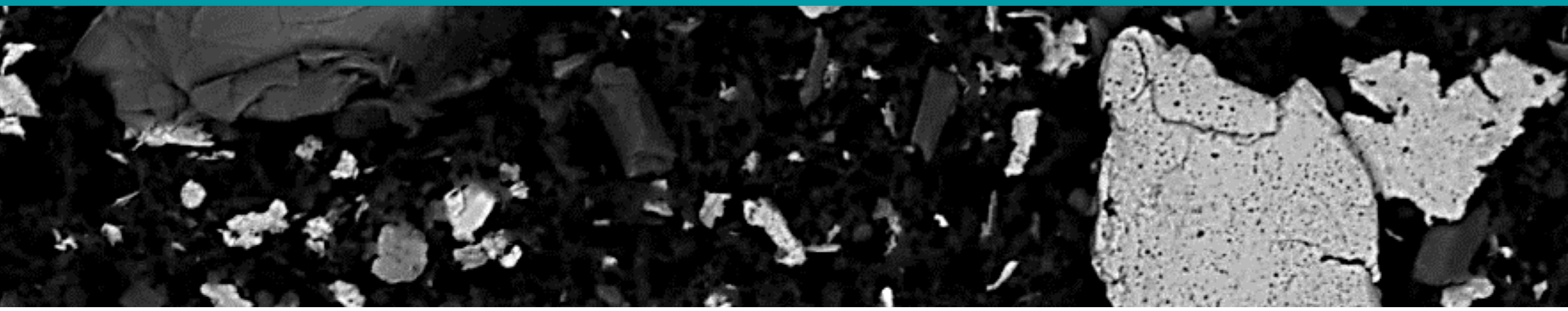
INTERPRETING SEM–EDS RESULTS
REAL-WORLD EXAMPLES



Fluid Life's new **SEM-EDS analysis** is far superior for determining the size and composition of particles in a sample than any other single test offered in the past. These large particles (>10um) provide critical information about machine health, component wear and contamination and are often considered an early warning of abnormal wear, bearing fatigue and transmission failure.

But what do the reports and results look like? How do they relate to the results on your routine analysis reports? Do they make the decision-making process easier or more difficult?

Let's take a look at some real-world SEM-EDS analyses conducted for one of our mining customers operating in the Canadian Tundra. This customer sent in multiple samples for SEM-EDS analysis for various applications. Below is a summary of the SEM-EDS results, how they related to the routine oil analysis results, and what decisions were made for multiple scenarios.

1. Haul Truck Engine Nearing End of Life

The client noted elevated concentrations of copper and lead on an engine that was approaching the end of its target life (Fig 1.1). Immediate concern was significant bearing wear, and that the engine would not make it to the planned overhaul. The client did not want to deal with an unplanned and premature failure as planning/manpower resources and part availability had been a constant issue during the ongoing COVID-19 pandemic situation.

Sample Date	Wear Metals ppm: Aluminum	Iron	Copper	Lead
2020/10/04	3	2	0	0
2021/03/30	3	11	132	19
2021/03/23	3	11	144	18
2021/02/01	0	9	77	11

Fig 1.1 Screenshot of the Haul Truck Engine's most recent three oil analysis reports

Fluid Life representatives recommended that the SEM-EDS test be completed to build off the initial ICP Spectrometry results (wear metals ppm). SEM-EDS analysis was completed on engine oil samples taken on March 23rd and 30th, 2021.

Main Observations from March 23rd Sample

- **No copper >10um was detected in any form in the sample from March 23rd.**
- Many "unclassified" particles analyzed and determined to be composed of Zinc, Calcium, Phosphorous and Sulfur (Fig 1.2). Likely oil additives present as scale or flakes.
- Some traces of external contamination from detection of Silica based particles and salts (KCl and NaCl).

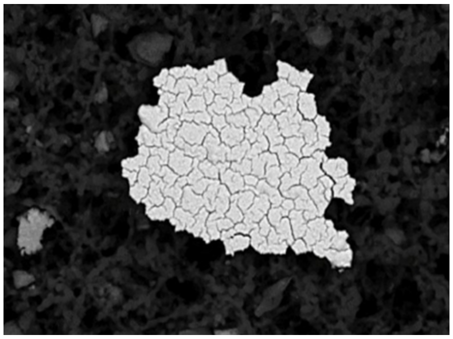


Fig 1.2. Image of "flakey" zinc-nickel coating particle.

