VTT Technical Research Centre of Finland

Ultrasound as a non-destructive tool to estimate polymer embrittlement

Rinta-aho, Jari; Sipilä, Konsta; Zak, Pavel; Sarsounova, Zuzana

Published in:
European NDE Symposium for NPP

Published: 07/05/2021

Document Version
Publisher's final version

European Tools and Methodologies for an efficient ageing management of nuclear power plant Cables

Ultrasound as a non-destructive tool to estimate polymer embrittlement

J. Rinta-aho (VTT & Uni. Helsinki), K. Sipilä (VTT),
P. Zak (ÚJV Řež), Z. Sarsounova (ÚJV Řež)

Content

1. Background and the research question
2. Specimens and ageing process
3. Measurements and Results
4. Conclusions

Nuclear power and material degradation

- Nuclear power is the most important source of low-carbon electricity in the EU
  - 25 % of all electricity
  - 50 % of low-carbon electricity
- European nuclear reactor fleet is growing old
  - Most of the reactors were built in the 1970s and 1980s
- We must understand material degradation phenomena for safe long-term operation of nuclear power plants

Cables in a nuclear power plant

- In a single NPP, there is approximately 1 500 km of electric cables
  - Some of these cables are exposed to gamma irradiation
- Gamma irradiation brittles polymers such as polyethylene used as insulator in cables
- Planned life-time of a NPP is 60-80 year
- A low-cost non-destructive estimation method for the embrittlement is required.

Our research question

- While polymers brittle, they usually becomes harder
- Hardening increases Young's modulus, therefore it can be monitored with sound velocity

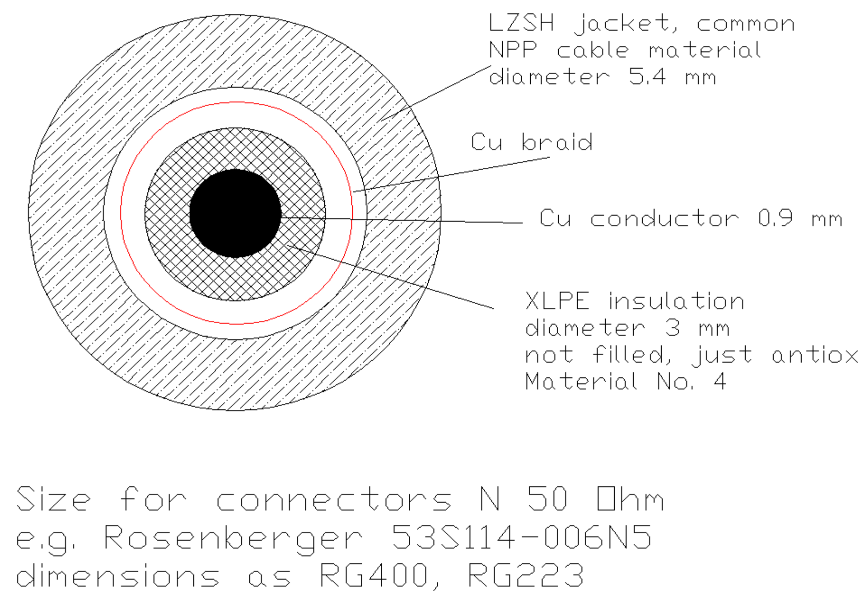
$$v = \sqrt{\frac{E}{\rho}\frac{1-\nu}{(1+\nu)(1-2\nu)}}$$

