Radiation-Induced Effects on Commercial 3D Printing Materials Exposed to High X-Ray Doses

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Introduction

BACKGROUND

Non-metallic **materials for 3D printing** are of increasing interest for the realization of components operating in **extreme radiation conditions**, such as particle accelerators, nuclear facilities, medical field, space missions, and repositories for radioactive waste. Considering the incomplete and limited existing data on this topic, a new research activity is being developed to broaden the available knowledge about **radiation effects on 3D printed parts**, using a **multi-scale approach**. Three non-metallic commercial materials commonly used for 3D printing have been selected for investigation:

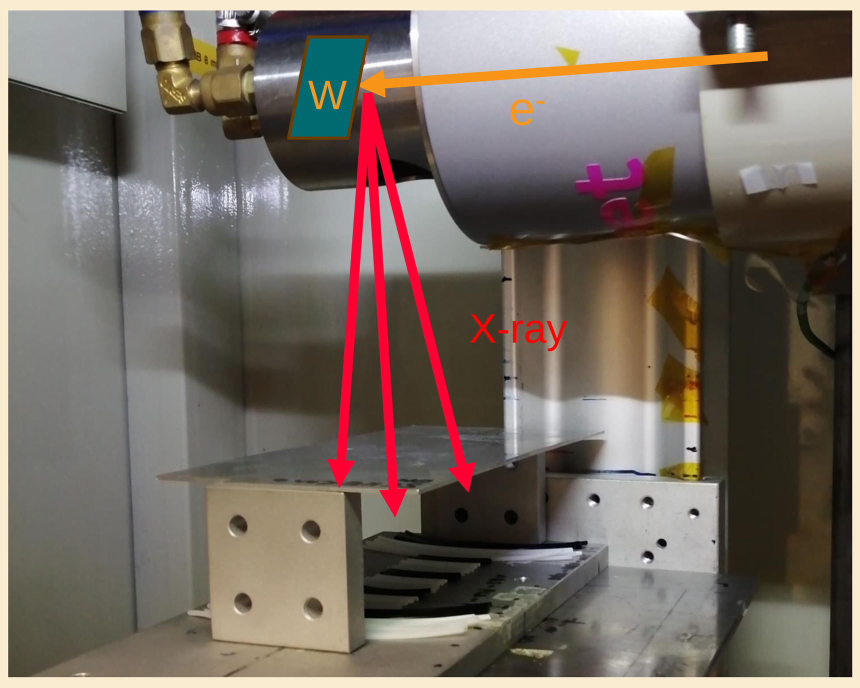
- Poly(lactic acid) (PLA): semi-crystalline polymer.
- Acrylonitrile butadiene styrene (ABS): amorphous material.
- Thermoplastic elastomer (TPE): composed by (at least) two distinct polymeric phases.

MAIN RADIATION EFFECTS ON POLYMERS

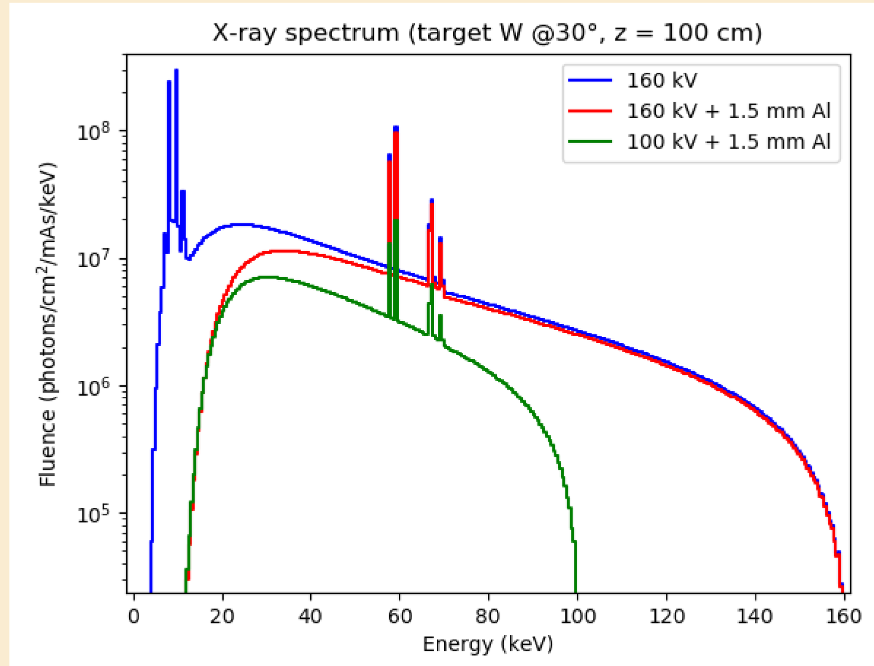
- SOFTENING - chain scission.
- HARDENING - cross-linking, polymerization.

