Report

Investigation of corrosion on core plugs on behalf of:

[redacted]

[redacted]

Dept. of Metal and Surface Engineering
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[redacted]

02.10.2015

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Danish Technological Institute, Dept. for Metal and Surface Engineering, has agreed to investigate corrosion on four used core plugs [redacted] as well as a new, unused core plug for reference.

- 2 small core plugs from the rear cylinder head (see figures 5 & 6)
- 2 large core plugs from the rear right of the engine block (see figures 3 & 4)
- 1 new, unused core plug for reference (see figures 1 & 2)

Background

[redacted] is experiencing corrosion on core plugs from [redacted]. The corrosion has led to a seeping coolant leakage, both externally and internally in the engine, which in unfortunate circumstances might lead to a total engine failure. The engine block is stated to be made of cast iron. The customer has stated that there is no apparent pattern indicating external influence, or a difference of the corrosion depending on the location of the plugs. Some of the core plugs are fitted internally, in contact with engine oil on the outside. Nonetheless corrosion can be observed on the inside of the plugs (see figure 5 & 6).

Odometer reading on [redacted] is 262,801 km and the number of core plugs used in the engine is 52. The submitted core plugs were taken from [redacted], which is of similar type as [redacted] which showed an identical damage pattern in February.

Chemical analysis has been performed on the antifreeze used with the corroded core plugs as well as a reference sample of new, unused Texaco Havoline XLC antifreeze (see DTI analysis report no. [redacted]). The analysis showed that the content of the two samples in question are comparable and consistent with the expected content according to the product leaflet.

Procedure

The four core plugs were examined and evaluated using:

- Visual inspection (Stereo Microscopy)
- Material/coating analysis (Energy Dispersive X-ray, EDX)

Results

Visual inspection

The four examined core plugs show clear signs of corrosion. The corrosion is observed in a limited area along the outer edge of the core plugs in the gap between the core plugs and the cast iron engine block. The corrosion type appears to be pitting corrosion with clear origin from the inside of the core plug (coolant side). See Annex 1.

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After cleaning of a used core plug, a yellowish surface corresponding to that of the new, unused reference core plug can be observed on part of the outer surface. Large grooves with material loss and in some places corrosion perforation can also be observed (see Annex 1).

Material/coating analysis
The cross section of a used core plug clearly shows a coating (see Annex 2). The chemical composition of the surface is mainly a copper-zinc coating. The chemical composition of the base material is mainly iron and carbon.
The cross section of the new, unused reference core plug clearly shows a surface coating (see Annex 3). The chemical composition of the surface is mainly a chrome-zinc coating. The chemical composition of the base material is mainly iron and carbon.

Comments
Material/coating analysis on the used core plug showed mainly iron and carbon, which means that the tested used core plug is probably made from normal mild steel. Furthermore, a thin corrosion protective coating consisting of copper and zinc of approximately 10 µm was also observed.

Material/coating analysis on the new, unused reference core plug showed primarily iron and carbon, which means that the new and unused reference core plug is probably also made from normal mild steel. Furthermore, a thin corrosion protective coating consisting of chrome and zinc of approximately 10 µm was also observed.

The two tested coatings are not of the same type and therefore not readily comparable. Both coatings have a limited protective effect and the coatings are therefore only suitable in non-aggressive environments. However, the coatings can be applied in controlled environments.

The visual inspection of the used core plugs showed clear signs of corrosion along the outer edge of the core plug in the joint between the plug and the cast iron block. Due to the shape of the plug (rounded edges), a narrow gap between the plug and the cast iron block will be formed where particles or impurities can build up because of poor circulation. After cleaning of a core plug large grooves and material loss is observed on the inside of the core plug, indicating that the attack started on the coolant side.

The chemical analysis of the used and the new antifreeze shows that the two fluids are comparable and in accordance with the product leaflet. The chemical analysis therefore does not explain the corrosion attacks on the core plugs. However, the age of the coolant is unknown and it is also unknown whether the coolant has been changed on [redacted] during its 262,801 km of operation.

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Conclusion
The used core plugs are made of plain mild steel with a copper-zinc coating. The new, unused reference core plug is also made from plain mild steel, but with a chrome-zinc coating. This means that the two surfaces are not comparable.

The corrosion is estimated to have started on the inside (coolant side) in the narrow gap between the core plug and the cast iron block.

The chemical analysis of new and used antifreeze with reference to the observed damages does not explain the corrosion on the used core plugs.

In the light of the above observations, the following damage scenarios are considered as probable:

- Air pockets in the cooling system, areas where the core plugs are not protected by the protective properties of the antifreeze.
- Covering corrosion, possible particles and impurities covering areas with poor circulation/fluid motion (the narrow gap between core plug and cast iron engine block).
- Substandard antifreeze used in the engine during previous service intervals.

Further evaluation of the cause of damage will require a review of the engine's maintenance protocol, investigation of the pH values in the engine cf. the manufacturer’s recommendations, compared with the observed damage.