<u>Does the Young's modulus increase enough to affect sound velocity?</u>

Specimens and ageing process

Specimens

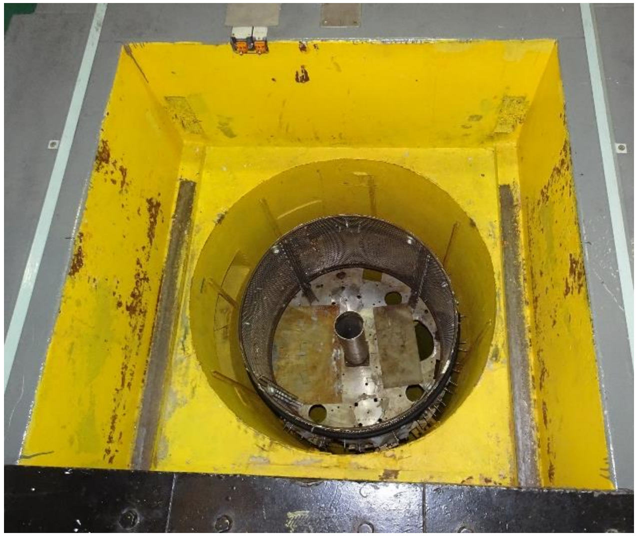
- Commercially available coaxial cable was used
- Industrial grade XLPE (with alumina trihydrate and antioxidants)

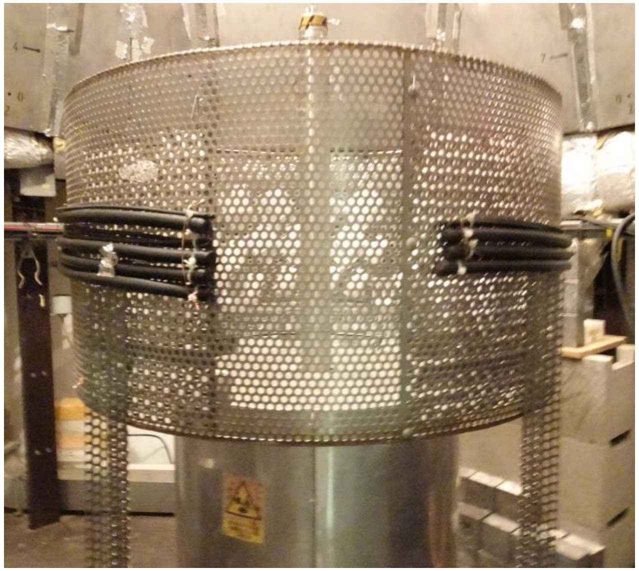


Radiation ageing in UJV

- High dose rate radiation ageing:
  - Average temperature 20 °C
  - Dose rate 400 Gy/h
  - Total doses of withdrawals: 67 kGy / 134 kGy / 202 kGy / 269 kGy / 336 kGy

- Medium dose rate radiation ageing:
  - Average temperature 46.6 °C
  - Dose rate 59.4 Gy/h
  - Total doses of withdrawals: 51.2 kGy / 110 kGy / 168 kGy / 227 kGy / 286 kGy

