SEM and EPMA Analysis of Spark Plug Electrode Erosion

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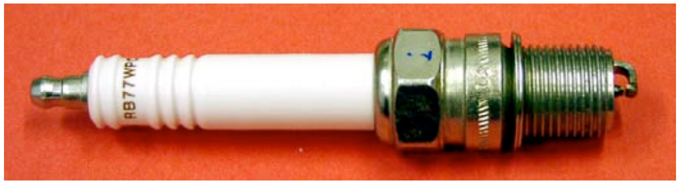
Background

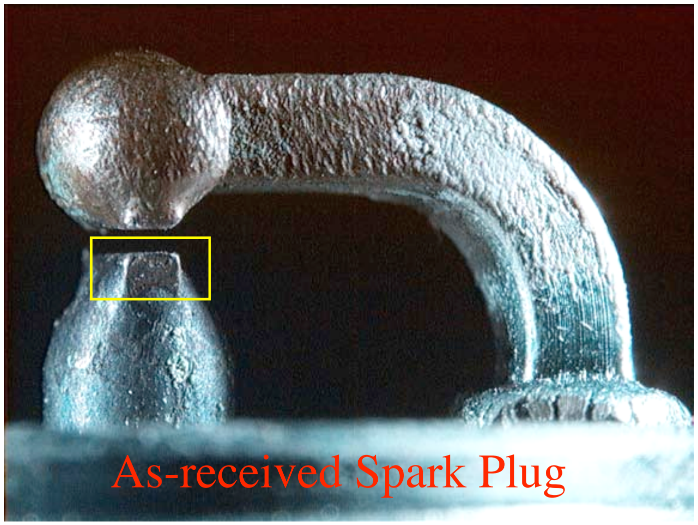
- Advanced ignition systems are a key technology to achieve cost, performance, and emission goals for lean and stoichiometric natural gas (NG) industrial engines for distributed power generation (e.g. power generation for buildings, complexes, etc.)
- Wear of spark plug electrodes resulting in gap growth limits the long-term reliability and performance of ignition systems. Current plug lifetimes for industrial NG engines are only on the order of 2-6 months of continuous operation, necessitating costly downtime replacement. Lifetime goals are at least 1 year.
- Increases in cylinder pressures, compression ratios, and ignition voltages to achieve further reductions in emissions will result in even more aggressive ignition conditions.
- Improvement of erosion and corrosion resistance of electrodes is a critical issue to achieve emission reduction and performance goals

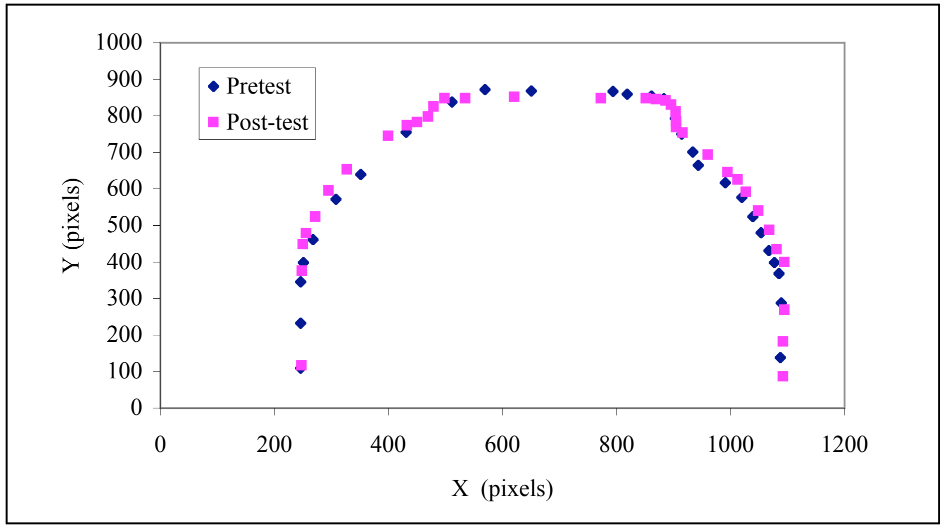


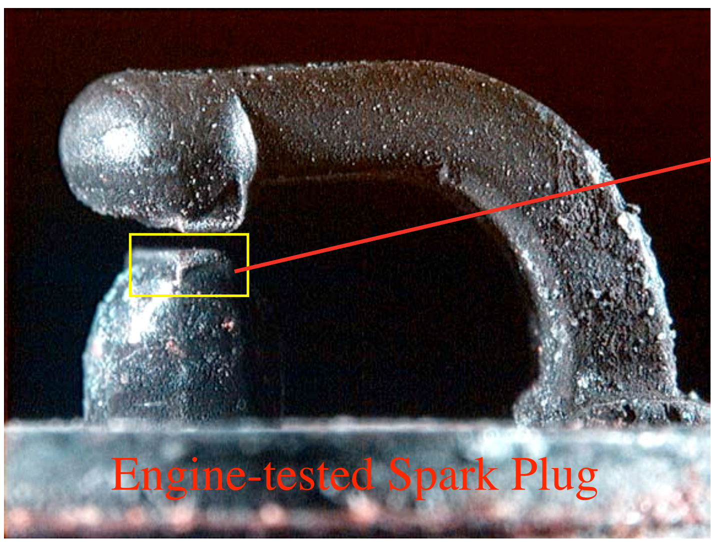
Objectives

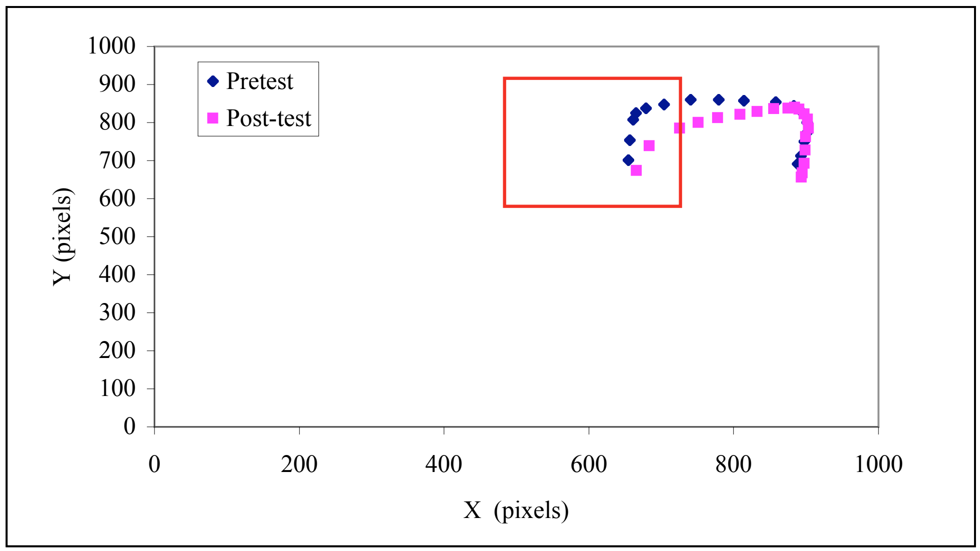
- Characterize a range of field and engine tested spark plugs to elucidate the mechanism(s) of electrode wear.
- Based on this insight, select alternative alloys or develop new alloys to improve erosion and corrosion resistance and extend the lifetime of the spark plugs

