Irradiation induced aging of SLA and FDM 3D printed high performance polymers

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Introduction: 3D printing of high-performance polymers enables the production of functional components with complex geometries that cannot easily be obtained by conventional manufacturing methods. A concern is the possible degradation of the materials properties of the 3D printed polymers under the irradiation conditions in particle accelerators and detectors. In the present study we have characterised the mechanical properties of different high-performance SLA and FDM 3D printed polymers for potential use in superconducting magnets before and after gamma and proton irradiation. Since in superconducting accelerator magnets irradiation occurs at low temperature in inert atmosphere, at the CERN IRRAD facility we have irradiated identical samples in ambient air and immersed in liquid helium [1], [2].

Dynamical Mechanical Analysis (DMA) to assess irradiation induced aging of polymers:

Irradiation induced changes of viscoelastic materials properties are monitored by DMA. The storage modulus (G'), which is related to sample stiffness, and the loss modulus (G''), which is a measure of dissipated energy have been recorded during temperature sweeps in torsion mode, at a frequency of 1 Hz and a ramp in temperature by 2 K/min. Changes of the glass transition temperature (T_g) and of the rubbery storage modulus can reveal effects such as irradiation induced crosslinking and chain scission.

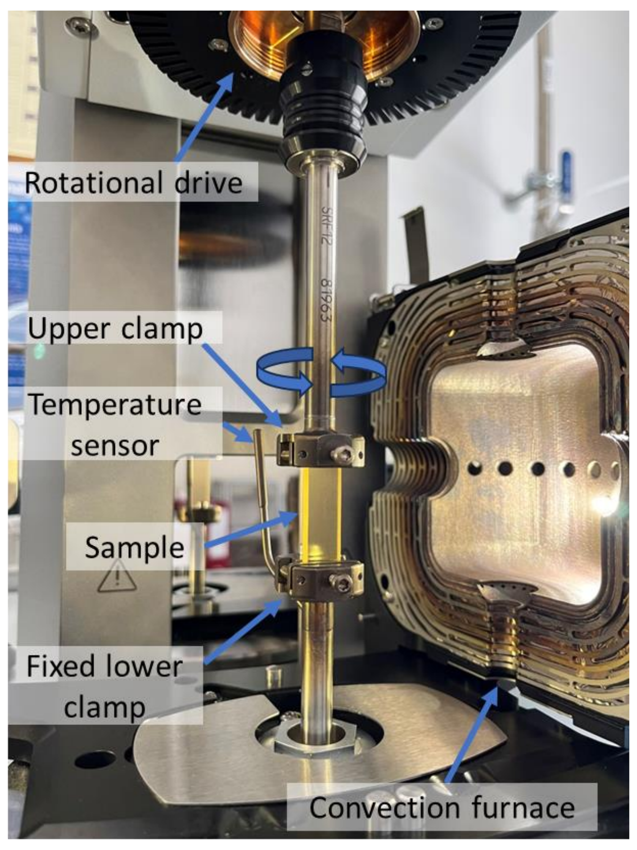

Fig. 1: DMA instrument.

