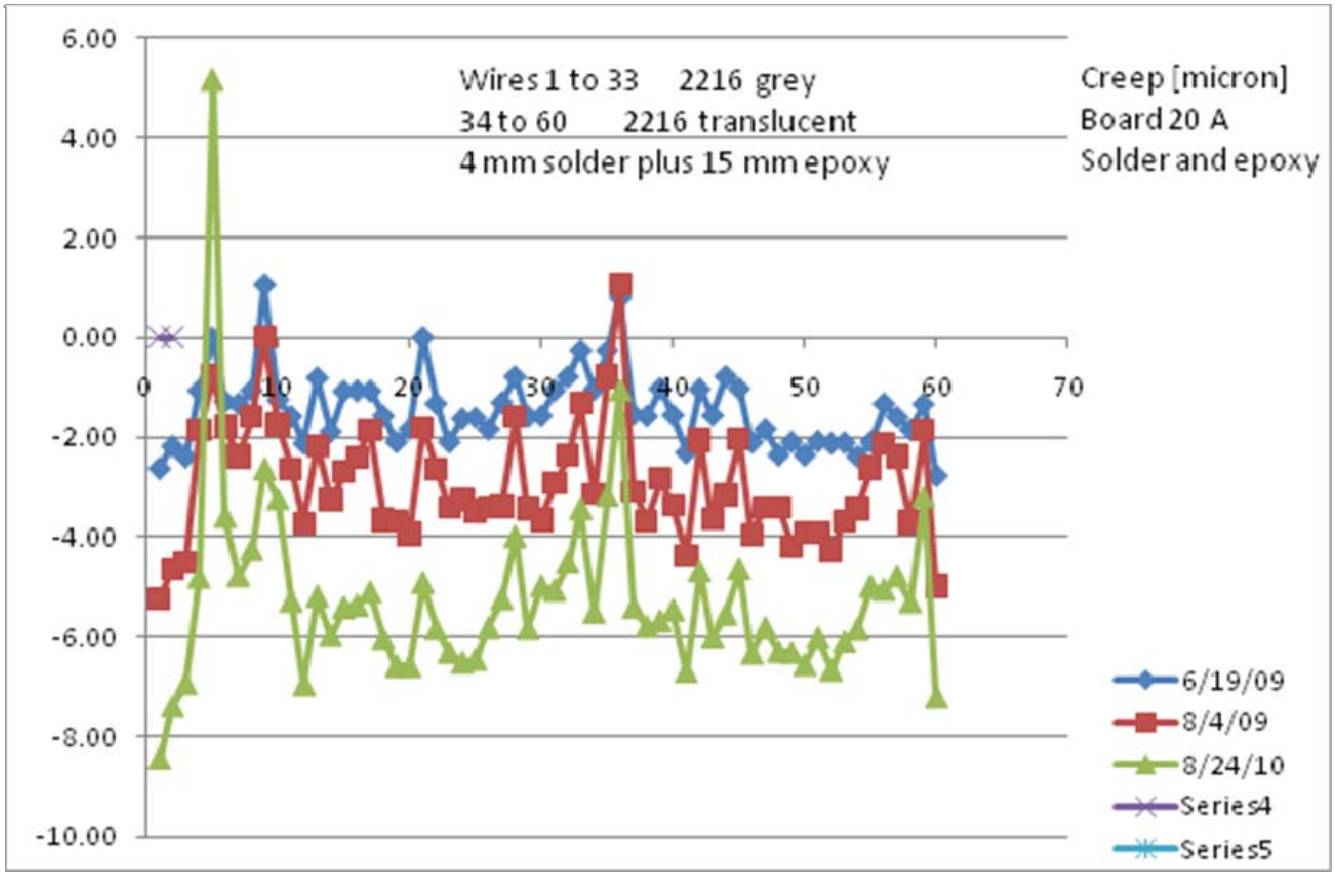

8/2/10
0.00
-20.00
-40.00
-60.00
-80.00
-100.00
-120.00
-140.00
-160.00
-180.00
0
10
20
30
40
50
60
Creep [micron]
Board 17 A
Solder only
Stepped pads
8/2/10

