Investigation of High Intensity UV Lights on FPI and MPI

September 24, 2014

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Purpose

- High Intensity UV lights available.
- Standards/Specs not fully caught up.
- ASTM E 2297 update in 2010; 2011 ASTM E07.03 Subcommittee.
  - ASTM E 1417, ASTM E 1444 updates in 2011/12 reference ASTM E 2297.
  - Good changes => Emission Spectrum, Visible light.
- Warning note in ASTM E 2297 6.5.2 precipitated technical concerns on high intensity UV lights.

(Warning—When a high intensity UV-A lamp (light sources that produce light intensity greater than 10,000 µW/cm2 at 38.1 cm (15 in.)) is used for inspection, care must be exercised to prevent the UV fading of indications and that the excess blue light that is produced, does not mask blue/white indications.)

- 2012 A4A NDT Forum – Sherwin paper, "UV-A LED's: Are they all the same?"
- 2006 ISU Studies (Lopez), Magnaflux papers (Geis) => Emission spectrum, Visible light.

How do we interpret the warning statement?

Purpose

- Pratt requires high intensity 'torch' inspection on critical rotating parts (in excess of 10,000 µW/cm2).
- Boeing: PODs for FPI/MPI all done with Mercury Vapor lights (max= 6000 uW/cm2); Need to do POD work for higher intensities.
- Other OEMs = No response at all.
- Delta recently conducted a study to alleviate internal concerns.
  - 'Apparent crack lengths' from IN718 panels (internal POD study).
    - Measured fatigue cracks at varying intensities with LED and Mercury Vapor lights.
  - UV fade experiment with TAM panels, IN 718 panels (fatigue cracks), and Al-quench crack blocks.
- Conclusions: 1) LED UV lights produced better contrast; 2) Fading due to extreme UV exposure did occur, but was beyond standard practice.
- Recommend 'independent industry study' or 'no further changes'.
  - Revision to ASTM E 2297, ASTM E 1444, ASTM E 1417 => No interpretation!

Delta performed experiments to satisfy concerns

FPI: Procedure

Equipment needed:

- TAM panels
- Two anodized Al quench-crack blocks
- 6 FPI POD study panels
- Mercury vapor light source (Gould Bass CR2000)
- UV 'torch'/flashlight (Spectroline Opti-Lux 365 UV Light)
- UV light meters (DLM-1000, and XRP-3000 Accu-MAX)

Procedure:

- Process all panels with post-emulsifiable, Ultra-high sensitivity = ZL-37.

Apparent Crack Length

- For the 6 FPI POD study panels, measure the 'apparent crack length' using the mercury vapor light at 1000 uW/cm2 (at the surface), then move the light back and measure at 1500 uW/cm2, then 3000 uW/cm2, then 6000 uW/cm2;
- Then repeat with LED UV 'torch'/flashlight at 1000, 1500, 3000, 6000, 10,000, and 15,000 uW/cm2.

Experiment to address glare and UV fade concerns

FPI: Procedure

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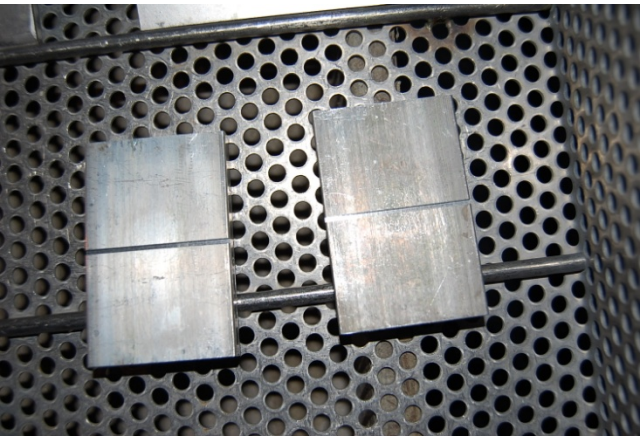
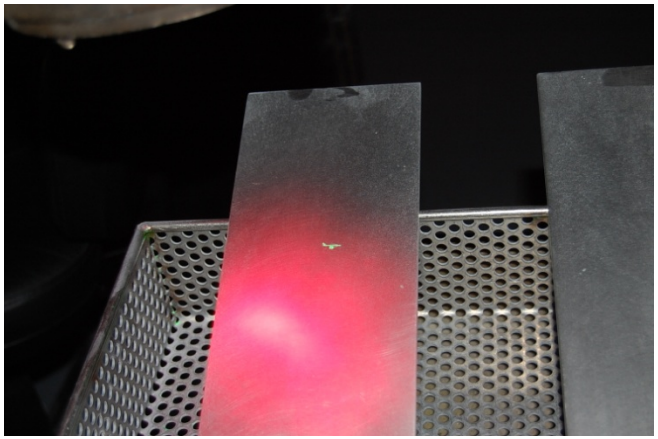
UV Fading

- For the anodized Al quench-crack blocks and the TAM panel, perform regular UV fade test with Mercury Vapor UV and LED UV Lights;
  - Place high intensity UV light source directly on the surface (1/2” offset); examine the part every 5 minutes until fading is noticed.

- Extended UV Fade on TAM panel, POD cracks.
  - Every 15 minutes for 6+ hours with both MV and LED.





Regular & Extreme UV fade studies

FPI: Apparent Crack length – Mercury Vapor

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Table 1. 'Apparent Crack length' (inches) versus UV intensity using Gould Bass CR2000 Mercury Vapor UV Light.

