Concevoir d'appareils mécaniques microscopiques inspirés du corps humain

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28 FÉVRIER 2006

Laboratoire de micro- et nanofabrication par écriture directe

Micro- and nanofabrication laboratory by direct-write

ÉCOLE POLYTECHNIQUE MONTRÉAL

crepec
centre de recherche en plasturgie et composites

Parcours et formation

- **Génie mécanique (Polytechnique), orientation en technologies spatiales**

Été 96: Tribologie

1996: Échange

Stage 97-98: Groupe d'analyse thermique

- **M.Ing. Génie aérospatial (Polytechnique), Structures et matériaux**

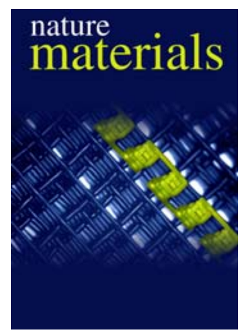
Été 97: Viscoélasticité

Stage 99 : Groupe matériaux avancés

- **Ph.D. Génie aérospatial (** *University of Illinois at Urbana-Champaign (UIUC)* **)**

1999–2000:

Pont en composites



2000–2003:

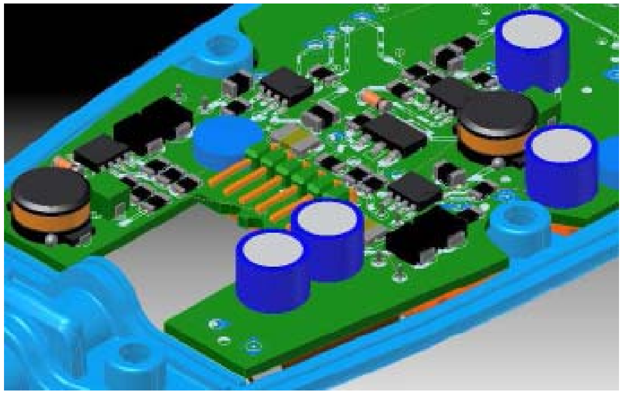
Microtechnologie

Matériaux auto-réparateurs

- **Problématique**
  - **Les polymères sont utilisés dans une grande gamme d'applications.**

Matériaux composites de haute performance

Boîtier d'appareil



Assemblage de composantes électroniques

  - **Lors de chargements, ces matériaux sont susceptibles à la propagation de fissures (ou création de fissures).**
  - **Ces fissures peuvent mener à la rupture mécanique ou électrique de l'appareil.**
  - **Ces fissures sont difficiles à détecter et à réparer.**

