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NASA-DoD Lead-Free Electronics Project
IST Evaluation of Reliability

Thirty-three coupons were received and subjected to incoming inspection and prescreening prior to an Internal Stress Test (IST) evaluation for reliability. The coupons were identified with three digit numbers, sequentially starting with 121 through 153.

The IST test coupon TV06060 is designed with two discreet sets of test circuits P1/S1 and P2/S2. This is a six layer coupon with the power circuit P1 and sense circuit S1 drilled at .008" on a .040" grid. Power circuit P2 and sense circuit S2 drilled at .008" on a .032" grid. All interconnections are plated through holes (PTH).

At prescreening the resistances of all coupons were measured and found to be within acceptable limit for an IST evaluation. Capacitance measurements were taken and found to be too low (30 pF to 40 pF) to be sensitive to material changes. Registration varied by .004" +/- .001".

The coupons were segregated into groups. Eighteen coupons were tested on the .040" P1/S1 circuits. Six coupons were tested "as received" (control) and six coupons were tested after preconditioning three time to 230°C (3X230°C, tin/lead assembly simulation) and six coupons were test after precondition three times to 260°C (3X260°C, lead-free assembly simulation). Fifteen coupons were tested on the .040" P2/S2 circuits. Five coupons were tested "as received" (control) and five coupons were tested after preconditioning three time to 230°C (3X230°C, tin/lead assembly simulation) and five coupons were test after precondition three times to 260°C (3X260°C, lead-free assembly simulation).

Testing was performed by powering on the power circuit P1 or P2 and monitoring the sense circuit S1 or S2 respectively. The coupons were tested to 150°C heating in three minutes +/1 five seconds followed by cooling to ambient in approximately two minutes. Usually IST testing continues to failure or end of test at 500 cycles. In this case testing continued until any circuit exhibited a 10% increase in resistance or end of test at 1000 IST cycles.

The results suggested that these coupons are robust at 500 cycles. One group, coupons preconditioned 3X260°C had an early failure at three cycles (coupon 123). Based on a microsection evaluation (see below) the early failure was edited out of the data set. The .032" grid coupons were more robust than the .040" grid coupons. There were two failure modes presented in the data, power circuit failure which reflect failure

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at the internal interconnection and sense circuit failure which reflect failure in the barrel of the hole.

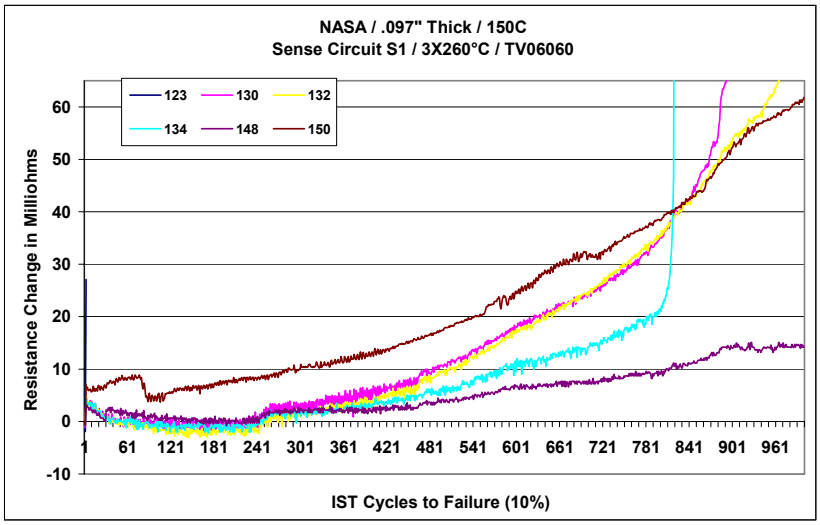
Overview of IST Cycles to Failure
Table 1

Overview of IST Cycles to Failure						
Circuits ->	P1/S1 - .040" Grid			P2/S2 .032" Grid		
Precon->	As Rec.	3X230°C	3X260°C	As Rec.	3X230°C	3X260°C
Mean	988	737	950	1000	967	1000
Std Dev	31	144	74	0	75	0
Min	925	619	*3	1000	833	1000
Max	1000	1000	1000	1000	1000	1000
Range	75	381	180	0	167	0
Coef Var	3.1%	19.6%	7.8%	0.0%	7.7%	0.0%
Failed On	S1	S1/P1	S1	N/A	P2	N/A

* Data edited out of the results

Resistance graphs were processed for all test groups. The resistance graph demonstrates the damage accumulation (increase in resistance) at maximum test temperature (150°C) which is plotted against thermal cycles. The graphs generally demonstrated that most coupons exhibited a gradual increase in resistance until failure. Coupons that failed on the power circuit were more prone to accelerated damage accumulation after approximately 3% increase in resistance. The sample graph 1, coupons 134 in light blue, demonstrates an acceleration in damage accumulation after ~3% increase in resistance while the other circuit failed at a steady rate.

Typical Resistance Graph Power Circuit S1 – 3X260°C - .040" Grid
Graph 1



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Four microsections were processed:

1. Coupon 123, tested as received, failed S1 in 3 IST cycles,
2. Coupon 146, preconditioned 3X230°C, failed S1 in 618 IST cycles
3. Coupon 128, preconditioned 3X230°C, failed P1 in 833 IST cycles
4. Coupon 137, preconditioned 3X260°C, no failure 1000 IST cycles (end of test)

Microscopic review and failure analysis revealed three conditions of concern: thin platting, barrel cracks due to metal fatigue and cohesive delamination.

Thin Copper: Thin electrolytic copper in the barrel of the PTH is a primary influence in coupon reliability. Coupon 123 failed in three thermal cycles due to thin copper and plating voids. Coupons with very low copper, even if they pass electrical test (ET), tend to fail catastrophically in a few IST cycles. This has been classified as an "infant mortality" failure for the purpose of this study.

XS# 3727 – Coupon 123, Failed S1, Three IST Cycles, Tested As Received

Photo 1

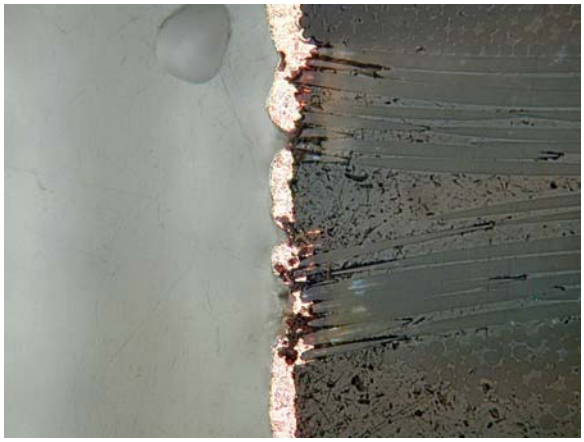
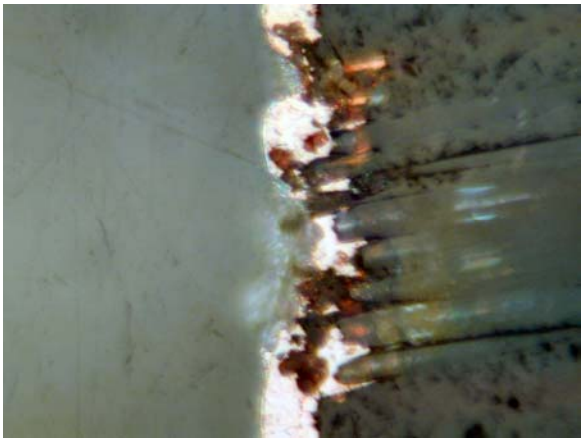


Photo 2



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Metal Fatigue Barrel Cracks *– Metal fatigue type barrel cracks are a wear out mechanism. The crack usually develops over time and transverse the copper of the interconnect at a 20 to 50 degree angle. A metal fatigue crack will typically propagate between copper crystals. These cracks are frequently closed at ambient. This type of failure mode is consistent with slowly accumulating resistance that does not accelerate during the life of the test. Robust coupons which survive thousands of IST cycles will present this failure mode.*

Coupon 128 and 146 were preconditioned 3X230°C and demonstrated the typical metal fatigue type of wear out failure that is associated with a robust coupon.

XS# 3737 – Coupon 146, Failed S1, 169 IST Cycles, Precon 3X230°C

Photo 3

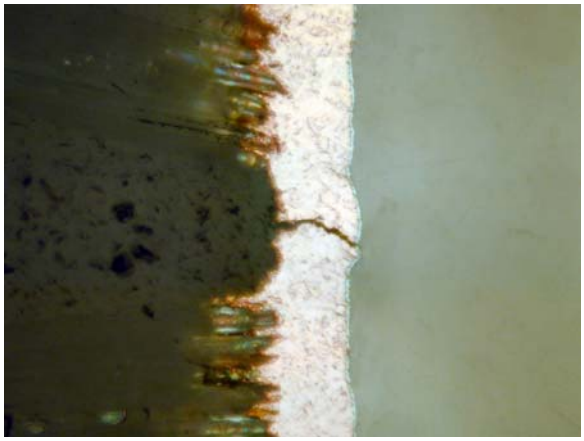
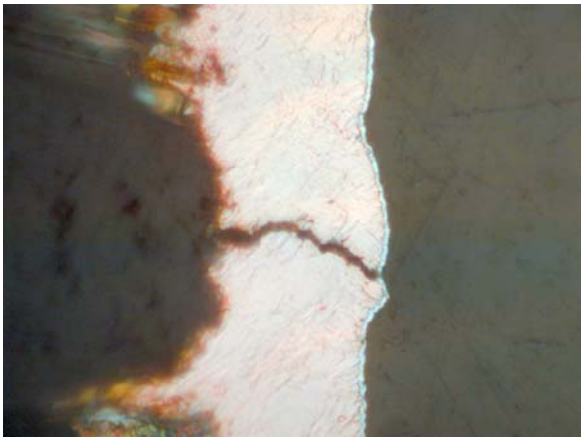


Photo 4



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Dielectric Degradation: *Z-axis expansion can cause materials to crack. These cracks are usually horizontal and can bridge between PTHs. The condition may cause a change in the electrical properties of the PWB or a path for conductive anodic filament (CAF) growth. There are two significant effects of delamination in reliability test results: stress focusing delamination and stress relieving delamination.*

> *"Stress focusing" delamination can have the effect of causing stresses to be focus into the barrel of the hole causing reduced IST cycles to failure. On occasion this type of failure may exhibit a condition where the delamination ends at a barrel crack. This is a relatively rare effect of material degradation.*
>
> *"Stress relieving" delamination can have the effect of reducing stress in the barrel of the hole causing an increase in IST cycles to failure. This type of failure is seen where the delamination does not end at a barrel crack. This is the most common effects of delamination.*

Recently we have been categorizing delamination into groups including cohesive, adhesive, decomposition and crazing.

Cohesive Degradation; *Cohesive degradation is the breakdown of the chemistry of a material. This condition is usually found internally within a dielectric layer rather than at material interfaces. The crack produces acute angles and ends in a sharp point. This type of delamination may traverse "B" and "C" stage layers.*

Adhesive Delamination: *Adhesive Delamination may be predominately a mechanical failure that occurs at the interface of the epoxy to glass or "B" stage to "C" stage, epoxy to glass or epoxy to copper (oxide coating). There is usually a visible interface that the crack follows and the delamination stays within it own layer. Viewed in a cross section this delamination may be bulging in the center and end in sharp point or the a micro-thin line that follow the exact topography of the edge of a glass bundle*

Material decomposition: *This condition looks like bubbles in the dielectric. The bubbles are around and may have cracks associated with them that appear to provide a path for out gassing to an internal pad or barrel of the PTH. The material may appear carbonized.*

Crazing: *Crazing is a separation between individual glass fibers and the epoxy. It presents a glass bundle with a silver sheen. There may be copper wicking associated with crazing that is continuous with the edge of the drilled hole.*

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Coupon 137 did not fail by end of test at 1000 IST cycles. Microscopic evaluation demonstrated that this coupon presented a cohesive degradation of the dielectric material. Since this condition did not degrade the power or sense circuits in the IST coupon it is assumed that this condition was stress relieving.