Microscopic effects may lead to macroscopic changes. Radiation effects on polymers strongly depend on the material composition, and in general on the irradiation conditions such as temperature, atmosphere, and dose rate.

Experimental setup



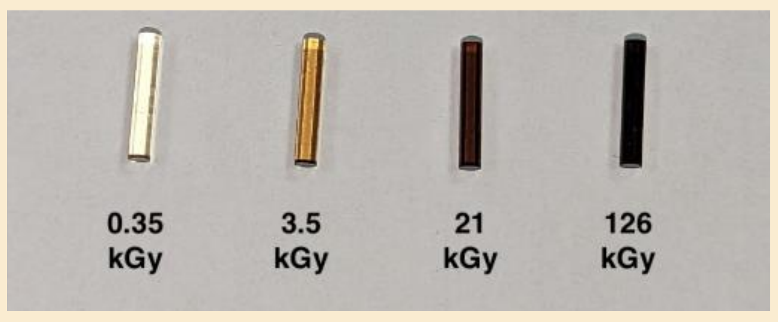
Irradiation setup @ Hubert Curien Laboratory



X-ray tube spectrum from SpekPy

IRRADIATION SETUP

- X-ray tube at 160 kV, inherent filtering of 4 mm of Be.
- Room temperature (monitored) and air atmosphere.
- Experimental dosimetry: radiophotoluminescent RPL glasses + ion. chamber.



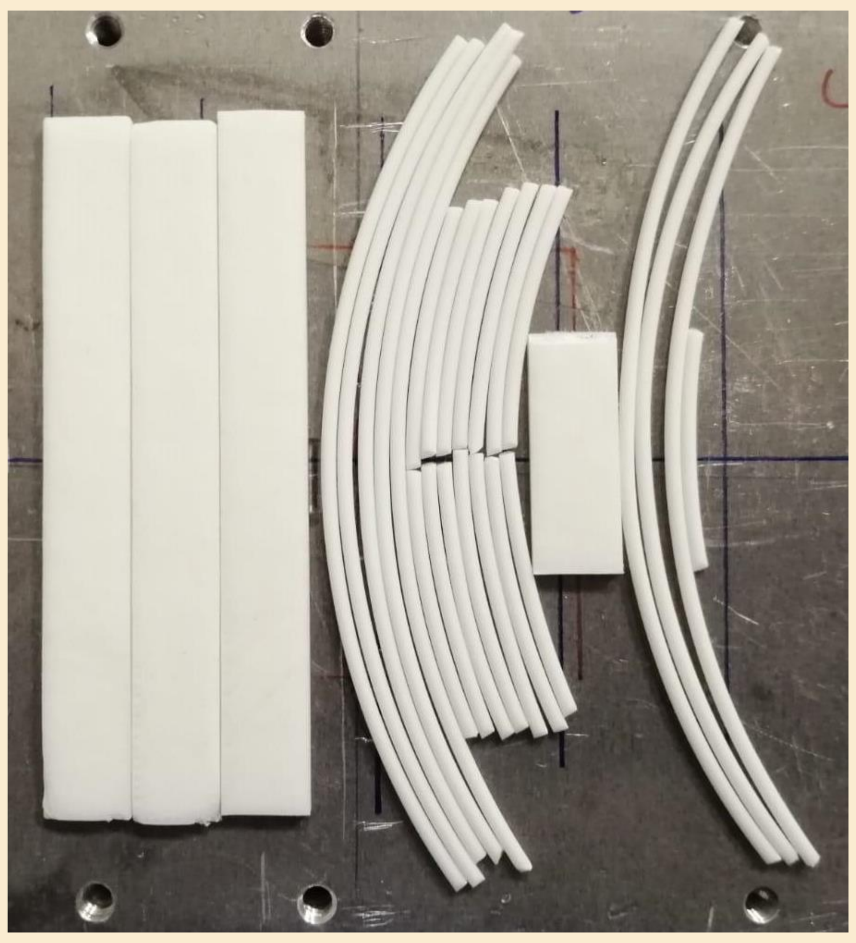
Irradiated RPL dosimeters

IRRADIATION CONDITION

- Monte Carlo simulations (GEANT4 and PHITS) to optimize the irradiation setup → additional 1.5 mm Al filter to improve dose homogeneity.
- Surface dose inhomogeneities on the irradiation plane ±15%.
- **Dose rates: 0.2 and 0.6 Gy/s.**
- **Doses from 45 kGy to 1 MGy.**
- Extensive facility use: 90+ days of irradiation.