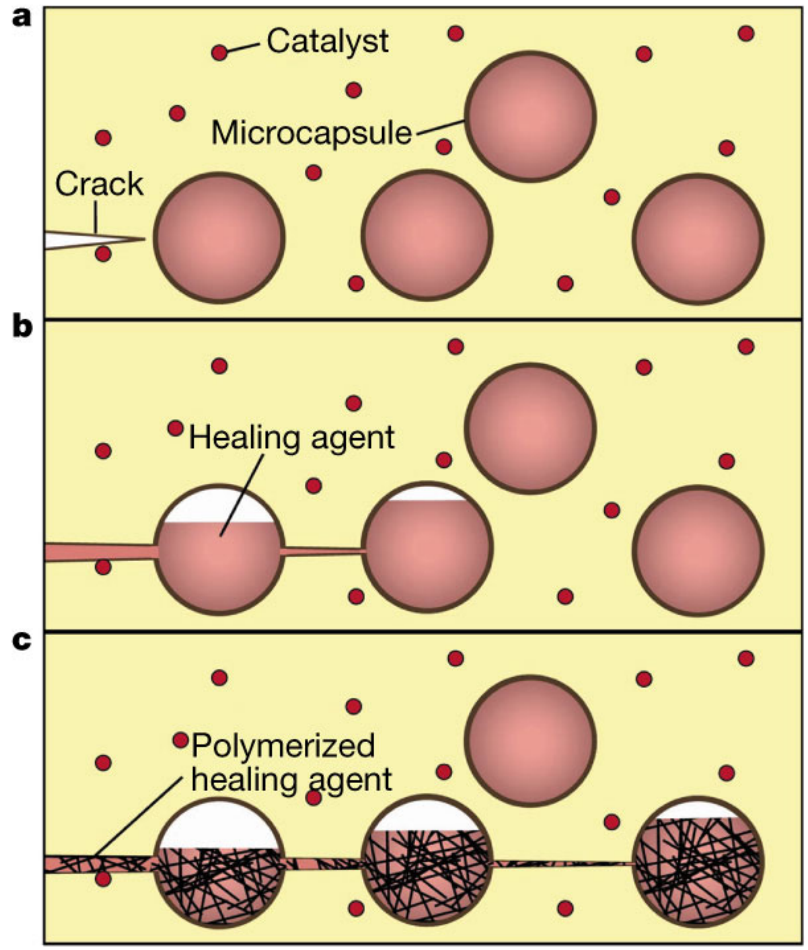
Matériaux auto-réparateurs

Concept

a) **Un agent réparateur (colle) est encapsulé à l'intérieur de microcapsules dispersées dans un polymère contenant un catalyseur.**

