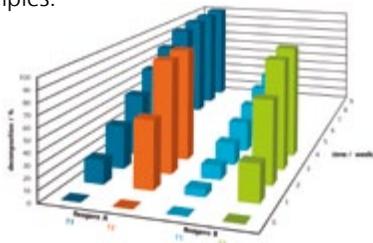


Recycling of Cyanate-Based Thermosets and Reuse of Recyclates

Another feature is the recyclability of the thermosetting resins. The recycled materials can be reused in the preparation of new thermosets.

Different kinds of decomposition agents and temperatures have been applied, and figure 9 shows the dependency of both parameters on the decomposition rate for selected examples.



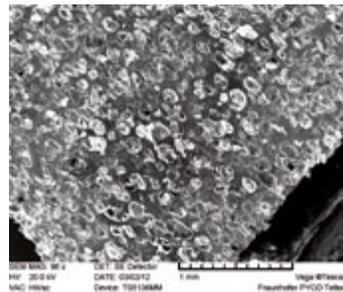
9: Decomposition rate in dependency to temperature and kind of decomposition agent; T1: 20°C, T2: 40°C

The recyclate can be added to different resin mixtures for the preparation of new materials. Figure 10 shows two foams, with different percentages of recyclate.



10: Foams containing 22% and 13% recyclate

Further mixture ratios are possible due to the excellent miscibility of the components. Structure and surface of these foams are homogeneously as shown in the SEM-exposure in figure 11. The whole recycling process of the cyanate resins is easy to handle and simple.



11: SEM-exposure: Foam structure (96x magnification)

Outlook

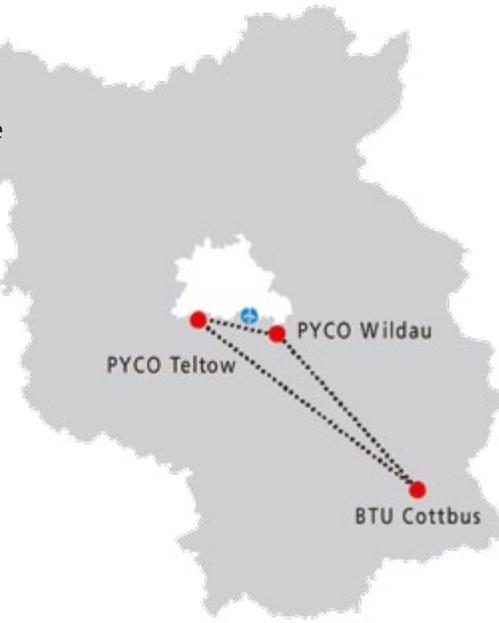
Beside the described simple method of recycling and repair for cyanate-based thermosets the recycling of other thermosetting materials and repairing methods for fiber-reinforced materials would be very eligible. Some are published by other groups, e.g. the recycling and more seldom repairing methods for epoxide-anhydride and epoxide-amine (K. El Gersifi et al., Polymer Degradation and Stability, 2006, 91, 690; W. Dang et al., Polymer, 2005, 46, 1905)

Fraunhofer PYCO is developing simple recycling and repairing methods for further thermosets as well.

Location Berlin-Brandenburg

New solutions require new approaches: The locations of the research institute in Teltow and Wildau, where the metropolis of Berlin and the federal state of Brandenburg meet, offer optimal conditions for innovative scientific research.

Here, the products of tomorrow emerge from ideas and visions. Therefore, the institute's scientists have formed a creative research network with renowned universities, well-known large-scale enterprises, and various innovative medium-sized companies. Additionally, new synergy arises from the integration in the third largest location of aerospace industry in Germany.



Fraunhofer Research Institution for Polymeric Materials and Composites PYCO

Dipl.-Ing. (FH) Karina Klauke
 Kantstrasse 55
 14513 Teltow, Germany
 Phone +49 3328 330-294
 Fax +49 3328 330-282
 karina.klauke@pyco.fraunhofer.de
 www.pyco.fraunhofer.de



12: Main building

Repair and Recycling of Fiber-Reinforced Cyanate-Based Resins



Motivation

Thermosets are important lightweight construction materials in many technologies, e.g. in the automotive and aircraft industry. Up to now the most used disposals are land-filling, burning or milling and recovery as filler material in small amounts due to the high degree of crosslinking of thermosets. Since the production of thermosets has increased strongly over the last years, recycling and repair become more and more important. The high potential application Carbon Fiber-Reinforced Composites (CFRP) is one of the forces. Up to 90% of it is using thermosets for the matrix. Fraunhofer PYCO has been developing a simple recycling method in order to decompose cyanate-based thermosetting resins and Fiber-Reinforced Composites (FRP) in its components and to reuse it for new materials. Based on this principle a repairing method was engineered.