Methods

FILAMENTS vs PRINTED SAMPLES



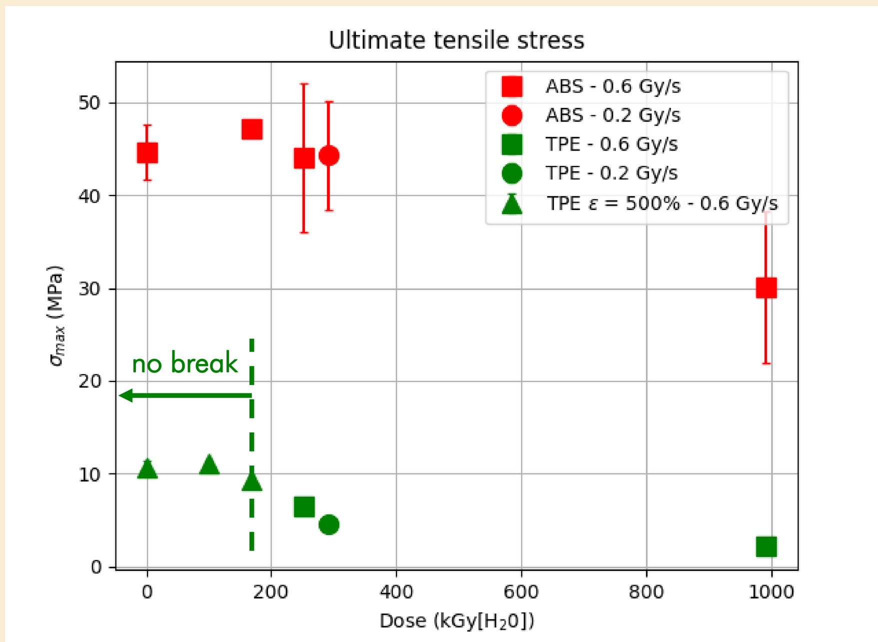
PLA samples: printed and filaments

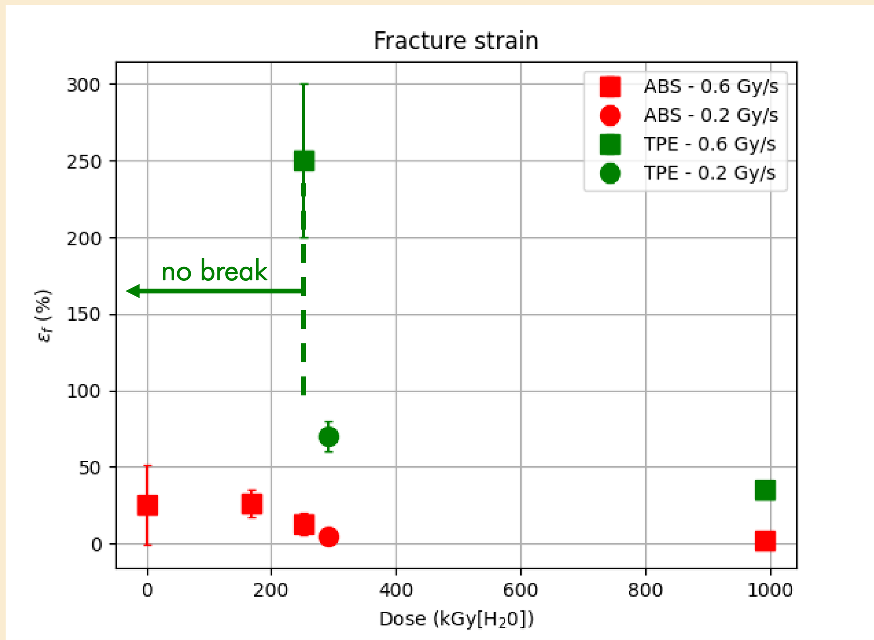
TEST AND ANALYSIS:

- Tensile test – mech. properties.
- DSC – thermal properties.
- Raman and FTIR spectrometry – chemical properties.
- Optical microscopy.