Actual Crack length/Intensity	1000 uW/cm^2	1500 uW/cm^2	3000 uW/cm^2	5700 uW/cm^2
0.378	0.381	0.382	0.382	0.382
0.340	0.338	0.338	0.339	0.340
0.156	0.145	0.145	0.146	0.148
0.135	0.132	0.132	0.132	0.133
0.122	0.118	0.119	0.121	0.121
0.106	0.103	0.102	0.103	0.103
0.099	0.096	0.097	0.097	0.098
0.073	0.068	0.068	0.070	0.070
0.040	0.037	0.038	0.038	0.038
0.024	0.023	0.024	0.024	0.024
0.022	0.020	0.021	0.021	0.021
0.013	0.011	0.011	0.012	0.012
0.010	0.008	0.008	0.008	0.008
0.010	0.009	0.010	0.010	0.010

Increasing UV intensity results in equivalent or better detectability via 'apparent crack lengths'. This was true for both mercury vapor UV lights and high-intensity LED UV light.

FPI: Apparent Crack length – LED

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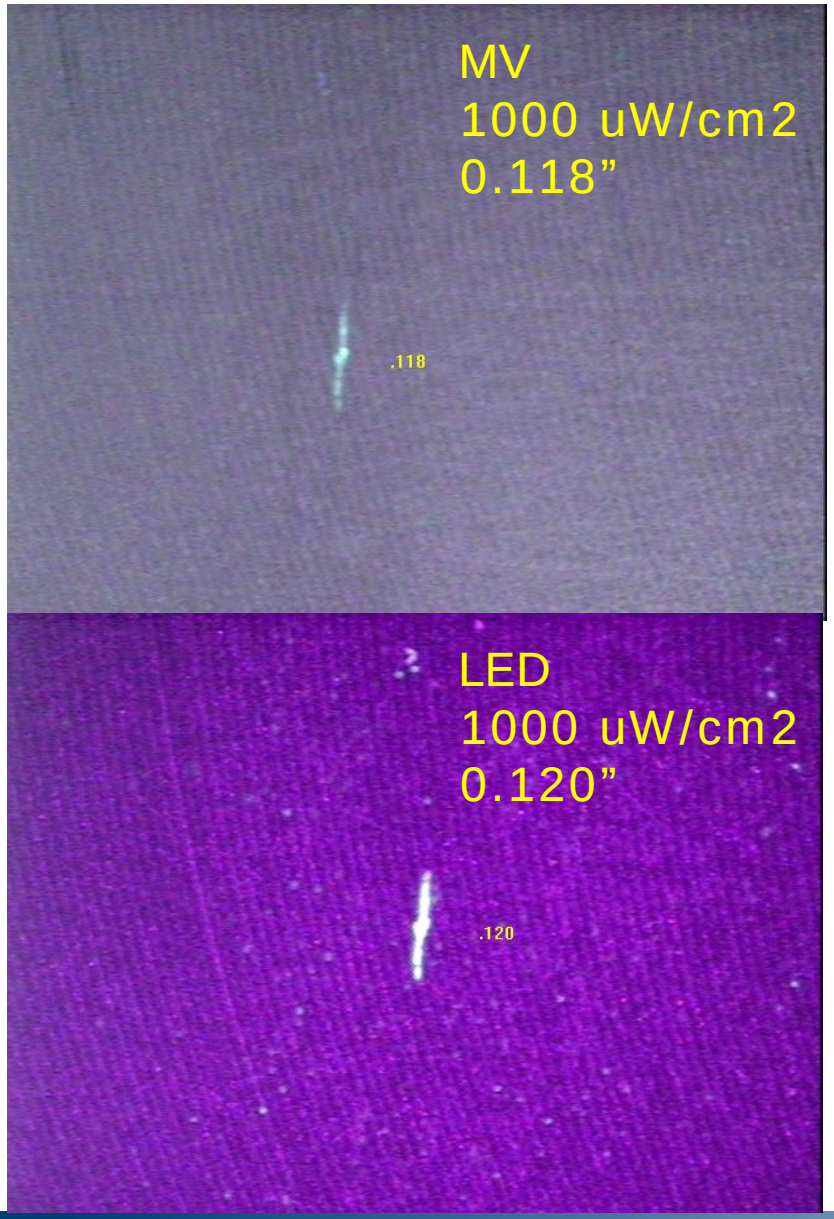
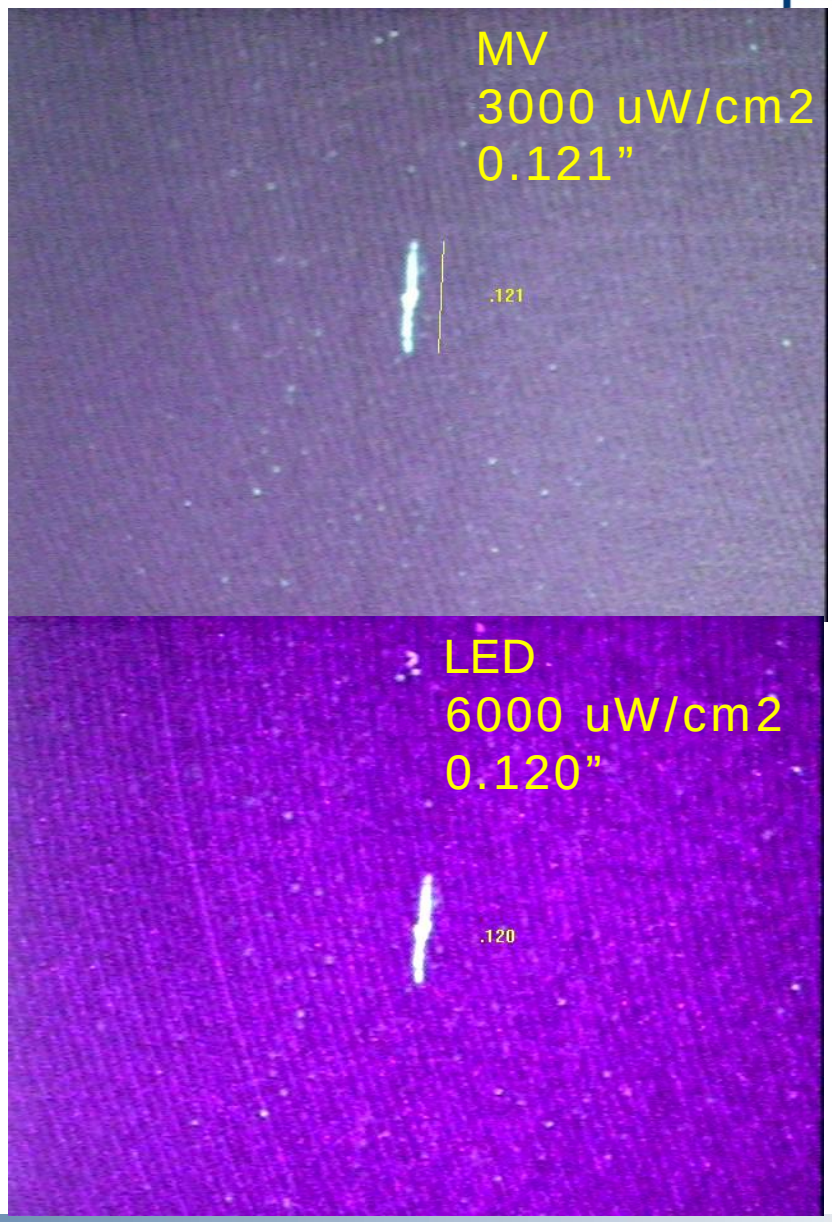
Table 2. 'Apparent Crack length' (inches) versus UV intensity using portable Spectroline Opti-Lux 365 UV Light (battery powered flashlight/torch).