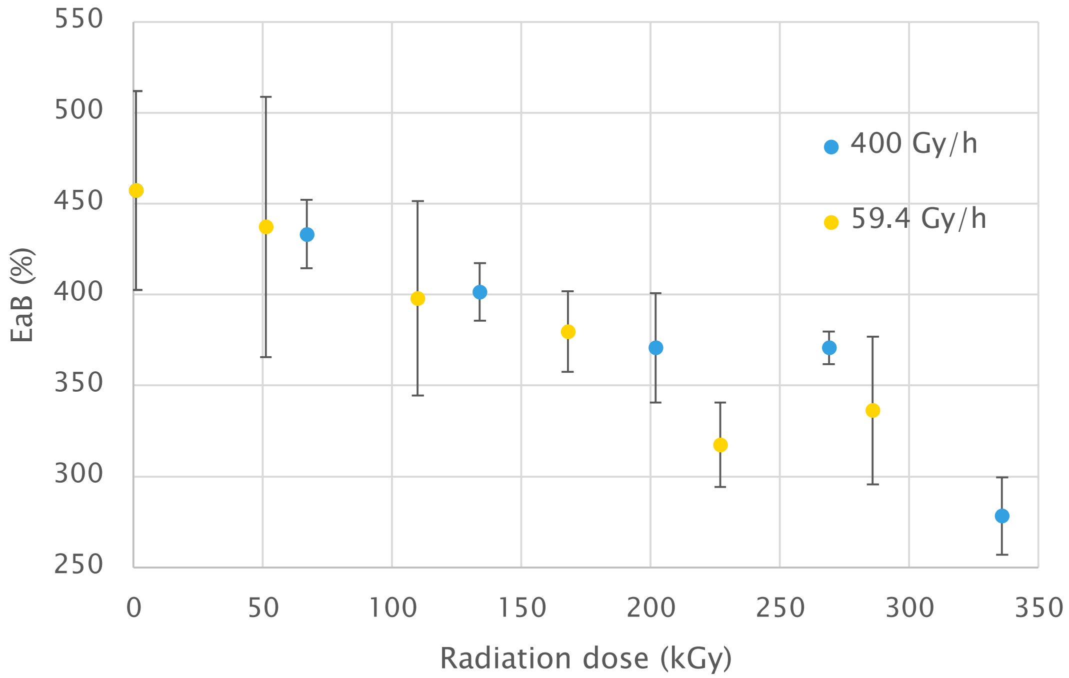


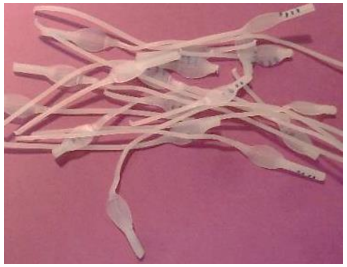


Measurements and results

Tensile properties measurement

Instron 3366, software Bluehill 3
Tubes: without extensometer, 50 mm/min, L= 30 mm, 20 pts/s, smooth steel grips 12.5(h)x38(w)mm





Initial properties

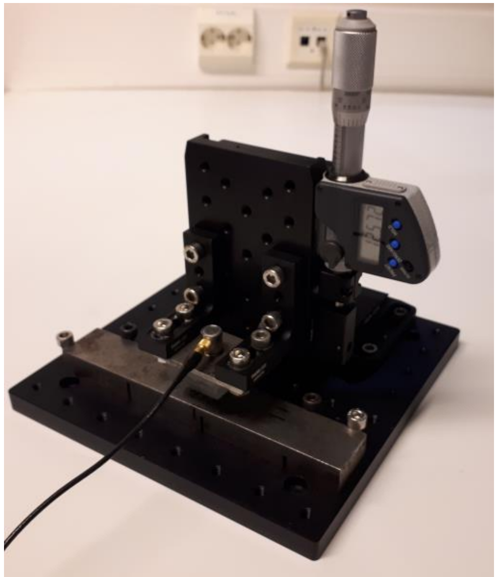
400 Gy/h – 336 kGy

59.4 Gy/h – 286 kGy

Sound velocity setup

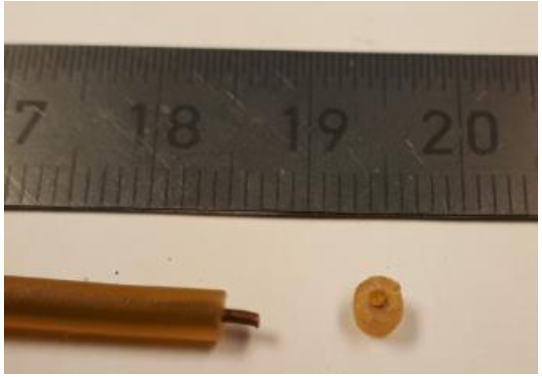
- Ultrasound transducer with 10 mm delay line (5 MHz, GE)
- Digital micrometer (Mitutoyo)
- Panametrix Model 5077PR pulser-receiver
- Tektronix TDS 5034 B oscilloscope (sampling rate 5 Gs/s)
- Off-the-shelf fine mechanics from Thorlab

