

## MECHANICAL BEHAVIOR OF FLAX BIOCOMPOSITES EXPOSED TO ADBLUE AND WATER

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### Abstract

Flax-fibre-reinforced epoxy biocomposites are attractive for lightweight and recycling-oriented structures, yet the hygroscopic nature of flax reinforcement raises concerns about their durability under exposure to water and automotive operating fluids. This study evaluates the gravimetric uptake and tensile behaviour of woven flax/epoxy laminates after immersion in water and AdBlue. Laminates based on plain-weave flax fabric and the epoxy system were prepared by hand lay-up using three fabric layers. The fibre volume fraction was 46.4 %. Flat specimens were conditioned by immersion for 720 h at 20 °C. Gravimetric measurements showed an average mass gain of 9.50 wt % after water exposure and 8.00 wt % after AdBlue exposure. Tensile tests were performed on a Shimadzu AG-X 50 kN machine equipped with an integrated extensometer at 2 mm/min in accordance with ISO 527-4. The reference specimens reached an average tensile strength of  $68.39 \pm 2.99$  MPa and an apparent tensile modulus of  $6.89 \pm 0.16$  GPa. Water conditioning reduced these values to  $62.11 \pm 3.89$  MPa and  $5.31 \pm 0.32$  GPa, whereas AdBlue caused a greater decrease to  $57.43 \pm 2.83$  MPa and  $4.69 \pm 0.17$  GPa. Although water produced the higher gravimetric uptake, AdBlue caused the more pronounced deterioration in tensile performance, suggesting that the severity of degradation was not governed solely by the absorbed mass.

**Keywords:** Flax fibre, epoxy biocomposite, water ageing, AdBlue, gravimetric uptake

### 1. INTRODUCTION

Flax-fibre-reinforced polymer composites are among the most promising natural-fibre systems for lightweight engineering applications because they combine low density, renewable origin and competitive specific mechanical performance [1]. Nevertheless, recent application-oriented studies on flax/epoxy laminates exposed to humid or wet-service environments show that environmental durability remains a major barrier to broader structural deployment [2].

A key limitation of flax-based composites is the hygroscopic behaviour of the lignocellulosic reinforcement. Moisture uptake may lead to fibre swelling, matrix plasticization and degradation of the fibre-matrix interface, which in turn reduces stiffness, strength and dimensional stability [3-7]. In addition, moisture already present in flax fabrics prior to laminate manufacturing can adversely affect composite quality and the resulting mechanical response [8].

Besides water exposure, components operating in vehicle-adjacent environments may also come into contact with AdBlue, i.e. the commercial aqueous urea solution AUS 32 used in SCR systems [9]. The present work therefore compares the gravimetric uptake and tensile behaviour of a plain-weave flax/epoxy laminate in three states: unconditioned, water-conditioned and AdBlue-conditioned. The aim is to quantify how fixed-time immersion influences mass gain, tensile strength, strain at maximum stress and apparent tensile modulus.

## 2. MATERIALS AND METHODS

### 2.1 Material system and specimens

The tested laminate was manufactured by hand lay-up from three layers of plain-weave flax fabric with an areal weight of 400 g/m<sup>2</sup>. The polymer matrix consisted of epoxy resin LH 288 and hardener H 505 (Havel Composites), mixed in a mass ratio of 100:26. After lay-up, the laminate was allowed to cure for 24 h and was then further cured at room temperature for 14 days. The final laminate thickness was 3.8 mm on average. The measured fibre volume fraction was 46.4 %. Flat tensile specimens with nominal dimensions of 250 x 25 x 3.8 mm were machined from the laminate.

### 2.2 Conditioning procedure

Three specimen groups were considered: an unconditioned reference group, a water-conditioned group and an AdBlue-conditioned group. Conditioning was performed by full immersion for 720 h at 20 °C. After removal from the liquid, the conditioned specimens were freely air dried at room temperature for 24 h before tensile testing. Gravimetric data were recorded before immersion and after the 720 h immersion period, allowing the mass gain induced by each conditioning medium to be evaluated. The present dataset therefore represents a comparative fixed-time exposure study.

