Effect of moisture aging on the interfacial strength of adhesive joints: An overview

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Introduction

Adhesives are severely affected by environmental factory and service conditions, such as humidity. In adhesive joints, although the adhesives and substrates can degrade their properties in humid environments, **failure after moisture degradation is mainly interfacial**.
Therefore, a literature review on the influence of this factor on the interfacial properties of adhesive joints is performed.

Mechanisms and effects of moisture aging

Water diffusion may happen in four different ways, Figure 1 [1]:

1. Diffusion into the **adhesive**;
2. Diffusion into the **interface** between the adhesive and the substrate;
3. Diffusion **by capillarity in the pores and cracks of the adhesive**;
4. Diffusion through the **substrate**.

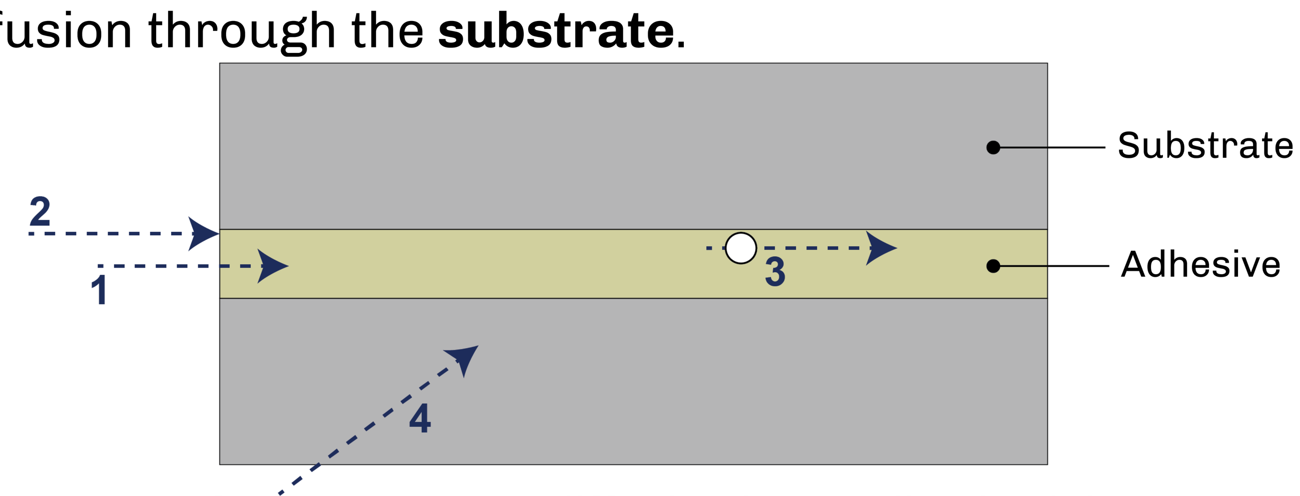

Figure 1 – Water diffusion in an adhesive joint.

1. Diffusion into the adhesive

Water can be absorbed by polymers, such as the adhesive or the resin of composite substrates, as free water and bound water, Figure 2 [2]:

- **Free water**, which **fills the free spaces** on the polymeric chain;
- **Bound water**, which **forms hydrogen bonds** with the chain.

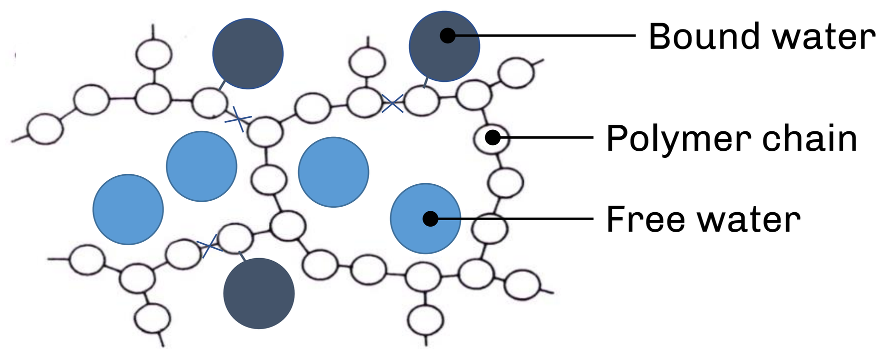

Figure 2 – Free water and bound water in a polymer.