Aarhus, October 2, 2015
[redacted]

[redacted]

2015.10.02

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Annex 1.1

Visual inspection

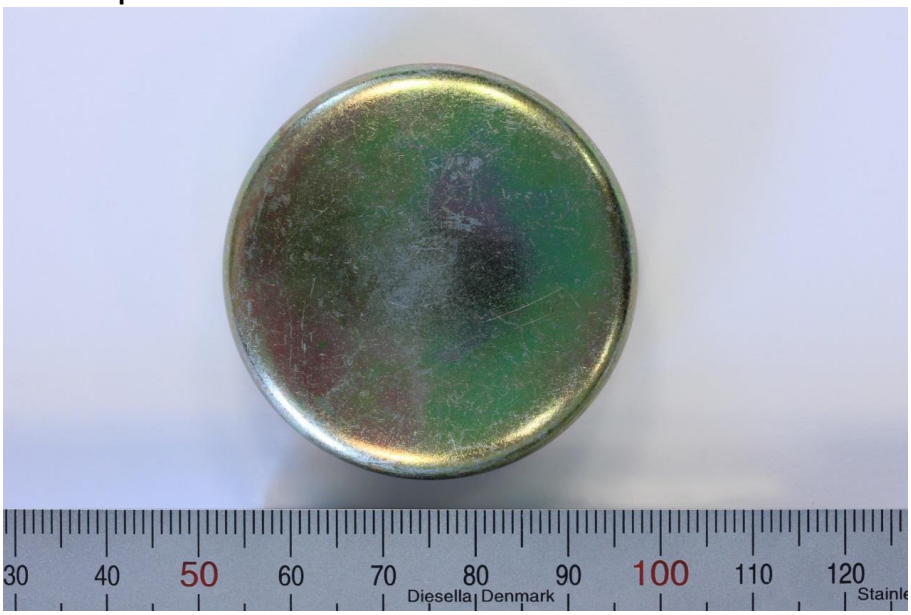

Figure 1: Inside, new unused core plug for reference.

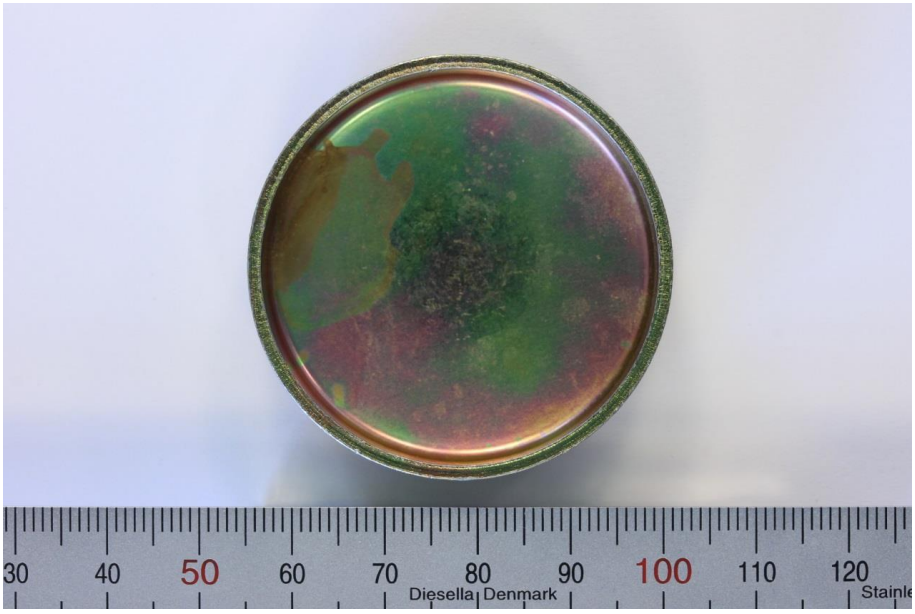

Figure 2: Outside, new unused core plug for reference.

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Annex 1.2

Visual inspection

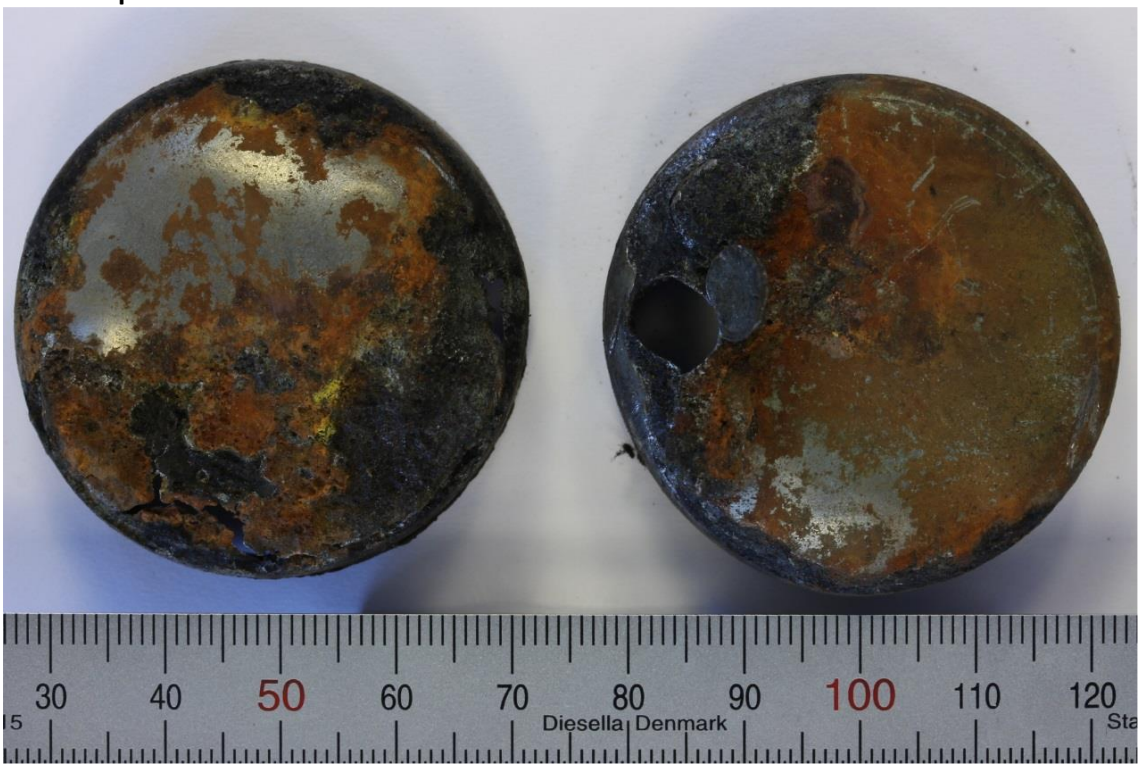

Figure 3: Inside - 2 large core plugs from r/h side of rear engine block.