Actual Crack length/Intensity	1000 uW/cm^2	1500 uW/cm^2	3000 uW/cm^2	6000 uW/cm^2	10000 uW/cm^2	15000 uW/cm^2
0.378	0.381	0.381	0.382	0.383	0.383	0.383
0.340	0.339	0.340	0.341	0.341	0.341	0.341
0.156	0.148	0.148	0.149	0.149	0.149	0.150
0.135	0.132	0.132	0.132	0.133	0.133	0.134
0.122	0.120	0.120	0.120	0.120	0.120	0.121
0.106	0.103	0.102	0.103	0.103	0.103	0.104
0.099	0.098	0.098	0.098	0.098	0.098	0.099
0.073	0.068	0.068	0.070	0.070	0.070	0.071
0.040	0.037	0.038	0.038	0.038	0.038	0.039
0.024	0.023	0.024	0.024	0.024	0.024	0.024
0.022	0.020	0.021	0.021	0.021	0.021	0.021
0.013	0.011	0.011	0.012	0.012	0.012	0.012
0.010	0.008	0.008	0.008	0.008	0.008	0.009
0.010	0.009	0.010	0.010	0.010	0.010	0.010

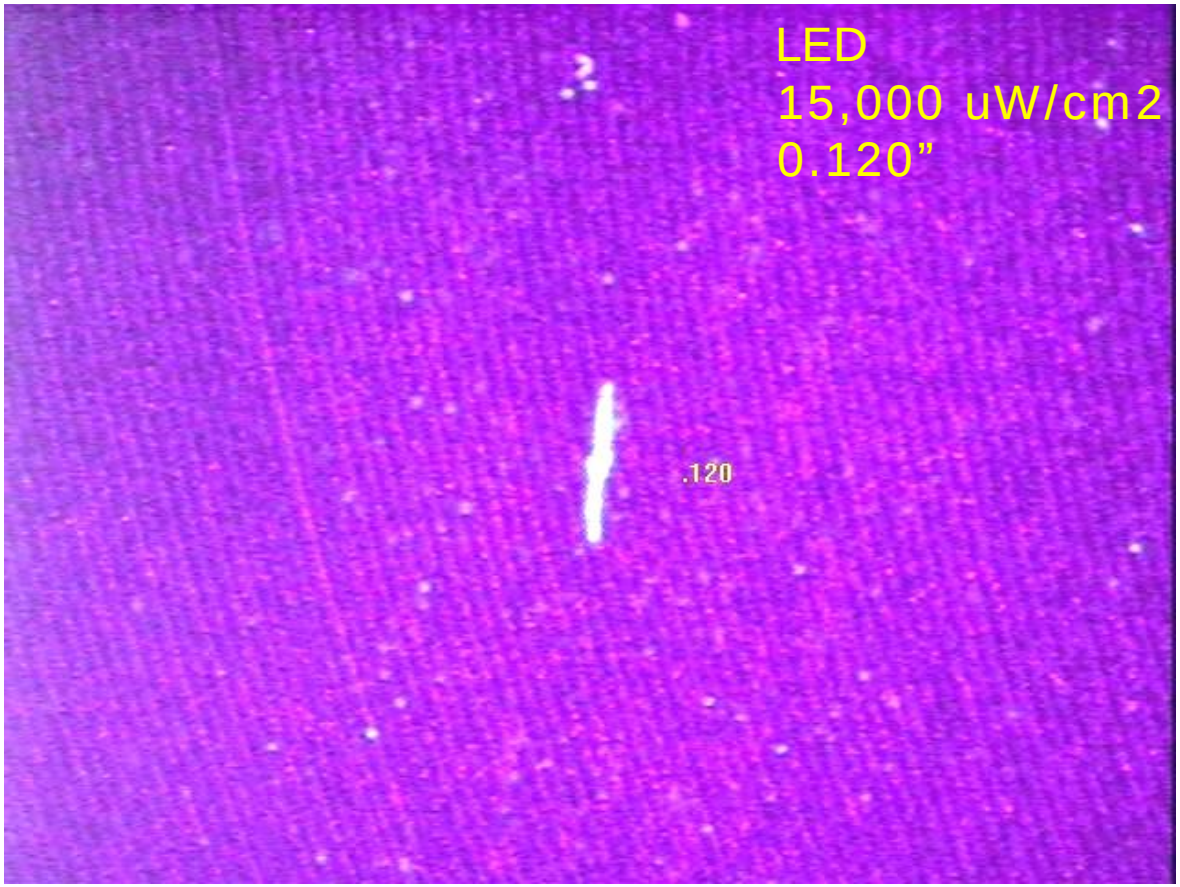
At the same intensity level, LED lighting provided a more-accurate representation of the crack length. This was true across the board, and did not vary even at smaller crack lengths.

