A new generation of easily crosslinkable polyethylene copolymers Easy XL

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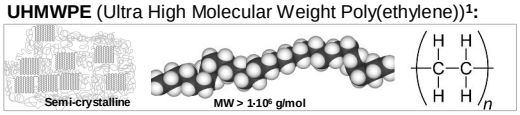
INTRODUCTION

UHMWPE (Ultra High Molecular Weight Poly(ethylene))[1]:



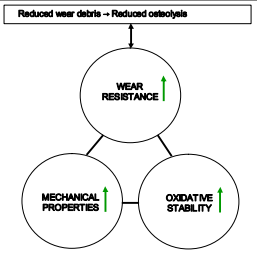
Problem: long-term implant failure due to failure of UHMWPE component. Primary cause of implant loosening: **wear** of UHMWPE results in UH particle formation⇒ osteolysis.

Osteolysis (bone resorption) around the implant (indicated by arrows).

State of the Art:
GUR1020 & GUR1050, crosslinked for wear reduction
UHMWPE Paradigm[2]:
balancing wear, oxidation and mechanical properties.
Issues due to crosslinking by gamma radiation:

- remaining free radicals → oxidation
  - remelting: removes most free radicals, but reduces crystallinity
  - annealing below Tm: does not remove all free radicals
- Reduced yield stress, impact & fracture resistance

New developments:
- Stabilization with e.g. vitamin E to reduce oxidation
- Sequential crosslinking to reduce total radiation dose

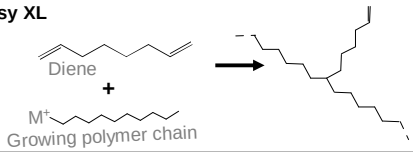


Goal: new PE grade with good wear resistance, better oxidative stability and improved mechanical properties

APPROACH

Incorporate dienes in growing PE chain:

Easy XL

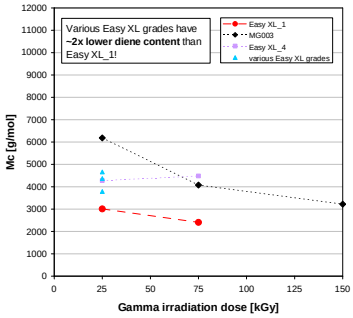


Hypothesis :
Incorporation of diene in UHMWPE will leave a pendant unsaturation from which quickly a crosslink is generated.[3]

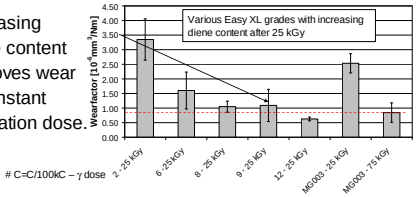
1 Unsaturation in the polymer increases the **crosslinking efficiency**
2 Lower number of **radicals** required; might reduce **oxidative degradation**
3 Adapting molecular architecture (MW) could optimize **mechanical properties**

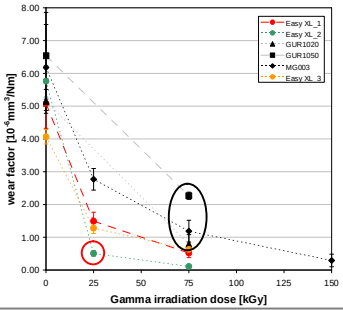
RESULTS

1 Easy crosslinkable: network densities & wear levels of highly crosslinked homopolymers after only 25 kGy! **Easy XL_2** very low wear at 25 kGy.

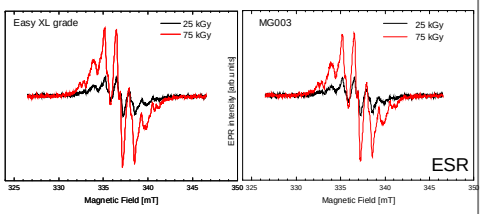


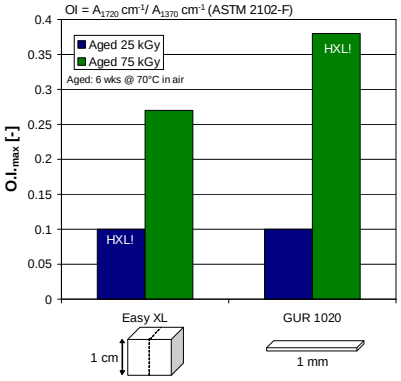
Increasing diene content improves wear at constant irradiation dose.





2 Less remaining free radicals: 3 times lower amount of remaining free radicals since amount of remaining free radicals seems dose dependent only (ESR data). The amount of radicals seems to correlate to the observed Oxidation Index (O.I.).

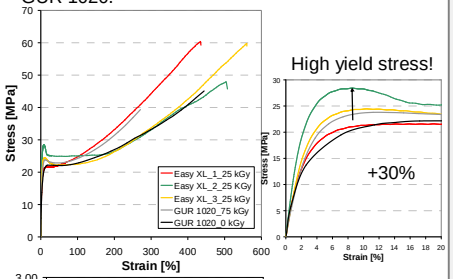


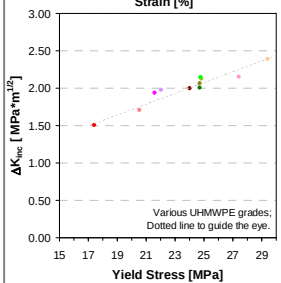


O.I. of highly crosslinked Easy XL is **3x lower** than O.I. of highly crosslinked homopolymer (GUR 1020)!

To completely remove oxidation: add HALS (Hindered Amine Light Stabilizers) stabilizer! Please also visit poster *#2309.*

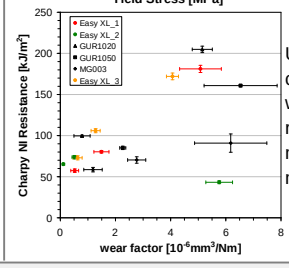
3 Improved Mechanical properties: **Easy XL_2**: M_w~500 kg/mol! Therefore high crystallinity (70%) and + 6 MPa yield stress. Rest of tensile curve after HXL quite similar to non-irradiated GUR 1020.





High yield stress indicates high ΔK_{inc}!

MW and branching levels control the crystallinity and with that the yield stress.



Upon increased crosslinking (→ low wear) impact resistance gets much closer for all materials.

CONCLUSION

- Diene-ethylene copolymers are easily crosslinkable → sterilization dose gives wear levels of highly crosslinked homopolymers
- Diene-ethylene copolymers are more oxidative resistant than homopolymers due to lower irradiation dose
- Easy XL_2 is a mechanically very interesting new grade with: + 30% yield stress, indications for better Fatigue Crack Propagation resistance and very low wear
- Optimizing diene content and MW can shift wear, oxidation and mechanical properties at the same time!

References:
1 Kurtz, S. M.; The UHMWPE handbook, 2004, Elsevier.
2 Gomez-Barrena, E et al. *Acta Orthopaedica* **2008**, *79 (6)*, 832.
3 L. Costa et al. *Polymer Degradation and Stability*, **2008**, *93*, 1695.