EFFECT OF FIBRE VOLUME CONTENT ON THE MECHANICAL PERFORMANCE OF NATURAL FIBRE REINFORCED THERMOPLASTIC COMPOSITES

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Abstract

Natural fibre thermoplastic composites may be manufactured using a film stacking process, where fibre-preforms and matrix films are stacked alternately. The process has shown great potential due to the high flexibility referring to the stacking sequence and the using of simple tooling concepts, which may easily be scaled for industrial applications. As impregnation takes place through-the-thickness, the flow length is short and of particular interest when thermoplastic processing due to the high melt viscosities, particularly important when working with natural fibres and relatively low temperatures. In this study, flax fibres were impregnated by various thermoplastic matrix materials suitable to being processed at lower temperatures. Here we aim to study the impregnation of the natural fibres by varying the provided amount of matrix material within the film stacking process. Impregnation trials showed interesting potential of reducing the content of matrix material. This leads to a reduced thickness of the composite whilst maintaining the structural load bearing capability due to the unchanged presence of the fibre material. Starting from a fibre volume content of 50 % we demonstrate an increase it up to 77 %. Whilst we note no effect on the strength, we observed notable improvement in the flexural moduli.

1. Introduction

With increasing need to address aspects such as recyclability and environmental safety, a demand for newly developing sustainable materials [1,2] has been increasing [3]. Natural fibres such as hemp, flax, kenaf and sisal are being considered as reinforcing fibres for both thermoplastic and thermosetting polymer composites [4]. Usually, natural fibres production consumes 60-80 % less energy compared to synthetic fibres [5,6]. In addition, natural fibres offer superior properties such as high specific stiffness and strength due to a very low density, higher fatigue strength, impact energy absorption and an excellent acoustic and mechanical damping behaviour [6–10]. Of those, flax fibres seem to be favoured due to their relatively consistent seasonal properties, rather advanced processing industrialization and magnitude of availability. Along with the development of surface properties for favourable adhesion with thermoplastic matrices, cost effect processes such as compression moulding allow us to tune the fibre volume fraction precisely. This work reports a study of the effect of the fibre volume fraction on the flexural properties of thermoplastic matrix, flax fibre composites.

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2. Materials

Single flax fibres and UD-woven flax fibre fabrics (ampliTex UD type 5009 (abbr. ampUD)) with an area weight of 300 g/m² were provided by Bcomp Ltd. (Fribourg, Switzerland). Thermoplastic polymers were considered as matrix materials which should meet requirements such as inherently high tensile modulus and strength along with a heat deflection temperature above 100 _C and a melt temperature below 190 ◦C. Polyoxymethylene-copolymer (coPOM) was used as a reference matrix material for this work.

3. Methods

Films with a width of 80mm and a thickness of approximately 100 um were produced using a Collinr (Dr. Collin GmbH, Germany) Teach-Line extruder associated with a slit die.The composites were manufactured via film stacking [5] using pre-dried fabrics (vacuum oven at 110–120 ◦C at 200 mbar for 15 minutes) and polymer films which have been stacked alternately in a steelmould. The target fibre volume content of 50 wt% was used in order to calculate the number of alternating layers required for flax fabric and polymer films. Six unidirectional (UD) flax layers were stacked to press coupons of about 2mm thickness. The mould has been placed in a press and was heated up to 180 ◦C using a high pressure water heating system. Once that temperature was reached, a force of 96 kN was applied resulting in a cavity pressure of 10 bar. After 8 minutes pressing, the mould was cooled down whilst the pressure was maintained.

Flexural composite properties (modulus and maximum stress) were determined via three point bending measurements in accordance to ISO 14125. The experiments have been carried out under considerationof the effect of the performed fibre surface treatments on the mechanical properties. Tests were conducted using samples with longitudinal (0◦) and transverse (90◦) fibre orientation. Therefore, a universal material testing machine (walter+bai AG, Switzerland) was used. The forces were recorded by a 1 kN load cell. The flexural deflection was measured via an external linear variable differential transformer (LVDT).

4. Results

The use of polymer films with different thicknesses allows one to define the fibre volume content before manufacturing the actual composite. The fraction of the fibres may be calculated based on the fibre and polymer weight prior to the manufacturing process and panel mass after processing. Therefore, the weight of matrix material that has not impregnated the fibres but instead created a burr has to be subtracted from the initial weight.

By altering the amount of thin films within the film stacking process it is possible to increase the fibre volume fraction significantly. Initially, 0.2 mm thick films have been used to create composites, leading to a fibre volume content of approximately 50 %. This particular fraction of matrix material is often used as a reference and within our study employed to investigate the saturation of the fibres by the polymer matrix. Later in time during the project, film materials with a significantly reduced thickness, being 0.05 mm, were manufactured, ebaling the above mentioned increase in fibre volume fraction.

Based on the areal weight of the flax fibre UD fabric and the components' densities, the theoretical fibre volume content can be calculated at certain values and plotted as a function of the matrix film thickness, Figure 1 (left). Composites with a higher fibre volume fraction have been produced by gradually reducing the amount of polymer prepared in the film stacking process. The difference in the

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fibre volume content is reflected in a better compaction of the fibre bundles which leads inevitably to a reduced thickness of the composite (see Figure 1 (right)).