FPI Apparent Crack Length: MV vs LED





FPI: High Intensity LED UV-A Background



Increasing the UV intensity for LED caused an increase in the background. However, the contrast was enhanced (i.e., signal-to-noise ratio) at increasing UV levels, causing a brighter indication, resulting in **better** overall detectability.

FPI: UV Fade – Al Quench Crack Blocks

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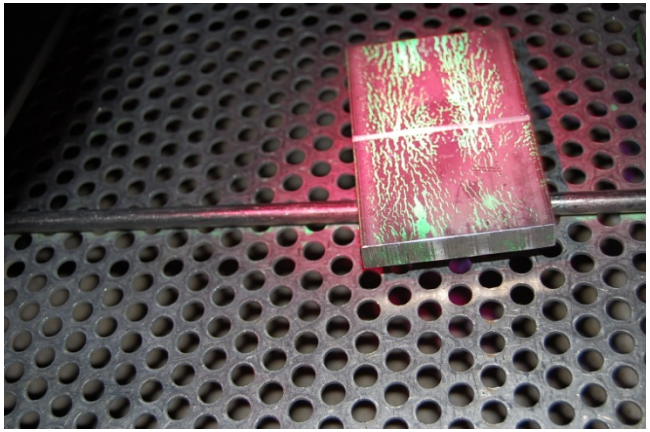
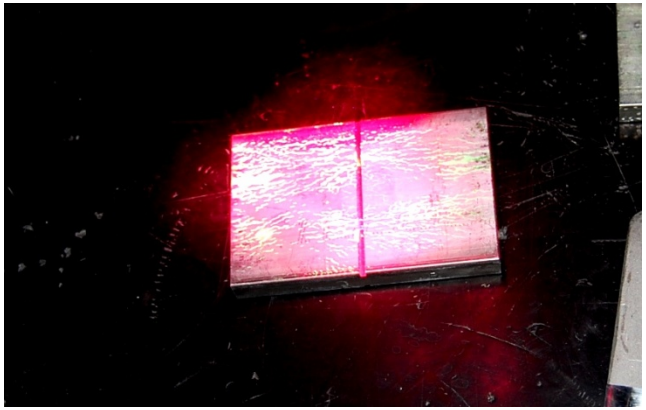


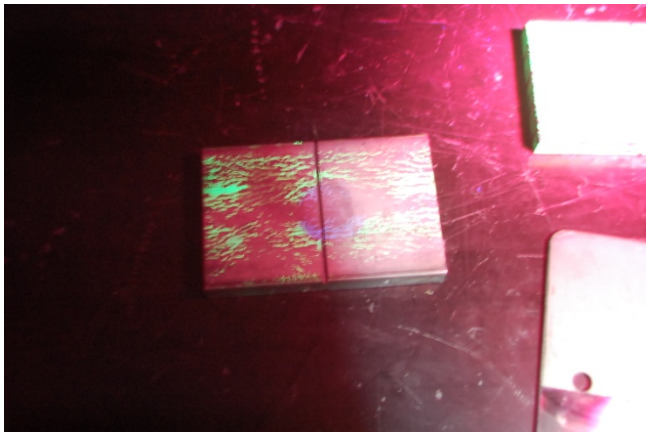
Start

Al quench crack blocks
~40,000 uW/cm2 exposure.



