Hygrothermal ageing of adhesives subjected to cyclic humidity conditions

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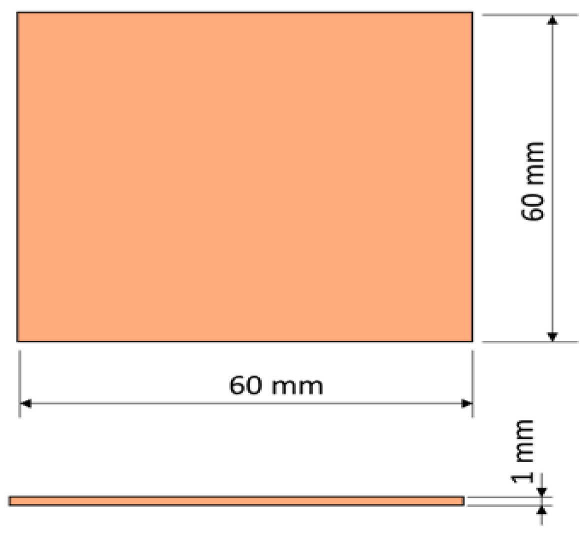
Introduction

The application of adhesive joints is still limited due to the significant influence of the hygrothermal ageing on the performance of the joints. Analysis of adhesive properties degraded by aggressive environments has attracted many attentions [1]. Generally, water absorption process can be simulated with the Fick´s law of diffusion, in which the water diffusion of the adhesive is a function of the square root of time divided by the thickness of the specimen. However, in some cases water diffusion is a two-stage procedure.

Experimental methodology

To investigate the water diffusion process, bulk plate with the thickness of 1 mm was manufactured and immersed in distilled water (Fig. 1).

Figure 1 - Bulk plate adhesive according to ISO/DIS 294-3



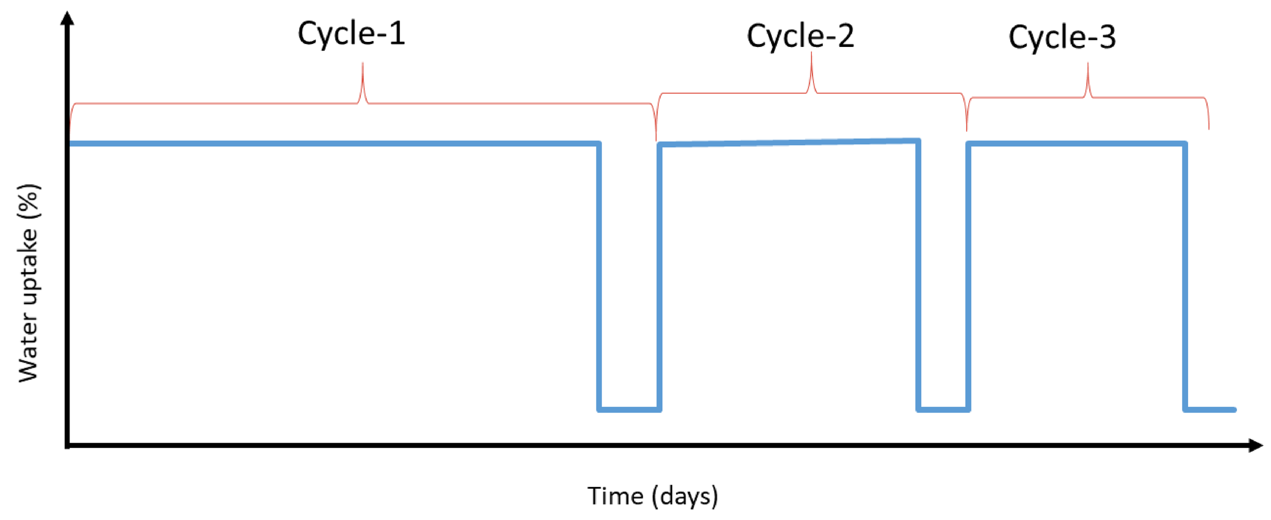


Figure 2 - Aging time for each cycle where the level of water uptake is controlled