### 2.3 Tensile testing and data processing

Tensile testing was carried out on a Shimadzu AG-X 50 kN Autograph machine in accordance with ISO 527-4 [10]. The test speed was 2 mm/min and strain was measured using the machine's integrated extensometer with a gauge length of 150 mm. Ten specimens were tested in each conditioning state. Engineering stress was calculated from the recorded force using the nominal cross-section area, and engineering strain was calculated from extensometer displacement and gauge length. To suppress the effect of preload differences between specimens, each force record was zero-shifted to its initial value. The apparent tensile modulus was estimated as the secant slope between 0.05 % and 0.25 % strain.

## 3. RESULTS AND DISCUSSION

The principal tensile-test results are summarized in **Table 1**. **Figure 1** presents the average engineering stress-strain curves, **Figure 2** shows boxplots of the principal tensile descriptors, **Figure 3** compares gravimetric uptake with the retention of tensile properties, and **Figure 4** shows representative SEM images of the fracture surfaces. The reference specimens exhibited the steepest initial slope and the highest peak stress, while both conditioning media shifted the response towards lower stiffness and lower maximum stress. At the same time, the strain at maximum stress increased after exposure.

**Table 1** Summary of tensile-test results for the investigated conditioning states

| Condition          | <i>n</i> | <i>F</i> <sub>max</sub> (kN) | <i>σ</i> <sub>max</sub> (MPa) | <i>ε</i> at <i>σ</i> <sub>max</sub> (%) | <i>E</i> <sub>app</sub> (GPa) |
|--------------------|----------|------------------------------|-------------------------------|-----------------------------------------|-------------------------------|
| Reference (dry)    | 10       | 6.497 ± 0.284                | 68.39 ± 2.99                  | 1.98 ± 0.14                             | 6.89 ± 0.16                   |
| Water-conditioned  | 10       | 5.900 ± 0.370                | 62.11 ± 3.89                  | 2.22 ± 0.12                             | 5.31 ± 0.32                   |
| AdBlue-conditioned | 10       | 5.456 ± 0.269                | 57.43 ± 2.83                  | 2.44 ± 0.17                             | 4.69 ± 0.17                   |

As shown in **Table 1**, the reference specimens reached an average tensile strength of 68.39 ± 2.99 MPa and an apparent tensile modulus of 6.89 ± 0.16 GPa. Water conditioning reduced the average tensile strength by 9.2 % and the apparent modulus by 22.9 % relative to the reference state. The AdBlue-conditioned group exhibited the largest reduction, with tensile strength lower by 16.0 % and apparent modulus lower by 31.9 %. At the same time, the strain at maximum stress increased from 1.98 ± 0.14 % for the reference group to 2.22 ± 0.12 % after water exposure and 2.44 ± 0.17 % after AdBlue exposure.

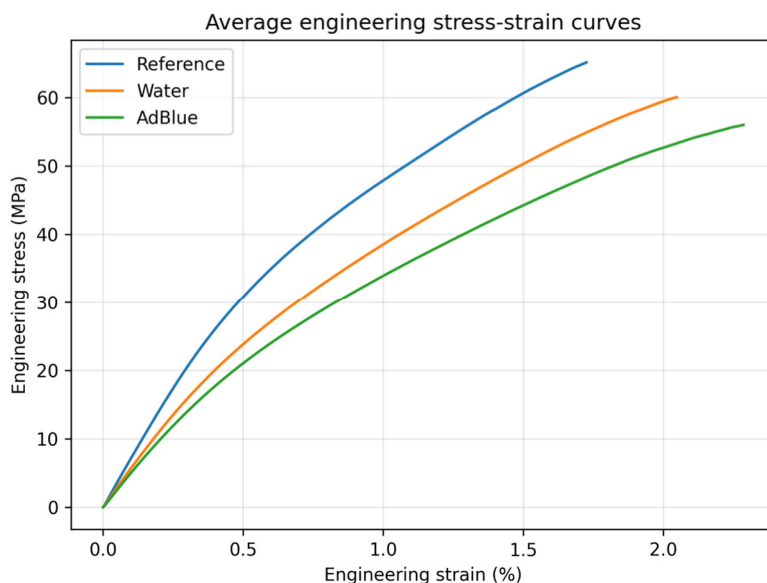


**Figure 1** Average engineering stress-strain curves for the reference, water-conditioned and AdBlue-conditioned flax/epoxy composites