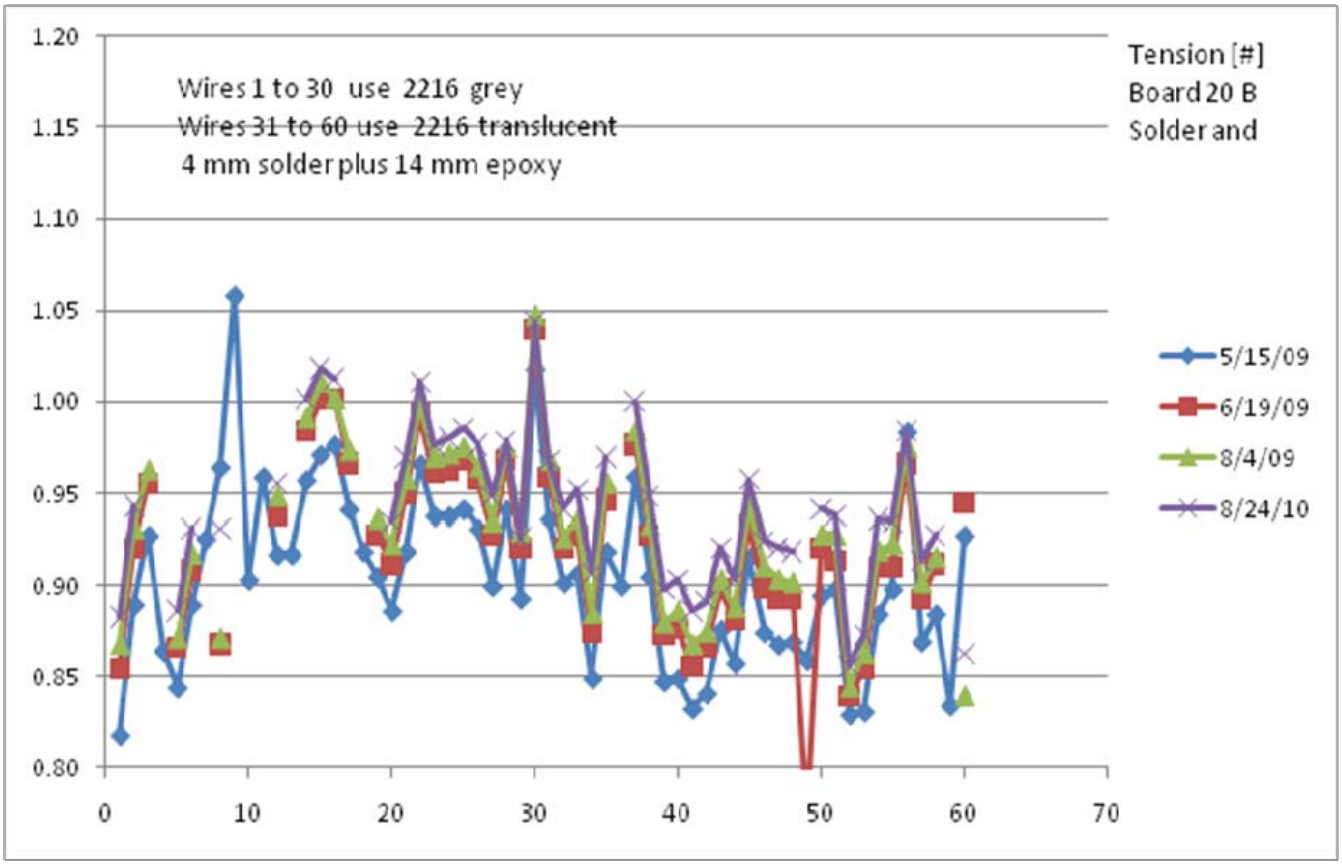

3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
10
20
30
40
50
60
Tension [#]
Board 17 B
Solder only
Stepped pads
7/8/2008
8/2/2010

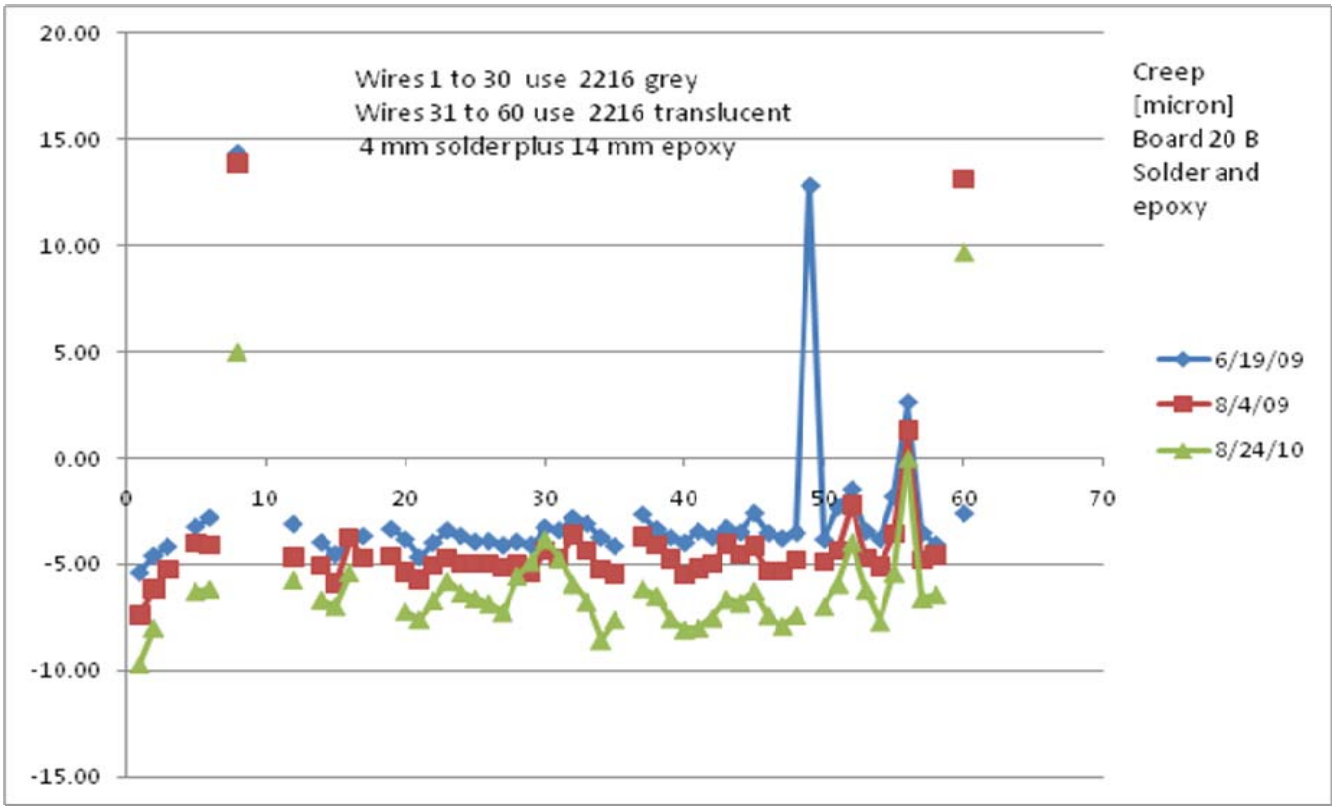

Pad[mm]
20
15
10
5
0
0
10
20
30
40
50
60
Board 17 B
Pad length
vs wire #
Pad[m...