Polynomial Curve-Fitting Illustrates Erosion of Engine-Tested Spark Plug

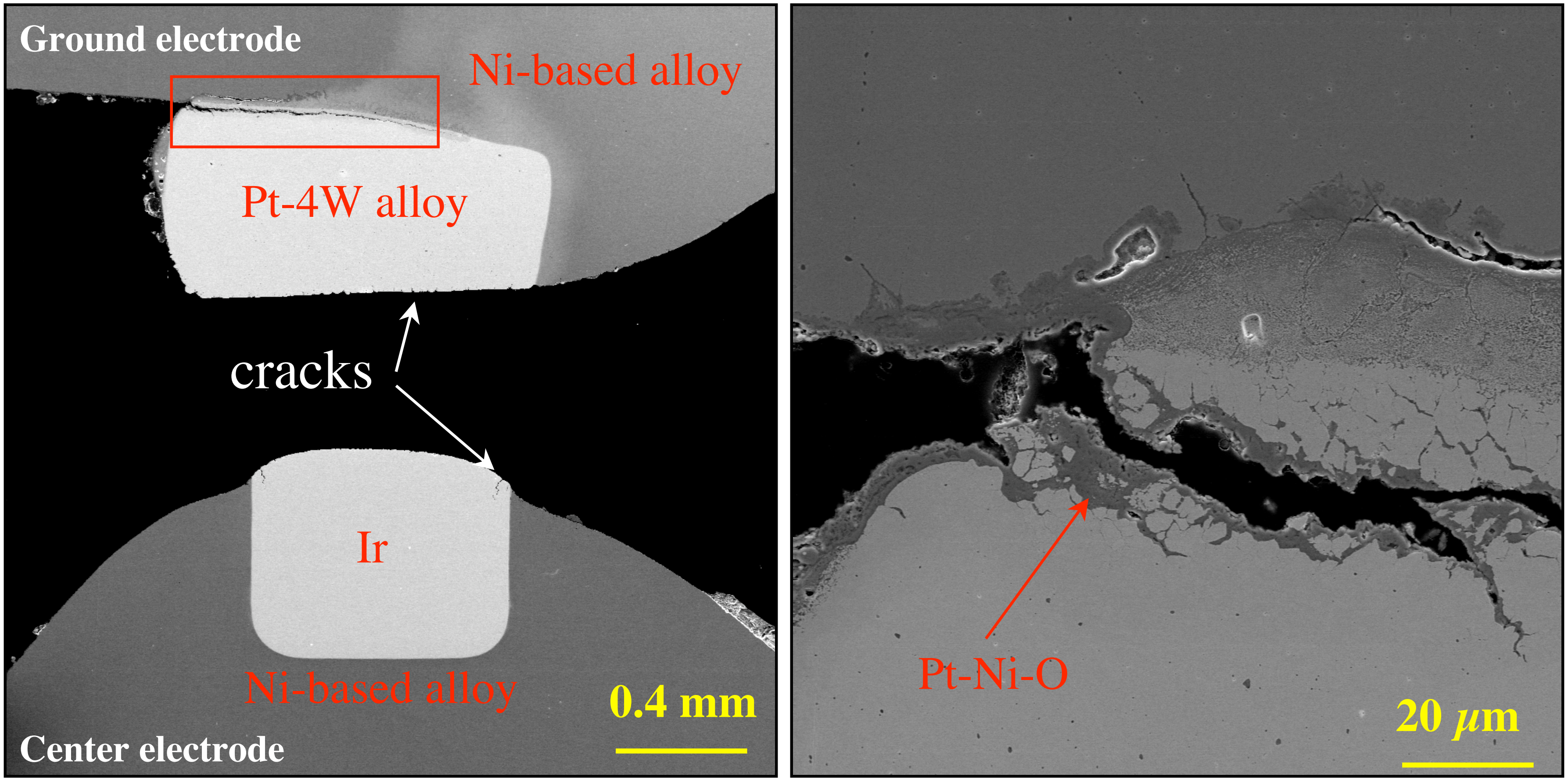








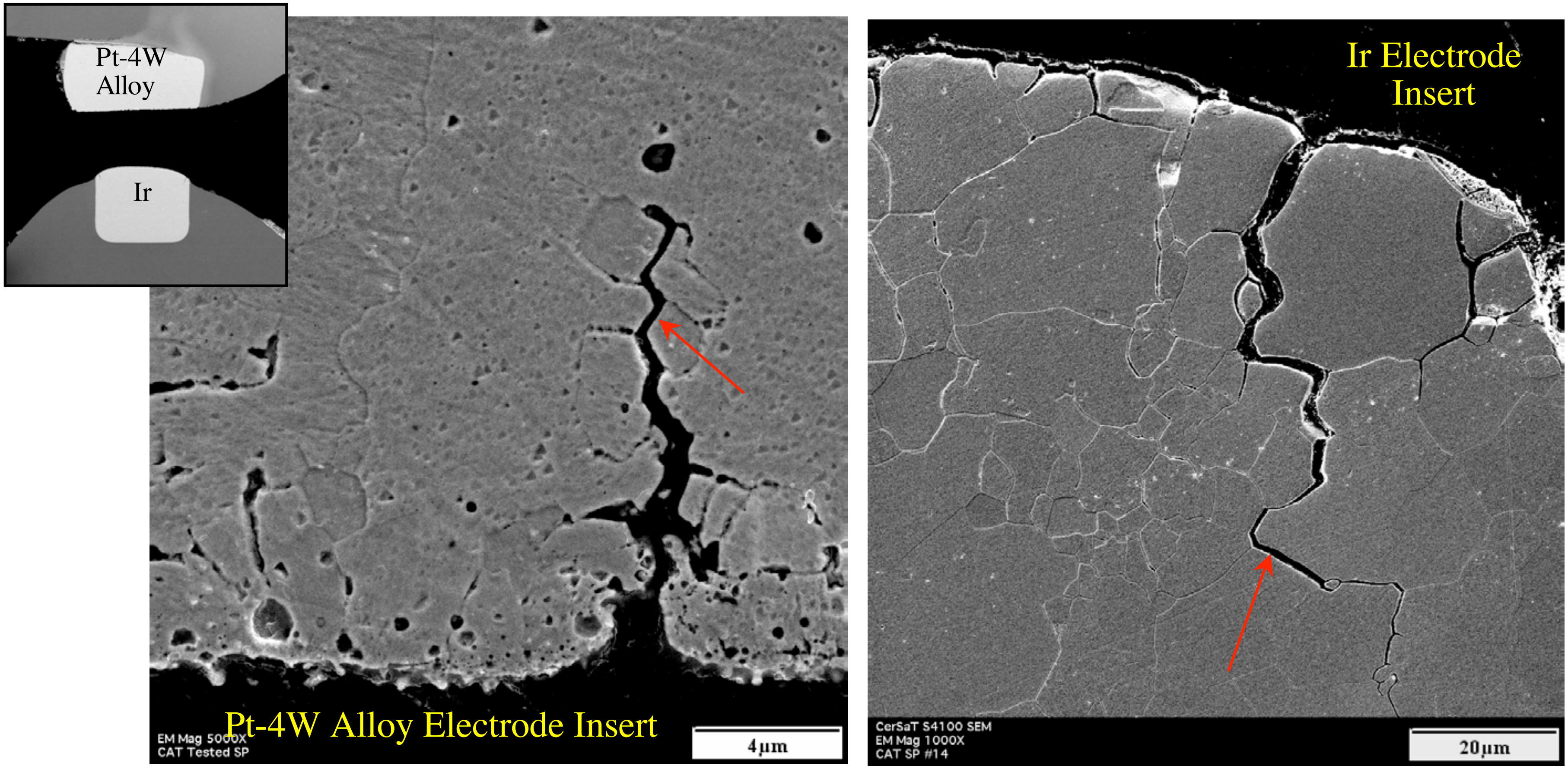
Substantial Crack Generation and Growth Observed Between Pt-4W Alloy Insert and Ni-Based Electrode After Natural Gas Engine Service



-An oxide-based (Pt-Ni-O) reaction zone formed between Pt-4W based alloy and the Ni-based electrode (~95% Ni).

- Crack generation and oxide-based interface significantly degrade the ignitability of spark plugs

Substantial Intergranular Cracking Occurred in Both Pt-4W alloy and Ir Electrode Inserts After Field Service



