General Conclusions

Over the past 150 years, scientific researchers have examined the adhesive abilities of insects, spiders, reptiles, and geckos by examining their adhesive systems, climbing abilities, and adhesion mechanisms. Moreover, the anti-adhesive properties of some plants have attracted interest in understanding superhydrophobicity and self-cleaning properties. These properties are related to the anti-adhesion of water and dirt. Finally, the strong behaviour of spider silk has suggested interesting applications because of its structural and mechanical properties.

In nature, the common key of adhesive (Chapters 1-5), antiadhesive (Chapters 6-7) and strong (in Chapter 8) properties of materials exists at the nanoscale: from the super-adhesive terminal unit contacts of geckos (spatulae, ~200 nm wide and 15-20 nm thick) to the finest super-anti-adhesive structure of lotus leaves (nanotubules, diameter of ~200 nm) to the fibroin protein of spider silks.

In Chapter 1, we demonstrate that living Tokay geckos (*Gekko gecko*) display adhesion times following Weibull statistics. The Weibull shape (m) and scale (t_0) parameters quantitatively describe the statistics of adhesion times of different geckos (male and female) on glass and Poly(methyl meth-acrylate) (PMMA) ($m_{PMMA} \approx 1$ and $t_{0PMMA} \approx 800$ s *versus* $m_{Glass} \approx 2$ and $t_{0Glass} \approx 23$ s).

Chapter 2 confirms that the Weibull modulus has a value in the restricted range of 1-1.2 when both virgin and machined PMMA surfaces are considered.

Chapter 3 highlights the normal adhesive abilities of living Tokay geckos adhering to PMMA and glass surfaces. The normal safety factor λ, the ratio between the maximum normal adhesive force and the body weight, was thus determined as $\lambda_{PMMA} = 10.23$ on PMMA surface and $\lambda_{Glass} = 9.13$ on glass surface. In addition, the self-renewal of the gecko's adhesive system after moulting was documented.

Chapter 4 investigates the adhesion angles of living Tokay geckos at two different hierarchical levels of the feet and toes. The adhesion angles between opposing front and rear feet (β_F) and between the first and fifth toe of each foot (β_T) on different inverted surfaces (steel, aluminium, copper, Poly(methyl meth-acrylate), and glass) have been experimentally measured. The resulting angle α was computed as α= (180°-β)/2 and found to be to 28° (α_{F_FR-RL}) and 30° (α_{F_FL-RR}) for the opposing front and rear feet and 26° (α_{T_FR}), 29° (α_{T_FL}), 28° (α_{T_RR}), and 26° (α_{T_RL}) between the first and fifth toe of each foot. Such results are consistent with the recently described multiple peeling theory: as the number of hierarchical level n increases, the dimensionless adhesion strength parameter λ decreases and determines a decrease of the adhesion angle α.

Chapter 5 ends the first section of this study on adhesive materials. In this chapter, the shear adhesive force of four non-climbing living cockroaches (*Blatta Orientalis* Linnaeus) was investigated using a centrifuge machine on six surfaces (steel, aluminium, copper, two sand papers (Sp 50, Sp150), and a common paper sheet). The shear safety factor was determined as the ratio between the maximum shear adhesive force and the body weight: the cockroach's maximum shear adhesive factor is 12.1 on Sp150, whereas the minimum shear adhesive factor is 1.9 on steel surface.

Chapter 6 displays the effects of two superficial industrial processes (plasma and thermoforming) on the surface wettability of polystyrene (PS). This analysis was developed in collaboration with the Indesit Company and suggests that plasma and thermoforming are ideal treatments to tune the wettability and enhance hydrophilic or hydrophobic behaviour of PS surfaces, respectively.

Chapter 7 shows how an artificial biomimetic hydrophobic polystyrene (PS) surface can be constructed by copying a natural lotus leaf with a simple template method at room temperature and atmospheric pressure. Two parameters were used to compare the artificial PS surface *vs* the natural lotus leaf: the contact angle, of 149° *vs.* 153°, and the drop sliding speed, of 417 mm/s *vs.* 319.4 mm/s, respectively.

Chapter 8 is concerns the natural stretchable egg sac silk stalks of the cave spider *Meta menardi*. Bundles of about 150 threads (each of ~6 μm in diameter) connecting the egg sac (cocoon) to the cave ceilings were tested to determine stress-strain curves, and the stress results were analysed with Weibull statistics. The maximum stress, strain, and toughness modulus reach the values of 0.64 GPa, 750 %, and 130.7 MJ/m^3, respectively. The average value of the Weibull modulus (m) is in the range 1.5-1.8, and that of the Weibull scale parameter (σ_0) is in the range 0.33-0.41 GPa with a high correlation coefficient (R^2 = 0.97).

As the mechanisms in nature governing adhesive, anti-adhesive, and strong properties become better understood, these mechanisms will be imported into human technology. A super-adhesive and reusable material has great potential for space applications (*i.e.* connections between space components or suits and gloves for astronauts, which would allow them to remain attached to the external side of a space shuttle without awkward cables); a super-hydrophobic and self-cleaning material could have great utility for civil engineering applications (*i.e.* the glass windows of skyscrapers or external building coverings) or even air transport security (*i.e.* a superficial pattern to anti-ice airplane wings) or home technology (*i.e.* the internal faces of refrigerators or freezers and the surfaces of bathroom fittings or tiles). Finally, a super-stretchable material has potential industrial applications for air transport security (*i.e.* security systems to decrease the velocity of an airplane or large webs to stop hijacked airplanes).

Although efforts to industrialize products like those mentioned above are considerable, only a few patents have been duly deposited at the European Patent Office in these fields of research. In particular, the number of patents with the words "super adhesive reusable" as title keywords is equal to zero, whereas there are eight patents for inventions with the title keywords "self cleaning super hydrophobic" during the last eight years (i.e. a current rate of one European patent per year) and only one patent with the keyword "super stretchable" has been deposited in 1987.

As we survey, the current cutting-edge technology, we understand the multitude of possibilities that exist to become Innovators who develop new products in these fields of scientific research. Nevertheless, only a deep and detailed knowledge of what happens in nature and the understanding of how nature has optimized each process, mechanism, and animal to its own habitat will allow the development of new engineered products.