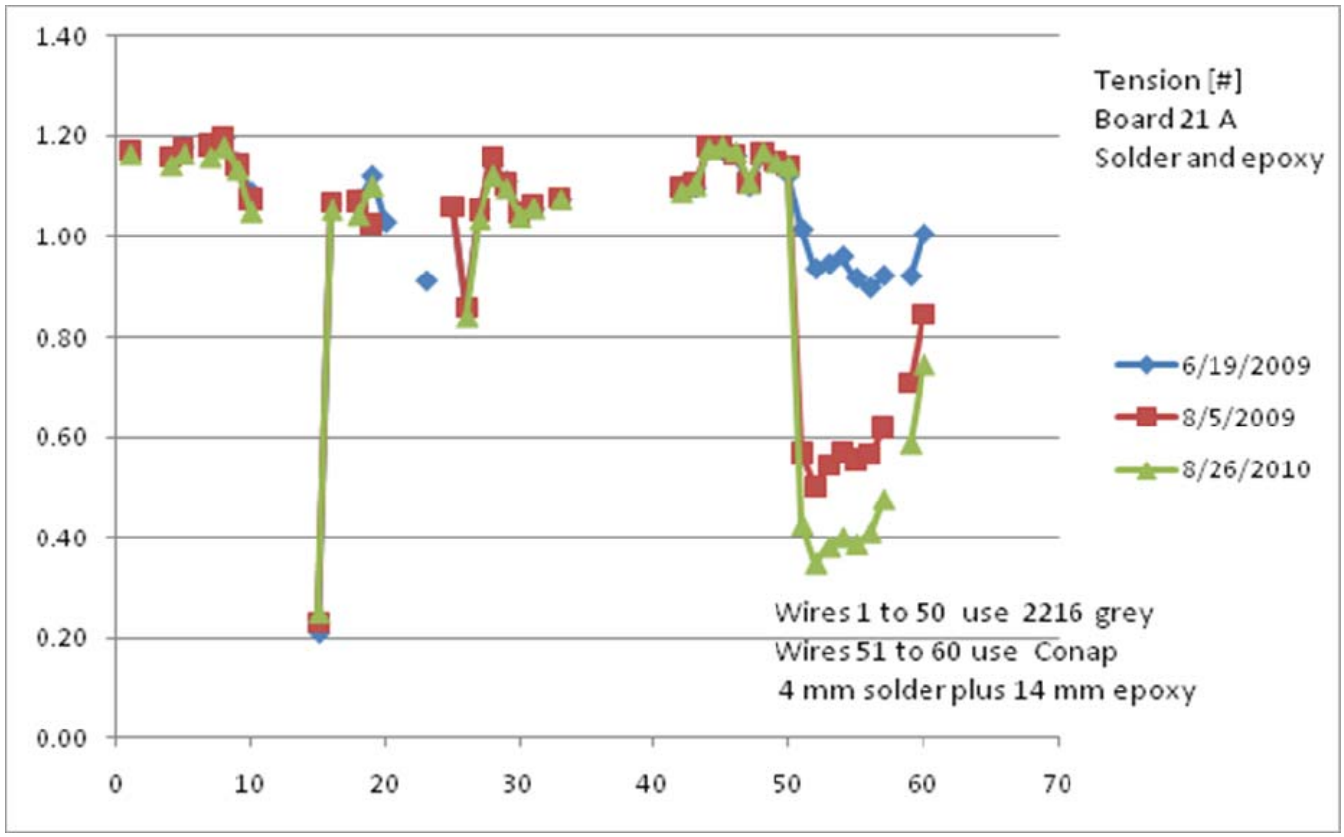

8/2/2010
0.00
-20.00
-40.00
-60.00
-80.00
-100.00
-120.00
-140.00
-160.00
-180.00
0
10
20
30
40
50
60
Creep [micron]
Board 17 B
Solder only
Stepped pads
8/2/2010

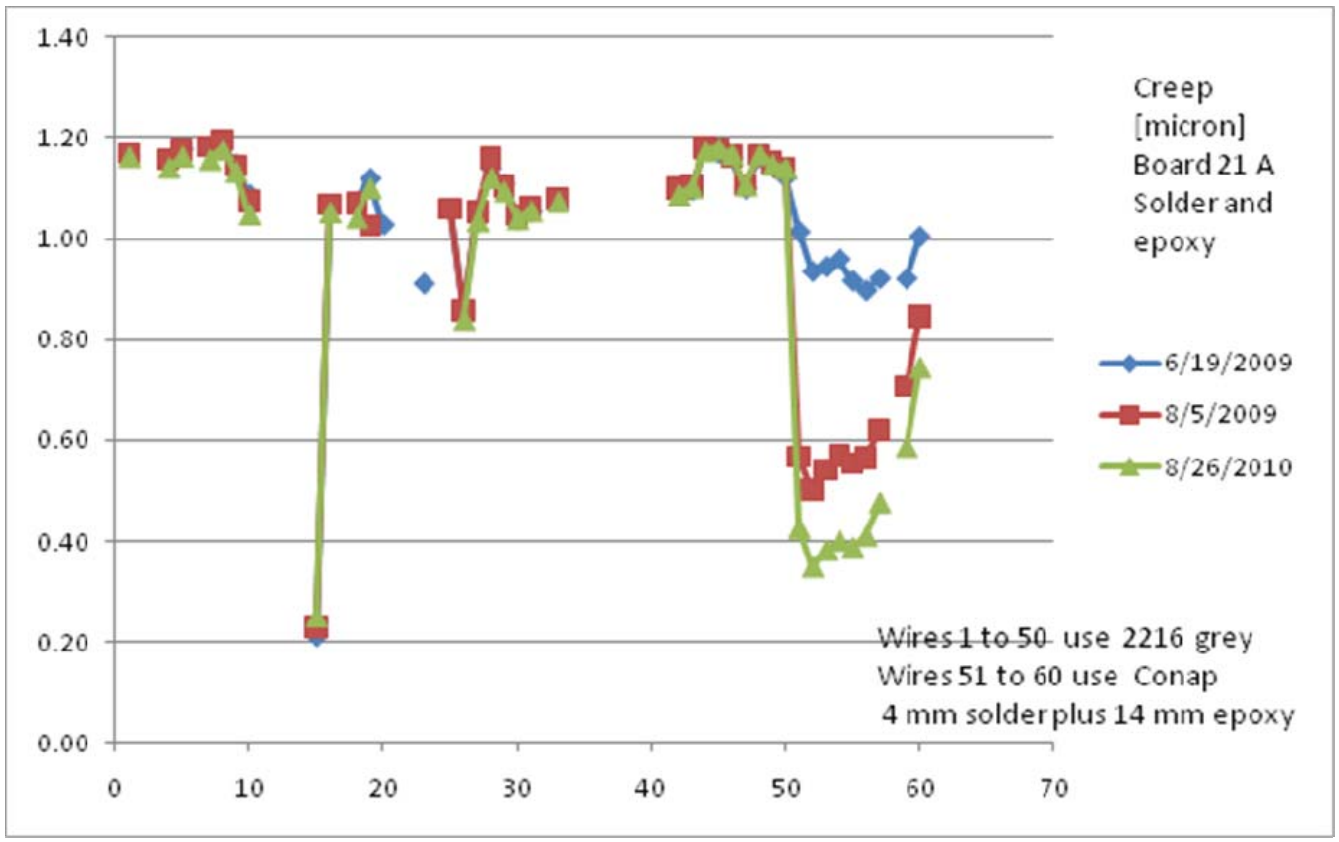

Wires 1 to 33 2216 grey
34 to 60 2216 translucent
4 mm solder plus 15 mm epoxy
Tension [#]
Board 20 A
Solder and epoxy
5/15/09
6/19/09
8/4/09
8/24/10
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0
10
20
30
40
50
60
70

