EFFECT OF WATER AGEING ON FATIGUE DAMAGE OF RUBBERWOOD/RECYCLED POLYPROPYLENE COMPOSITES

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ABSTRACT

In this work, tension-tension fatigue performances of rubberwood flour reinforced recycled polypropylene composite (RWPC) under constant amplitude sinusoidal load control at 60% UTS, frequency of 4 Hz, R = 0.1, and at room temperature were investigated for unaged composite and after exposure to the water ageing conditions. From this series of tests, the corresponding stress-strain was obtained. The hysteresis loops throughout fatigue testing were examined, and the variation of secant modulus per cycle throughout the specimen lifetime was quantified. It was demonstrated that exposure to moisture reduced the initial tensile strength from 26.33 MPa to 12.19 MPa. Consequently, the fatigue strength of the RWPC also reduced from 630,030 cycles to 406,932 cycles as a consequence of the water ageing. The fatigue hysteresis loop showed that the non-ageing composite has a more open area and extensive tensile creep and more extensive fatigue damage compared to the aged composite as a result of their higher fatigue strength.

1 INTRODUCTION

The demand for wood polymer composite (WPC) in automotive applications, furniture, outdoor building materials, and others [1-3] increases due to their low price, robustness in design, and good environmental attributes. Hence, with the increase of interest in using cellulosic fibre composite such as rubberwood/PP (RWPP) in many applications, some of it might be exposed to cyclic or alternating loads during the service. The utilization of RWPP composite in structural materials applications presents significant challenges due to their fatigue reliability under various load circumstances. Structural materials often experience fatigue failure below their tensile strength [3,4].

WPC, like any natural fibre-based composite, is susceptible to moisture and prone to absorb it in a humid environment or when immersed in water [2]. Regrettably, the material will deteriorate as a result of moisture absorption, particularly at the interface of the composites. The mechanical properties of the composite will be degraded as a result of the poor fibre/matrix interface which will impair a good stress transfer during the applications [5]. While the influence of hydrothermal ageing has been extensively studied in static conditions [2], their effect on the fatigue behaviour of the wood polymer composite has been poorly studied. Hence, the consideration factors such as moisture study in conjunction with fatigue loading are crucial in order to properly evaluate and model the effects of the service loads and conditions on the candidate materials to ensure safe fatigue design

Thus, the aim of this paper is to study the effect of moisture on the fatigue damage of rubberwood/recycled polypropylene composite (RWPC) observed through hysteresis loops and stiffness evaluation captured throughout the test.

2 METHODOLOGY

The composite granule containing 50.3 wt.% recycled PP, 37.5 wt.% rubber wood flour, and 7 wt.% calcium carbonates as filler. The formulation for this rubberwood/ recycle PP has been optimised and palletised in an earlier study an optimum ratio as established earlier [1]. The granules later were gradually compressed moulded and heated from room temperature to 190 °C and optimum of 1000 psi was applied at the optimum temperature using a hot press machine (Carver, USA). The samples were cut into a flat dumbbell shape according to ASTM D638 with dimensions of 13x136x4 mm (width, length, and thickness) as shown in Figure 1. More details manufacturing process are given in the authors' previous work [3].

The water ageing process was carried out at room temperature. Ten specimens were fully immersed in tap water for 30 days. At the end of the immersion time, the specimens were weight and dried in the drying oven at 80°C until their weight changes measurement is stable. The non-ageing and water-aged specimens were subjected to a static tensile test with a cross-head speed of 2 mm/min till failure. The tension-tension fatigue tests were carried out using a 20kN Shimadzu (Japan) servo-hydraulic testing machine (Figure 2) at a frequency of 4 Hz and stress ratio (R = 0.1). The applied stress of 60 % ultimate tensile strength (UTS) is used and the composite is subjected to cyclic loading for up to 1.5 million cycles or till failure. The test was carried out in tension-tension control mode at a frequency of 4 Hz and stress ratio (R = 0.1). The machine is equipped with 4830 controllers, allowing the stress versus strain loop to be captured at log intervals with 50 data points recorded at each cycle.

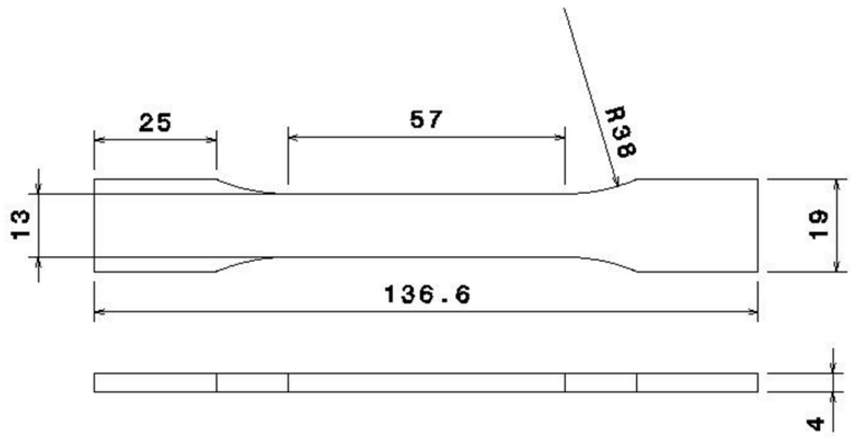

Figure 1: Schematic of specimen geometry and dimensions in mm.