Coalescence of intergranular cracks and subsequent material flake-off in Pt and Ir electrodes (the dominant mechanism) would further accelerate the erosion process and limit the long-term durability and performance of spark plugs

Field Tested Industrial Natural Gas Engine Spark Plug Electrode Degradation

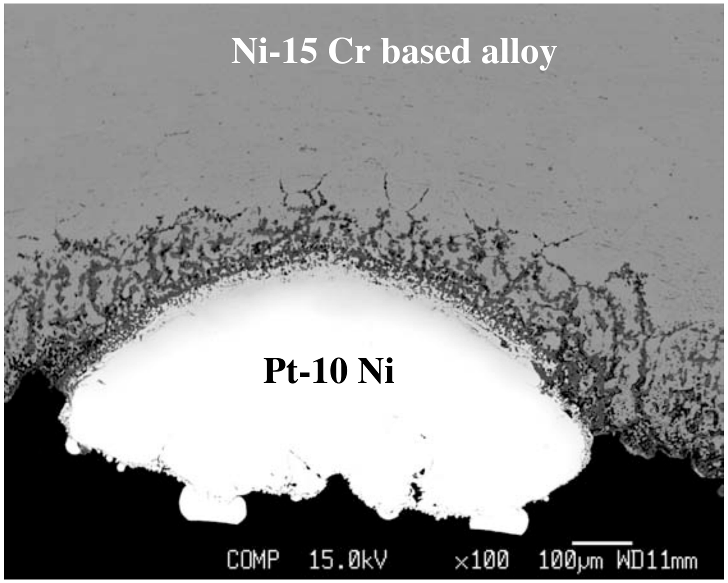
- Oxidation/cracking at Ni-electrode/Pt-4W insert interface
- Intergranular cracking of both Pt-4W and Ir inserts
- Pt-4W insert exhibits greater wear/cracking than Ir insert. Ir insert more difficult to manufacture, adding cost, which limits its use .

Are These Modes of Degradation Unique?

Examine a range of laboratory and engine tested spark plugs

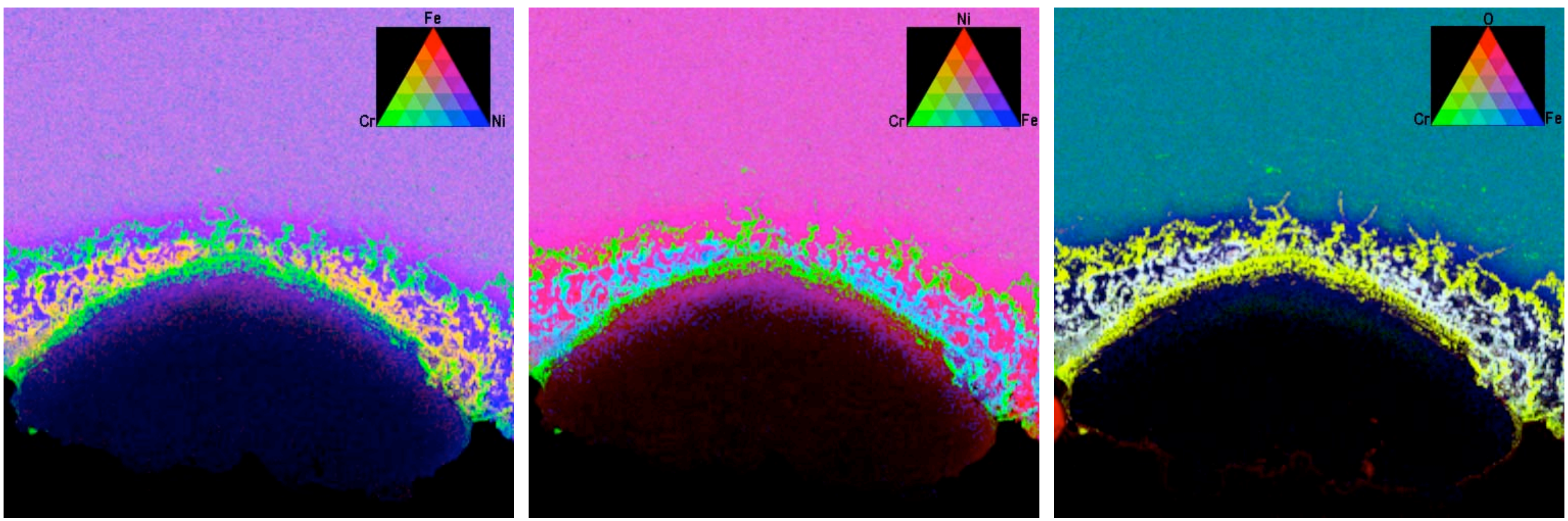
- Different types of engines
- Range of electrode alloy and insert materials