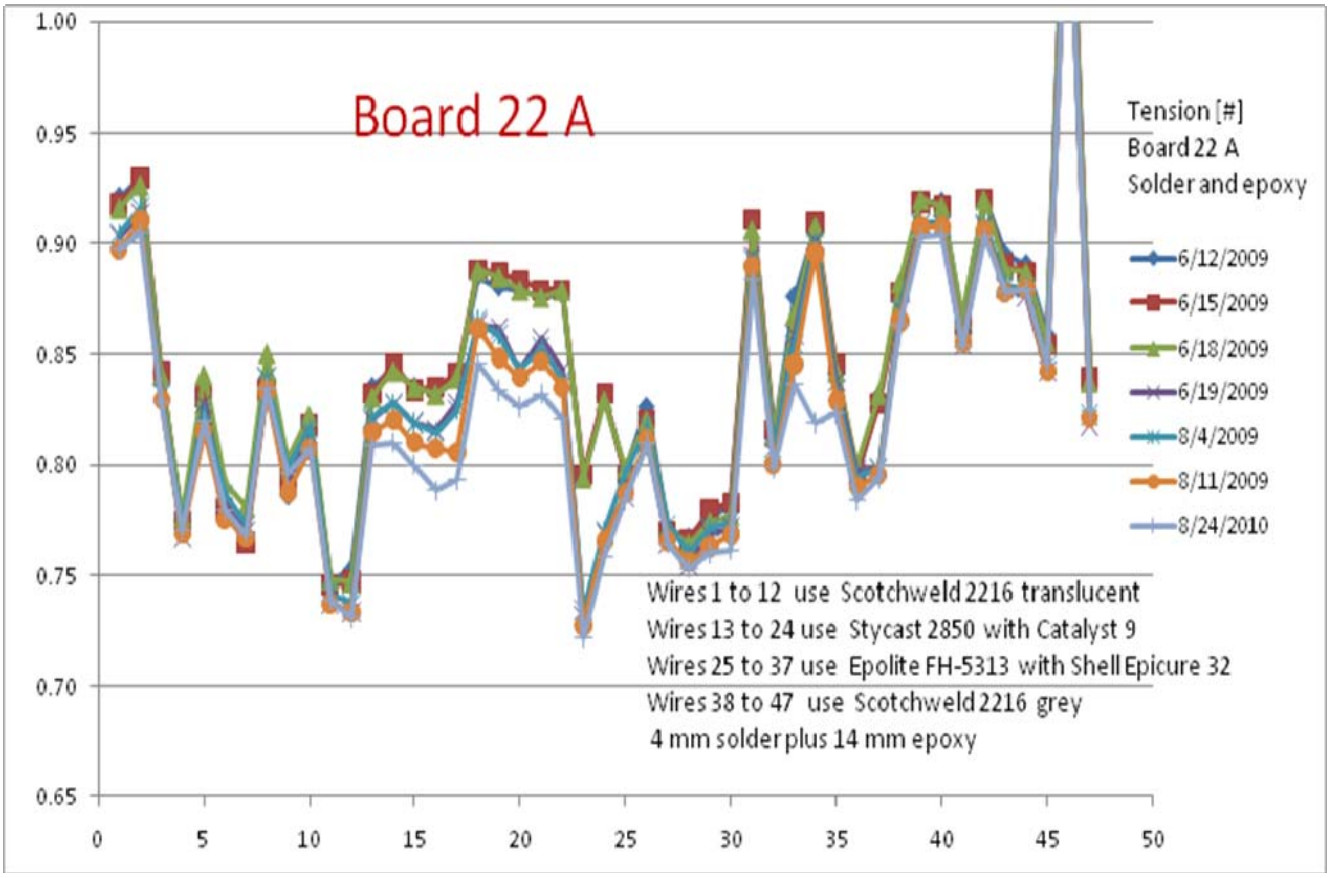

Wires 1 to 33 2216 grey
34 to 60 2216 translucent
4 mm solder plus 15 mm epoxy
Creep [micron]
Board 20 A
Solder and epoxy
6/19/09
8/4/09
8/24/10
Series4
Series5
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
0
10
20
30
40
50
60
70

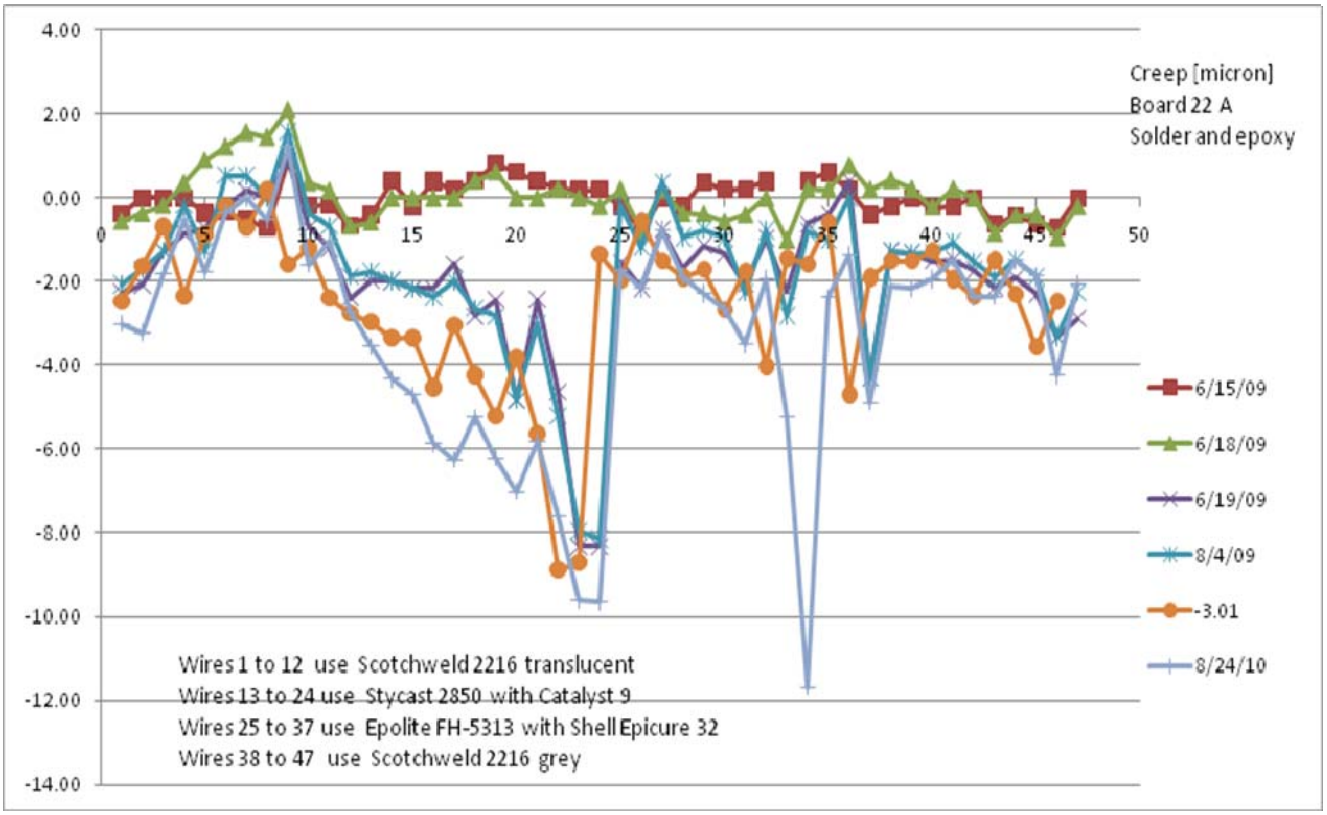

Wires 1 to 30 use 2216 grey
Wires 31 to 60 use 2216 translucent
4 mm solder plus 14 mm epoxy
Tension [#]
Board 20 B
Solder and
5/15/09
6/19/09
8/4/09
8/24/10
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0
10
20
30
40
50
60
70