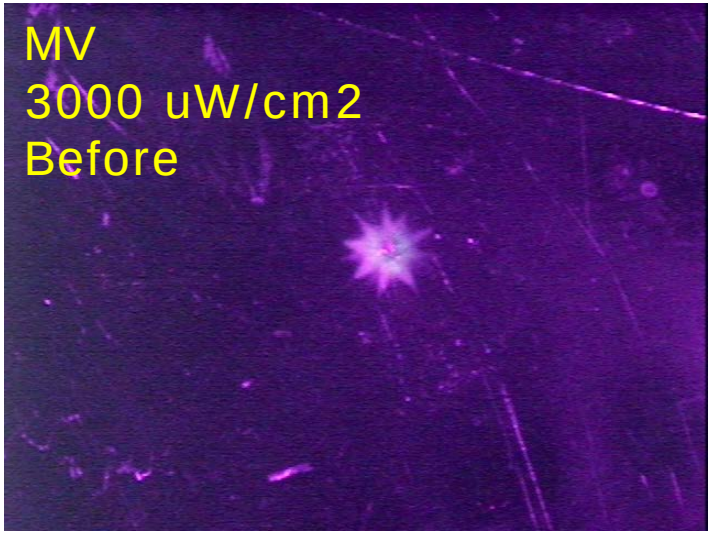
5 min

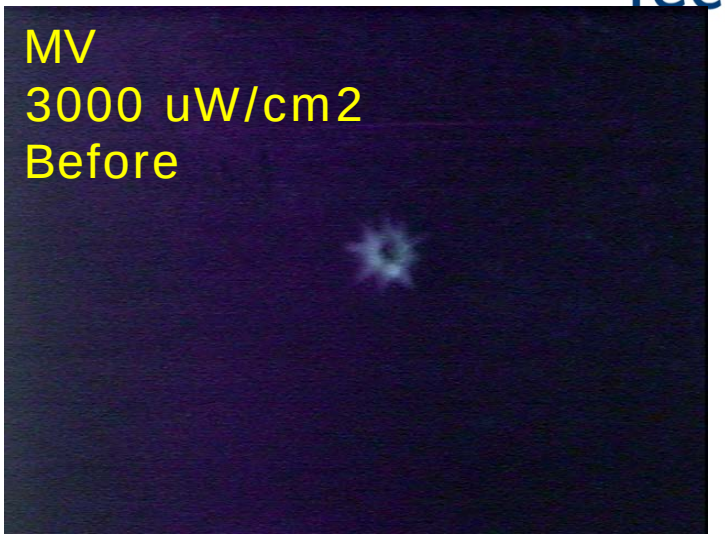
10 min



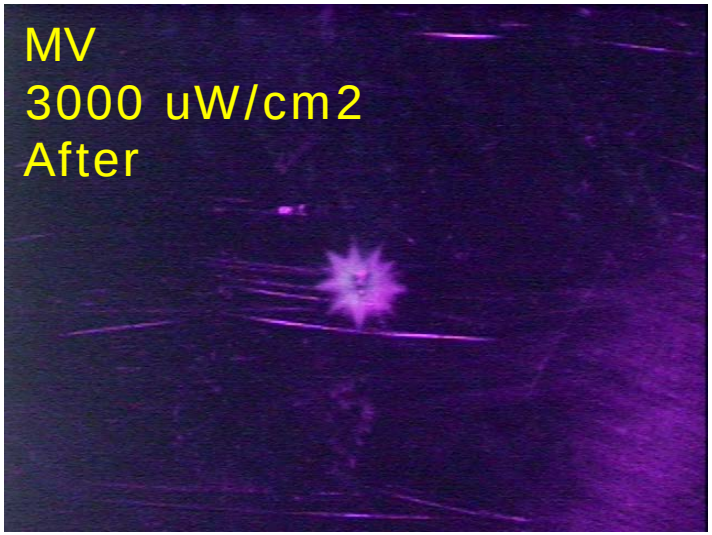
Fading of indications due to intense UV light does occur, but at times so lengthy, and intensities so great, it is not representative of FPI at Delta. Typically, any area of the part is only exposed to UV light for seconds.

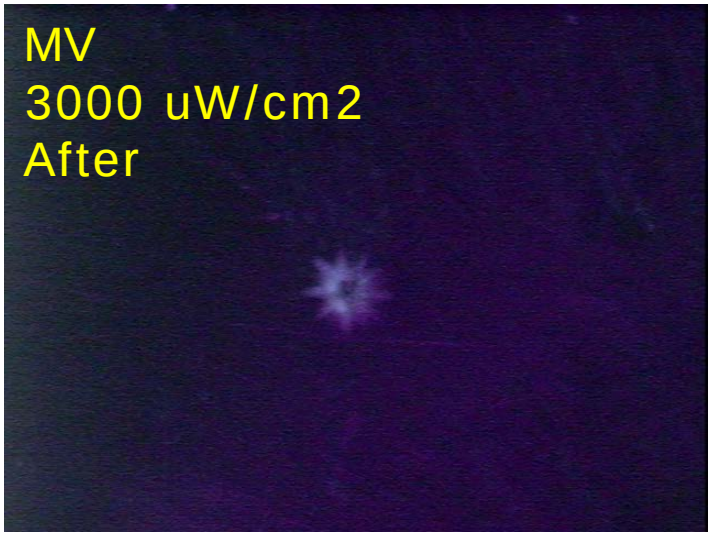
FPI: UV Fade – TAM Panel





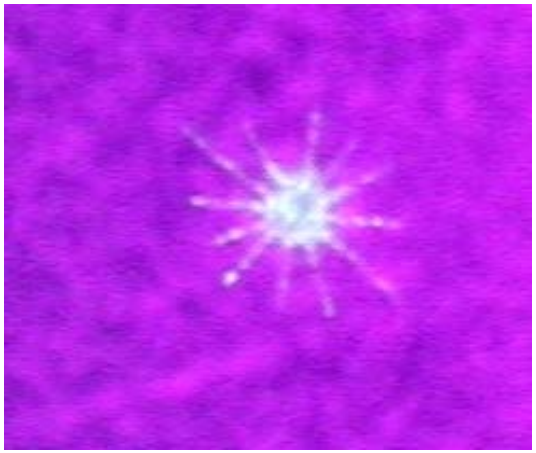
Surface exposed to Mercury Vapor light at 15” for 6 hours (3000 uW/cm2).





