INFLUENCE OF WATER ABSORPTION ON TENSILE AND FLEXURAL PROPERTIES OF COMPOSITE SAMPLES

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https://doi.org/10.37904/metal.2024.4908

Abstract

In this study, the comparative experimental research was performed to quantify the effect of distilled water absorption on the mechanical characteristics of composite samples. The composite samples were reinforced with para-aramid fabric Twaron CT 747. The experimental part involved the fabrication of composites using three different methods: vacuum-assisted resin transfer method (VARTM), autoclave technology and hot-pressing technology. The fabricated samples were immersed in distilled water according to EN ISO 62. The highest water absorption was obtained for the samples produced by the hot-pressing method and this value was 12.1%. Subsequently, mechanical tests were performed, specifically the tensile test according to EN ISO 527-1 and the three-point bending test according to EN ISO 178. The main objective was to compare the tensile and flexural properties of the unexposed and exposed samples. The highest tensile and flexural strengths were obtained for the samples produced by the VARTM method. For these samples, the decrease in tensile strength after immersion was 8.3%. The flexural strength of these samples decreased by 11.4% compared to the unexposed samples. The experimental results showed degradation in the mechanical properties of the samples that were immersed in distilled water. The extent of this degradation depended on the applied manufacturing technology.

Keywords: Tensile properties, flexural properties, composite materials, strength, degradation

1. INTRODUCTION

In the field of materials engineering, composite materials represent an advanced group of materials. They consist of a reinforcement material that is dispersed in a matrix to provide a synergistic effect [1, 2]. Based on this effect, the strengths of the individual components are utilized to create a material with new properties. For this reason, composites are suitable for use in aerospace, automotive, space and military applications [3, 4].

The widely used composite materials in the form of reinforcement are aramids, specifically Kevlar® and Twaron® [3, 5]. Aramids are synthetic organic polymers that are characterized by their extraordinary mechanical properties and chemical resistance [6]. Their structure is composed of linear chains that are formed by recurrent monomeric units.There are two functional groups in each monomer unit: terephthalic acid and aromatic diamine (m-Phenylenediamine) [4, 6]. The molecules are connected to each other by hydrogen bridge bonds. The regular arrangement of phenylene cores and amide groups with the hydrogen bridge bonds gives the chains a high stiffness and at the same time causes a high density of the structure of the arrangement [1, 6].However, despite their excellent properties, it is evident that the environment in which para-aramids are

used has a fundamental effect on their behavior and performance. Temperature extremes, humidity, exposure to chemicals and UV radiation are factors that significantly influence mechanical properties (loss of strength and stiffness) and contribute to degradation [1, 6, 7].

This study focuses on the influence of water absorption on the tensile and flexural properties of the para-aramid Twaron CT 747 composite samples fabricated by vacuum-assisted resin transfer method (VARTM), autoclave technology and hot-pressing technology. The aim of this study was to compare how the manufacturing technologies of the composites affect the absorption of distilled water, especially in the context of their mechanical properties.

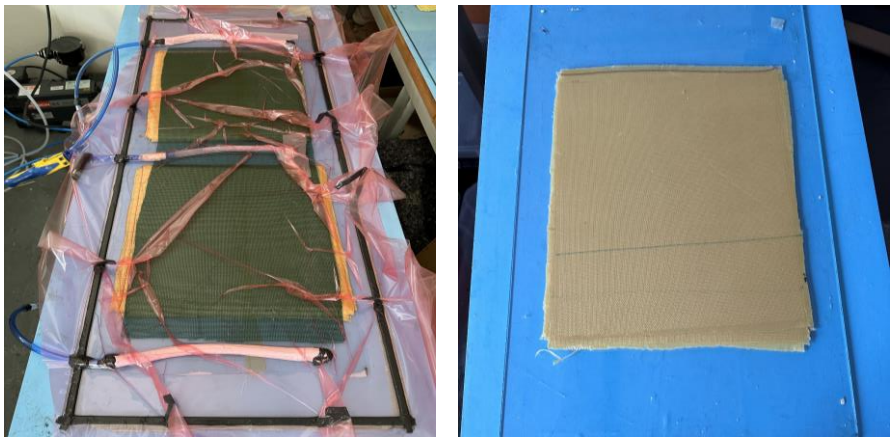
2. MATERIALS AND METHODS

Composite samples were made from commercially available para-aramid fabric Twaron CT 747 (Teijin Aramid, Germany). Twaron CT 747 para-aramid fabric with the density of 1440 kg/m^3 is characterized by the linear yarn density of 3360 dtex in the warp and weft direction. The area weight of the fabric is 410 g/m^2 [8].

