

Breakdown and Partial Discharge Characteristics of Transformer Board and Insulating Paper Materials in Liquid Nitrogen

Technology
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M. Garzem, M. Grunwald, R. Schnorrenberg, R. Schumacher, C. Humpert

Introduction

Typical insulating materials used in superconducting devices have excellent performance at cryogenic temperatures but at **high costs**:

- Fiber reinforced plastic (FRP)
- Polyimide (PI) and polytetrafluoroethylene (PTFE)
- Polypropylene laminated paper (PPLP)

Possible alternative **cost-saving** materials:

- Transformer boards (cellulose) impregnated with LN₂
- Insulating papers (cellulose, cotton) impregnated with LN₂

Investigated sheet materials:

Name	Material	Thickness d (μm)	Density (g/cm ³)	Dielectric strength E_{BD} (kV/mm)
<i>Transformer board materials</i>				
TI	cellulose, calendered	500, 800	1.2	56 ^a
TIII	cellulose, shapeable	500, 800	0.9	46 ^a
TD12	lower purity cellulose, calendered	500, 800	1.15	51 ^a
<i>Insulating paper materials</i>				
Grade 3	cotton (50 %), cellulose (50 %)	130	1.0	75 ^a / 75 ^e
Grade 4	cotton	130	1.1	75 ^a / 83 ^e
Grade K	cellulose	130	1.1	70 ^a / 78 ^e
PPLP	PP (50 %), cellulose (50 %)	125	0.91	110 ^b / 108 ^e
<i>Synthetic insulating sheets</i>				
PI	Kapton® HN	125	1.42	154 ^c
PTFE	Teflon® FEP	125	2.15	70–260 ^d

^a data sheet values, impregnated with mineral oil, at 23 °C

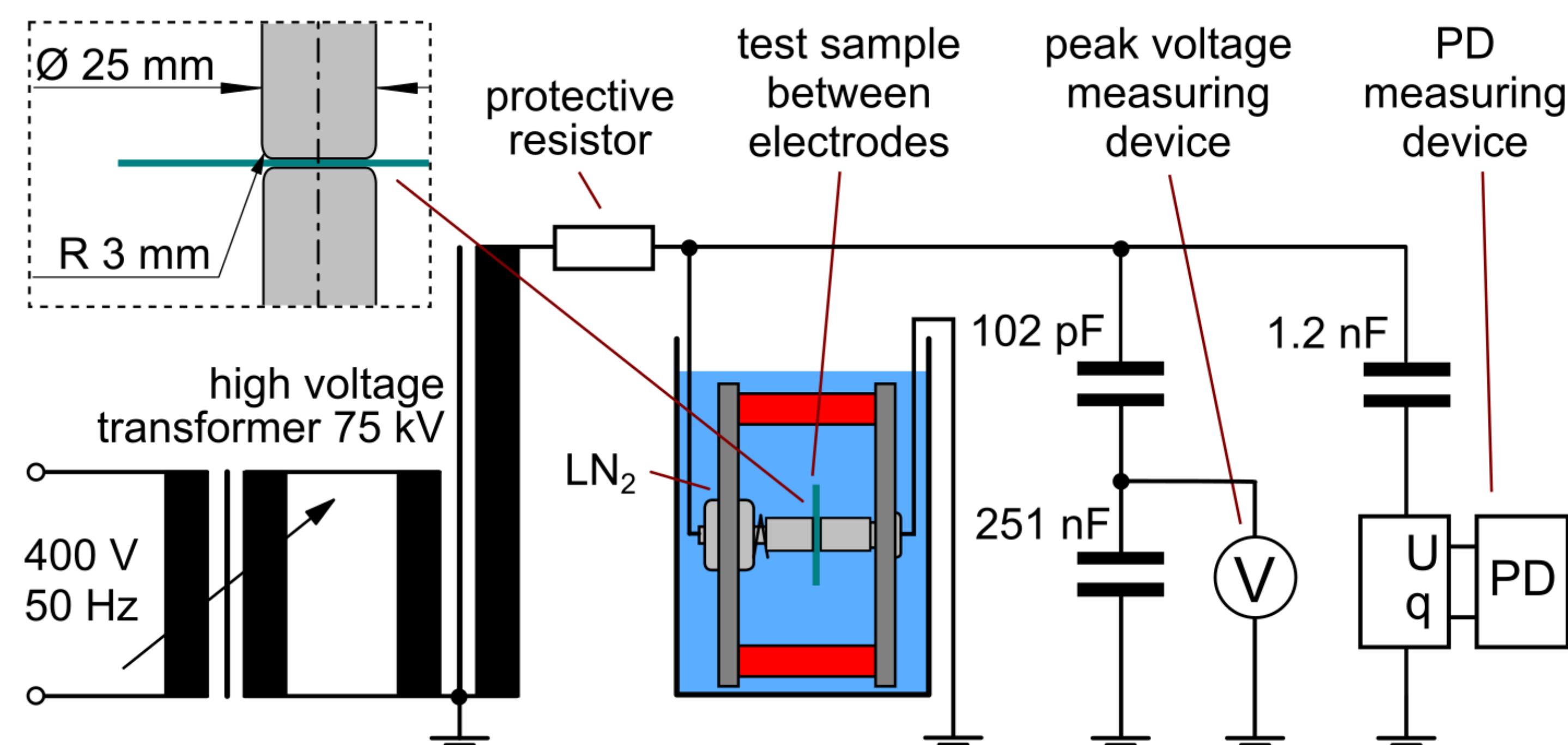
^b data sheet value, impregnated with the synthetic oil dodecylbenzene (DDB), at 90 °C

