Characterization of Erosion and Failure Processes of Spark Plugs After Field Service in Natural Gas Engines

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Advanced Reciprocating Engine Systems

15th International Conference on Wear of Materials, San Diego, CA, April 24-28, 2005

Research jointly sponsored by the U.S. Department of Energy, Office of Distributed Energy, Distributed Energy Materials Program and Advanced Reciprocating Engine Systems program, under Contract DE-AC05-00OR22725 with UT-Battelle, LLC.

Outline of Presentation

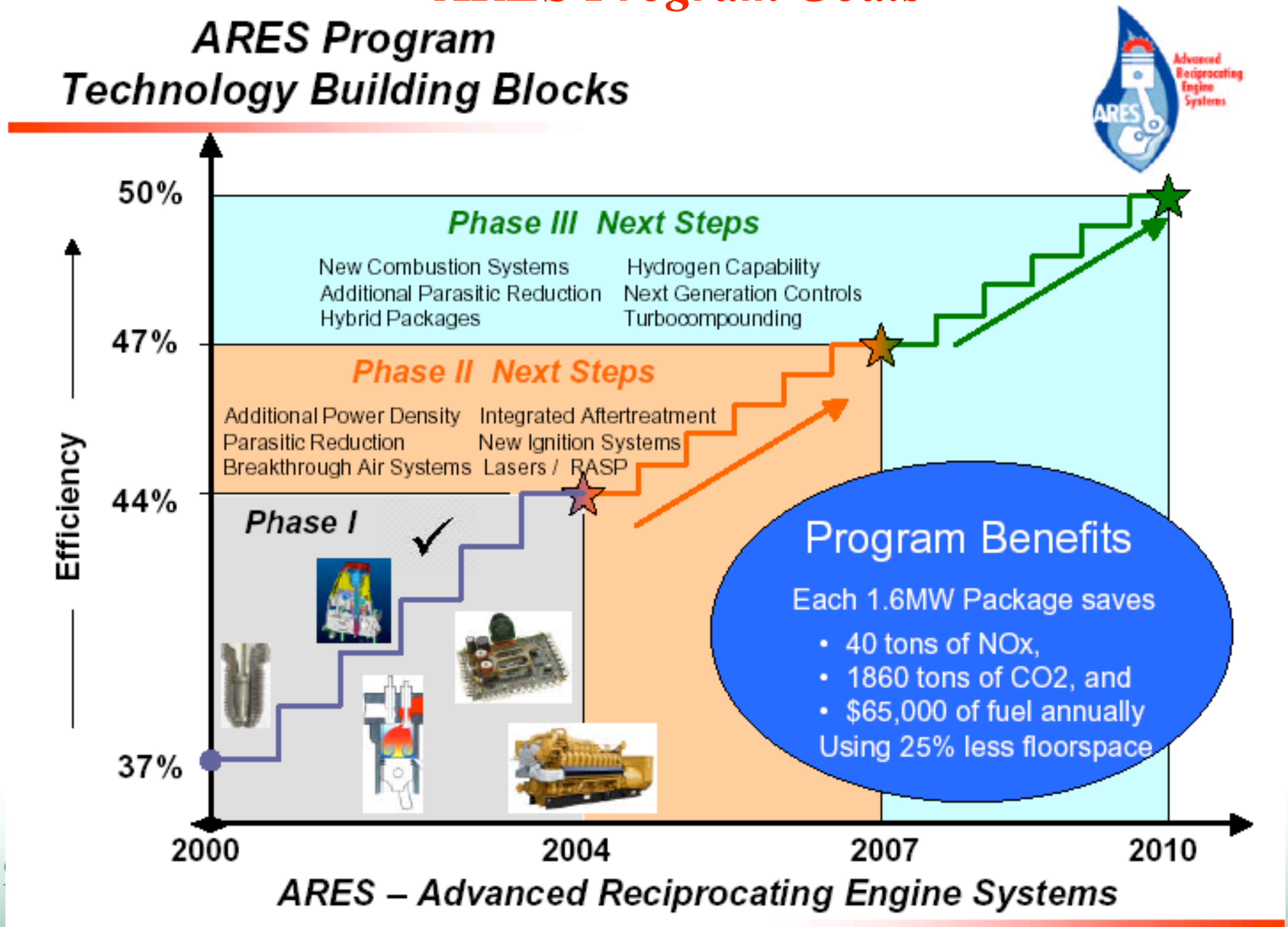
- ❑ Background
  - \- ARES program
  - \- Objective
  - \- Approaches
- ❑ Spectroscopic and Metallurgical Investigations
- ❑ Summary

DOE Advanced Reciprocating Engine System (ARES) Program Goals (2000-2010)

A Commercial Engine by 2010 with:

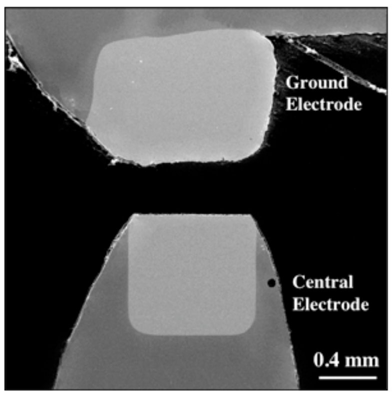
- High Efficiency - Fuel-to-electricity conversion efficiency of at least 50%
- Environmental Superiority - NO_x < 0.1 g/hp-hr (natural gas)
- Reduced Cost of Power - Energy cost, including O&M, at least 10% less than current state-of-the-art engines
- Fuel Flexibility - Adaptable to future firing with dual fuel capabilities, include further adaptation to hydrogen
- Reliability and Maintainability - Equivalent to current state-of-the-art engines

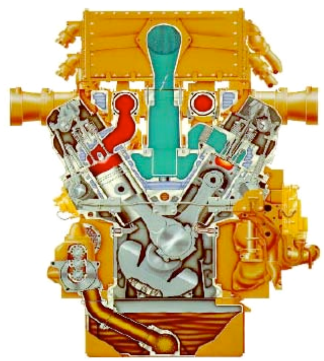
ARES Program Goals



Motivation of This Study

- Advanced ignition system is a key technology to achieve cost/performance/emission characteristic goals for lean and stoichiometric engines
- Corrosion/erosion of spark plugs limits the long-term reliability and performance of ignition systems and, thus ARES
- Increased in cylinder pressures, compression ratios, and ignition voltages will further limit the ignition performance and ARES developments
- Improvement of high-temperature corrosion/erosion resistance of electrodes is a critical issue to maintain the long-term durability of spark plugs





