Self-healing polymers in space environment

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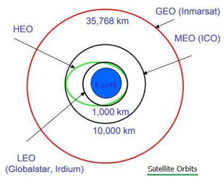
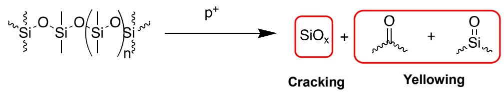
Introduction



GEO orbit:

- Very low pressure ($P < 10^{-10}$ bar)
- Protons, electrons and photons flux from solar wind
- Temperature ranging from -100 to +150 °C

Poly(dimethylsiloxane) (PDMS) degradation under proton irradiations

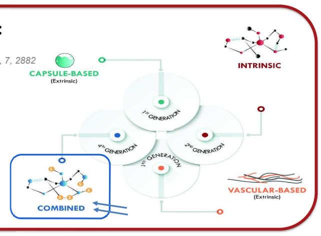


Russell et al. Journal of Spacecraft and Rockets 2002, 39 (6), 833
Planes et al. Journal of Spacecraft and Rockets 2016, 53 (6), 1128
Huszank et al. The Journal of Physical Chemistry C 2013, 117 (49), 25884

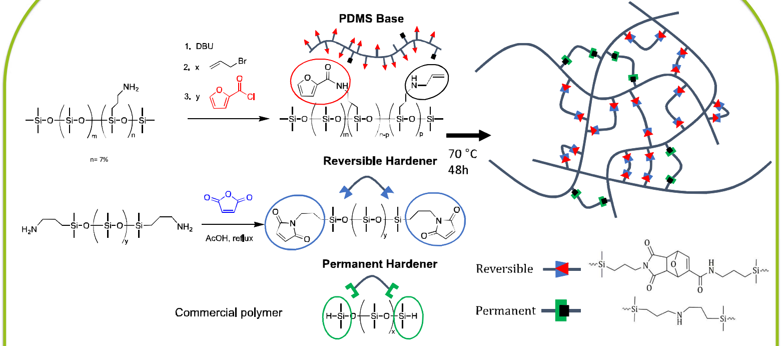
Self-Healing strategies:

Utrera-Barrios et al. *Materials Horizon*, 2020, 7, 2882
White et al. *Nature*, 2001, 409, 794
Wudl et al. *Science* 2002, 295, 5560, 1698

- Unlimited number of self-healing compared to extrinsic systems

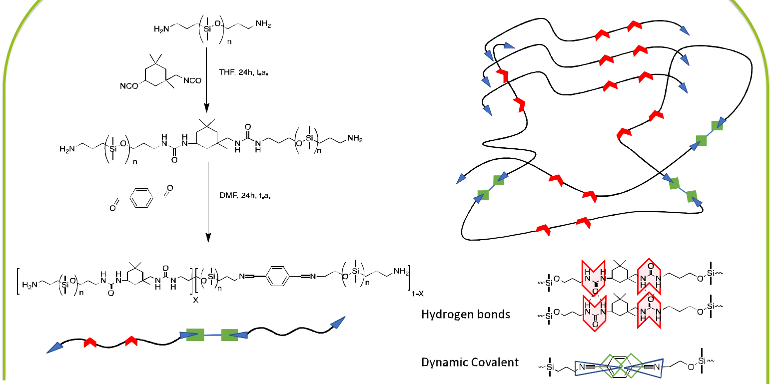


Diels-Alder/Allyl System



D. Yilmaz et al. *Materials Today Chemistry* 2022, 24, 100860

Urea/Imine System



Self-Healing process

1) 140 °C 1 h

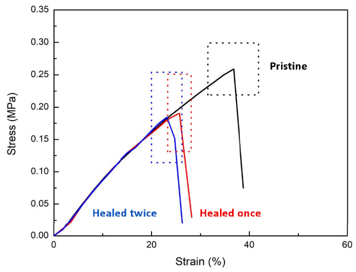
2) 70 °C 48 h

- Self-Healing after **Thermal treatment**
- **Colored** materials

- Self-Healing at **room temperature**
- **Uncolored** materials

25 °C 1h

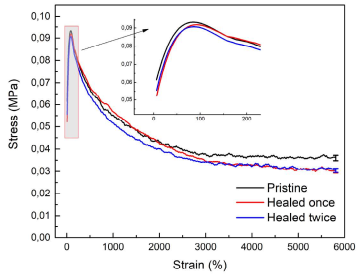
Mechanical analysis



- **Strain ~40%**
- **Low Stretchability**
- **Partial Self-Healing after Thermal treatment**

