

Enzymatic degradation of plastics waste: a geometric model



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Polyester waste: recycling by enzymatic de-polymerisation?



PET bottle waste



96% after 24h



PET textile waste
swimwear
lining



82%



PET fiber waste
automotive scrap



36%



PET/PBT textile
swimwear
trunk



15%



PBT



0%

What do enzymes need? Prepare the polyesters:

enzymes act only at the **surface**

they “need space” to act:

amorphous substrate (avoid crystals!)

substrate **mobility** (avoid glass!)

natural temperature range (enzymes are proteins)

roughly 40–70°C

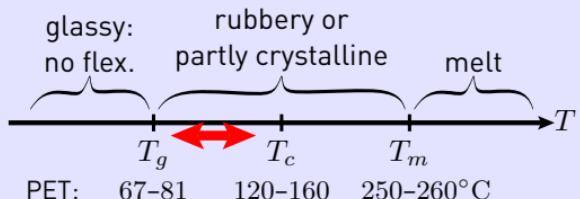
water

prepare:

melt + quench

mill + sieve: break into pieces $\sim 300\mu m$

de-polymerise:



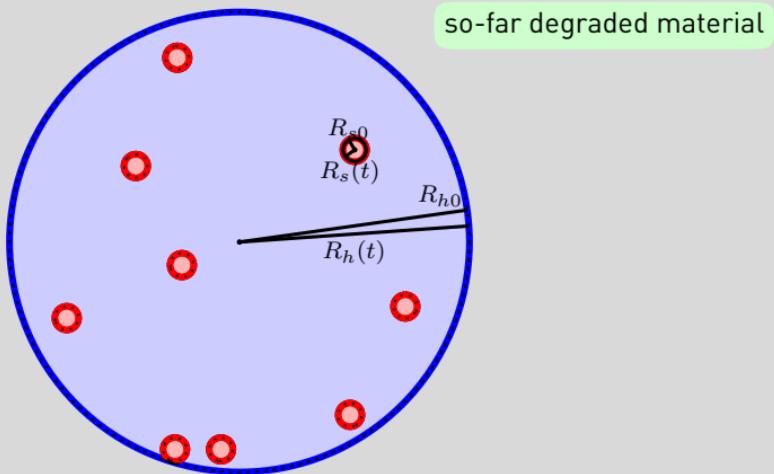
**The growing crystallites
are a problem!**

initial crystallinity + nucleation
crystal growth!

Competition: de-polymerisation vs. crystal growth

model: one shrinking sphere: amorphous material: degradable

many growing spheres: (partly) crystalline material: not degradable



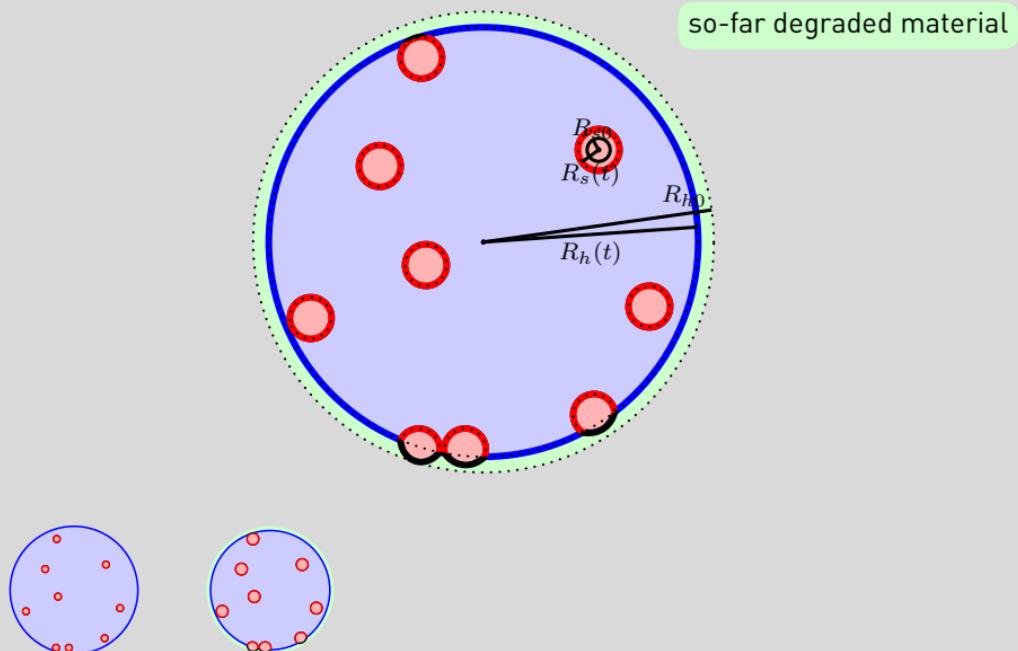
parameters: $N_s, \dot{R}_s/\dot{R}_h, R_{s0}/R_{h0}, [\dot{N}_s]$

depend on material, composition, preparation, processing temperature, ...

