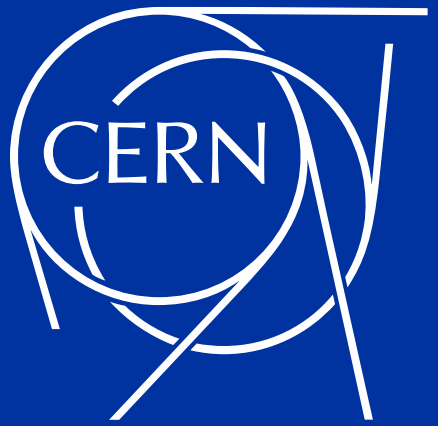


Visit at the 19th international conference on Deformation, Yield and Fracture of Polymers in Kerkrade, Netherlands

Polymer laboratory meeting

Dávid Máté Parragh

11/04/2024

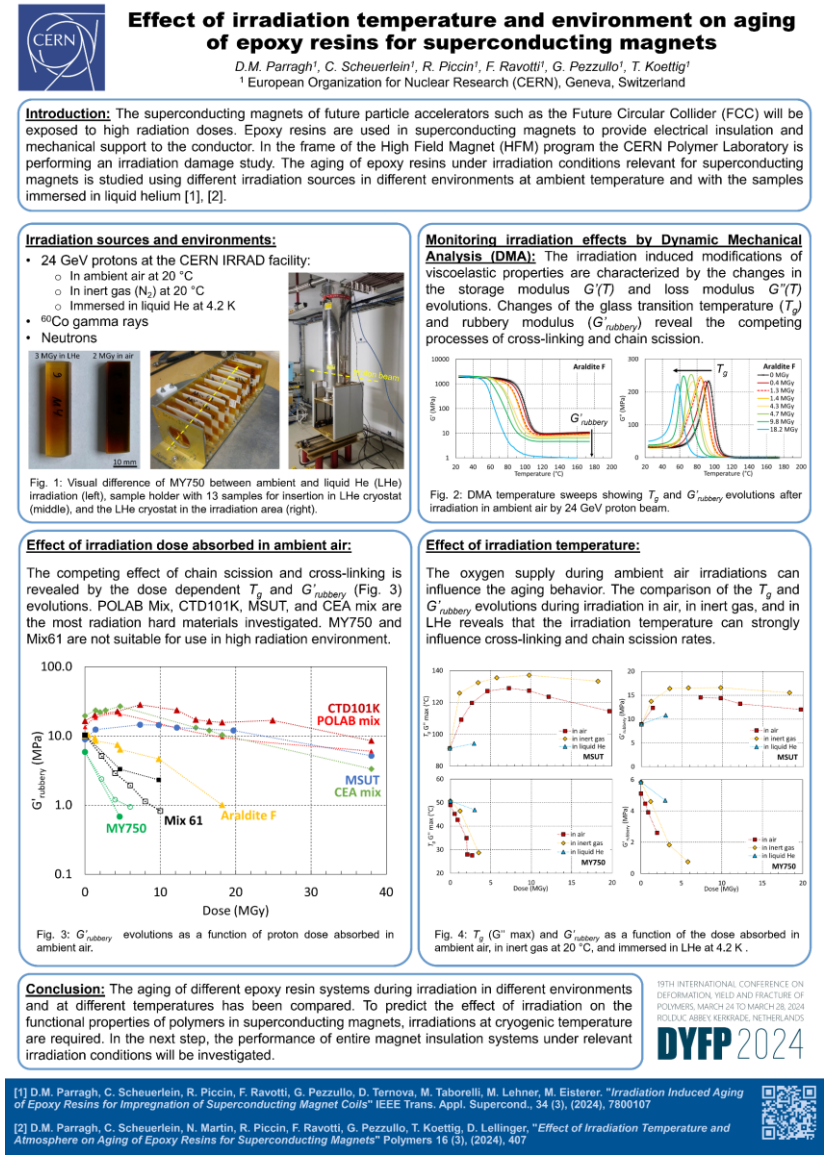
The conference

- Internation conference on **Deformation, Yield and Fracture of Polymers**, 24-28 March 2024, Kerkrade, Netherlands

