In-depth characterisation of low temperature high voltage axial insulator breaks for the ITER cryogenic supply line

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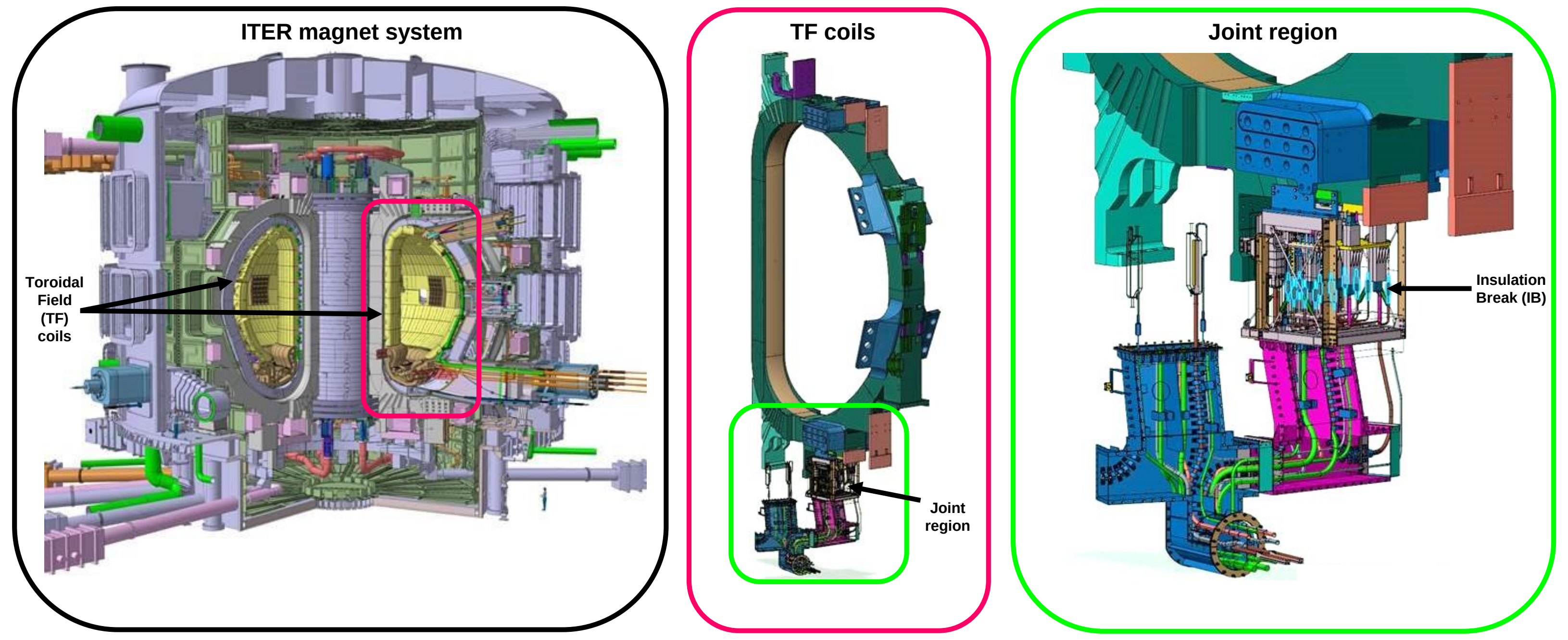
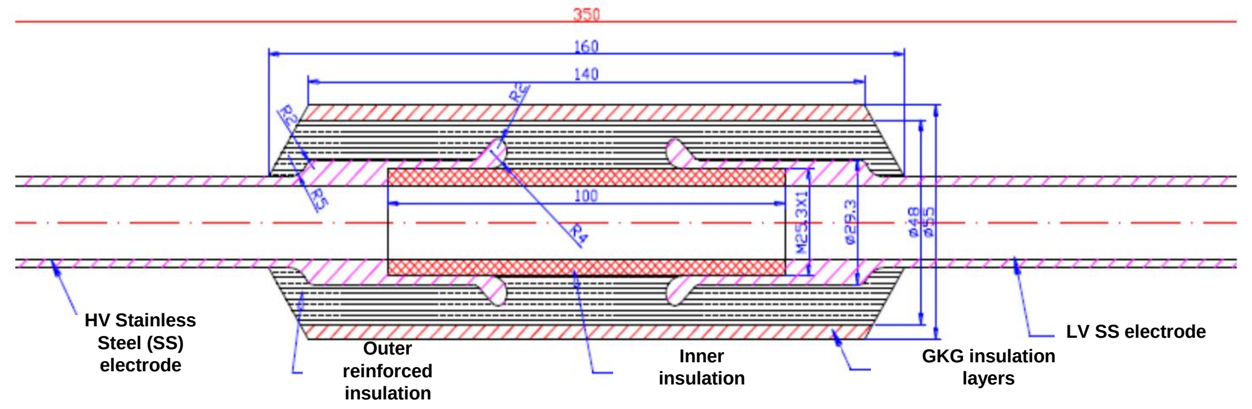
Abstract: Cable-in-conduit conductors of the ITER magnet system are directly cooled by supercritical helium. Insulation breaks are required in the liquid helium feed pipes to isolate the high voltage system of the magnet windings from the electrically grounded helium coolant supply line. They are submitted to high voltages and significant internal helium pressure and will experience mechanical forces resulting from differential thermal contraction and electro-mechanical loads. Insulation breaks consist essentially of stainless steel tubes overwrapped by an outer glass – fibre reinforced composite and bonded to an inner composite tube at each end of the stainless steel fittings. For some types of insulator breaks Glass – Kapton – Glass insulation layers are interleaved in the outer composite. Following an extensive mechanical testing campaign at cryogenic temperature combined with leak tightness tests, the present paper investigates through non-destructive and destructive techniques the physical and microstructural characteristics of the low temperature high voltage insulation breaks and of their individual components, thus allowing to correlate the structure and properties of the constituents to their overall performance.

