



THE EFFECT OF SURFACE OXIDATION ON IHLP INDUCTOR PERFORMANCE AND RELIABILITY

Overview

Under certain environmental conditions such as high moisture and elevated temperatures or in the presence of ionic contamination, a slight amount of surface oxidation has been found to form on the surface of a small percentage of IHLP inductors. The following report contains construction details, the results of analysis, and a summary of the reliability testing performed regarding the formation of surface oxidation.

Construction

The IHLP inductor is constructed using a self supporting wirewound coil. The two ends of the coil are welded to a lead frame that acts as a carrier through the manufacturing operation at VISHAY, and as the final termination pads when the part is singulated from the lead frame.

After the inductor coil is welded to the lead frame, a powdered iron body is pressed around the inductor coil. The characteristics of the powdered iron enhance the magnetic properties of the inductor and also give the inductor its final shape or footprint.

In its raw form, the iron powder is a fine mesh powder that is highly conductive. In order to improve the magnetic properties, the iron powder is passivated. The iron powder is passivated by subjecting the powder to an acid, which chemically forms an iron phosphate protective layer around each iron particle. The protective layer that is formed around each iron particle insulates each particle from another and also acts as a moisture barrier against oxidation.

After the passivation process, the passivated iron powder is mixed with a resin binder. The purpose of the resin binder is to bind the particles together when they are pressed around the inductor coil. The resin binder also serves to offer some protection against oxidation, but the main purpose of the resin is to act as a binder.

After the iron powder is mixed with the resin binder, this homogeneous mixture is pressed around the inductor coil to form the body of the inductor. The inductor is then subjected to an elevated temperature cure to cure the epoxy binder, giving the inductor body its mechanical strength.

Following the curing operation, the IHLP inductors are singulated from the lead frame, 100% electrically tested, printed and packaged for shipping.

Vishay Dale

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Reliability Testing

IHLP inductors have been subjected to the following reliability tests:

1. Bias Humidity Test – 1000 hours at 85 C and 85% RH with 10% of full current applied
2. HAST Test – 48 hours at 125 C, 100% RH and 2X atmospheric pressure.

Prior to testing, all parts were serialized and Photographs were taken, and electrical parameters were recorded.

After testing, photographs were again taken and electrical parameters were recorded.

Test Results

Bias Humidity test results indicated no electrical test failures (see attached data). A small amount of oxidation was apparent on the inductors following Bias Humidity testing (see attached photographs).

HAST Test results indicated no electrical failures (see attached data). More extensive oxidation was apparent on the inductors following HAST testing (see attached photographs) The oxidation observed on the HAST tested parts exceeded the oxidation on any IHLP inductors returned by a customer.

Analysis

Cross sectional analysis has been performed on oxidized IHLP inductors to determine if the oxidation was able to penetrate below the surface of the inductor body. (See attached VISHAY Laboratory Report). The report concluded that the oxidation layer was confined to the surface of the inductor body and did not penetrate to the inductor coil.

Samples of oxidized inductors were sent to an outside Laboratory for FTIR (Fourier Transformation Infrared) Spectroscopy analysis (see attached FTIR report). The FTIR analysis revealed that some of the discolored material observed on the inductors was an amine or amide-based organic material. These materials are used as curing agents in epoxy materials. The results of these analyses indicated that the source of at least some of the discolored material on the inductors is the epoxy resin that is added to the iron powder during the manufacturing process.

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Conclusion

Based on the analysis performed on inductors displaying surface oxidation and the sequence of reliability tests performed by VISHAY there is no evidence that the oxidation has a detrimental effect on the performance or reliability of the IHLP inductors. This conclusion is further supported by the performance of the IHLP inductors in field applications. VISHAY has confirmed there have been no customer complaints for returns for electrical defects that have resulted from the formation of oxidation since the IHLP series was introduced approximately 5 years ago with nearly 20 million units in the field.

Eduard Zorov

A handwritten signature in black ink, appearing to read "Eduard Zorov", written over a horizontal line.

QA Manager
Vishay Israel
Beer-Sheva plant

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Biased Humidity Test - 1000hrs @ 85°C and 85%RH (MIL-STD-202 Method 103)

