Certificate of Analysis

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Lab No. V0608725 (NATINM)
Report Date: May 21, 2018

[redacted]

Sample Description:
Lab Number V0608725 – Sample ID: Hydraulic Filter

Dear Nancy:

Thank you for your confidence in SGS Herguth Laboratories, Inc. Please accept this report and attachments as our conclusion to the above numbered project/sample description.

Conclusion: The filter contains a significant amount of fluorinated substance, similar in appearance to broken down Teflon-like material. Most of the substance has too low a signal to count with the automated feature analysis without confusing it with carbon. It appears to be the major component from the filter. The other debris extracted from the filter is mostly steel and silicate. 61.6% of the particulate is <4µm in equivalent diameter.

Sample preparation: The entire filter was immersed in 0.45µm filtered isopropyl alcohol and agitated in an ultrasonic sink for 30min. 2ml of the sediment/solution were drawn through a 0.8µm polycarbonate filter for analysis. The specimen was analyzed using 20keV beam energy and automated feature analysis. 2500 particles were analyzed by backscatter electron and x-ray microanalysis.

The classification rules were determined by defining trends in elemental composition using the 21 elements in Table 3, normalized to 100%. Carbon is not included in this normalization, as carbon is usually present in all particles and tends to skew the other elemental concentrations low, especially in the smaller particles, due to the carbon based substrate. The classification rules are defined in Table 1. The particles were assigned in order from top to bottom of the rules list.

Table 1. V0608725 Classification Rules

Classification	Rule
Steel	Fe >30%
Copper Alloy	Cu >20%
Zinc	Zn >20%
Cadmium	Cd >20%
Chromium	Cr >10%
Aluminum	Al >20% and Al>Si
Calcium	Ca >30%
Other Metals	Ti or Mn or Co or Ni or Ag or Sn >20%
Silicate	Si >5%
Miscellaneous	All remaining particles

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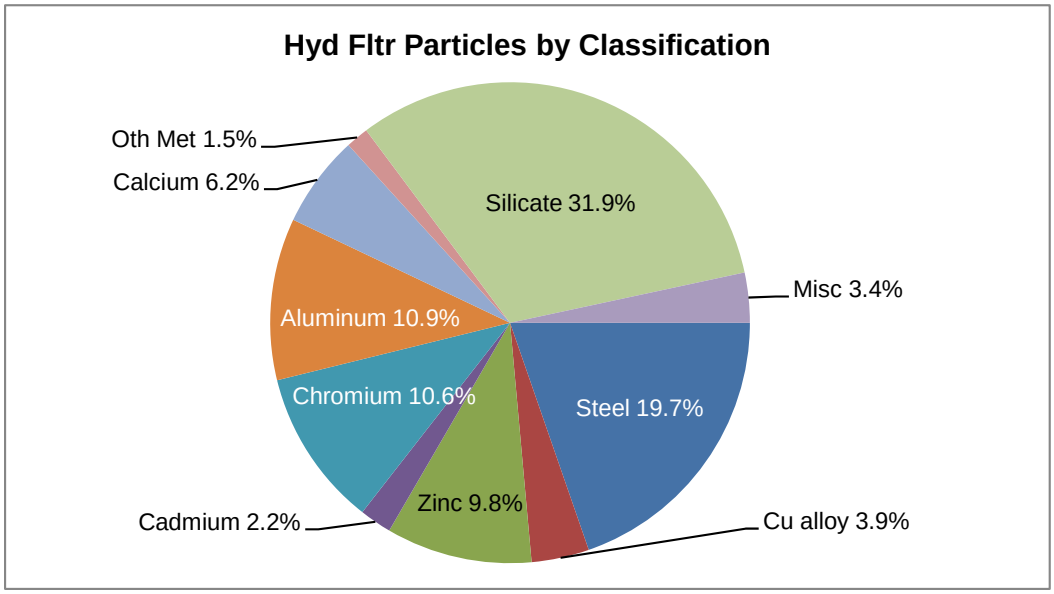
Graph 1 shows the particle distribution by classification.

Graph 1. V0608725



Graph 2 and Table 2 show the distribution of particles by equivalent diameter. Equivalent diameter is the diameter of a circle with the same area as that measured for the given particle.

Table 2. V0608725

Class	<1µm	1-2µm	2-3µm	3-4µm	4-6µm	6-10µm	10-14µm	14-25µm	25-50µm	>50µm
Steel	1.44%	7.36%	5.00%	2.36%	2.16%	0.96%	0.16%	0.16%	0.08%	0.00%
Cu alloy	0.16%	0.32%	0.56%	0.64%	0.64%	0.60%	0.48%	0.44%	0.04%	0.00%
Zinc	0.16%	0.92%	1.96%	1.84%	2.64%	1.72%	0.28%	0.24%	0.08%	0.00%
Cadmium	0.20%	0.88%	0.36%	0.36%	0.28%	0.08%	0.00%	0.00%	0.00%	0.00%
Chromium	0.16%	0.56%	1.12%	1.68%	3.52%	2.80%	0.52%	0.24%	0.00%	0.00%
Aluminum	0.00%	1.44%	2.72%	2.00%	2.68%	1.36%	0.32%	0.28%	0.08%	0.00%
Calcium	0.12%	0.92%	1.56%	1.24%	1.16%	0.84%	0.24%	0.12%	0.00%	0.00%
Oth Met	0.08%	0.48%	0.44%	0.12%	0.24%	0.08%	0.00%	0.04%	0.04%	0.00%
Silicate	0.32%	3.96%	7.84%	8.08%	7.28%	2.96%	0.76%	0.56%	0.12%	0.00%
Misc	0.08%	0.92%	0.64%	0.64%	0.68%	0.16%	0.12%	0.12%	0.00%	0.00%
Total	2.72%	17.76%	22.20%	18.96%	21.28%	11.56%	2.88%	2.20%	0.44%	0.00%