INTRODUCTION



⇑ **IBs will be placed at the helium supply (inlets) and return points (outlets) of the different cryogenic circuits foreseen in the ITER magnet system. Depending on the operating environment of these cryogenic circuits, the IBs will withstand different potentials and temperatures. A High-Voltage Low-Temperature (HVLT) IB will operate at 4.5 K and could experience a voltage difference of up to 28 kV in case of failure**



⇐ **Schematic drawing of a High-Voltage Low-Temperature (HVLT) IB (dimensions in mm)**

S. Langeslag, E. Rodriguez Castro, I. Aviles Santillana, S. Sgobba and A. Foussat, "Design of load-to-failure tests of high-voltage insulation breaks for ITER's cryogenic network", IOP Conf. Series: Materials Science and Engineering, 102 no.1, 012009, 2015

OBJECTIVE

The **aim** of the investigation is the material assessment of two individuals HVLT IBs for cryogenic use (IBDH109 and IBDH251), which already passed successfully prior qualification tests (mechanical, leak and high voltage tests).

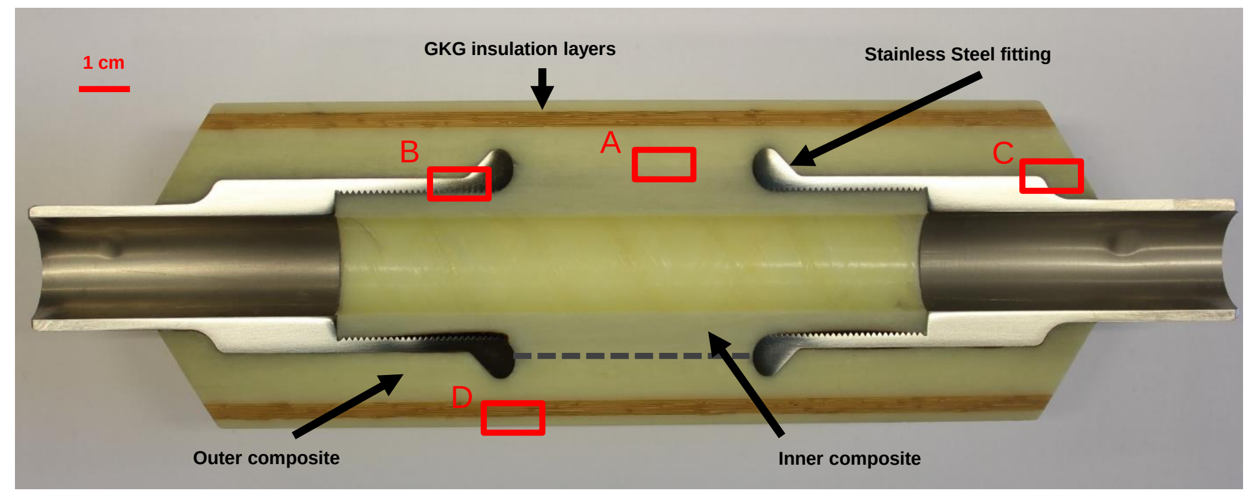
Examinations include:

1. Assessment of imperfections by:
   1.1. **inspections in axial plane** by microoptical examination
   1.2. **Penetrant Testing (PT)** according to ASTM E1417
   1.3. **inspection in radial plane** by visual examination
2. Measurement of the **density** of inner and outer insulation composites according to ASTM D792
3. Assessment of the **void fraction, fibre fraction and resin fraction** of both insulation composites according to ASTM D2584
4. Measurement of the **fibre orientation** by microoptical examination
5. Assessment of the **glass transition temperature (T_g)** of the resins according to IEC 61006 via Differential Scanning Calorimetry (DSC)

RESULTS

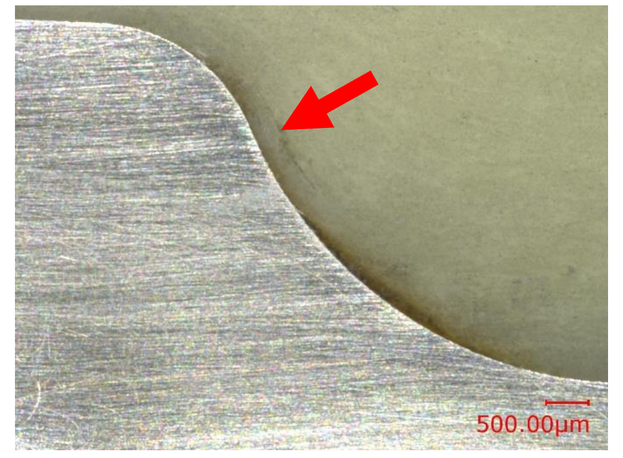
1. Assessment of imperfections

1.1. Inspection in axial plane

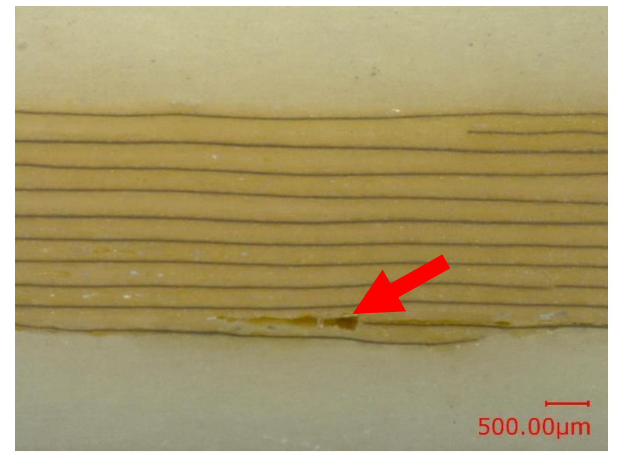


⇑ **Longitudinal cut of the IBDH251, showing the fields of views used for identifying specific features and their location**

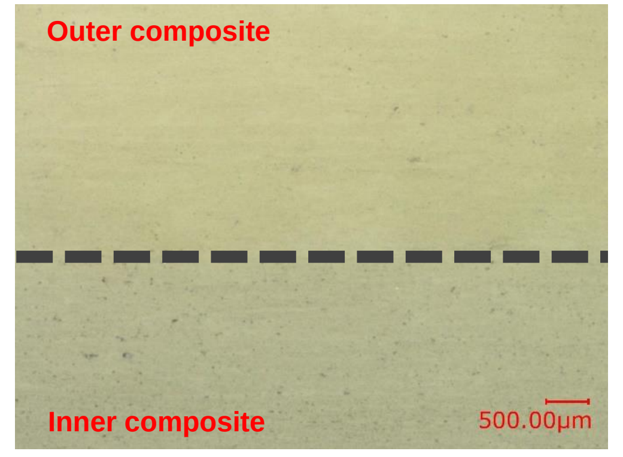
Field C: Crack around the SS fitting



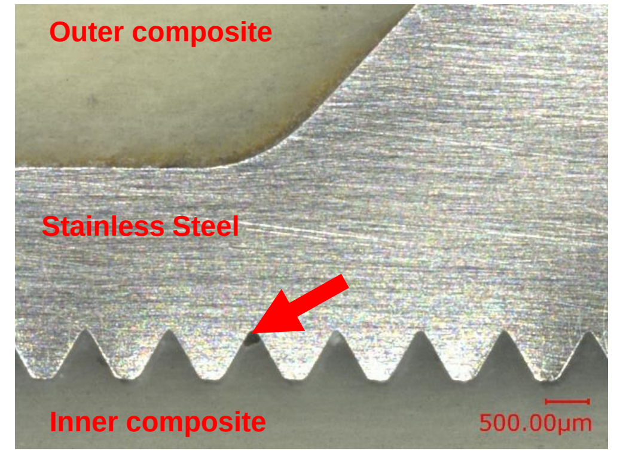
Field D: Void in the GKG insulation layers