Water, or other solvent that diffuses through the adhesive, can contribute to the swelling of the adhesive. As the adhesive swells in a joint, restricted by the substrates, it causes **interfacial stress**, which may lead to **interfacial failure**, Figure 3 [3].

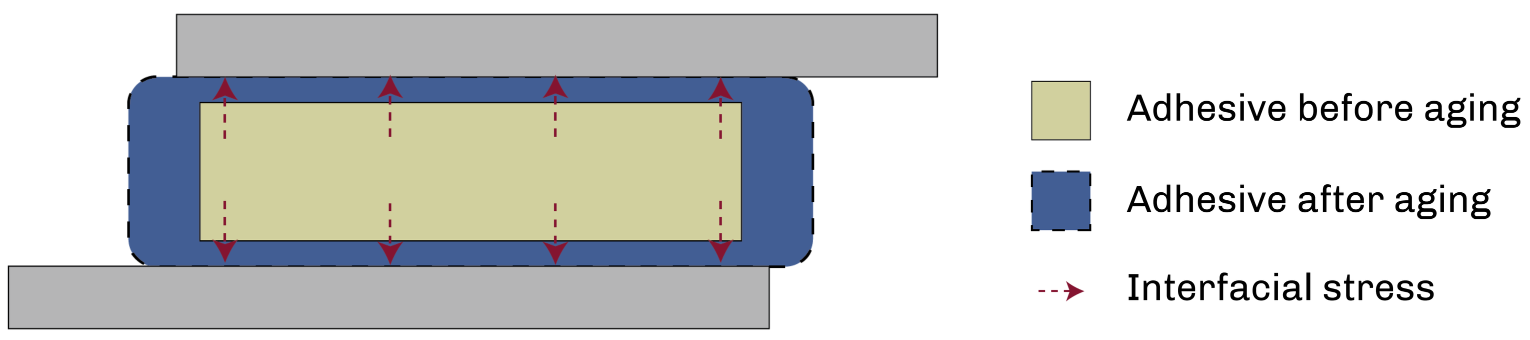

Figure 3 – Swelling of adhesive in an adhesive joint.

2. Diffusion into the interface between the adhesive and the substrate

Diffusion in the adhesive/substrate interface may occur due to the **difference in surface tension** between the "humid" adhesive and the substrate and between the "dry" adhesive and the substrate, which favors water diffusion into the joint, Figure 4 [4]. As the material in the interfacial area has more water, it is more degraded, which will contribute to **interfacial failure**.