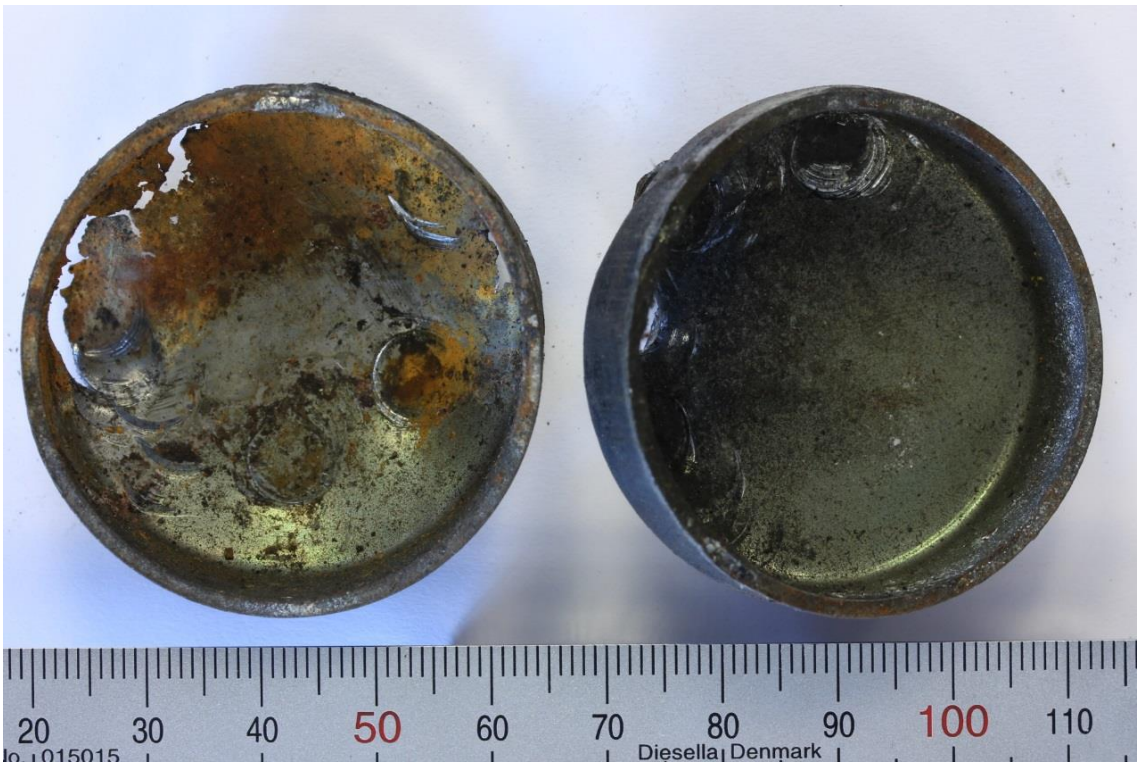

Figure 4: Outside, 2 large core plugs r/h side of rear engine block.

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Annex 1.3

Visual inspection

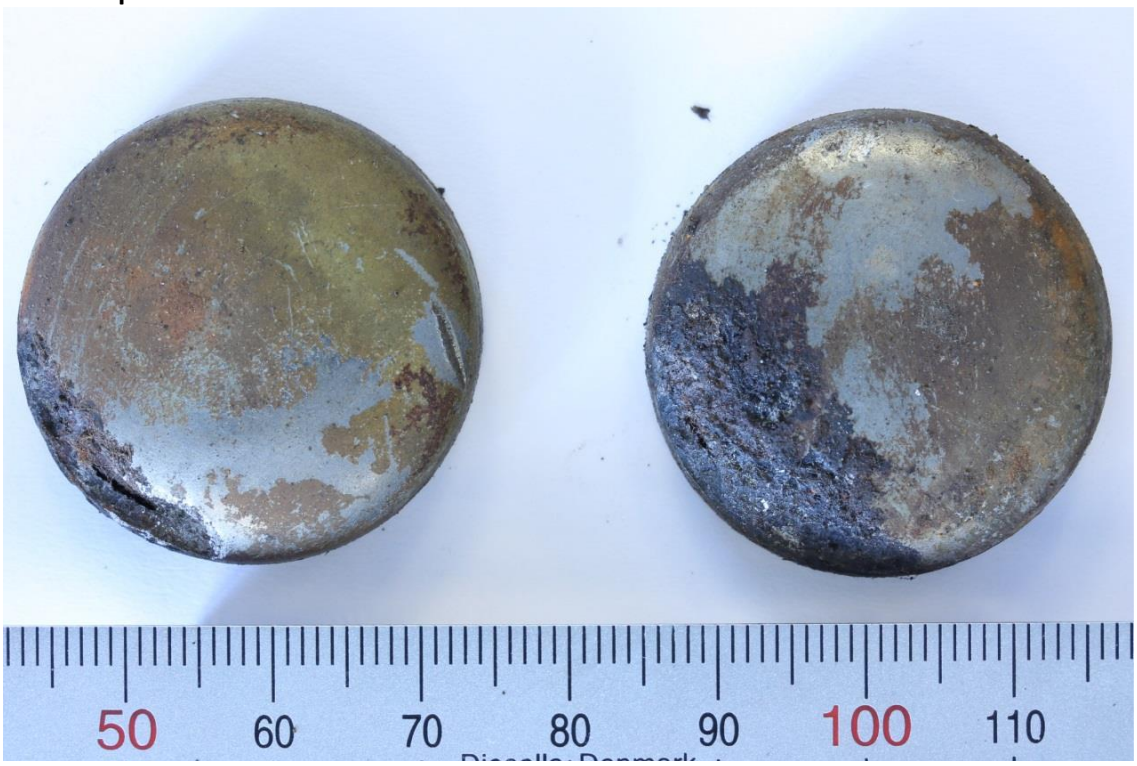

Figure 5: Inside - 2 small core plugs from rear cylinder head.