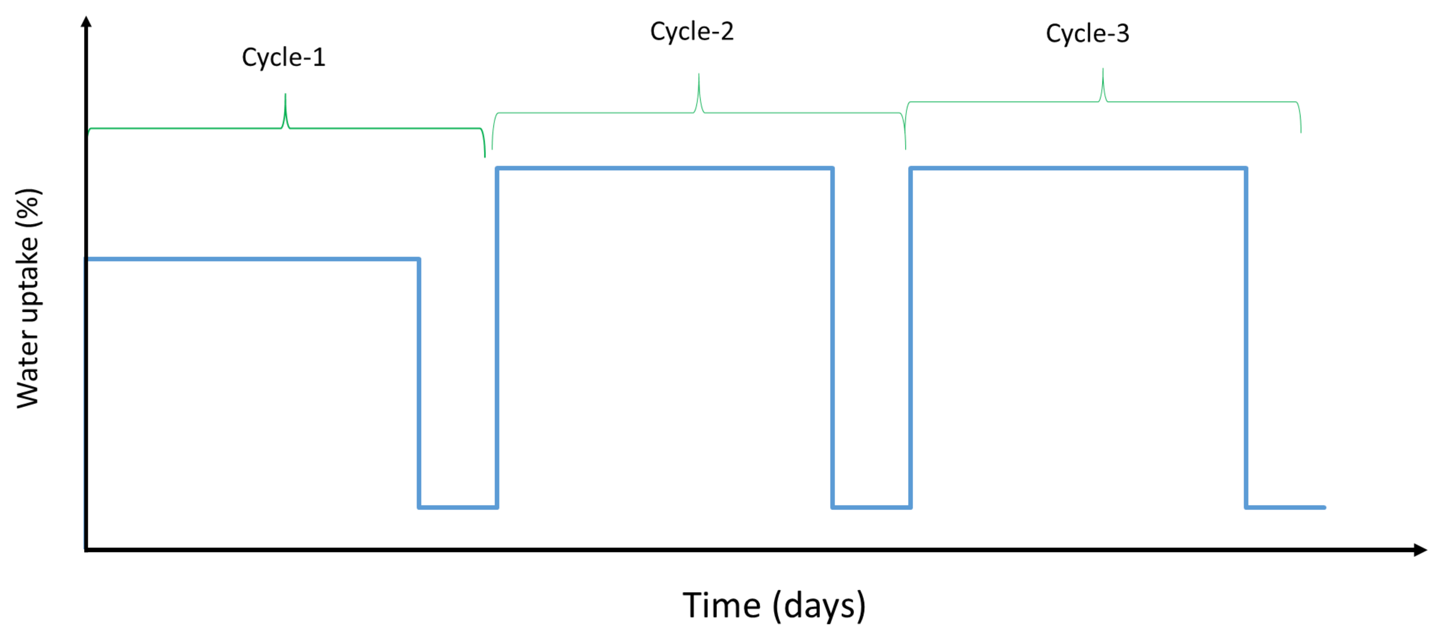


Figure 3 - Level of water uptake for different ageing cycle where the ageing time is controlled for each cycle

Fick`s law

The diffusion coefficient of the adhesives can be determined by using Eq. 1. The percentage of water absorption and desorption in the adhesive can be calculated by using Eqs. (2) and (3) respectively.

$$D = \pi\left(\frac{h}{4M_\infty}\right)^2\left(\frac{M_t}{\sqrt{t}}\right)^2 \qquad (1)$$

$$M_t = \left(1 - \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}e^{\left(\frac{-D_1(2n+1)^2\pi^2 t}{4h^2}\right)}\right) \times M_{1\infty} + \emptyset(t-t_d) * \left(1 - \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}e^{\left(\frac{-D_2(2n+1)^2\pi^2 t}{4h^2}\right)}\right) \qquad (2)$$

$$M_t = M_r + \left(\frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}exp\left(\frac{-D_d(2n+1)^2\pi^2 t}{4h^2}\right)\right) \times (M_\infty - M_r) \qquad (3)$$

Experimental results

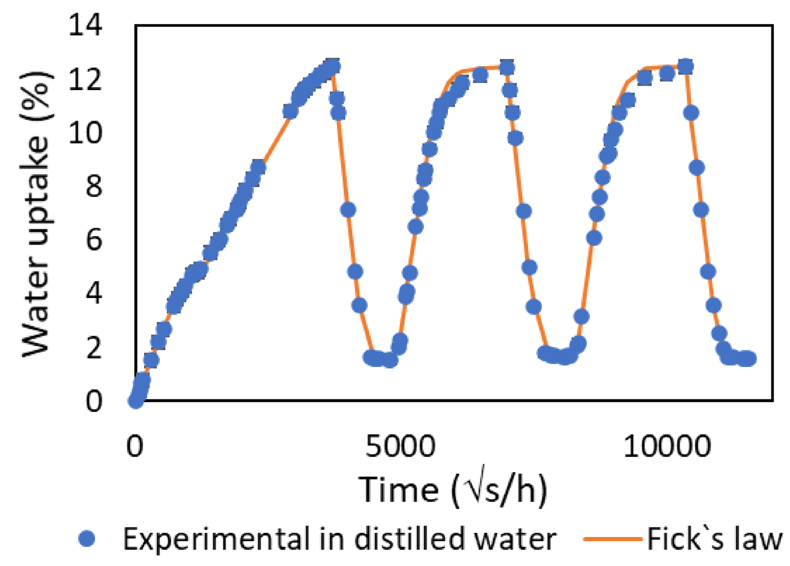


Figure 5 - Cyclic ageing by controlling the level of water uptake (12.49%) of the adhesive in distilled water