**Figure 1** and **Figure 2** further show that fluid conditioning reduced the slope of the stress-strain response, lowered tensile strength and broadened the distribution of individual tensile descriptors. This behaviour is consistent with a more compliant composite response after immersion. The observed trend agrees with published studies reporting matrix plasticization, fibre swelling and weakening of the fibre-matrix interface in moisture-aged flax composites [3-8]. **Figure 3** shows that water caused the higher average mass gain (9.5 wt%), whereas AdBlue resulted in a lower average mass gain (8.0 wt%). However, the same comparison demonstrates that AdBlue was associated with the lower property retention, with tensile strength and apparent modulus retained at 84.0 % and 68.1 % of the reference values, compared with 90.8 % and 77.1 % after water conditioning. This indicates that the magnitude of mechanical degradation was not governed solely by the total absorbed mass. **Figure 4** provides morphological support for this interpretation. The reference specimen exhibited a more compact fracture region with fibre bundles remaining more coherently embedded in the matrix, whereas the conditioned specimens showed more pronounced fibre pull-out, local debonding and bundle loosening. These features were most evident in the AdBlue-conditioned specimen, which is consistent with the strongest reduction in tensile strength and apparent tensile modulus measured after AdBlue exposure.

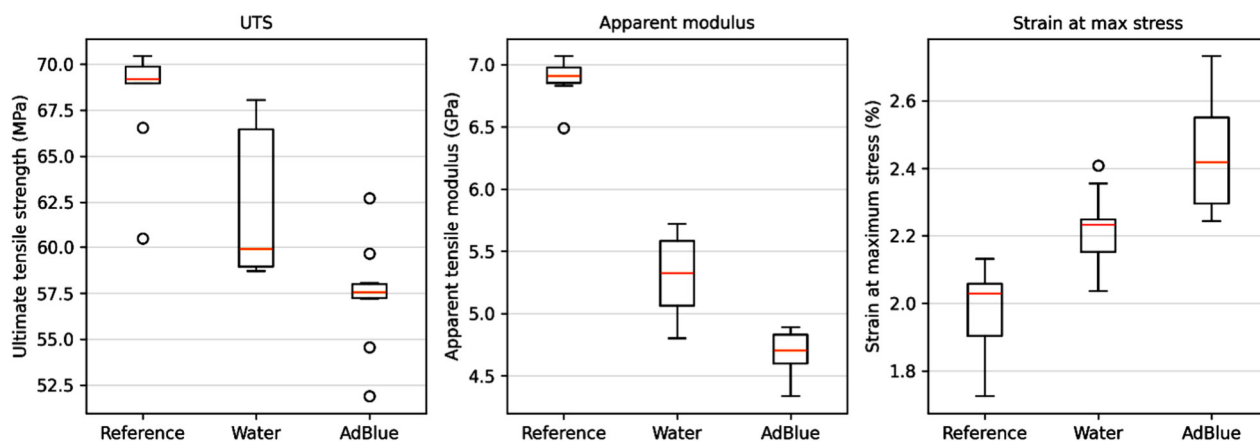


**Figure 2** Boxplots of ultimate tensile strength, apparent tensile modulus and strain at maximum stress for the investigated flax/epoxy composites