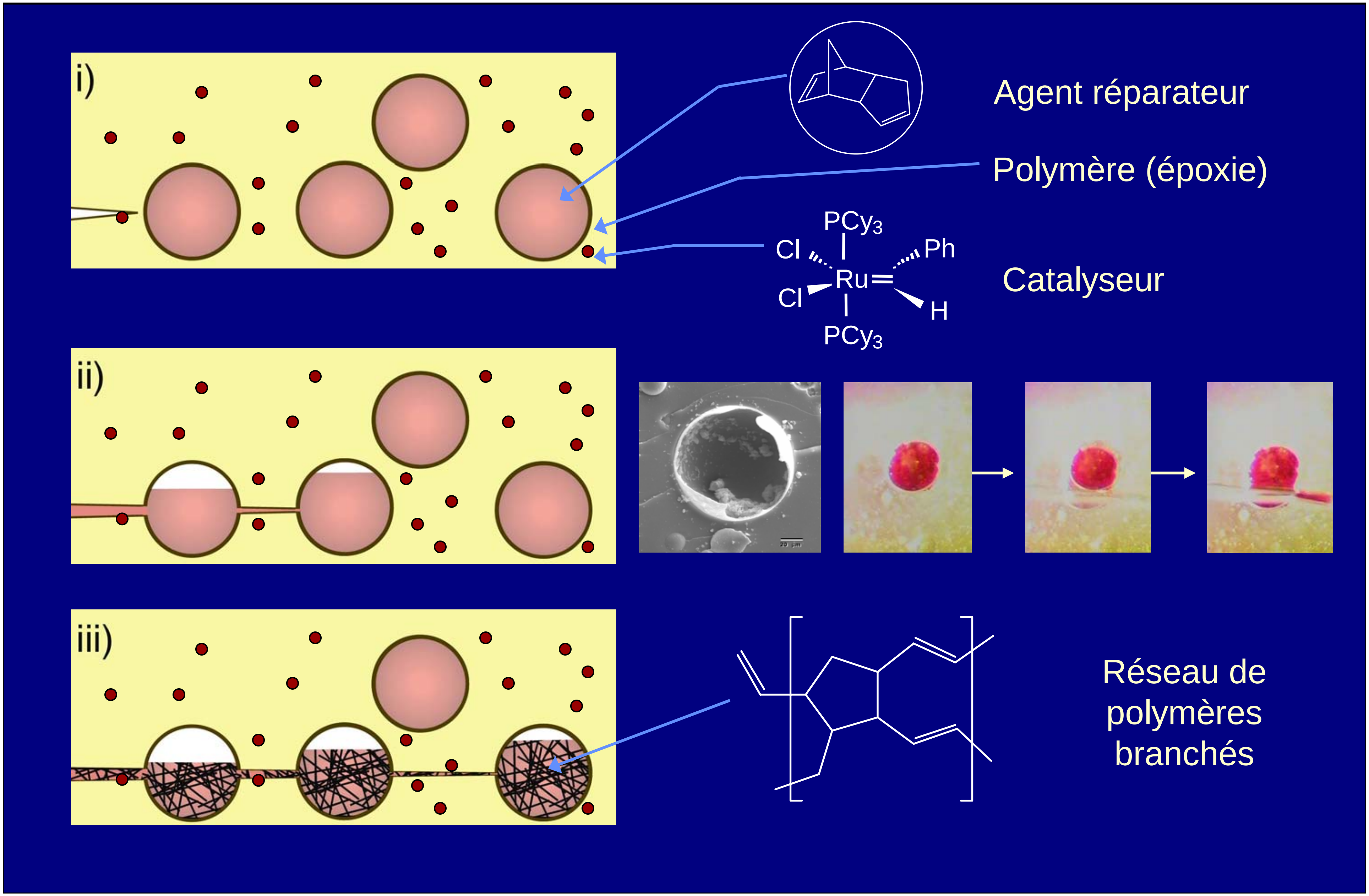
b) **Après l'endommagement du polymère, une microfissure se forme et brise les microcapsules relâchant l'agent réparateur.**