EPMA Analysis of Spark Plug After Severe Durability Test in an <u>Automotive Engine (749 hrs)</u>

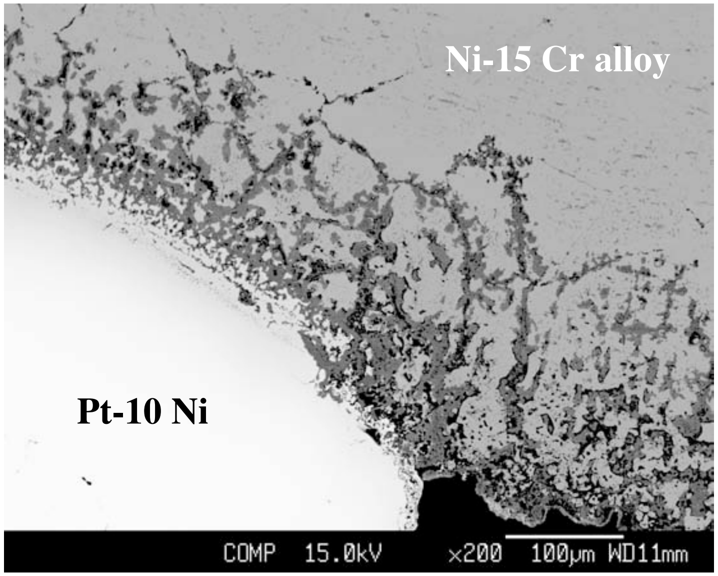


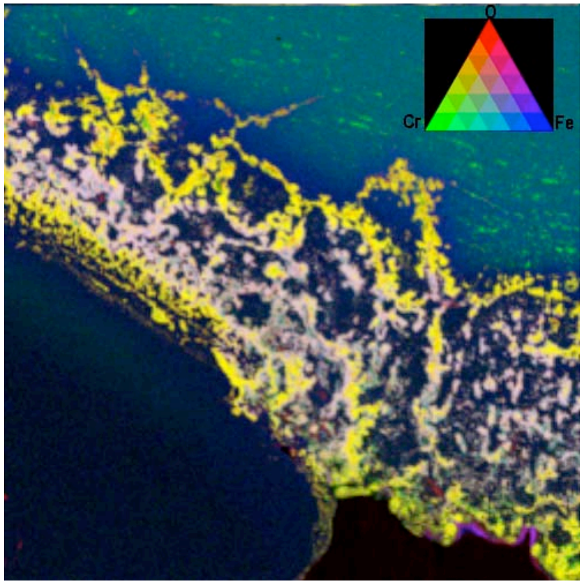
- **Local Melting of Pt-10Ni electrode insert**
- **Corrosive (and oxidation) attack at Pt-10Ni/Ni-15Cr based electrode insert. Similar to nature gas (NG) engines**

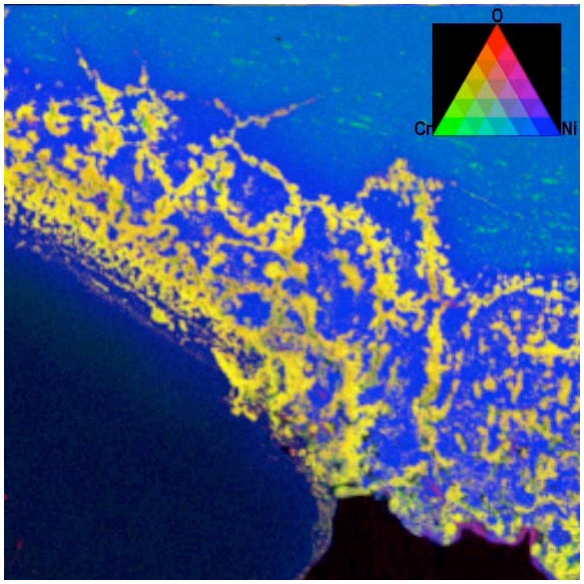
***Severe durability test: high thermomechanical stress was introduced under the high speed and high load condition**

