Kleinfeld
Technical Services, Inc.
Infrared Thermography
Finite Element Analysis
Process Engineering

Summary Report
Evaluation of the Effectiveness of Epner LaserGold Foil as a Radiant Heat Barrier Compared to a Competitor's Foil's Performance
Automotive Applications

For David Epner, President
Epner Technology, Incorporated

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Summary

In two comparisons of the performance of Epner LaserGold foil and a competitor's foil as barriers for radiant heat transfer, the Epner LaserGold outperformed the competitor's product. Tests were performed using a substrate of carbon fiber epoxy composite protected by the Epner LaserGold and by the competitor's foil ("CF") and similarly using the two foils on an aluminum substrate to reduce the heat transferred to a free standing target, corresponding to a car's driver, on the cool side of the aluminum plate. A comparison case of unprotected carbon fiber epoxy composite substrate was run. While the CF showed an improvement over the unprotected carbon fiber epoxy composite substrate, the protection provided by the Epner LaserGold was approximately two and a half times greater. The Epner LaserGold also was superior in reducing the heating of the free standing target exposed to the aluminum plate.

Protecting Formula 1 Car Carbon Fiber Epoxy Composite

The primary test was set up to simulate the radiant heating experienced by carbon fiber epoxy composite in Formula 1 race cars. It was reported that the carbon fiber composites in those cars face Inconel parts whose internal temperatures can be as high as 1200 to 1400°F. The surface temperatures of these Inconel parts were not specified. It was indicated that they are shiny and therefore would be expected to have a moderate to low emissivity. Typical distances between the Inconel and the composite panels were reported as 1 to 1.5". Some airflow in the channel occurs, but was not simulated. It was reported that the composite needed to be protected from exceeding temperatures of approximately 700°F in order to prevent failure of the epoxy. The foils were evaluated for their ability to reduce the temperature rise experienced by the composite. The cool side or back side of the composite was measured using a radiometric infrared (IR) camera. A thermocouple was also used to provide comparison readings.

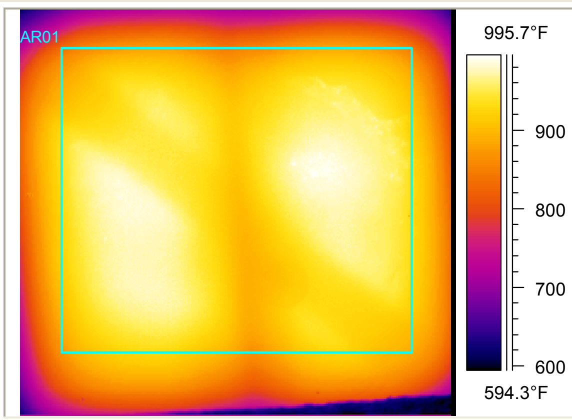
There will be a temperature drop through the thickness of the composite, from the front side of the to the accessible back side. This drop will depend on the thickness and properties of the composite and also on the heat load imposed on the front side. As the heat load increases, the temperature drop will increase, so that as the readings of the accessible side increase the hot side temperature is increasing even more. This implies that the less protection a foil provides to the composite, the greater the temperature rise on the hot side will be relative to the observable rise on the cool side.

Test Set-up

A hot plate operating at an average surface temperature of 939°F with matte black high temperature paint exhibiting an emissivity of approximately 0.95 was used as the heat source. Because of its high emissivity, it corresponds to a much hotter Inconel source. Based on the measured emissivity of the painted hot plate and an estimated emissivity for the Inconel of 0.4 (Perry's Chemical Engineer's Handbook, 4th ed., pg. 10-35, for nickel plate heated to 1110°F), the radiation emitted by the hot plate at 939°F is equivalent to that emitted by Inconel at 1277°F. This calculation neglects any reflected radiation component. The value agrees with the conditions reported for the race cars.

The hot plate was oriented vertically, facing the samples. The composites were placed parallel to the hot plate at a distance of 1.5 to 1.625". In accordance with guidance from the race car industry, the shiny side of the composite panels faced the heat source. No airflow was introduced to the test system, only natural convection due to the airflow caused by the hot surfaces occurred. The photos below show the setup. Binder clips were used to support the sample. They caused localized heating of the sample, which was ignored in developing the data. Images of the cool side of the composite were taken starting immediately after placing the sample in position and continuing until a steady state temperature was observed. The bare composite, with no foil protection of any type, failed after less than 75 seconds. Times are reported below as elapsed from the first image in the series. The first image for each series was taken about 10 to 20 seconds after the sample was in place.