1: Recycling and repair of a CFK-fender with thermoset matrix (© Torsten George)

Applications at a Glance

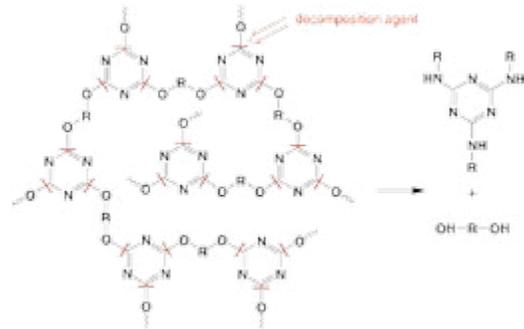
- Automotive
- Aerospace
- Railway transportation
- Naval architecture
- Construction or civil engineering

Properties at a Glance

- Simple recycling of fibers from fiber-reinforced materials (e.g. glass, carbon)
- About the same properties of virgin and recycled fibers
- Multiple recycling of fibers
- Simple repair of fiber-reinforced composites
- Simple recycling of the thermosetting resin
- Reuse of the recyclate in new thermosetting resin systems
- Preparation of solids and foams with recyclates
- Simple and easy to handle chemical process

Principle of Recycling and Repair of Cyanate-Based Thermosets

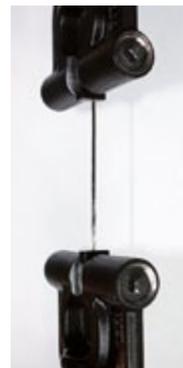
Cyanate-based thermosetting resins can be completely decomposed in their components by adding a special decomposition agent with little energy and material expense. The cyanurate crosslinking parts in the thermosetting resin are attacked by this chemical agent and 2,4,6-Triamino-s-Triazine derivatives and phenolic compounds are obtained, as shown in figure 2.



2: Decomposition of the cyanurate network

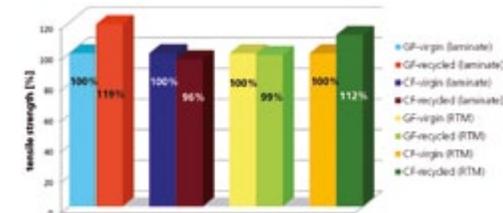
Recycling and Repair of CFRPs and GFRPs in Fiber-Reinforced Cyanate-Based Thermosets

Glass and carbon fibers in laminates and RTM-resins composed of cyanate-based thermosetting resins can be effectively separated from the thermosetting resin by the described method. The process of recycling and the application of the decomposition agent have no influence on the quality of the separated fibers. Investigations showed that the properties of the virgin and recycled fibers are the same. For this reason, laminates and RTM-resins with recycled glass and carbon fibers could

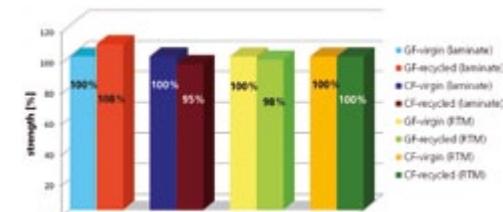


3: Carbon fiber in a test apparatus

be produced without any restrictions. The resulting fiber-reinforced thermosets show no significant differences compared to thermosets containing virgin fibers. Furthermore, multiple recycling of the fibers does not degrade the properties. The corresponding characteristic data are shown in figure 4 (tensile strength tests) and figure 5 (three-point bending tests). In some cases, properties of the fiber reinforced materials could be even improved by the use of the recycled fibers.



4: Tensile strength tests of laminates and RTM-resins with virgin and reused fibers



5: Three-point bending tests of laminates and RTM-resins with virgin and reused fibers

Figure 6 shows a carbon fiber reinforced laminate, where the thermoset of the tail section was removed by the decomposition agent and the pure carbon fiber is obtained.



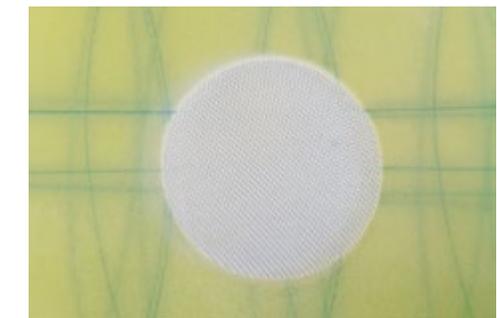
6: CF-reinforced laminate with partly removed thermoset

The advantage of the method compared to well-established procedures is that the recycling loop for the fibers is closed with little effort of energy. Figure 7 shows the cycle for carbon fiber-reinforced laminates as example starting with impregnated Carbon Fibers (CF), preparing CF-laminates, carrying out the recycling process, and obtaining the recycled fibers and resins that will be reused.



7: Recycling loop of CF-reinforced laminates

Another advantage of the new recycling-method is the repair of fiber-reinforced cyanate resins. A well-defined part of the damaged thermosetting resin can be chemically removed by addition of the decomposition agent without any destruction and decreasing of the properties of the fibers. After removal of the destroyed resin this area can be refilled. An optimal laminate will be achieved by using the parent thermosetting resin composition due to good compatibility with the building element and fibers.



8: Repair of GF-reinforced cyanate-based resin

Figure 8 shows an example for the remove of a well-defined part in a glass fiber-reinforced laminate. Of course, this repairing method can be applied to other types of fibers (e.g. carbon fibers, aramid fibers).