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Improving Corrosion Resistance of Soft Magnetic Composites for Induction Heat Treating Applications

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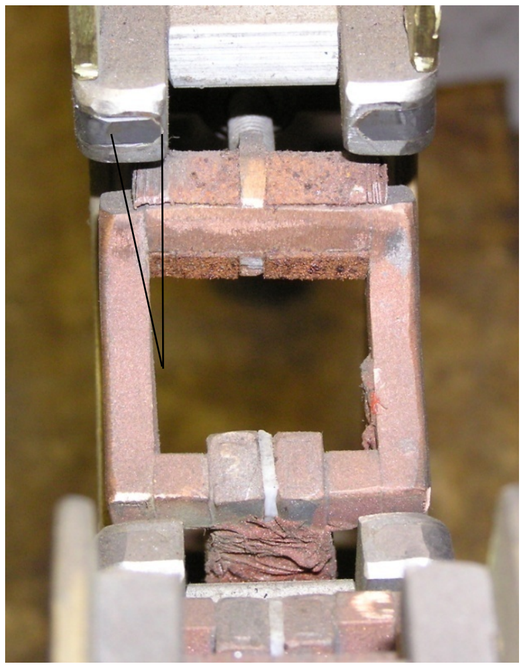
Background

- Manufacturers expects longer induction coil lifetime to compete todays global manufacturing environment
- The lifetime of an induction heat treating coil is often limited by either the thermal fatigue behavior of copper or the degradation of magnetic flux controllers (MFC's) used for induction system performance improvement.
- 2 types of MFC's are commonly used on induction heat treating coils
  - Iron Silicon Laminate Sheets (Laminations)
  - Soft Magnetic Composite Materials (SMC's)
- Corrosion is one the sources of limiting lifetime of MFC's (both laminations and SMC's)

Corrosion of MFC's in Induction Heat Treating Applications

- Corrosion of MFC's caused by combination of elevated temperatures and oxidizing agents (quenchants, air, steam)
- As MFC's corrode, local conductivity is increased, which can lead to reduced magnetic properties and increased losses
- Focus of the presentation is on corrosion prevention of SMC's



Rusted laminations on a crankshaft coil

Corrosion Prevention for SMC's

- SMC's for induction heat treating are manufactured with a protective layer on each particle and isolation between particles
- However, all SMC's have porosity and most SMC's are machined prior to their application on an induction heat treating coil
- The machining process removes protective coatings from the surface layer, providing a site for corrosion initiation
- Therefore, the most prospective method for corrosion protection is to apply a corrosion resistant layer over the surface of the machined concentrator to protect the surface and volume from oxidizing agents

Case Study Conditions

- Four commercially available SMC's were tested (Fluxtrol 100, Fluxtrol A, Fluxtrol 50 and Ferrotron 559H)
- 3 Different Ceramic Polymer Matrix Coatings with a thickness of 10 to 40 microns were compared
- 24 Samples were machined, etched and cleaned to the same dimensions prior to coating
- 12 of the 24 samples also underwent an additional surface preparation technique designed to seal near surface porosity prior to coating
- ASTM D 1735 humidity testing was done on all samples
  - Chamber temperature 100 C and 100% humidity
  - Samples evaluated at 24, 48, 72 and 168 hours

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Table of Results – Coating A

ASTM D1735			Surf. Prep.	Hours of Testing			
Sample	**Material**	**Coating**		**24**	**48**	**72**	**168**
H1	Fluxtrol A	A	Yes	No	No	No	No
H2	Fluxtrol A	A	No	No	No	No	No
H3	Fluxtrol 50	A	Yes	No	No	No	No
H4	Fluxtrol 50	A	No	No	No	No	No
H5	Fluxtrol 100	A	Yes	No	No	No	**Yes**
H6	Fluxtrol 100	A	No	No	No	No	No
H7	Ferrotron 559H	A	Yes	No	No	No	No
H8	Ferrotron 559H	A	No	No	No	No	No