2.1 Manufacture of the composite samples

Composite samples were produced for mechanical properties testing by using three manufacturing technologies: vacuum-assisted resin transfer molding (VARTM), autoclave technology and hot-pressing technology.

Composite samples PV were fabricated by VARTM method, which is shown in **Figure 1.** The para-aramid fabric Twaron CT 747 was stacked and placed in a vacuum foil. A vacuum was created by the action of the vacuum pump, which ensured that the fabric was saturated. The matrix (LG 700 epoxy resin and HG700 hardener) was used for the impregnation. The individual components were mixed in the ratio of 10:3. Composite panel was hardened at the temperature of 22 °C for 24 hours [9].



(a) (b)

Figure 1 VARTM method: (a) curing of the composite panels; (b) fabricated composite panels

Furthermore, for the production of the composite samples PA, autoclave technology was used. The para-aramid fabric Twaron CT 747 was impregnated with ER68 epoxy resin with an initial content of 20%. The fabric was vacuumed and placed in an autoclave. To ensure curing of ER68 epoxy resin, the curing temperature was set at (120 ± 5) °C and the pressure was 0.5 MPa. The process of curing was performed under a vacuum of 0.095 MPa. The curing time was 170 minutes [9].

To produce the composite samples PL, hot-pressing technology was used. The para-aramid fabric Twaron CT 747 was used, which was pre-impregnated with TH110 polyolefin. This fabric was stacked, bagged and placed

between two heated aluminum plates of a ZD40 testing machine. The machine applied a force of 300 kN to the prepregs for 20 minutes and the temperature was set at 135 ± 5 °C [9].

2.2 Mechanical testing

In this study, the composite samples were mechanically tested by tensile and three-point bending tests. To determine the tensile strength, a tensile test was performed in accordance with EN ISO 527-1 by using the INSTRON 5985 universal testing machine [10]. The dimension of these samples was (250 × 25 × 2.5) mm. The initial measuring length was set to 115 mm and the tensile test speed was 5 mm/min. A Zwick Z100 testing machine was used to determine the flexural strength and flexural modulus in accordance with EN ISO 178 [11]. The dimension of these samples was (80 × 15 × 5) mm. The speed of bending test was 2 mm/min.

The mechanical properties of unexposed composite samples (PV_A, PA_A and PL_A) and samples that were immersed in distilled water (PV_B, PA_B and PL_B) were tested. To determine the water absorption, the samples (PV_B, PA_B and PL_B) were dried in an oven at (50 ± 2) °C for 24 h according to ISO 62 [12]. Subsequently, the samples were immersed in distilled water. The test periods in distilled water were 24, 48, 72, 96, 144, 192, 264, 360 and 480 hours. The weight of the samples was measured by using a Citizon CY 720 laboratory scale with an accuracy of 0.001 g.

3. RESULTS AND DISCUSSION

This section includes the results obtained from tensile and three-point bending tests for unexposed composite samples and for samples that were immersed in distilled water.

3.1 Mechanical properties of the composite samples

During the tensile test, the following properties were determined: maximum tensile strength, tensile modulus and elongation. The three-point bending test provided the maximum flexural strength, flexural modulus and deformation at the ultimate flexural strength. **Table 1** shows the tensile and flexural test results for the composite samples PV_A, PA_A and PL_A. The results were calculated as arithmetic averages of the three tested samples.

Table 1 Tensile and flexural properties of unexposed composite samples PV_A, PA_A and PL_A

Composite		Tensile properties			Flexural properties		
		Tensile strength (MPa)	Tensile modulus (GPa)	Elongation (%)	Flexural strength (MPa)	Flexural modulus (GPa)	Deformation at the ultimate flexural strength (%)
Twaron CT 747	PV_A	561.7 ± 14.8	17.2 ± 0.5	6.3 ± 0.2	226.3 ± 4.1	16.1± 0.4	7.7± 0.5
	PA_A	496.3 ± 6.9	11.6 ± 0.7	5.7 ± 0.3	141.4 ± 6.3	11.6± 0.4	1.8± 0.2
	PL_A	434.3 ± 16.8	8.6 ± 0.4	8.9 ± 0.1	9.1± 0.5	0.8± 0.1	8.9± 0.5

The composite samples PV_A produced by VARTM technology showed the highest values of tensile and flexural strength. The ultimate tensile strength reached 561.7 MPa with an elongation of 6.3%. The flexural strength of the sample PV_A was 226.3 MPa. These samples PV_A also had the highest tensile and flexural modulus. The samples PA_A exhibited 14.3% higher tensile strength values than the samples PL_A, but the samples PL_A exhibited 56.1% higher elongation than the samples PA_A. The lowest flexural strength was obtained for the samples PL_A, which was 9.1 MPa.

