EFFECT OF MOISTURE ABSORPTION ON SELECTED MECHANICAL PROPERTIES OF NATURAL FIBER COMPOSITES BASED ON WOVEN FLAX FIBERS AND POLYPROPYLENE

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Abstract

In this work, an experimental investigation has been carried out to study the effect of moisture absorption on the tensile, flexural and impact properties of an unbalanced woven flax fiber-reinforced polypropylene composite. The thermoplastic matrix material was modified with the coupling agent maleic anhydride in order to improve the flax/PP adhesion and hence the mechanical properties. Results of the mechanical tests, conducted at room temperature, showed that both tensile and flexural modulus have decreased with increasing moisture content, while the strength values based on the tensile and flexural tests remained relatively unaffected. On the other hand a minor increase of the charpy impact strength with increased amount of moisture absorption has been observed.

1. Introduction

Plant based natural fibers as reinforcement in thermoplastic composites have become increasingly important in the past decades due to the increasing demand for developing sustainable and recyclable lightweight materials [1, 2]. Beside composites with non-aligned fiber arrangements, nowadays the focus is set on natural fiber composites based on continuous reinforcements such as unidirectional (UD) tapes, woven or non-crimp fabrics [3]. However, the lack of an economic manufacturing process is a major barrier for the use of continuous natural fiber reinforced polymers. To overcome this limitation in terms of short cycle times and reasonable low costs, the production of parts from semi-finished natural fiber organic sheets based on various fiber arrangements are therefore of interest [4, 5]. It is thus important to characterize the mechanical behavior of these materials in order to ensure their structural and functional applicability. One major issue in the successful use of plant fibers is the incompatibility between the hydrophobic nature of the thermoplastic matrix and the hydrophilic nature of the natural fibers. As a result of the poor fiber-matrix adhesion, void spaces around the fiber occur, which in turn lead to a higher moisture uptake. Several methods to improve the interfacial adhesion in composites have been proposed [6, 7]. However, grafting of the matrix polymer with hydrophilic functional groups such as maleic anhydride is the most suitable compatibilization method to improve the weak

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interfacial bonding between the non-polar matrix and the polar fibers [8, 9, 10, 11]. Another important aspect is the well-known high sensitivity of the fiber to absorb moisture in a humid atmosphere or when immersed in water [12]. The hydrophilic nature of the fibers can be mainly attributed to their chemical composition, being rich in cellulose [3, 13]. Water absorption leads to a degradation of the fiber-matrix adhesion inducing undesirable effects on the mechanical properties of the composite [9, 14-16]. In this study an experimental investigation was undertaken to characterize the influence of moisture absorption on the mechanical behavior of a woven flax fiber/maleic anhydride grafted polypropylene composite. This was accomplished in a series of tests in which test specimens were loaded to failure in quasi-static (tension and three-point bending) and under impact loading applying standardized test methods. All measurements were performed in both warp and weft direction as the flax fiber woven fabric is not balanced.

2. Experimental

2.1. Materials and test-specimen preparation

A commercial unbalanced flax fiber woven fabric (7 yarns/cm in warp and 11 yarns/cm in weft direction) with an area weight of 500 g/m², supplied by Composites Evolution Ltd. (Chesterfield, UK), was used as textile reinforcement in this work. The heterophasic polypropylene copolymer BD212CF supplied by Borealis AG (Vienna, A) was used as thermoplastic matrix material. In order to improve the interfacial bonding between the non-polar matrix and the polar natural fibers, the polypropylene matrix was modified with a commercially available coupling agent containing maleic anhydride (Scona TPPP 8112 FA, BYK-Chemie Ltd., D). The polymeric films were fabricated at Isosport Verbundbauteile Ltd. (Eisenstadt, A) by mixing 97 % by weight of BD212CF with 3 % by weight of Scona TPPP 8112 FA. All woven flax fiber reinforced polypropylene composites were fabricated by compression molding using the film stacking method. In a first step all woven flax textiles (400 x 400 mm squares) were dried in an oven at 80 °C for 40 minutes. Without any delay a stack of four layers of dry woven fabric (0°/90°) and eight layers of polymer films was placed between heated press plates of a compression molding press. The impregnation was achieved by applying pressure and temperature following the process cycle depicted in Fig. 1.