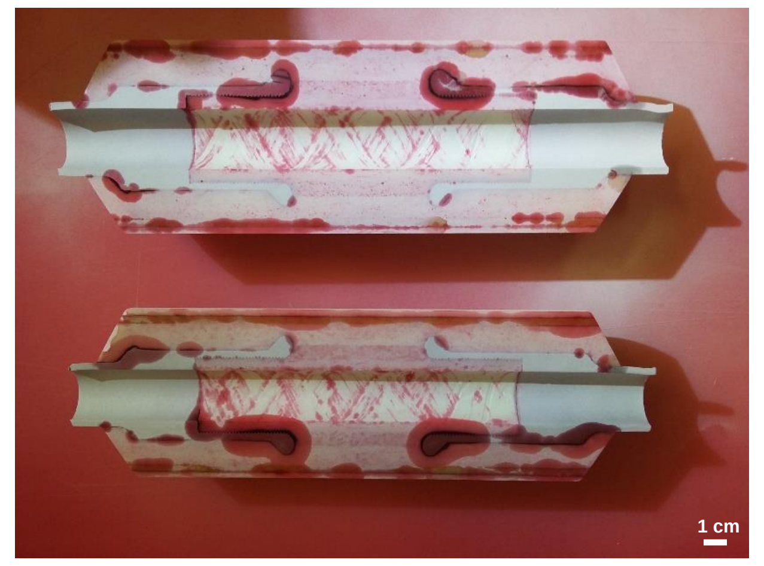
Field A: Good continuity between composites



Field B: Void around the SS fitting

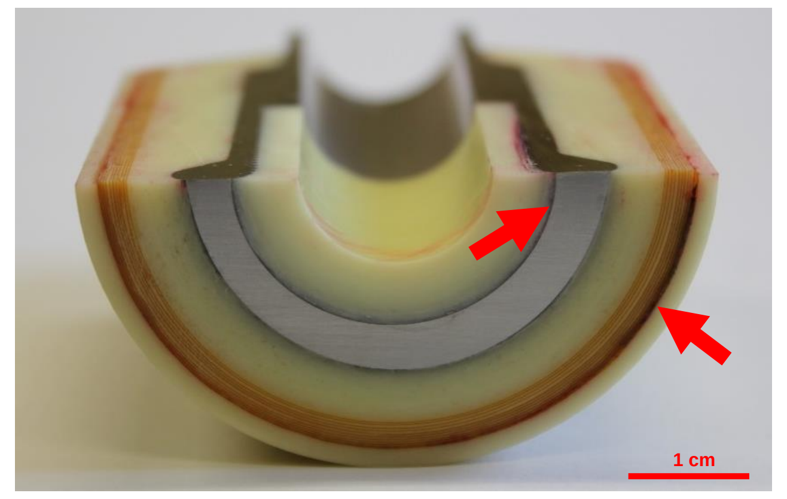


1.2. Penetrant testing (PT)



⇐ **Pronounced indications observed after PT for IBDH109. They are mainly located at the SS to composite interfaces, and in the GKG insulation layers**

1.3. Inspection in radial plane



⇐ **Indications for IBDH251. They were already identified by PT on the axial cut, located in the stainless steel to composite interface and in the last layer of the GKG insulation layers, respectively**