- Poster presentation: Effect of irradiation temperature and environment on aging of epoxy resins for superconducting magnets

DYFP 2024

19TH INTERNATIONAL CONFERENCE ON DEFORMATION, YIELD AND FRACTURE OF POLYMERS, MARCH 24 TO MARCH 28, 2024 ROLDUC ABBEY, KERKRADE, NETHERLANDS



Effect of irradiation temperature and environment on aging of epoxy resins for superconducting magnets

D.M. Parragh[1], C. Scheuerlein[1], R. Piccin[1], F. Ravotti[1], G. Pezzullo[1], T. Koettig[1]

[1] European Organization for Nuclear Research (CERN), Geneva, Switzerland

Introduction: The superconducting magnets of future particle accelerators such as the Future Circular Collider (FCC) will be exposed to high radiation doses. Epoxy resins are used in superconducting magnets to provide electrical insulation and mechanical support to the conductor. In the frame of the High Field Magnet (HFM) program the CERN Polymer Laboratory is performing an irradiation damage study. The aging of epoxy resins under irradiation conditions relevant for superconducting magnets is studied using different irradiation sources in different environments at ambient temperature and with the samples immersed in liquid helium [1], [2].

Irradiation sources and environments:

- 24 GeV protons at the CERN IRRAD facility:
  - In ambient air at 20 °C
  - In inert gas (N_2) at 20 °C
  - Immersed in liquid He at 4.2 K
- ^{60}Co gamma rays
- Neutrons

Fig. 1: Visual difference of MY750 between ambient and liquid He (LHe) irradiation (left), sample holder with 13 samples for insertion in LHe cryostat (middle), and the LHe cryostat in the irradiation area (right).

Monitoring irradiation effects by Dynamic Mechanical Analysis (DMA): The irradiation induced modifications of viscoelastic properties are characterized by the changes in the storage modulus $G'(T)$ and loss modulus $G''(T)$ evolutions. Changes of the glass transition temperature (T_g) and rubbery modulus ($G'_{rubbery}$) reveal the competing processes of cross-linking and chain scission.

Fig. 2: DMA temperature sweeps showing T_g and $G'_{rubbery}$ evolutions after irradiation in ambient air by 24 GeV proton beam.

Effect of irradiation dose absorbed in ambient air:

The competing effect of chain scission and cross-linking is revealed by the dose dependent T_g and $G'_{rubbery}$ (Fig. 3) evolutions. POLAB Mix, CTD101K, MSUT, and CEA mix are the most radiation hard materials investigated. MY750 and Mix61 are not suitable for use in high radiation environment.

Fig. 3: $G'_{rubbery}$ evolutions as a function of proton dose absorbed in ambient air.

Effect of irradiation temperature:

The oxygen supply during ambient air irradiations can influence the aging behavior. The comparison of the T_g and $G'_{rubbery}$ evolutions during irradiation in air, in inert gas, and in LHe reveals that the irradiation temperature can strongly influence cross-linking and chain scission rates.

Fig. 4: T_g (G'' max) and $G'_{rubbery}$ as a function of the dose absorbed in ambient air, in inert gas at 20 °C, and immersed in LHe at 4.2 K .

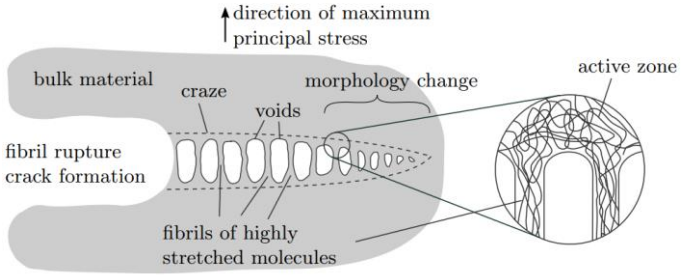
Conclusion: The aging of different epoxy resin systems during irradiation in different environments and at different temperatures has been compared. To predict the effect of irradiation on the functional properties of polymers in superconducting magnets, irradiations at cryogenic temperature are required. In the next step, the performance of entire magnet insulation systems under relevant irradiation conditions will be investigated.