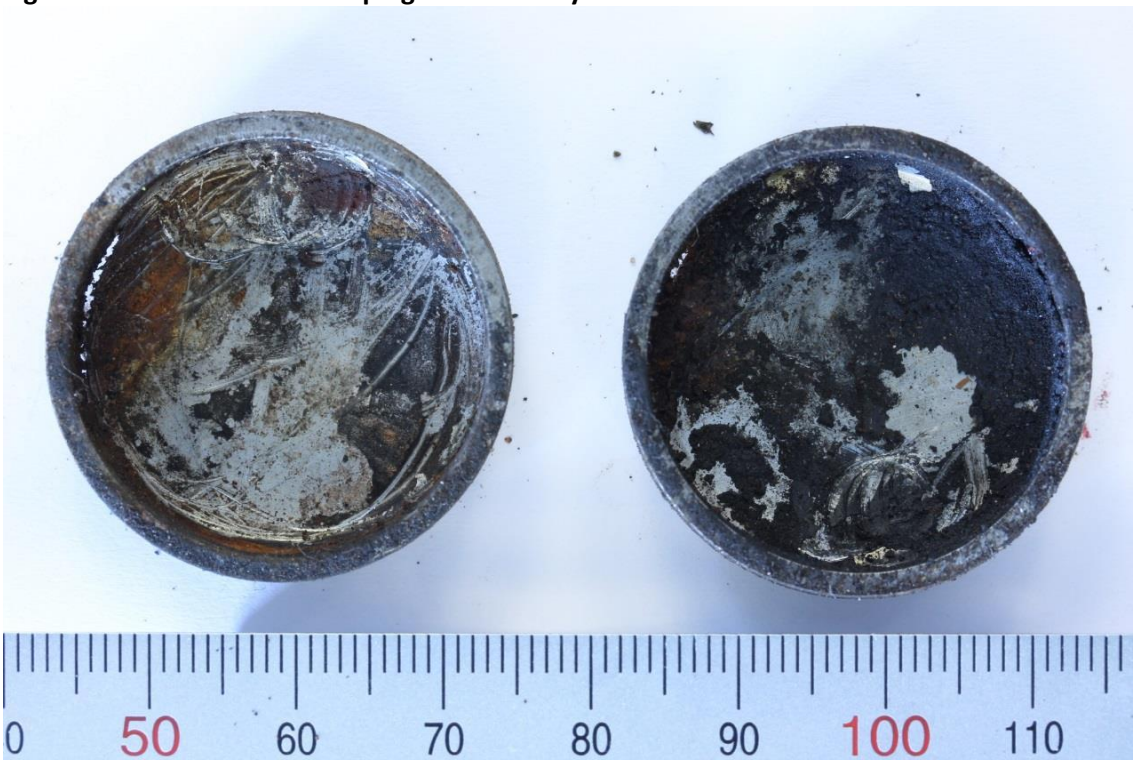

Figure 6: Outside, 2 small core plugs from rear cylinder head.