c) **La polymérisation se produit lors de la rencontre entre l'agent réparateur et le catalyseur.**



White et al., Nature (2001)

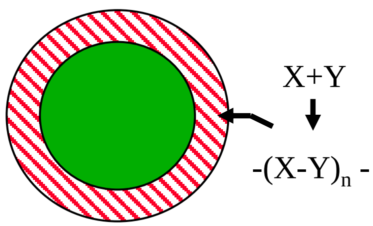
Matériaux auto-réparateurs: Concept



Matériaux auto-réparateurs: Microcapsules

Micro-encapsulation de l'agent réparateur

Polymérisation de la capsule



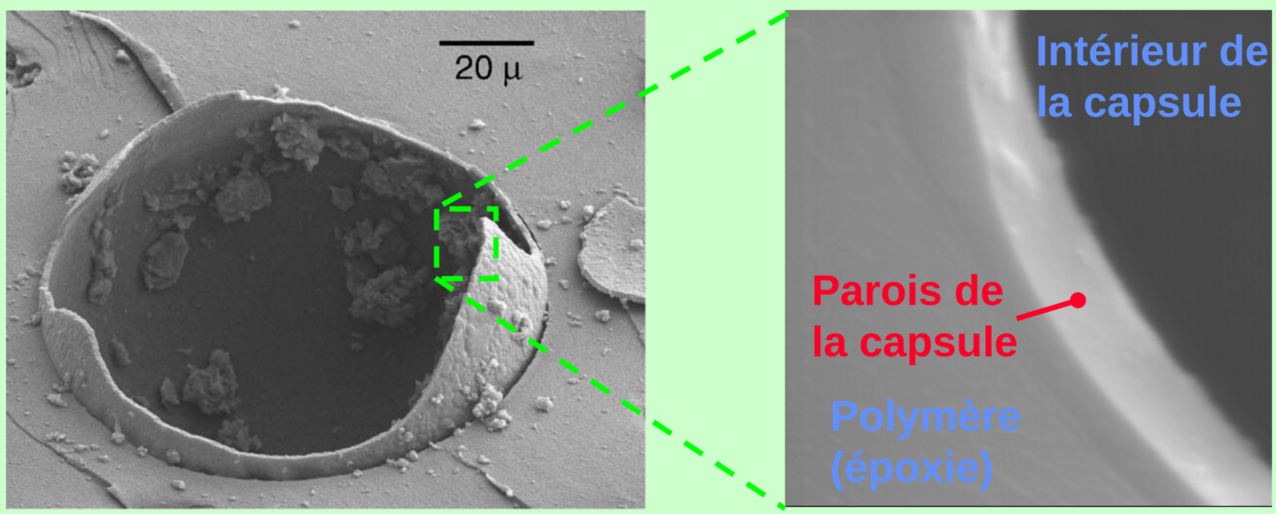
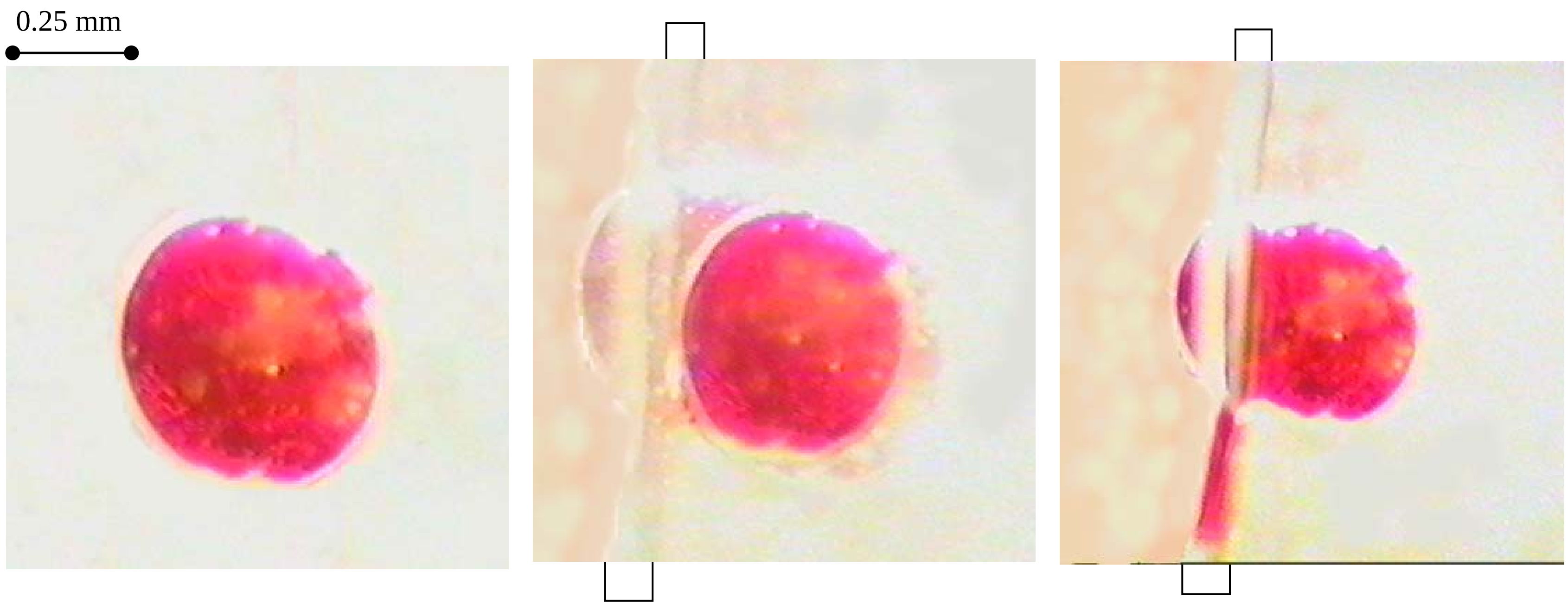


Image d'une microcapsule brisée prise par microscope SEM

(White, Nature 2001)