The infrared (IR) image and measurements of the hot plate at its maximum setting, as used for these tests, is shown below. No sample was present while taking this image.



IR information	Value
Ambient temperature	69.8°F
Atmospheric temperature	69.8°F
Label	Value
AR01 : max	1003.7°F
AR01 : min	827.8°F
AR01 : avg	939.3°F
AR01: stdev	28.7°F

The temperature statistics shown are for the blue analysis area, AR01, on the image.

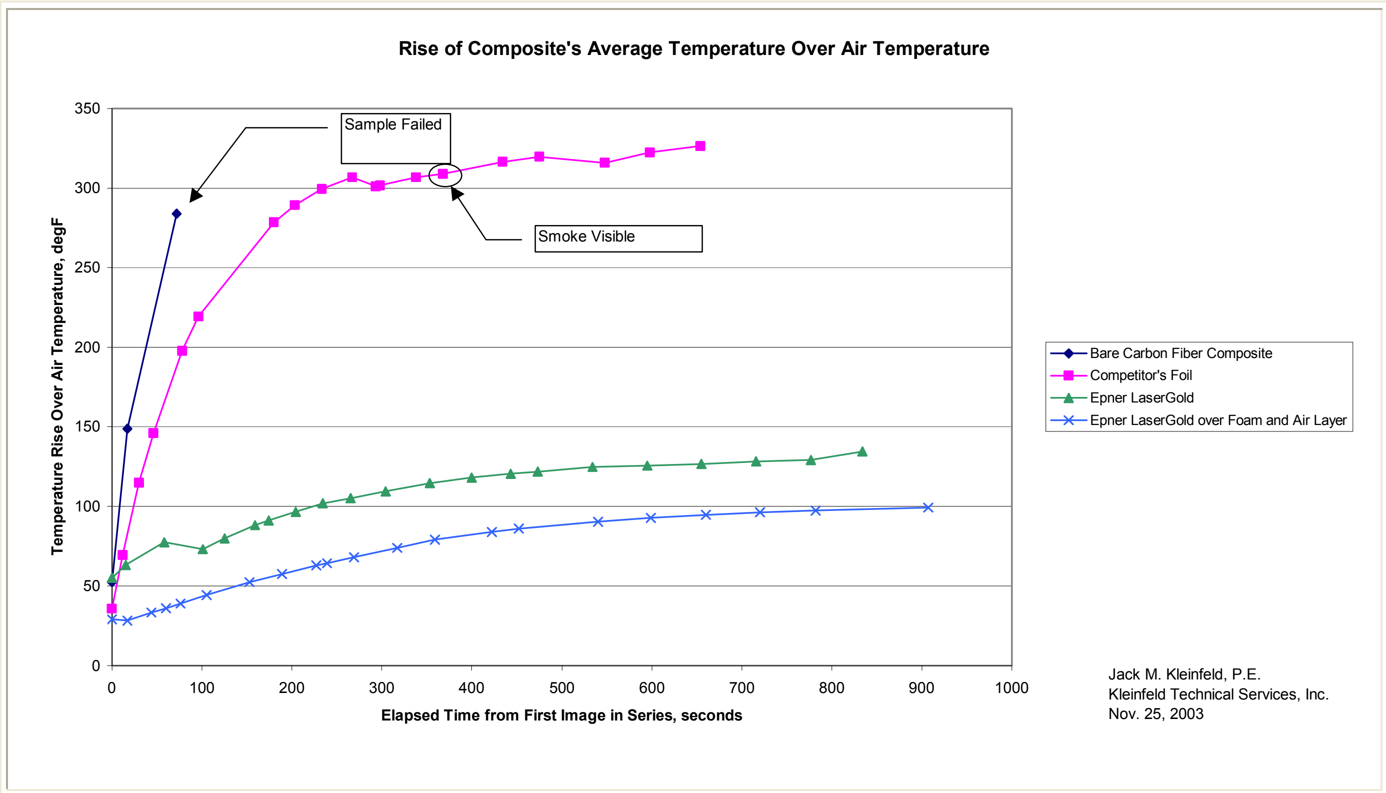
IR image of the hot plate before testing samples.