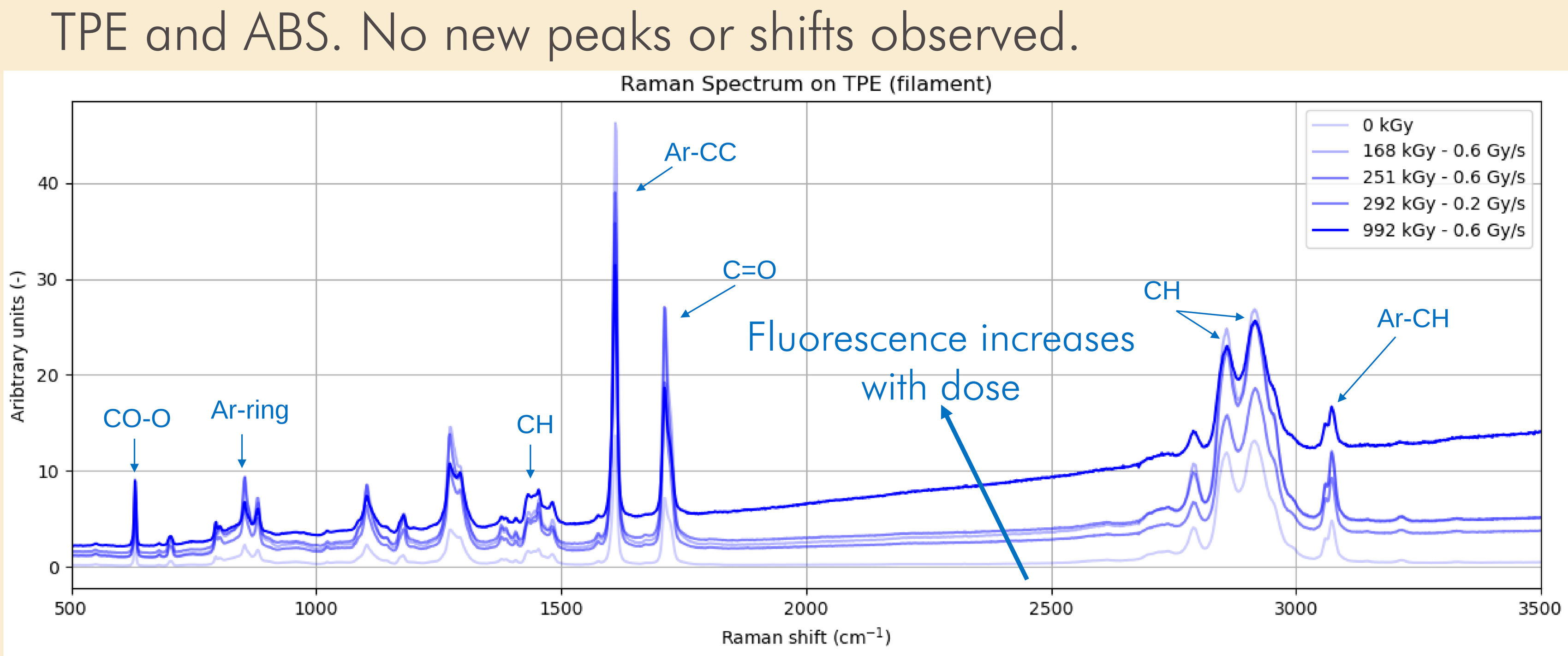
➢ x5 tested replicates.

Results and Discussion





- PLA exposed at >100 kGy **too fragile to be tested**.
- For the ABS and TPE the fracture strain and the ultimate tensile stress decrease progressively with dose. **TPE loses its elastomeric properties**.
- Radiation-induced fluorescence visible on the Raman spectrum for TPE and ABS. No new peaks or shifts observed.



Conclusions

- Proposed irradiation setup well suited for material characterization.
- PLA: the most rad-sensitive.
- Dose effects on mechanical properties significant in TPE and ABS after 200 kGy.
- The substantial changes in mechanical properties rather than chemical/thermal ones support the hypothesis of **chain scission** as the main radiation-induced effect.
- To be further investigated: dose rate effects and comparison between filaments and printed samples.
- Future experimental campaigns wills target the dependence of radiation effects on temperature and atmosphere in view of specific applications.

Bibliography

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