CAT®
GAS ENGINES

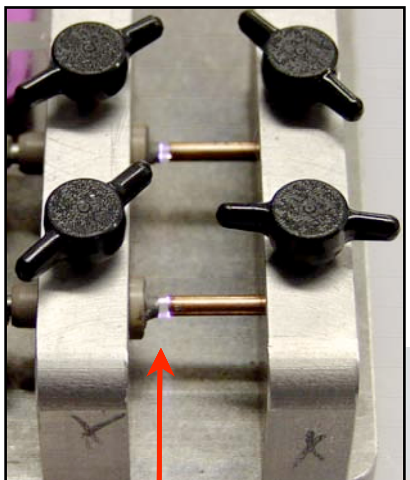
DRESSER
Waukesha

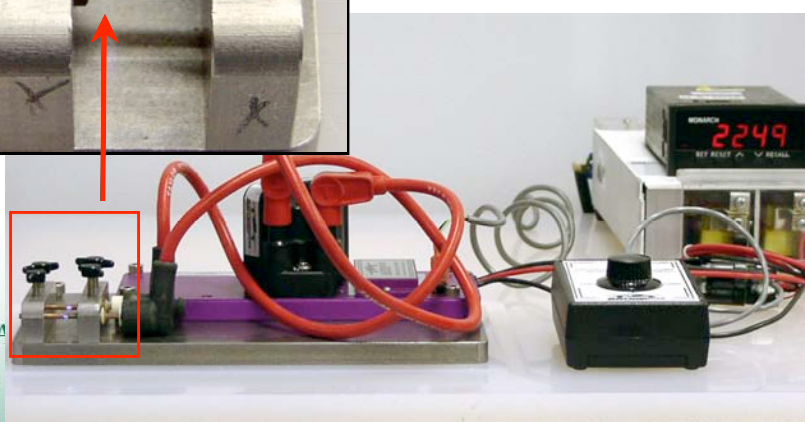
Objective

- Characterize optical spectra of spark plug arcs to evaluate the ignitability and erosion or age characteristics of spark plugs
- Characterize and measure spark plug erosion as a function of field-tested time
- Provide understanding of corrosion and erosion mechanisms of spark plugs in natural gas engine environments
- Provide design guidelines for ignition systems of advanced Advanced Reciprocating Engine Systems
- Develop advanced alloys to improve the corrosion/erosion resistance and extend the lifetime of electrodes and spark plugs

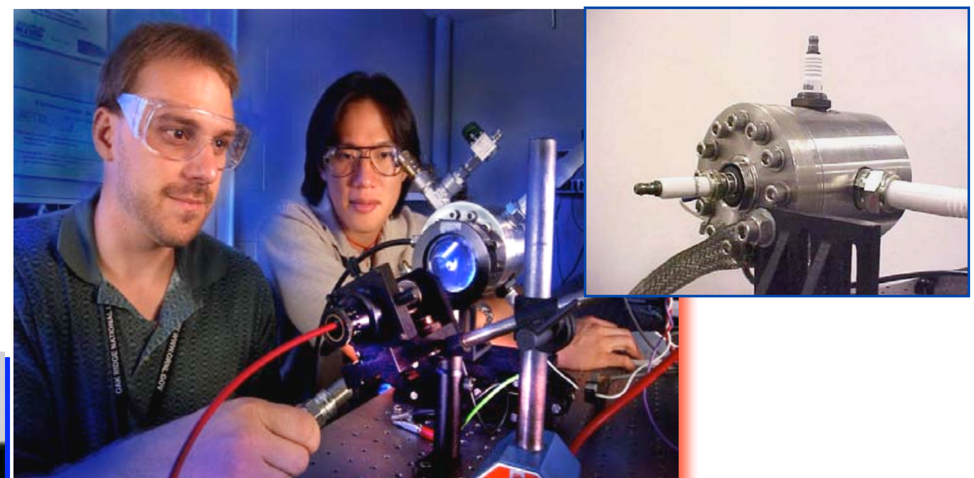
Integrated Approaches

- Develop diagnostic tool for measuring shot-to-shot erosion
- Mass spectroscopy analysis for field-tested spark plugs acquired from gas engine companies, i.e., CAT, Cummins, and Waukesha
- Identification of erosion/corrosion mechanisms of ground and center electrodes via systematic optical and SEM analysis
- Develop advanced alloys to significantly improve spark plug reliability and extend life performance