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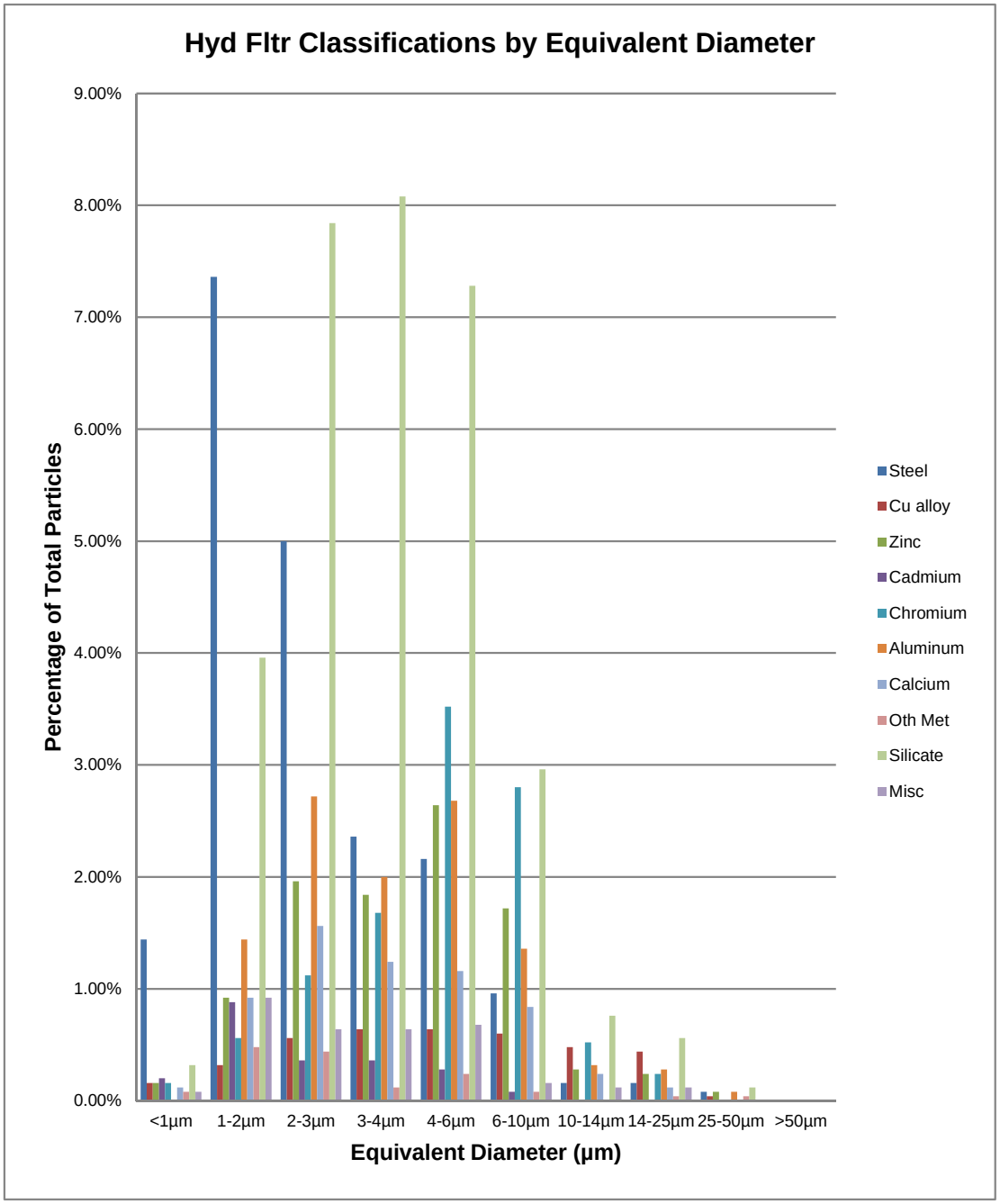
Graph 2. V0608725 Particles by Equivalent Diameter



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The average elemental concentrations for each classification are summarized in Table 3. The table may offer assistance in determining the general alloy of the component producing the metallic wear debris. It can also help determine the source of inorganic mineral dirt and other contaminants. When reading the table, find the classification of particle in the top horizontal row. Looking down that column you can see the percentage of other elements associated with that class of particle. This is the average concentration of all the particles in the class. For example, in trying to determine the source of the steel we look at other elements that might define the alloy, such as cobalt, chromium, manganese, and nickel.

