Development of Demisable Fiber Reinforced Plastic Composites

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Thorn Schleutker, Ali Gülhan, Susanne Röddecke, Erhard Kaschnitz, James Merrifield and James Beck

Presenting Author: Thorn Schleutker,

Supersonic and Hypersonic Technology Department,

German Aerospace Center DLR

Contact: Thorn.Schleutker@DLR.de

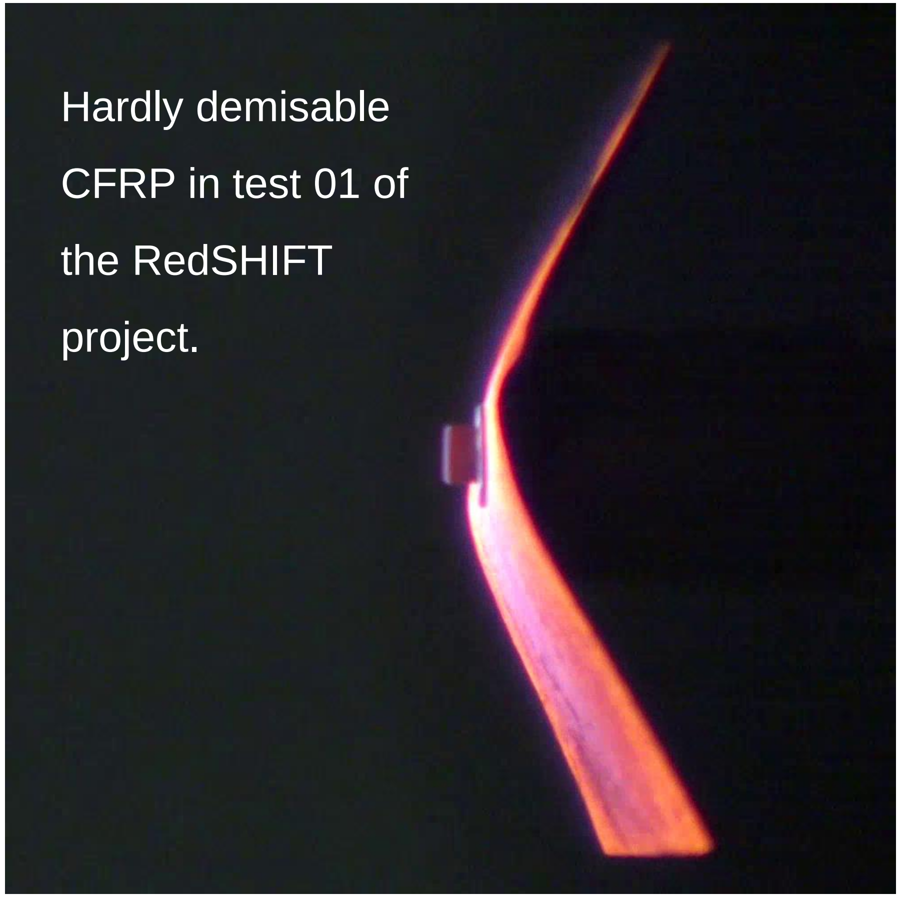
Background

Experimental entry flight simulations* show that fiber reinforced plastics (FRP) typically

- act like an ablative TPS material and
- have very high demise resistance.

There has been one exception: a CFRP tested in the CHARDEM project in 2015.

This indicates a potential in designing FRPs for demisability, which led to the COMP2DEM project presented here.



* See for example the test results of the ESA projects CoDM, SECRET and DHPT or the EU project ReDSHIFT.

Project Overview

COMP2DEM is a small ESA EXPRO study with a budget of 300.000 €.

The project aims to increase the understanding of composite demise behavior and to provide the information necessary for designing demisable composites.

The project consists of three parts:

- Thermophysical and experimental characterization of composites on material level,
- investigation of complex composite parts
- and demonstration of composite designed for enhanced demisability.

Partners

Many thanks go to the partners:

- Austrian Foundry Institute ÖGI (thermophysical characterization),
- Invent GmbH (sample manufacturing),
- Fluid Gravity Engineering and Belstead Research Ltd. (numerical simulations)

for their contribution!