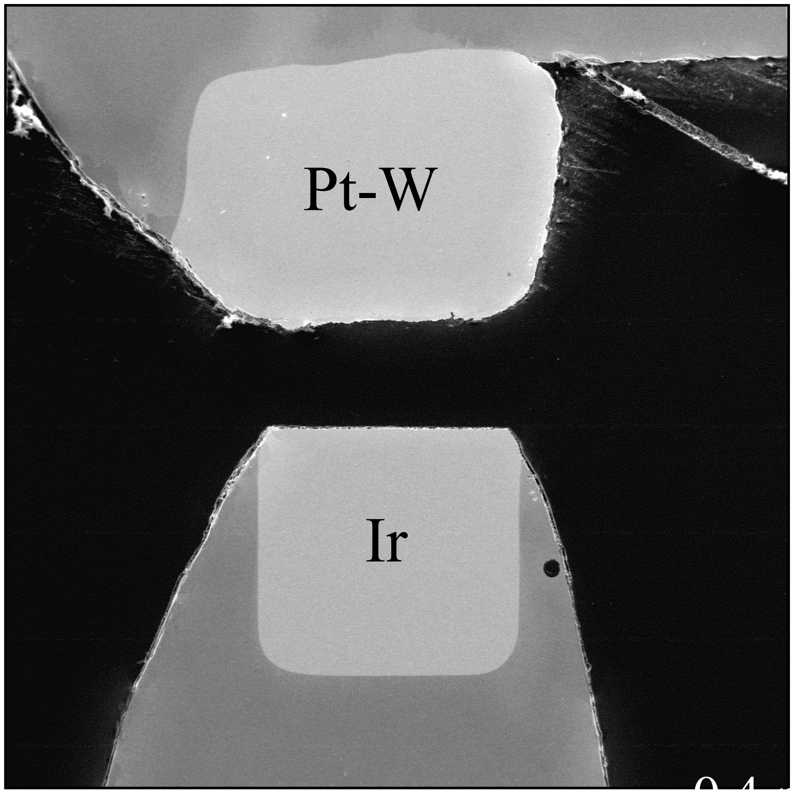


ORNL Electrode Screening Test Rig

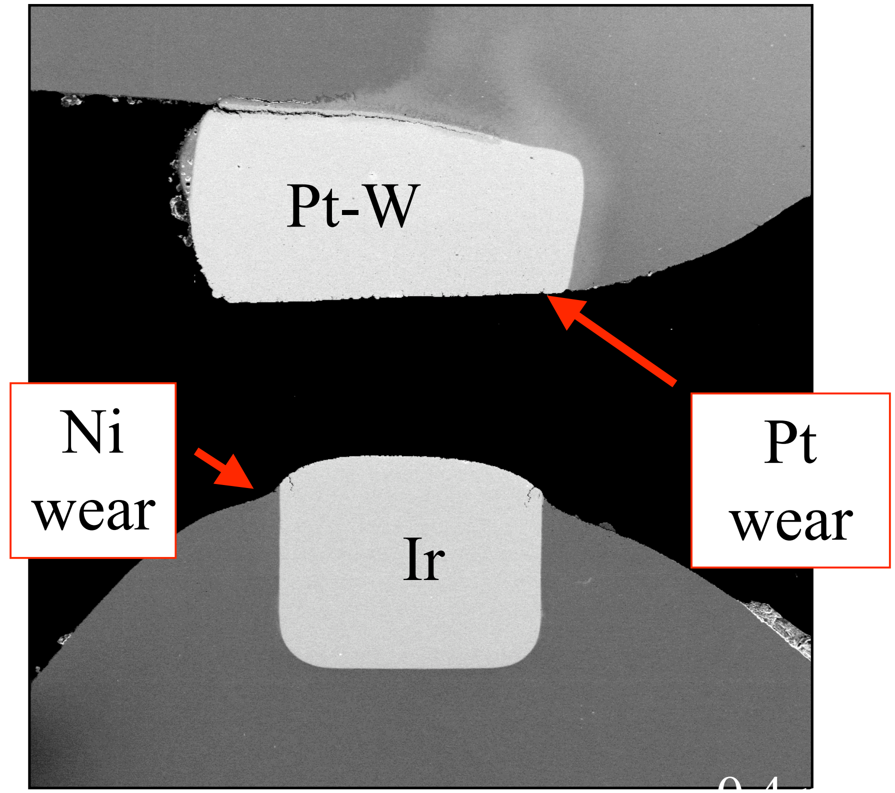


NTRC Spectroscopy Chamber

Substantial Spark Plug Erosion is Observable After Natural Gas Engine Service



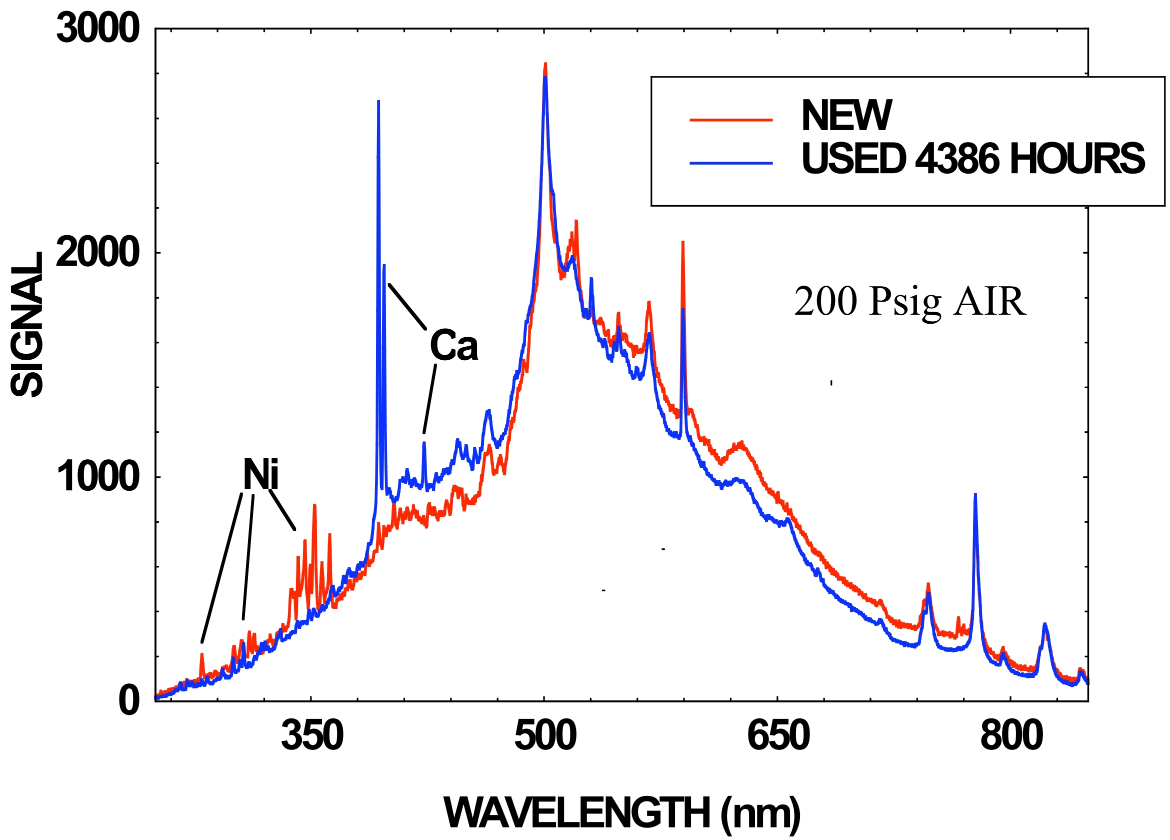
New



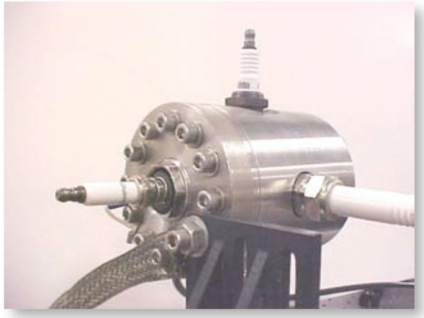
Used 4,386 hours

The tips of the spark plugs wear away until the gap distance is too large for the plug to fire

Mass Spectroscopic Analysis Detected Substantial Amount Calcium Present in Field Tested Spark Plugs