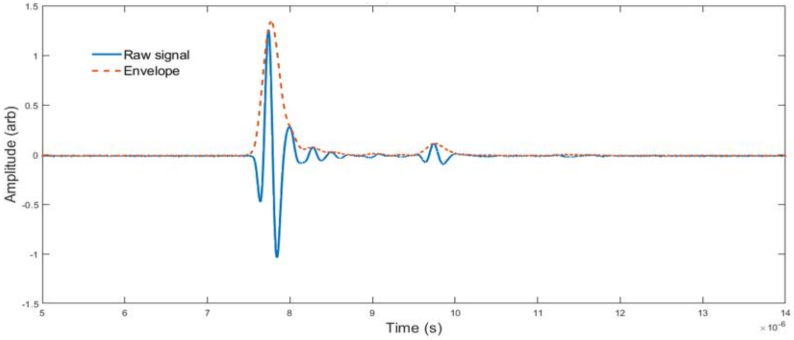
- The distance between the transducer and steel back plate is freely adjustable.



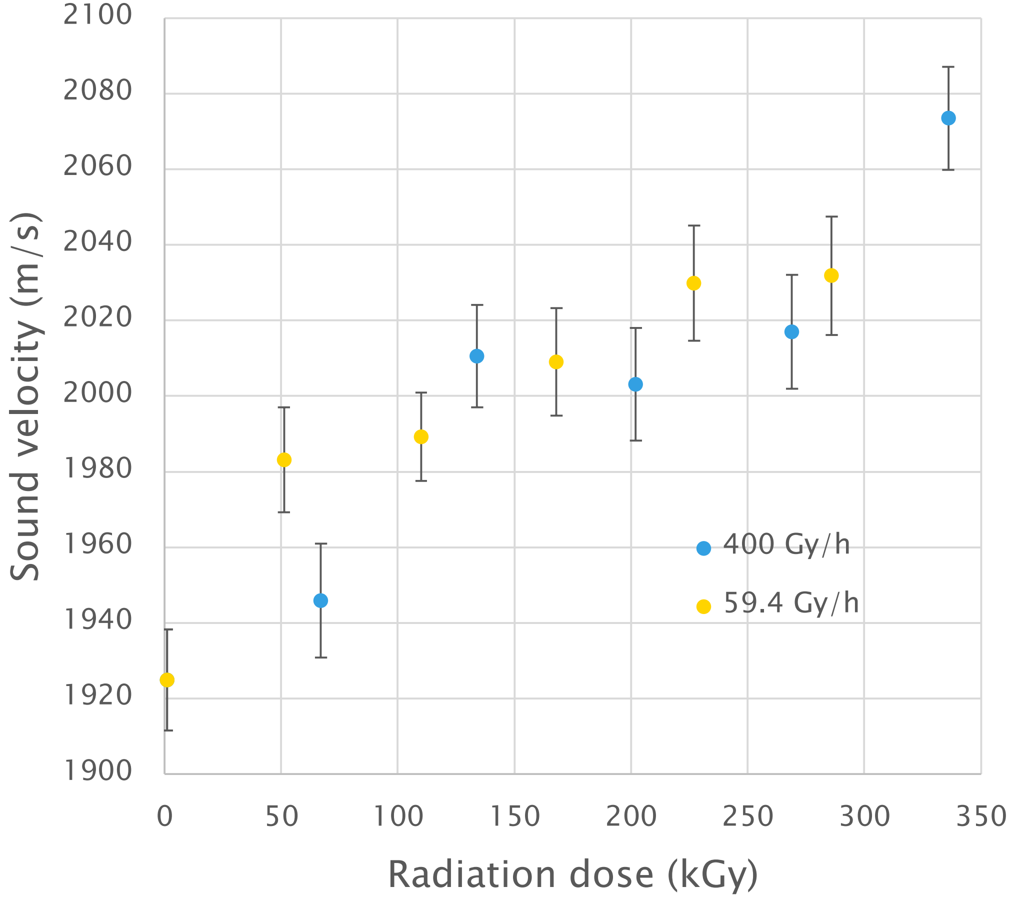
Sound velocity measurement

- A short (~2 mm) cylindrical piece of the insulator with a scalpel
- The specimen was placed on the measurement setup in standing position
  - Honey was used a contact agent
- The sound signals were recorded and specimen length measured simultaneously
- Sound velocity is $v = \frac{2l}{t}$