XS# 3739 – Coupon 137, No Failure, 1000 IST Cycles, Precon 3X230°C

Photo 5

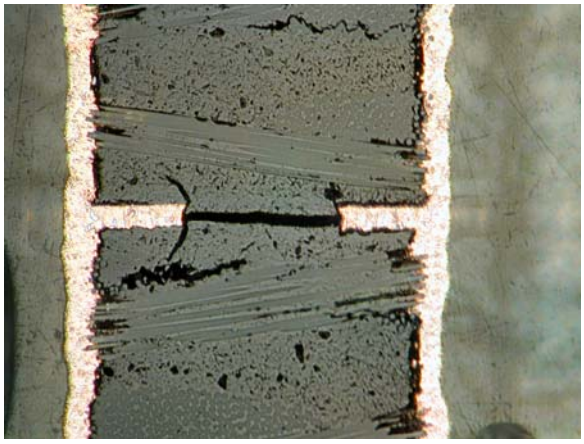

Photo 6

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Conclusion and Considerations:

1. Thin copper plating observed in coupon 123 is a quality liability. Boards with thin plating will be likely to fail during assembly or after a few thermal cycles. This catastrophic failure should occur within tens of thermal cycles making the condition easily identifiable in test data. If early failure occurs the reading could reasonably be edited out of the data with the justification that this condition is not a reflection of lead free assembly but rather a process variation.
2. The barrel cracks observed in the two coupons that were preconditioned to tin-lead assembly temperatures (3X230°C) present the typical failure mode found in robust coupons that survive thousands of cycles. If the test boards fail in this manor the results would be considered to offer a fair comparison between tin-lead and lead-free assembly and rework.
3. Capacitance measurements made on the coupon in the 30 pF range, which is too low to be sensitive to delamination and material degradation.
4. Coupon 137, preconditioned 3X260°C, had no failure in 1000 cycles but demonstrated cohesive degradation of the dielectric. Cohesive degradation may have artificially extended the thermal cycles to failure. Since capacitance measurements were found to be too low to be effective in the coupons, microsections will be required to be used as a referee for the presents of delamination. If boards are found to have extended cycles to failure after more aggressive assembly and rework than control boards or boards with less aggressive assembly and rework then delamination should be suspected and microsections processed.
5. Based on IST testing it appears the dielectric is susceptible to material failure in a lead free environment. This condition should not degrade the “electrical” reliability of the test vehicle but it may change the stresses expressed in the BGA. Our experience with delamination is limited to PWBs; we do not have experience in how internal material delamination will affect solder joints in BGAs or other components.

Respectfully submitted,

Paul Reid

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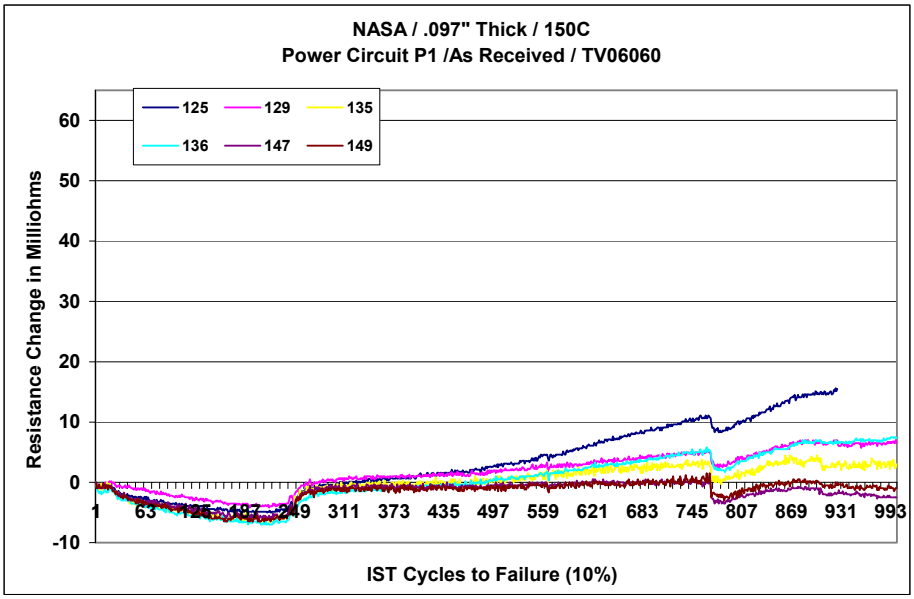
ISO 9001 : 2000

IST Data – E07_0082

IST Cycles to Failure – As Received – P1/S1 - .040" Grid
Table 2

IST Cycles to Failure - As Received - .040" Grid						
Coupon	**P1**	**%**	**S1**	**%**	**Comb**	**%**
125	N/A	2.3	925	10	925	S1
129	1000	1	1000	1.7	1000	Accept
135	1000	0.4	1000	3	1000	Accept
136	1000	1.1	1000	1.5	1000	Accept
147	1000	-0.4	1000	-0.2	1000	Accept
149	1000	-0.1	1000	0.1	1000	Accept
Mean	**1000**	**1**	**988**	**3**	**988**	
Std Dev	0	1	31	4	31	
Min	1000	0	925	0	925	
Max	1000	2	1000	10	1000	
Range	0	3	75	10	75	
Coef Var	**0%**		**3%**		**3%**	

Resistance Graph Power Circuit P1 – As Received - .040" Grid
Graph 2



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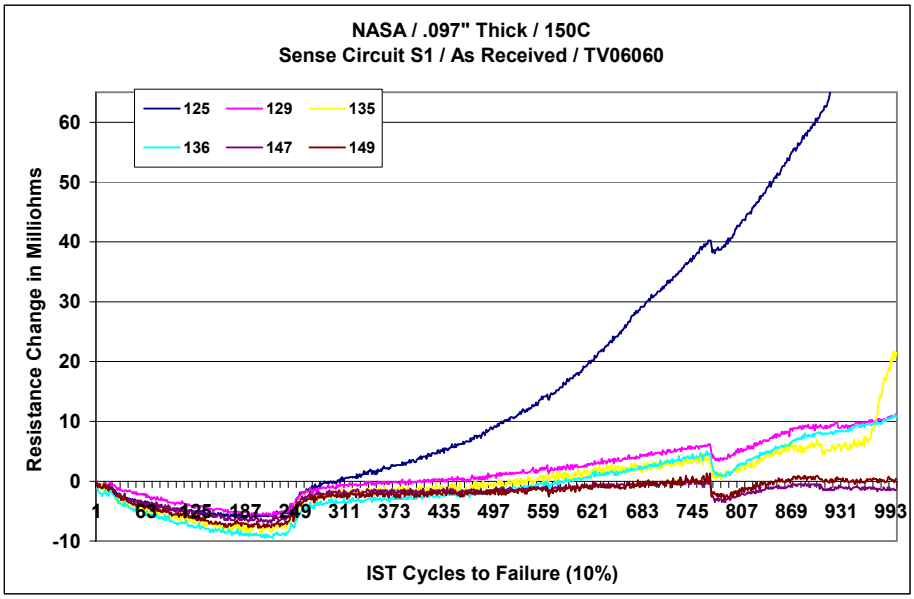
Resistance Graph Power Circuit S1 – As Received - .040" Grid
Graph 3



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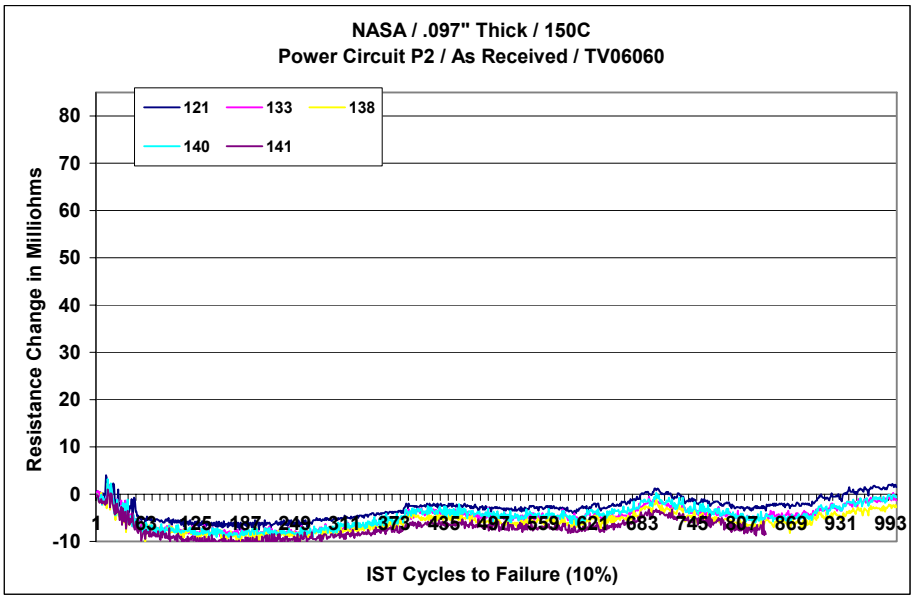
IST Cycles to Failure – As Received – P2/S2 - .032" Grid
Table 3

IST Cycles to Failure - As Received - .032" Grid						
Coupon	**P1**	**%**	**S1**	**%**	**Comb**	**%**
121	1000	0.2	1000	1.4	1000	Accept
133	1000	-0.1	1000	0.2	1000	Accept
138	1000	-0.2	1000	-0.2	1000	Accept
140	1000	0	1000	0	1000	Accept
141	1000	0	N/A	-1.1	1000	Post
Mean	**1000**	**0**	**1000**	**0**	**1000**	
Std Dev	0	0	0	1	0	
Min	1000	0	1000	-1	1000	
Max	1000	0	1000	1	1000	
Range	0	0	0	3	0	
Coef Var	**0%**		**0%**		**0%**	

Resistance Graph Power Circuit P2 – As Received - .032" Grid
Graph 4



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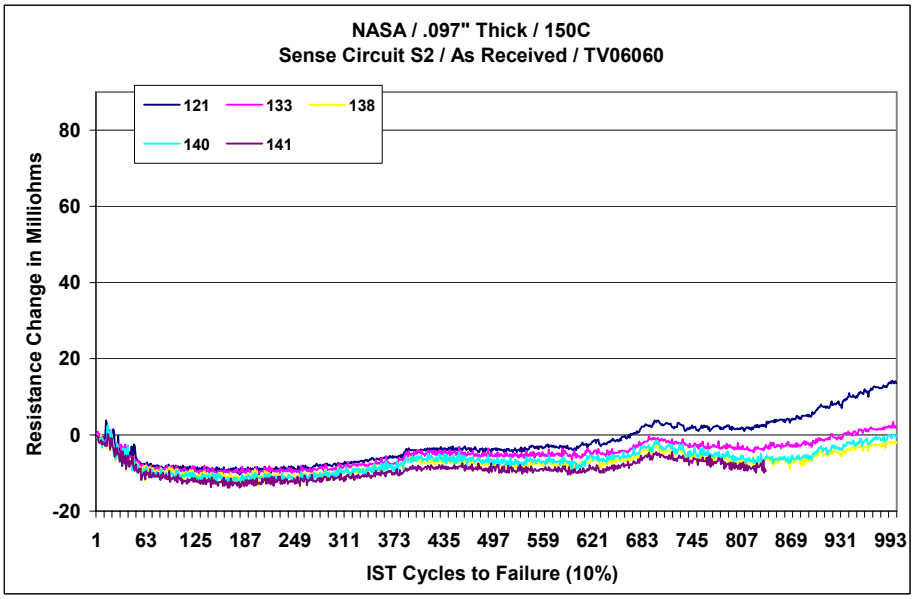
Resistance Graph Power Circuit S2 – As Received - .032" Grid
Graph 5