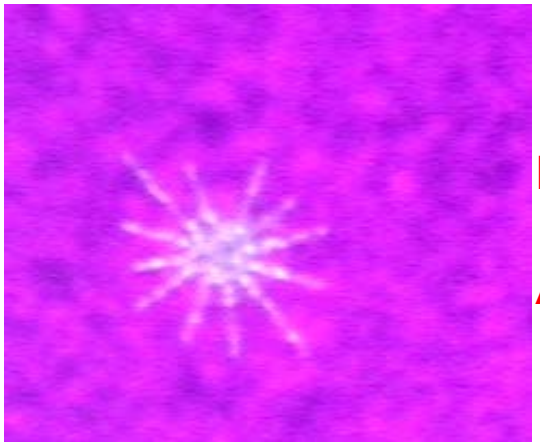
Fading does occur with extreme conditions, but still detected.

FPI: UV Fade – TAM Panel

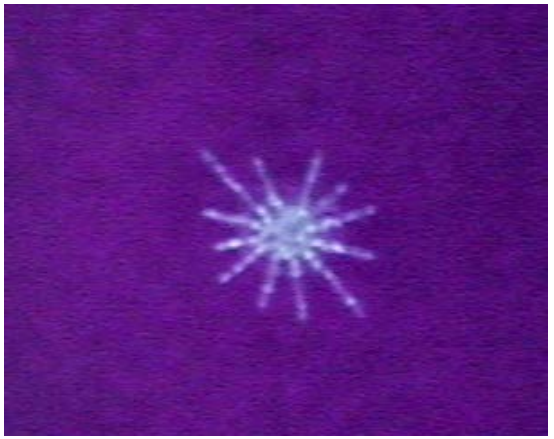


LED
11000 uW/cm2
Before

Surface exposed to LED light at 15” for 6 hours (11,000 uW/cm2).



LED
11000 uW/cm2
After

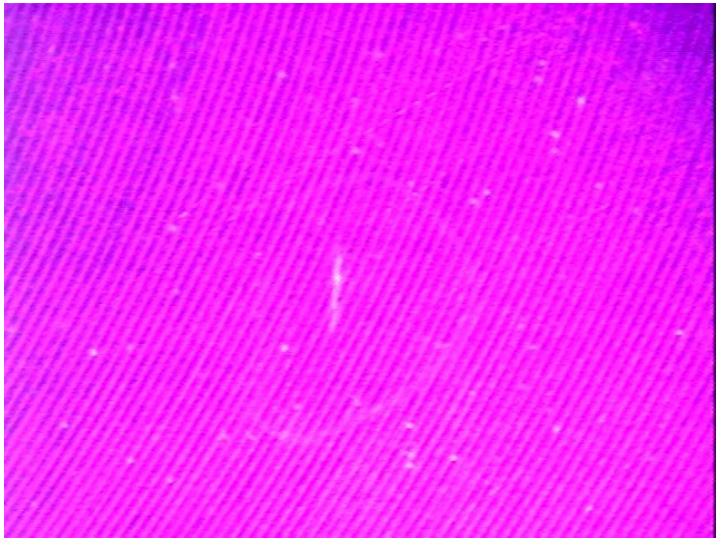


Even with extreme conditions, very minimal fading.

FPI: UV Fade – Fatigue Cracks on IN Panels

Table 3. Cracks lengths of fatigue cracks (IN 718 POD Panels) before and after extreme UV exposure.

Fatigue Crack length(in) - Actual	After 10 minute exposure to 40,000 uW/cm^2 UV light, measured with LED light	After 10 minute exposure to 40,000 uW/cm^2 UV light, Mercury Vapor light
0.099	0.098	0.096
0.122	0.121	0.119



Representative pictures of a crack after 10 minutes of extreme UV exposure, and then examined with a mercury vapor light (left), and LED light (right). The 0.099” crack measured 0.096” with mercury vapor light, and 0.098” with LED.

Which one is better?

UV Fade – Fatigue Cracks on IN718 Panels

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- The 0.99” long crack is barely visible with the Mercury Vapor light at 15 inches, and only measures 0.096”.

- The LED light produced a brighter indication, resulting in a more accurate measure of 0.098”.

- The background is indeed higher with the LED light versus the Mercury Vapor light. However, the contrast (i.e., signal-to-noise ratio) is much better with the LED lighting compared to the Mercury Vapor due to the much brighter indication.

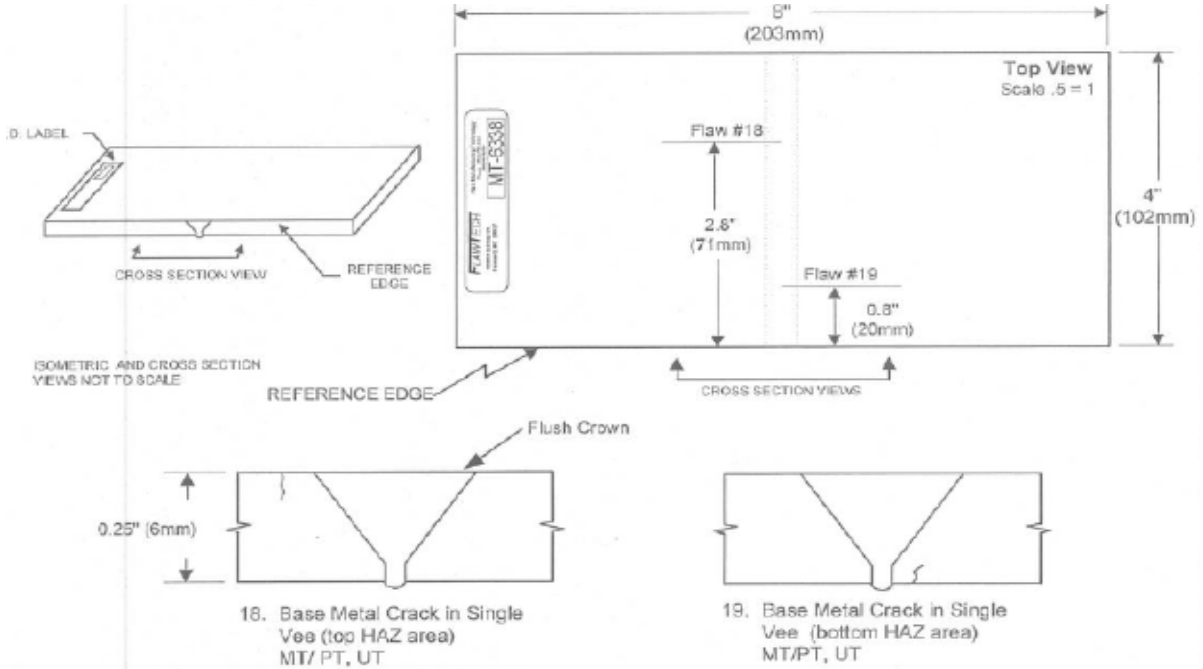
- This would positively affect the detectability of the crack (using LED light instead of Mercury Vapor).