Additional Test Condition

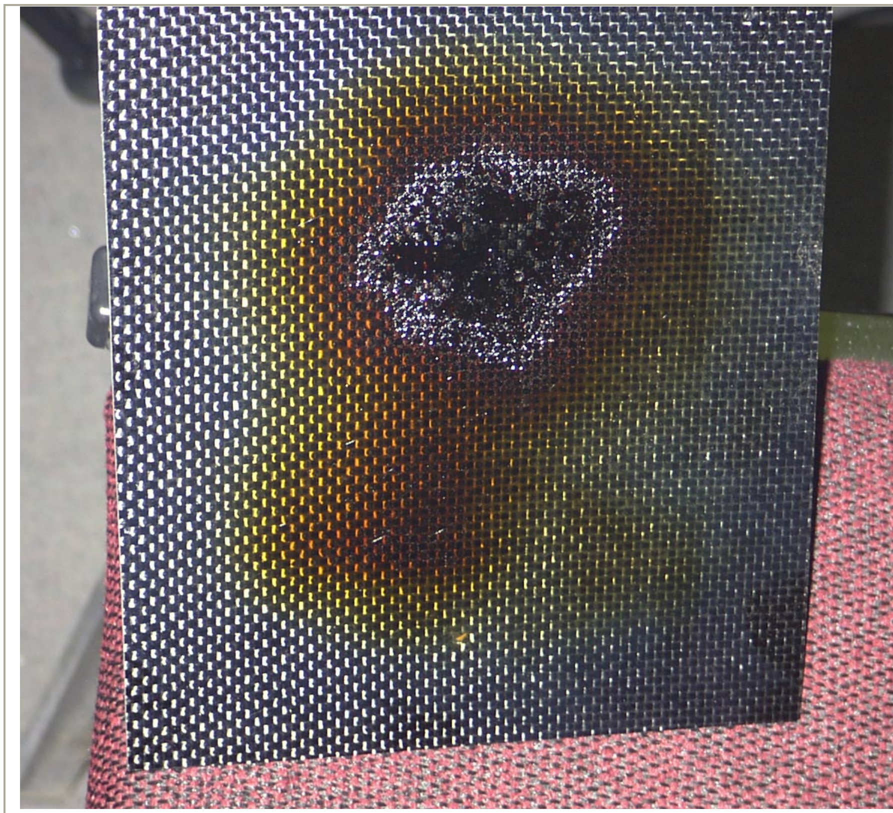
An additional configuration incorporating a layer of air and foam under the Epner LaserGold foil further improved the performance. In a situation where convective heat transfer across the gap between the hot source and the composite was a significant factor in the heating of the composite, such an insulative layer would be highly desirable.

Results

Results of the primary test, the performance of the foils as radiant heat barriers for protecting carbon fiber epoxy composite demonstrated a clear difference between the performance of the Epner LaserGold and the CF. The results are summarized below as plot of average temperature of the cool side of the composite, reported as rise above ambient air temperature, against elapsed time of the test. (This plot is also provided as a separate file.)