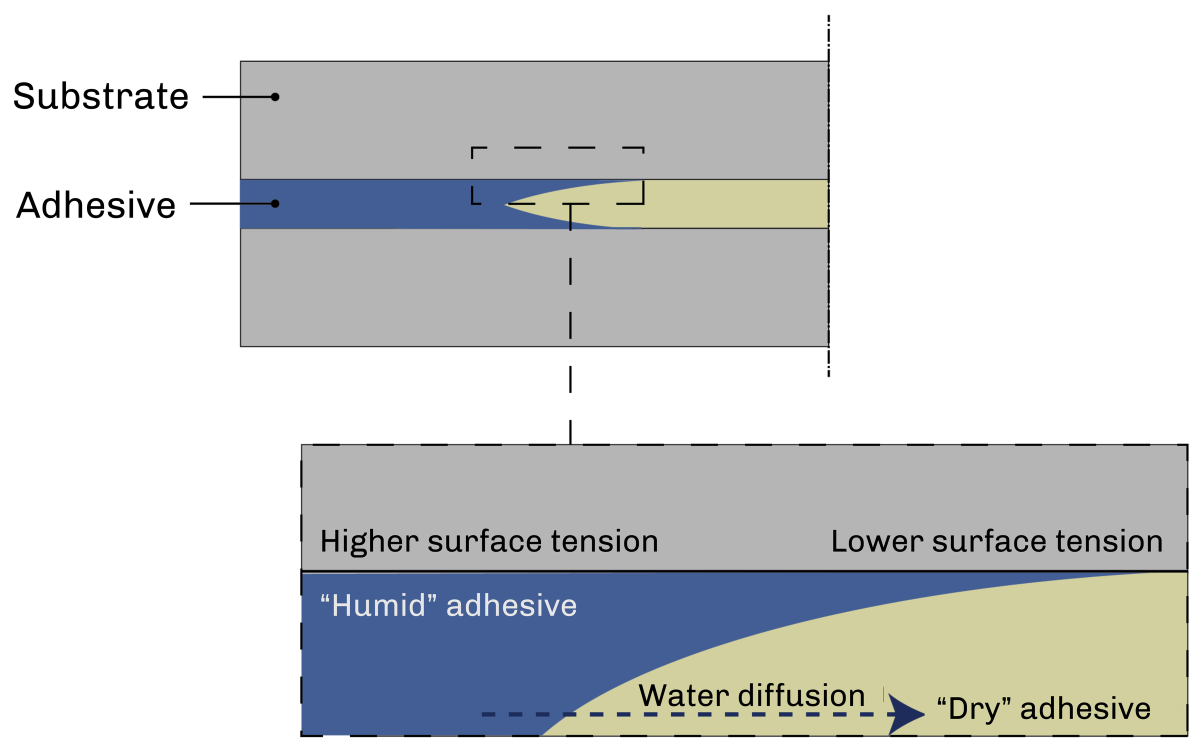

Figure 4 – Water diffusion through the adhesive/substrate interface.

3. Diffusion by capillarity in the pores and cracks of the adhesive

When water is adsorbed by porous solid materials, it will condensate [25]. Capillary diffusion can cause interfacial failure, through the process of, after condensing, creating an **osmotic pressure at the interface**, which causes the adhesive to **debond**, Figure 5.