Main Observations from March 30th Sample

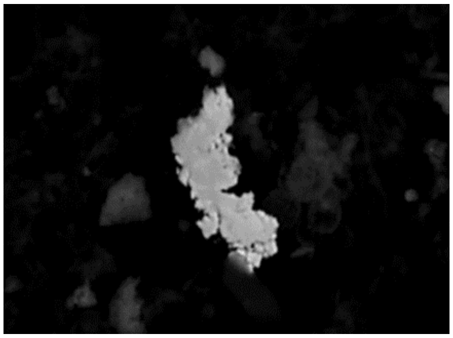


Fig 1.3 Image of single brass particle (copper-zinc) found in sample.

- Only one significant brass particle (copper and zinc based) was discovered in the March 30th oil sample (Fig 1.3). Remaining traces of copper particulate were found to only contain copper and oxygen.
- Outside contamination and "flakey coating" particles were very similar to the March 23rd sample and deemed insignificant.

SEM-EDS analysis confirmed that the elevated copper flagged on the routine oil analysis report was mostly dissolved in the oil and does not represent dangerous bearing wear. Fluid Life recommended that the customer consider the spinner debris as a deposit for significant copper wear. The client confirmed that due to the configuration of the spinner system, they would still expect some copper wear to be present in the oil if that was the case. They are confident in the SEM-EDS results suggesting that the copper found with the initial analysis is mostly dissolved in the oil.

The client changed the oil and will continue to monitor the following as possible causes for the increase in dissolved copper in this and all engines.

- Leaching from new oil cooler (if recently replaced)
- Engine temperatures (overheating or high operating temperatures)
- Degraded oil (extended in service oil hours)

In this case, the customer may have modified the existing engine change out schedule based on the initial oil analysis report. However, SEM-EDS results confirmed that the problem was not as severe as the initial report suggested and that the engine could carry on without any unplanned intervention at this point. The oil was changed, and more recent routine oil analysis reports suggest that the copper concentration is back down to acceptable levels.

2. Elevated Copper During Loader Engine Midlife

Like the Haul Truck example mentioned above, high copper levels triggered an SEM-EDS test after the fact. However, this loader engine was not nearing its end of life, being that total service was still under 10,000 hours. High copper had been detected over the past few samples (Fig 2.1).

Wear Metals (ppm)

Sample Date	Aluminum	Iron	Copper
2020/10/04	3	2	0
2021/04/10	3	13	398
2021/03/28	0	9	280
2021/03/07	0	8	202
2021/02/02	3	5	44

Fig 2.1 Screenshot of the Loader Engine's most recent wear metal concentrations.

SEM-EDS results suggested that no significant copper was found >10um in size. After following up with the customer, it is very likely that the increase in copper was due to a recent increase in workload (overheating and higher operating temperatures) and an extended oil drain (degraded oil) for this loader engine.

However, the SEM-EDS report (Fig 2.2 on next page) also showed something that was not initially flagged on the routine oil analysis report. Notable concentrations of silica-based particulate, that was not detected using ICP Spectrometry, confirmed minor amounts of external contamination. Also, a noticeable amount of Iron-based and variant steel alloys (Cr <2%, 2%<Cr<10%, Cr>10%) wear particles were observed. The platelet and chunky form of these steel particles suggested the presence of severe laminar wear.

SEM-EDS analysis detected wear particles for Iron-based particles (Fe > 10% in mass – Turbo Housings), low allow steel (Cr <2% - Liners, Crankshafts, Camshafts, Rings, Rods, etc.), medium alloy steel (2% > Cr > 10% - Rings, Coatings) and high alloy stainless steels (Cr > 10% - Valves, Piston Pins, Stainless Turbo Housings, etc.).

Additional to confirming that the elevated copper concentration on the initial was a non-issue, the SEM-EDS report provided some justification to ensure that the Loader Engine's intake system, dipstick and oil fill port are free of unfiltered air-dust entering the engine and causing wear. This additional action item would have likely been missed if only the routine oil analysis report was considered as silicon and aluminum concentrations were reported to be low.

Class name	Total Particles (particles / ml)	Summary (Each size - Maximum length [um])			
		10 ≦x < 20	20 ≦x < 40	40 ≦x < 100	100 ≦x < 5000
All classes	1897	1741	145	10	0
Unclassified	1030	979	50	0	0
Silica	579	516	58	0	0
Fe-based (Unclassified)	179	153	23	0	0
Steel (Cr <2%) - Wear	47	40	7	0	0
Contamination (Al/Si/K)	26	23	2	10	0
Steel - (2%<Cr<10%) - Wear	10	10	0	0	0
Contamination (Ca/S)	6	6	0	0	0
Silica - Fiber	6	2	3	0	0
Cu-based (Unclassified)	4	2	2	0	0
Additive - MoS	2	2	0	0	0
Mo-based	2	2	0	0	0
Overlay - Zn	2	2	0	0	0
Pb Alloy	2	2	0	0	0
Steel - (Cr>10%)	2	2	0	0	0

Fig. 2.2 Categorization of Analyzed Particles by Size and Elemental Composition via SEM-EDS for Loader Engine

3. Using SEM-EDS as a Troubleshooting Test

The client was dealing with an inspection of a Haul Truck that had reports of severe vibration that could be felt even in the truck cab. Initial routine troubleshooting was completed, and it was assumed the engine was the problem. The oil pan was pulled where nothing significant was found, the bearings were inspected and looked good as well, etc. However, when put back into service, the vibration persisted. The client decided to send in an oil sample for SEM-EDS analysis while the truck was still down due to vibration and further inspection.