Test Chamber

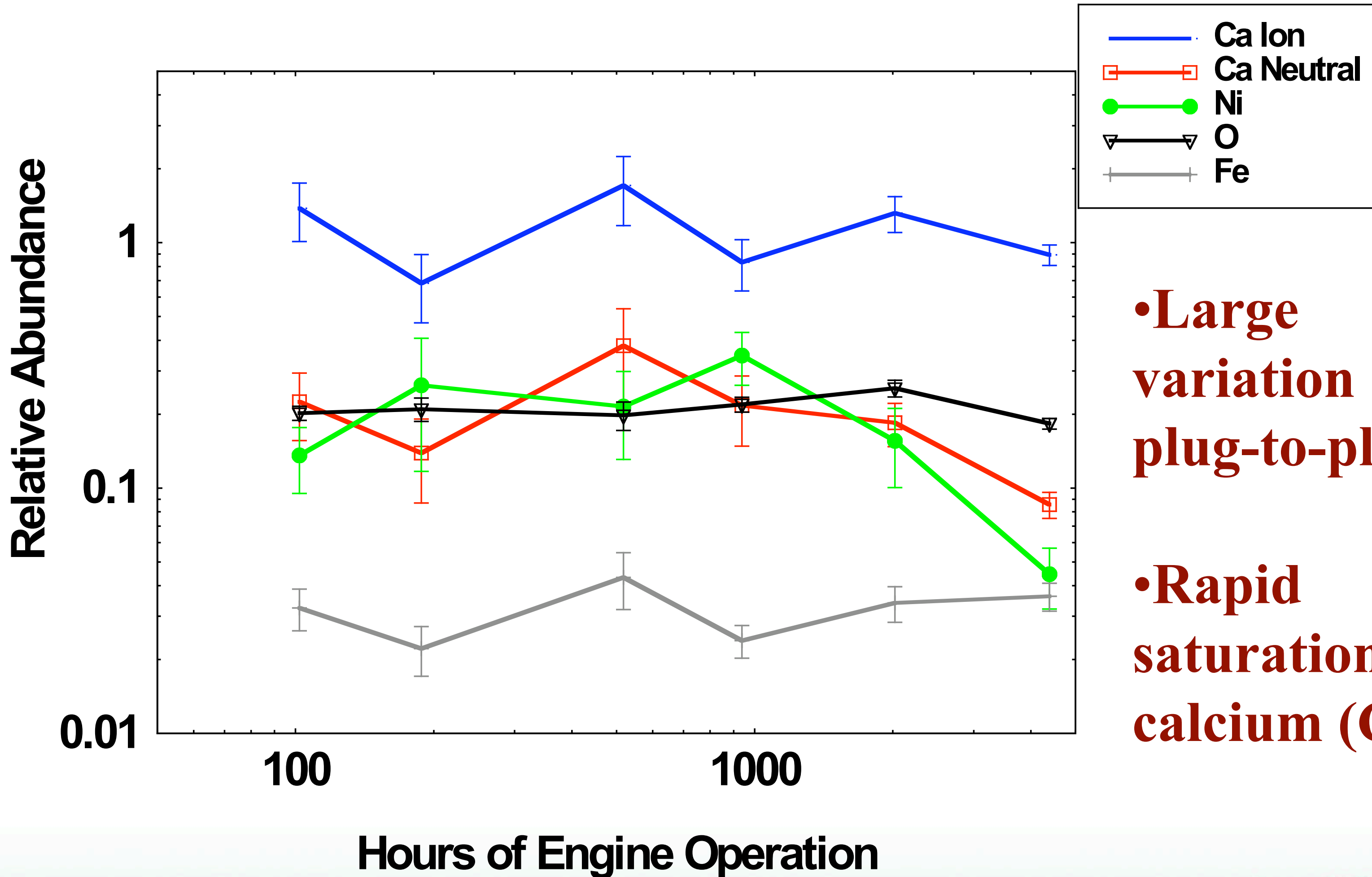


0-200 Psig

- Ca from the engine lubricant oil
- No detection of Pt, W or Ir from electrode tips

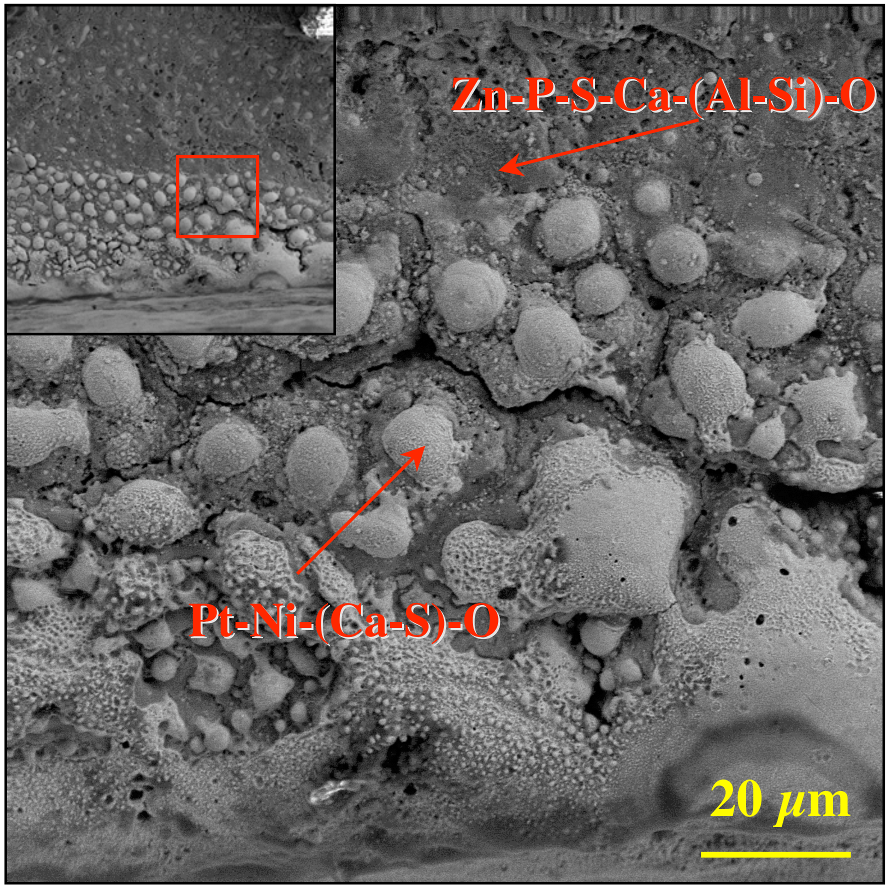
Detection of Ni in new spark plug suggests the erosion of Ni-based electrode due to sputtering process

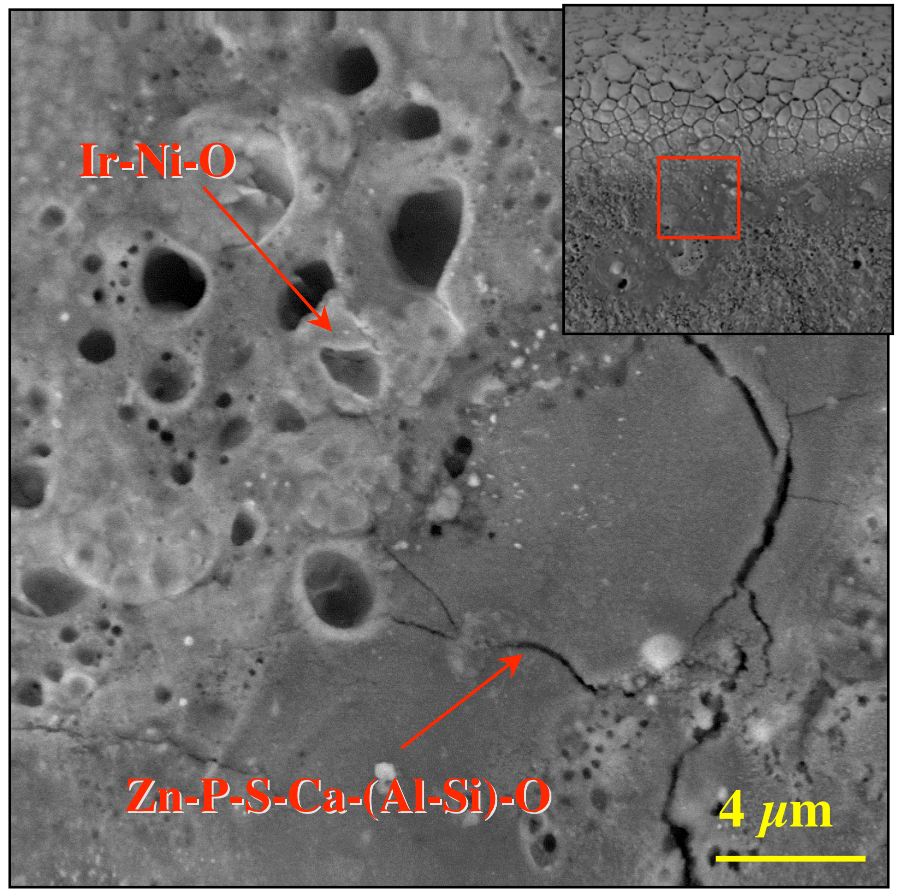
Chemical Elements Identification Made With Optical Emission Spectroscopy