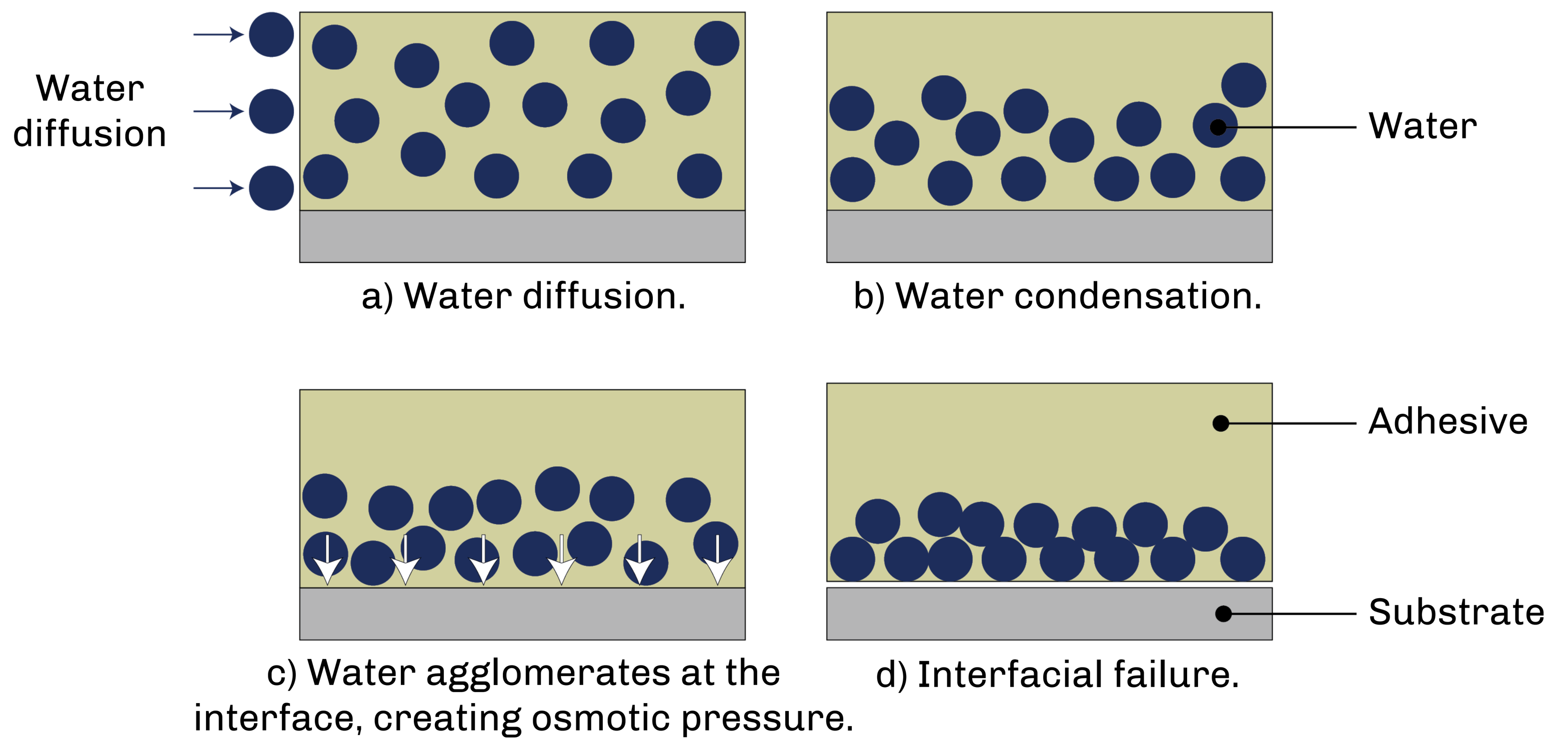

Figure 5 – Water diffusion in an adhesive joint.

4. Diffusion through the substrate

Substrates, typically, can be either composite materials or metals. **Metallic substrates** can create a corrosion layer or some **migration of components of the substrate to the surface** [6], these components or corroded areas will act as **contaminants**.
In composite substrates, the matrix is usually much more hydrophilic than the fibers, or other inclusions. Therefore an analogy between the phenomena described for adhesive joints and composite materials may be performed, where the **matrix corresponds to the adhesive** and the **fiber to the substrate**, Figure 6, which may cause **fiber/matrix debond** [2,7].