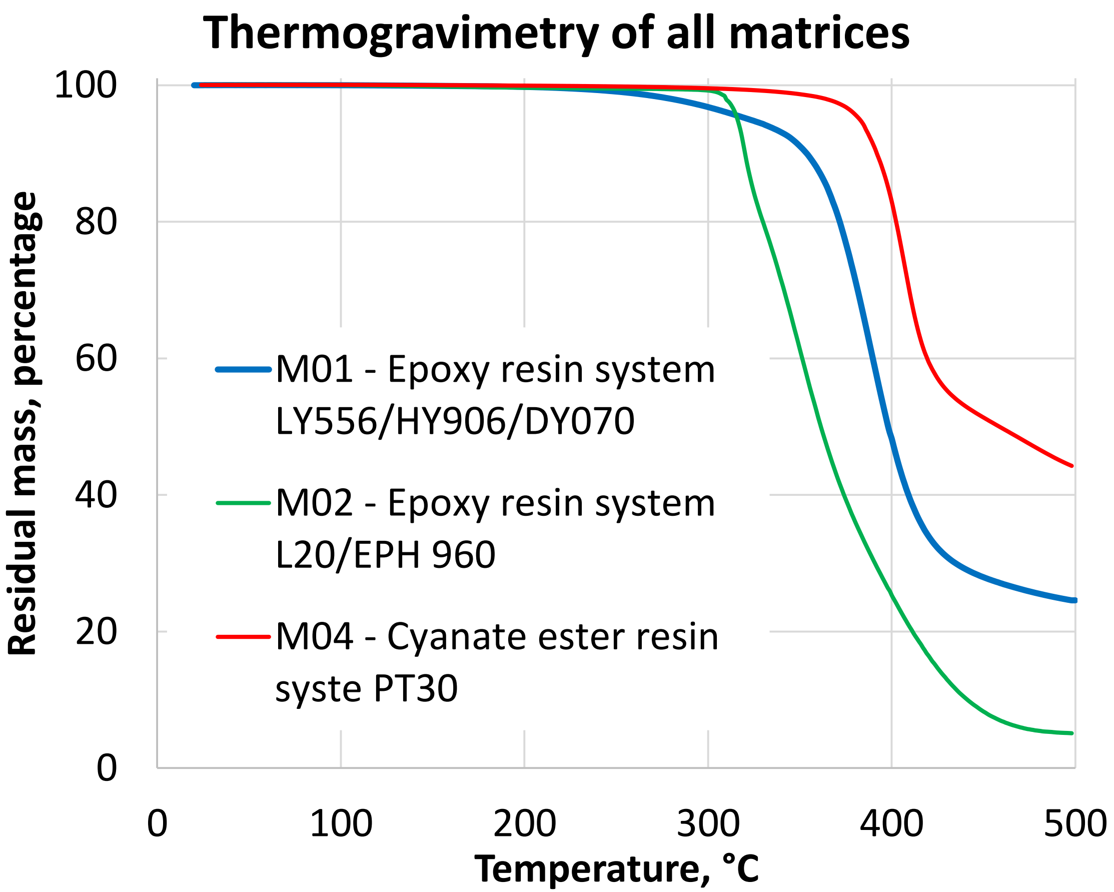
Material Characterization

Thermophysical Characterization

Thermophysical characterization included measurements of the specific heats (DSC), thermal diffusivity (LFA), thermal elongation (DIL) and mass loss over temperature (TGA).

Thermal conductivity and temperature dependent density were calculated from this data.

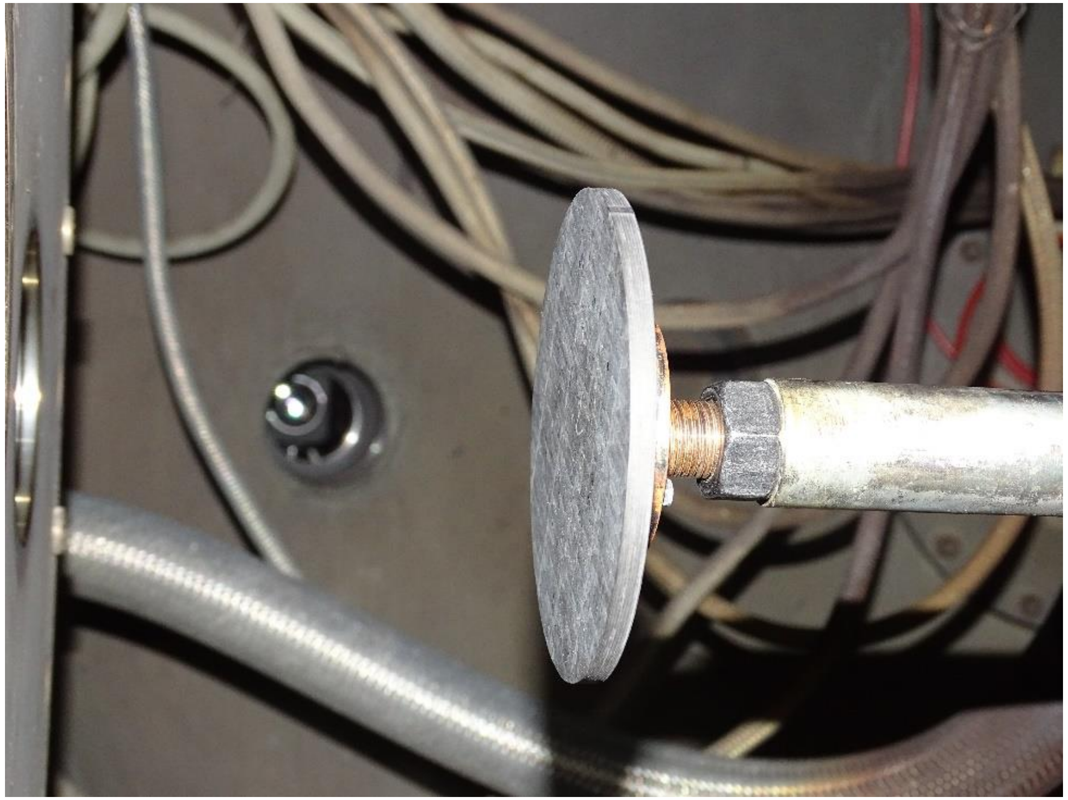
As we will see, the TGA (char residue) is the best indicator for a composites demise behavior, but not sufficient for prediction of demisability.