0149W	2525 4.7uH Initials		2525 4.7uH Finals		2525 4.7uH Deltas	
Serial #	PNID #P0545864		PNID #P0545864		PNID #P0545864	
	L	DCR	L	DCR	ΔL	ΔDCR
61	4.08	37.8	4.046	38.03	-0.83%	0.61%
62	4.191	37.95	4.158	38.32	-0.80%	0.98%
63	4.321	37.98	4.255	38.26	-1.52%	0.75%
64	4.412	37.91	4.351	38.08	-1.38%	0.46%
65	4.279	38.11	4.23	38.25	-1.14%	0.36%
66	4.253	37.96	4.215	37.95	-0.88%	-0.02%
67	4.259	38.03	4.216	38.26	-1.02%	0.62%
68	4.385	38.68	4.33	38.79	-1.26%	0.28%
69	4.361	38.13	4.319	38.14	-0.96%	0.02%
70	4.387	38.16	4.337	38.2	-1.13%	0.09%
71	4.111	37.71	4.074	37.84	-0.90%	0.35%
72	4.166	37.94	4.132	38.29	-0.82%	0.92%
73	4.195	37.87	4.141	38	-1.28%	0.35%
74	4.177	37.98	4.134	38.13	-1.04%	0.41%
75	4.373	38.11	4.283	38.07	-2.05%	-0.11%
76	4.209	37.87	4.177	38.09	-0.76%	0.58%
77	4.187	38.07	4.156	38.42	-0.75%	0.93%
78	4.301	38.02	4.255	38.19	-1.06%	0.44%
79	4.117	37.63	4.081	37.84	-0.87%	0.57%
80	4.229	37.97	4.196	38.19	-0.78%	0.57%
81	4.55	37.98	4.477	38.45	-1.61%	1.23%
82	4.293	37.91	4.252	38.13	-0.95%	0.59%
83	4.41	37.92	4.309	38.19	-2.30%	0.72%
84	4.182	38.1	4.149	38.26	-0.79%	0.43%
85	4.102	37.85	4.067	38.06	-0.85%	0.55%
86	4.196	37.99	4.158	38.17	-0.92%	0.47%
87	4.309	38.05	4.271	38.04	-0.89%	-0.03%
88	4.196	37.96	4.147	37.97	-1.18%	0.03%
89	4.164	38.08	4.131	38.3	-0.79%	0.57%
90	4.03	38.36	3.998	37.99	-0.80%	-0.96%
91	4.234	38.07	4.201	38.42	-0.77%	0.92%
92	4.435	37.95	4.35	38.29	-1.91%	0.90%
93	4.247	37.96	4.208	38.13	-0.92%	0.43%
94	4.135	37.85	4.103	37.81	-0.78%	-0.12%
95	4.155	37.93	4.123	38.04	-0.76%	0.30%
96	4.273	37.77	4.234	37.77	-0.91%	0.00%
97	4.331	38.09	4.261	38.36	-1.62%	0.70%
98	4.234	37.81	4.194	37.7	-0.94%	-0.29%
99	4.184	37.98	4.126	38.11	-1.39%	0.34%
100	4.187	37.99	4.146	38.09	-0.98%	0.26%
101	4.165	37.89	4.132	38.19	-0.79%	0.78%
102	4.159	37.9	4.125	37.79	-0.82%	-0.29%
103	4.376	38.08	4.268	38.13	-2.46%	0.14%
104	4.136	37.73	4.093	37.87	-1.04%	0.36%
105	4.054	37.83	4.022	37.9	-0.79%	0.18%
106	4.161	38.04	4.131	38.1	-0.72%	0.17%
107	4.094	38.18	4.06	38.48	-0.82%	0.79%
108	4.214	38.2	4.179	38.33	-0.83%	0.33%

109	4.145	37.74	4.112	37.82	-0.81%	0.20%
110	4.226	38.07	4.17	38.24	-1.34%	0.44%
111	4.147	37.91	4.112	38	-0.84%	0.25%
112	4.389	38	4.332	38.06	-1.30%	0.16%
113	4.121	37.77	4.085	37.82	-0.88%	0.14%
114	4.099	37.78	4.065	37.94	-0.82%	0.43%
115	4.318	38.53	4.276	38.64	-0.97%	0.28%
116	4.236	37.89	4.198	38.04	-0.90%	0.40%
117	4.352	38.2	4.294	38.1	-1.33%	-0.26%
118	4.397	38.04	4.352	38.18	-1.03%	0.37%
119	4.209	37.72	4.172	38	-0.89%	0.73%
120	4.274	37.92	4.234	38.08	-0.93%	0.41%
121	4.192	38.01	4.159	38.39	-0.78%	0.99%
122	4.251	38.12	4.211	38.48	-0.93%	0.94%
123	4.254	37.98	4.215	38.12	-0.93%	0.36%
124	4.206	38.13	4.172	38.26	-0.82%	0.35%
125	4.323	38.01	4.242	38.3	-1.87%	0.76%
126	4.12	37.9	4.085	37.96	-0.86%	0.16%
127	4.286	38.46	4.236	38.84	-1.17%	0.99%
128	4.355	38.04	4.254	38.25	-2.33%	0.55%
129	4.29	37.91	4.245	38.05	-1.04%	0.36%
130	4.202	37.94	4.167	38.2	-0.83%	0.68%
131	4.181	38.02	4.15	38.41	-0.73%	1.02%
132	4.339	37.95	4.294	38.32	-1.05%	0.97%
133	4.139	37.77	4.087	38.32	-1.26%	1.46%
134	4.16	37.79	4.126	37.92	-0.81%	0.34%
135	4.129	37.85	4.089	38.09	-0.98%	0.64%
136	4.162	37.78	4.131	37.92	-0.74%	0.36%
137	4.427	38.14	4.372	38.43	-1.25%	0.77%
Average	4.235	37.98	4.19	38.15	-1.06%	0.44%
Stdev	0.104	0.178	0.093	0.221	0.39%	0.39%