[1] D.M. Parragh, C. Scheuerlein, R. Piccin, F. Ravotti, G. Pezzullo, D. Ternova, M. Taborelli, M. Lehner, M. Eisterer, "*Irradiation Induced Aging of Epoxy Resins for Impregnation of Superconducting Magnet Coils*" IEEE Trans. Appl. Supercond., 34 (3), (2024), 7800107

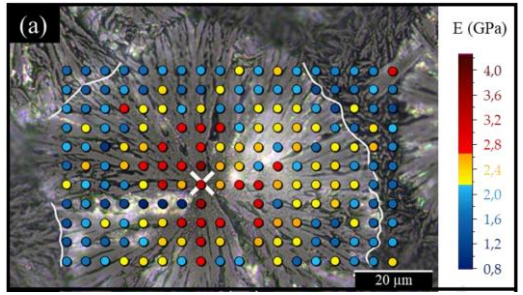
[2] D.M. Parragh, C. Scheuerlein, N. Martin, R. Piccin, F. Ravotti, G. Pezzullo, T. Koettig, D. Lellinger, "*Effect of Irradiation Temperature and Atmosphere on Aging of Epoxy Resins for Superconducting Magnets*" Polymers 16 (3), (2024), 407

Session topics

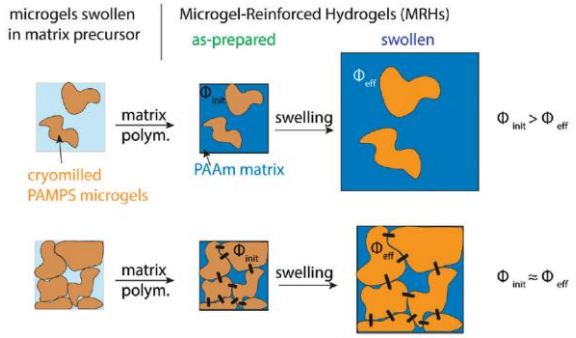
- Molecular Modeling
- Surfaces, Contact & Adhesion
- Fracture & Toughness
- Physics of Glasses
- Biological & Bioinspired
- Soft Matter & Rubbers
- Fatigue & Durability
- In-Situ Observations
- Semi-Crystalline Polymers



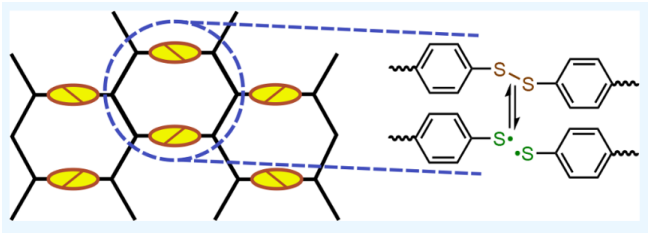
Laschuetza, Tobias, and Thomas Seelig. "Finite Element Analyses Of Crazing In Glassy Polymers Under Cyclic Mode I Loading."



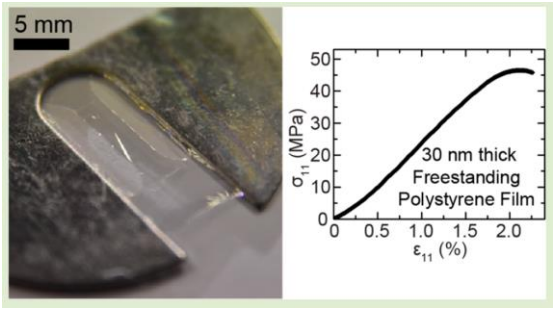
Grondin, Jérémy, et al. "Intraspherulitic mechanical heterogeneities and microstructure of i-PP highlighted by nanoindentation and atomic force microscopy." Polymer 285 (2023): 126391.