- **Large variation plug-to-plug**
- **Rapid saturation of calcium (Ca)**

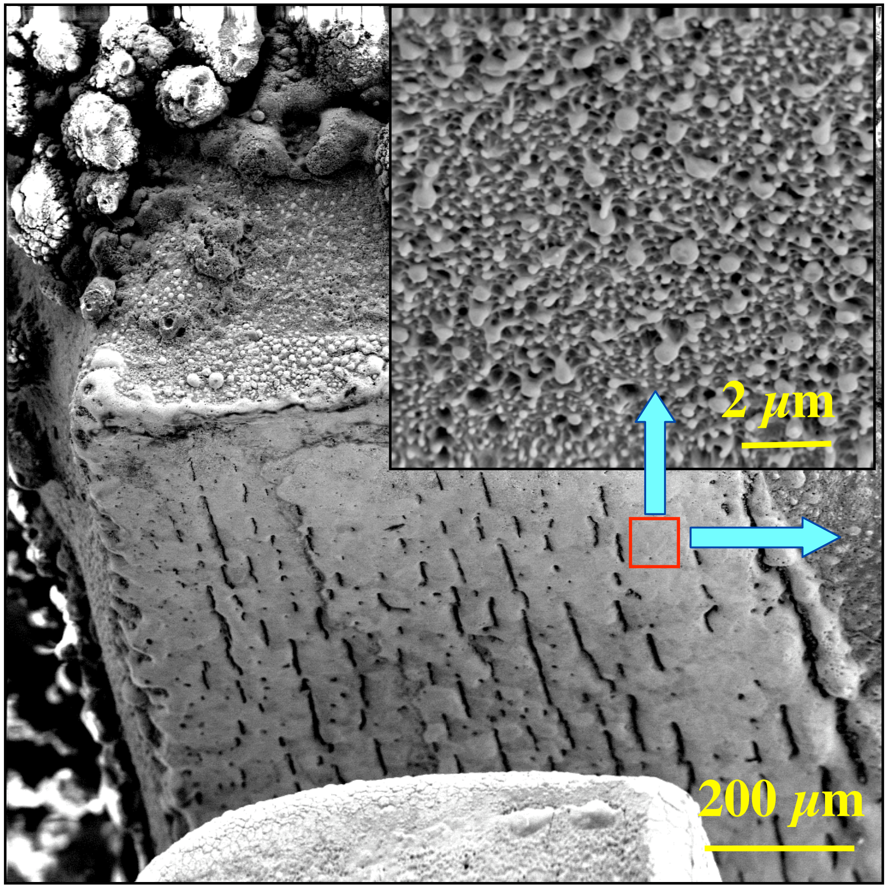
Substantial Oxidation Plus Glassy Phase Formation Observed in Both Pt-Alloy and Ir Electrode Side Surfaces After Field Service

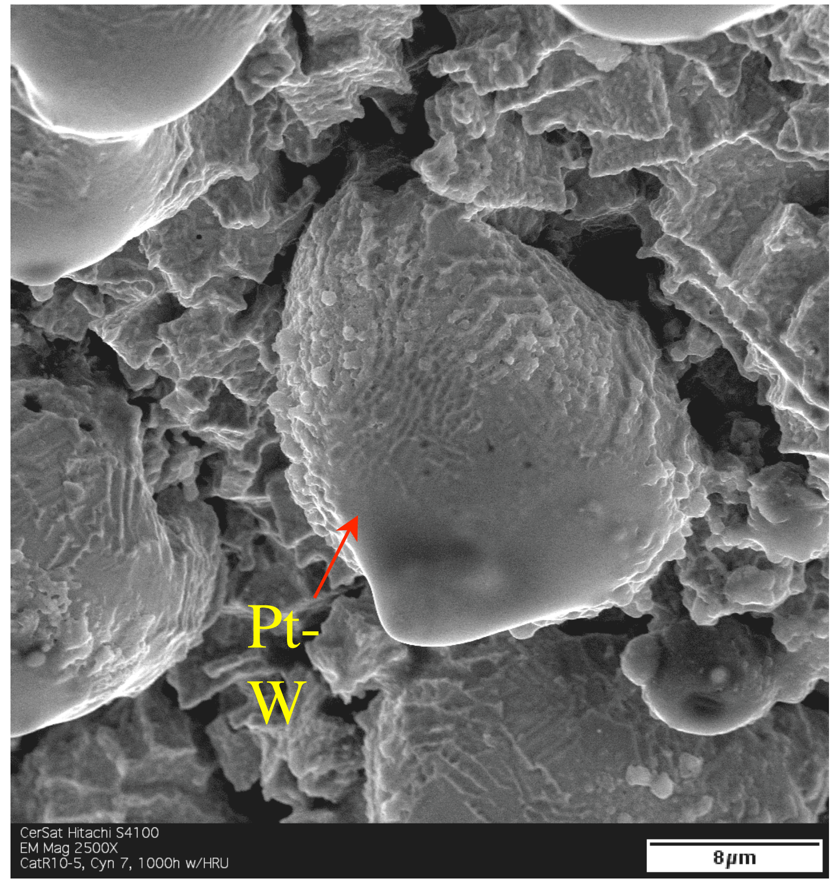




The Ca content in glassy phase is significant, and the presence of Ca (and also P) could reduce the softening point and viscosity of glass, consequently enhancing the erosion process