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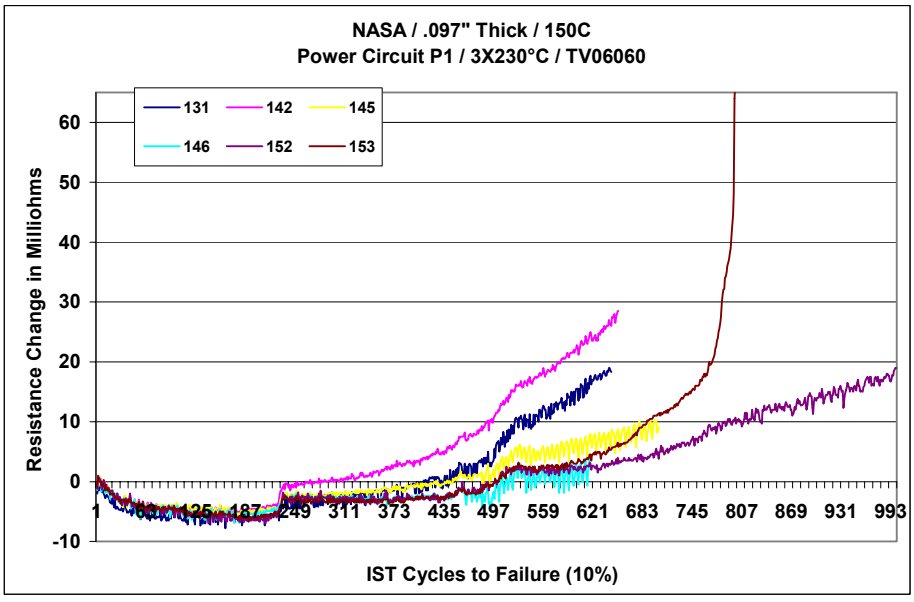
IST Cycles to Failure – 3X230°C – P1/S1 - .040" Grid
Table 4

IST Cycles to Failure - 3X230°C - .040" Grid						
Coupon	**P1**	**%**	**S1**	**%**	**Comb**	**%**
131	N/A	2.7	645	10	645	S1
142	N/A	4.1	652	10	652	S1
145	N/A	1.4	704	10	704	S1
146	N/A	0.5	619	10	619	S1
152	1000	2.8	1000	5.3	1000	Accept
153	799	10	N/A	6.7	799	Post
Mean	**900**	**4**	**724**	**9**	**737**	
Std Dev	142	3	157	2	144	
Min	799	1	619	5	619	
Max	1000	10	1000	10	1000	
Range	201	10	381	5	381	
Coef Var	**16%**		**22%**		**20%**	

Resistance Graph Power Circuit P1 – 3X230°C - .040" Grid
Graph 6



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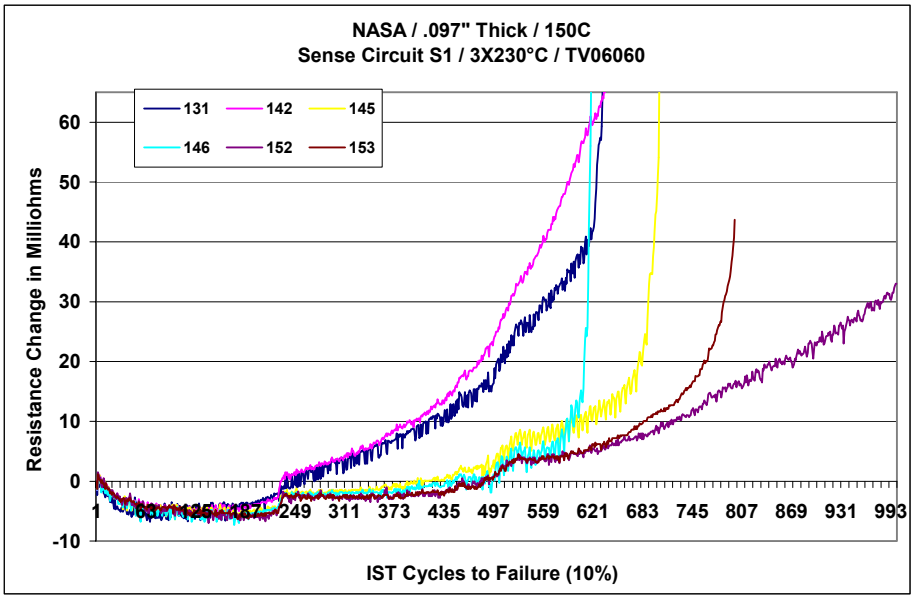
Resistance Graph Power Circuit S1 – 3X230°C - .040" Grid
Graph 7



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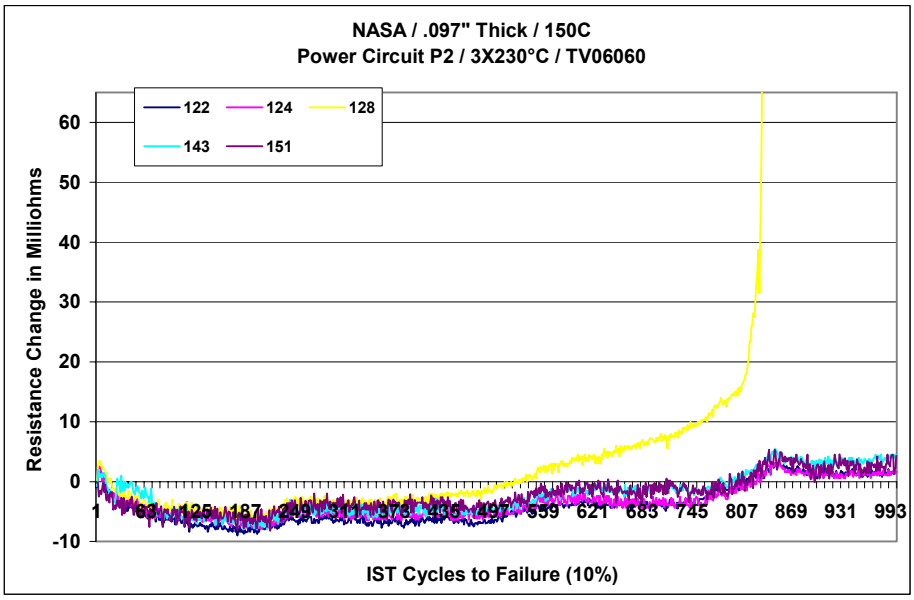
IST Cycles to Failure – 3X230°C – P2/S2 - .032" Grid
Table 5

IST Cycles to Failure - 3X230°C - .032" Grid						
Coupon	**P1**	**%**	**S1**	**%**	**Comb**	**%**
122	1000	0.2	1000	7.2	1000	Accept
124	1000	0.2	1000	1.6	1000	Accept
128	833	10	N/A	5	833	Post
143	1000	0.5	1000	2	1000	Accept
151	1000	0.3	1000	0.6	1000	Accept
Mean	**967**	**2**	**1000**	**3**	**967**	
Std Dev	75	4	0	3	75	
Min	833	0	1000	1	833	
Max	1000	10	1000	7	1000	
Range	167	10	0	7	167	
Coef Var	**8%**		**0%**		**8%**	

Resistance Graph Power Circuit P2 – 3X230°C - .032" Grid
Graph 8



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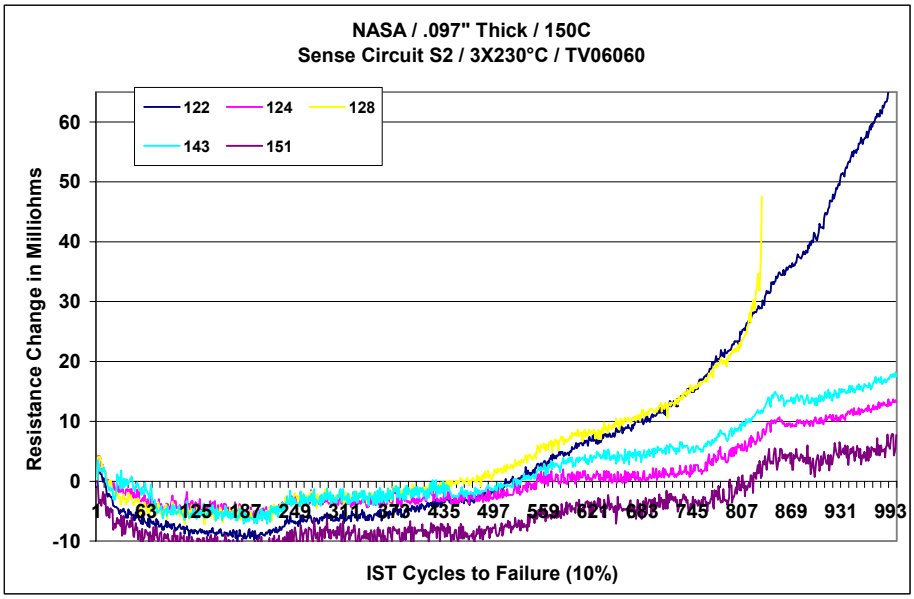
Resistance Graph Power Circuit S2 – As 3X230°C - .032" Grid
Graph 9



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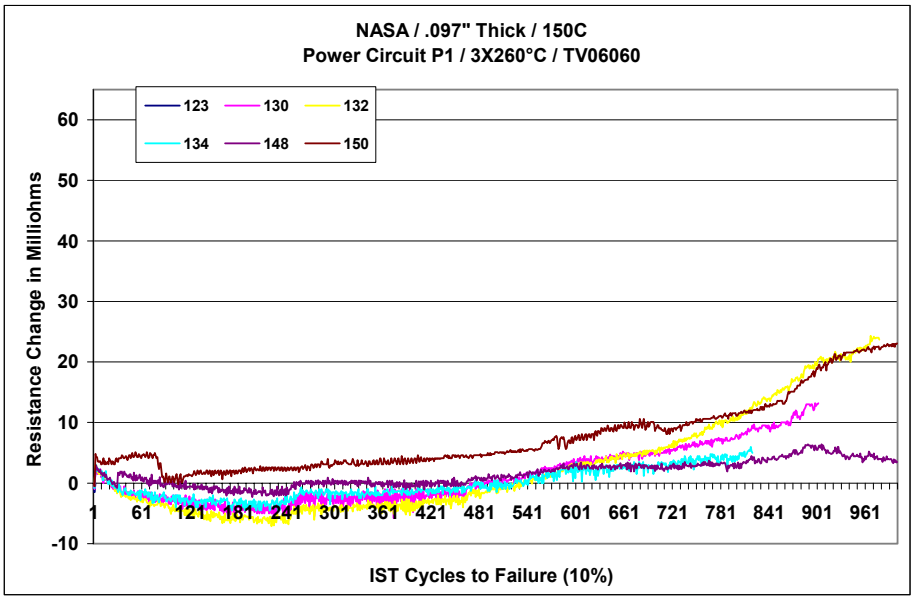
IST Cycles to Failure – 3X260°C – P1/S1 - .040" Grid
Table 6

IST Cycles to Failure - 3X260°C - .040" Grid						
Coupon	**P1**	**%**	**S1**	**%**	**Comb**	**%**
123	1000	-0.2	3	10	1000	S1
130	N/A	2	903	10	903	S1
132	N/A	3.6	978	10	978	S1
134	N/A	0.8	820	10	820	S1
148	1000	0.5	1000	2.3	1000	Accept
150	1000	3.3	1000	8.5	1000	Accept
Mean	**1000**	**2**	**940**	**8**	**950**	
Std Dev	0	2	78	3	74	
Min	1000	0	820	2	820	
Max	1000	4	1000	10	1000	
Range	0	4	180	8	180	
Coef Var	**0%**		**8%**		**8%**	