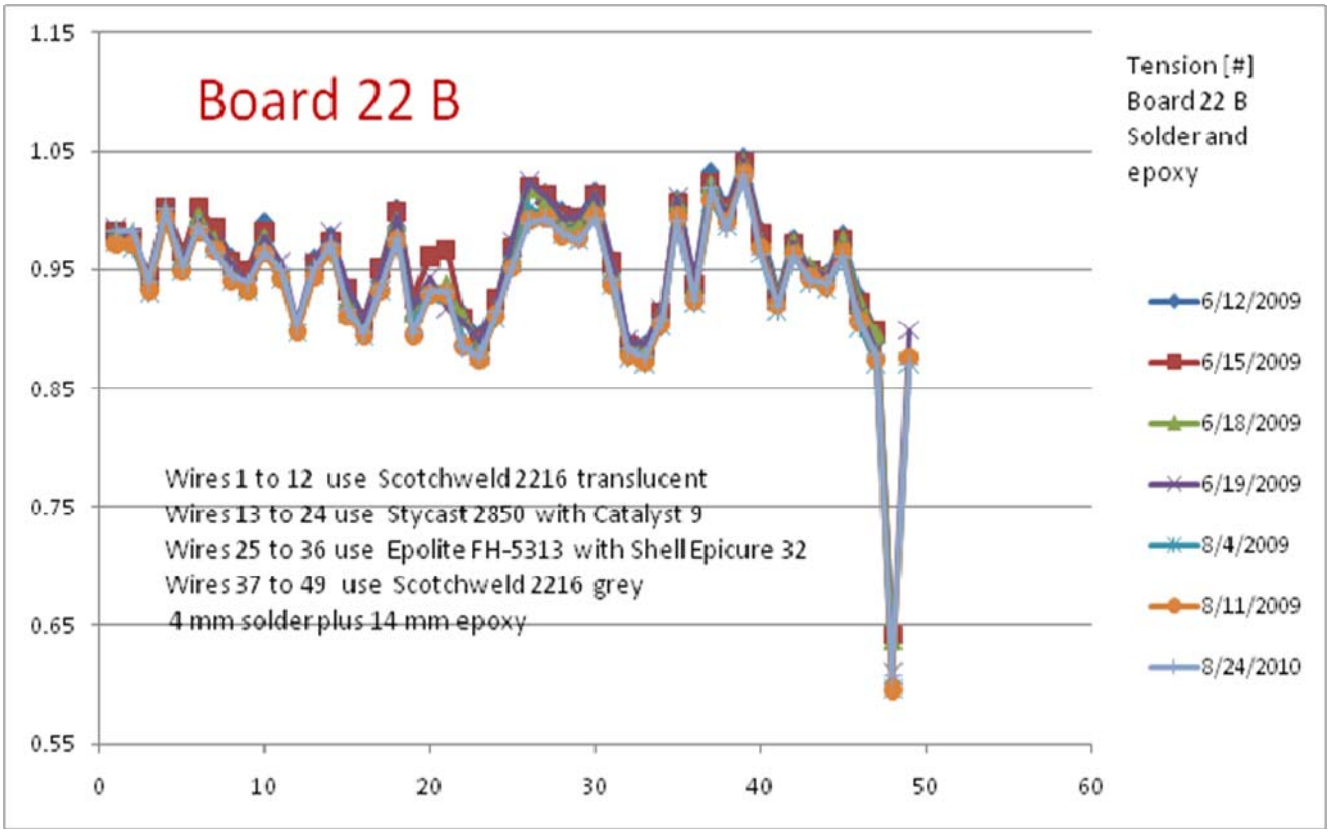

Wires 1 to 30 use 2216 grey
Wires 31 to 60 use 2216 translucent
4 mm solder plus 14 mm epoxy
Creep
[micron]
Board 20 B
Solder and
epoxy
6/19/09
8/4/09
8/24/10
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
-15.00
0
10
20
30
40
50
60
70

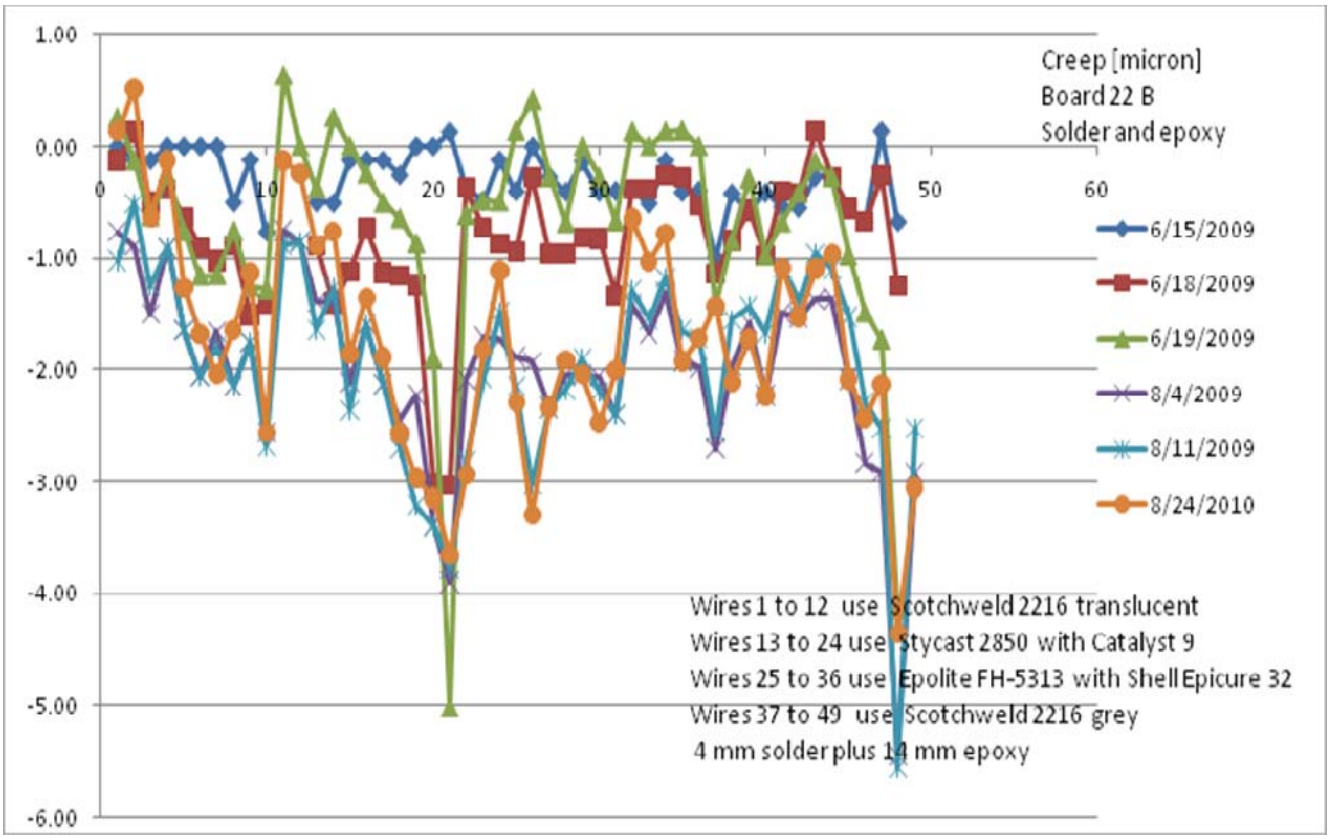

1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
10
20
30
40
50
60
70
Tension [#]
Board 21 A
Solder and epoxy
6/19/2009
8/5/2009
8/26/2010
Wires 1 to 50 use 2216 grey
Wires 51 to 60 use Conap
4 mm solder plus 14 mm epoxy