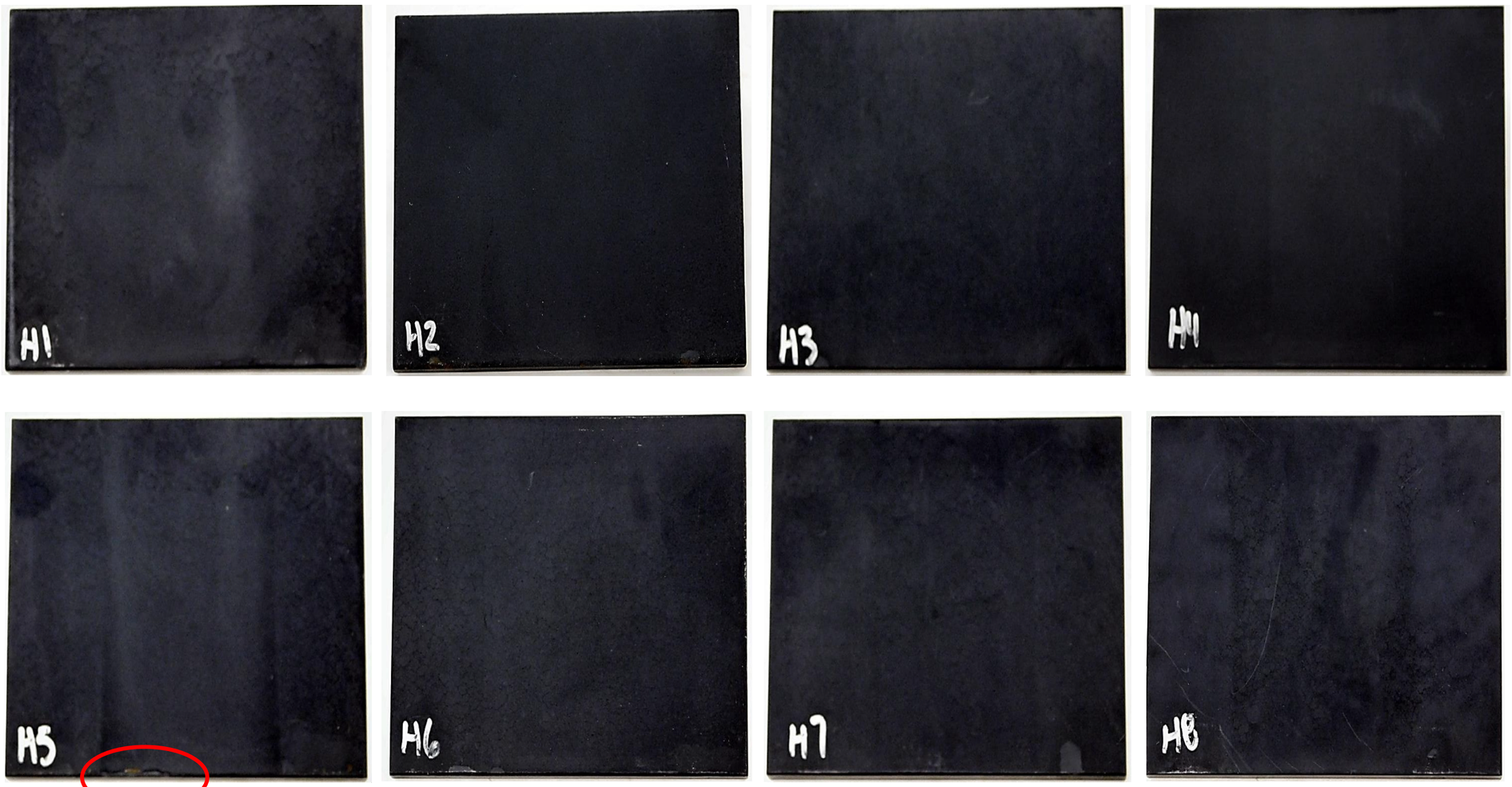
Table of Results – Coating B

ASTM D1735			Surf. Prep.	Hours of Testing			
Sample	**Material**	**Coating**		**24**	**48**	**72**	**168**
H9	Fluxtrol A	B	Yes	No	No	No	No
H10	Fluxtrol A	B	No	No	No	No	No
H11	Fluxtrol 50	B	Yes	No	No	No	No
H12	Fluxtrol 50	B	No	No	No	No	Yes
H13	Fluxtrol 100	B	Yes	Yes	Yes	Yes	**Yes**
H14	Fluxtrol 100	B	No	Yes	Yes	Yes	Yes
H15	Ferrotron 559H	B	Yes	No	Yes	Yes	Yes
H16	Ferrotron 559H	B	No	No	No	No	No