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Annex 1.4

Visual inspection

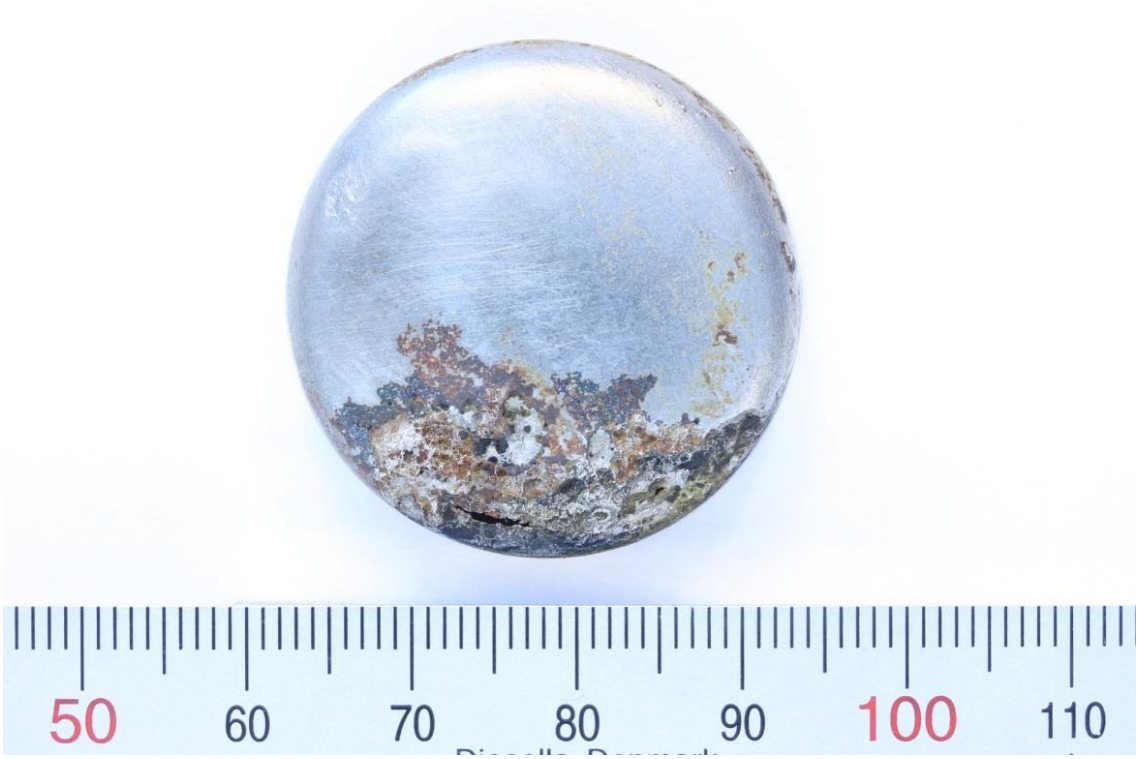

Figure 7: Inside - 1 small core plug from rear cylinder head after cleaning with acetone and ultrasound.

Figure 8: Outside, 1 little core plug from rear cylinder head after cleaning with acetone and ultrasound.

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Annex 2.1

Material/coating analysis (EDX) – used core plug

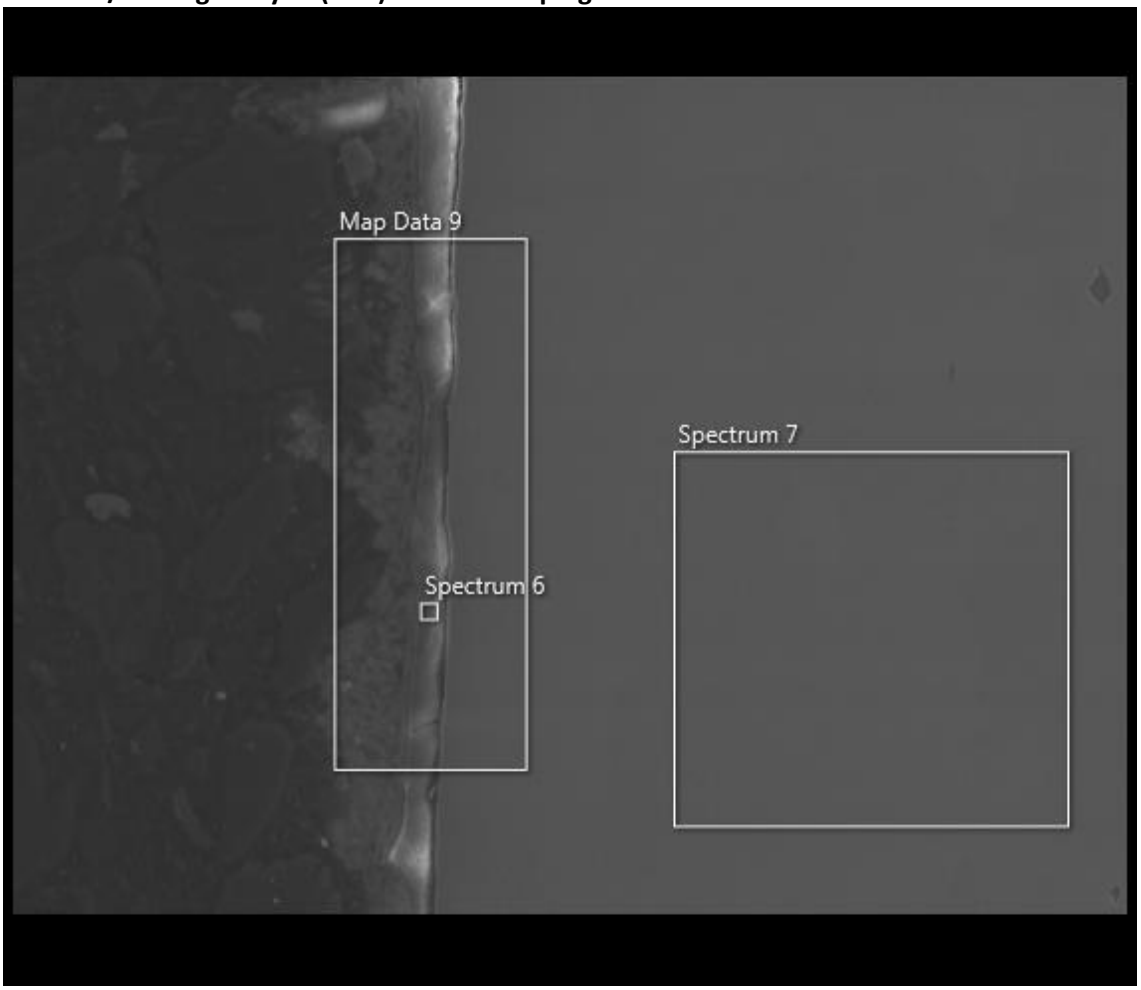

Figure 9: Cross section of used core plug magnified 4,000x.