Results from 48hrs in HAST Chamber at 125°C, 100%RH and 2.3kg/cm²

P/N		IHLP-2525CZ-01			Qty		100		
Value		4.7uH			Date		24-Jul-03		
Serial #	L1 (uH)	L2 (uH)	ΔL (uH)	Q1	Q2	ΔQ	R1 (mΩ)	R2 (mΩ)	ΔR (mΩ)
1	4.393	4.490	2.17%	33.261	33.458	0.59%	39.152	39.064	-0.23%
2	4.388	4.529	3.11%	32.913	33.078	0.50%	39.397	39.281	-0.30%
3	4.413	4.417	0.09%	33.397	33.626	0.68%	38.731	38.667	-0.17%
4	4.545	4.710	3.52%	34.399	34.711	0.90%	38.478	38.327	-0.39%
5	4.497	4.642	3.14%	34.643	34.140	-1.47%	38.269	38.213	-0.15%
6	4.371	4.478	2.40%	32.845	33.244	1.20%	38.903	38.834	-0.18%
7	4.359	4.514	3.43%	33.347	33.797	1.33%	38.381	38.336	-0.12%
8	4.533	4.624	1.96%	34.651	34.750	0.28%	38.574	38.666	0.24%
9	4.400	4.584	4.01%	33.212	33.982	2.27%	38.520	38.477	-0.11%
10	4.414	4.543	2.85%	33.574	34.002	1.26%	38.675	38.592	-0.22%
11	4.465	4.645	3.86%	34.283	34.528	0.71%	38.579	38.536	-0.11%
12	4.330	4.500	3.79%	33.205	33.583	1.12%	38.443	38.397	-0.12%
13	4.400	4.567	3.68%	33.461	33.536	0.22%	39.335	39.239	-0.24%
14	4.438	4.570	2.90%	33.725	34.133	1.19%	38.320	38.289	-0.08%
15	4.312	4.414	2.32%	32.586	33.101	1.56%	38.607	38.543	-0.17%
16	4.363	4.500	3.04%	32.855	33.482	1.87%	38.878	38.805	-0.19%
17	4.320	4.485	3.68%	32.099	33.181	3.26%	38.549	38.528	-0.05%
18	4.364	4.470	2.37%	32.962	33.463	1.50%	38.477	38.439	-0.10%
19	4.448	4.592	3.14%	33.804	33.838	0.10%	38.731	38.694	-0.10%
20	4.296	4.418	2.77%	32.762	33.244	1.45%	38.231	38.151	-0.21%
21	4.396	4.520	2.74%	33.465	33.823	1.06%	38.390	38.344	-0.12%
22	4.407	4.562	3.39%	33.022	33.527	1.51%	38.616	38.565	-0.13%
23	4.382	4.528	3.22%	33.130	33.490	1.08%	38.569	38.502	-0.17%
24	4.429	4.537	2.37%	33.613	33.676	0.19%	38.491	38.433	-0.15%
25	4.349	4.517	3.72%	32.864	33.353	1.47%	38.888	38.826	-0.16%
26	4.334	4.481	3.28%	32.771	33.218	1.35%	39.106	39.013	-0.24%
27	4.329	4.479	3.34%	32.756	33.114	1.08%	38.710	38.684	-0.07%
28	4.463	4.597	2.91%	33.269	33.545	0.82%	39.363	39.312	-0.13%
29	4.502	4.651	3.18%	34.329	34.754	1.22%	38.559	38.496	-0.16%
30	4.392	4.579	4.07%	33.475	33.770	0.88%	38.590	38.561	-0.08%
31	4.439	4.563	2.72%	34.109	34.054	-0.16%	38.487	38.442	-0.12%
32	4.709	4.813	2.16%	36.467	36.508	0.11%	38.749	38.711	-0.10%
33	4.444	4.666	4.76%	33.812	33.803	-0.03%	38.609	38.565	-0.11%
34	4.397	4.509	2.48%	33.309	33.504	0.58%	38.967	38.904	-0.16%
35	4.352	4.561	4.57%	32.847	33.635	2.34%	38.646	38.625	-0.05%
36	4.445	4.655	4.53%	33.468	33.817	1.03%	39.057	38.992	-0.17%
37	4.427	4.600	3.78%	33.136	33.405	0.81%	39.086	39.047	-0.10%
38	4.452	4.588	2.98%	33.687	34.143	1.34%	38.813	38.904	0.23%
39	4.447	4.648	4.31%	33.797	34.256	1.34%	38.576	38.546	-0.08%
40	4.395	4.533	3.04%	33.077	33.469	1.17%	39.046	38.955	-0.23%
41	4.429	4.574	3.17%	33.462	34.433	2.82%	38.129	38.085	-0.12%
42	4.474	4.682	4.45%	33.786	34.007	0.65%	38.988	38.936	-0.13%
43	4.379	4.680	6.42%	32.856	33.248	1.18%	38.967	38.943	-0.06%
44	4.409	4.581	3.75%	32.948	33.548	1.79%	38.961	38.927	-0.09%
45	4.335	4.509	3.87%	32.747	33.662	2.72%	38.603	38.552	-0.13%
46	4.405	4.532	2.79%	33.055	33.439	1.15%	38.989	38.965	-0.06%
47	4.428	4.521	2.04%	33.301	33.839	1.59%	38.925	38.881	-0.11%
48	4.389	4.558	3.71%	32.948	33.730	2.32%	38.633	38.588	-0.12%
49	4.411	4.525	2.51%	33.530	33.625	0.28%	38.794	38.716	-0.20%
50	4.364	4.555	4.20%	33.172	33.884	2.10%	38.617	38.523	-0.24%
51	4.357	4.478	2.70%	32.388	32.380	-0.02%	39.032	38.827	-0.53%
52	4.382	4.542	3.53%	32.776	32.980	0.62%	39.054	39.016	-0.10%
53	4.452	4.730	5.88%	33.393	33.826	1.28%	38.937	38.906	-0.08%
54	4.452	4.634	3.93%	33.566	34.157	1.73%	39.332	38.956	-0.97%
55	4.417	4.565	3.25%	33.382	33.690	0.91%	38.708	38.681	-0.07%