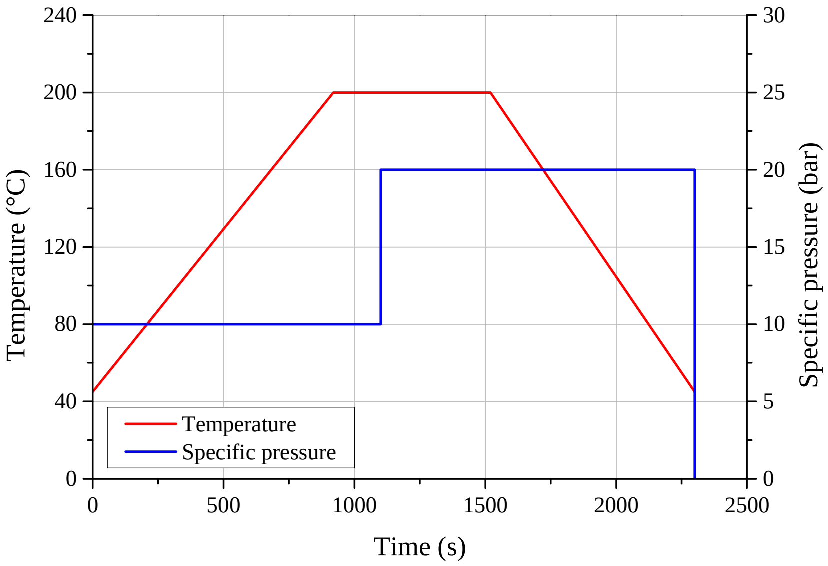

Figure 1. Process parameters of the film stacking cycle for the manufacturing of a woven flax fiber/maleic anhydride grafted polypropylene composite.

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The nominal thickness of all composite panels was approximately 3 mm and assuming that there were no voids in the laminates, the fiber weight fraction varied from 57.2% to 59.6%. Specimens for tensile and flexural tests were manufactured according to DIN EN ISO 527-4 [17] (specimen type 1B) and DIN EN ISO 14125 [18], respectively. For the non-instrumented impact tests, rectangular test specimens were prepared in accordance to ISO 179-1 [19]. To avoid effects associated with moisture pick-up from the air environment all specimens were dried in a vacuum oven at 60 °C for 48 h. A climatic chamber has been used for specimens´ conditioning at 23 °C and 65 % r.H. for a specified period of time, whereas the moisture uptake was determined gravimetrically in periodic time intervals.

2.2. Test methods

Tensile strength and modulus of both dry and wet specimens were determined in accordance with DIN EN ISO 527-4 [17]. A 10kN universal tensile/compression testing machine (Z010, Zwick/Roell, Ulm, D) was used with a displacement rate of 2 mm/min. To measure the local strain distribution of the test specimens, optical full-field strain measurements were performed using the 3D image correlation photogrammetry system ARAMIS (GOM, Braunschweig, D). A stochastic dot pattern was applied to one side of all specimens using white and black aerosol sprays. The selected measuring window covered nearly the entire free gage length of the specimens (50 x 6.5 mm). Prior to testing, the system was calibrated with calibration plates to correct distortions of the lenses and to calibrate the position of the two digital CCD cameras to each other. The flexural strength and modulus of both dry and wet specimens were determined using the three-point bending test method according to DIN EN ISO 14125 [18]. The cross head speed applied was 2 mm/min. Each specimen was loaded on a universal tensile/compression testing machine (Z010, Zwick/Roell, Ulm, D) equipped with a 10 kN load cell. It should be noted that the specimens did not break under three-point bending therefore the maximum peak load in the load-deflection was used for the calculation of the flexural strength values. Impact testing was carried out according to DIN EN ISO 179-1 [19] using the pendulum impact tester CEAST Resil 25 (CEAST, Torino, I) to determine the charpy impact strength of dry and wet samples. The unnotched and notched specimens were tested edgewise.

3. Results

Figure 2 shows the results of the performed tensile tests with flax fiber/maleic anhydride grafted polypropylene specimens in both the warp and weft direction. Tensile strength values for both test directions do not vary significantly with increasing moisture content. As expected, the higher number of weft yarns leads to a slightly higher tensile strength and modulus compared to the warp direction. On the other hand tensile modulus values were found to decrease which increasing moisture content up to 3 wt%. Similar results have also been observed from Muñoz and García-Manrique [3].