Table 3. Hyd Fltr, Elemental Concentrations per Particle Classification

Element	Steel	Cu alloy	Zinc	Cadmium	Chromium	Aluminum	Calcium	Oth Met	Silicate	Misc	Total
O	1.8	15.3	1.9	0.4	4.4	16.8	8.3	2.1	17.5	22.6	10.3
Na	0.8	1.0	1.6	1.4	2.0	1.0	0.9	3.0	2.4	5.0	1.7
Mg	0.3	0.3	1.1	0.6	0.9	1.3	5.5	1.0	10.6	1.6	4.2
Al	1.3	0.9	3.2	1.5	2.5	53.2	1.7	2.7	4.6	3.2	8.4
Si	1.1	0.5	2.9	1.5	3.7	1.4	3.2	3.4	35.0	1.4	12.5
P	0.8	0.6	8.1	1.8	3.7	1.3	1.1	1.7	1.4	5.1	2.3
S	0.7	17.5	4.2	1.6	3.0	4.1	1.0	2.0	2.3	21.0	3.6
Cl	0.6	0.6	2.1	1.1	1.4	1.0	0.5	2.1	6.2	9.3	3.0
K	0.3	0.3	0.7	2.3	0.7	0.5	1.8	0.9	1.2	1.9	0.9
Ca	0.5	0.4	1.3	1.2	1.2	0.8	55.5	1.3	1.8	2.1	4.6
Ti	0.6	1.0	0.7	0.9	2.2	0.6	0.4	17.3	0.8	1.0	1.1
Cr	1.5	0.5	12.7	1.5	43.8	1.0	0.6	1.5	0.9	1.9	6.8
Mn	0.5	0.6	1.2	1.1	1.7	0.7	0.6	2.5	0.9	1.9	1.0
Fe	78.9	1.1	4.7	2.6	9.8	1.8	2.4	7.0	3.3	4.0	18.8
Co	1.2	0.5	1.1	0.9	1.1	0.9	1.0	1.3	1.1	2.0	1.1
Ni	3.1	0.8	1.3	1.3	1.5	4.7	0.9	3.8	1.4	1.7	2.1
Cu	1.5	53.7	1.8	1.3	1.9	2.3	1.2	1.8	1.7	2.4	3.7
Zn	1.5	1.5	45.2	3.3	10.0	2.7	1.7	4.3	2.7	4.4	7.4
Ag	0.7	0.9	1.0	0.4	1.1	1.0	1.1	2.4	1.0	2.0	1.0
Cd	0.9	0.8	1.8	68.7	1.2	1.0	0.4	1.5	1.3	2.6	2.6
Sn	1.2	1.2	1.6	4.8	2.3	2.1	10.1	36.2	1.8	3.2	2.9

Figures 1 through 16 are backscatter electron images with their associated x-ray spectra. Backscatter images show brightness relative to atomic number and density.

Respectfully submitted,

Guy Nadeau
Laboratory Technical Specialist

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Figure 1. Fluorinated Substance

