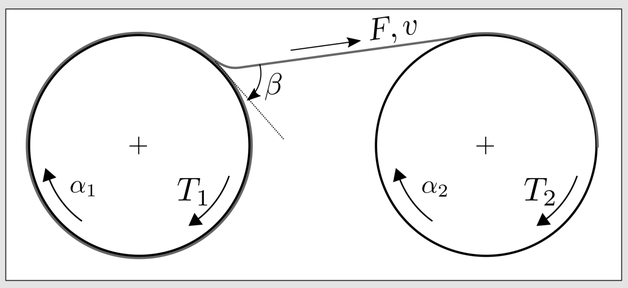
Optimization of DDP test parameters through DoE for TP-AFP process improvement

Background

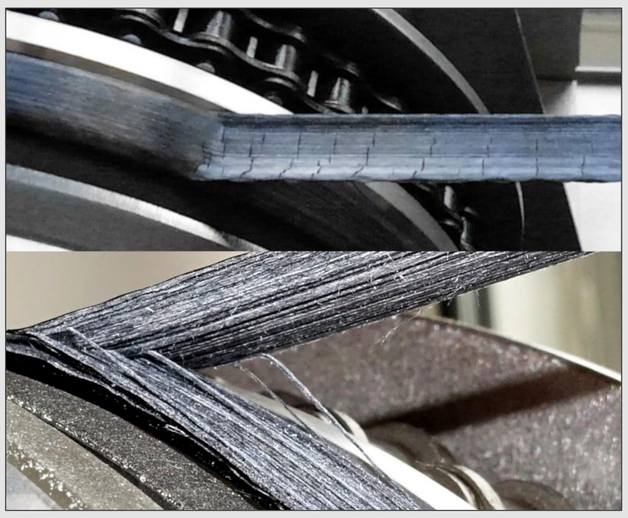
The properties of laminates produced with thermoplastic in situ automated fiber placement (TP-AFP) depend on a large number of process parameters such as the temperature at the nip point or the layup speed. The preferred testing method to examine the effects of these parameters on the consolidation quality is the Double Drum Peel (DDP) test in order to save time and costs. The adhesive energy of wound rings is measured by unwinding the tape through two drums while controlling the peel angle β and the peel speed v. The most important outcome of this test is the critical energy release rate G_c. With the design of experiments (DoE) method, optimized setpoint values for β and v were determined.



Double Drum Peel (DDP) test

Objectives

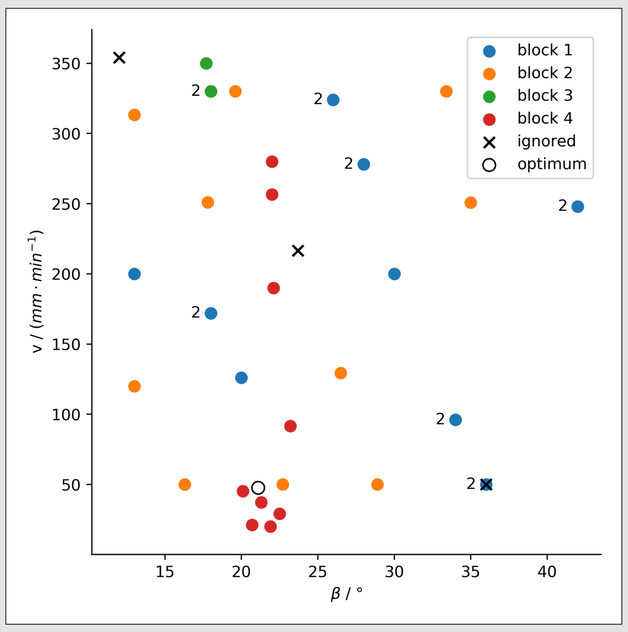
The output of the DDP test is highly sensitive to β and v regarding the causation of undesired failure mechanisms such as fiber kinking and fiber bridging, the ability of the test to show a distinct G_c-plateau with small deviation and the ability of the test setup to show a small deviation of β and G_c. Hence, the length of the G_c-plateau was maximized while the deviations $s(G_c)$ and $s(\beta)$ as well as the number of kinking bands n_{kink}, the number and height of overshoots n_o resp. $\bar{o}$ and the deviation $\Delta\beta$ of β from its setpoint value was minimized.



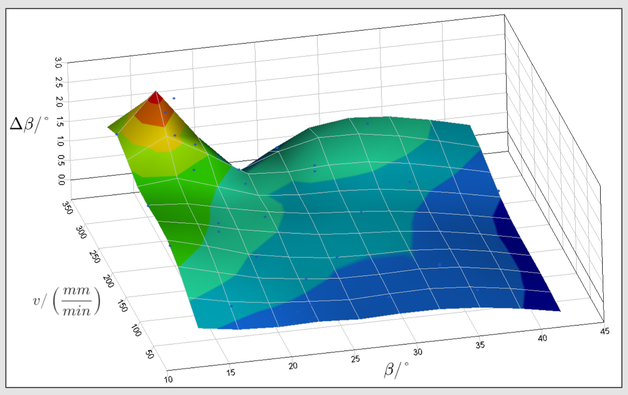
Fiber kinking (top) and fiber bridging (bottom)

Methodology

The experimental design was created with the help of commercial software in numerous blocks and by restricting the search space iteratively. Surrogate models for the responses were created using polynomial and more sophisticated models such as radial basis functions. The trade-off between the objectives was done by setting limits and weighting factors and making analytical and numerical optimization on the surrogate models. Additionally, an acceptable member off the pareto front was picked.



