Evaluation of polyfurfuryl alcohol for high performance hemp fibre reinforced composites

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Polyfurfuryl alcohol, PFA, was evaluated as suitable resin system for high performance, hemp fibre reinforced composites.

Furfuryl alcohol is produced by acid digestion of sugar cane bagasse or other hemi-cellulose rich agricultural by-products, followed by a hydrogenation step. A renewable thermoset resin with excellent rigidity and fire retardant properties is yielded by acid-catalysed self-polymerization of furfuryl alcohol at elevated temperature (Schmitt, 1974). Considering that there are only a few biobased thermoset resins on the market and that there is a high demand for green composites, one could wonder why the use of PFA is not widespread in natural fibre composites. In literature, the formation of water during condensation curing of polyfurfuryl alcohol is considered as the main problem since the release of steam can result in foaming, blistering and porosity. Several strategies can be applied to manage moisture during processing and reduce the influence on composite properties. However, according to the state of the art, the strength of natural fibre reinforced PFA composites is limited which hinders adoption in high performance applications (Domínguez & Madsen, 2014; Resch-Fauster et al, 2018).

In this study, the influence of process parameters on the properties and porosity content of hemp fibre reinforced PFA composites was evaluated. Prepregs were prepared by Basaltex, Belgium, using hemp satin fabrics and PFA resin provided by the H2020 Ssuchy consortium and TransFurans Chemicals, Belgium, respectively. To reduce the influence of water during processing, the prepregs were B-staged at 100°C for 4 min to evaporate solvent water and the mould was opened at various intervals during compression moulding. The mould was opened, and steam released, in the first part of the cycle, before gelation of the resin. The curing cycle was completed at high pressure to disperse the remaining water into small particles.

Thermal gravimetric analysis, TGA, and oven curing experiments indicated that a high curing degree is reached within 4 min when the B-staged prepreg is processed at 150 – 155°C. In addition, complete curing can be assumed after 20 min. Based on these findings, the mould was opened within the first 5 min of the production process. The moments of steam release are summarized in the second column in figure 1. Contrary to the expectations, the processing protocol did not have a significant influence on composite properties and porosity content meaning that B-staging of the prepregs was sufficient to limit blistering and porosity. However, although the theoretical stiffness was achieved, the average strength was approximately 2,5 times lower. The porosity content measured by computed tomography was 5-12% which is a partial explanation for the limited strength performance. However, significantly better performance was reported for epoxy resin composites using the same fabric and having similar porosity content. In addition, acid degradation of the fibres is largely avoided by the use of a mild acid catalyst. Therefore, the inherent brittleness of the resin is suggested as additional explanation. Resin properties will be shown at the conference to explore this hypothesis.

To conclude, B-staging was sufficient to allow composite production. While the theoretical stiffness was achieved, the reinforcing effect of hemp fibres could not be fully exploited in terms of strength. Relatively high porosity content and inherent brittleness of the resin were suggested as potential explanation. The biobased nature and excellent fire retardant properties of hemp fibre reinforced polyfurfuryl alcohol composites can be exploited in stiffness dominated designs where strength is of lesser importance.

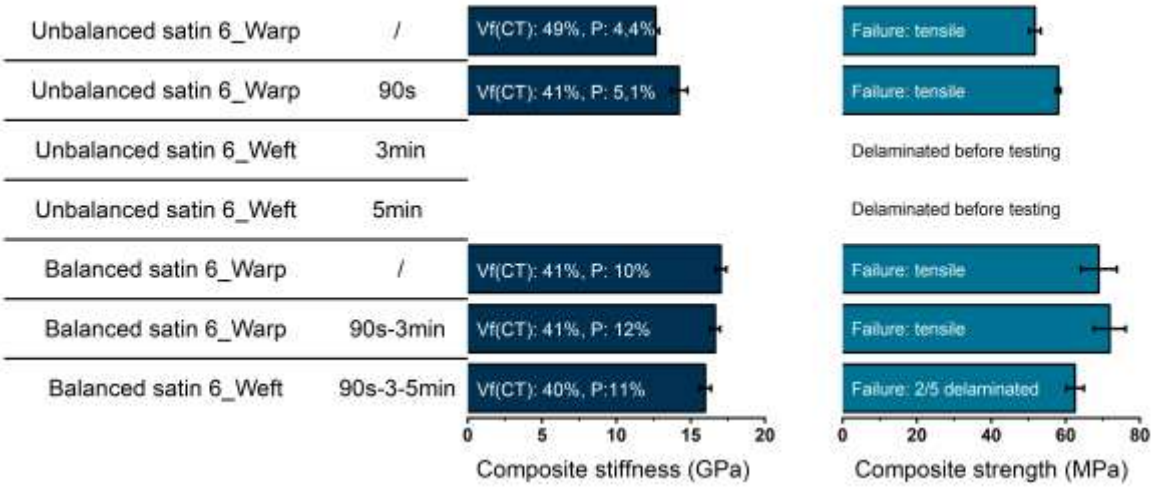

Figure 1: Composite stiffness and strength of unbalanced and balanced satin hemp reinforced polyfurfuryl alcohol composites. The second column refers to the mould opening moments to release steam during production. Vf(CT) and P refer to the fibre volume fraction and porosity content, respectively, measured by computed tomography.

References

Domínguez, J. C. & Madsen, B. (2014) Development of new biomass-based furan/glass composites manufactured by the double-vacuum-bag technique. *Journal of Composite Materials*, 49(24), 2993-3003.

Resch-Fauster, K., Džalto, J., Anusic, A. & Mitschang, P. (2018) Effect of the water absorptive capacity of reinforcing fibers on the process ability, morphology, and performance characteristics of composites produced from polyfurfuryl alcohol. *Advanced Manufacturing: Polymer & Composites Science*, 4(1), 13-23.

Schmitt, C. R. (1974) Polyfurfuryl Alcohol Resins. *Polymer-Plastics Technology and Engineering*, 3(2), 121-158.