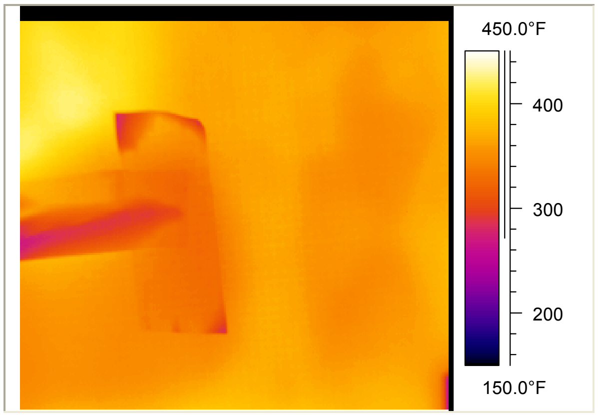
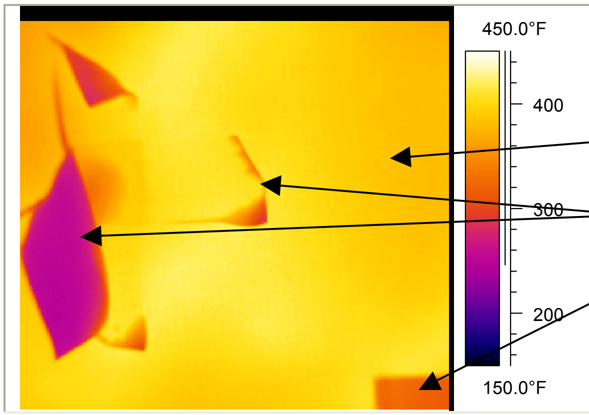
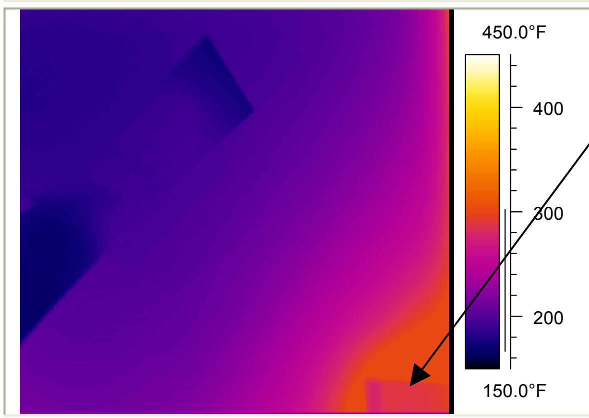
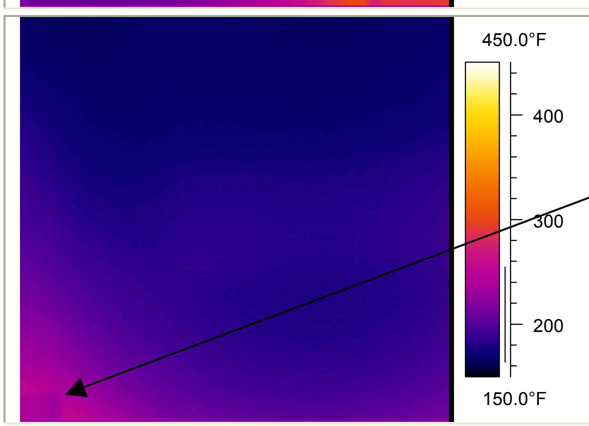
The unprotected composite sample failed very quickly and its test was aborted before a steady temperature was reached. The failed material is shown below.


Failed bare composite after test.

The data for the four runs of the primary test are tabulated below. This is the data used for the plot presented above.

Rise of Composite's Average Temperature Over Air Temperature							
Elapsed Time, sec	Bare Carbon Fiber Composite, °F	Elapsed Time, sec	Competitor's Foil, °F	Elapsed Time, sec	Epner LaserGold, °F	Elapsed Time, sec	Epner LaserGold over Foam and Air Layer, °F
0	52	0	36	0	55	0	29
17	149	12	70	15	63	17	28
72	284	30	115	58	78	44	33
		46	146	101	73	60	36
		78	198	125	80	76	39
		96	219	159	88	105	44
		180	278	174	91	153	52
		203	289	204	97	189	58
		233	300	234	102	227	63
		267	307	265	105	239	64
		293	301	304	109	269	68
		298	302	353	115	317	74
		338	307	400	118	359	79
		368	309	443	121	422	84
		434	317	473	122	452	86
		475	320	534	125	540	91
		548	316	595	126	599	93
		598	322	655	127	660	95
		654	326	716	128	720	96
				777	129	782	97
				834	135	907	99

Infrared images of the composites at the end of each test are shown below in a common temperature scale to enable visual comparisons between them. They are presented in an ironbow palette to represent the temperatures. The CF sample is hotter than the bare composite because of the early failure of the bare composite, which prevented the unexposed side from heating as much as it would have at steady state. Note that the temperatures reported are actual temperatures, not rise above ambient. Most images show tape used to hold a thermocouple on the surface for measurement confirmation. This area was not included in the temperature measurements used to evaluate the results. The areas in the bottom corners that are locally heated by the binder clips used to support the sample were also excluded from the temperature measurements.

IR image of Composite at End of Test, Ironbow Palette	Test Case
	Bare composite. Failed before reaching steady state temperature.
	Competitor's foil. (CF) Region of interest. Tape. Binder clip. Direct comparison is between this image and the next.
	Epner LaserGold. Binder clip.
	Epner LaserGold over layer of foam and air. Binder clip.