Figure 2: Testing arrangement

3 RESULTS AND DISCUSSION

The water-aged RWPC experienced a reduction in their initial tensile strength as a result of moisture exposure. Their initial tensile strength reduced from 26.33 MPa to 12.19 MPa. The fatigue life (N_f) of the unaged RWPC at 60% UTS is 630,030 cycles while for the water-aged composite, their fatigue life is reduced to N_f = 406,932 cycles. The degradation in the fatigue strength of the composite is due to the presence of moisture from the ageing process has reduced the interface bonding between the fibre and matrix thus weakening their strength [1].

During cyclic loading of the RWPC, the material experience a hysteresis ellipse-shaped loop due to the viscoelastic characteristics of the polymer matrix and friction between de-bonded and delaminated surfaces. The slope of the maximum peak to minimum peak of the load-displacement curve (secant modulus) decreases from the initial first cycle with a value of E_1 to EN during cycle N, representing stiffness degradation. Shifting of the load-displacement curve due to cyclic creep of the polymeric matrix may also occur. Figure 3 showed the first and last hysteresis loop captured in the tension-tension fatigue test for the non-ageing and water-aged specimens. It can be observed that the last cycle of both RWPCs shifted along the positive strain axis. As fatigue damage accumulates under fixed amplitude load control, the materials become more compliant, resulting in changes in the amplitude of fatigue strains and indicating extensive creep has occurred.

In non-aged RWPC (Figure 3a), the loop area of the last cycle is observed to be more as the cycle progress. Figure 3(b) shows the hysteresis loop for the water-aged RWPC. It was observed that the loop area of the first and last cycle appeared to be almost identical, suggesting that very little volume damage occurred in the composite system prior to their failure [6]. At the same time, the presence of moisture reduced the fatigue resistance of the RWPC.