2. Density

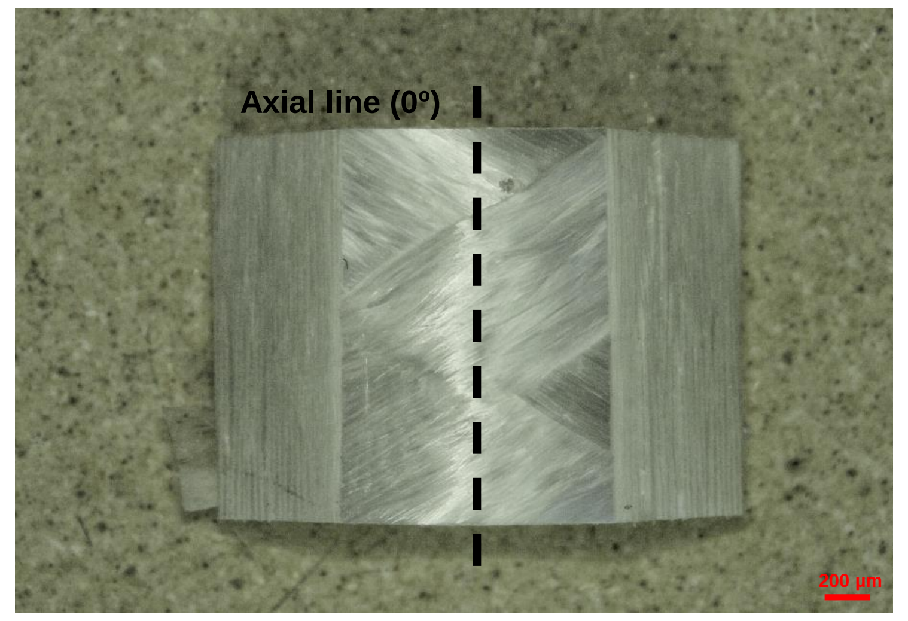
	IBDH109	IBDH251
Inner composite	1.88 g/cm³ ± 0.01 g/cm³	1.91 g/cm³ ± 0.00 g/cm³
Outer composite	1.86 g/cm³ ± 0.01 g/cm³	1.84 g/cm³± 0.02 g/cm³

3. Void, fibre and resin fraction

	IBDH109			IBDH251		
	Vol. Fibre	Vol. Resin	Vol. Void	Vol. Fibre	Vol. Resin	Vol. Void
Inner composite	48.6 % ± 0.1 %	49.7 % ± 0.4 %	1.7 % ± 0.1 %	50.6 % ± 0.1 %	47.5 % ± 0.2 %	1.9 % ± 0.1 %
Outer composite	46.9 % ± 0.1 %	51.3 % ± 0.1 %	1.8 % ± 0.0 %	45.6 % ± 1.5 %	52.2 % ± 1.5 %	2.2 % ± 0.0 %

4. Fibre orientation

	IBDH109	IBDH251
Inner composite	± 60.6° ± 3.3°	± 60.8° ± 2.2°
Outer composite	± 70.4° ± 3.1 °	± 73.5° ± 4.4°



⇐ **Braid pattern of the inner composite of IBDH109 after firing**

5. Glass transition temperature (T_g)

	IBDH109			IBDH251		
	T_{g1}	T_{g2}	T_{g3}	T_{g1}	T_{g2}	T_{g3}
Inner composite	124 °C	131 °C	n.a.	122 °C	134 °C	n.a.
Outer composite	114 °C	129 °C	130 °C	122 °C	135 °C	n.a.

DISCUSSION

1. **Assessment of imperfections:** Imperfections are observed in the axial and radial planes of the IBs and confirmed by PT. However, they are not forming a continuous network along the interfaces, and therefore they do not impair the strength and the leak tightness of the assembly.

2. **Density:** The repeatability is high, and similar densities are obtained for both IBs, meaning that a stable process was achieved during the fabrication leading to homogeneous and dense composites.

3. **Void, fibre and resin fraction:** Consistent and reproducible results within the range of the strict acceptance criteria defined for a safe operation of the IBs are obtained.

4. **Fibre orientation:** The braid angles, measured with respect to the main axis, resulted in similar values for each composite of both IBs confirming repeatability and robustness of fabrication.

5. **Glass transition temperature (T_g):** An incomplete polymerisation of all studied composites is evident for the first heat cycle. However, since both IBs successfully passed the test included in the validation protocol, the impact of incomplete polymerisation on overall performance can be considered negligible.

CONCLUSIONS

To the extent of the investigations performed, the results are within the range of the strict acceptance criteria defined for a safe operation of the IBs, therefore a reliable overall performance of the analysed HVLT IBs is expected based on the outcome of our investigations.

Acknowledgments: The cryogenic cycling, mechanical and electrical measurements and leak tightness tests were carried out by the Magnet Infrastructure Facilities for ITER (MIFI) under the supervision of ITER Organisation. T_g was measured by A. Rivière at the chemistry laboratory of CERN (TE/VSC/SCC), PT was performed by A.M. Piguiet of the Materials and Metrology section of CERN (EN/MME/MM).

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Presented by S. Sgobba
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