Matériaux auto-réparateurs

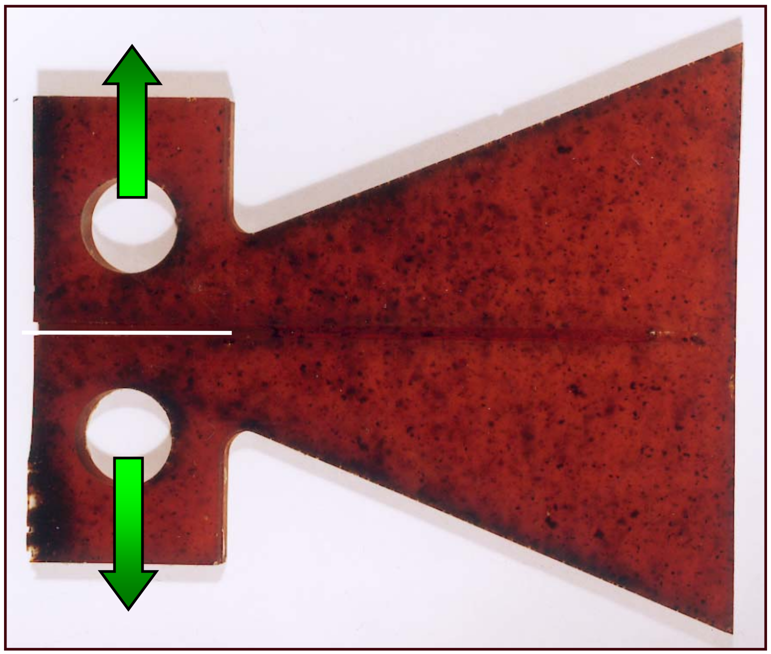
Transport de l'agent réparateur



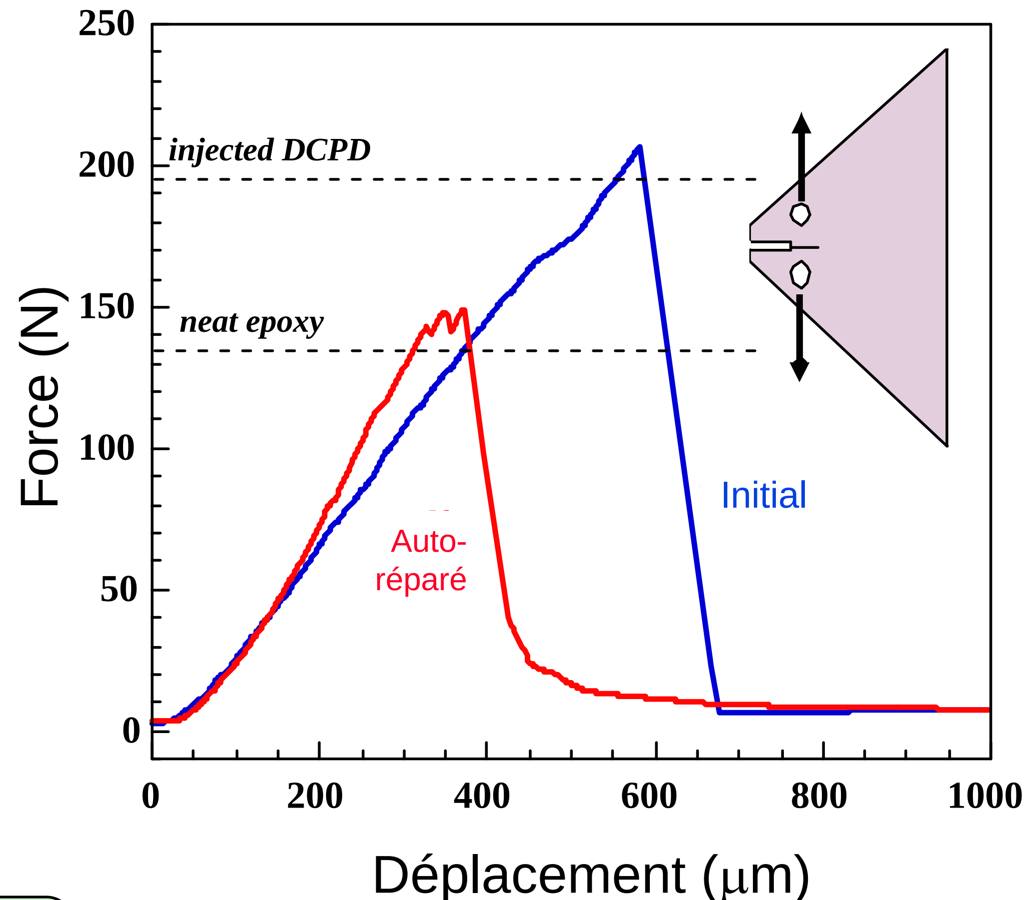
- Séquence d'images vidéo montrant la rupture et la propagation de l'agent réparateur
- Une encre rouge a été ajoutée pour visualisation
- Temps écoulé entre chaque image (~ 1/15 s)

