SELF-HEALING PROCESSES IN PLANTS – A TREASURE TROVE FOR BIOMIMETIC SELF-REPAIRING MATERIALS

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ABSTRACT

After an artificial injury in succulent leaves of *Delosperma cooperi* and *Delosperma ecklonis* rapid wound sealing by deformation of the entire leaf takes place within approximately 90 minutes. On the basis of comparative anatomical and biomechanical analyses of the closely related species conclusions can be drawn on necessary boundary conditions allowing self-sealing by leaf deformation and movement. An analytical model of the underlying principle found in *D. cooperi* has been developed as basis for the transfer into bio-inspired self-repairing materials.

1. INTRODUCTION

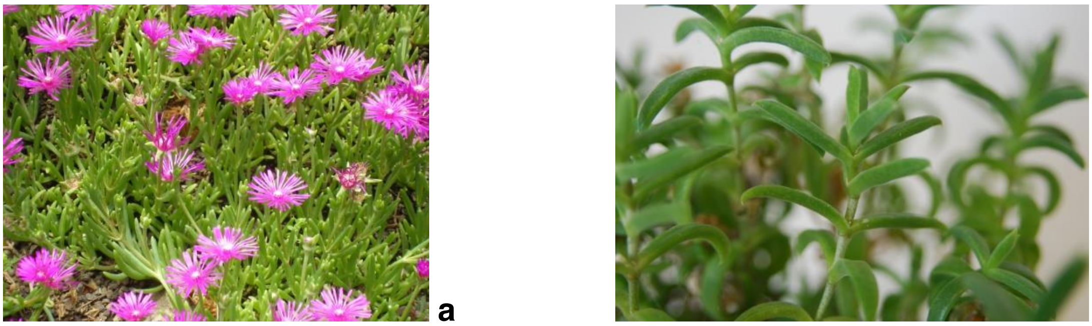
In the course of 3.8 billion years plants have evolved the amazing capacity to seal and heal wounds. In all plants examined we identified firstly a self-sealing phase and secondly a self-healing phase. The rapid self-sealing prevents the plants from desiccation and from infection by pathogenic germs. This gives time for the subsequent self-healing of the injury which in addition to wound closure also results in the (partly) restoration of mechanical properties of the plant organ.

Based on a variety of self-sealing and self-healing processes in plants different functional principles were successfully transferred into bio-inspired self-repairing materials [1,2]. Inspired by rapid self-sealing processes in the twining liana *Aristolochia macrophylla* and related species a biomimetic PU-foam coating for pneumatic structures was developed [3]. With respect to low coating weight and thickness of the foam layer maximum repair efficiencies of 99.9 % have been obtained [4-6]. Other role models are the weeping fig (*Ficus benjamina*) and the rubber tree (*Hevea brasiliensis*), in which the coagulation of latex is involved in the sealing of lesions [7]. Different self-sealing strategies for elastic materials are developed showing significant mechanical restoration after a macroscopic lesion [8,9].

In this study, three main aspects of self-repairing mechanisms are addressed: (1) the underlying principles and boundary conditions necessary for self-sealing in *Delosperma* leaves, (2) the evolutionary interaction between self-repair abilities of closely related *Delosperma* species and their respective ecological niches, and (3) the translation of the results into a reasonable concept for bio-inspired technical self-repairing materials

2. MATERIALS AND METHODS

Plant material — Both, *Delosperma cooperi* (Hook f.) L. Bolus and *Delosperma ecklonis* (Salm-Dyck) Schwantes are members of the Aizoaceae family, native to South Africa (Fig. 1). They are perennial plants forming dense lawns. *D. cooperi* reaches sizes of approximately 20-40 cm in height, with fleshy leaves and a trailing stem that hangs down. *D. ecklonis* grows to a height of approximately 25 cm having also succulent leaves. Test plants of *D. cooperi* and *D. ecklonis* were obtained from greenhouse cultivations in the Botanical Garden of the University of Freiburg (Germany).



a **b**

Figure 1: (a) *Delosperma cooperi*: flowering plants in the open field of the Botanic Garden Freiburg, (b) *Delosperma ecklonis* in the greenhouses of the Botanic Garden Freiburg.

Anatomical analyses — Thin sections of leaves were cut with a microtome from embedded material. Toluidinblue staining was used for discrimination between different leaf tissues. Parameters of cells and tissues were determined with the image analysis software IMAGEJ.