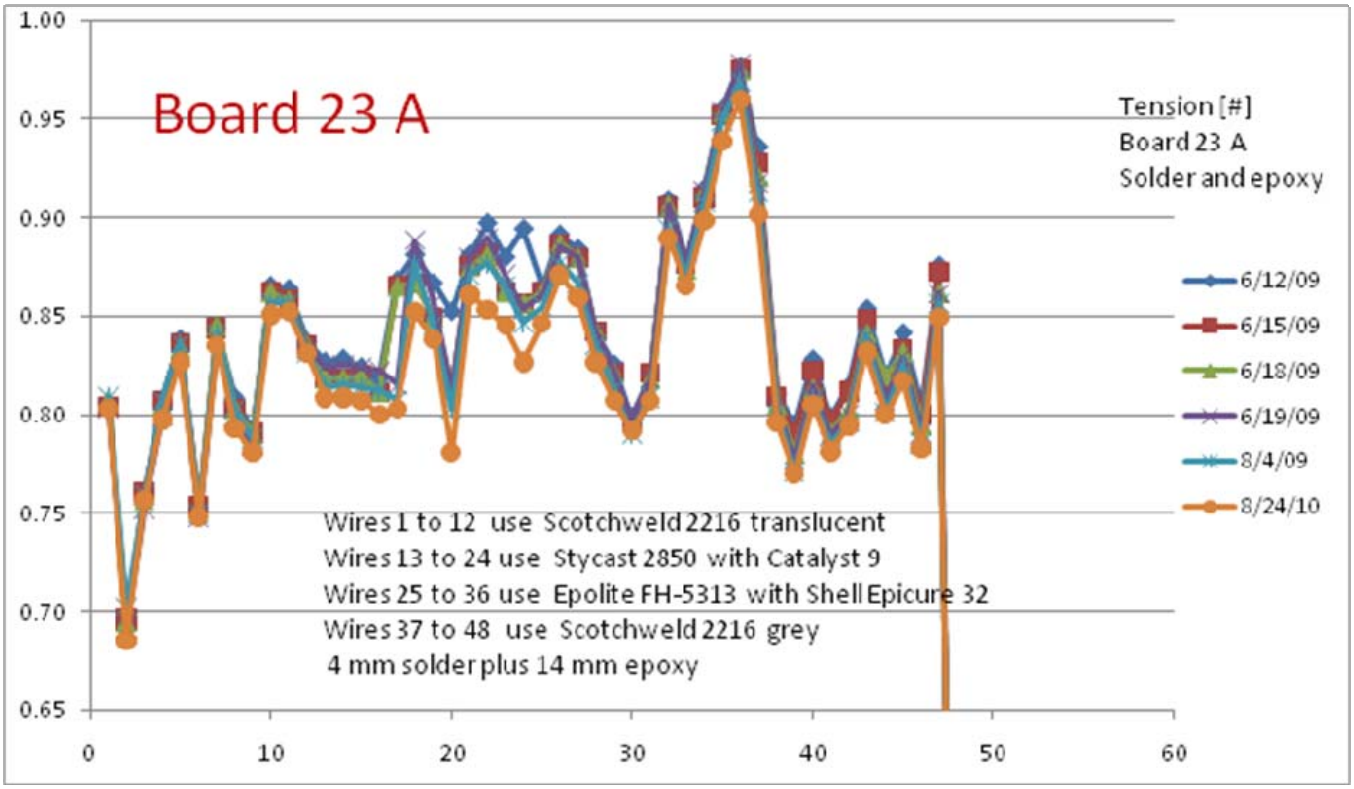

1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
10
20
30
40
50
60
70
Creep
[micron]
Board 21 A
Solder and
epoxy
6/19/2009
8/5/2009
8/26/2010
Wires 1 to 50 use 2216 grey
Wires 51 to 60 use Conap
4 mm solder plus 14 mm epoxy