Delta has therefore allowed the use of these lights with *only* a “do not dwell” caution added.

Magnetic Particle Inspection Studies

Equipment needed:

- Flawtech panels.
- Mercury vapor light source (Gould Bass CR2000).
- Micro-gas discharge light source (Spectroline Maxima).
- UV 'torch'/flashlight (Spectroline Opti-Lux 365 UV Light).
- UV light meters (DLM-1000, and XRP-3000 Accu-MAX).
- Steel bolts = crack sizes of 0.034”, 0.079” 0.095”, 0.100”, 0.159”, 0.190” 0.282”.
- Ketos Ring.



Similar studies for MPI – Fluid chemistry.

MPI: Procedure

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UV Fading

- For the Flawtech panels, KETOS ring and bolt with 0.034” crack and bolt with 0.282”, perform UV fade test;
  - Place source such that UV reading is off-scale at the surface; examine the part every 5 minutes. Repeat study for each light source type (micro-gas discharge, mercury vapor, LED).

- For the KETOS ring and bolt with 0.034” crack and bolt with 0.282” crack, perform ‘extended’ UV fade test;
  - Place source 15” away from surface; take UV reading; examine the part every 15 minutes. Repeat study for each light source type.

Apparent Crack Length

- For the Flawtech panels (0.200" long cracks in different configurations), and bolts.
  - Measure the 'apparent crack length' using the mercury vapor light at 1000 uW/cm2 (at the surface), then move the light back and measure at 1500 uW/cm2, then 3000 uw/cm2, then 6000 uW/cm2 (or max as you can get); Then repeat with UV 'torch'/flashlight and micro-gas discharge light at 1000, 1500, 3000, 6000, 10,000, and 15,000 uW/cm2.

MPI: Apparent Crack Length Results

- No major difference in 'apparent' crack length was observed in using either the mercury vapor, micro-gas discharge lamp, or the LED light.
- Similar to the FPI study, at the same intensity level, LED lighting provided a more-accurate representation of the crack length.
- As intensity was increased, a slight increase in 'apparent' crack size was noted, also across all crack lengths. Smaller sizes not impacted disproportionally.
- Increasing the UV intensity for LED caused an increase in the background. However, the contrast was enhanced (i.e., signal-to-noise ratio) at increasing UV levels, causing a brighter indication, resulting in better overall detectability.
- Panels also provided a glare example.
- Bolts had tricky cracks.

Actual Crack length / Intensity	1000 uW / cm²	1500 uW / cm²	3000 uW / cm²	6000 uW / cm²	10000 uW / cm²	15000 uW / cm²
0.034	0.032	0.032	0.033	0.033	0.034	0.034
0.079	0.077	0.077	0.077	0.078	0.078	0.079
0.095	0.096	0.097	0.097	0.098	0.098	0.098
0.100	0.104	0.101	0.102	0.103	0.103	0.104
0.159	0.155	0.156	0.156	0.157	0.158	0.158
0.190	0.187	0.188	0.188	0.189	0.191	0.191
0.282	0.283	0.282	0.282	0.283	0.283	0.284

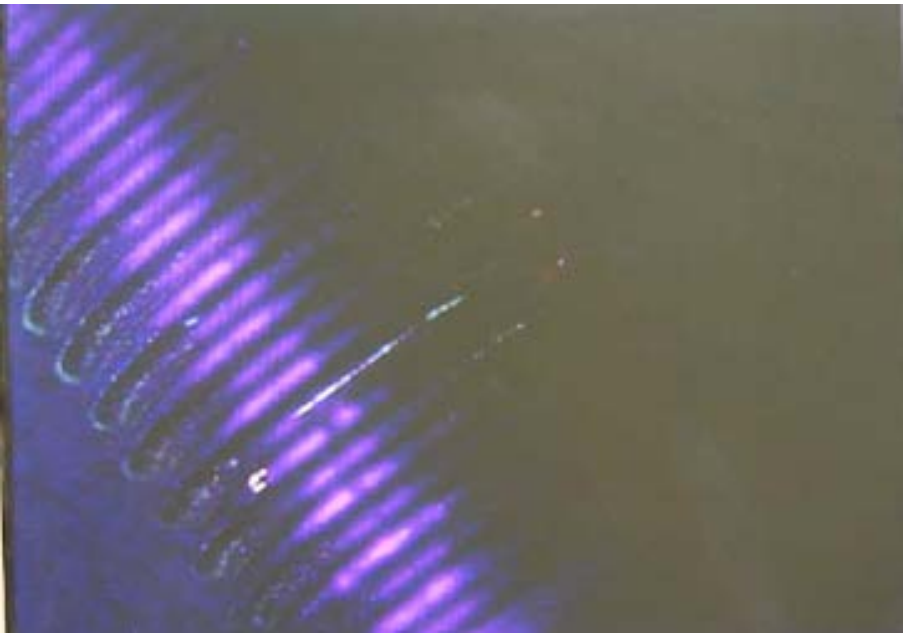
LED lighting provided a more-accurate representation of the crack length.