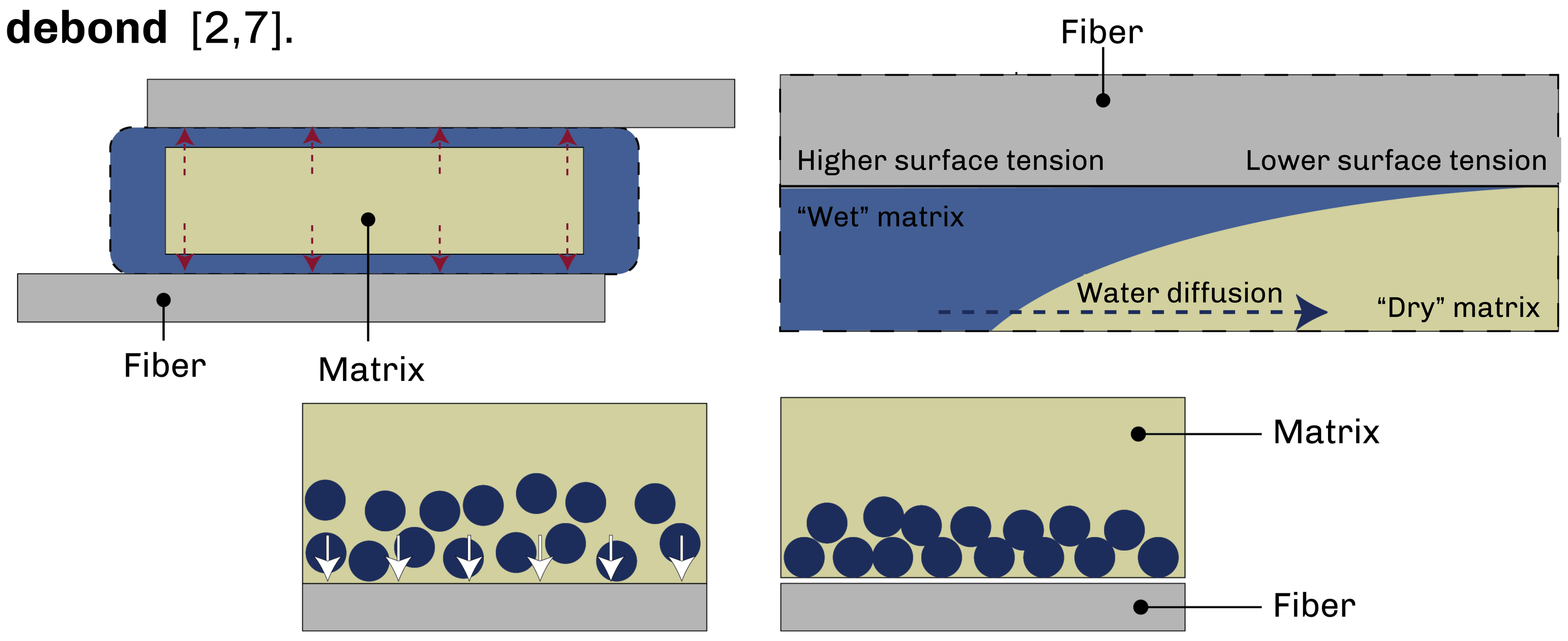

Figure 6 – Matrix/fiber and adhesive/substrate analogy.

Conclusions

It was concluded that moisture diffusion can contribute to a **reduction in joint strength** and a higher likelihood of **interfacial failure**. Water absorption causes interfacial failure because of **swelling** (which, when the adhesive is restricted by the substrates, creates interfacial stresses), **absorption along the interface** (which promotes a higher degradation of the interfacial region) and **condensation near the interface** (which creates interfacial stress due to osmotic pressure). Finally, an analogy may be done between the **matrix/fiber interface and the adhesive/substrate interface.**

References

[1] Comyn, J., *Durability of structural adhesives.* Applied Science, London, 1983.
[2] Barbosa, A., L. da Silva, and A. Öchsner, Hygrothermal aging of an adhesive reinforced with microparticles of cork. Journal of Adhesion Science and Technology, 2015. 29(16): p. 1714-1732.
[3] Grangeat, R. (2019). Durabilité des assemblages collés en environnement humide: instrumentation par capteurs à fibre optique (Doctoral dissertation, Nantes).
[4] Zanni-Deffarges, M. P., & Shanahan, M. E. R. (1995). Diffusion of water into an epoxy adhesive: comparison between bulk behaviour and adhesive joints. International Journal of Adhesion and Adhesives, 15(3), 137-142.
[5] Cognard, P. (2004). Collage des Composites: Construction Aerospatiale, Automobile et Ferroviaire. Ed. Techniques Ingénieur.
[6] Cambier, S. M., Posner, R., & Frankel, G. S. (2014). Coating and interface degradation of coated steel, Part 1: Field exposure. Electrochimica Acta, 133, 30-39.
[7] Eftekhari, M., & Fatemi, A. (2016). Tensile behavior of thermoplastic composites including temperature, moisture, and hygrothermal effects. Polymer Testing, 51, 151-164.

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