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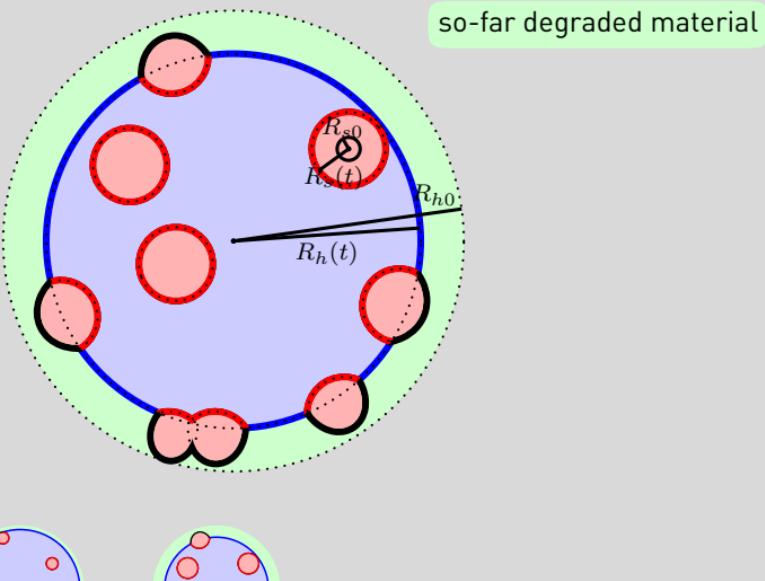
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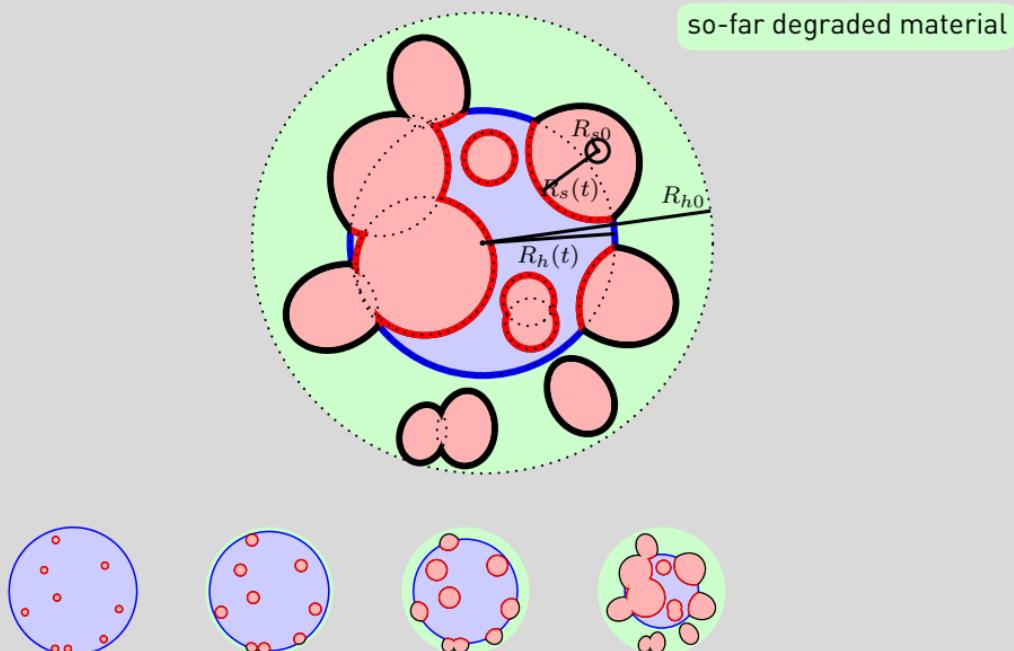
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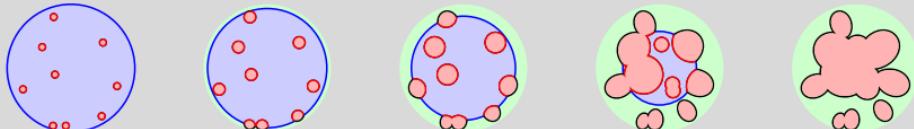
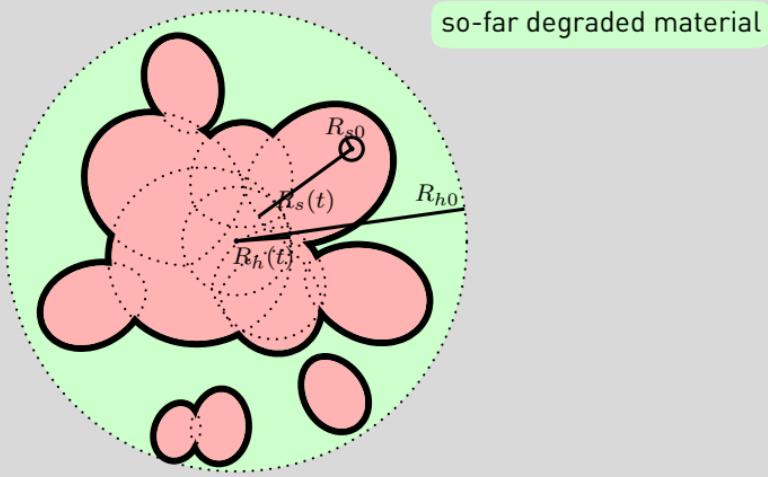
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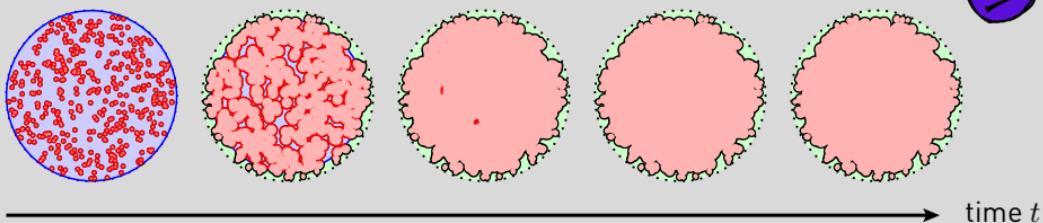
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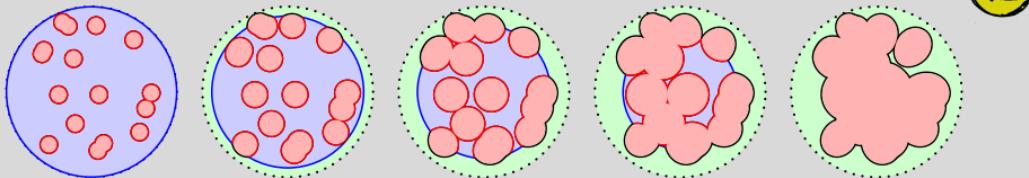
Competition: de-polymerisation vs. crystal growth