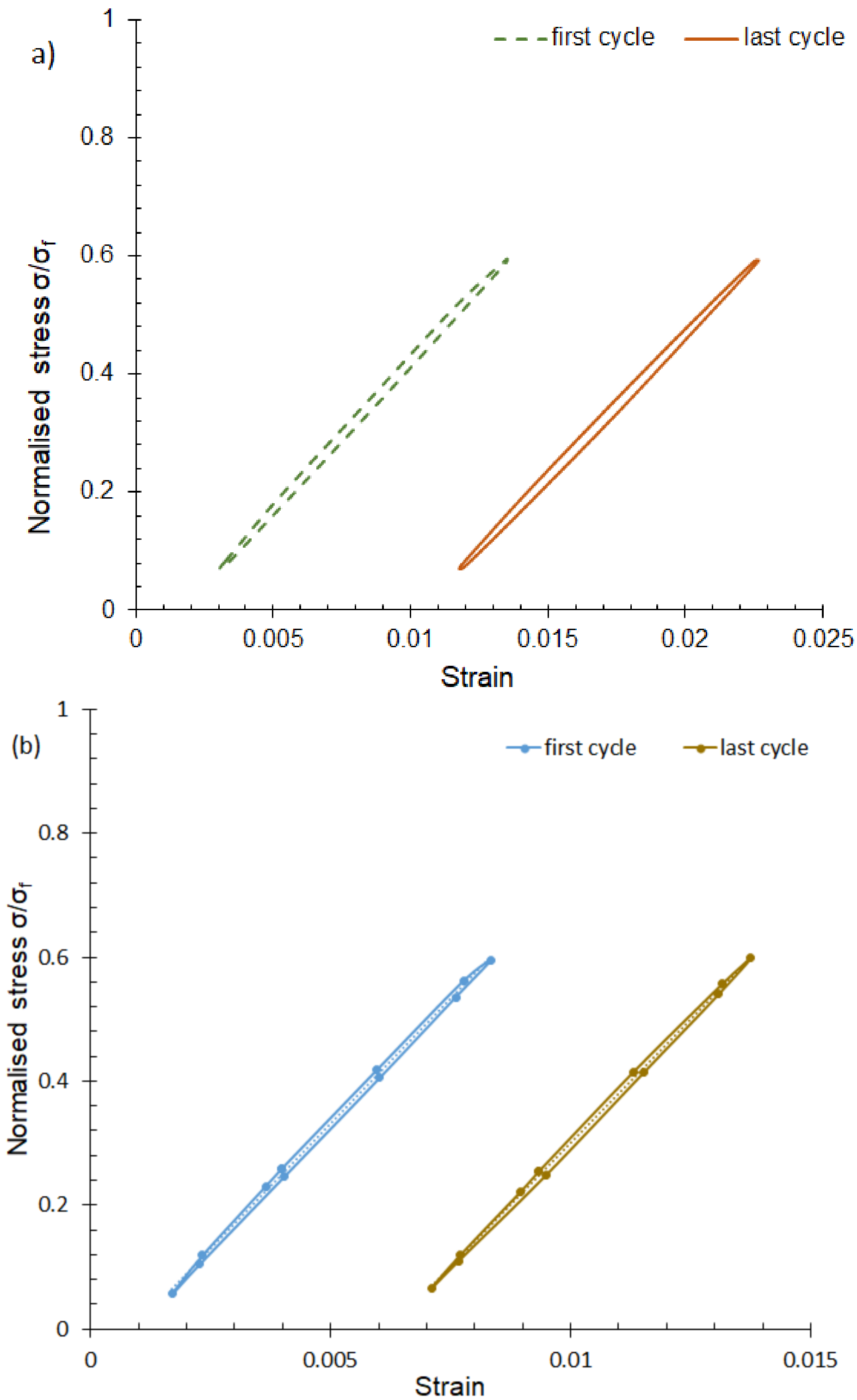

Figure 3: Fatigue hysteresis loop of (a) non-ageing and (b) water-aged RWPC at 60% UTS

The stiffness evaluation of the composite under cyclic loading was calculated using secant modulus from the hysteresis curve for each cycle and plotted in Figure 4. Stiffness degradation in composites is an indication of the initiation of crack progressing in the composite and loss of interfacial bond between fibre and matrix. Theoretically, crack density in the transverse direction increases with increasing numbers of cyclic loading due to matrix splitting along the fibres. This damage prevents the load transfer between fibres. As a result, fibre failure can occur before reaching the maximum stress measured in the case of monotonic tensile tests [7]. Subsequently, the strength of fatigue resistance and secant modulus will reduce with the increasing fatigue life cycle [8]. It is also observed in this study that the degradation in dynamic modulus in unaged RWPC is more pronounced compared to the aged RWPC. This indicated that the composite experienced smaller volume damage prior to its failure and fractured dominated.

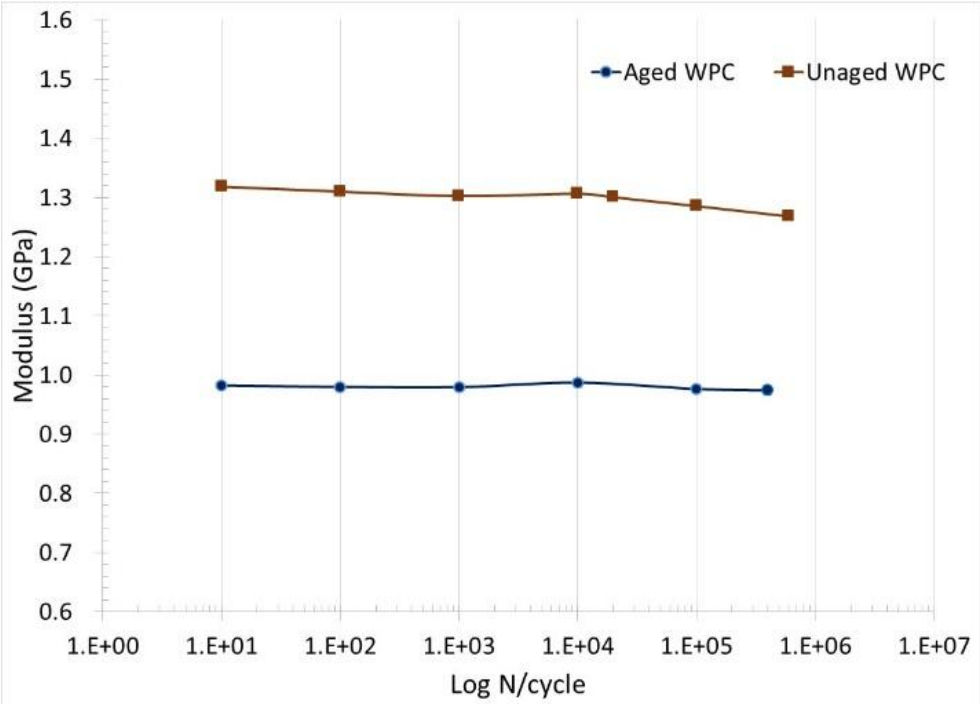

Figure 4: Stiffness variation as a function of cycles to failure of non-ageing and water-aged rubberwood/recycled PP composites

4 CONCLUSIONS

The stress-strain hysteresis loop and secant modulus are used to assess the tension-tension fatigue damage behaviour in the RWPC. Exposure to the moisture reduced the initial tensile and fatigue strength of the RWPC from 630,030 cycles to 406,932 cycles when tested at 60% UTS. The fatigue hysteresis loop showed that the non-ageing composite has a more open area and extensive tensile creep and more extensive fatigue damage compared to the water-aged composite as a result of their higher fatigue strength.

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