Table of Results – Coating C

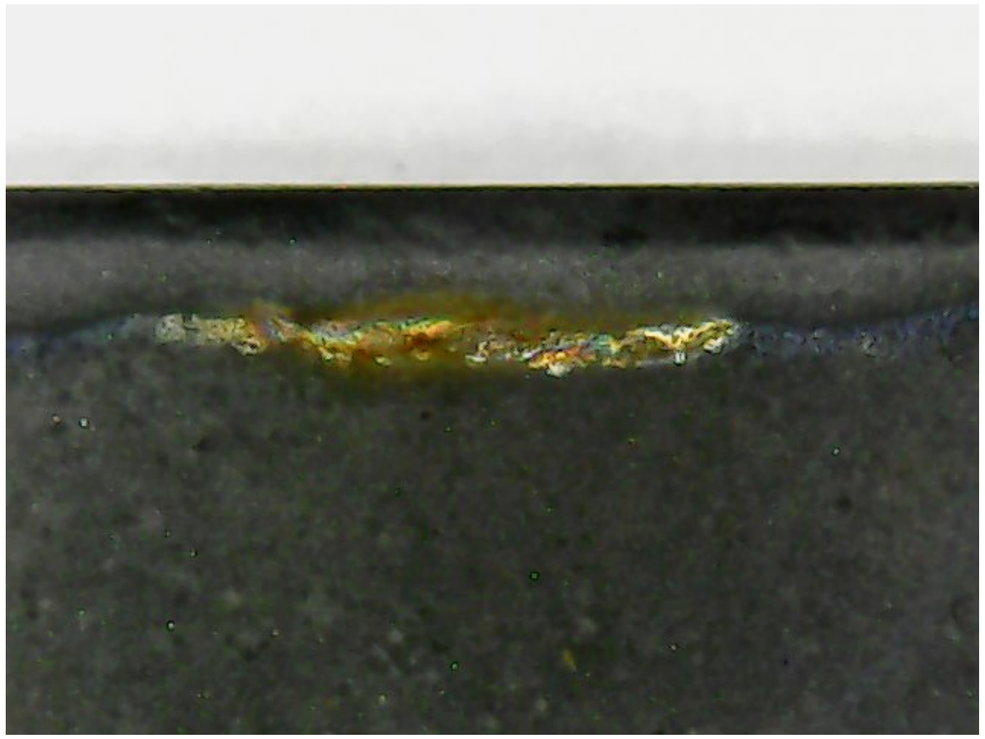
ASTM D1735			Surf. Prep.	Hours of Testing			
Sample	**Material**	**Coating**		**24**	**48**	**72**	**168**
H17	Fluxtrol A	C	Yes	No	No	Yes	Yes
H18	Fluxtrol A	C	No	No	No	Yes	Yes
H19	Fluxtrol 50	C	Yes	No	No	Yes	Yes
H20	Fluxtrol 50	C	No	No	No	Yes	Yes
H21	Fluxtrol 100	C	Yes	No	No	Yes	**Yes**
H22	Fluxtrol 100	C	No	No	No	Yes	Yes
H23	Ferrotron 559H	C	Yes	No	No	No	No
H24	Ferrotron 559H	C	No	No	No	Yes	Yes

Coating A Samples after 168 Hours



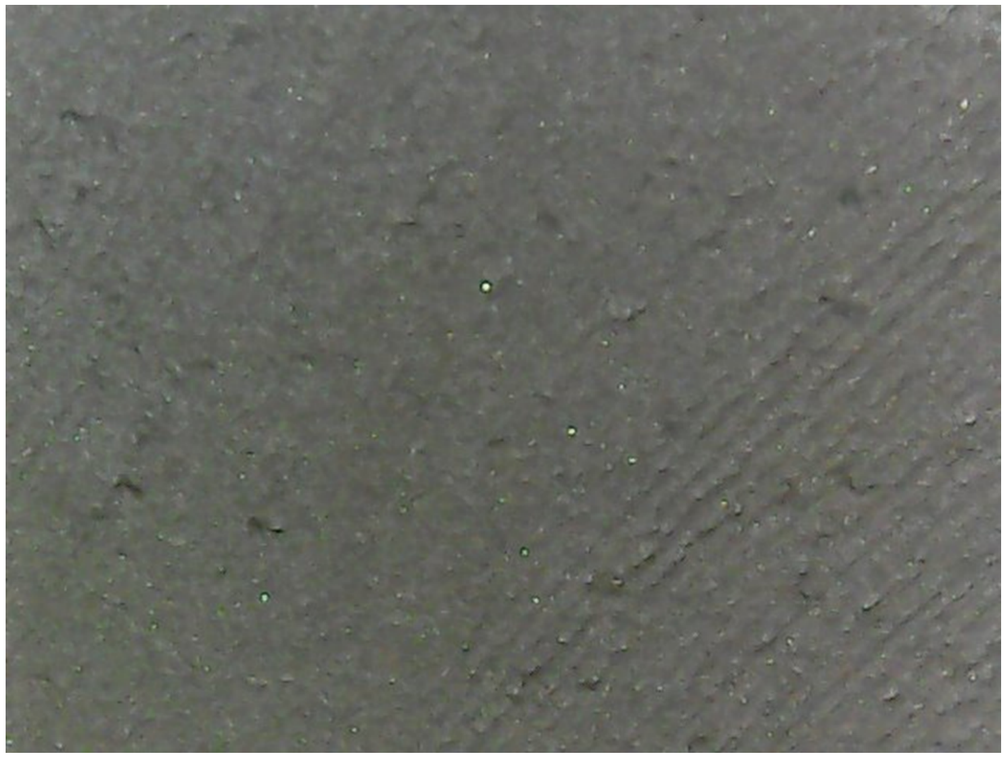
Defect Observed on Fluxtrol 100 Sample with Additional Surface Preparation – Coating A