Resistance Graph Power Circuit P1 – 3X260°C - .040" Grid
Graph 10



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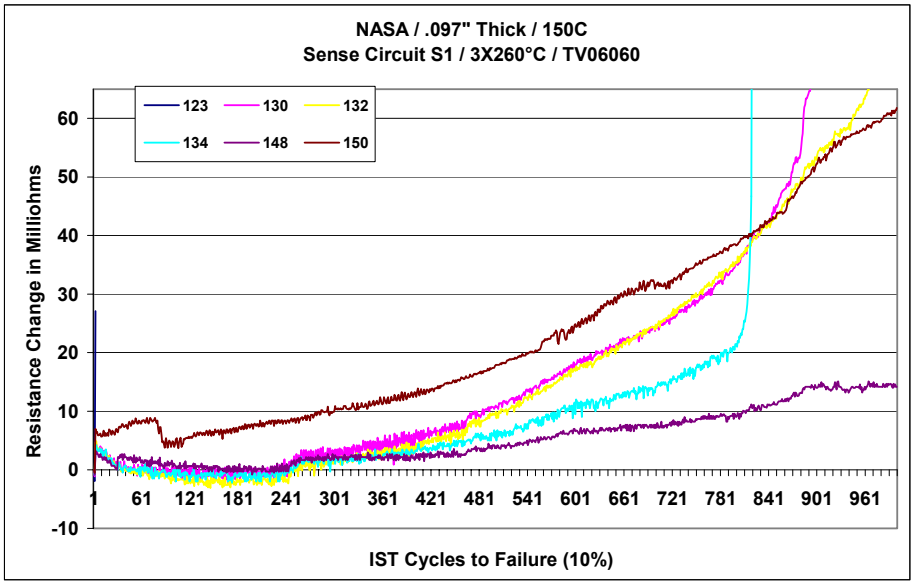
Resistance Graph Power Circuit S1 – 3X260°C - .040" Grid
Graph 11



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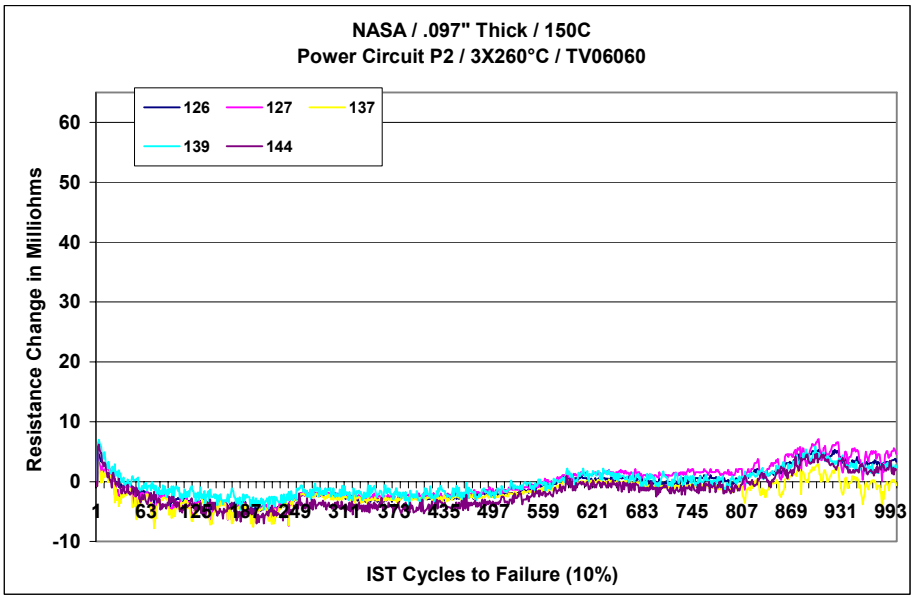
IST Cycles to Failure – 3X260°C – P2/S2 - .032" Grid
Table 7

IST Cycles to Failure - 3X260°C - .032" Grid						
Coupon	**P1**	**%**	**S1**	**%**	**Comb**	**%**
126	1000	0.4	1000	1.2	1000	Accept
127	1000	0.6	1000	1.7	1000	Accept
137	1000	0	1000	0.2	1000	Accept
139	1000	0.3	1000	0.6	1000	Accept
144	1000	0.2	1000	1.2	1000	Accept
Mean	**1000**	**0**	**1000**	**1**	**1000**	
Std Dev	0	0	0	1	0	
Min	1000	0	1000	0	1000	
Max	1000	1	1000	2	1000	
Range	0	1	0	2	0	
Coef Var	**0%**		**0%**		**0%**	

Resistance Graph Power Circuit P2 – 3X260°C - .032" Grid
Graph 12



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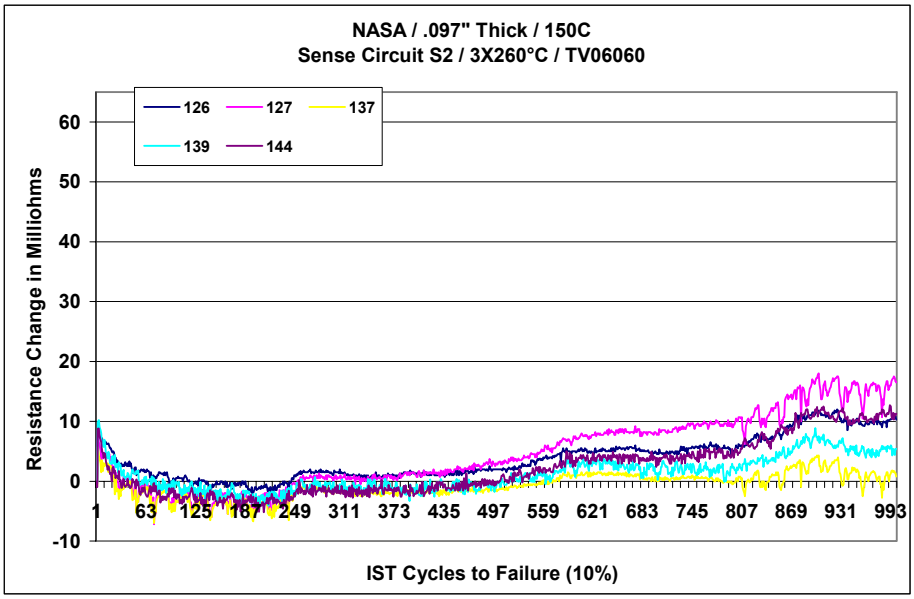
Resistance Graph Power Circuit S2 – As 3X260°C - .032" Grid
Graph 13



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ISO 9001 : 2000

Prescreening
Table 8

Resistance in Milliohms - Registration in Mils					
COUPON	**P1**	**P2**	**S1**	**S2**	**REG**
131	455	593	530	715	3
142	455	590	481	653	3
145	449	581	466	634	5
146	452	591	462	623	3
152	444	585	414	560	5
153	449	592	439	595	3
122	446	578	469	632	5
124	446	588	428	578	3
128	454	592	476	642	3
143	448	586	445	606	5
151	463	605	489	664	3
123	459	596	535	724	3
130	440	568	469	637	3
132	445	583	460	627	3
134	452	597	442	599	5
148	445	587	415	561	5
150	464	608	486	655	5
126	454	596	467	632	5
127	452	590	498	678	3
137	444	584	432	584	3
139	460	602	478	642	3
144	448	583	451	616	5
125	459	603	480	651	3
129	452	596	456	621	3
135	453	590	465	632	3
136	463	604	507	686	3
147	442	577	401	543	5
149	449	585	435	586	5
121	448	581	485	656	3
133	447	589	425	573	5
138	457	599	465	629	3
140	457	597	467	641	3
141	447	581	446	601	5
Mean	**451**	**590**	**463**	**627**	**4**
Std Dev	6.3	9.0	30.8	41.9	1.0
Min	440	568	401	543	3
Max	464	608	535	724	5
Range	24	40	134	181	2
Coef Var	1.4%	1.5%	6.7%	6.7%	

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	PWB Interconnect Solutions Inc						
Contact:	Micro Section Test Report						
Project	PWB ENG						
	E07-0082						
Note:							
Cross section#	3727						
Customer				PTH			
Manufacturer				Copper			
ID#	123		Top	0.0016			
Design				0.0014			
Test Conditions	a/r			0.0011			
IST Failure Mode	S1	PTH		0.0010			
Cycles to 10 %	3			0.0009			
INT'l				0.0009			
PTH				0.0010			
		PTH		0.0010			
Drilled Hole		0.0139		0.0014			
Finished Hole		0.0113	Bottom	0.0019			
			Mean Barre	0.0011			

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	PWB Interconnect Solutions Inc				Date:	14-Jan-08	
Contact:	Micro Section Test Report						
Project	PWB ENG						
	E07-0082						
Cross section#	3737						
Customer					PTH		
Manufacturer					Copper		
ID#	146			Top	0.0019		
Design					0.0016		
Test Conditions	3 X 230				0.0012		
IST Failure Mode	S1				0.0011		
Cycles to 10 %	619				0.0010		
INT'l					0.0010		
PTH					0.0011		
		PTH			0.0012		
Drilled Hole		0.0139			0.0015		
Finished Hole		0.0105		Bottom	0.0020		
				Mean Barrel	0.0012		
Cross section#	3738						
Customer					PTH		
Manufacturer					Copper		
ID#	128			Top	0.0020		
Design					0.0013		
Test Conditions	3 X 230				0.0012		
IST Failure Mode	P2				0.0010		
Cycles to 10 %	833				0.0010		
INT'l					0.0010		
PTH					0.0011		
		PTH			0.0010		
Drilled Hole		0.0139			0.0012		
Finished Hole		0.0109		Bottom	0.0019		
				Mean Barrel	0.0011		
Cross section#	3739						
Customer					PTH		
Manufacturer					Copper		
ID#	137			Top	0.0017		
Design					0.0015		
Test Conditions	3 X 230				0.0012		
IST Failure Mode	P2/S2				0.0012		
Cycles to 10 %	1000				0.0010		
INT'l					0.0011		
PTH					0.0013		
		PTH			0.0012		
Drilled Hole		0.0139			0.0020		
Finished Hole		0.0109		Bottom	0.0021		
				Mean Barrel	0.0013		

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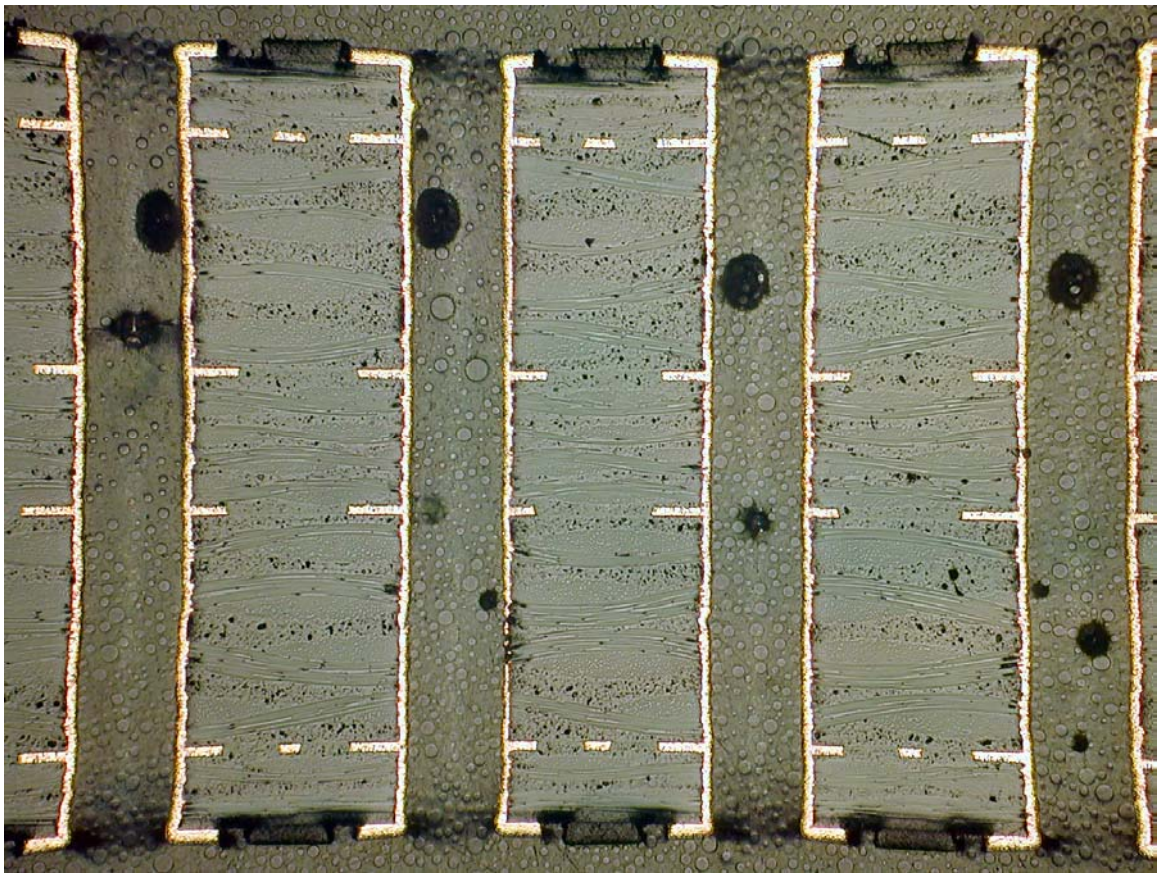
XS# 3727 – Coupon 123, Failed S1, Three IST Cycles, Tested As Received
Photo 7