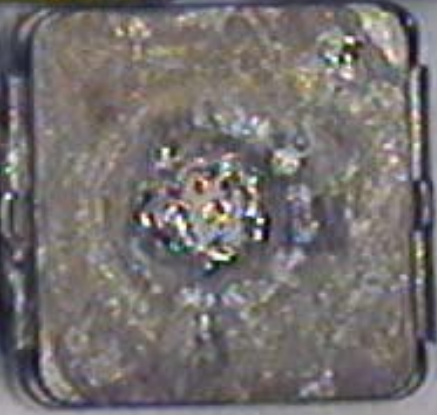
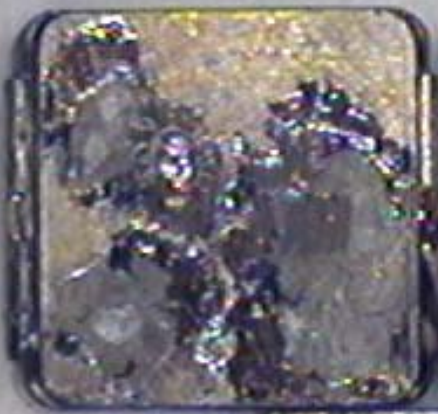
56	4.459	4.676	4.64%	33.031	33.743	2.11%	38.674	38.652	-0.06%
57	4.468	4.697	4.89%	33.762	34.060	0.87%	38.509	38.472	-0.10%
58	4.450	4.716	5.63%	33.750	34.048	0.88%	38.523	38.486	-0.10%
59	4.426	4.647	4.77%	33.127	33.370	0.73%	39.224	39.195	-0.07%
60	4.431	4.567	2.97%	33.570	33.833	0.78%	38.618	38.587	-0.08%
61	4.456	4.669	4.56%	33.651	34.017	1.08%	38.846	38.822	-0.06%
62	4.342	4.558	4.73%	32.244	32.657	1.27%	38.799	38.77	-0.07%
63	4.470	4.571	2.22%	33.725	33.822	0.29%	39.069	39.011	-0.15%
64	4.556	4.719	3.46%	34.507	34.919	1.18%	38.681	38.587	-0.24%
65	4.376	4.538	3.57%	33.298	33.576	0.83%	38.869	38.84	-0.07%
66	4.365	4.524	3.53%	33.046	33.458	1.23%	38.800	38.798	-0.01%
67	4.362	4.461	2.23%	33.124	33.602	1.42%	38.628	38.6	-0.07%
68	4.377	4.529	3.35%	32.807	33.344	1.61%	39.480	38.822	-1.69%
69	4.393	4.571	3.90%	33.223	33.457	0.70%	38.707	38.679	-0.07%
70	4.429	4.656	4.87%	33.961	34.132	0.50%	38.512	38.486	-0.07%
71	4.376	4.569	4.23%	33.256	33.413	0.47%	38.517	38.486	-0.08%
72	4.504	4.601	2.10%	34.460	34.666	0.59%	38.446	38.406	-0.10%
73	4.422	4.552	2.86%	33.577	33.801	0.66%	38.802	38.739	-0.16%
74	4.476	4.752	5.80%	34.108	34.519	1.19%	38.486	38.461	-0.07%
75	4.415	4.538	2.72%	32.964	33.487	1.56%	38.959	38.926	-0.08%
76	4.423	4.594	3.73%	33.143	33.542	1.19%	38.556	38.565	0.02%
77	4.401	4.550	3.27%	33.306	33.632	0.97%	38.652	38.649	-0.01%
78	4.423	4.631	4.49%	33.698	34.189	1.44%	38.467	38.469	0.01%
79	4.449	4.638	4.08%	33.818	34.016	0.58%	38.945	38.817	-0.33%
80	4.377	4.556	3.93%	33.003	33.460	1.37%	39.057	38.965	-0.24%
81	4.356	4.601	5.33%	32.781	33.672	2.64%	38.891	38.803	-0.23%
82	4.394	4.481	1.94%	33.489	33.264	-0.68%	38.798	38.906	0.28%
83	4.457	4.657	4.30%	33.521	34.024	1.48%	38.940	38.941	0.00%
84	4.417	4.594	3.86%	32.510	33.534	3.05%	38.366	38.324	-0.11%
85	4.384	4.503	2.64%	32.430	33.448	3.04%	38.646	38.591	-0.14%
86	4.365	4.564	4.36%	33.048	33.856	2.39%	38.405	38.379	-0.07%
87	4.402	4.639	5.11%	33.359	33.491	0.39%	38.705	38.66	-0.12%
88	4.382	4.486	2.31%	33.149	33.421	0.81%	38.307	38.279	-0.07%
89	4.358	4.558	4.38%	32.819	33.297	1.44%	38.683	38.643	-0.10%
90	4.444	4.649	4.40%	33.292	33.443	0.45%	39.353	39.288	-0.17%
91	4.476	4.680	4.36%	34.145	34.243	0.28%	38.565	38.516	-0.13%
92	4.395	4.505	2.43%	32.989	31.287	-5.44%	39.169	39.136	-0.08%
93	4.359	4.535	3.87%	33.443	33.821	1.12%	38.325	38.275	-0.13%
94	4.345	4.577	5.06%	32.915	33.582	1.99%	38.610	38.615	0.01%
95	4.348	4.564	4.73%	32.820	33.538	2.14%	38.573	38.461	-0.29%
96	4.468	4.676	4.44%	33.344	33.757	1.22%	38.923	38.906	-0.04%
97	4.412	4.633	4.77%	32.825	33.664	2.49%	38.871	38.832	-0.10%
98	4.399	4.691	6.22%	33.302	33.751	1.33%	38.406	38.366	-0.10%
99	4.429	4.620	4.14%	33.440	33.533	0.28%	38.714	38.678	-0.09%
100	4.400	4.629	4.95%	33.348	33.571	0.67%	38.915	38.856	-0.15%
Average	4.412	4.579	3.62%	33.348	33.711	1.07%	38.742	38.688	-0.14%
Max	4.709	4.813	6.42%	36.467	36.508	3.26%	39.480	39.312	0.28%
Min	4.296	4.414	0.09%	32.099	31.287	-5.44%	38.129	38.085	-1.69%

Before HAST



After HAST







September 16, 2003

Mr. Steven Axtell, Ph.D.
Vishay Dale Electronics
1122 23rd Street
Columbus, NE 68602-0609

SUBJECT: Organic Material on Iron Coupon
LEGEND No: 2003080351

1.0 INTRODUCTION

LEGEND TECHNICAL SERVICES, INC. (LEGEND) received two-iron coupon samples from a representative of Vishay Dale Electronics on August 21, 2003. LEGEND was requested to identify the foreign material on the surface of the samples using Fourier transform infrared spectroscopy utilizing an ATR objective. Mr. Axtell requested the analysis. The results are reported in section 4.0.