- Defect observed is near a corner of the sample
- Subsequent coating trials have shown the possibility to eliminate this defect by using a radius instead of a square corner



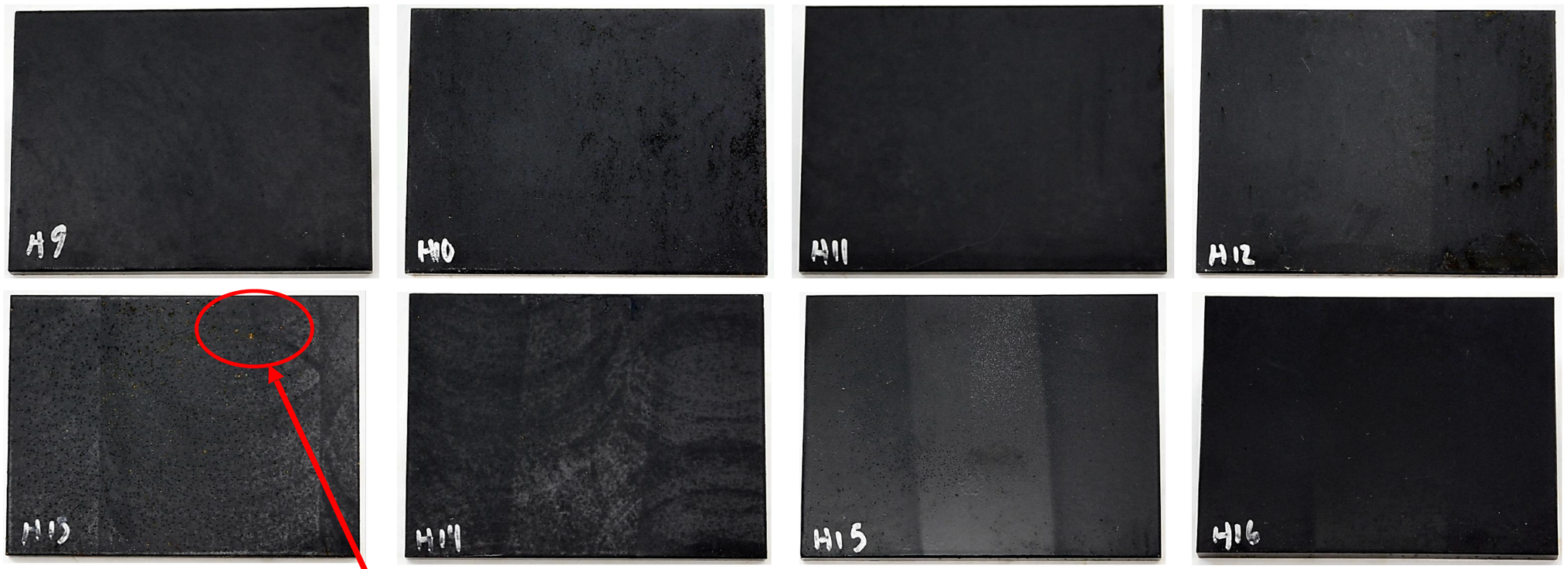
Magnified Fluxtrol 100 Coating A Samples after 168 Hours of Testing in Central Region

Standard



Additional Surface Preparation

Coating A Samples after 168 Hours



Magnified Defect Observed on Fluxtrol 100 Sample with Additional Surface Preparation – Coating B

- Defect observed on the regular surface region
- Multiple pinhole defects appear to be present in the coating

Coating C Samples after 168 Hours

Defects Observed Sample with Coating C

- Multiple defects observed near the sample corners
- Level of corrosion appears to be much more pronounced than on samples with Coating A or B

Conclusions

- Four commercially available SMC were coated with three different ceramic polymer mixture-based materials
- All the materials were tested by ASTM D1735 humidity test for 24, 48, 72 and 168 hours in a chamber that was maintained at 100oC at 100% humidity
- The results showed promise for improving the corrosion resistance of SMC's in induction heat treating applications.
- The best results were obtained by Coating A. No appreciable change was noticed in 7 out of 8 samples. For the eighth sample some corrosion was noticed at the edge of the sample, which can likely be resolved by adding a small radius to the corner.
- The testing did not provide any advantage or disadvantages of use of an additional surface preparation method. Additional surface preparation may prove advantageous in limiting the depth of corrosion, but additional trials are required to determine this.

Future Work

- Study different surface preparation techniques and coating techniques for efficient corrosion prevention
- Field tests of the coatings on heat treatment coils to determine the impact of the coatings on induction coil lifetime
- Study of the influence of various levels of corrosion on the critical properties of the SMC's

Questions

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