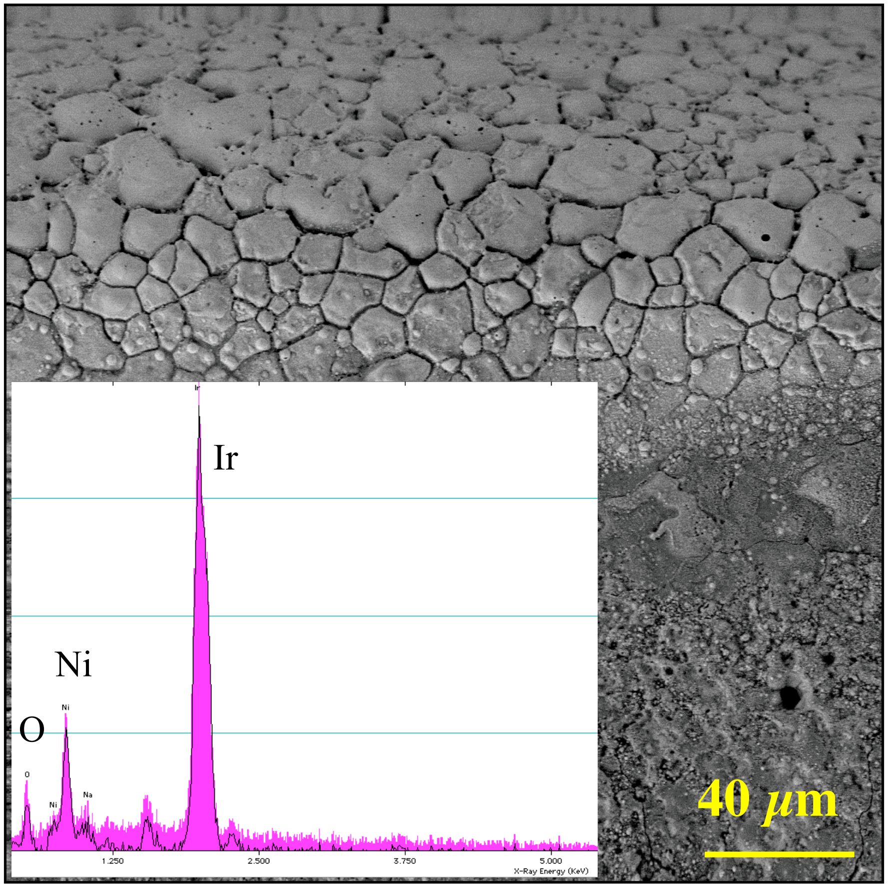
Substantial Line-Cracks Observed on Pt-Alloy Electrode Surface After Field Service

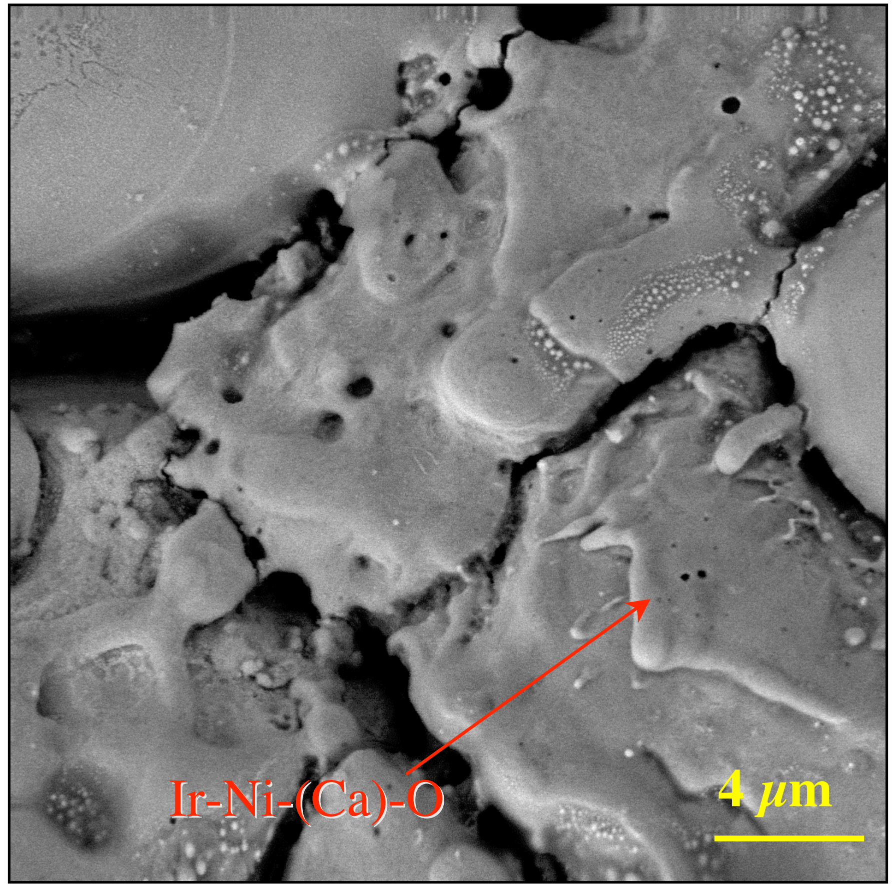




Formation of droplet-like morphology likely from local melting of the Pt-W Alloy
Separation of large Pt-W particulates (20-40 μm) also observed

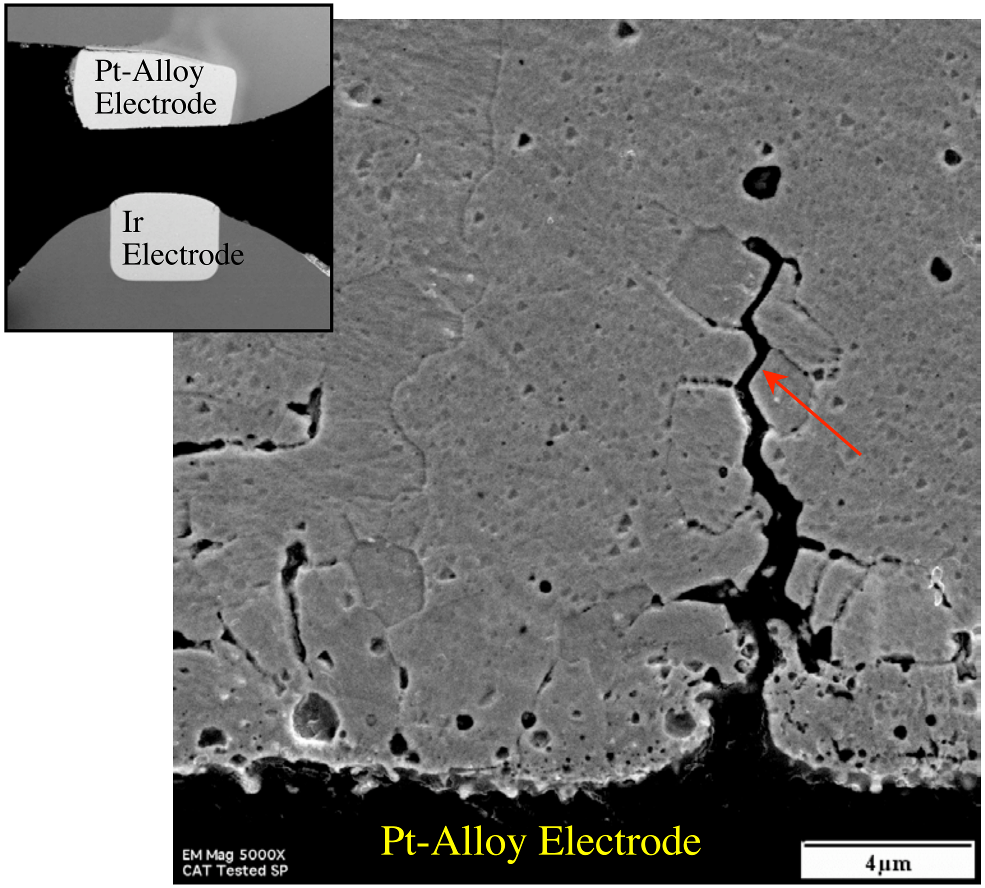
Substantial Oxidation With Crack Formation of Ir Electrode Surface Observed After Field Service

