RESEARCH PROJECT

“Heat? Shield!”

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Polymer Composites as Heat Shields

Bastian Treiber is a student in the Elite Graduate Program “Macromolecular Science” at the University of Bayreuth. As part of his doctoral research at the Chair of Polymer Engineering under Prof. Holger Ruckdäschel, he is working on high-temperature-stable, polymer-based composite materials that are suitable as durable heat shields under extreme conditions.

High-Temperature Materials for Re-entry

When spacecraft enter the Earth’s atmosphere, they are exposed to extreme conditions. This is caused by the very high entry velocity, which strongly compresses the air in front of the vehicle. As a result, temperatures rise rapidly to values exceeding 2000 °C. To protect a spacecraft from this enormous heat, thermal protection systems (TPS) have been developed - without them, space-flight would not be possible.

For missions in low Earth orbit, such as those involving the Space Shuttle, ceramic tiles were used for this purpose. For deep-space missions, the loads are even higher due to re-entry speeds of approximately 40,000 km/h. In such cases, polymer-based composite materials are used as heat shields, as they are structurally more robust than ceramic tiles. In NASA’s current Artemis missions to the Moon, so-called glass fiber-reinforced phenol-formaldehyde resins are utilized.

In his doctoral thesis, Bastian Treiber is investigating various polymer-based composite materials that offer a range of advantages over the glass fiber-reinforced phenol-formaldehyde resins currently in use. To test and evaluate these high-performance composites for their suitability as heat shields, he completed a several-month research stay – supported by the Elite Graduate Program “Macromolecular Science” – in the renowned research group of Dr. Joseph Koo at the University of Texas at Austin.

Polymer Composites: Materials with Extreme Properties

Reinforced polymer composites have interesting properties: They can be manufactured in large formats and in virtually any shape, have a low density, and are therefore very lightweight. In addition, they possess exceptionally good mechanical properties, which are due to reinforcement with carbon or glass fibers. These materials are non-meltable and difficult to ignite, even though they contain carbon – an effect attributable to their high-crosslinking density. This property profile makes reinforced polymer composites particularly attractive for the use as heat shields.

Ablative Heat Shields

The composite materials traditionally used belong to the class of so-called ablative heat shields. In these systems, the heat shield is gradually eroded by decomposition during exposure, while the resulting decomposition gases cool the surface. However, phenol-formaldehyde resins have disadvantages. For example, water is produced during the curing process, and its presence in the material must be prevented.

Bastian Treiber therefore investigated various systems that do not exhibit these drawbacks during curing. Furthermore, a targeted selection of resin components – such as so-called benzoxazines – enables the development of glass fiber-reinforced composites with improved properties. These composites are tested under extreme conditions at temperatures exceeding 2200 °C and in oxygen-

rich environments. While steel can be cut very quickly under these conditions, only the front side of the composite becomes charred. The back side of a disc made from the aforementioned benzoxazine-based composites, with a thickness of only 1.5 cm, remains relatively cool at about 160 °C.

The use of such advanced composites as ablative heat shields is particularly interesting, as they allow for higher loads during atmospheric re-entry.

Fire away: Glass-fiber-reinforced plastic composites undergo endurance testing at temperatures exceeding 2,200 °C and in an oxygen-rich environment. These materials are suitable for use as ablative heat shields.

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