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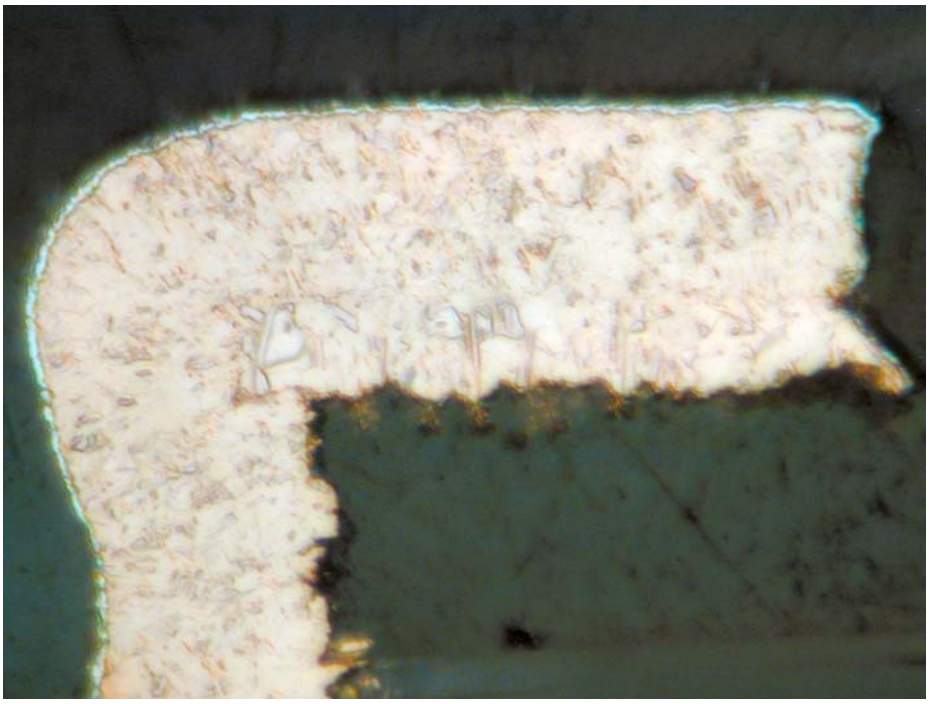
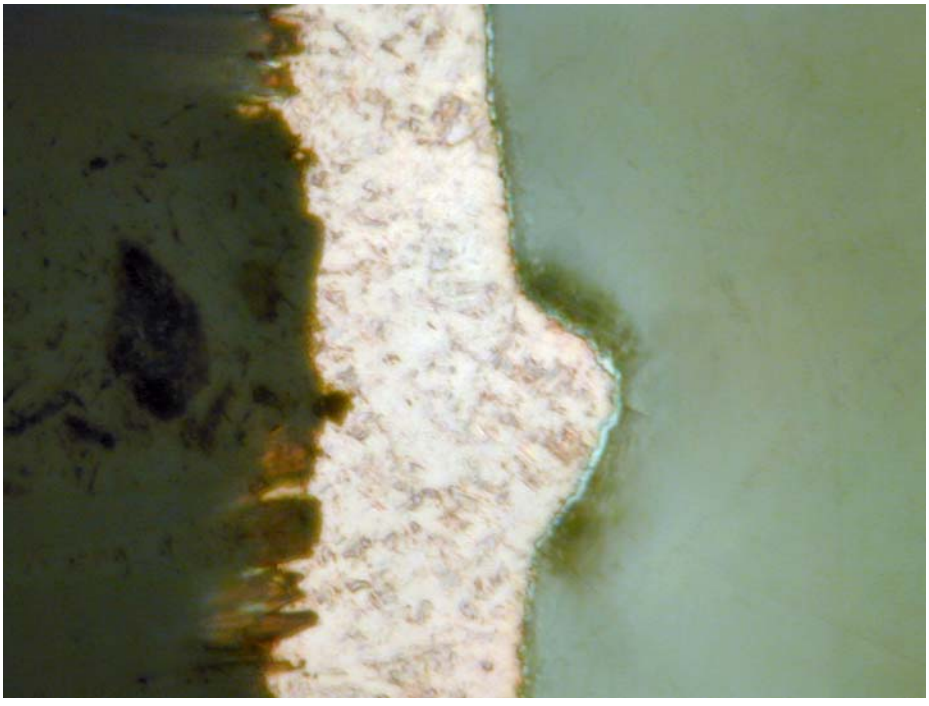
XS# 3727 – Coupon 123, Failed S1, Three IST Cycles, Tested As Received
Photo 8



XS# 3727 – Coupon 123, Failed S1, Three IST Cycles, Tested As Received
Photo 9



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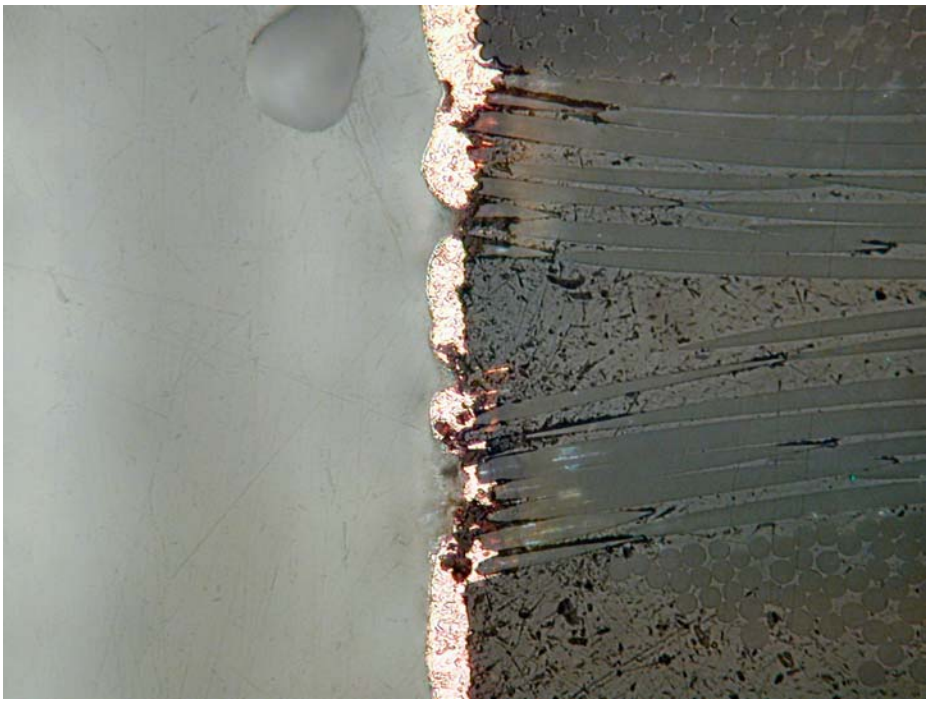
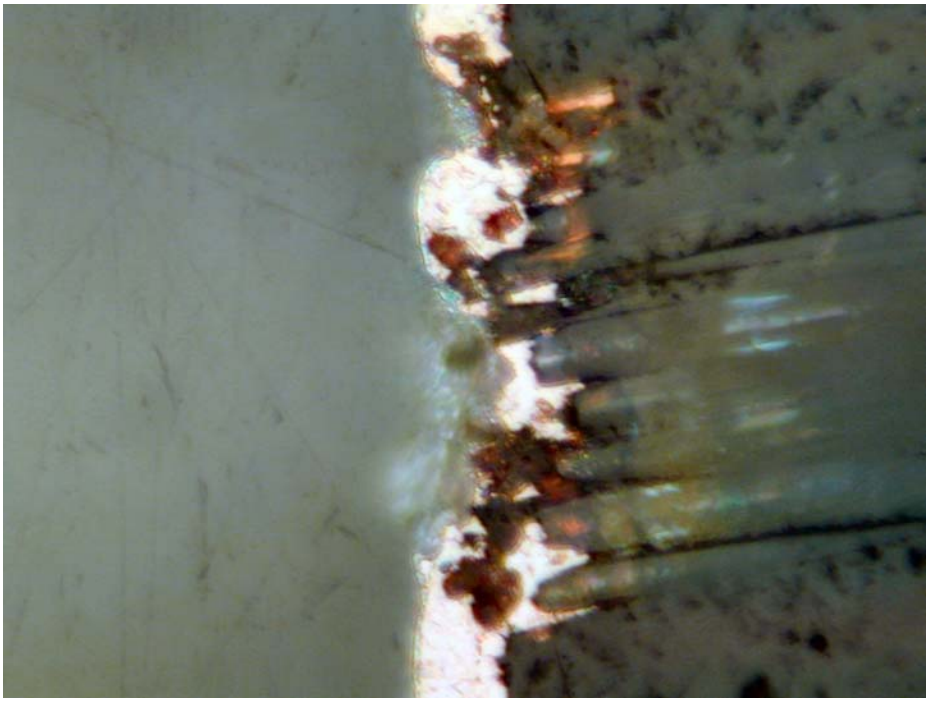
XS# 3727 – Coupon 123, Failed S1, Three IST Cycles, Tested As Received
Photo 10



XS# 3727 – Coupon 123, Failed S1, Three IST Cycles, Tested As Received
Photo 11



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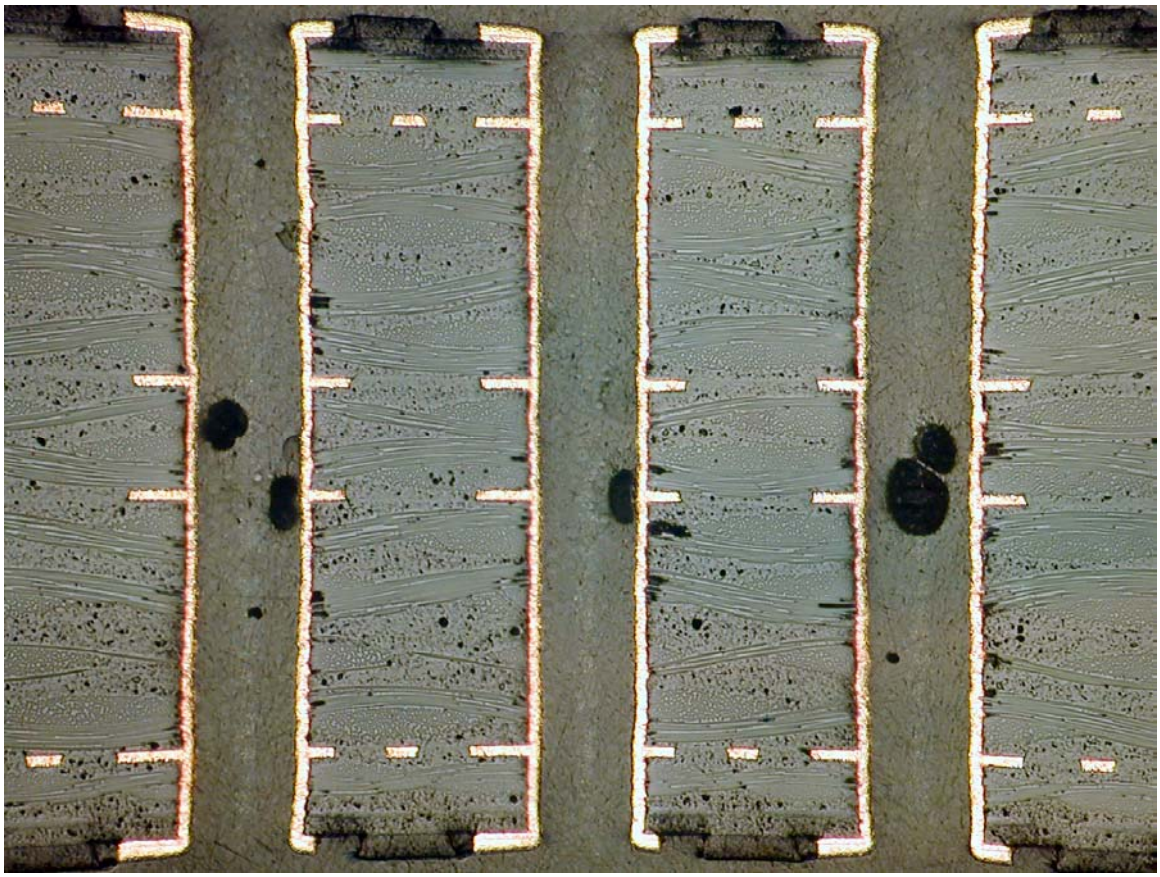
XS# 3737 – Coupon 146, Failed S1, 169 IST Cycles, Precon 3X230°C
Photo 12