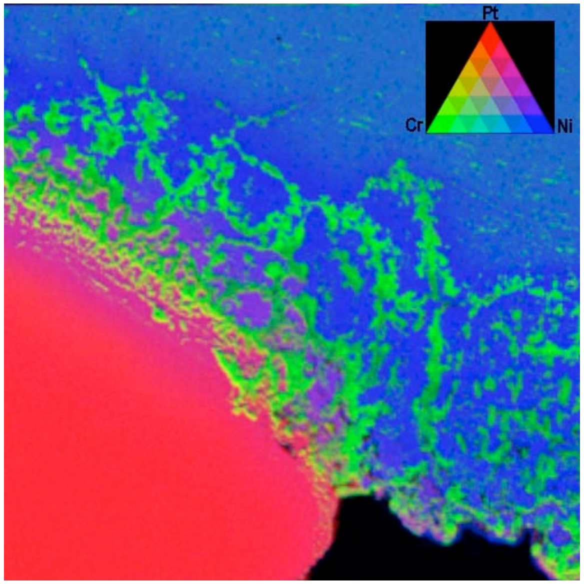


Extensive Internal Oxidation of Ni-15Cr Based Electrode Alloy

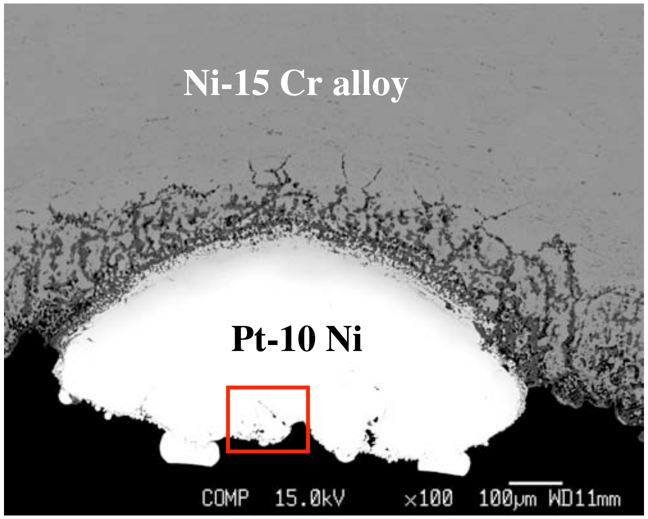


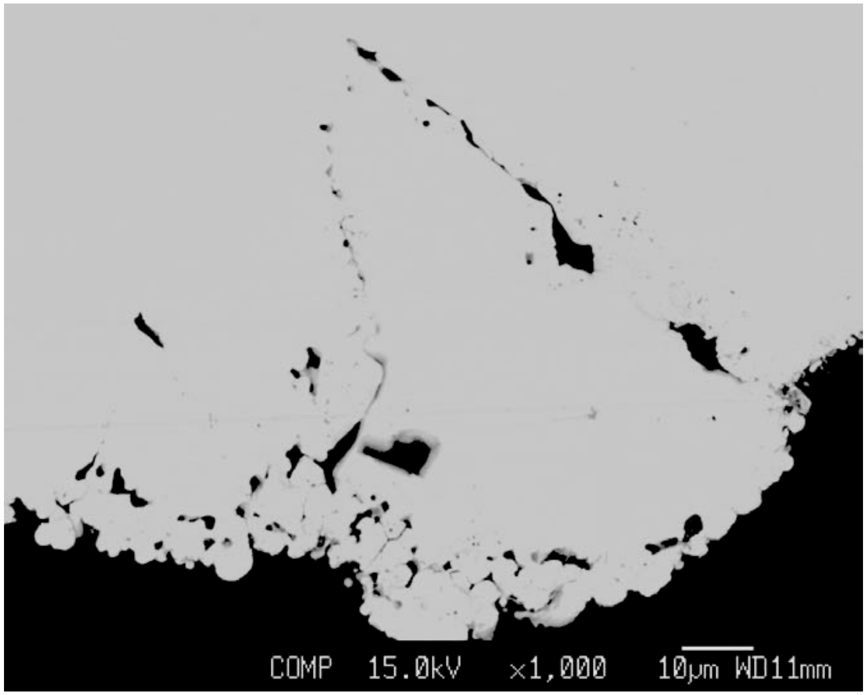


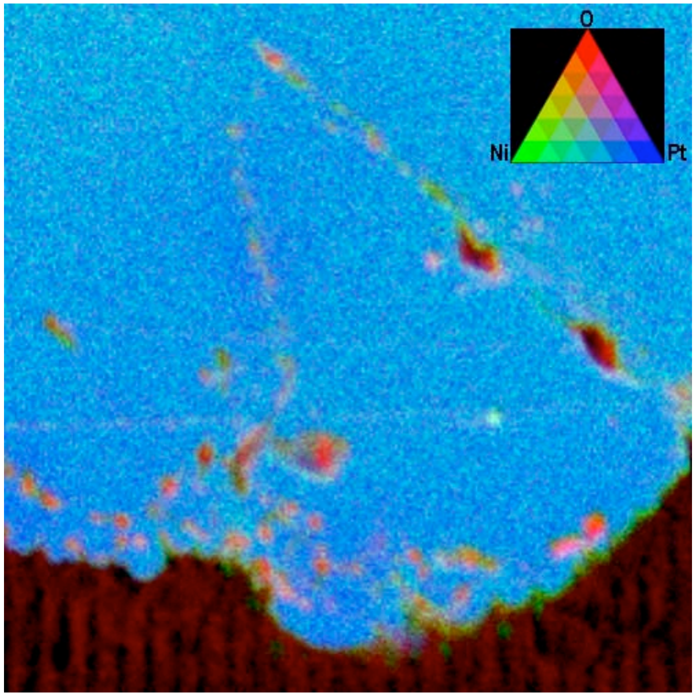




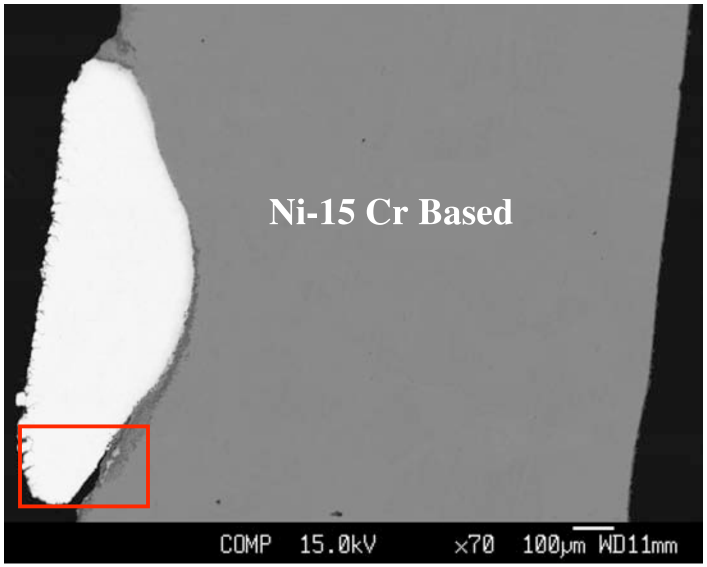
Internal Formation of NiO at Grain Boundaries in Pt-10Ni Alloy Electrode Insert