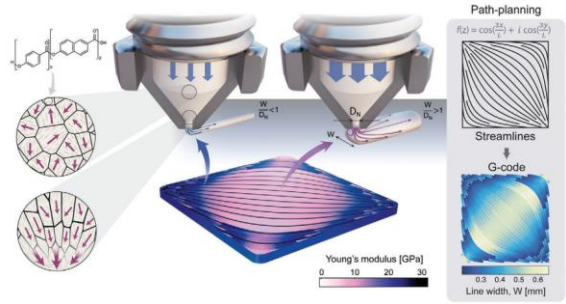
Kessler, Michael, et al. "Influence of the Degree of Swelling on the Stiffness and Toughness of Microgel-Reinforced Hydrogels." Macromolecular Rapid Communications 44.16 (2023): 2200864.



Lewis, Broderick, Joseph M. Dennis, and Kenneth R. Shull. "Effects of dynamic disulfide bonds on mechanical behavior in glassy epoxy thermosets." ACS Applied Polymer Materials 5.4 (2023): 2583-2595.



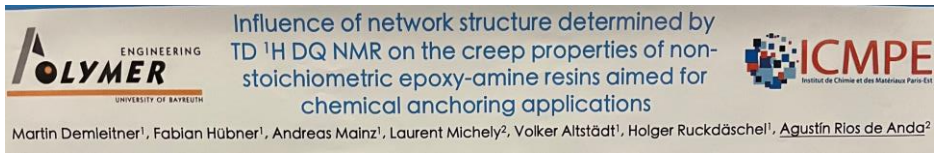
Bay, R. Konane, and Alfred J. Crosby. "Uniaxial extension of ultrathin freestanding polymer films." ACS Macro Letters 8.9 (2019): 1080-1085.



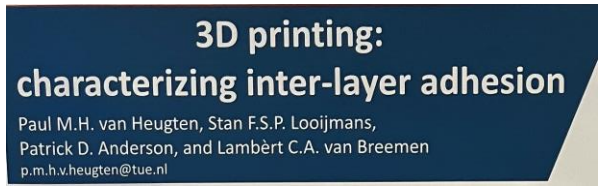
Houriet, Caroline, et al. "3D Printing of Flow-Inspired Anisotropic Patterns with Liquid Crystalline Polymers." Advanced Materials 36.11 (2024): 2307444.

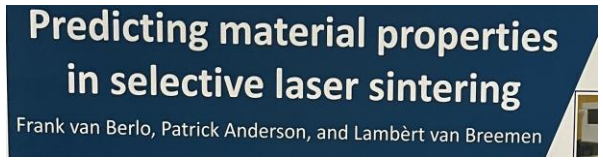
Poster session highlights

Glassy polymers



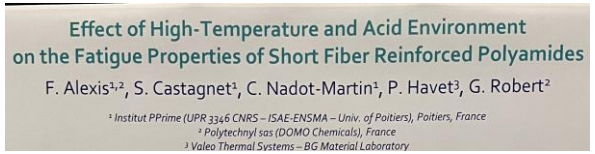
3D printing



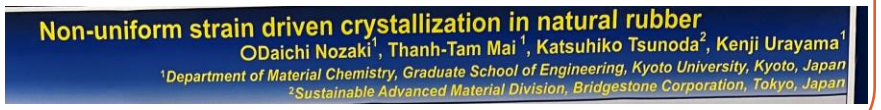


Semi-crystalline polymers

Fibre-reinforced polymers



Miscellaneous



References

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- **Oral program**
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- **Poster program**
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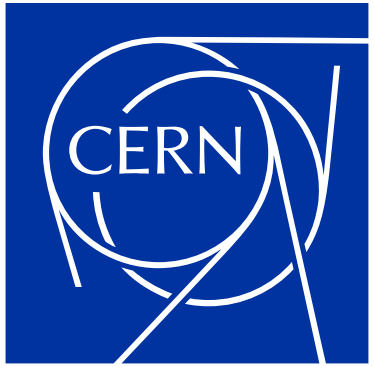
  - https://www.dyfp-conferences.org/files/file/%7B54325e2a-4d4a-4325-b927-919ed02f971a%7D/DYFP%202024%20posters%20-%20session%20II.pdf



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