The comparison of the foils' performance on a head to head basis for protection of the substrate, using carbon fiber epoxy composite, is between the two cases using foil only. The Epner LaserGold rejected sufficient radiation to maintain the back of the composite at 135°F above ambient. The CF only rejected sufficient radiation to allow the back of the composite to reach 326°F above ambient, or 2.4 times the rise of the Epner LaserGold. Either foil's performance would be enhanced by the addition of an insulation layer under the foil. This was demonstrated with the Epner LaserGold using a layer of foam and air. With the additional, convective and conductive transport barrier, the Epner LaserGold reduced the rise of the back of the composite to 99°F, for an improvement of an additional 27% over the Epner LaserGold alone. The temperatures of the hot side of the composite using the CF might make the requirements for the insulating material more severe. The material would be exposed to higher temperatures with the CF than with the Epner LaserGold and a more expensive material might be needed to provide adequate life.

Protecting Drivers

A secondary test was set up to simulate the impact on the heat exposure of a race car driver. The temperature measured was that of the back (cool or unexposed side) of a file folder representing the driver or the driver's clothing.

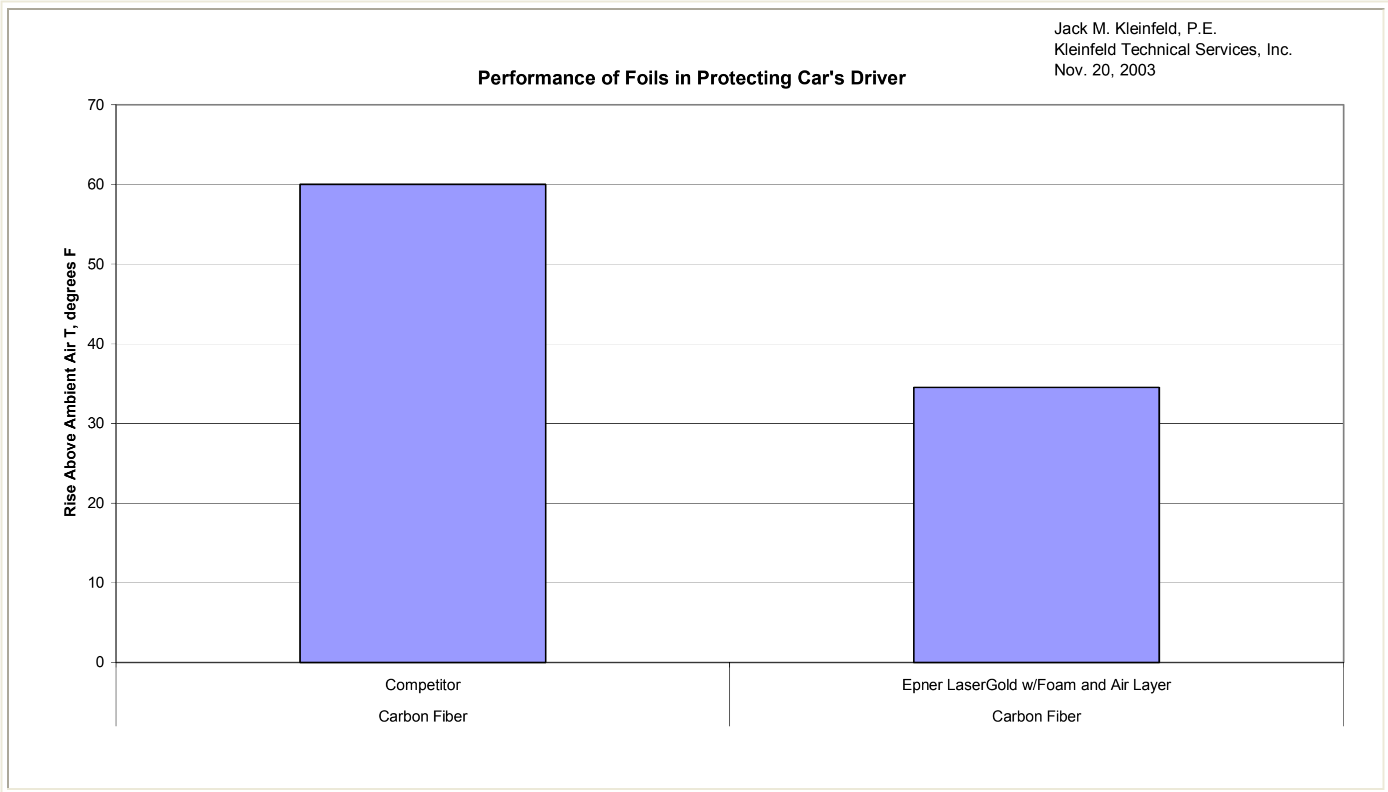
Test Set-up

Two configurations were used for this test. In one, the same carbon fiber epoxy composite was used as in the primary test. The composite was tested with CF on the hot side and with Epner LaserGold over a foam and air layer on the hot side. In the other, the substrate used was aluminum plate. In a Winston Cup or NASCAR or similar car, the plate forms part of the cabin enclosure. The aluminum plate had the CF and Epner LaserGold foils placed on the side exposed to the hot plate. An additional condition with Epner LaserGold on both sides of the aluminum plate was also evaluated.

The temperatures of the file folder target were observed and an image captured when steady state was reached. Photos of the set up for the driver heat-loading test are shown below. The plate was 1.5" to 1.635" from the hot plate, and the file folder target was 5.25" from the plate.