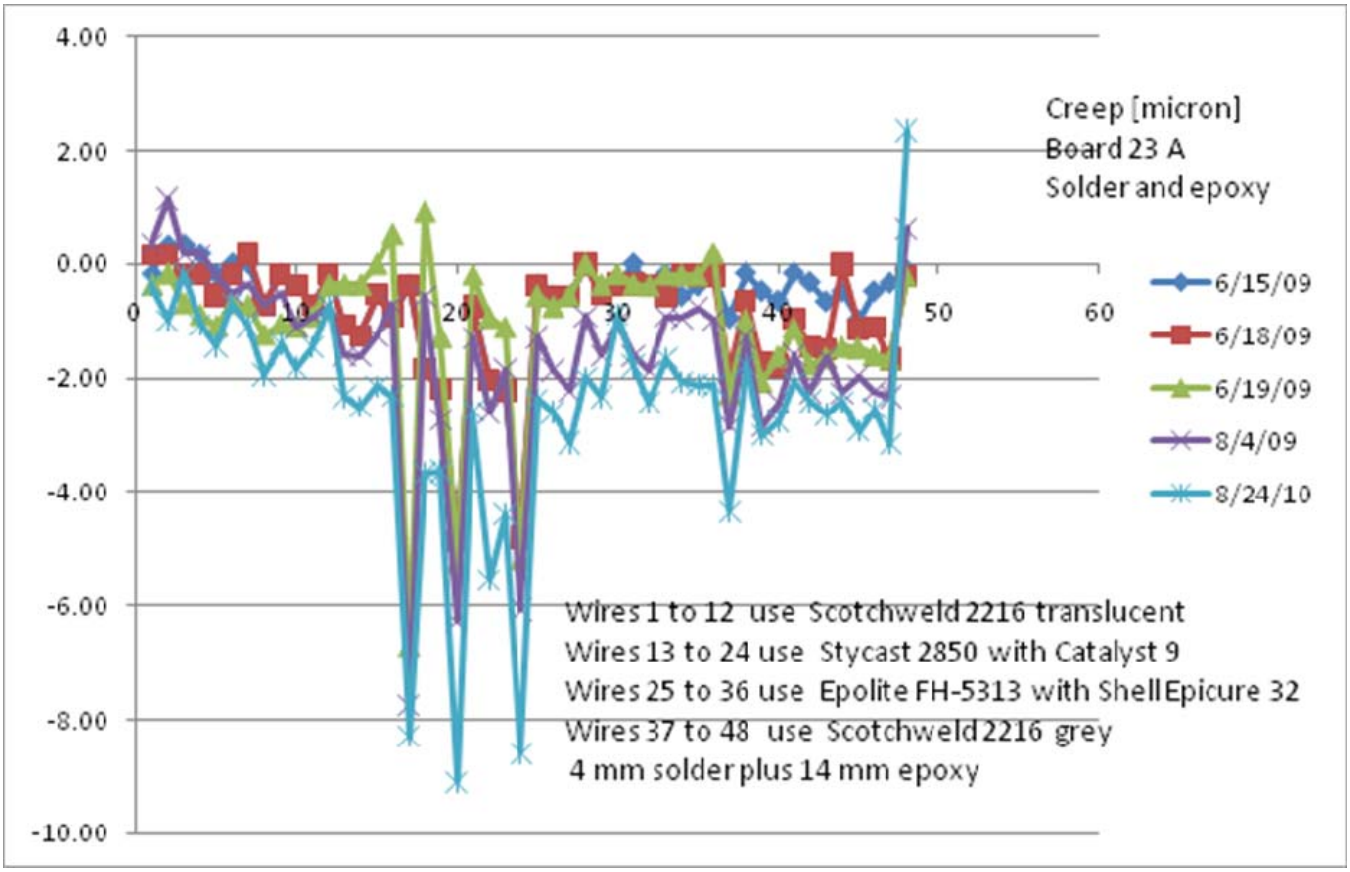

Board 22 A
Tension [#]
Board 22 A
Solder and epoxy
6/12/2009
6/15/2009
6/18/2009
6/19/2009
8/4/2009
8/11/2009
8/24/2010
Wires 1 to 12 use Scotchweld 2216 translucent
Wires 13 to 24 use Stycast 2850 with Catalyst 9
Wires 25 to 37 use Epolite FH-5313 with Shell Epicure 32
Wires 38 to 47 use Scotchweld 2216 grey
4 mm solder plus 14 mm epoxy
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0
5
10
15
20
25
30
35
40
45
50

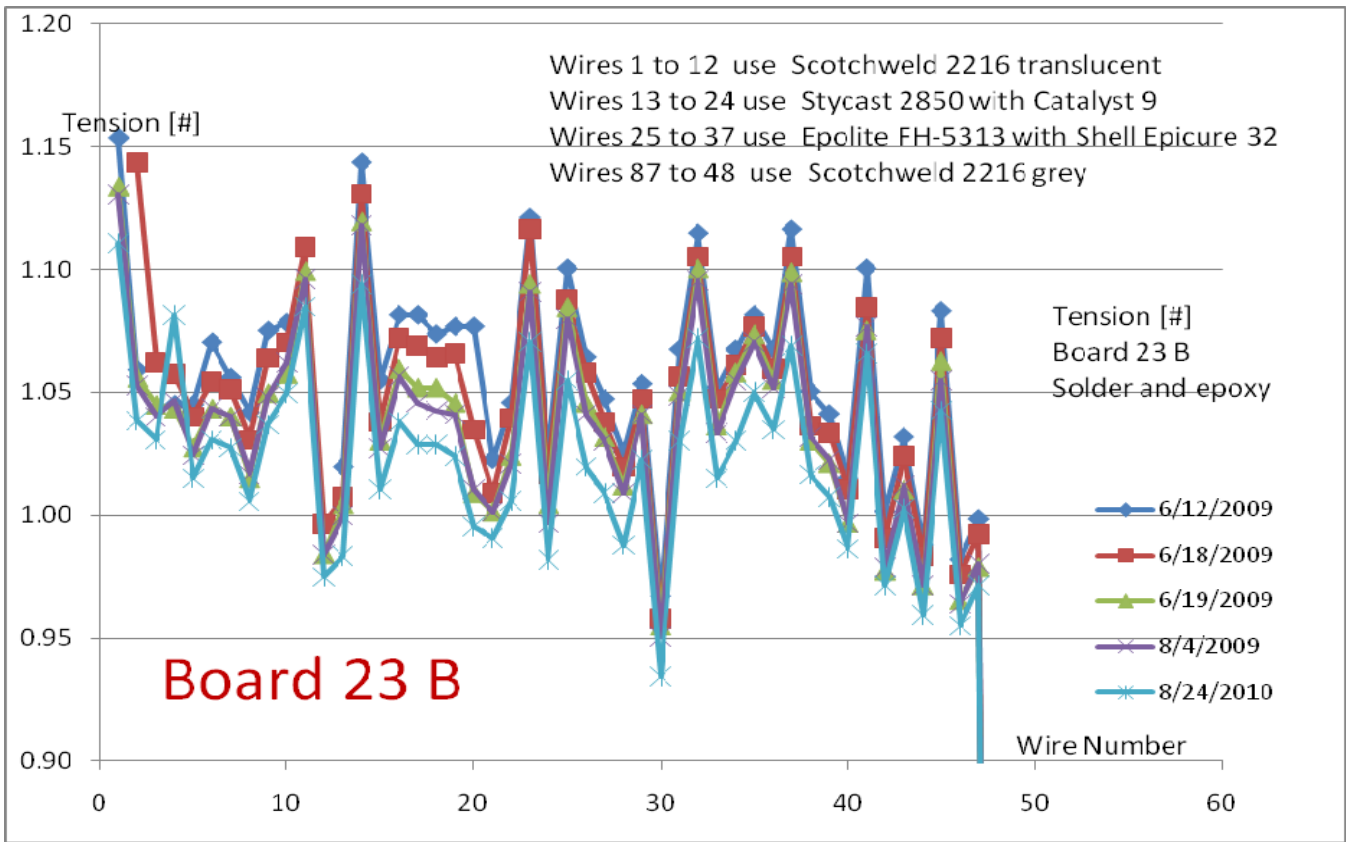

Creep [micron]
Board 22 A
Solder and epoxy
6/15/09
6/18/09
6/19/09
8/4/09
-3.01
8/24/10
Wires 1 to 12 use Scotchweld 2216 translucent
Wires 13 to 24 use Stycast 2850 with Catalyst 9
Wires 25 to 37 use Epolite FH-5313 with Shell Epicure 32
Wires 38 to 47 use Scotchweld 2216 grey
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
-14.00
0
5
10
15
20
25
30
35
40
45
50