Figure 2 shows the tensile and flexural diagrams of the unexposed composite samples PV_A, PA_A and PL_A, which were fabricated by using the three technologies (see Section 2.1).

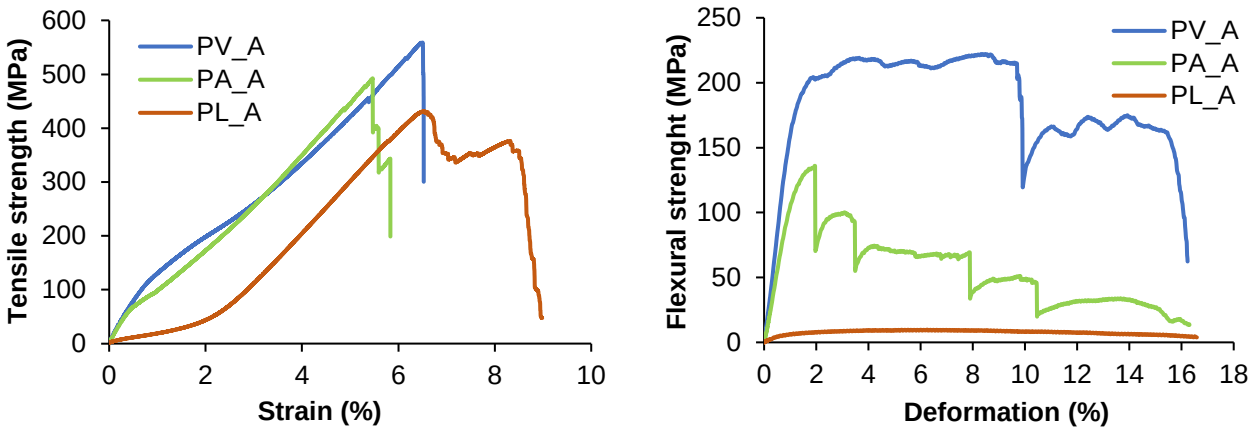


Figure 2 Mechanical properties of the unexposed composite samples PV_A, PA_A and PL_A: (a) tensile diagram; (b) bending diagram

In the area of ultimate strength, as documented in the tensile diagram (**Figure 2**), the samples showed instability crack propagation across the layer that was accompanied by delamination of these layers. This effect, which is shown in **Figure 2**, presents as a form of abrupt drops. Analogous to the tensile diagrams, abrupt drops were also observed in the bending diagrams as a result of the delamination of the layers. In addition to delamination of the layers, other irregularities indicating matrix disruption were also observed.

3.2 Water absorption

The water absorption of the composite samples PV_B, PA_B and PL_B was measured at regular intervals, see Section 2.2. The percentage of water absorption was determined according to the equation (1)

$$c = \frac{m_2 - m_1}{m_1} \times 100\ \% \quad (1)$$

where: c - percentage of water absorption (%), m_1 - initial weight of the sample before immersion(g), and m_2 - current weight of the sample after immersion(g).

The calculated values of the percentage of water absorption are shown in **Figure 3**. These values of water absorption were calculated from three measurements, from which the average value was determined.

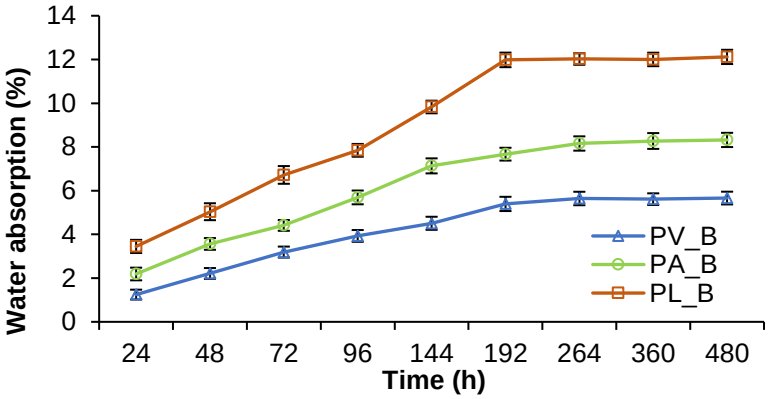


Figure 3 Dependence of the water absorption on the immersion time of the composite samples PV_B, PA_B and PL_B

Figure 3 shows that the highest water absorption value was obtained for sample PL_B after 480 hours of immersion in distilled water. This value was 12.1%. These values were lower for the samples PV_B and PA_B. The percentage of water absorption for samples PV_B was 5.7% and for samples PA_B was 8.3%.