Results

Because of the larger distances involved and the additional step of heat transfer from the back of the plate to the file folder, less thermal loading was observed on the file folder than occurred on the back of the carbon fiber composite directly in the primary test. The low emissivity of the aluminum plate, which was unfinished, also contributed to the low level of radiant heating of the file folder. If the aluminum surfaces in the actual vehicles are painted or dirty, raising their emittance, the load on the driver and the cabin will increase significantly. Under those conditions, the impact of the foils will be greater. The observed rise above ambient air temperature of the file folder for the two tests using the composite plate is shown in the first bar graph below. The improvement using the Epner LaserGold, from a 60°F rise down to a 35°F rise, is due to both the performance of the foil and the impact of the foam and air layer under it. The observed rise above ambient air temperature for the CF, for Epner LaserGold, and for Epner LaserGold on both sides of the aluminum plate is shown in the second bar graph below. (I have also provided separate files of the graphs.)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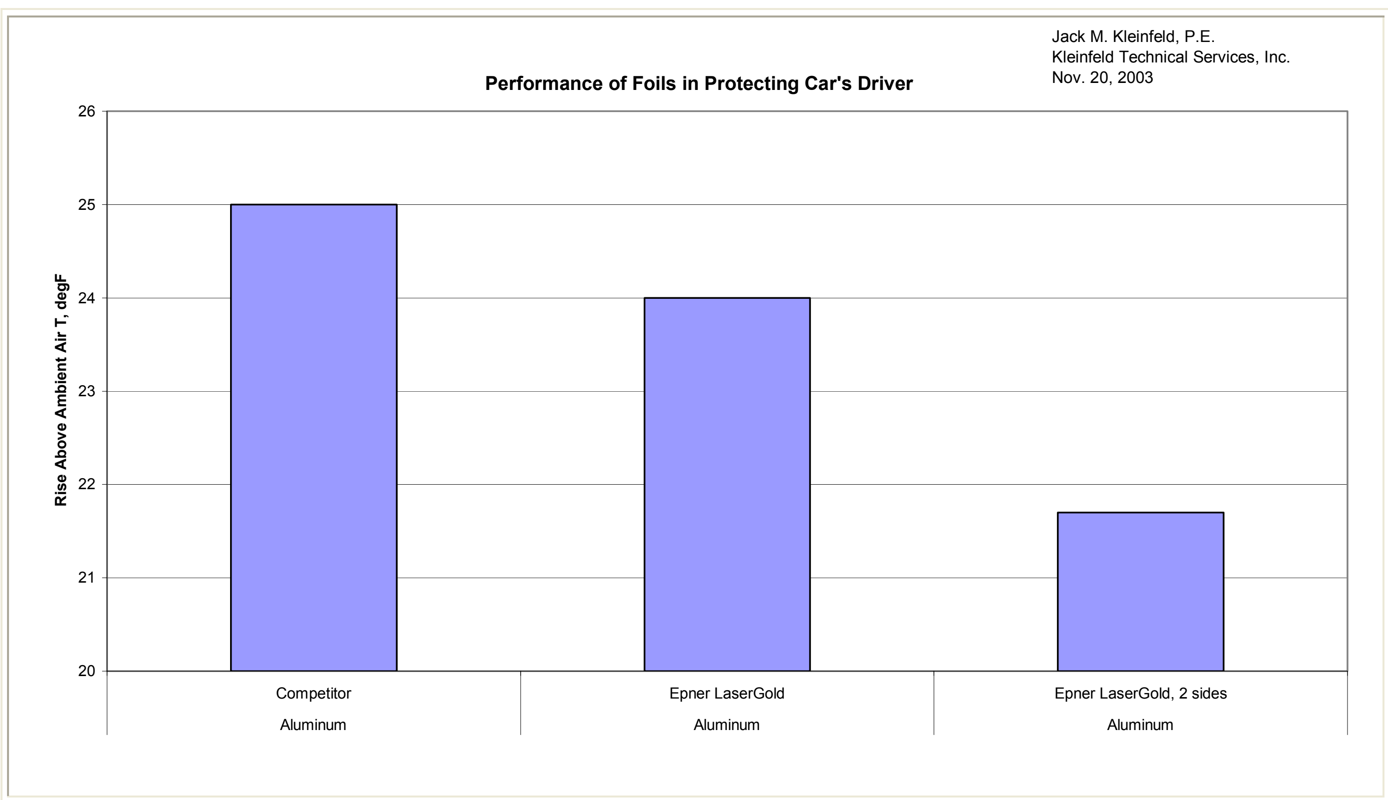