The effect of moisture on the flexural properties of the investigated natural fiber thermoplastic composite is illustrated in Fig. 3 for both the warp and weft direction. It should be noted that warp and weft in the test specimens was perpendicular to the applied bending forces. Despite the basic difference in loading conditions, the diagram reveals, that there are similar characteristics between tensile and flexural loading. The flexural modulus seems to be less affected by moisture absorption which agrees well with investigations published by Muñoz and García-Manrique [3]. Results of the flexural strength measurements for both test directions reveal that the absorbed moisture does not affect that material property up to 1.5 wt%. After a moisture content of 1.5 wt% and under consideration of the calculated standard deviations the flexural strength was found to decrease slightly. This may be caused by a weakened interfacial adhesion between fiber and matrix.

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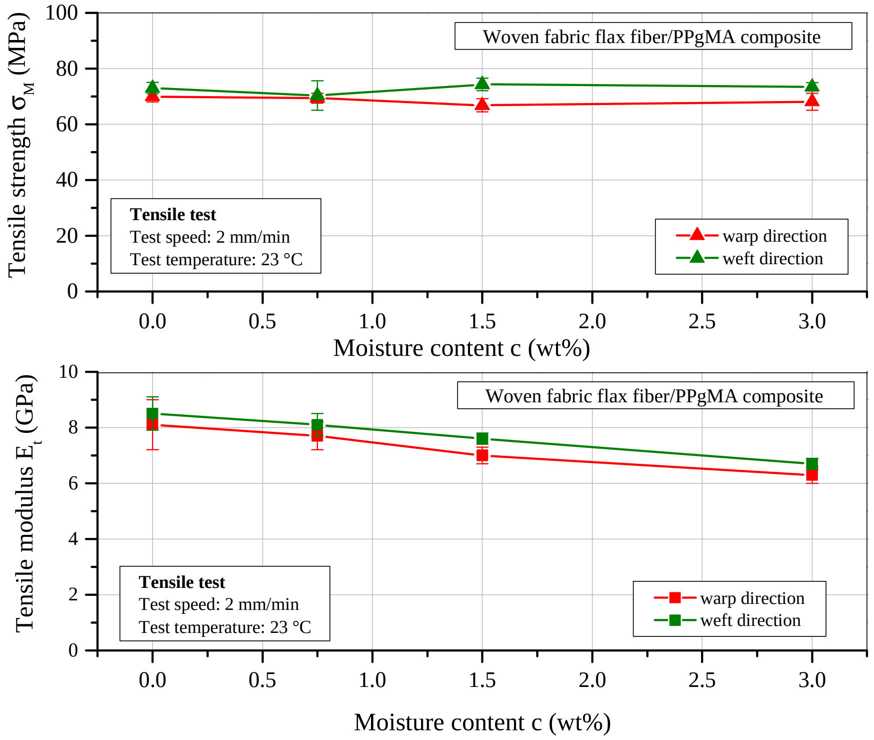

Figure 2. Influence of moisture content on tensile modulus and strength of a woven flax fiber/maleic anhydride grafted polypropylene (PPgMA) composite tested in warp and weft direction.