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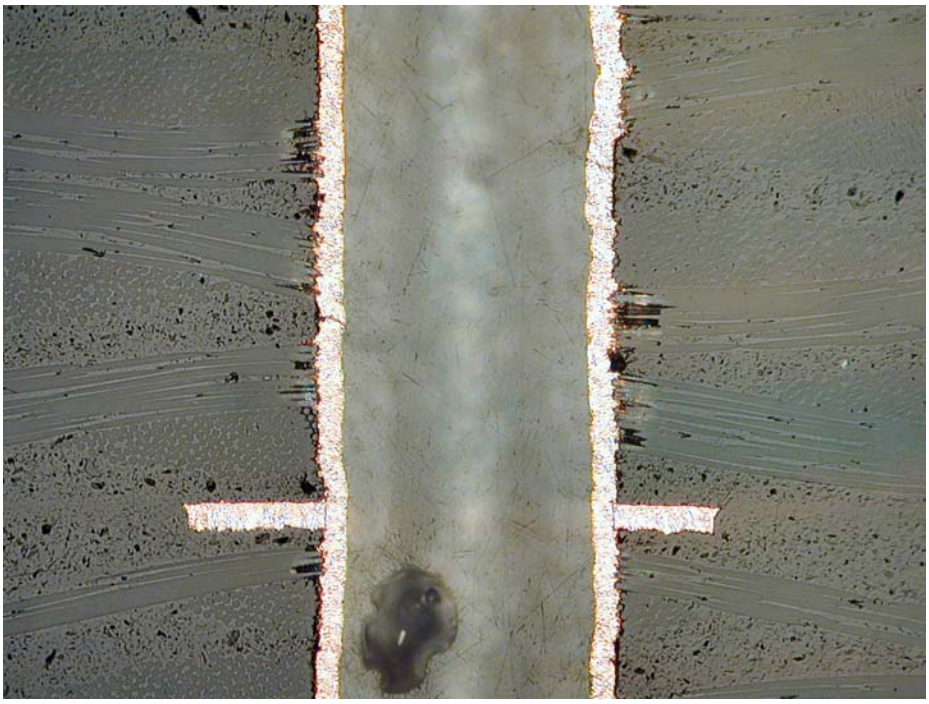
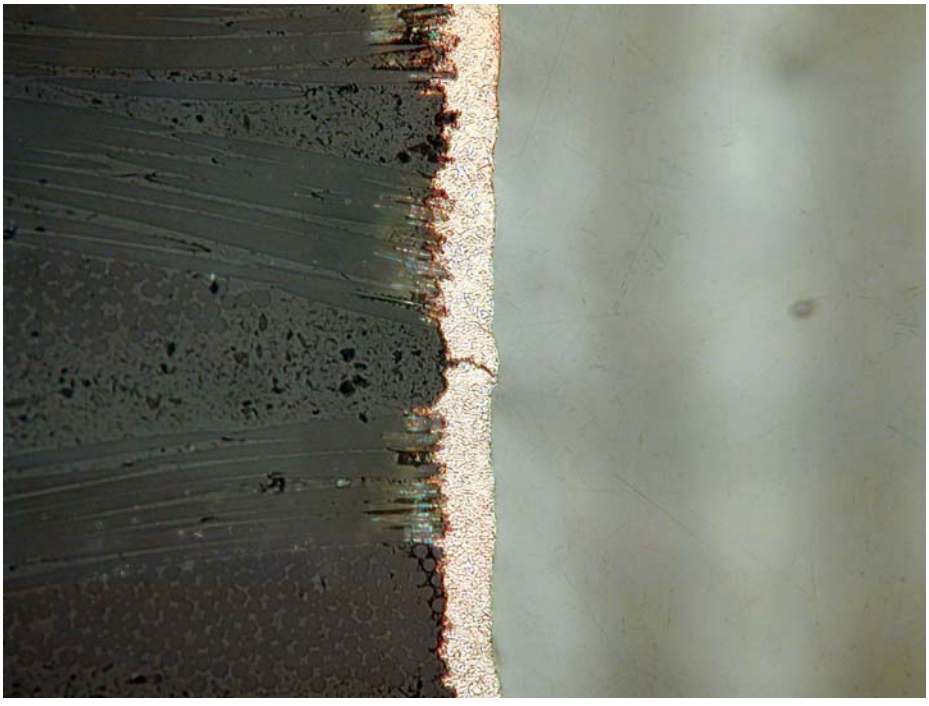
XS# 3737 – Coupon 146, Failed S1, 169 IST Cycles, Precon 3X230°C
Photo 13



XS# 3737 – Coupon 146, Failed S1, 169 IST Cycles, Precon 3X230°C
Photo 14



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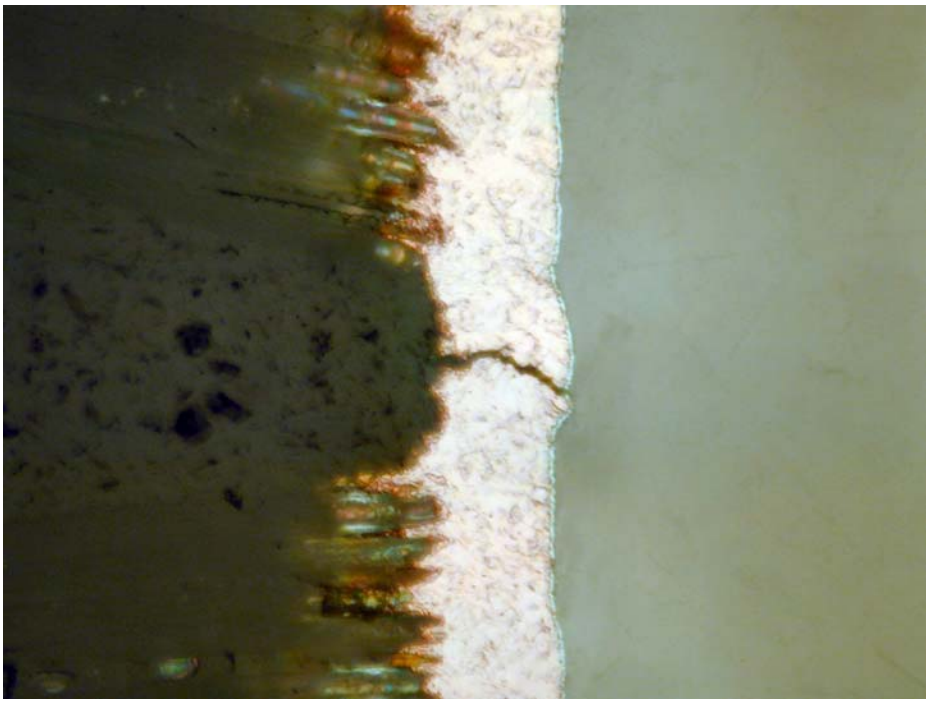
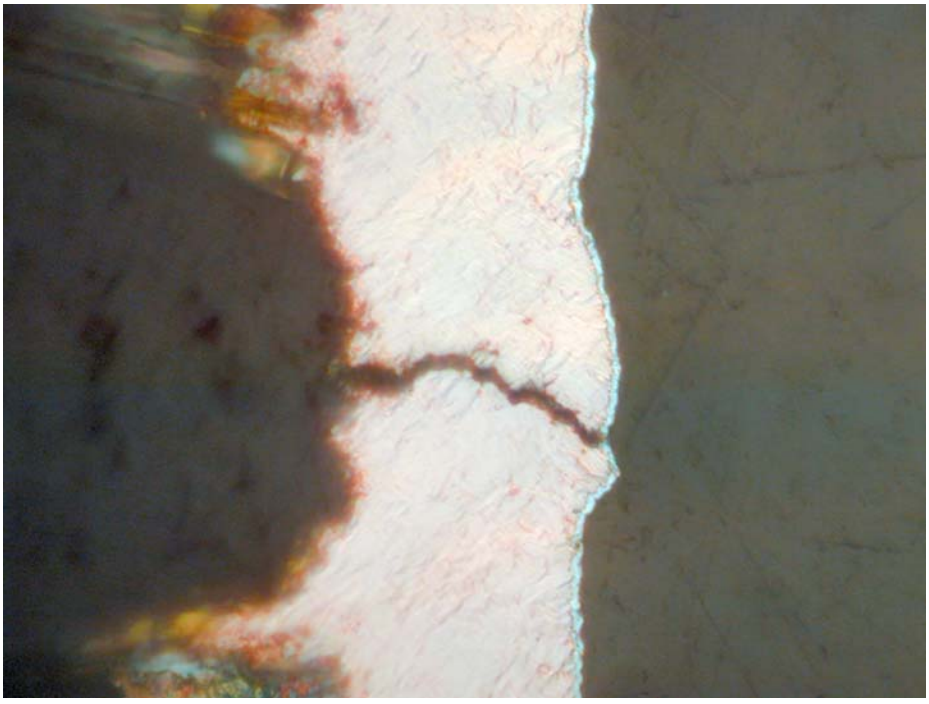
XS# 3737 – Coupon 146, Failed S1, 169 IST Cycles, Precon 3X230°C
Photo 15



XS# 3737 – Coupon 146, Failed S1, 169 IST Cycles, Precon 3X230°C
Photo 16



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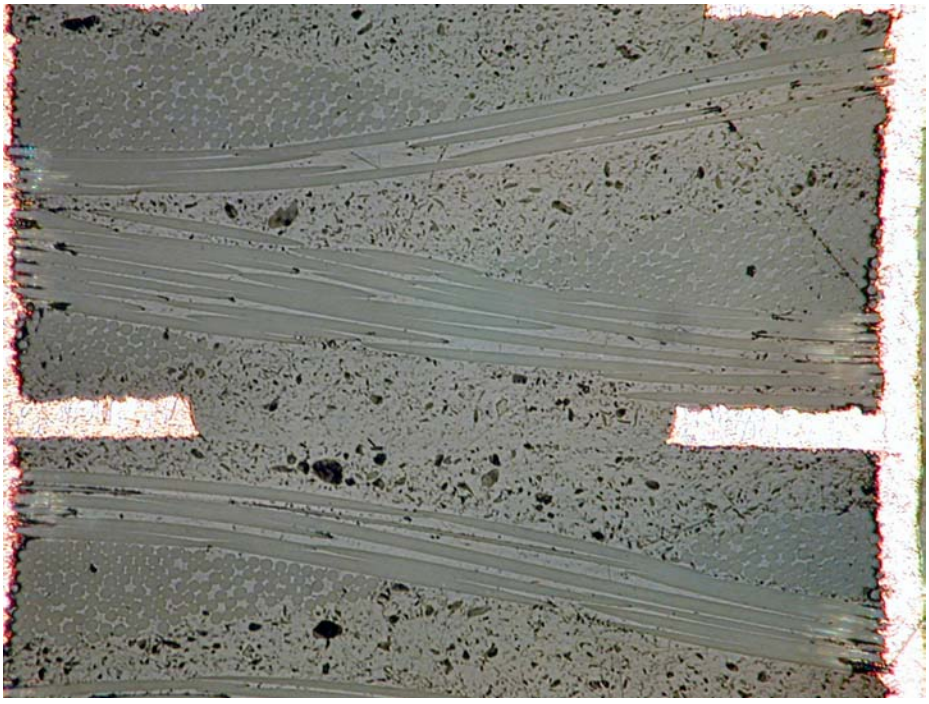
XS# 3737 – Coupon 146, Failed S1, 169 IST Cycles, Precon 3X230°C
Photo 17