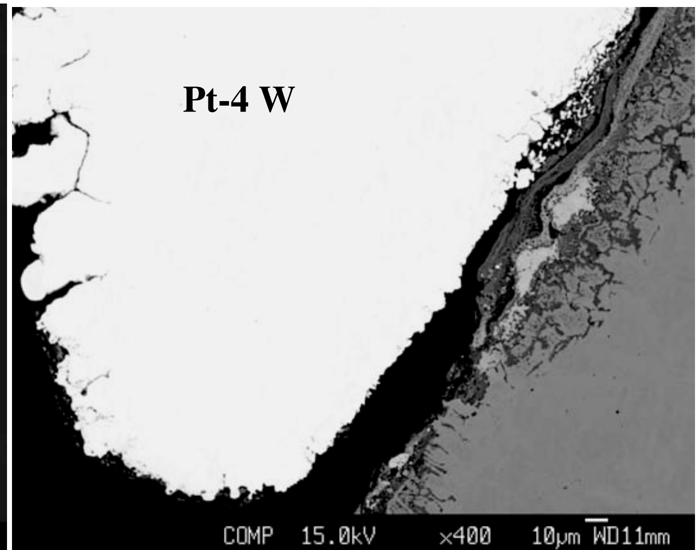




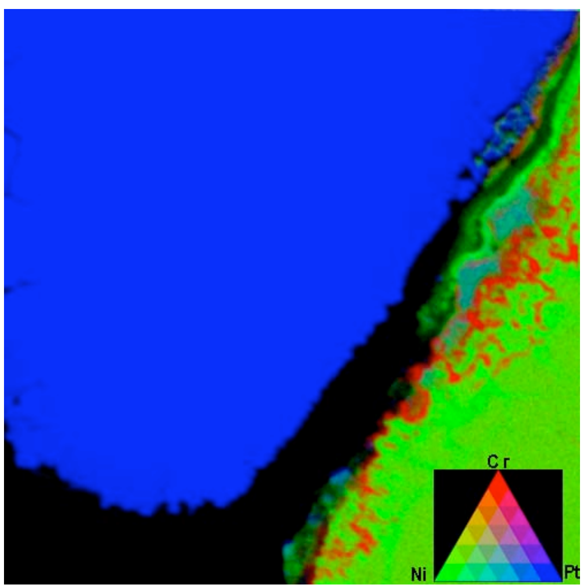


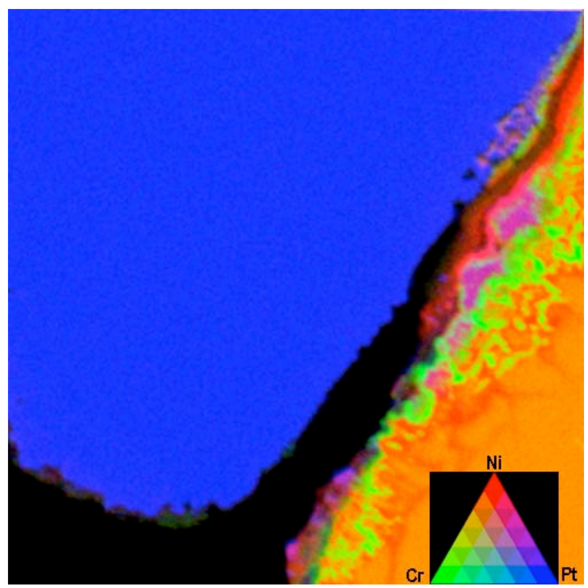
EPMA Analysis of Spark Plug After Severe Durability Test (108 hrs) <u>Lab Engine Testing</u>

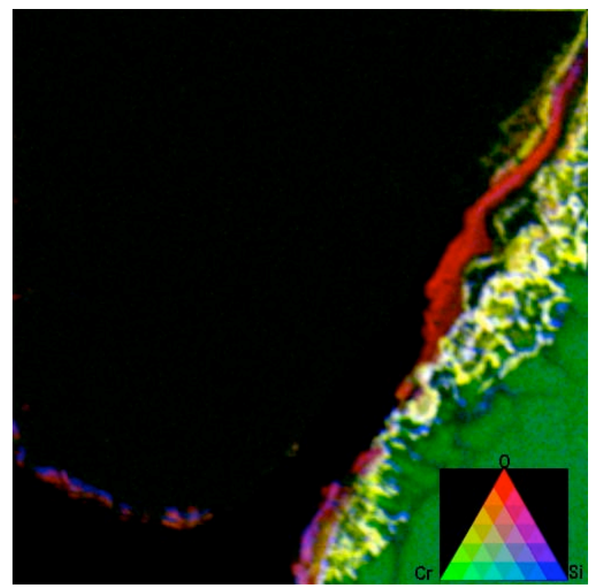




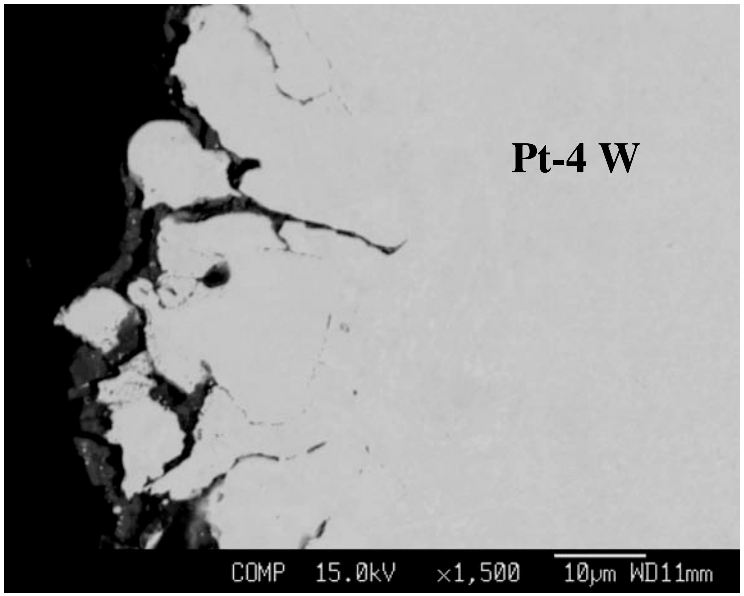
- Interface attack with Ni-based electrode, similar to NG and automotive engine