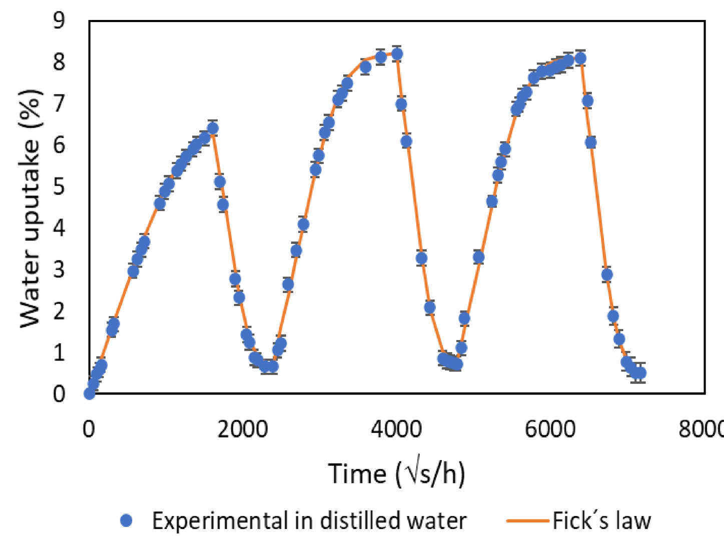


Figure 6 - Cyclic ageing by controlling the ageing time (1 month) of the adhesive in the

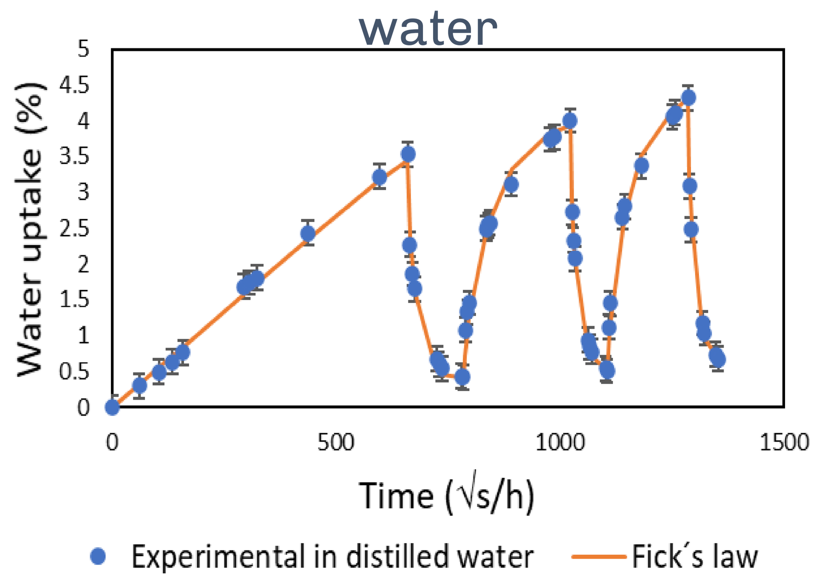


Figure 7 - Cyclic ageing by controlling the ageing time (5 days) of the adhesive in distilled water