Mechanical analyses — Biomechanical properties of the entire leaves and of single tissue layers were studied in tensile tests performed on a custom-made micro-tensile-testing device (Fig. 2).

Self-repair mechanisms — Leaves were injured artificially with a razor blade. Tests were carried out with different cutting depth damaging various numbers of tissue layers. Three types of injuries were examined: longitudinal, transversal, and circular cuts.

Self-repair efficiency — In order to quantify the self-repair properties by leaf movement maximum bending angle and maximal angle velocity were measured at different air humidity.

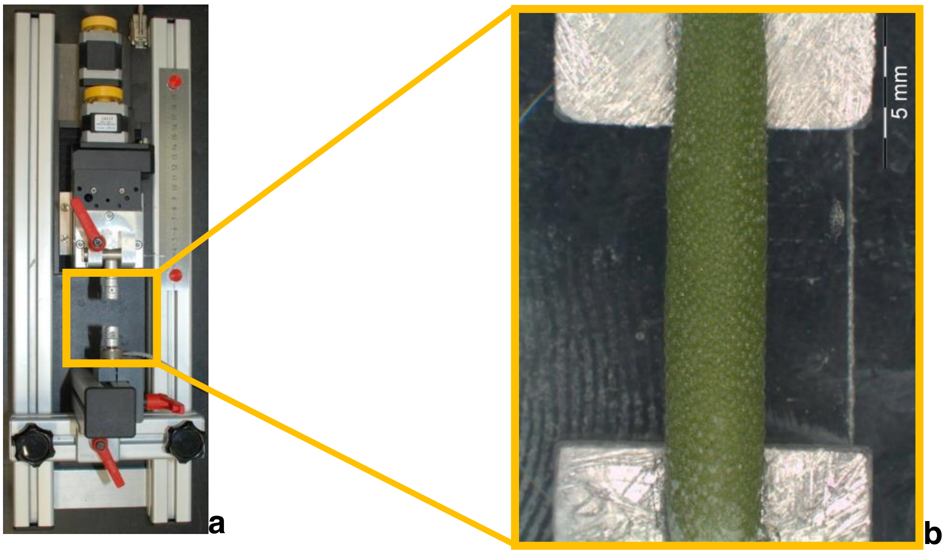


Figure 2: (a) Custom-made experimental set-up for tensile tests of small samples, (b) detailed view showing an entire leaf of *D. cooperi* glued on the measuring stage.

3. RESULTS AND DISCUSSION

Anatomical analyses —The form of leaf cross-sections in *D. cooperi* range from oval to round, whereas leaf form of *D. ecklonis* is three-cornered. Cross-sections of leaves of both species reveal a centripetal arrangement of five tissue types consisting of an outer layer of epidermis with window cells, a peripheral ring of chlorenchyma, a thin net made of vascular bundles, an inner ring of parenchyma and a strand of vascular bundles in the leaf centre. The vascular tissue consists in part of wide-band tracheids, a specialized type of tracheids that prevent cell collapse under water stress.

Mechanical analyses — Mechanical properties of the entire leaf and of single tissue layers were measured in tensile tests which render the basis for calculating Young's modulus and tensile strength [1,2].

Self-repair mechanisms — After an artificial injury wound sealing takes place by deformation and movement. Two principles are involved: (1) rolling in of the fringes of the lesion within a few minutes, and (2) curvature or contraction of the entire leaf within a time span of up to 90 minutes. Subsequent wound healing leads to a callus formation in the wound region [1,2].

Self-repair efficiency — Significant differences in maximum bending angle can be found at different air humidity. Dynamics of motion can be described by at least two characteristic curve shapes if bending angles are plotted over time [1,2].

Analytical model — An analytical model describing the self-sealing process in *D. cooperi* is developed. Based on geometrical and mechanical data of the entire leaf and its tissue layers the model describes stress-states of intact leaves and self-sealing of wounded leaves with regard to elastic and to visco-elastic behavior [10].

4. CONCLUSION

Quantitative anatomical and mechanical analyses and the development of models of the self-repairing process found in model plants are prerequisites for a successful transfer into innovative biomimetic self-repairing materials. In cases where mainly physical-chemical processes are involved a transfer is especially promising.

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