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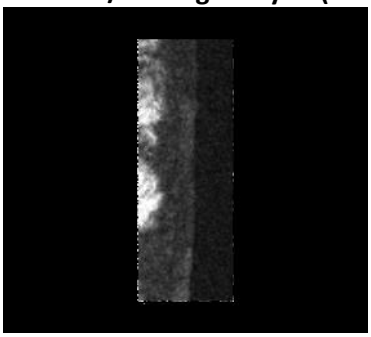
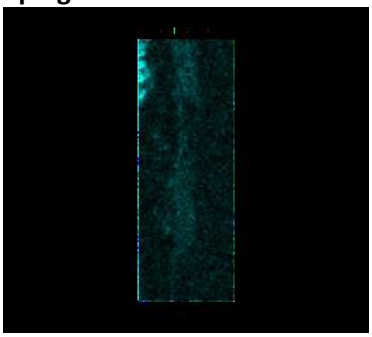
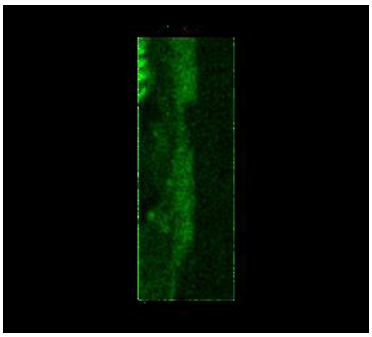
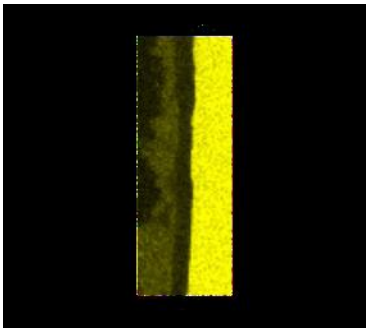
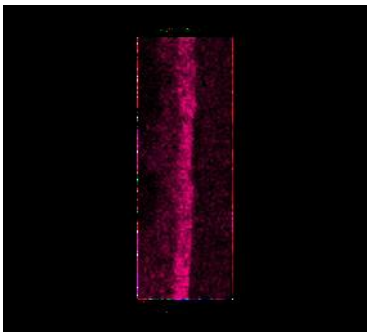
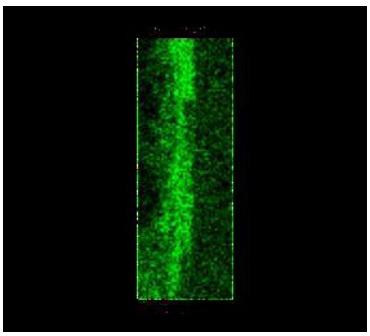
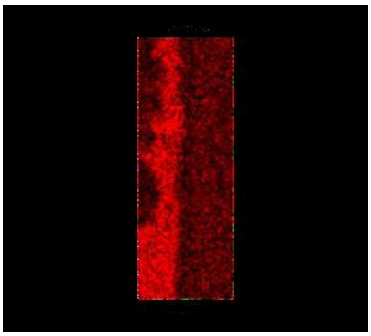
Annex 2.2

Material/coating analysis (EDX) – used core plug

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Annex 2.3

Material/coating analysis (EDX) – used core plug

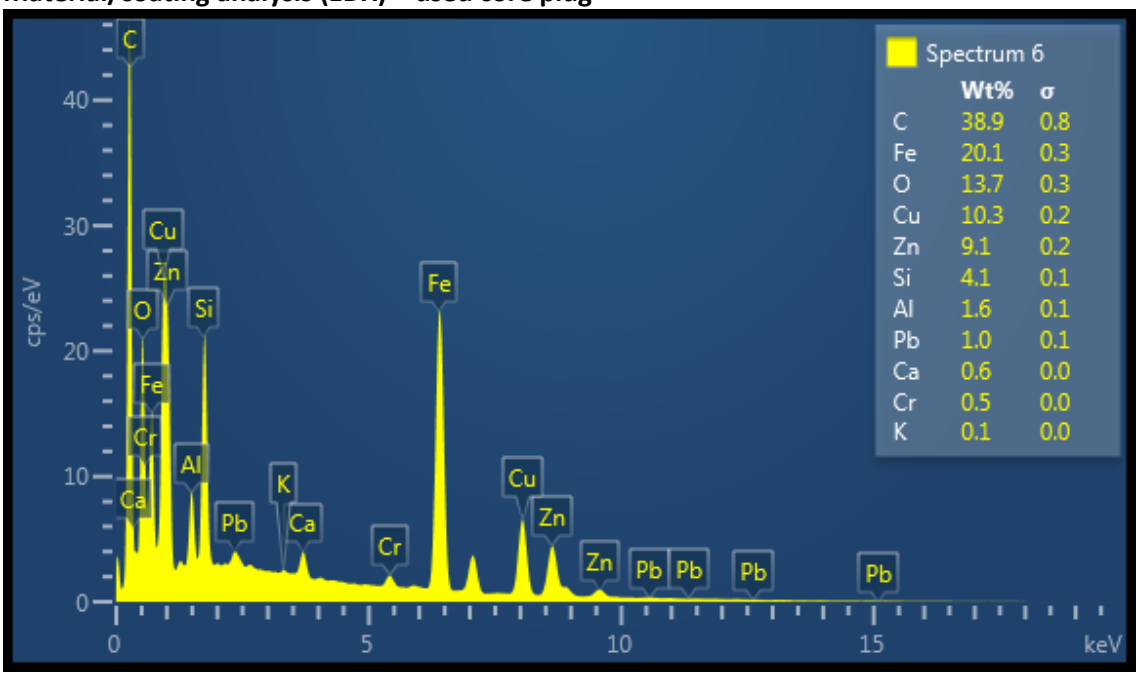

Figure 10: Spectrum of coating on used core plug.