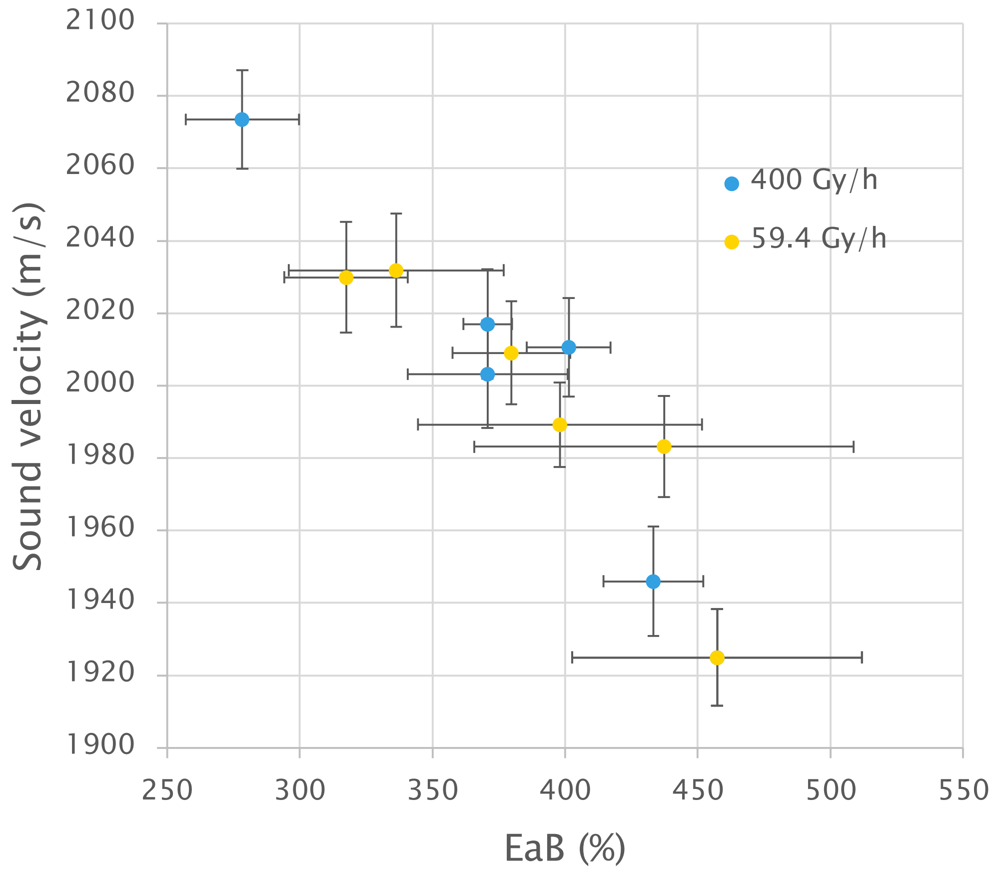


Radiation dose and sound velocity



- Sound velocity clearly increases while material is irradiated
- Dose rate seems to have no effect on the sound velocity

Sound velocity and EaB



- Clear negative correlation between sound velocity and EaB
- No clear effect caused by dose rate

Conclusions

- Polyethylene brittles while it is exposed to gamma radiation
  - The dose rate seems to have no effect.
- Irradiation increases Young's modulus
  - This increases the sound velocity
- There is a clear correlation between the sound velocity and embrittlement

<u>Ultrasound can be used as a low-cost method to estimate embrittlement non-destructively</u>

Thank you!

- Contact:
  Jari Rinta-aho
  jari.rinta-aho@vtt.fi

The TeaM Cables project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 755183