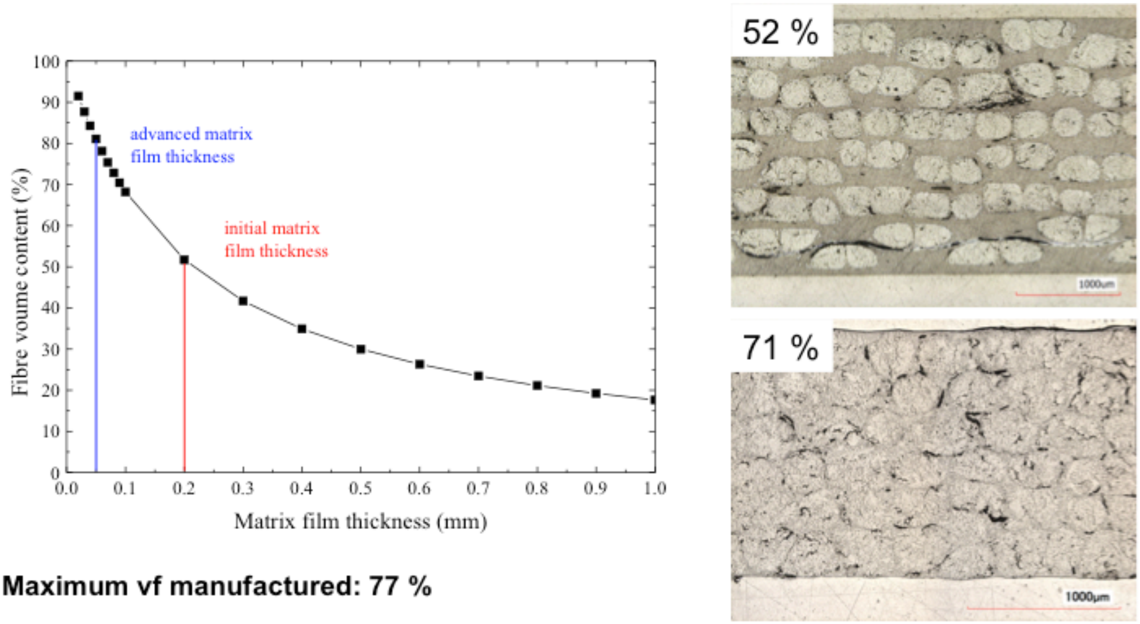

Figure 1: Shows (left) the measured fibre volume fraction as a function of matrix film thickness and (right) optical micrscopy cross section images of the manufactured composites with matrix contents of 52 % and 71 %.

Flexural tests were conducted at different fibre volume contents and compared to previously manufactured composites. The individual curves, meaning the properties of the UD composites tested in longitudinal direction, are shown in Figure 2. The black curves represent the AmpUD-coPOM reference material (fibre volume fraction of 53 %), while the blue and the red curves show the stress-strain results for specimens having a 72.5 % and 76.7 % fibre volume fraction respectively. With increasing fibre volume content, more gradually shedding of the applied load occurs after failure. The higher vf specimens were better able to sustain stress after failure. In comparison, the reference material failed more suddenly after the maximum strength was reached. In addition, the stress-strain behaviour of the reference composite revealed a much smaller linear-elastic region in comparison with pure polymer behaviour of the polymer coPOM.

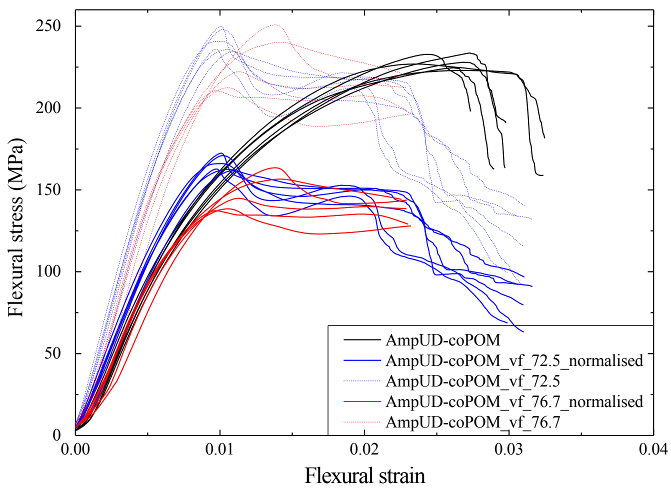

Figure 2: Shows the longitudinal flexural stress versus strain for flax fibre reinforced coPOM at different fibre volume contents. The dashed lines are the measured data, while the solid lines

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indicate fibre volume fraction normalized results (50%).