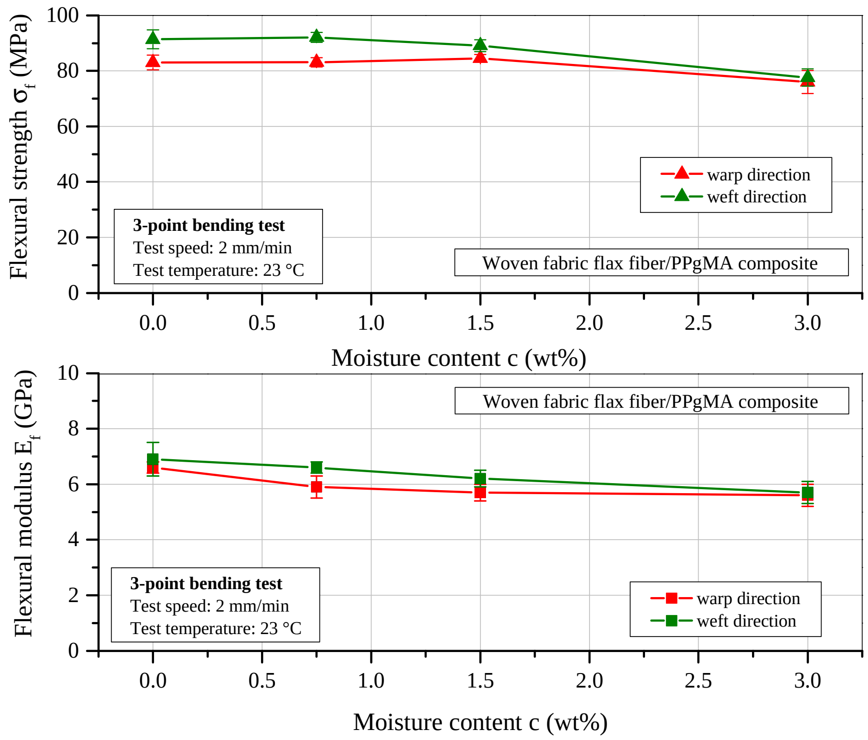

Figure 3. Influence of moisture content on flexural modulus and strength of a woven flax fiber/maleic anhydride grafted polypropylene (PPgMA) composite tested in warp and weft direction.

The unnotched and notched charpy impact strength of the woven flax fiber/maleic anhydride grafted polypropylene composite is shown in Fig. 4. Warp and weft direction in the test specimens were aligned parallel to the support length of 80 mm, respectively. As can be seen from the graph, moisture absorption results in a tendential increase of the notched charpy impact strength, when the specimens were tested in both warp and weft direction. The trend of increasing notched charpy impact strength with increasing moisture content was also found for the unnotched charpy impact strength but the scatter of the experimental data determined for the unnotched specimens is typically quite large.

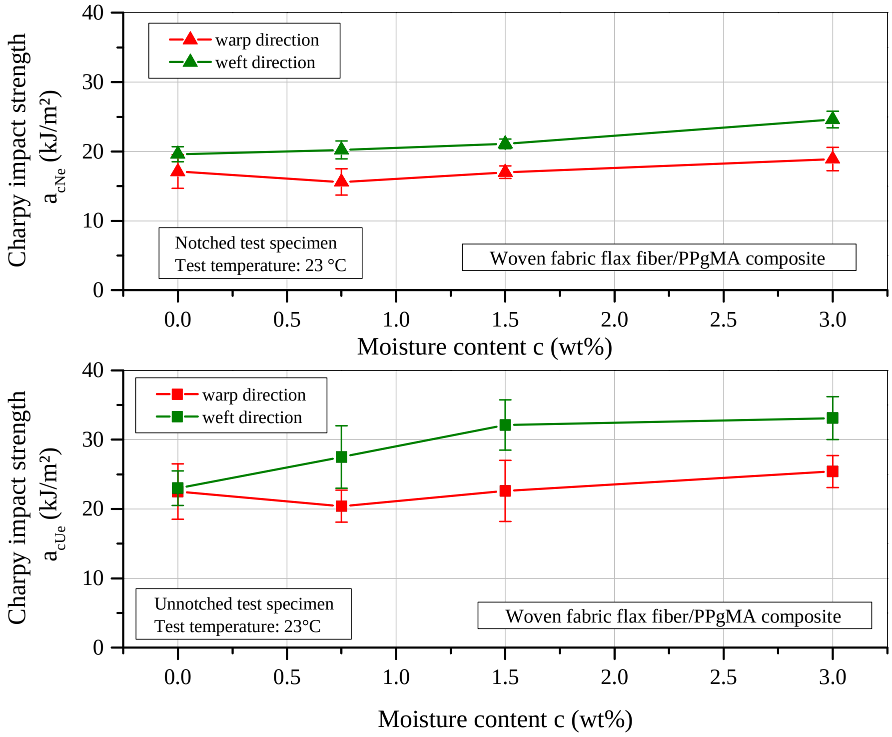

Figure 4. Influence of moisture content on charpy impact strength of a woven flax fiber/maleic anhydride grafted polypropylene (PPgMA) composite tested in warp and weft direction.

4. Conclusions

The effect of moisture absorption on the mechanical properties of a flax fiber/maleic anhydride grafted polypropylene composite has been studied by immersion of standardized specimens in a climatic chamber at 23 °C and 65 % r.H. An unbalanced woven fabric was used as textile reinforcement, hence all experimental investigations were carried out in both the warp and weft direction. Tensile as well as flexural moduli were found to decrease with moisture absorption, while tensile and flexural strength values remained relatively unaffected. Absorption up to a content of 3 wt% results in a minor increase of the charpy impact strength. Future research work will focus on the fatigue behavior of this composite material which is an important step towards its possible application in structural lightweight parts. Ongoing research activities will further include the replacement of the currently non-biodegradable thermoplastic matrix with a bio-degradable polymer hereby taking into account environmental concerns.

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