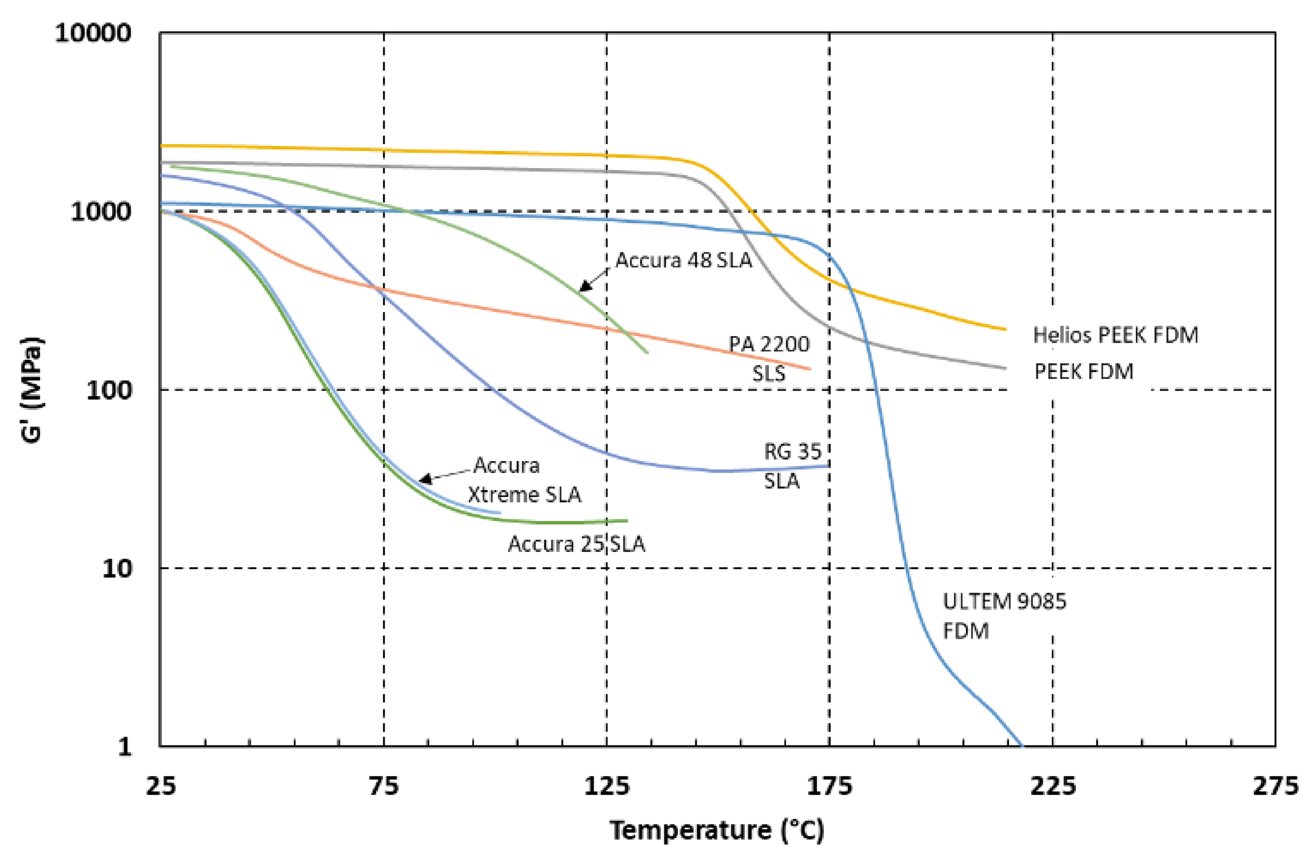

Fig. 2: G'(T) of different SLA and FDM printed polymers.