XS# 3737 – Coupon 146, Failed S1, 169 IST Cycles, Precon 3X230°C
Photo 18



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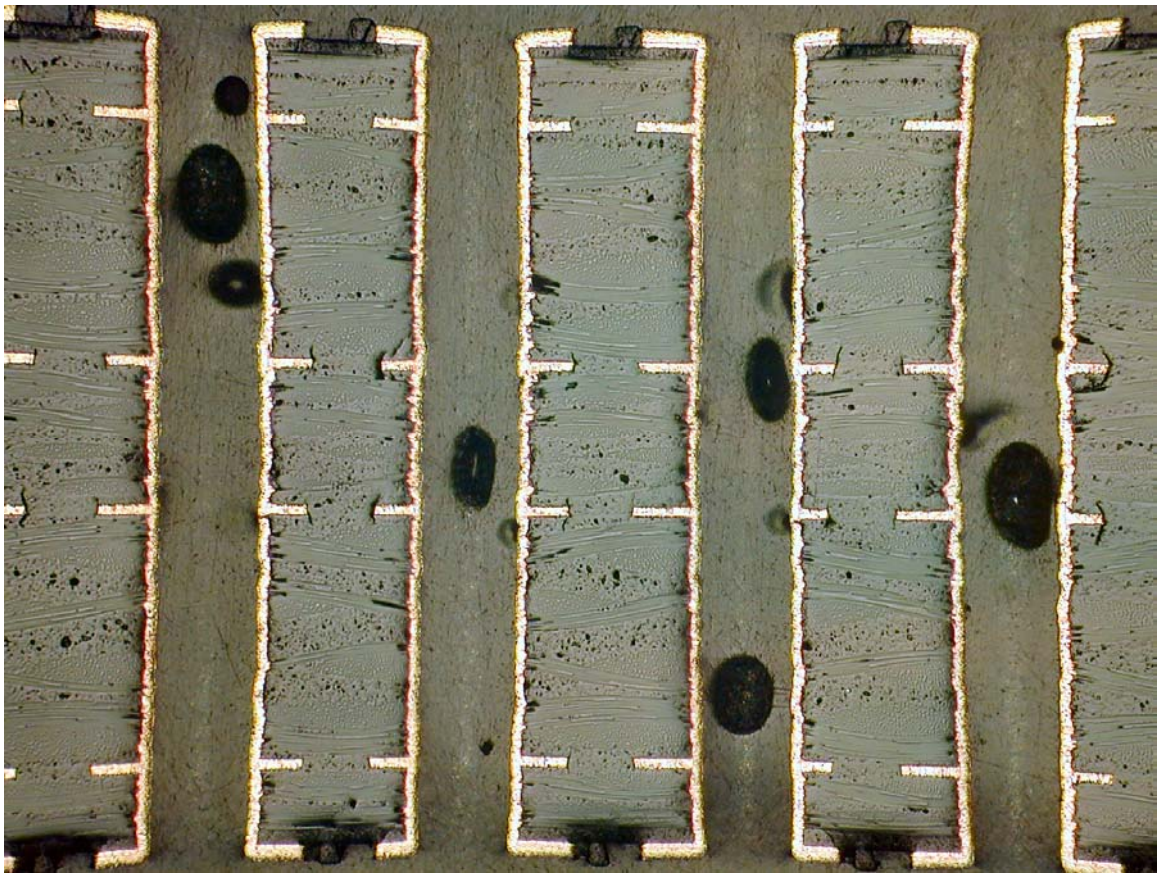
XS# 3738 – Coupon 128 Failed P2, 833 IST Cycles - Precon 3X230°C
Photo 19



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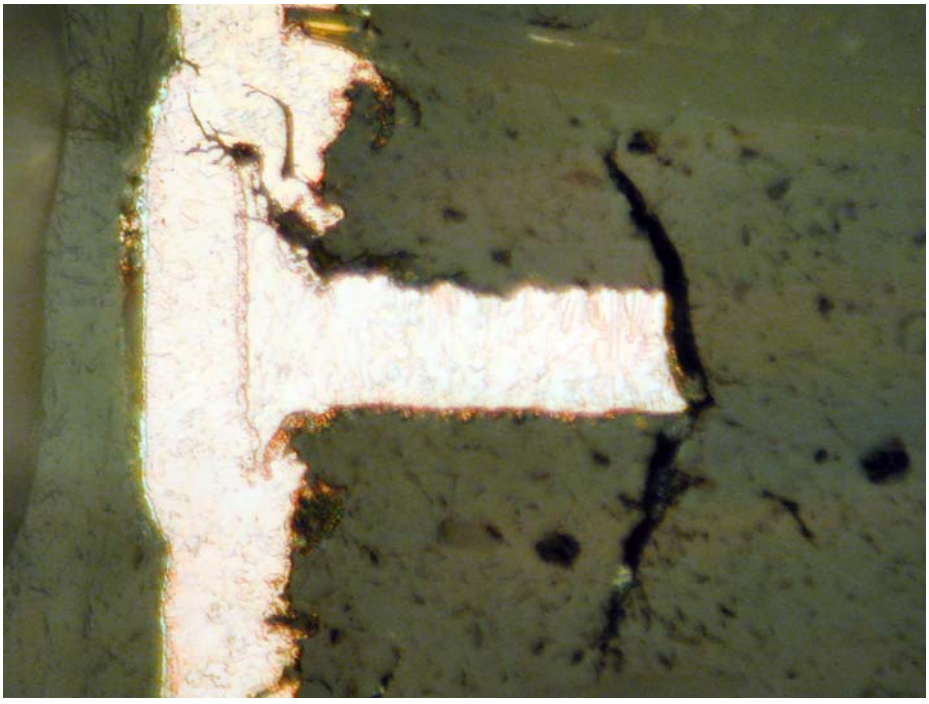
XS# 3738 – Coupon 128 Failed P2, 833 IST Cycles - Precon 3X230°C
Photo 20

XS# 3738 – Coupon 128 Failed P2, 833 IST Cycles - Precon 3X230°C
Photo 21



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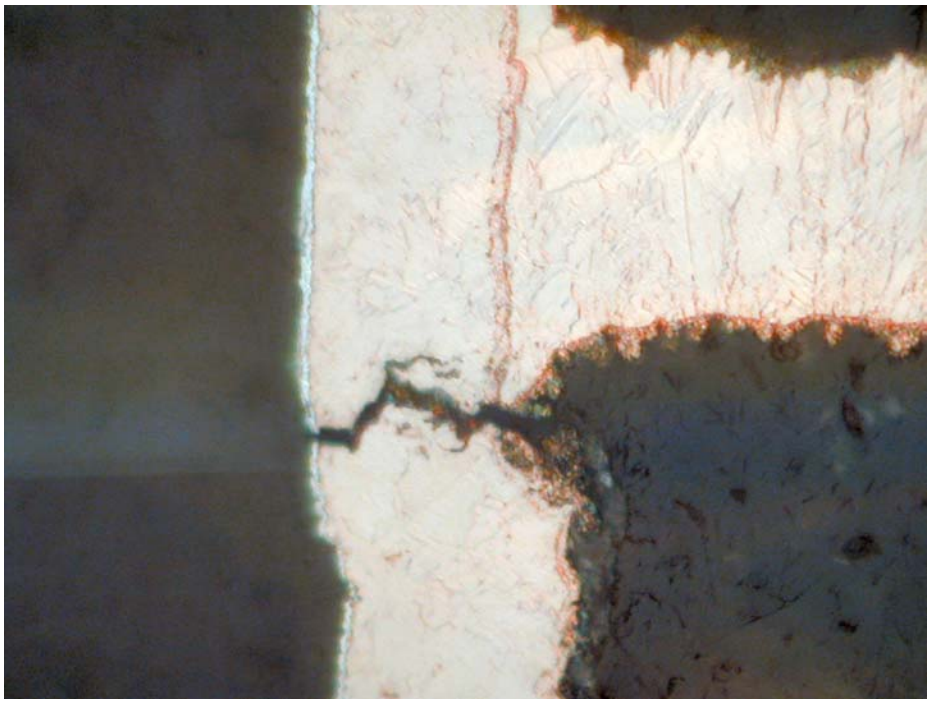
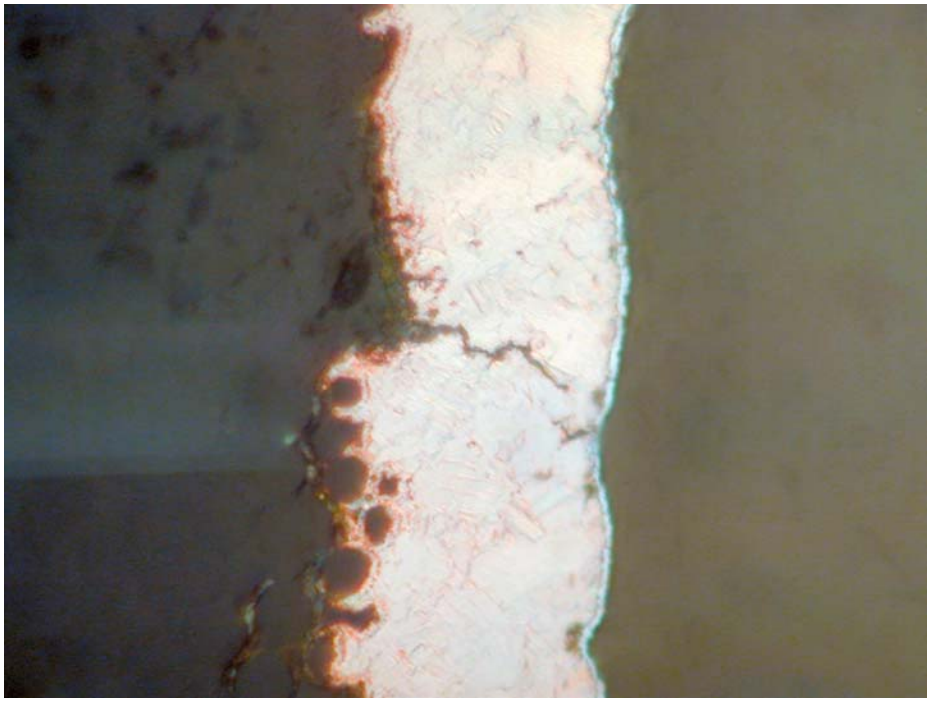
XS# 3738 – Coupon 128 Failed P2, 833 IST Cycles- Precon 3X230°C
Photo 22