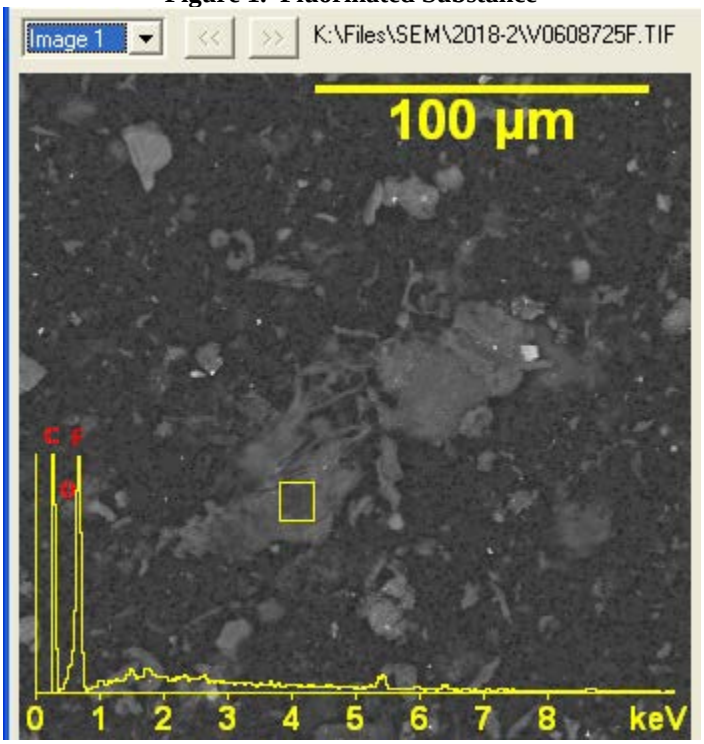

Figure 2. Fluorinated Substance

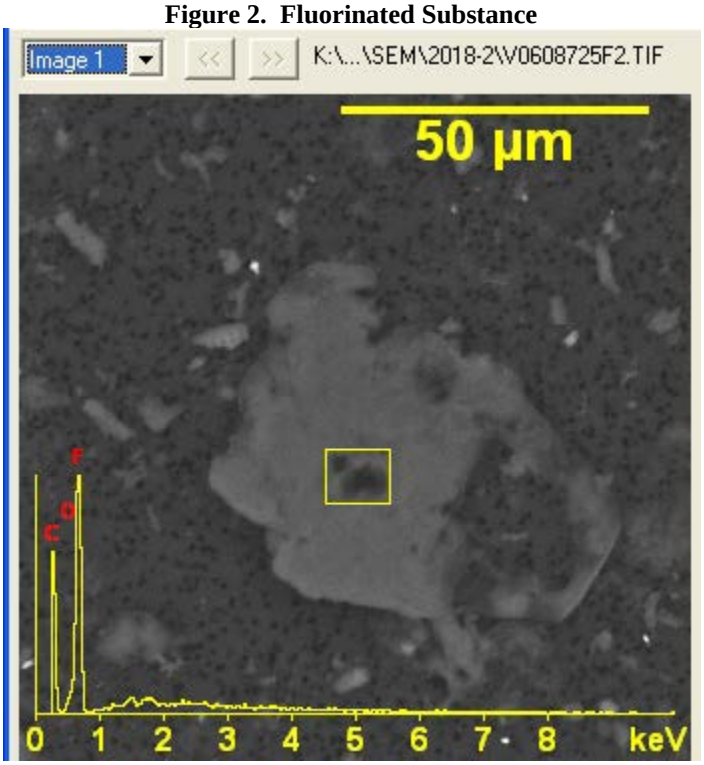

Figure 3. Fluorinated Substance

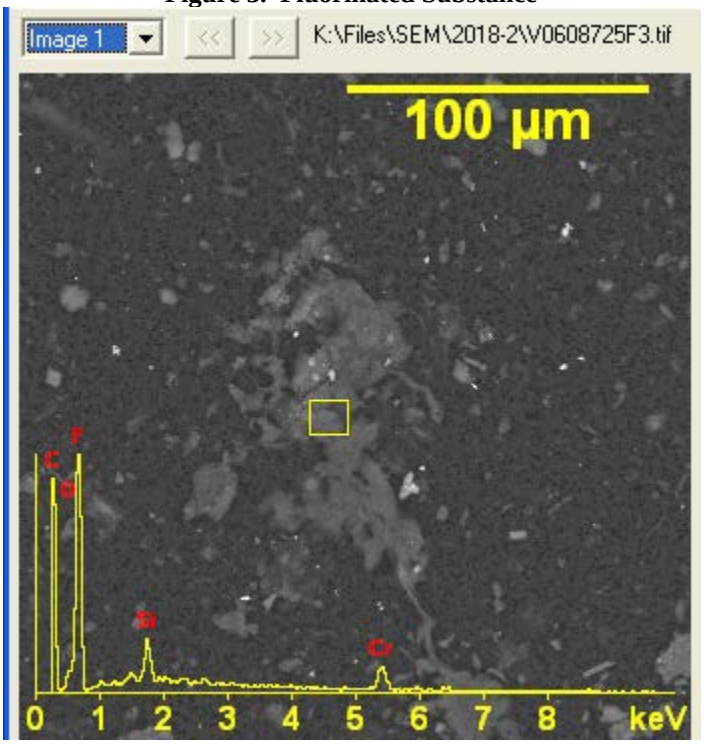

Figure 4. Fluorinated Substance