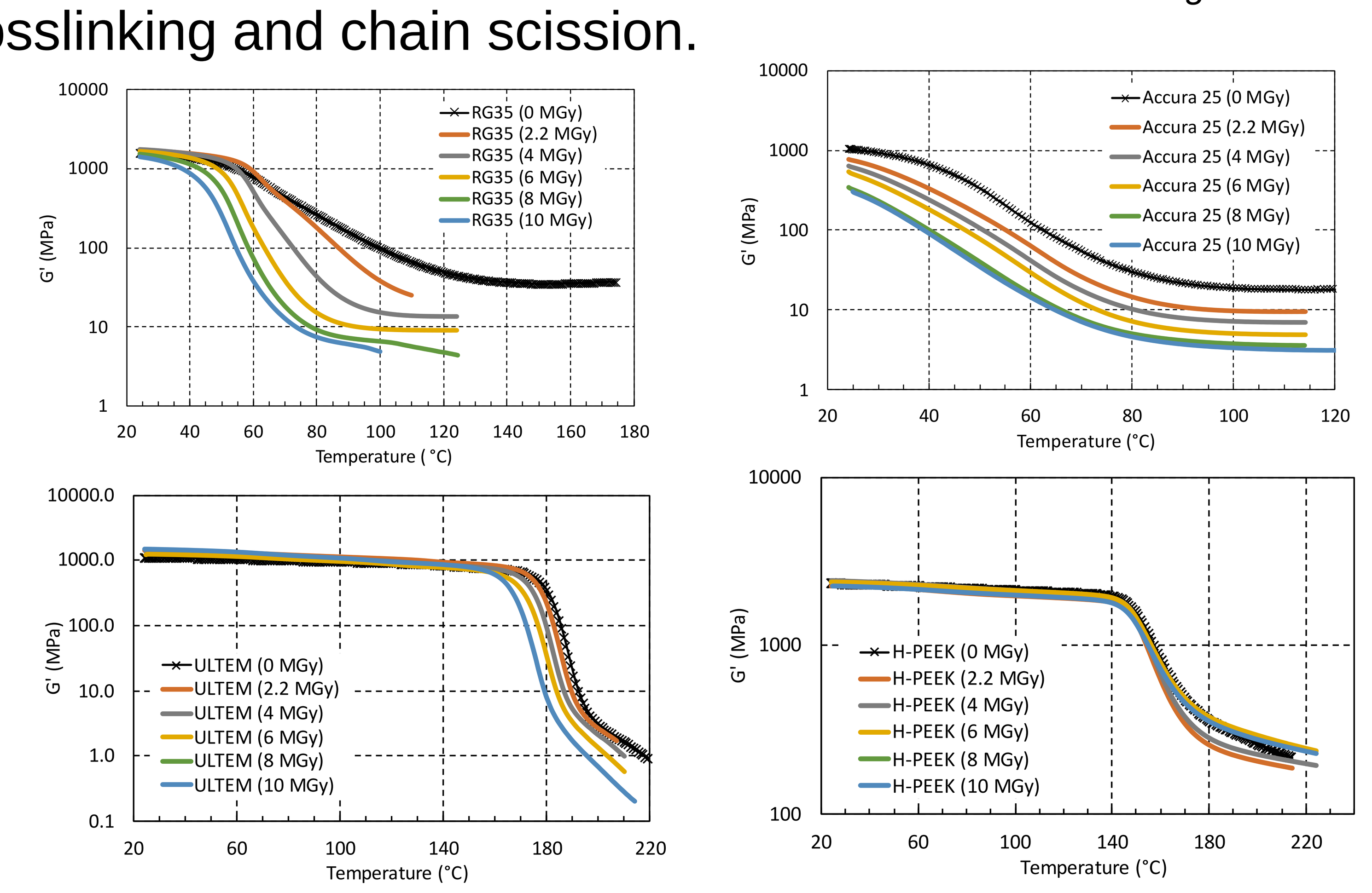

Fig. 3: G'(T) of (a) RG35 (b) Accura 25 (c) ULTEM 9085 and (d) Helios PEEK before and after gamma irradiation of CTD101K epoxy up to 10 MGy.

Short beam tests:

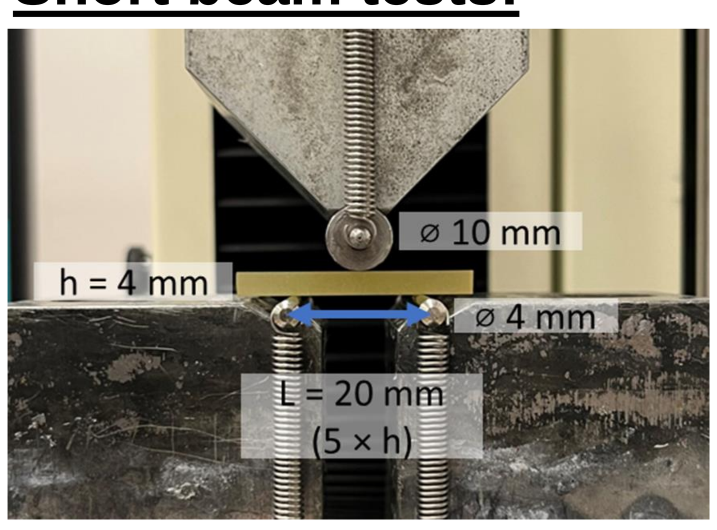

Fig. 4: Short beam test.