2.0 SAMPLE IDENTIFICATION

LABORATORY NUMBER	CLIENT IDENTIFICATION
2003080351	Iron Coupons

3.0 METHODOLOGY

The samples were analyzed using a Thermo Nicolet Nexus 470 Fourier transform infrared spectrometer (FTIR) equipped with a Thermo Nicolet Continuum infrared microscope, utilizing an ATR objective. The ATR objective is used to examine surface contamination by means of reflectance. Several areas, including dark, reddish, rust colored and clean areas were analyzed.

4.0 RESULTS

Based on the infrared spectra, both the dark residue and the reddish residue were similar in chemical composition and displayed spectral absorbencies consistent with amide or amine based materials. The best library spectral matches were polyamide 6 and zein (protein). The rust colored areas and the clean area on the coupon did not show evidence of organic material.

Copies of the infrared spectra are enclosed for review.

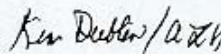
5.0 REMARKS

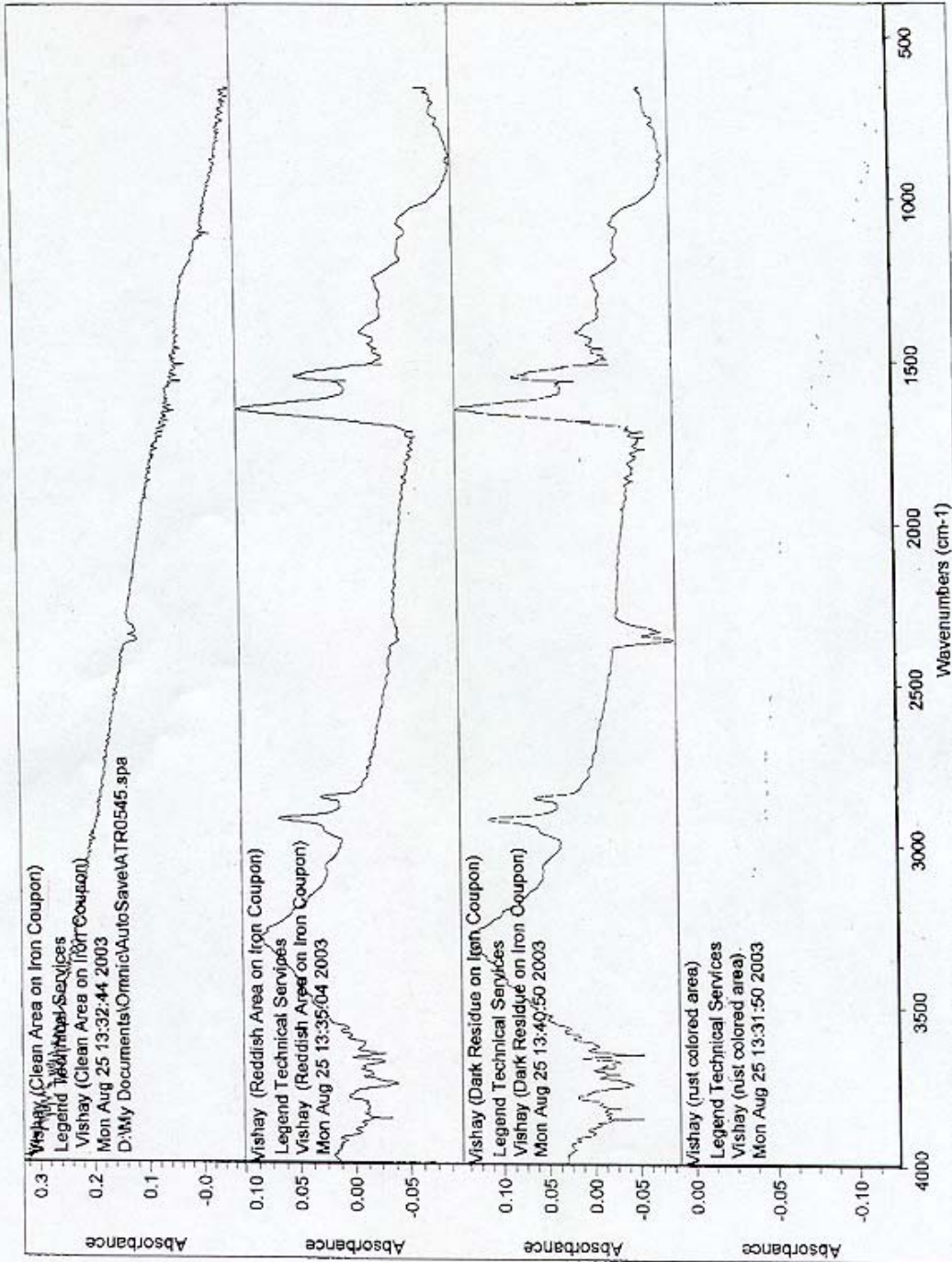
The unconsumed samples will be held for thirty days from the date of this report and then discarded unless other instructions are received by the client.