Routine oil analysis results (Fig 3.1) suggested the ingression of external contamination and some resulting wear based on the elemental concentrations reported (elevated silicon, aluminum, and iron). Zinc, which is mainly reported as an additive on the routine analysis reports, was also slightly elevated.

Wear Metals		
Silicon (Si)	Aluminum (Al)	Iron (Fe)
21	9	57

Fig 3.1 Screen shot of Haul Truck Engine's elemental concentrations.

SEM-EDS analysis (Fig 3.2) confirmed the results reported with routine analysis, with the sample showing an abnormal number of outside contaminants including Silica (<40um) and Al/Si/K (<20um) along with an elevated amount of low-alloy steel (Cr <2%) and Iron based wear particles, with the majority having chord diameter below 40um and showing laminar wear. However, it was also reported that a significant amount of zinc overlay wear particles (Fig 3.4) having chord diameter up to 100um were present in the sample. Zinc based particles with different wear modes were observed, including laminar wear (Fig 3.4), adhesive wear, and cutting wear. This indicates that severe wear is occurring within the component.

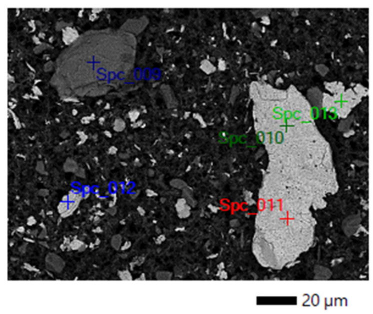


Fig 3.3 Image of large external contaminant particle (top left) and large zinc overlay particle (right)

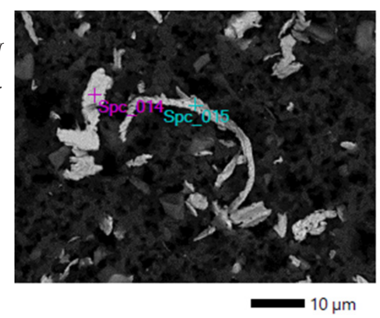


Fig 3.4 Image of large zinc based laminar wear particle.

Class name	Total Particles (particles / ml)	Summary (Each size - Maximum length [um])			
		10 ≦x < 20	20 ≦x < 40	40 ≦x < 100	100 ≦x < 5000
All classes	25205	22280	2770	151	0
Overlay - Zn	17654	15446	2072	113	0
Steel (Cr <2%)	3776	3455	315	19	0
Unclassified	1350	1219	135	0	0
Silica	1175	991	180	0	0
Fe-based	925	864	68	0	0
Contamination (Al/Si/K)	175	178	0	0	0
Additive - MoS	50	51	0	0	0
Ti Based	50	51	0	0	0
Cu-based	25	25	0	0	0
S-based	25	0	0	19	0

Fig. 3.2 Categorization of Analyzed Particles by Size and Elemental Composition via SEM-EDS for Haul Truck Engine

Due to the confirmation of dirt and dust via routine analysis and SEM-EDS analysis, it was recommended to the customer to inspect for sources of ingression including the air intake system (piping, turbocharger, coolers, etc.) and engine (intake ports, cylinder head and piston/cylinders).

At this point, troubleshooting continues as the client tries to determine the source of ingression and vibration, and if the detection of larger wear particles (steel, zinc based, etc.) is due to external contaminants or to the vibration as well. It was recommended that they take additional samples for follow up once the ongoing inspection is complete.

In general, SEM-EDS was able to conclude that the level, location and type of wear occurring in the engine was more severe than initially thought by simply looking at the wear metal and contaminant concentrations.

Summary

This client focused on SEM-EDS analysis for engines due to the criticality of this component type and the limitations associated with ICP Spectrometry (inability to produce accurate and valid particle counts on engine oils).

While other component type sample reports may provide particle counts and other forms of large particle analysis, few will be as clear and concise as the Fluid Life SEM-EDS option. SEM-EDS analysis may not be required on every sample, but it is a great option for determining the size, distribution, composition, and origin of hundreds of larger particles in any oil, grease, filter, or process material sample, a critical but often neglected element of oil analysis.

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