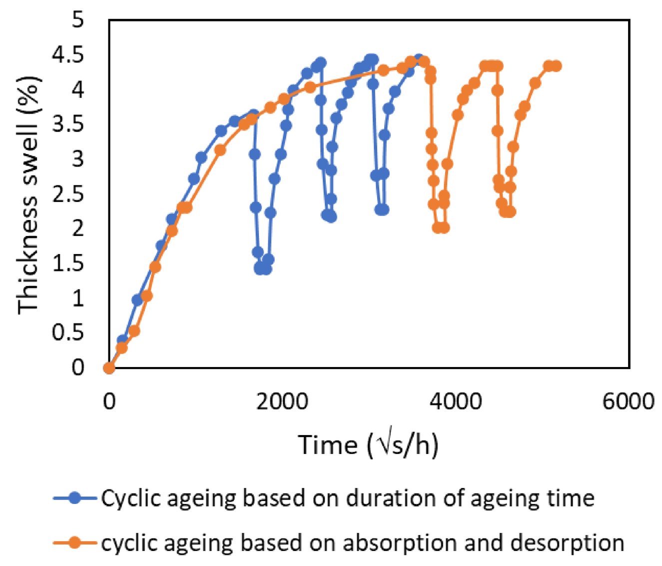


Figure 8 – The thickness swelling of two different ageing cycles

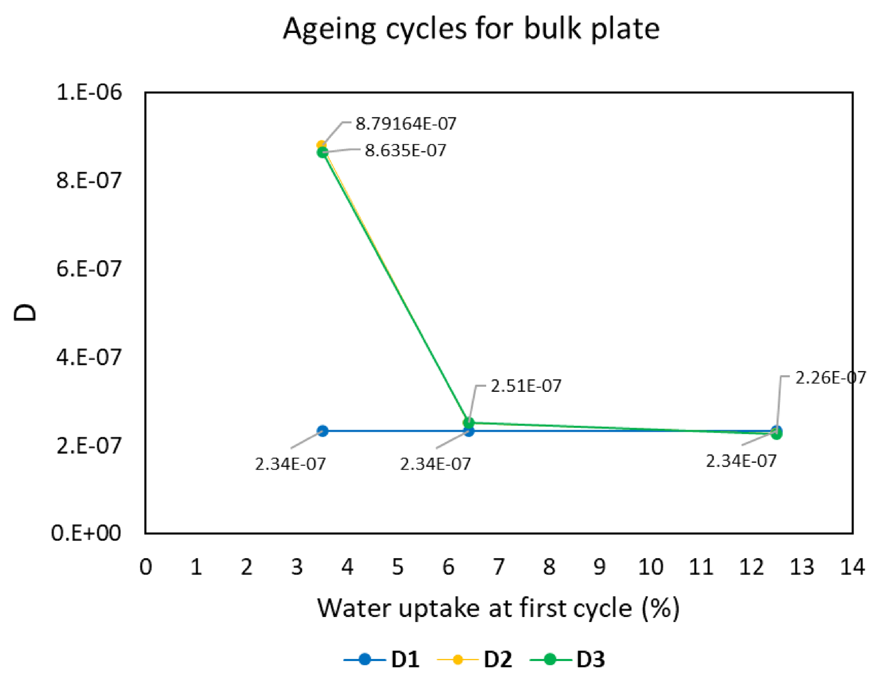


Figure 9 – Comparisons of the diffusion coefficient of the ageing cycles

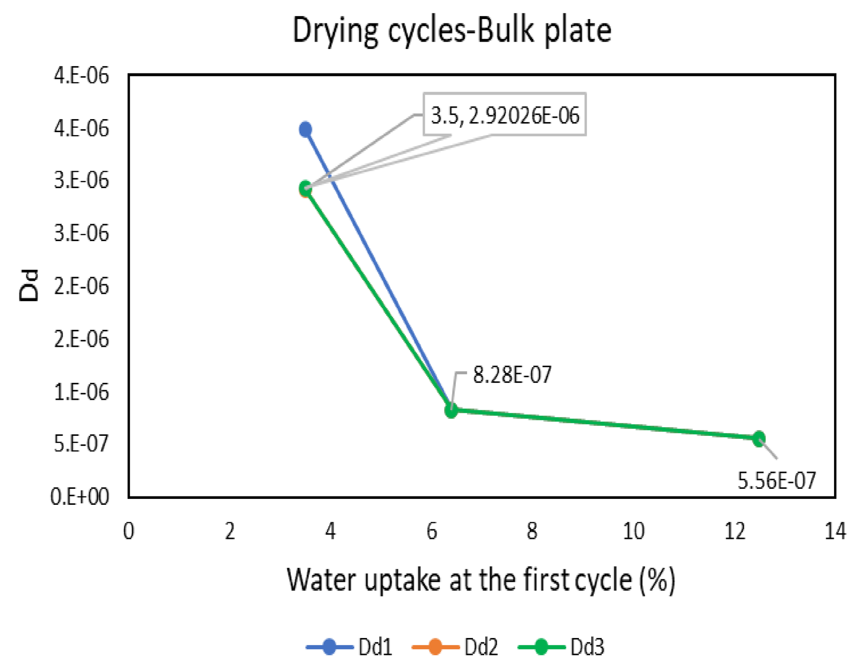


Figure 10 – comparisons of the diffusion coefficient of the drying cycles

Conclusions

Cyclic ageing of the same adhesive offered a very striking difference between diffusion coefficient (*D*).
In cyclic ageing the *D* is different for different ageing cycles. For the second cycle the value of *D* increases but it almost remains constant for the next cycles. It means that the aging time to reach the same level of water uptake is shorter for the second cycle compared to the first cycle. Therefore the diffusion coefficient of single cycle ageing for cyclic aging is neoconservative. The adhesive demonstrated that the thickness swelling is increased very progressively when performing hygrothermal ageing in distilled water. More moisture is absorbed in distilled water, consequently the thickness swelling is also higher for ageing in distilled water.

References

[1] Viana, G., et al., *Behaviour of environmentally degraded epoxy adhesives as a function of temperature.* The Journal of Adhesion, 2017. **93**(1-2): p. 95-112.
[2] Machado, J., et al., *Effect of hygrothermal aging on the quasi-static behaviour of CFRP joints varying the overlap length.* Composite Structures, 2019. **214**: p. 451-462.