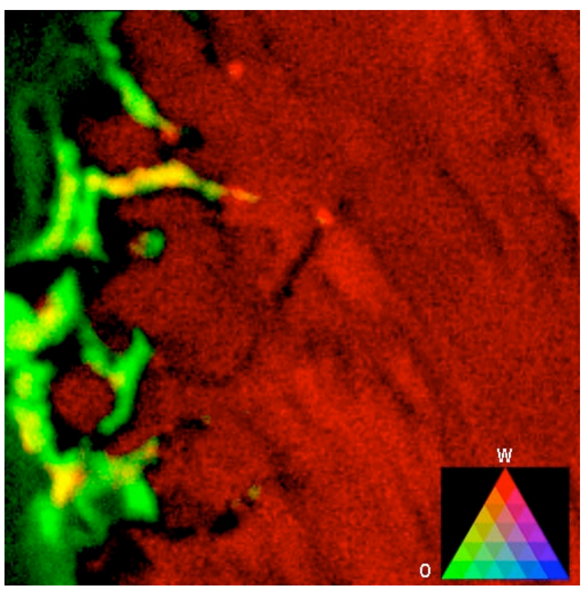


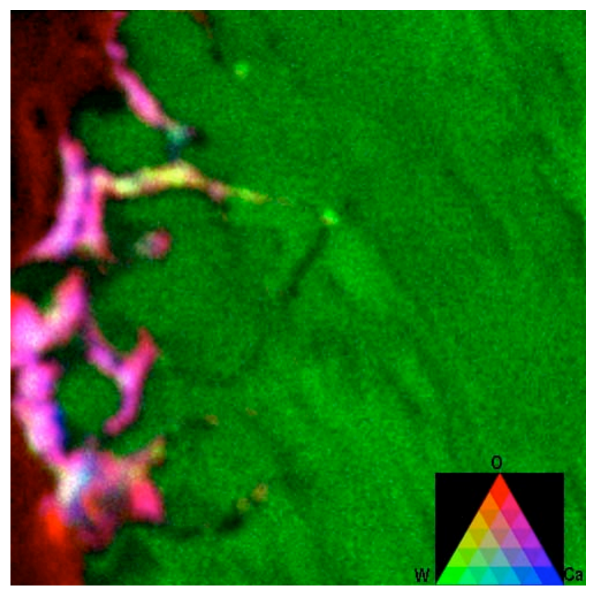


Internal Attack of Pt-4W Electrode Insert

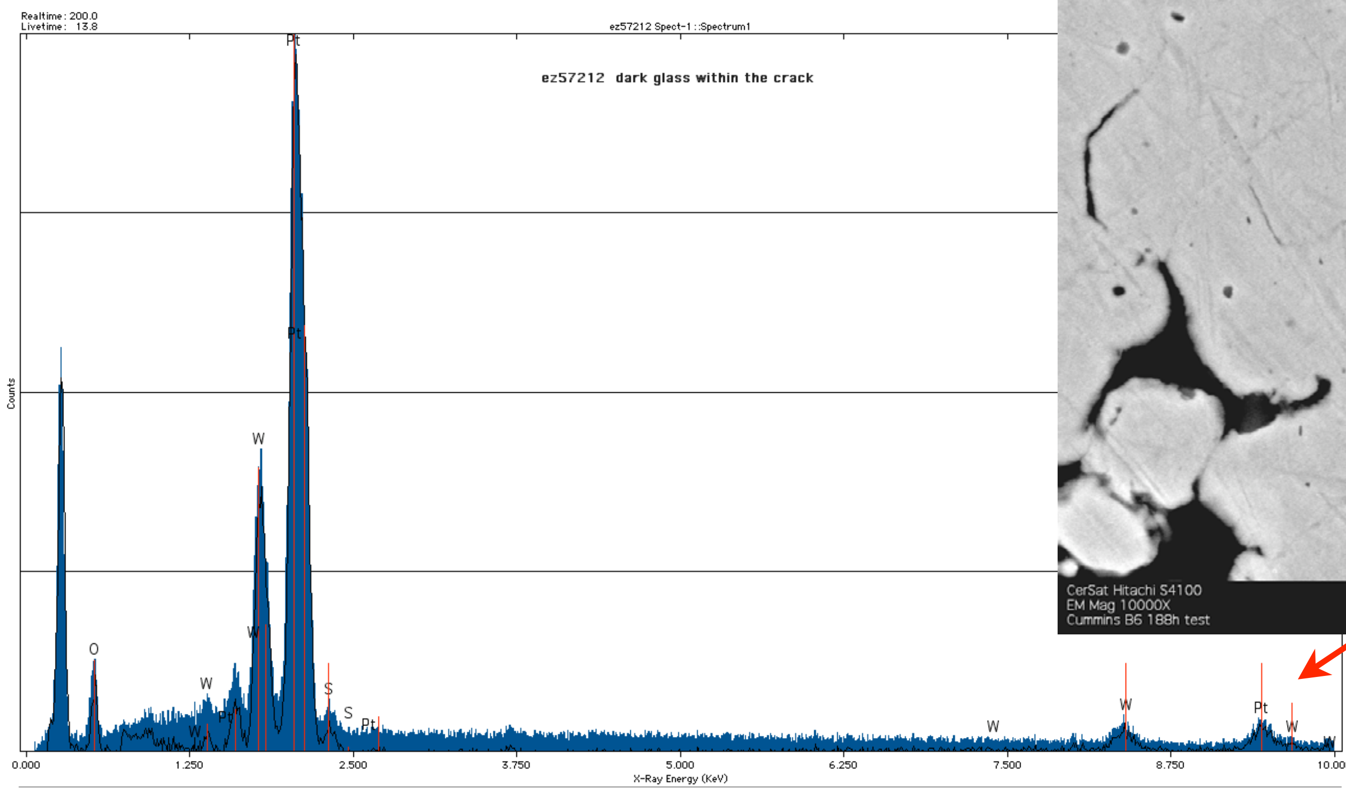


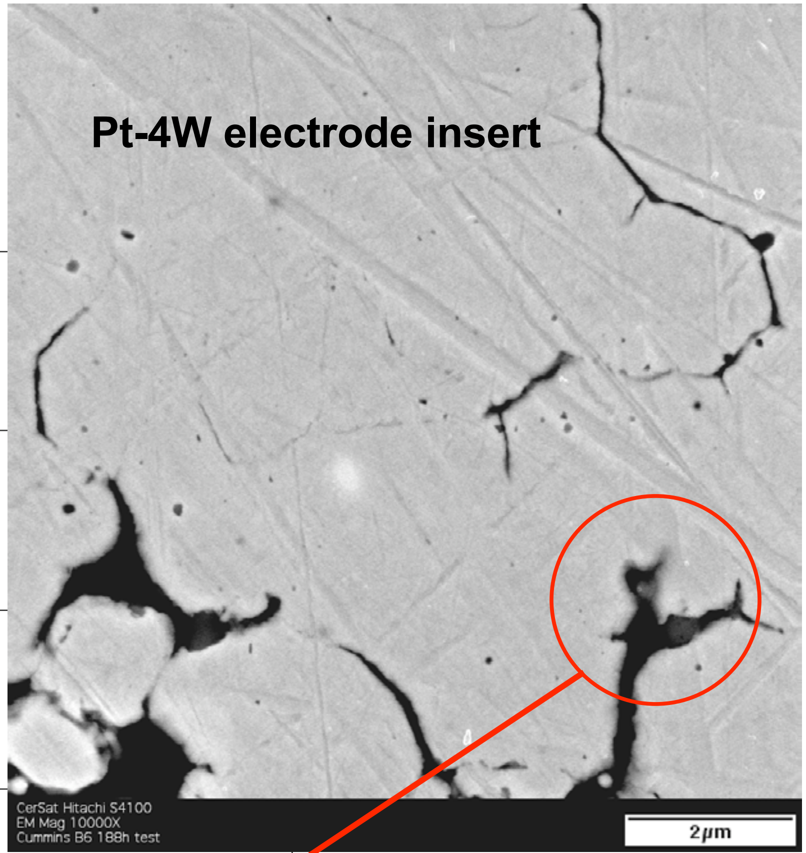
- Formation of internal W-containing oxide and subsequent volatilization contribute to intergranular cracking and accelerates corrosive wear