^c data sheet value, in air, at 23 °C

^d data sheet value, 70 kV/mm for 25 μm film, 260 kV/mm for 500 μm film, in air, at 23 °C

^e own measurement, impregnated with Shell Diala S2 ZU-I, at 23 °C

Experimental Setup



Drying and impregnation process

- Undried specimen stored at 30 %rh, 24 °C, > one week
- Drying of paper materials at 115 °C, < 0.75 mbar, > 16 h
- Impregnation in LN₂ at normal pressure directly after drying

Measurement of AC breakdown (BD) voltage V_{BD}

- Slew rate of applied voltage: 0.5 kV/s to 1.0 kV/s
→ BDs occur between 10 s and 20 s after start of the test.
- Calculation of dielectric strength using thickness d : $E_{BD} = V_{BD} / d$

Measurement of AC inception V_{inc} and extinction voltage V_{ext} of partial discharges (PDs)

- Slew rate of applied voltage: 200 V/s
- Criterion: apparent charge over / under 5 pC for 60 s

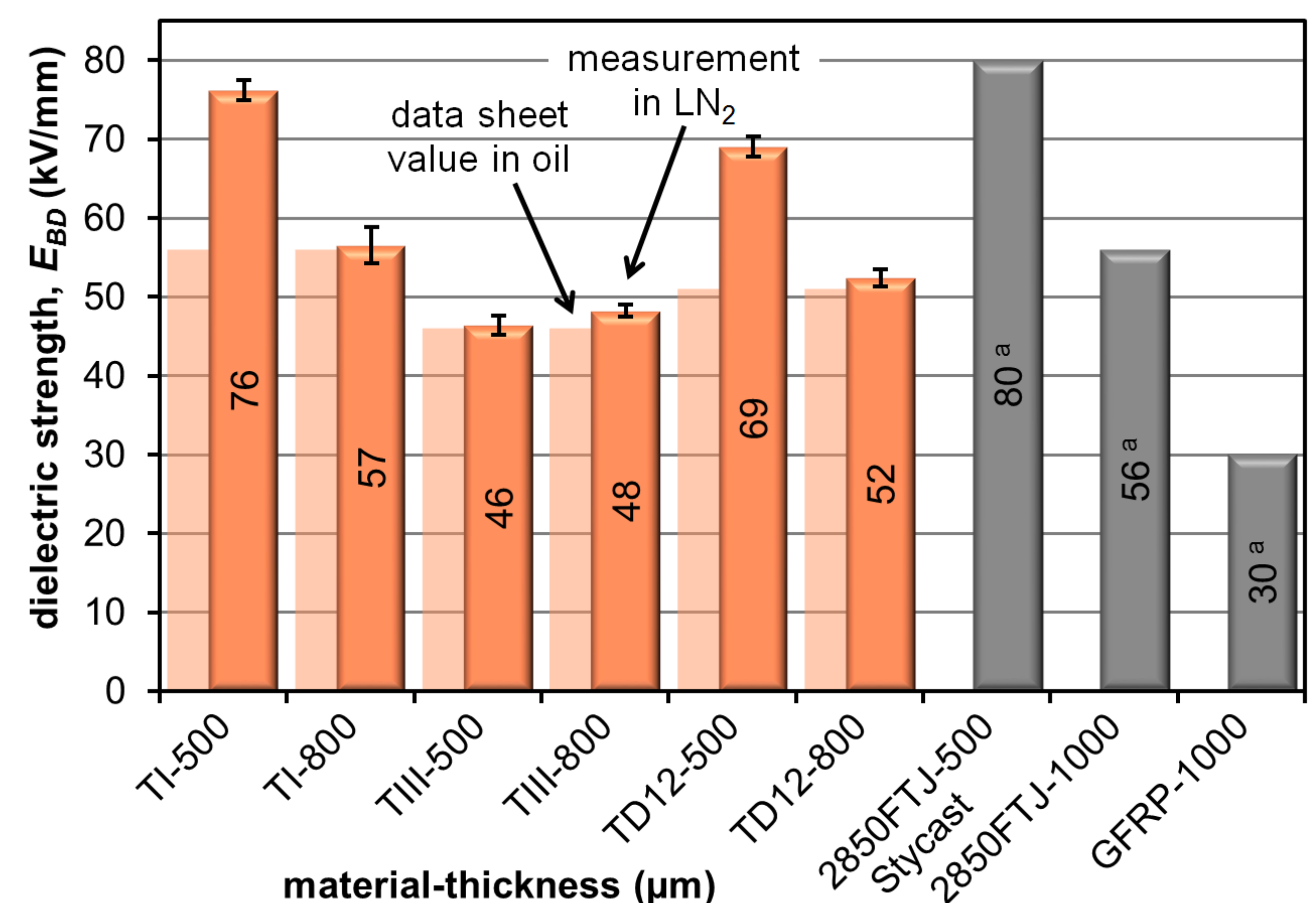
General

- 10 samples (100 mm × 100 mm) of each material type
- Calculation of arithmetic mean and standard deviation
- All results given as peak value divided by square root of two