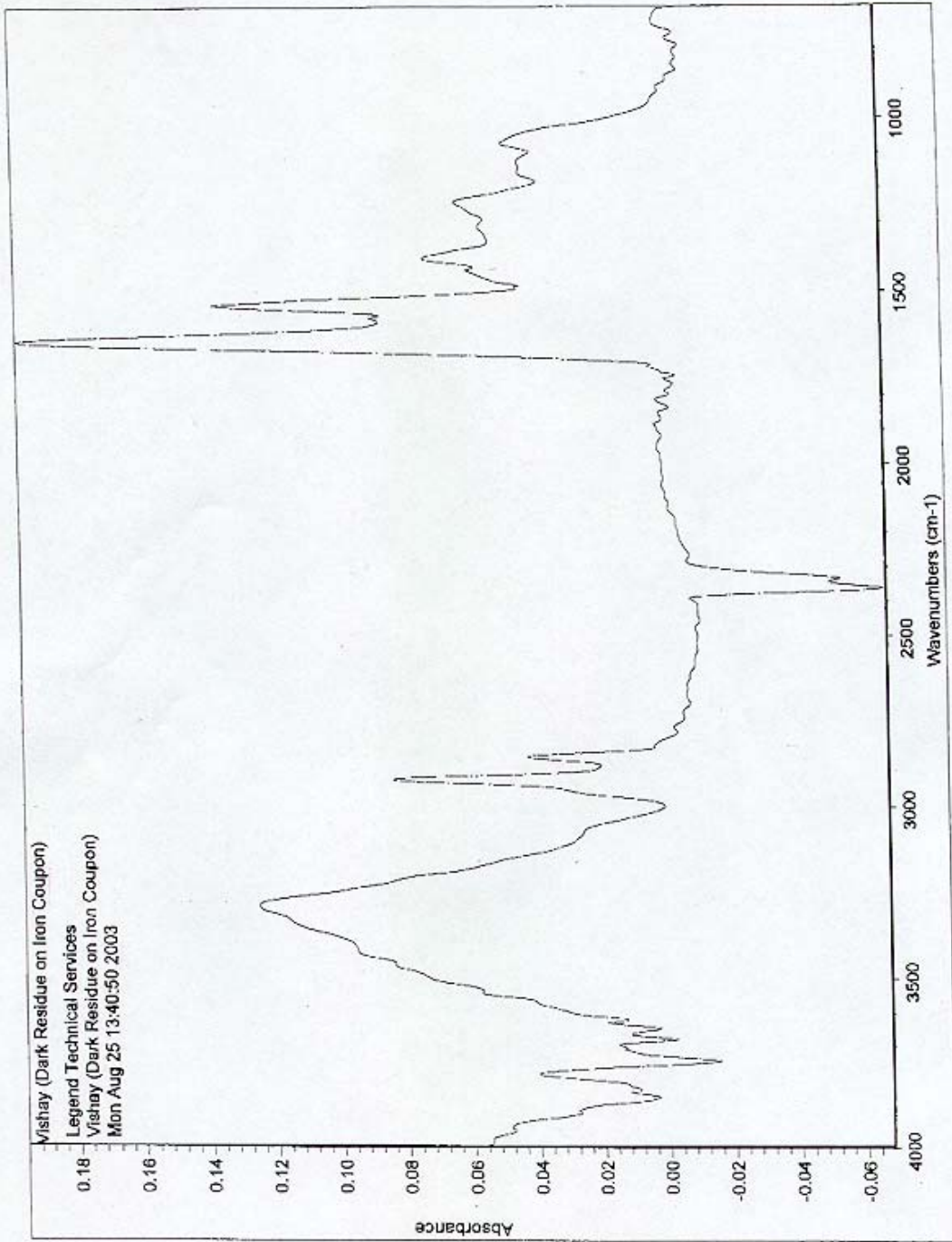
This report shall not be reproduced except in full, without the written authorization of LEGEND TECHNICAL SERVICES, INC.

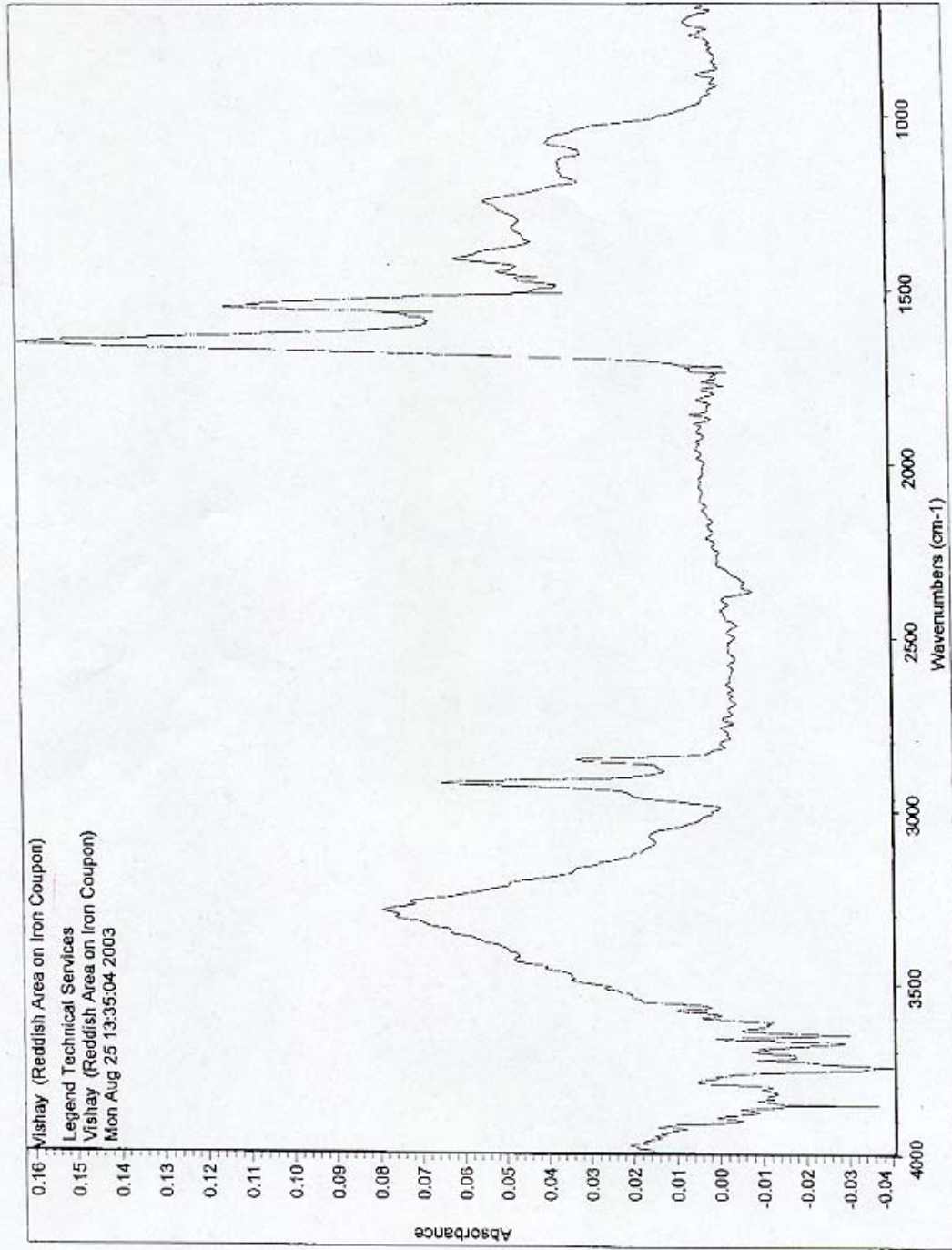
Submitted by,
LEGEND TECHNICAL SERVICES, INC.