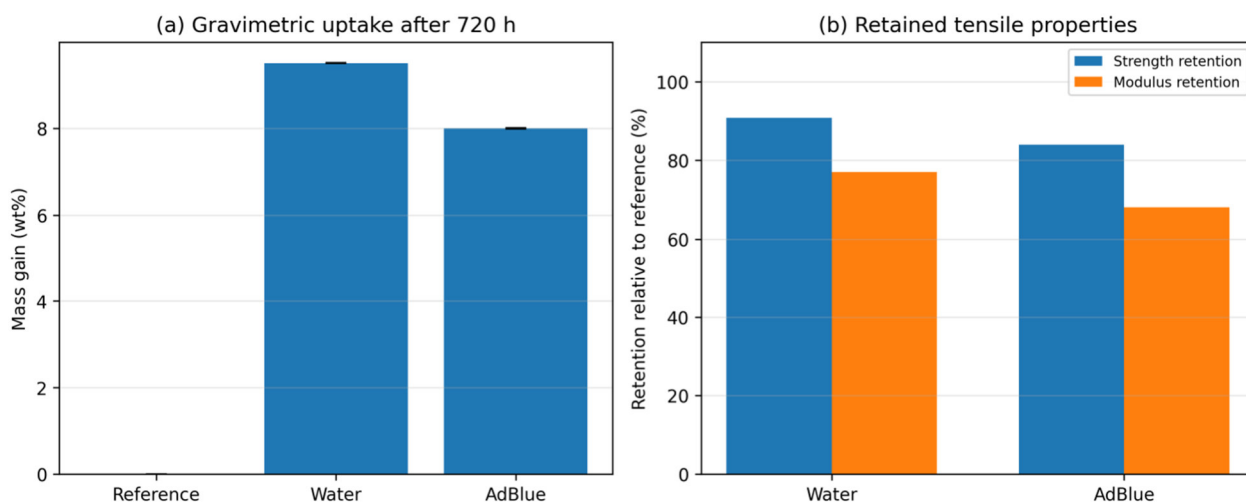


**Figure 3** Comparison of gravimetric uptake and retained tensile properties of the investigated flax/epoxy composites: (a) mass gain after 720 h immersion and (b) retained tensile strength and apparent tensile modulus relative to the dry reference state

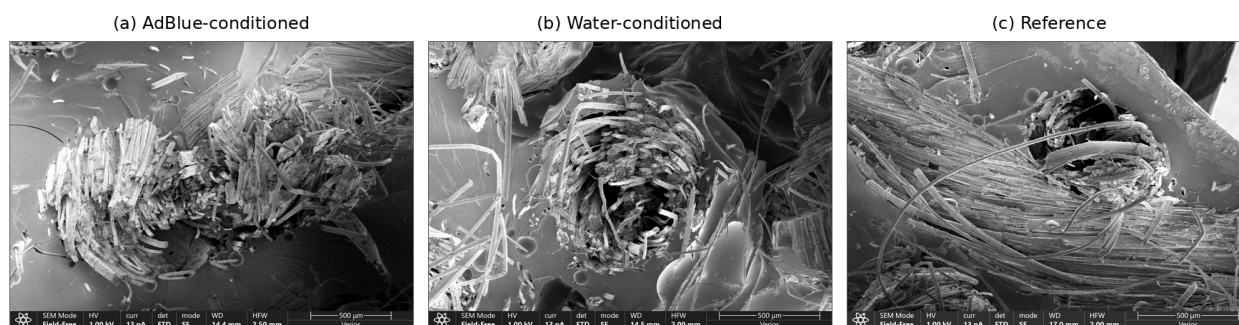


**Figure 4** Representative SEM images of fracture surfaces of (a) AdBlue-conditioned, (b) water-conditioned and (c) reference flax/epoxy composites [own study]

#### 4. CONCLUSION

The tensile behaviour of the investigated flax/epoxy biocomposite depended strongly on the conditioning medium. After 720 h of immersion at 20 °C, both water and AdBlue reduced tensile strength and apparent tensile modulus relative to the dry reference state. The dry reference specimens showed the highest tensile strength (68.39 MPa) and apparent modulus (6.89 GPa), whereas the AdBlue-conditioned group showed the lowest values (57.43 MPa and 4.69 GPa). Conditioned specimens also reached maximum stress at higher strain, indicating an increase in compliance after exposure. Gravimetric measurements showed that water caused the larger mass gain (9.50 wt %) compared with AdBlue (8.00 wt %), yet AdBlue produced the stronger decrease in tensile performance. SEM observations of the fracture surfaces were consistent with this mechanical response, as the conditioned specimens exhibited more pronounced fibre pull-out and interfacial loosening than the reference state, with the most disrupted morphology observed after AdBlue exposure. Within the investigated conditions, the degradation severity was therefore not governed solely by total absorbed mass, and fluid-specific interactions with the fibre-matrix interphase appear to play an important role. Future work should complement the present dataset with broader fractographic documentation and local chemical analysis so that the mechanical changes can be linked directly to degradation mechanisms.

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