Acknowledgment

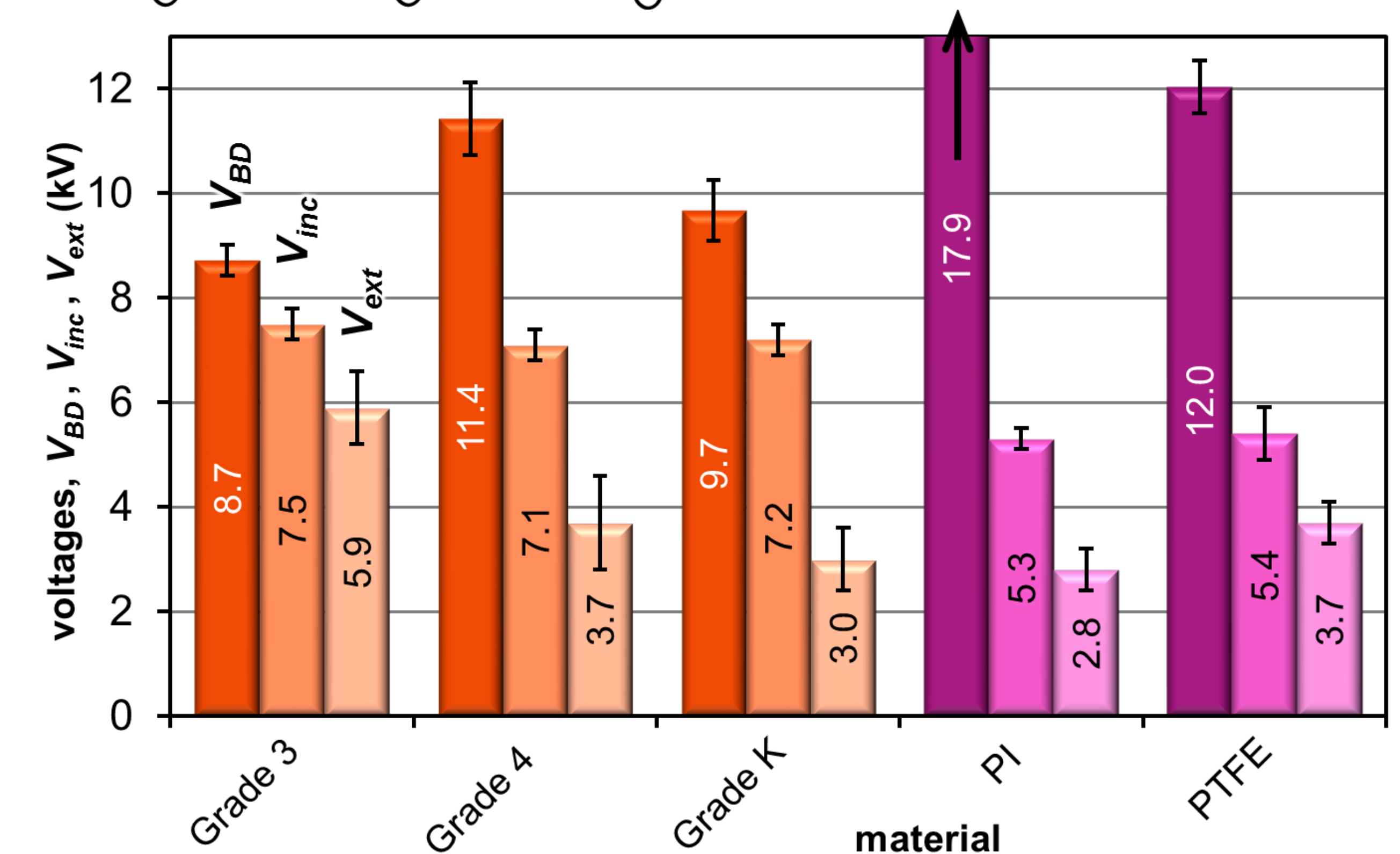
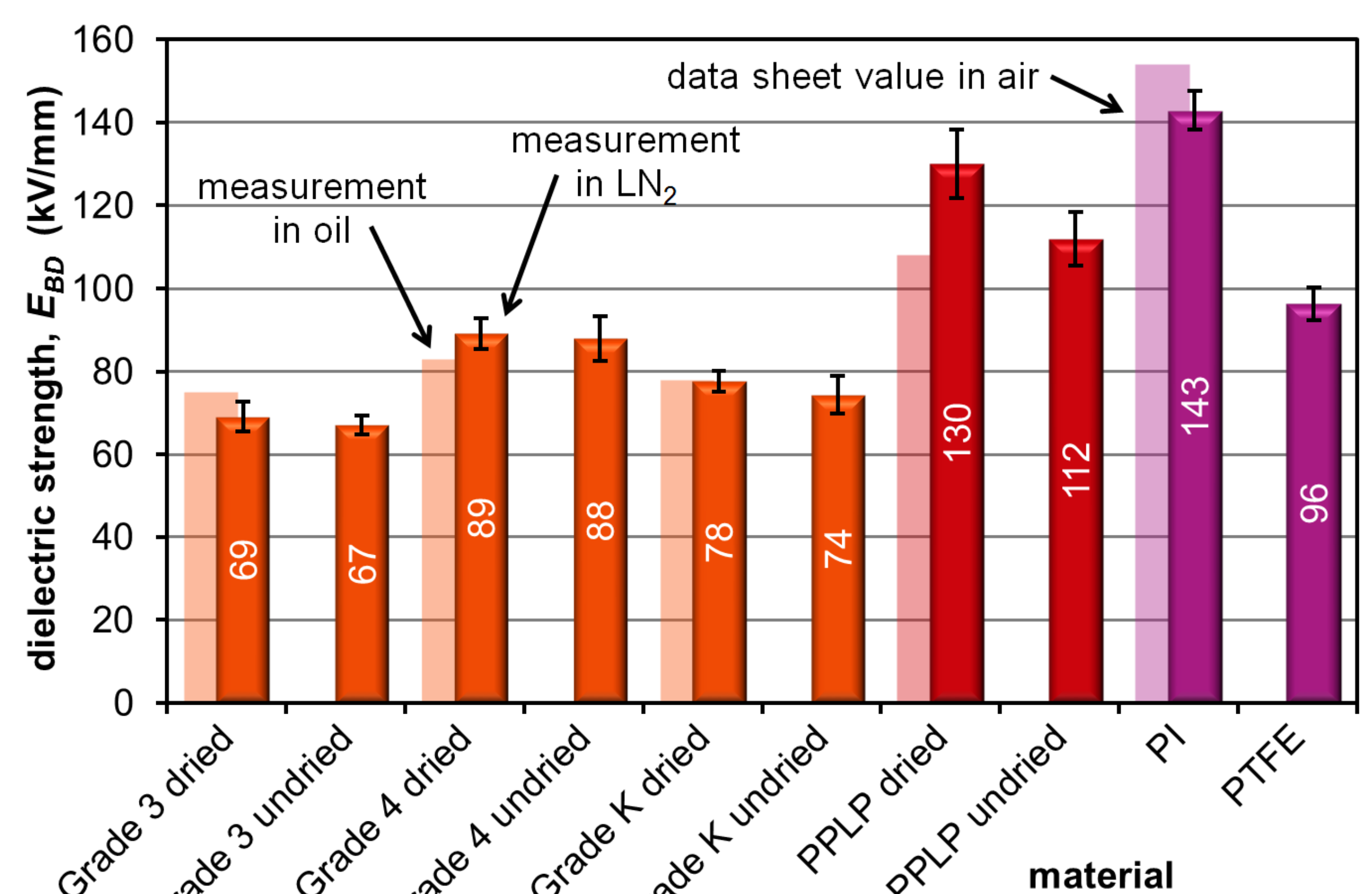
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Transformer Board Materials



^a J. Hong; J. II Heo; S. Nam; H. Kang (2014): Analysis on the Dielectric Characteristics of Solid Insulation Materials in LN₂ for Development of High Voltage Magnet Applications. IEEE Trans. Appl. Supercond. 24 (3)

Insulating Papers



Conclusion

BD performance of transformer board materials in LN₂

- comparable to the performance of oil-impregnated materials
- comparable to epoxy and better than FRP materials

BD performance of conventional insulating papers in LN₂

- comparable to the performance of oil-impregnated paper
- independent of the degree of dryness
- reaching 60% to 70% of PI and PPLP performance

PD performance of conventional insulating papers in LN₂

- comparable or better than PI and PTFE due to smaller ϵ_r

Promising characteristics of board and paper materials!

