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FLAME-RETARDANT COMPOSITES AND ANALYSIS OF THEIR RESIDUAL STRENGTHS AFTER TAILORED FLAME TESTS.

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ABSTRACT

Fibre-reinforced polymers (FRPs) are increasingly used for mobility applications due to their excellent properties in lightweight design. In addition to adequate mechanical properties, flame retardancy is a critical requirement for most of these applications. Because FRPs are usually combustible, flame retardants are required. However, they can impair the properties of composites and should therefore be used as little as possible. Typically, the surfaces of structural components are exposed to flames, therefore this work focuses on the protection of the outer layers. In this study, GFRPs are locally modified with red phosphorus (RP) to achieve flame-protective behaviour at low RP content.

Vacuum-assisted (VA) hand lamination is a simple process to manufacture composites when position or layer wise changes of the matrix resins are desired. One typical problem while, e.g., curing plies with and without flame retardants is the convey of particles into unmodified layers (Figure 1, left). As a result, the particle content on the surface is lower than intended. A previous study published in [1], demonstrated that pre-curing of modified layers based on thermokinetic models solved this challenge. Thereby, it was possible to ensure that the modification remains in the desired layers so that the filler content can be kept as low as necessary. Based on these results, the present study focusses on the transfer to VA resin transfer moulding (VARTM), which is a frequently used industrial manufacturing process. With particle-filled resins, often a filter effect occurs, resulting in a multidimensional particle gradient (Figure 2, left). This issue is circumvented using a slightly modified “Combined Prepreg and Infusion” (CPI) method (Figure 2, right) [2]. Previous to the infusion with pure resin (VARTM), selected layers were impregnated with modified epoxy resin, pre-cured to a B-stage and stacked with unmodified dry fibres. To verify an adequate bonding between the pre-cured and non-pre-cured layers, mechanical tests were conducted. The combined manufacturing process has proven to be a suitable method for the partial application of flame retardants in FRP while maintaining the high quality and reproducibility of the VARTM-process while simultaneously retaining the expected mechanical properties. Furthermore, it was possible to manufacture fully modified references with less pores than in vacuum-assisted hand lamination, which is relevant for the comparison of test results.

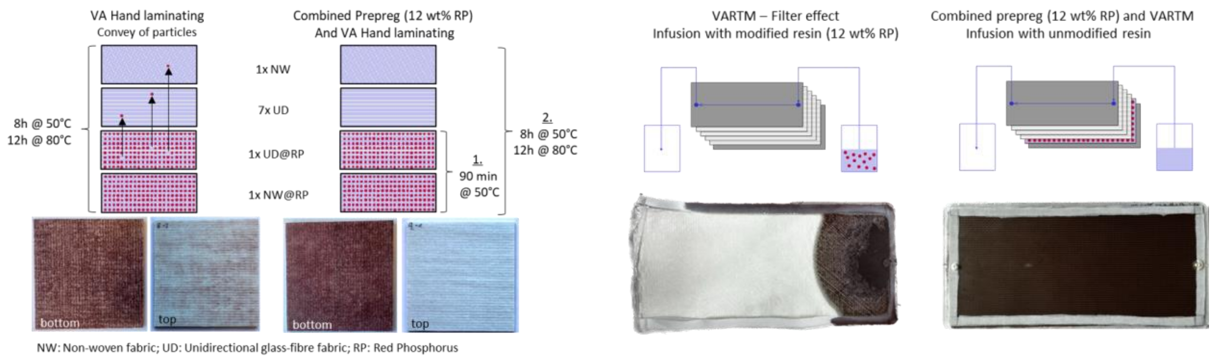

Figure 1: Left: Avoidance of particle convey using modified pre-cured layers while vacuum-assisted hand laminating. Right: Filter effect in particle loaded VARTM-process and solution via CPI-method.

Several test methods for testing the fire properties of FRPs are standardised, but these usually require very large test specimens and special devices, such as a cone calorimeter. As part of this study, flame tests were developed to enable a qualitative comparison of different laminates using as little material as possible. Various lay-ups were examined using optical analyses and compared by determining the burning and afterburning times as well as the mass loss and the temperatures at various points during the fire tests. Using microscopy images of cross-sections, it was possible to determine how many layers of the composite were damaged by the fire scenario (Figure 2). Subsequently, burned specimens were tested with regard to their residual (compression) strength (Compression after Flame Test – CAF), as it is relevant for mobility applications whether load-bearing ceilings or walls collapse after a fire or if people can escape.

The fire and CAF test set-ups allow for qualitative analysis as the specimens only fail in the layers damaged by fire. The results indicate that the residual strengths vary depending on the amount of FR modified in the prepregs, with higher modification leading to higher fire resistance and, therefore, higher residual strength. The analysis of the cross-sections of the burnt-through laminate layers confirms this result. Already the modification of one layer improves the flame-retardant effect on the composite. Furthermore, it is proven that the use of a glass fibre non-woven increases the flame resistance due to its non-directional fibres. The combined analysis method enables an initial assessment of the behaviour of materials in the event of a fire and its effects and thus their safety and reliability on a small scale. It can be used as a screening method to initially avoid complex and costly procedures and, if necessary, to carry out more in-depth analyses based on the initial assessment.

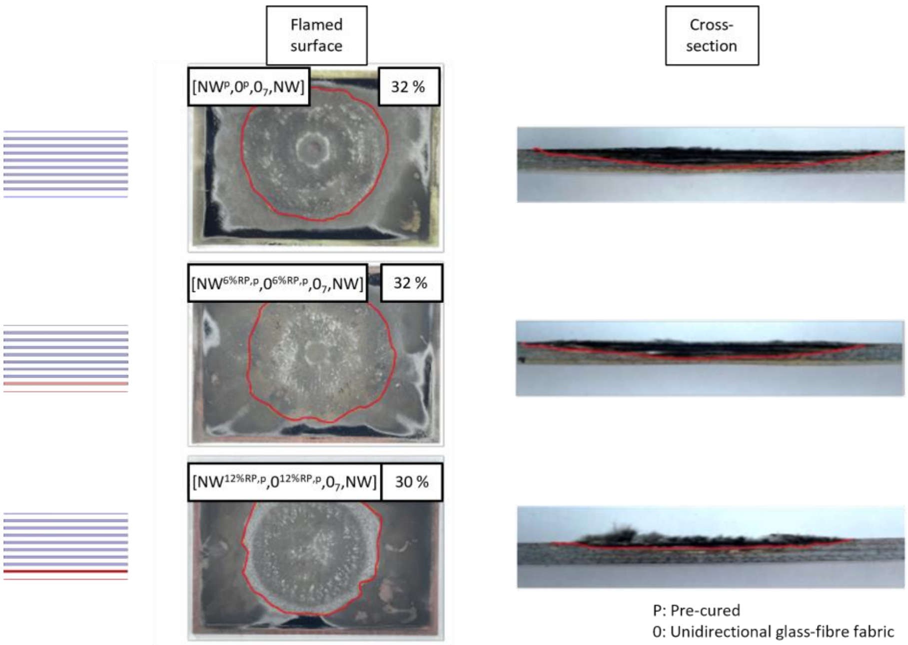

Figure 2: Flamed surfaces and cross-sections of three of the tested configurations. Reduced extent after the same fire load (180 s) with just 12 wt% RP in 1/8 of the load-bearing layers.

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