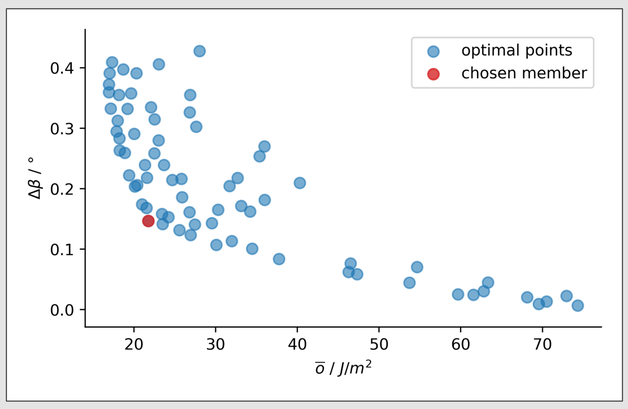
Experimental design



Surrogate model for $\Delta\beta$

Results

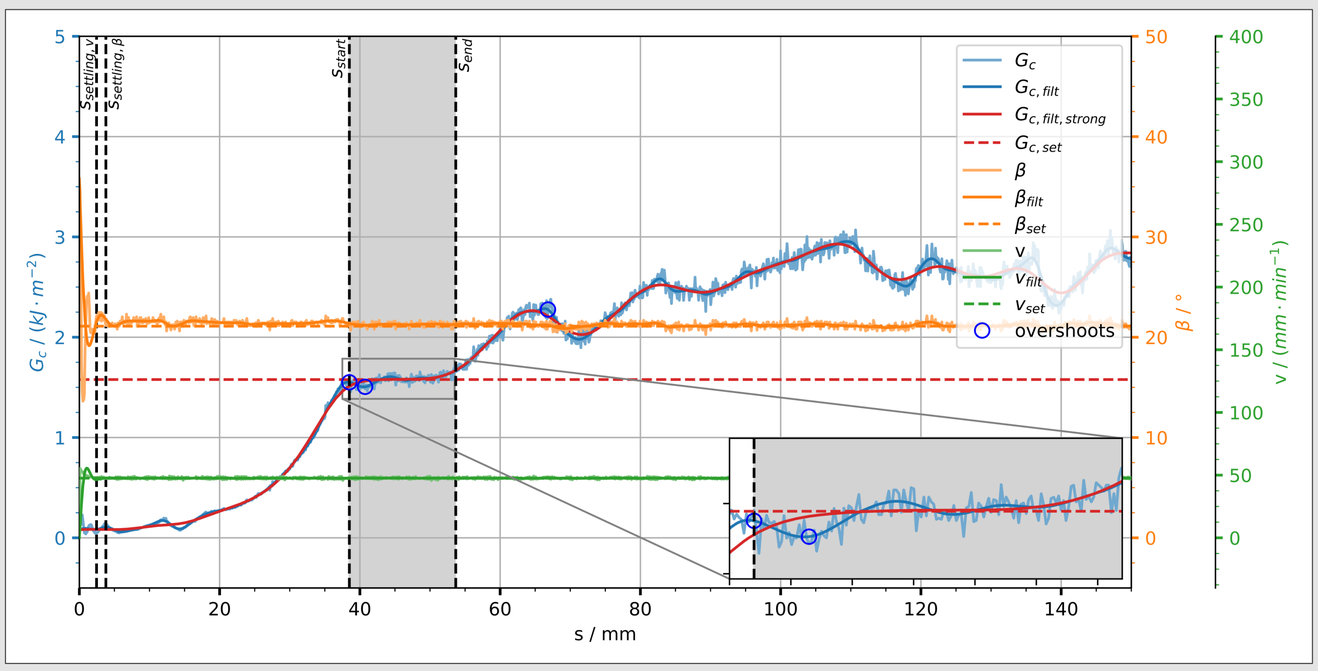
The responses $s(G_c)$, n_{kink} and n_o reveal an unfavorable influence of high β-values and no significant influence of v. The remaining responses show a significant interaction effect and especially $\Delta\beta$ and $s(\beta)$ reveal undesirable results for very low values of β and high values of v. The optimum was found for $\beta = 22{,}1°$ and $v = 47{,}6\,\frac{mm}{min}$.



Pareto front

Conclusion

The presented study reveals the importance of adequate setpoint values for β and v in order to test for pure delamination with reasonable variances and standard deviations. Sound recommendations for testing parameters of CF-PPS tape were presented which meet the recommendations stated as $20° < \beta < 50°$ in order to reduce energy losses due to local bending at the crack tip leading to fiber kinking and to prevent both extensive tensile and bending stresses of the unattached section of the unwound ring. Furthermore, this range ensures nearly constant mode mixity of $G_{II} \approx 0{,}6 \cdot G_I$ between the opening mode I and the shearing mode II.



Critical energy release rate G_c, β, v and overshoots

Contact
Institute of Structures and Design
Dipl.-Ing. P. Dreher
patrik.dreher@dlr.de
+49 711 68 62 81 29
dlr.de/bt

Deutsches Zentrum für Luft- und Raumfahrt

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