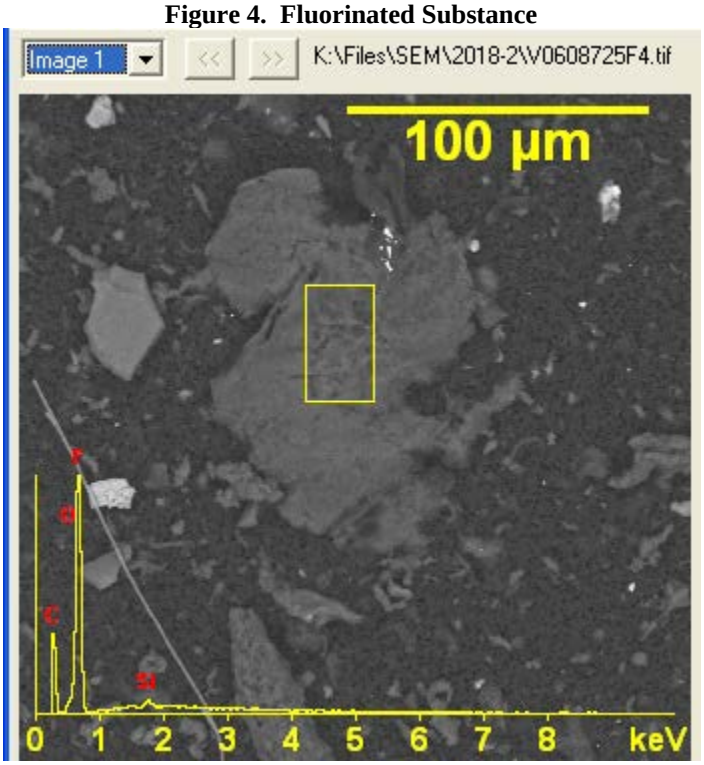

Figure 5. Fluorinated Substance

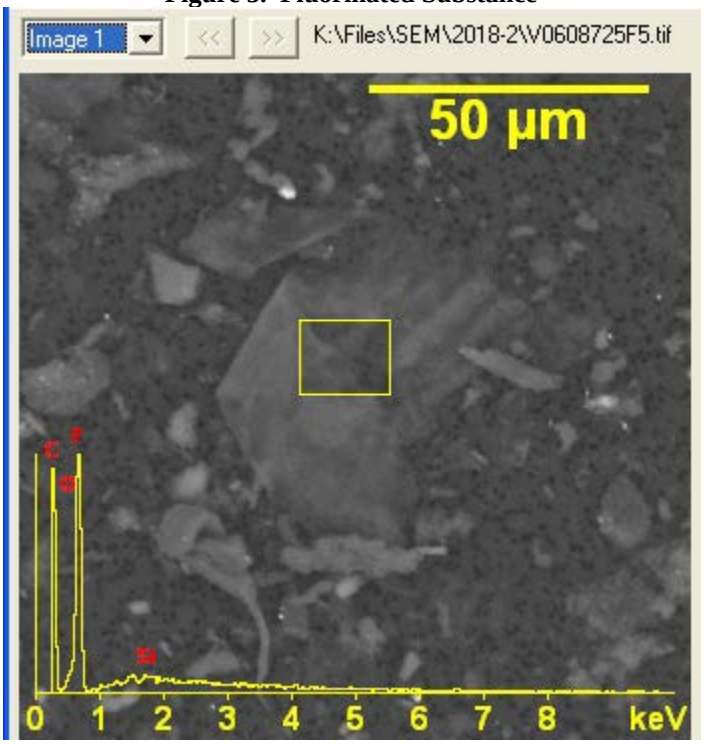

Figure 6. Steel

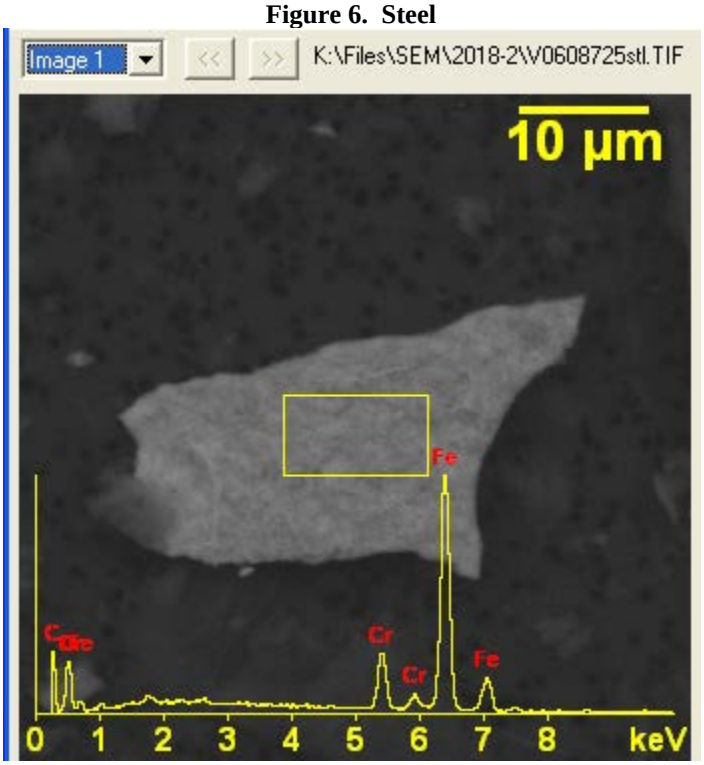

Figure 7. Steel

