Compression fatigue after impact testing of thermosetting composites

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Introduction

The use of structural adhesives and composite materials for example in aircraft, wind energy, automotive or marine industry requires highly durable and reliable materials. Many fibre reinforced composites show excellent fatigue strength to weight ratios [1], but are also sensitive to localized impact loadings [2-3]. Considering the operational lifetimes of 20 years and a number of loading cycles from 10^8 to 10^9 for example in wind turbine rotor blades [4] the combined impact and fatigue performance of fibre reinforced structural materials is an important issue. Impact damage may occur during operation as well as during manufacturing, transport or maintenance of fibre reinforced composite parts.

Therefore the fracture mechanics and fatigue properties of the materials used have to be investigated and optimized. One approach to improve the interlaminar fracture toughness of composites and their impact damage resistance can be the use of new resin systems. Especially for wind turbine rotor blades the dynamic long term stability and fatigue damage tolerance plays an important role.

Experimental

This study focuses on the post-impact compression fatigue performance of glass and carbon fibre reinforced composites. Epoxy and polyurethane matrix based fibre reinforced laminates, manufactured by VARTM-process, are subjected to low velocity impacts with different impact energies. Used matrix systems were Bakelite EPR L 1100 + EPH 294 epoxy/amine and a polyurethane resin formulation from Henkel. To compare glass and carbon fibre laminates a special test setup and geometry was designed. After impact loadings with different impact energies the delamination damages of the tested specimens were investigated. The delaminated areas of the CFRP laminates were measured by ultrasonic c-scans; for the glass fibre reinforced laminates the delaminated areas were evaluated optically.

From the residual static compression strengths the upper load spectrum limits for fatigue testing are derived. Run outs were defined for specimens which underwent $2 \cdot 10^6$ load cycles without failure.

Results and Discussion

At low impact energies the static failure mechanisms are dominated by the matrix properties. The epoxy shows much bigger delaminated areas in comparison to the polyurethane matrix system. At higher impact energies the differences between both matrix materials are less pronounced, since more fibre fracture takes place in the impact location. Reasons for the improved impact resistance of the polyurethane matrix are its higher fracture toughness and better fibre-matrix-adhesion.

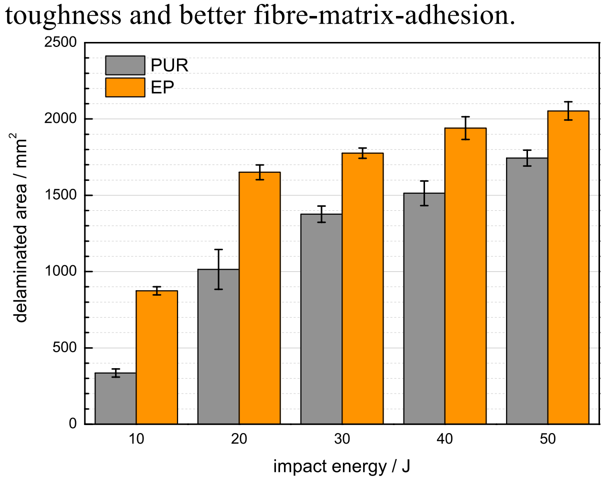

Figure 1: Delaminated areas of epoxy and polyurethane based glass fibre reinforced laminates after different impact loadings

At same impact energies the residual compression strengths of the polyurethane laminates are around 1.5 to 1.6 times higher compared to the standard epoxy. Comparing specimens with similar damage

– this means similar delaminated areas – it can be seen that 50 J impact energy are needed for polyurethane laminates to obtain the same impact damage as with epoxy at 20 J (Fig. 1).

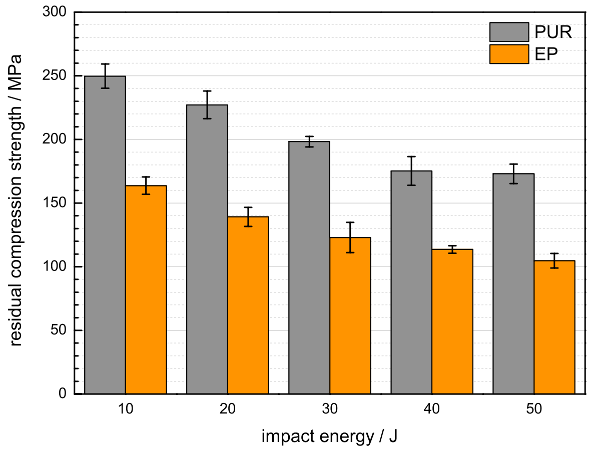

Figure 2: Residual static compression strengths after different impact loadings

But also in this case the polyurethane matrix system shows around 1.3 times higher residual compression strength (Fig. 2). This means that in static testing the polyurethane based composites are more damage resistant as well as more damage tolerant than the epoxy based references.

Compression S/N curves were derived of glass and carbon fibre reinforced laminates subjected to 30-J-impacts. The polyurethane laminates exhibit the best fatigue performance. With carbon fibre reinforcement the polyurethane shows a slightly better dynamic damage tolerance for high numbers of load cycles compared to the glass fibre reinforcement.

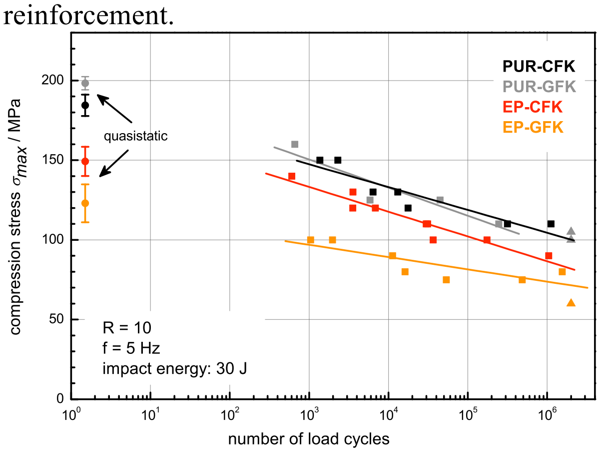

Figure 3: Compression S/N curves of glass and carbon fibre reinforced polyurethane and epoxy after 30 J impact loading

The combination of the brittle epoxy system and carbon fibre results in intermediate fatigue properties thanks to good fibre properties. Glass fibre reinforced epoxy shows the lowest residual compression strength in static and dynamic testing. The shallow slope of the S/N curve implies a good fatigue damage tolerance but on a much lower level compared to the other investigated materials.

Conclusion

The use of polyurethane matrix systems significantly improved the damage resistance and damage tolerance of glass and carbon fibre reinforced composites compared to an epoxy reference system. At impact energies of 30 J the static residual compression strength are dominated by the matrix system used, while under dynamic compression after impact testing the good mechanical properties of the carbon fibre becomes more visible. Glass fibre reinforced polyurethane has the highest static residual compression strength while the combination of polyurethane and carbon fibre seems to be best in fatigue properties.

Acknowledgements

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