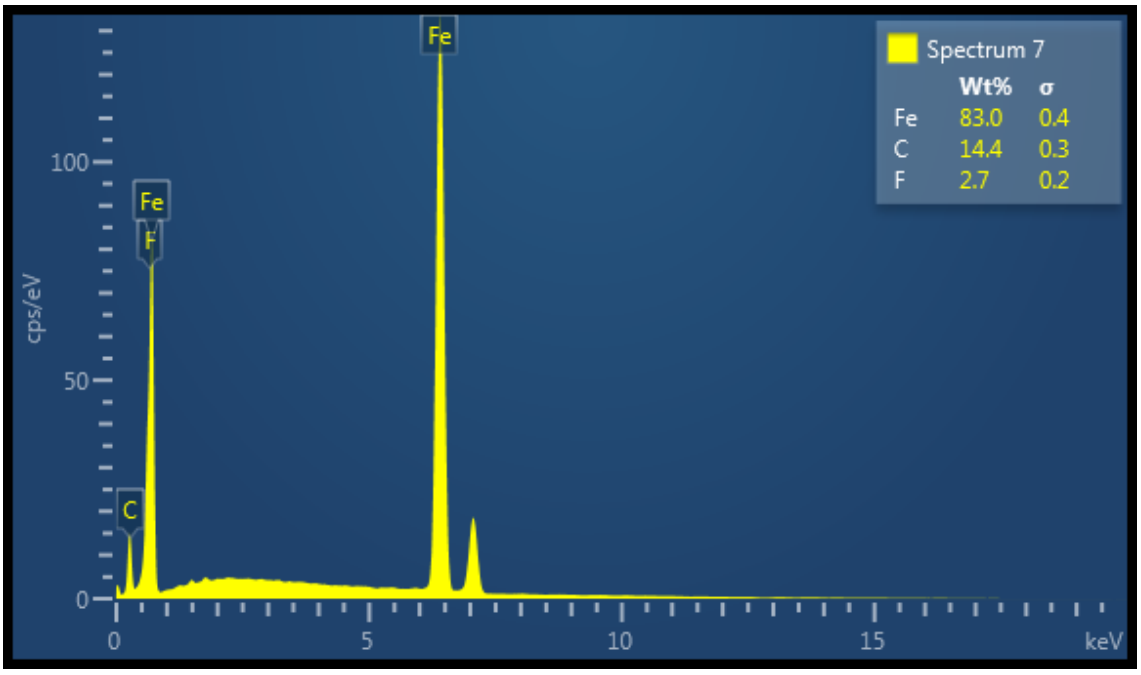

Figure 11: Spectrum of base material for used core plug

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Annex 3.1

Material/coating analysis (EDX) – new, unused core plug for reference.

Figure 12: Cross section of new, unused core plug magnified 4,000x.

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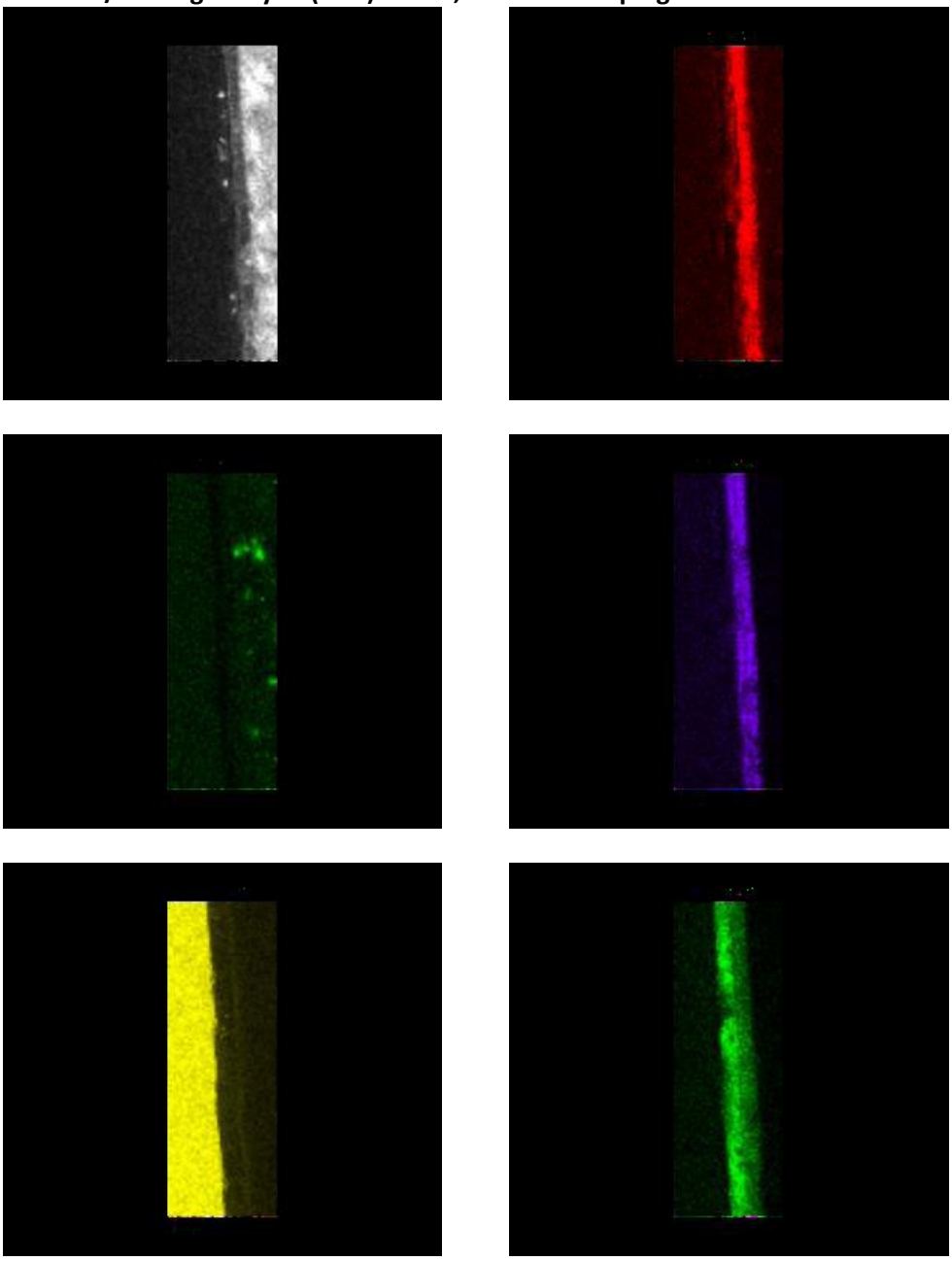
Annex 3.2

Material/coating analysis (EDX) – new, unused core plug for reference.