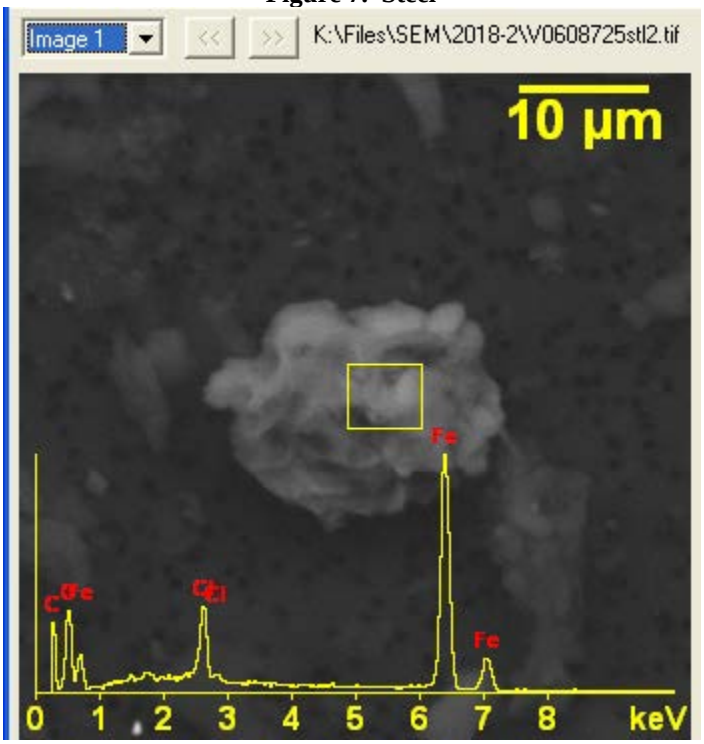

Figure 8. Silicate

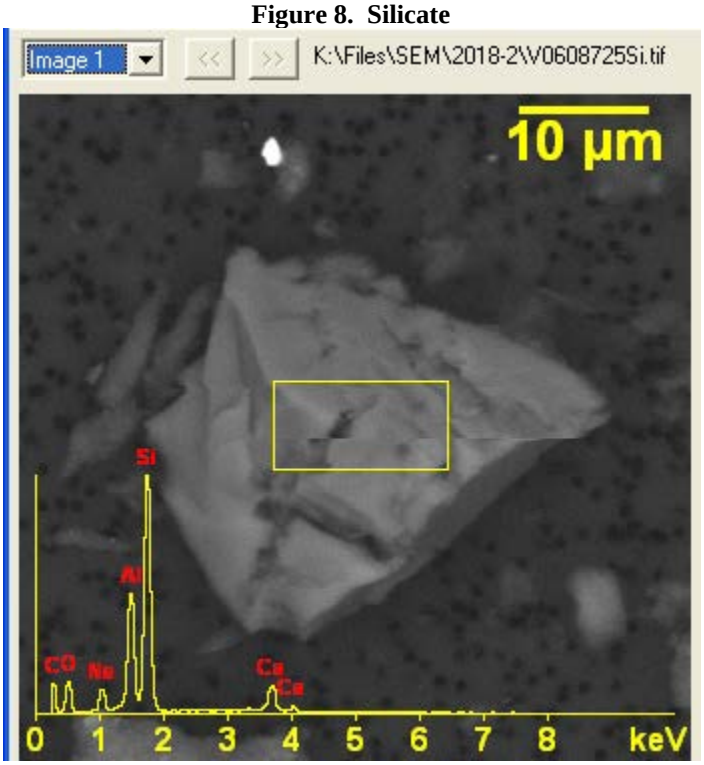

Figure 9. Silicate

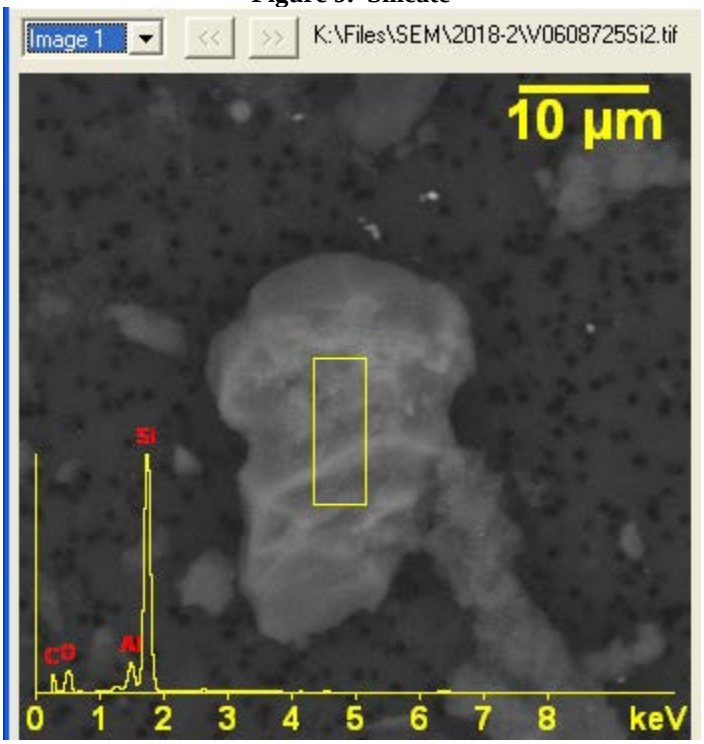

Figure 10. Aluminum

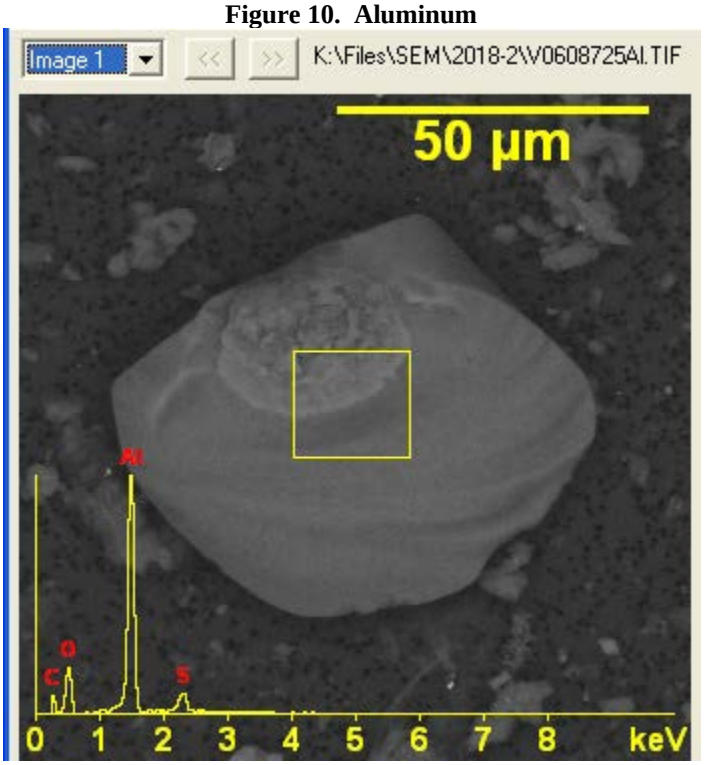