careful! there is more than just the total initial crystallinity

many small



few big (same initial volume-fraction!, same growth rate!)



parameters: $N_s, \dot{R}_s/\dot{R}_h, R_{s0}/R_{h0}, (\dot{N}_s)$

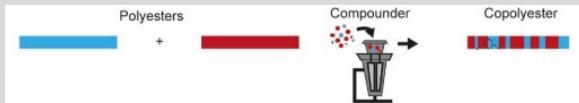
depend on material, composition, preparation, processing temperature, ...

How to slow down crystallisation?

“Classic” optimisation: understand the parameters for every material
including their temperature dependence, ...
sort materials (!?)
optimize parameter compromises
repeat the procedure also for mixtures (!?)

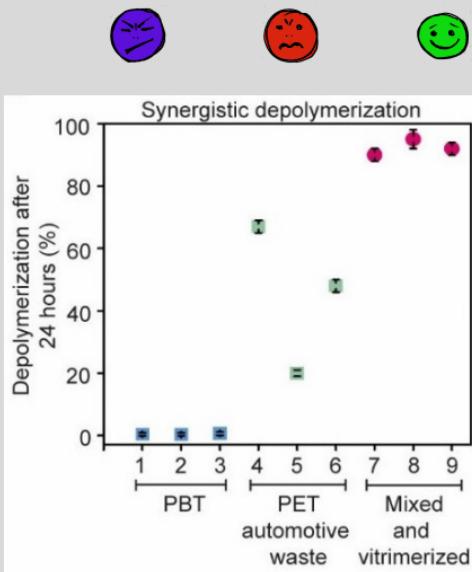
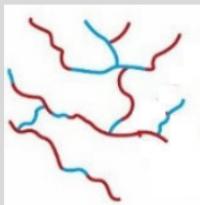
Radical new idea: Mixing rather than sorting

melt transesterification: increase randomness along chains
works for blends: 75%+25% of PET+PBT or of PET+PTT



vitrimerisation:

cross-link chains to form a random network



This was really a group effort:



Ludwik Leibler (Gulliver lab, CNRS)



Andrew Griffiths (Biochemistry lab, ESPCI)



Hernan Garate (SIMM lab, ESPCI/CNRS/PSL)



Yannick Rondelez (Gulliver lab, ESPCI)



... and me (Gulliver lab, CNRS) ...

and Costantino Creton (SIMM lab, CNRS)

and Clément Freymond (SIMM lab, ESPCI)

and Louise Breloy (SIMM lab, ESPCI)

... plus industrial contacts ...