Nov. 20, 2003
Performance of Foils in Protecting Car's Driver
Rise Above Ambient Air T, degrees F
70
60
50
40
30
20
10
0
Competitor
Carbon Fiber
Epner LaserGold w/Foam and Air Layer
Carbon Fiber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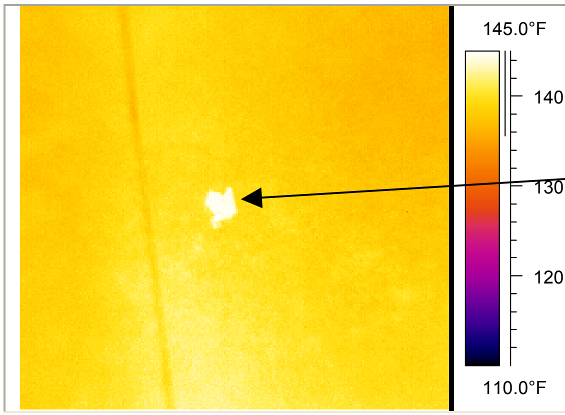
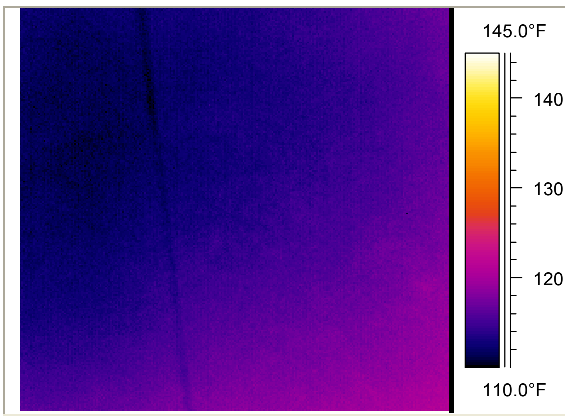
Nov. 20, 2003
Performance of Foils in Protecting Car's Driver
Rise Above Ambient Air T, degF
26
25
24
23
22
21
20
Competitor
Aluminum
Epner LaserGold
Aluminum
Epner LaserGold, 2 sides
Aluminum

IR images for direct comparison of the results of the secondary test are presented below. They are use a common temperature scale for each plate material to allow for direct visual comparison of the results.

<table>
<tr><th>IR image of File Folder Facing Composite Plate at End of Test, Ironbow Palette</th><th>Test Case</th></tr>
<tr><td>
</td><td>Competitor's Foil (CF).

Note that the spot caused by the marker was not included in any measurements.</td></tr>
<tr><td>
</td><td>Epner LaserGold over foam and air layer.</td></tr>
</table>