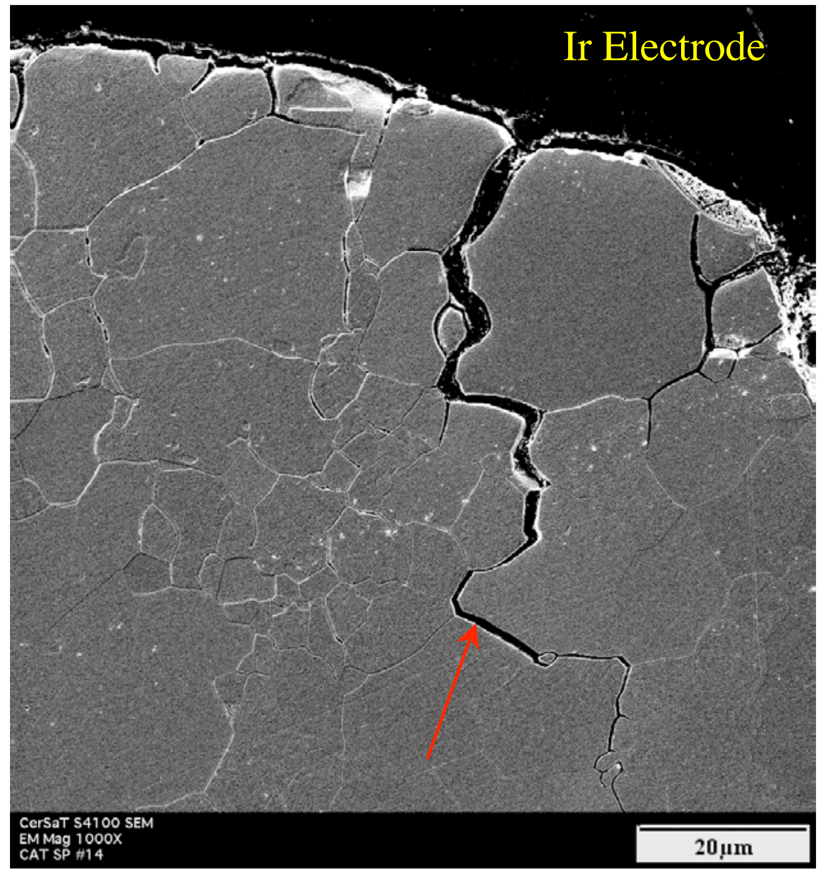




Mud-crack morphology of Ir electrode is significantly different from that observed on Pt-W alloy electrode

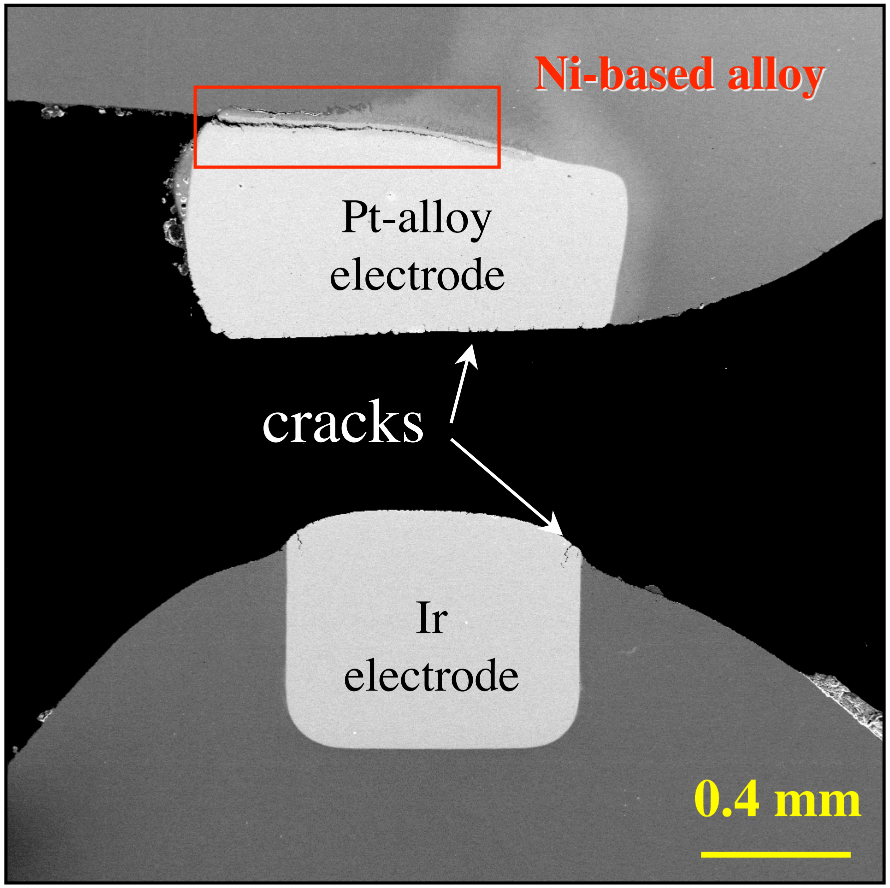
Substantial Intergranular Cracking Occurred in Both Pt-alloy and Ir based Electrode After Field Service