XS# 3738 – Coupon 128 Failed P2, 833 IST Cycles- Precon 3X230°C
Photo 23



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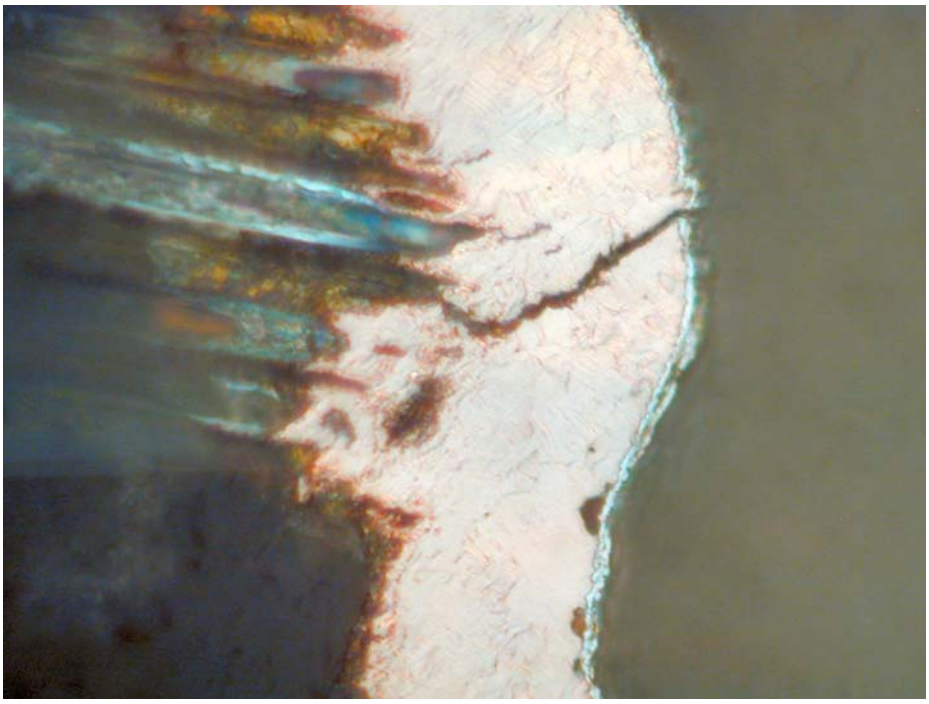
XS# 3738 – Coupon 128 Failed P2, 833 IST Cycles - Precon 3X230°C
Photo 24



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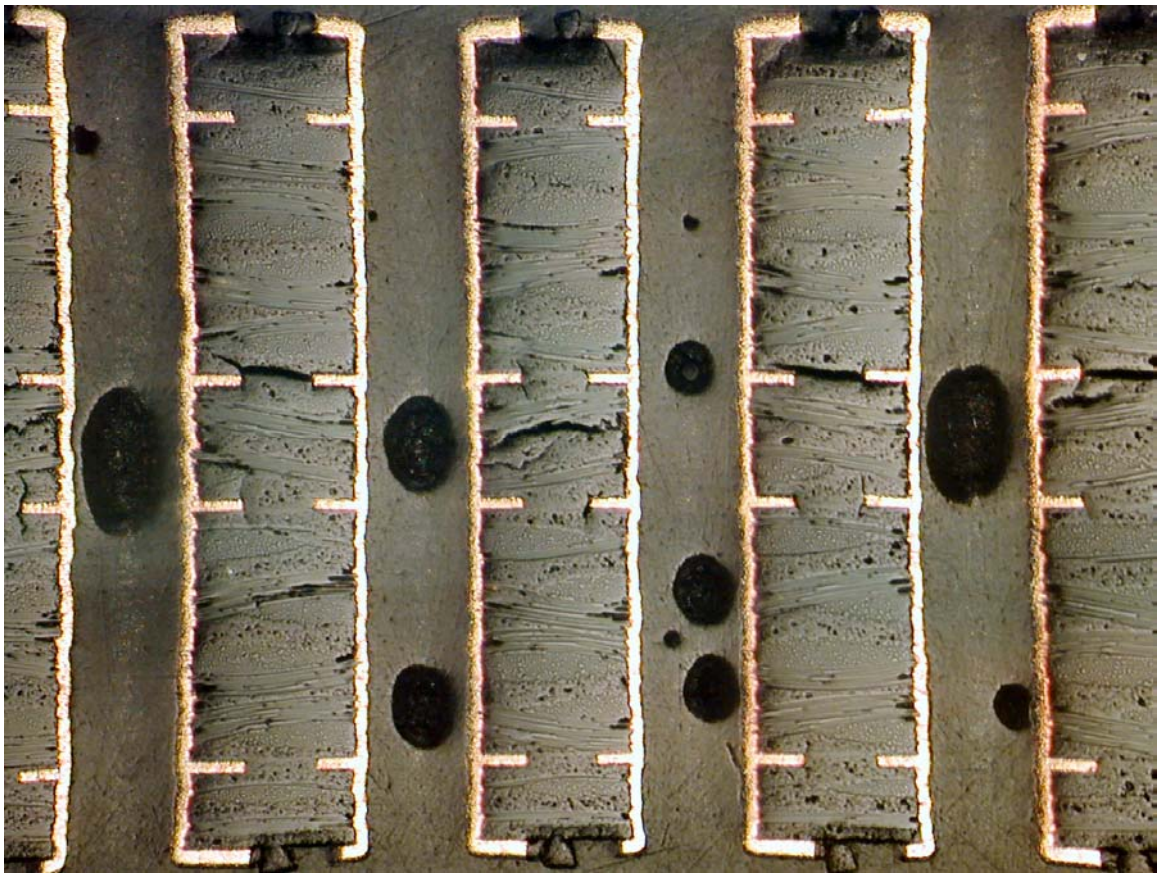
XS# 3739 – Coupon 137, No Failure, 1000 IST Cycles, Precon 3X230°C
Photo 25



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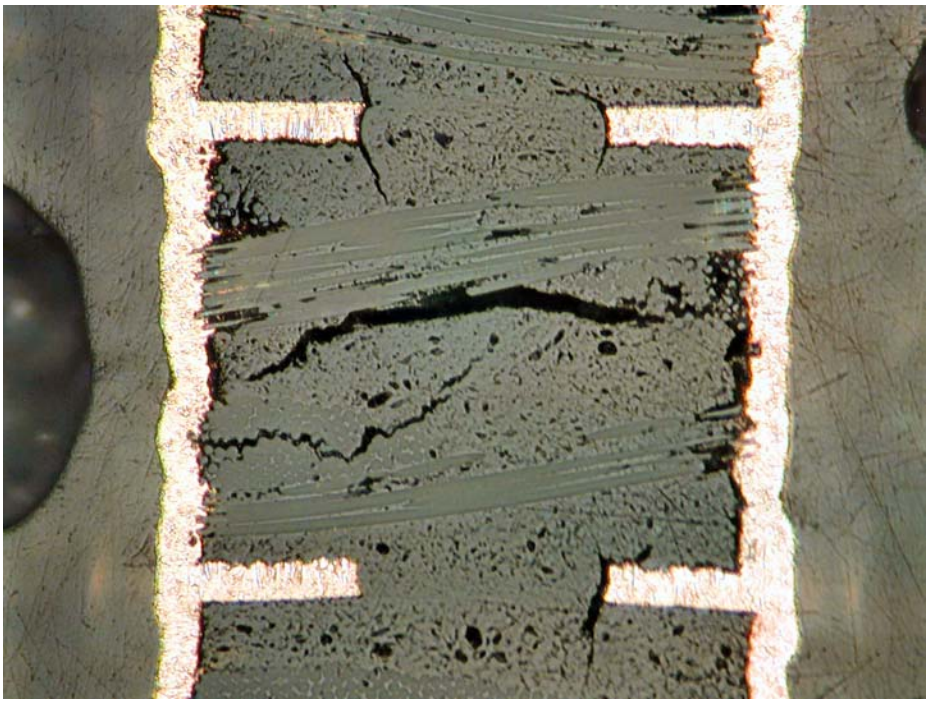
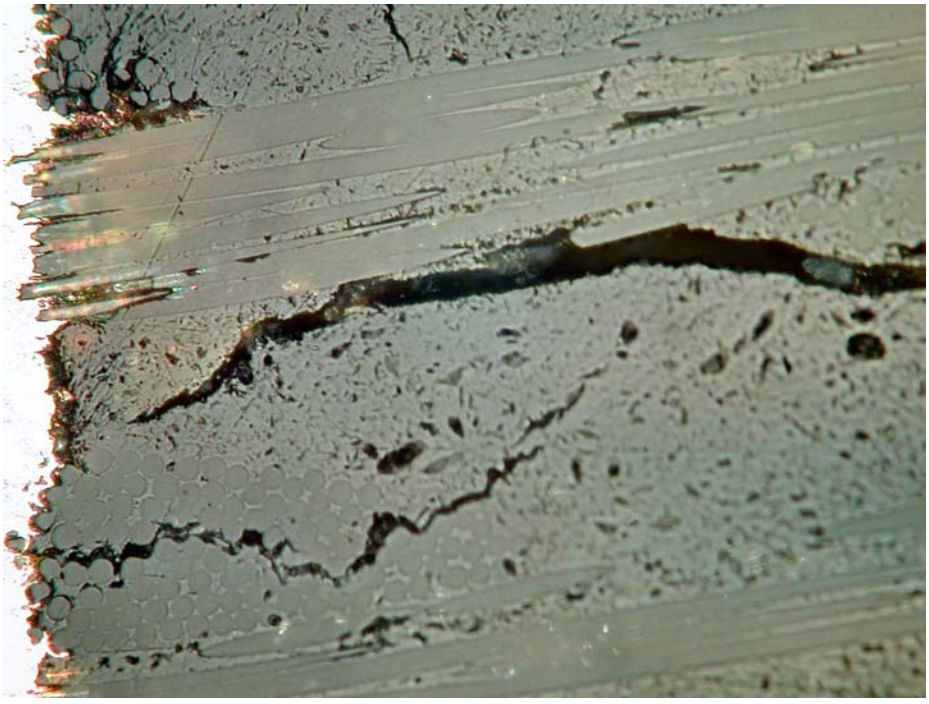
XS# 3739 – Coupon 137, No Failure, 1000 IST Cycles, Precon 3X230°C
Photo 26



XS# 3739 – Coupon 137, No Failure, 1000 IST Cycles, Precon 3X230°C
Photo 27



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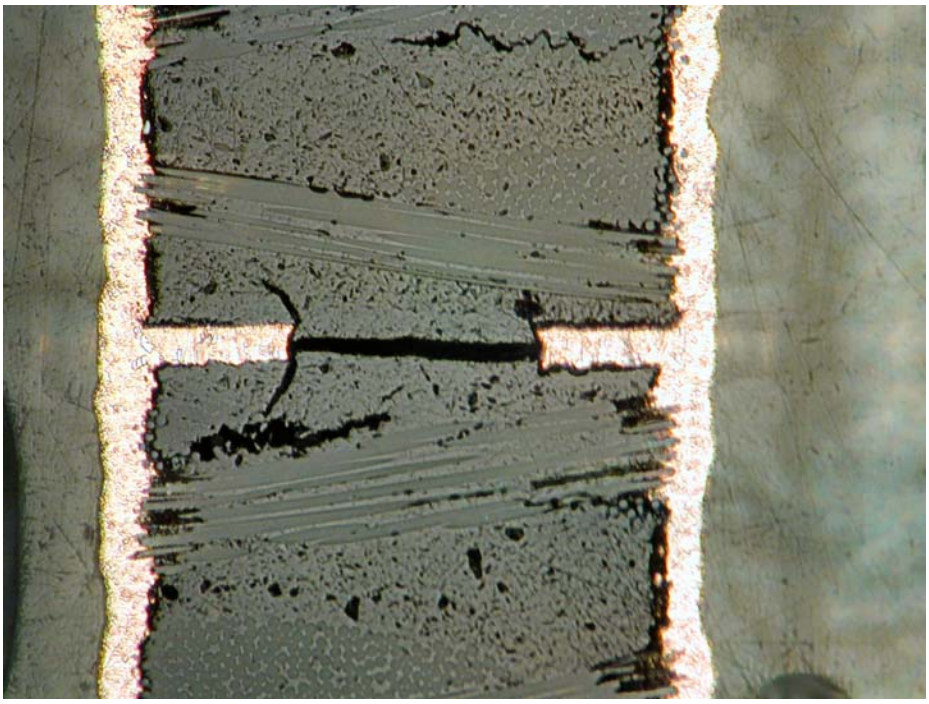
XS# 3739 – Coupon 137, No Failure, 1000 IST Cycles, Precon 3X230°C
Photo 28



XS# 3739 – Coupon 137, No Failure, 1000 IST Cycles, Precon 3X230°C
Photo 29

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XS# 3739 – Coupon 137, No Failure, 1000 IST Cycles, Precon 3X230°C
Photo 30