- **Strain >5800%** no break
- **High Stretchability**
- **Total Self-Healing at 25°C**

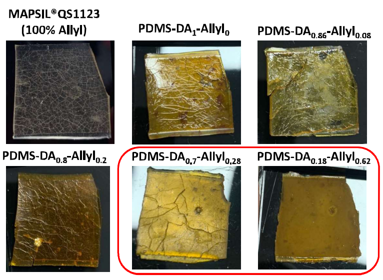
→ Self-Healing during traction experiment ?

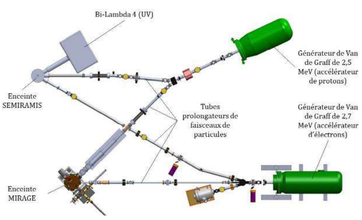


Proton irradiation

Macroscopic view

- **Dual network** based materials **less degraded**



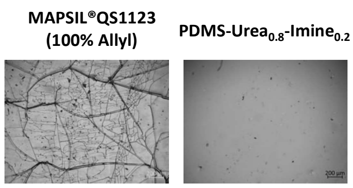


Proton irradiation facility at ONERA

Irradiation conditions:

- Protons 240 keV
- Fluency: 3 10^{15} $p^{+}.cm^{-2}$
- Temperature: 40°C
- $P < 10^{-5}$ mbar
- Flux: 9.5 10^{10} $p+.cm^{-2}.s^{-1}$

Optical Microscopy

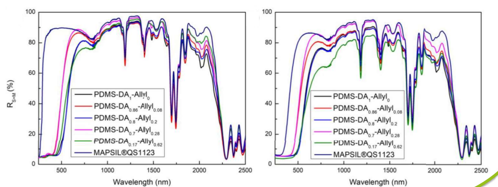


UV-Vis-NIR

- **Conservation** of optical properties

Before irradiation

After irradiation

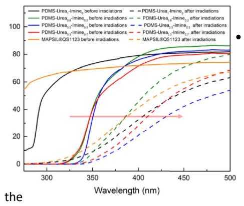


Sample name	α_S before irradiation	α_S after irradiation	Rate of change (%)	$\Delta(\alpha_S)$
Control sample	0.10	0.21	124	0.12
PDMS-Urea$_1$-Imine$_0$	0.20	0.34	65	0.14
PDMS-Urea$_{0.8}$-Imine$_{0.2}$	0.19	0.25	33	0.06
PDMS-Urea$_{0.5}$-Imine$_{0.5}$	0.39	0.53	34	0.14
PDMS-Urea$_{0.3}$-Imine$_{0.7}$	0.22	0.32	42	0.10

$$\alpha_S = \frac{\int_{250}^{2500} A(\lambda) I_S(\lambda) d\lambda}{\int_{250}^{2500} I_S(\lambda) d\lambda}$$

Solar absorptivity (α_S) reflects the ability to absorb light from the sun

UV-Vis



- PDMS-Urea$_{0.8}$-Imine$_{0.2}$ exhibits **best optical properties**

Conclusion

1st Approach

- Synthesis & characterization of PDMS based Self-Healing materials through a dual network (Permanent/Reversible)
- Colored & Self-Healing materials at 70°C
- Limitation of cracks thanks to the covalent part of the double network bringing closer self-healing moities
- Proton irradiations allow self-healing

Development of a new approach in order to get transparency while keeping Self-Healing properties: ⟹

New Approach

- Synthesis & characterization of PDMS based Self-Healing materials through a dual network (Supramolecular/Dynamic covalent)
- High stretchability
- **Transparent & Self-Healing at room temperature**
- **No crack after proton irradiation**