Figure 11. Calcium

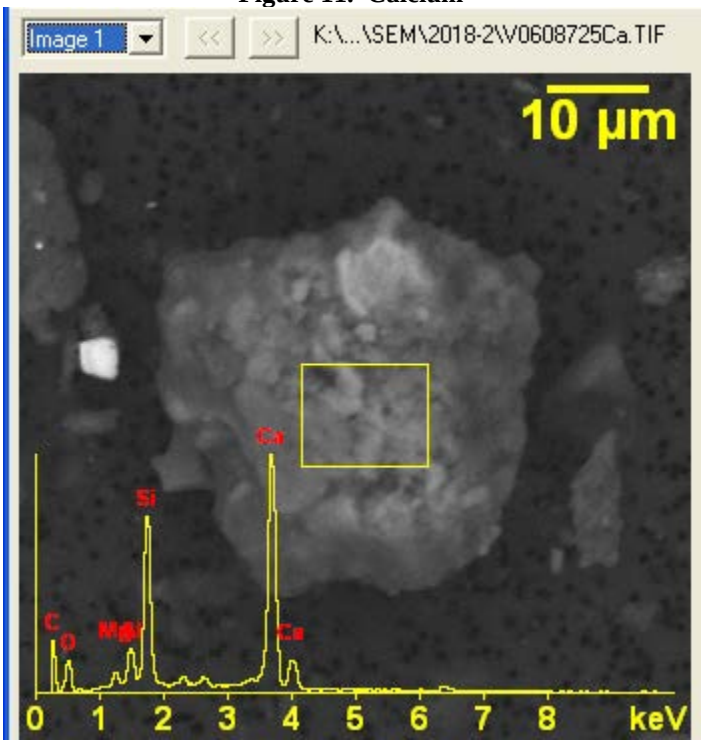

Figure 12. Cadmium

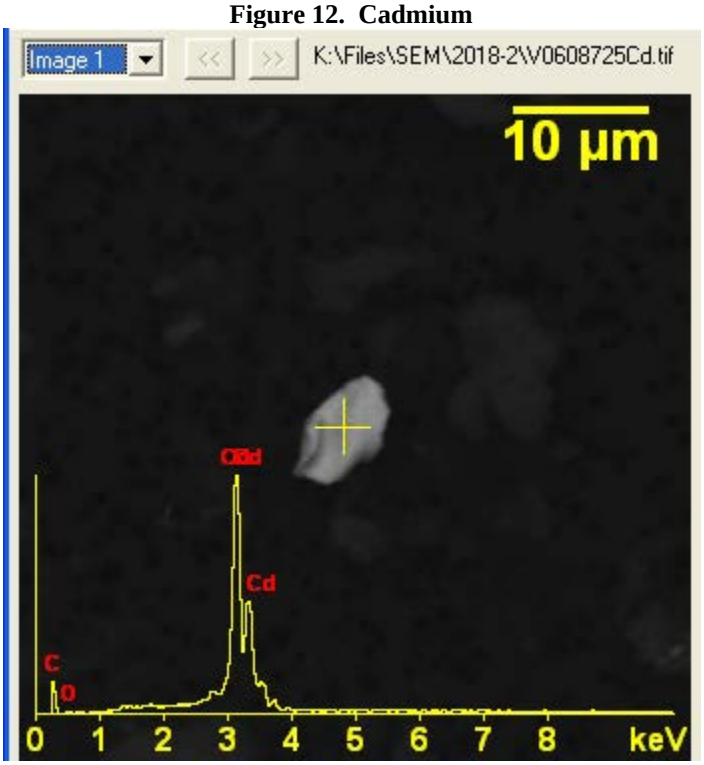

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Figure 13. Copper Alloy