Matériaux auto-réparateurs

Efficacité de la réparation



Échantillon pour test mécanique
(White, Nature 2001)



Récupération jusqu'à 90% de la ténacité initiale du matériau

Matériaux auto-réparateurs dans les médias

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Autonomic healing of polymer composites

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Structural polymers are susceptible to damage in the form of cracks, which form deep within the structure where detection is difficult and repair is almost impossible. Cracking leads to mechanical degradation[1–3] of fibre-reinforced polymer composites; in microelectronic polymeric components it can also lead to electrical failure[4]. Microcracking induced by thermal and mechanical fatigue is also a long-standing problem in polymer adhesives[5]. Regardless of the application, once cracks have formed within polymeric materials, the integrity of the structure is significantly compromised. Experiments exploring the concept of self-repair have been previously reported[6–8], but the only successful crack-healing methods that have been reported so far require some form of manual intervention[10–18]. Here we report a structural polymeric material with the ability to autonomically heal cracks. The material incorporates a microencapsulated healing agent that is released upon crack intrusion. Polymerization of the healing agent is then triggered by contact with an embedded catalyst, bonding the crack faces. Our fracture experiments yield as much as 75% recovery in toughness, and we expect that our approach will be applicable to other brittle materials systems (including ceramics and glasses).

Figure 1 illustrates our autonomic healing concept. Healing is accomplished by incorporating a microencapsulated healing agent and a catalytic chemical trigger within an epoxy matrix. An approaching crack ruptures embedded microcapsules, releasing healing agent into the crack plane through capillary action. Polymerization of the healing agent is triggered by contact with the embedded catalyst, bonding the crack faces. The damage-induced triggering mechanism provides site-specific autonomic control of repair. An additional unique feature of our healing concept is the use of living (that is, having unterminated chain-ends) polymerization catalysts, thus enabling multiple healing events. Engineering this self-healing composite involves the challenge of combining polymer science, experimental and analytical mechanics, and composites processing principles.

We began by analysing the effects of microcapsule geometry and properties on the mechanical triggering process. For example, capsule walls that are too thick will not rupture when the crack approaches, whereas capsules with very thin walls will break during processing. Other relevant design parameters are the toughness and the relative stiffness of the microcapsules, and the strength of the interface between the microcapsule and the matrix. Micromechanical modelling with the aid of the Eshelby–Mura equivalent inclusion method[19] has been used to study various aspects of the complex three-dimensional interaction between a crack and a microcapsule. An illustrative result from these studies is presented in Fig. 2a, which shows the effect of the relative stiffness of the microcapsule on the propagation path of an approaching crack. The crack, the sphere and the surrounding matrix are subjected to a far-field tensile loading, σ_∞, perpendicular to the crack plane.

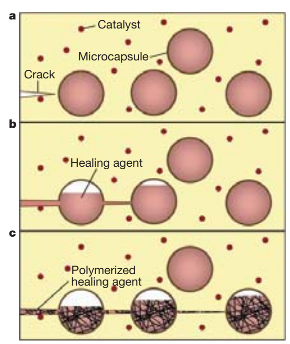

Figure 1 The autonomic healing concept. A microencapsulated healing agent is embedded in a structural composite matrix containing a catalyst capable of polymerizing the healing agent. **a**, Cracks form in the matrix wherever damage occurs; **b**, the crack ruptures the microcapsules, releasing the healing agent into the crack plane through capillary action; **c**, the healing agent contacts the catalyst, triggering polymerization that bonds the crack faces closed.

The Washington Post

Thursday, February 15, 2001

A Plastic That 'Heals' Itself

Innovation Could Extend Life of Everyday Items

By Guy Gugliotta
Washington Post Staff Writer

For years, scientists have tried to find an easier way to repair plastic—to make a tennis

ing special resin-filled capsules stored within the material itself.

"I wish I could say it was a case of waking up one morning, jumping out of bed and shouting, 'Eureka!'" said lead researcher

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MSNBC	Washington Post
National Geographic	Wired Magazine

Matériaux auto-réparateurs

But à long terme?