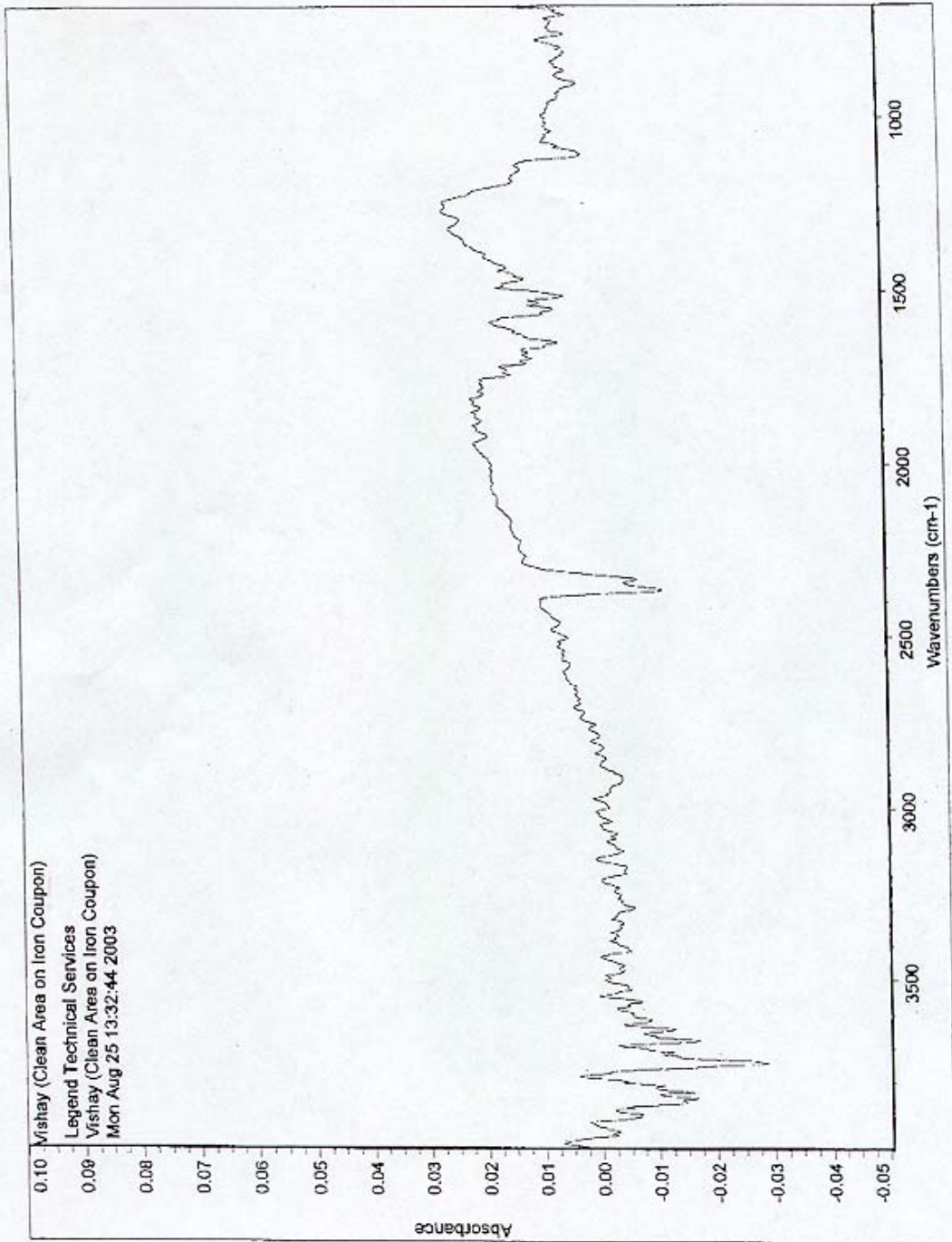

Kelly French
Chemist II/Supervisor

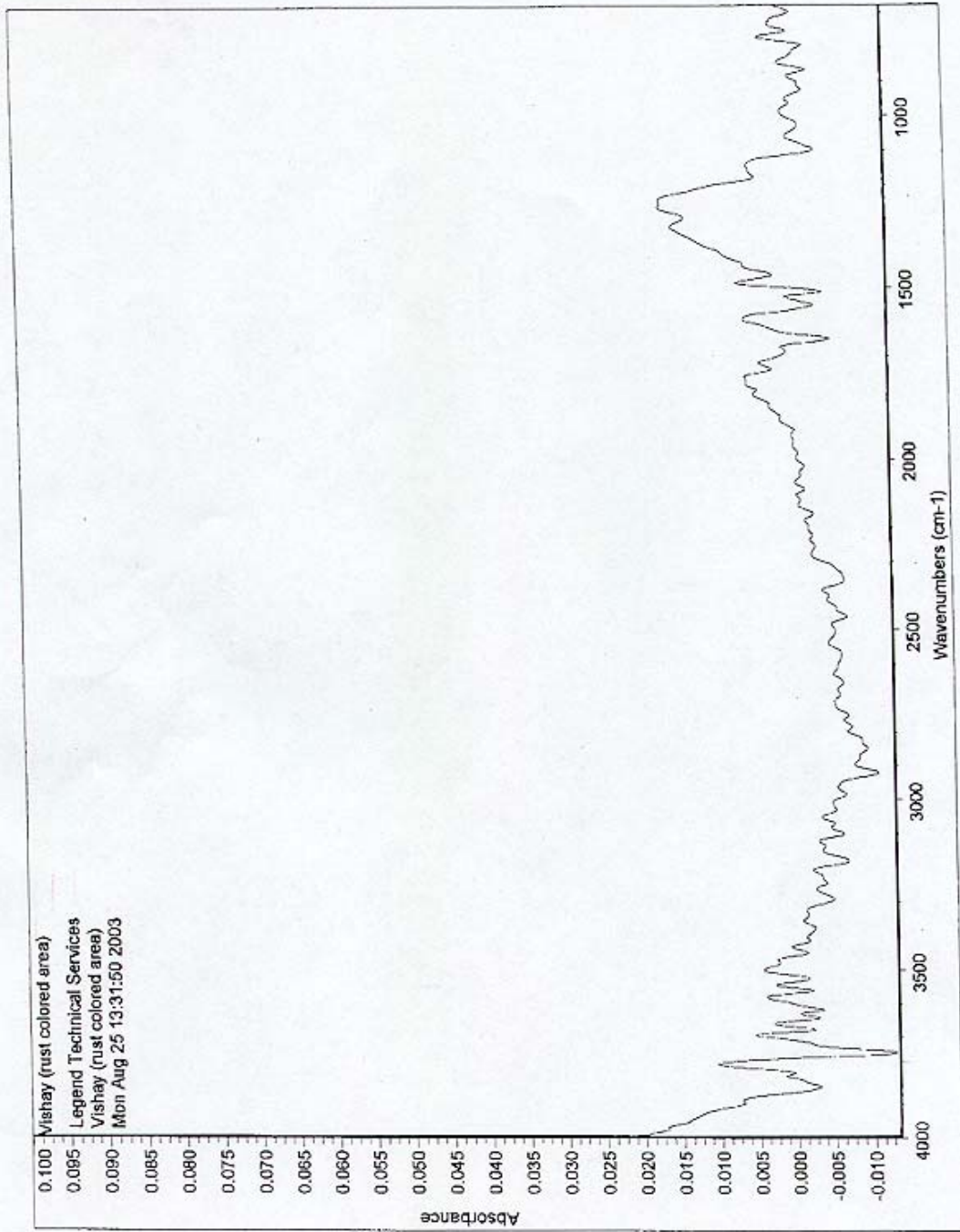

Kimberly Dublin,
Chemist II













VISHAY DALE
Material Laboratory Request/Report

Laboratory Report No.	70465
Date Received	8/7/03
Date Completed	8/28/03

Vishay Location: <u>Yankton</u>	Department #: _____
Originator: <u>Gary Bougger</u>	Charge #: <u>9396110</u>
Date: <u>8/7/03</u>	RR #: _____
Sample Description: <u>Inductor</u>	P.O. #: _____
Part #/Style: <u>IHLP-2525CZ</u>	Lot #: _____
Date Code: _____	Appl. Spec: _____
Vendor: _____	Ref. Report #: _____
No. of Samples: <u>2</u>	CC: _____

WORK REQUESTED

Pot and section to determine how far oxidation penetrates into the part.
1 part oxidized has over-coating applied to top surface.
1 part not oxidized does not have over-coating applied.

ANALYSIS RESULTS

The units were cross-sectioned in the area of interest with no discoloration observed below the surface material. Reference the following detailed analysis.