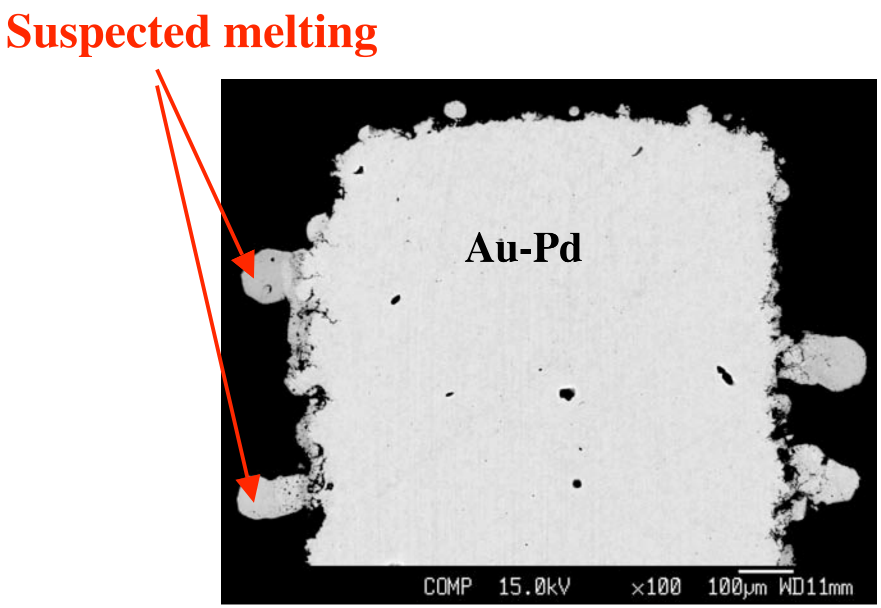


Similar Internal Oxidation of Pt-4W Electrode Insert Was Observed After Field Test in Natural gas Engine

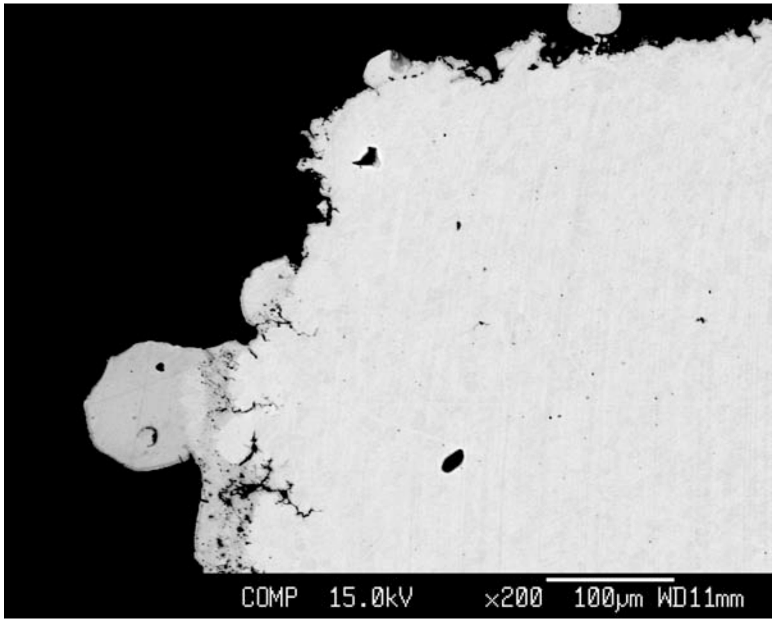


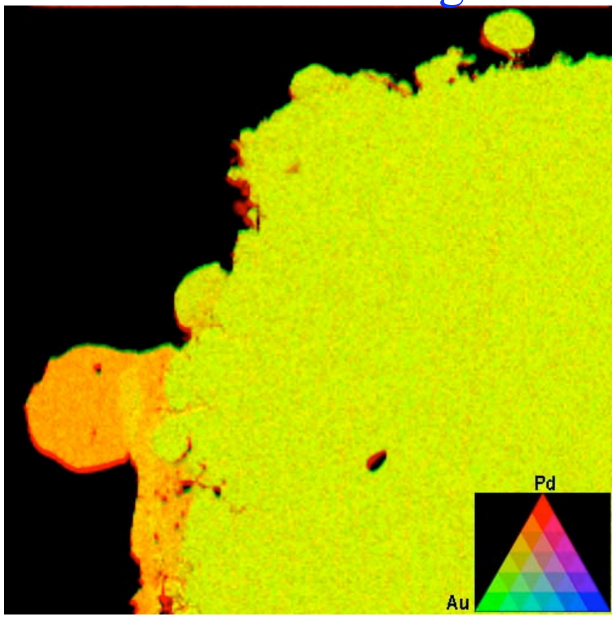


EPMA Analysis of Au(Pd) Electrode Insert After Field Test in Natural Gas Engine



- Alternative material to Pt-based alloy: no W, Ni additions that can oxidize selectively
- Observation suggests local melting of Au-Pd alloy (lower melting point than Pt)
- Analysis showed loss of Au element (enrich in Pd) consistent with volatilization of Au during melting





Summary of Observations

- Similar pattern of attack observed over a range of engine environments suggests fundamental materials issues play a significant role in spark plug wear and lifetimes

- Key issues are oxidation attack at the Pt-based alloy/Ni-Electrode interface, internal oxidation of the Ni-electrode alloys, and corrosion cracking of Pt and Ir electrode inserts

- Oxidation-driven issues related to W and Ni additions to Pt contribute to the observed cracking

- Materials selection/alternative alloys should focus on improved compatibility with Pt inserts and resistance to internal oxidation

- Alternatives to Pt alloy inserts should have melting points higher than that of both Pt-10Ni and Pt-4W alloy, and limit alloying additions which can internally oxidize selectively
(Note that alloying additions also need to be made with regards to achieving desired breakdown voltages and manufacturability of electrodes