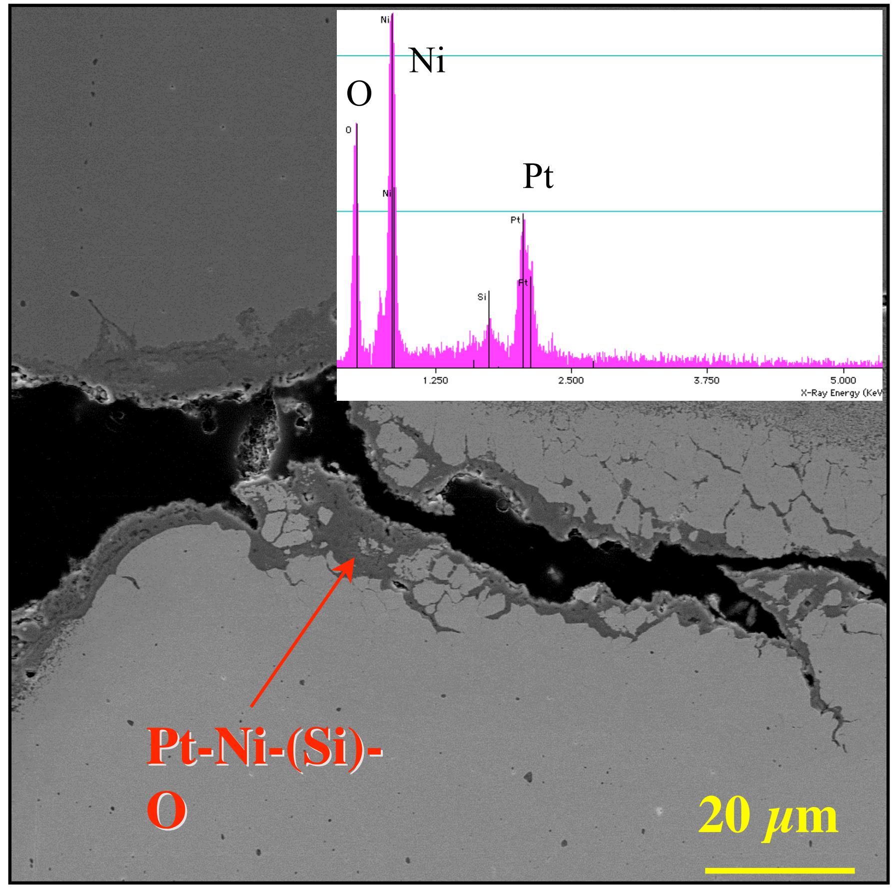




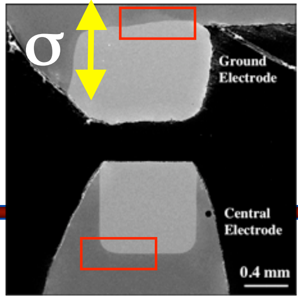
Coalescence of intergranular cracks and subsequent material flake-off in Pt and Ir electrodes (the dominant mechanism) would further accelerate the erosion process and limit the long-term durability and performance of spark plugs

Substantial Crack Generation and Growth Observed Between Pt-alloy and Ni-based Electrode After Field Service

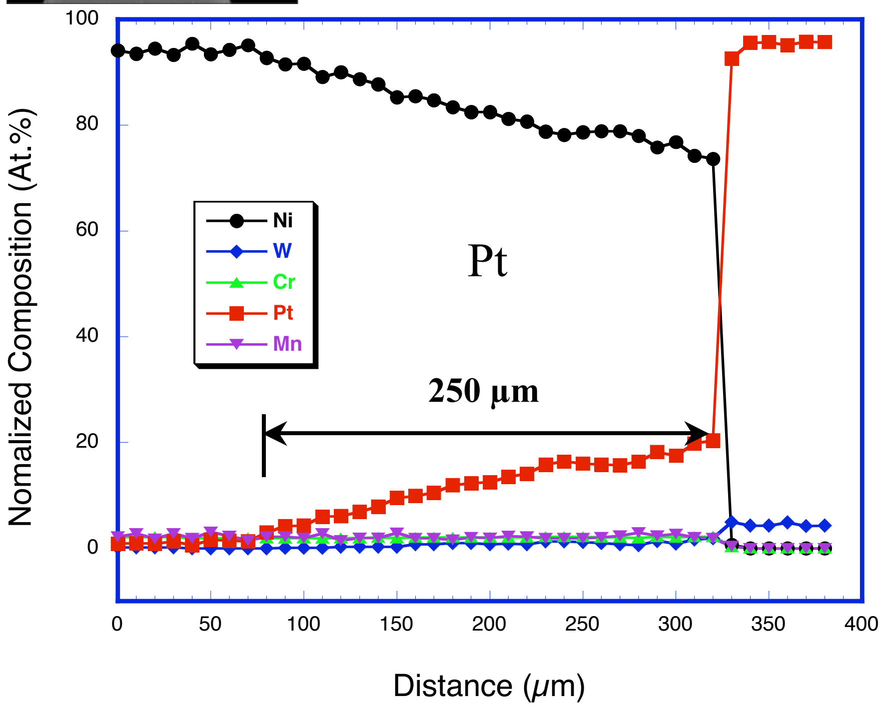


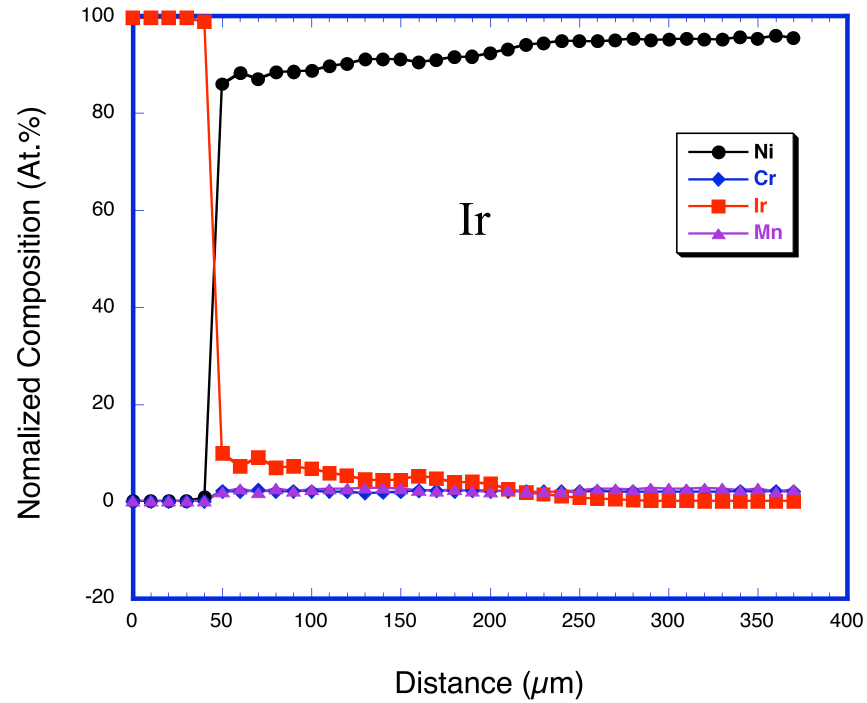


An oxide-based (Pt-Ni-O) reaction zone, which is brittle in nature, formed between Pt and Ni-based electrode. Crack generation and growth and oxide-based interface could significantly degrade the ignitability/performance, and ultimate cause failure of spark plugs



Significant Interdiffusion of Pt and Ir with Ni Observed in the As-received Spark Plugs





Pt-Ni$_{ss}$ could readily oxidize and form Pt-Ni-O at elevated temperatures (~ 1000°C) in air

Thermal stress generated during operation could readily cause the crack initiation and growth

Summary of Observations

- Pt and Ir tips are eroding but not sputtering
- Large amounts of Ca present around the tips
- Oxide scale containing enriched with Ca observed on both electrode side surfaces
- Periodic crack-lines formation due to localized material corrosion/erosion observed on Pt-alloy electrode tip surface after field service
- Substantial oxidation plus mud crack formation also observed on the Ir central electrode tip surface region
- Generation and coalescence of intergranular cracks would accelerate the material erosion process of electrodes and further limit the lifetime of spark plugs
- The crack initiation and growth in oxide phase formed between the Pt-W insert and Ni-based electrode would significantly degrade the plugs' ignitability/performance and ultimately result in failure of the spark plugs