Number of Pages	3	Work Performed By	Lori Bender	Date	8/28/03
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As-Received Condition

Unit Markings

None

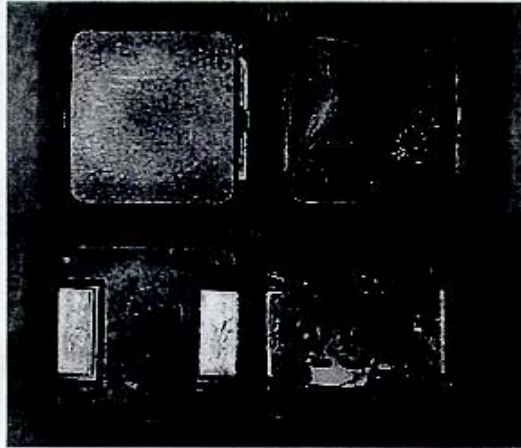


Figure 1. Shows a top view and a bottom view of the two units that were received into the Material Engineering lab.

Figure 1.

External Examination

External examination of the units noted that the unit with the over-coating applied has a brown to orange discoloration through out the area where the over-coat was present. The discoloration had more of a charred appearance rather than a rust or oxidized appearance. The number tag located on the bottom side of the over-coated unit also appeared to indicate a heat or charred appearance with the tag material curling or melting and also discolored. The other unit with no over-coating did not appear to be discolored. Reference the following photographs in Figure 2.

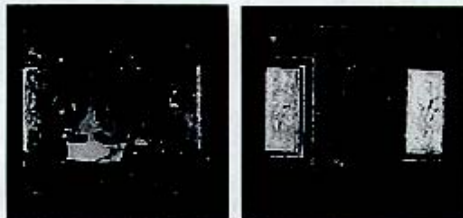


Figure 2. Shows a magnified view of the over-coated unit and the unit with no over-coat.

Figure 2.