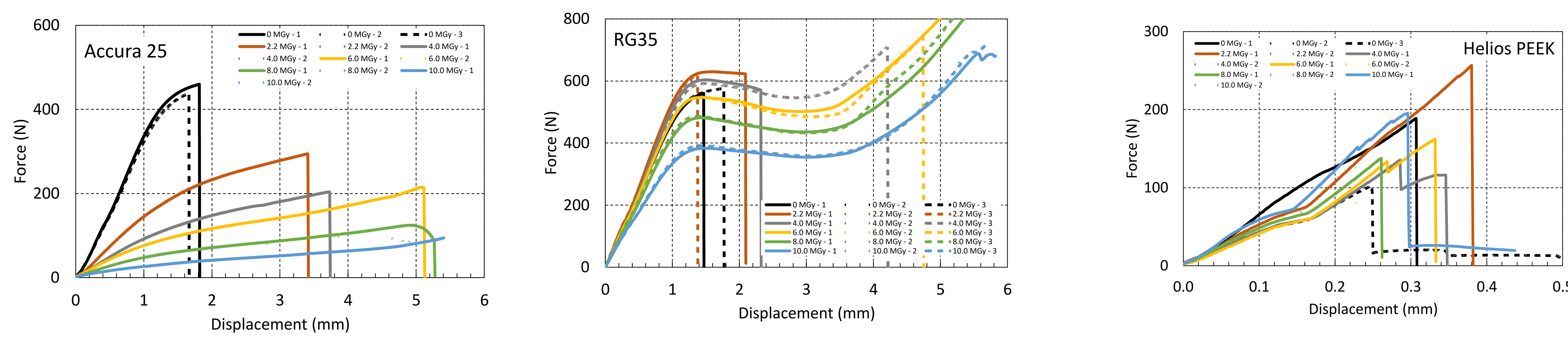

Fig. 5: Short beam force-displacement curves of (a) Accura 25, (b) RG35 and (c) Helios PEEK after ^{60}Co irradiation in ambient air up to 10 MGy.

Effect of irradiation source and environment:

Comparison of the G'(T) evolutions after 3 MGy dose absorbed in liquid helium and of initially identical samples after 2 MGy dose in ambient air (Fig. 6) shows that irradiation induced cross-linking and chain scission rates are reduced at low temperature. The presence of oxygen also influences the irradiation induced aging.

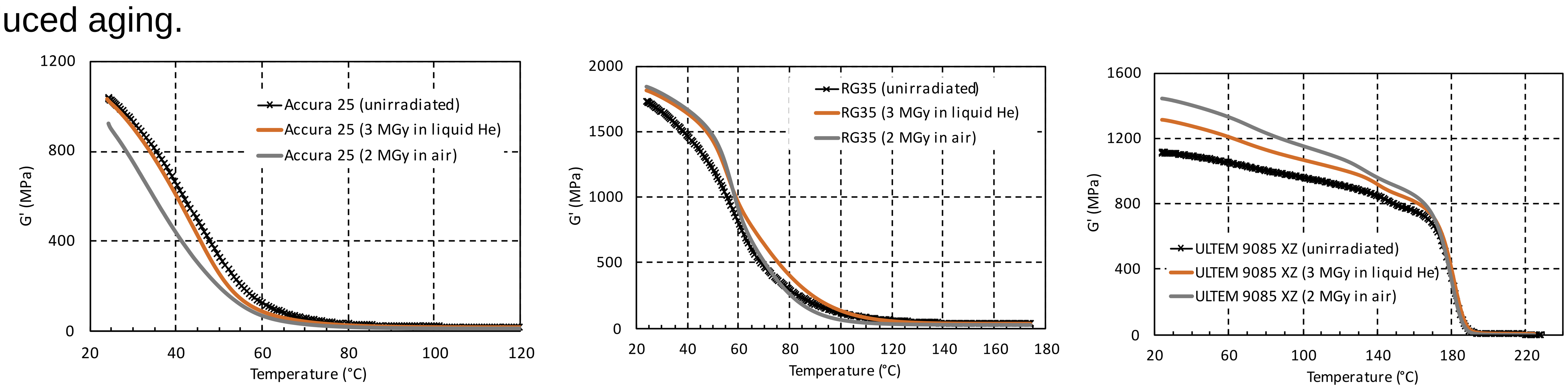

Fig. 6: G'(T) of (a) Accura 25 (b) RG35 and (c) ULTEM9085 before and after a proton dose of 3 MGy in liquid helium and 2 MGy in air.

Fig. 7: Cryostat for proton irradiation in liquid helium.

Summary: The effect of irradiation on the functional properties of a wide range of polymers for potential use in superconducting magnets is being studied by the CERN polymer laboratory. From the 3D materials tested so far, the FDM printed PEEK and ULTEM9085 are the most radiation resistant. Among the SLA printed materials RG35 exhibits comparatively good radiation hardness. The irradiation environment, and in particular the irradiation temperature can have a strong effect on irradiation induced aging rates and is subject of further studies.

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[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