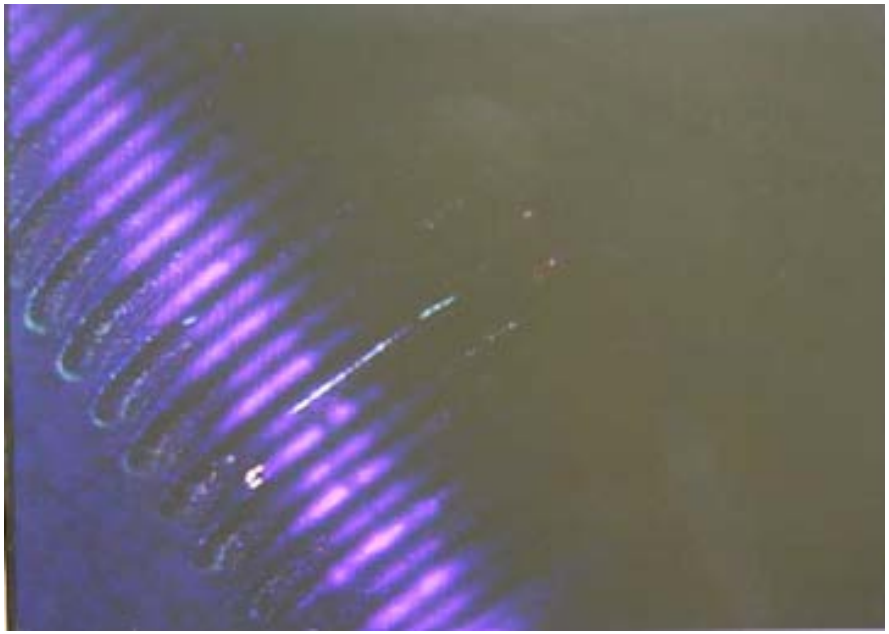
MPI: UV Fade Results

- Concluded to be little to no change after the extreme UV exposure, within the measurement error.
- Measurements were taken to see if the 'apparent crack length' had changed as a result of UV fading. There was no change in length and it was concluded UV Fading was negligible.
- Same conclusions for the Mercury Vapor UV light and the micro-gas discharge UV lamps.
- The KETOS ring also showed no difference in holes detected before and after the UV fade.
- Some fading of the steel bolt cracking was noted after about 20 minutes (apparent crack length), but this timeframe was deemed extreme (as well as the extreme exposure).
- After 6 hours, slight fading was noticed (apparent crack length) for each light source type, with the LED showing the greatest amount of fade.
- However, this fading was still deemed to be negligible as the crack lengths did not change, though the apparent brightness did vary. This extreme measure was deemed not representative of the process at Delta (i.e., typically the part is under UV light on for a few seconds).

Similar result to FPI.

MPI: UV Fade Results





BEFORE AND AFTER (20 MINUTES) PHOTOS OF THE CRACK AFTER EXPOSURE TO ~40,000 uW/cm2 UV INTENSITY WITH LED LIGHT.

Negligible difference after extreme UV exposure.

Conclusions - FPI

- Increasing UV intensity results in equivalent or better detectability via 'apparent crack lengths'. This was true for both mercury vapor UV lights and high-intensity LED UV light.
- At the same intensity level, LED lighting provided a more-accurate representation of the crack length. This was true across the board, and did not vary even at smaller crack lengths.
- Fading of indications due to intense UV light does occur, but at times so lengthy, and intensities so great, it is not representative of FPI at Delta. Typically, any area of the part is only exposed to UV light for seconds.
- Increasing the UV intensity for LED caused an increase in the background. However, the contrast was enhanced (i.e., signal-to-noise ratio) at increasing UV levels, causing a brighter indication, resulting in better overall detectability.
- UV Fade experiment on the TAM panel using post-emulsifiable (Class 2, Level 4) penetrant produced some fading after 20 minutes, but the 5th star crack (smallest crack) was still visible even after 90 minutes.
- The quench crack blocks did show fading after 10 minutes of exposure to **extreme** UV intensity. Therefore, it is recommended that a caution note be added to avoid dwelling and limit total exposure of any one area to 5 minutes or less.

High intensity UV lights allowed at Delta.

Conclusions - MPI

- Increasing UV intensity results in equivalent or better detectability via 'apparent crack length'. This was true for both mercury vapor UV lights, micro-gas discharge lights, and high-intensity LED UV light.

- At the same intensity level, LED lighting provided a more-accurate representation of the crack length.

- Fading of indications due to intense UV light does occur, but at times so lengthy, and intensities so great, it is not representative of MPI at Delta. Typically, any area of the part is only exposed to UV light for seconds.

- Increasing the UV intensity for LED caused an increase in the background. However, the contrast was enhanced (i.e., signal-to-noise ratio) at increasing UV levels, causing a brighter indication, resulting in better overall detectability.

- UV Fade experiment produced negligible fading after 20 minutes, when the test was concluded. Typically, any area of the part is only exposed to UV light for seconds.

Don't put unnecessary burdens on industry w/o data.