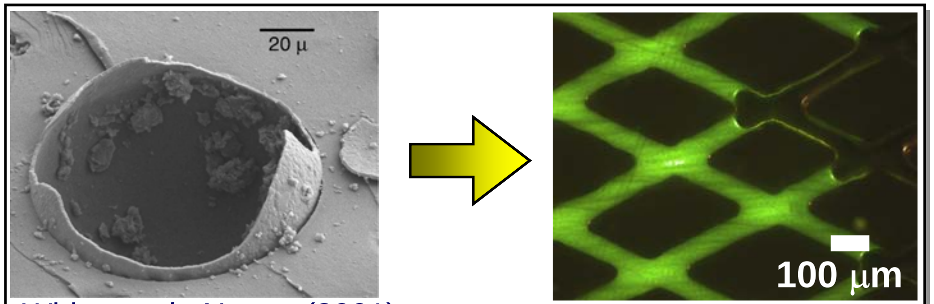
Avant

Après*

* Images tirées du film Terminator 2

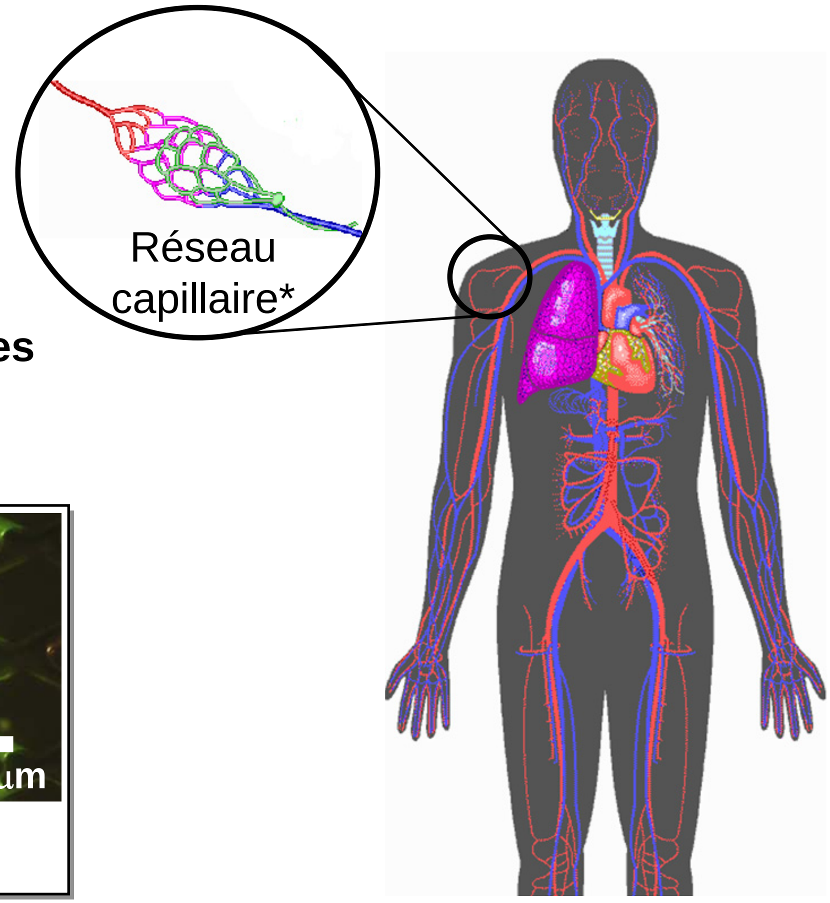
Matériaux auto-réparateurs

- **Deuxième génération de matériaux auto-réparateurs**
  - **Transport continuel de l'agent réparateur afin d'obtenir une réparation répétitive**
- **But**
  - **Reproduction d'un réseau microvasculaire à l'intérieur d'un matériau structural**
- **Caractéristiques du réseau**
  - **Résolution du micromètre, nombreuses inter connectivités, large réseau 3D, section circulaire des canaux**



White *et al.*, *Nature* (2001)

Microcapsules aux canaux



Système circulatoire humain*

*Images tirées des sites www.innerbody.com et Microangela