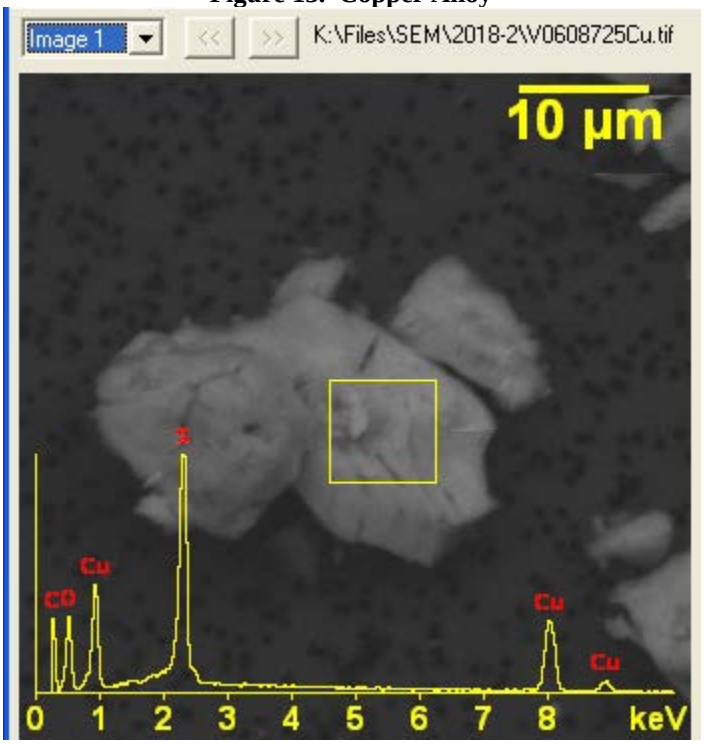

Figure 14. Chromium

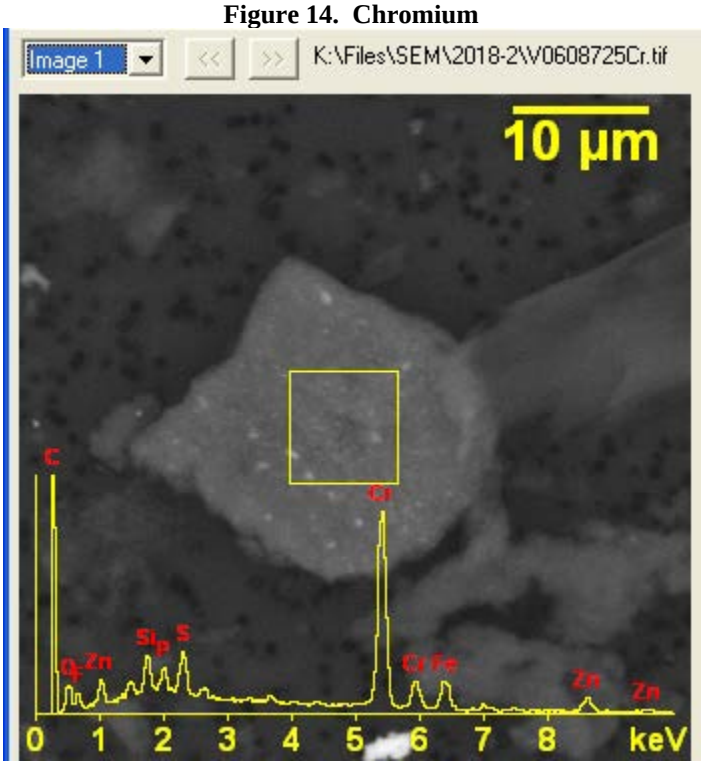

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Figure 15. Zinc

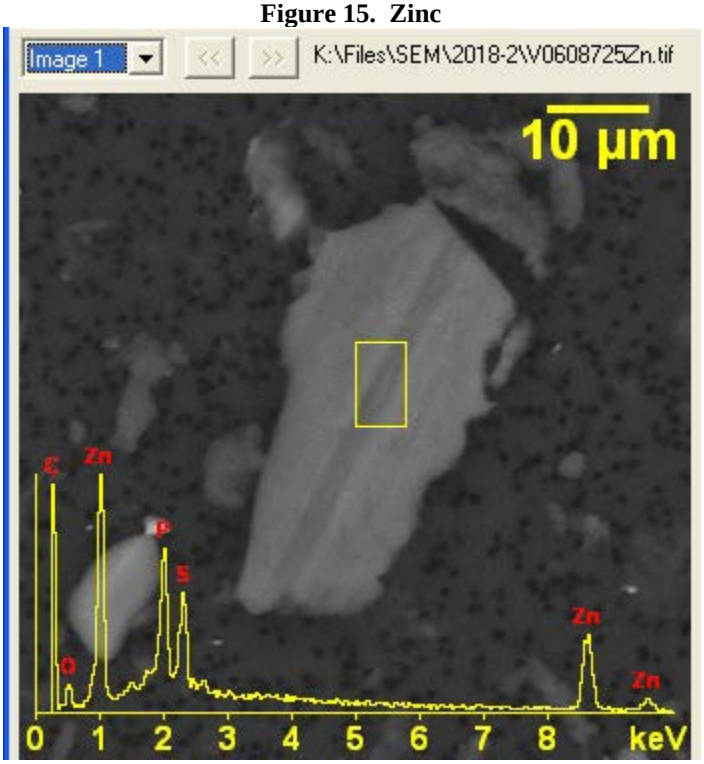

Figure 16. Tin