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Annex 3.3

Material/coating analysis (EDX) – new, unused core plug for reference.

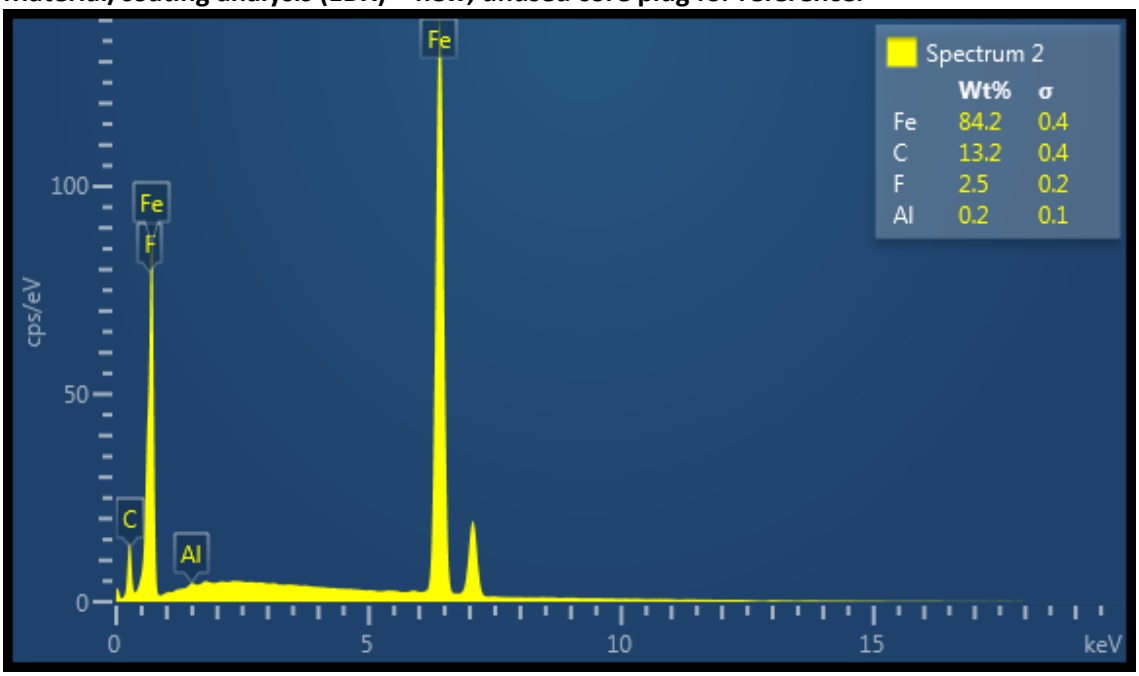

Figure 13: Spectrum of base material for new, unused core plug.

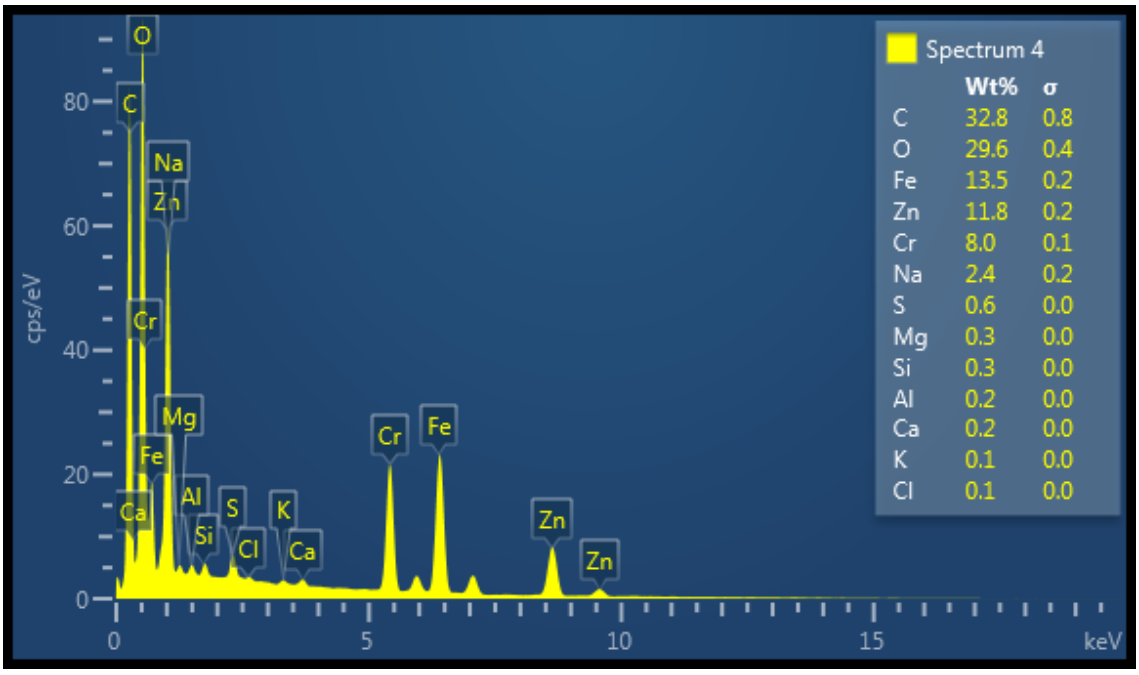

Figure 14: Spectrum of coating on new, unused core plug for reference.