In addition to the longitudinal samples, UD transverse fibre orientation specimens were extracted from the manufactured composites and were tested in three-point bending test. The recorded stress-strain curves are shown in Figure 3. The reference specimens were measured to have an average stiffness of 2.7 GPa and strength of 41.1 MPa. The mechanical properties appear to reduce considerably with increased fibre volume content, whereas the strain at maximum stress is less affected than stiffness and strength. This drop of the characteristic mechanical properties was expected. The reason is that transverse properties are well-known to be matrix dominated and since the fibres themselves are highly anisotropic (low transverse properties), they act as weak element rather than as reinforcement. As the matrix content was gradually reduced to an achievable minimum, the material capable of carrying the load was eliminated. In fact, the cross-sectional area was reduced by 33 %, predominately by thickness changes due to the partial elimination of the matrix, compared to specimens of the reference material.

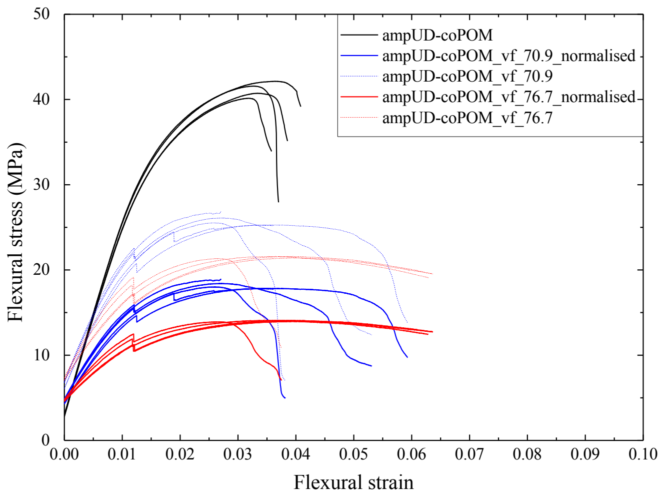

Figure 3: Shows the transverse flexural stress versus strain for flax fibre reinforced coPOM at different fibre volume contents. The dashed lines are the measured data, while the solid lines indicate fibre volume fraction normalized results (50%).

5. Conclusion

This aspect implies that when one elevates the fibre volume content, the composite adapts the load-response behaviour of the fibre. This aspect is additionally proven by the reduction of the strain at failure, suggesting a higher brittleness of the composite. In particular, test specimens have reached the maximum stress at significantly lower strain, being between 1 % and 1.25 % compared to 2.5 % of the reference material. The transverse properties are adversely effected by increasing fibre volume content. Indeed, the matrix seems to play an important role in transverse properties due to the relatively weak intra-fibre strength of the flax fibres.

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7. References

[1] M.M. Kabir, H. Wang, K.T. Lau, F. Cardona, Chemical treatments on plant-based natural fibre reinforced polymer composites: An overview, Compos. Part B Eng. 43 (2012) 2883–2892. doi:10.1016/j.compositesb.2012.04.053.

[2] U. Huner, Effect of Water Absorption on the Mechanical Properties of Flax Fiber Reinforced Epoxy Composites, Adv. Sci. Technol. Res. J. 9 (2015) 1–6. doi:10.12913/22998624/2357.

[3] A.K. Mohanty, M. Misra, L.T. Drzal, Surface modifications of natural fibers and performance of the resulting biocomposites: An overview, Compos. Interfaces. 8 (2001) 313–343. doi:10.1163/156855401753255422.

[4] B. Baghaei, M. Skrifvars, L. Berglin, Characterization of thermoplastic natural fibre composites made from woven hybrid yarn prepregs with different weave pattern, Compos. Part A Appl. Sci. Manuf. 76 (2015) 154–161. doi:10.1016/j.compositesa.2015.05.029.

[5] Z.N. Azwa, B.F. Yousif, a. C. Manalo, W. Karunasena, A review on the degradability of polymeric composites based on natural fibres, Mater. Des. 47 (2013) 424–442. doi:10.1016/j.matdes.2012.11.025.

[6] D.B. Dittenber, H.V.S. Gangarao, Critical review of recent publications on use of natural composites in infrastructure, Compos. Part A Appl. Sci. Manuf. 43 (2012) 1419–1429. doi:10.1016/j.compositesa.2011.11.019.

[7] O. Faruk, A.K. Bledzki, H.-P. Fink, M. Sain, Biocomposites reinforced with natural fibers: 2000–2010, Prog. Polym. Sci. 37 (2012) 1552–1596. doi:10.1016/j.progpolymsci.2012.04.003.

[8] S. Kalia, B.S. Kaith, I. Kaur, Pretreatments of natural fibers and their application as reinforcing material in polymer composites—A review, Polym. Eng. Sci. 49 (2009) 1253–1272. doi:10.1002/pen.21328.

[9] D.N. Saheb, J.P. Jog, Natural Fiber Polymer Composites : A Review, Adv. Polym. Technol. 18 (1999) 351–363.

[10] F. Duc, P.E. Bourban, C.J.G. Plummer, J. -a. E. Månson, Damping of thermoset and thermoplastic flax fibre composites, Compos. Part A Appl. Sci. Manuf. 64 (2014) 115–123. doi:10.1016/j.compositesa.2014.04.016.

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