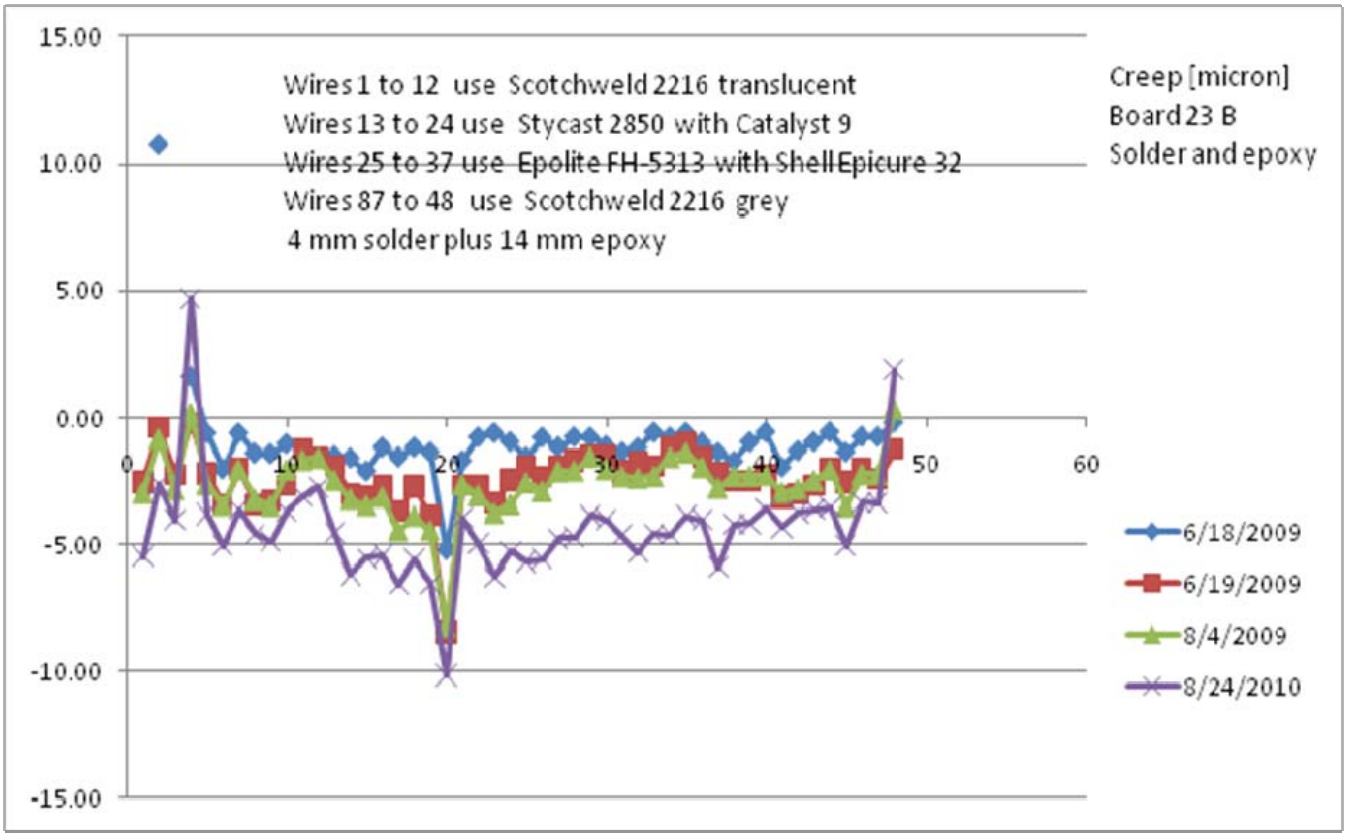

Board 22 B
Tension [#]
Board 22 B
Solder and
epoxy
6/12/2009
6/15/2009
6/18/2009
6/19/2009
8/4/2009
8/11/2009
8/24/2010
Wires 1 to 12 use Scotchweld 2216 translucent
Wires 13 to 24 use Stycast 2850 with Catalyst 9
Wires 25 to 36 use Epolite FH-5313 with Shell Epicure 32
Wires 37 to 49 use Scotchweld 2216 grey
4 mm solder plus 14 mm epoxy
1.15
1.05
0.95
0.85
0.75
0.65
0.55
0
10
20
30
40
50
60


Creep [micron]
Board 22 B
Solder and epoxy
6/15/2009
6/18/2009
6/19/2009
8/4/2009
8/11/2009
8/24/2010
Wires 1 to 12 use Scotchweld 2216 translucent
Wires 13 to 24 use Stycast 2850 with Catalyst 9
Wires 25 to 36 use Epolite FH-5313 with Shell Epicure 32
Wires 37 to 49 use Scotchweld 2216 grey
4 mm solder plus 14 mm epoxy
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
0
10
20
30
40
50
60


Board 23 A
Tension [#]
Board 23 A
Solder and epoxy
6/12/09
6/15/09
6/18/09
6/19/09
8/4/09
8/24/10
Wires 1 to 12 use Scotchweld 2216 translucent
Wires 13 to 24 use Stycast 2850 with Catalyst 9
Wires 25 to 36 use Epolite FH-5313 with Shell Epicure 32
Wires 37 to 48 use Scotchweld 2216 grey
4 mm solder plus 14 mm epoxy
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0
10
20
30
40
50
60


Creep [micron]
Board 23 A
Solder and epoxy
6/15/09
6/18/09
6/19/09
8/4/09
8/24/10
Wires 1 to 12 use Scotchweld 2216 translucent
Wires 13 to 24 use Stycast 2850 with Catalyst 9
Wires 25 to 36 use Epolite FH-5313 with Shell Epicure 32
Wires 37 to 48 use Scotchweld 2216 grey
4 mm solder plus 14 mm epoxy
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
0
10
20
30
40
50
60


Wires 1 to 12 use Scotchweld 2216 translucent
Wires 13 to 24 use Stycast 2850 with Catalyst 9
Wires 25 to 37 use Epolite FH-5313 with Shell Epicure 32
Wires 87 to 48 use Scotchweld 2216 grey
Tension [#]
Board 23 B
Solder and epoxy
Tension [#]
Board 23 B
Solder and epoxy
6/12/2009
6/18/2009
6/19/2009
8/4/2009
8/24/2010
Wire Number
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0
10
20
30
40
50
60


Wires 1 to 12 use Scotchweld 2216 translucent
Wires 13 to 24 use Stycast 2850 with Catalyst 9
Wires 25 to 37 use Epolite FH-5313 with Shell Epicure 32
Wires 87 to 48 use Scotchweld 2216 grey
4 mm solder plus 14 mm epoxy
Creep [micron]
Board 23 B
Solder and epoxy
6/18/2009
6/19/2009
8/4/2009
8/24/2010
15.00
10.00
5.00
0.00
-5.00
-10.00
-15.00
0
10
20
30
40
50
60