3.3 Mechanical properties of the composite samples after water absorption

The results of tensile and flexural tests of the composite samples PV_B, PA_B and PL_B that were immersed in distilled water are shown in **Table 2.**

Table 2 Tensile and flexural properties of the composite samples after immersion in distilled water

Composite		Tensile properties			Flexural properties		
		Tensile strength (MPa)	Tensile modulus (GPa)	Elongation (%)	Flexural strength (MPa)	Flexural modulus (GPa)	Deformation at the ultimate flexural strength (%)
Twaron CT 747	PV_B	515.2±3.6	14.1 ± 0.3	6.6± 0.2	200.6 ± 6.8	13.9 ± 0.5	2.7 ± 0.5
	PA_B	433.0±0.8	9.2 ± 0.8	6.1± 0.1	114.2±2.8	8.7±0.7	1.7±0.4
	PL_B	364.7± 14.3	4.6 ± 0.2	10.0± 0.5	6.8±0.4	0.5±0.1	7.5±0.1

Figure 4 shows a comparison of the tensile and three-point bending test results for the unexposed samples (PV_A, PA_A and PL_A) and the samples that were immersed in distilled water (PV_B, PA_B and PL_B).

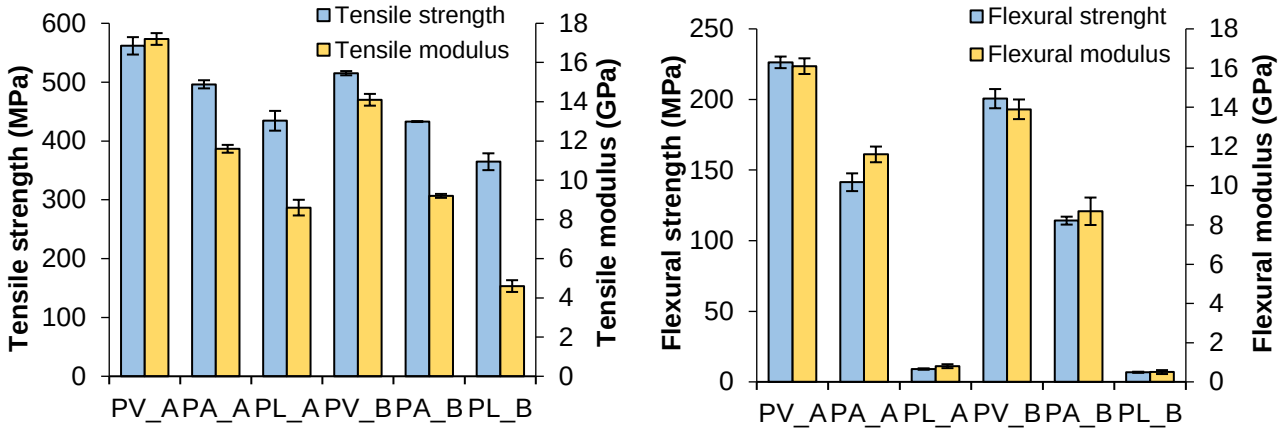


Figure 4 Comparison of tensile and three-point bending test results

4. CONCLUSION

This article is focused on the evaluation of the effect of water absorption on the mechanical properties of the composite samples reinforced with para-aramid fabric Twaron CT 747, which were produced by the technologies in Section 2.1. Based on the results, the following conclusions can be obtained:

- The highest values of tensile and flexural strength were achieved by the samples PV_A. The tensile strength was 561.7 MPa and the flexural strength was 226.3 MPa. The lowest values of tensile and flexural strength were achieved by the samples PL_A, specifically the tensile strength was 434.3 MPa and the flexural strength was 9.1 MPa.
- The highest water absorption value was 12.1% for the samples PL_B. The water absorption of the samples PA_B was 8.3% and the lowest value was 5.7% for the samples PV_B.

- In terms of tensile and flexural comparison, it was found that after immersion, the tensile strength of the samples PV_B decreased by 8.3% compared to the unexposed samples PV_A. The tensile modulus also decreased, by 18.0%. The samples PA_B showed a 12.8% decrease in tensile strength compared to the samples PA_A, with a decrease in tensile modulus and flexural modulus. A decrease in tensile strength of 46.5% was also observed for PL_B samples compared to PL_A samples.

This research demonstrates that immersion of the composite samples in distilled water has a significant effect on the mechanical properties, which may affect their suitability for specific applications. The results obtained can serve as input for the design and selection of materials in areas where components are exposed to water.

ACKNOWLEDGEMENTS

The work presented in this paper was supported by the specific research projects "SV23-216" and "SV24-216" at the Department of Mechanical Engineering, University of Defence in Brno and was supported by the Project for the Development of the Organization "VAROPS (DZRO VAROPS) Military autonomous and robotic assets" by the Ministry of Defence of Czech Republic.

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