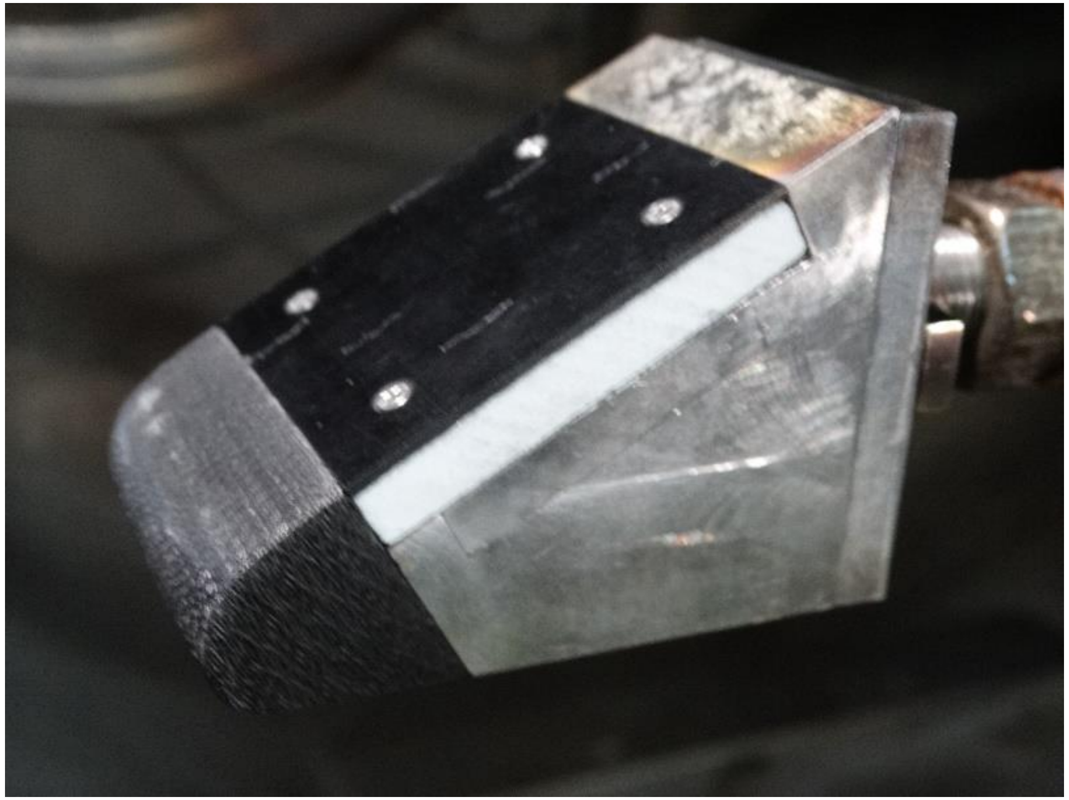


Wind Tunnel Setups

Stagnation setup (left): Cylindrical samples with 5mm thickness and 100mm diameter on standard holder.

Tangential setup (right): Square sheets with 0.6-1.5mm thickness (8 plies) and 50mm side length on small wedge holder.





Expectation for material behavior

Extreme 1

Full thermal decomposition of the matrix with no or negligible char yield.

Subsequent mechanical ablation of dry fibers.

Real composites

Some behavior in between the extremes?

Extreme 2

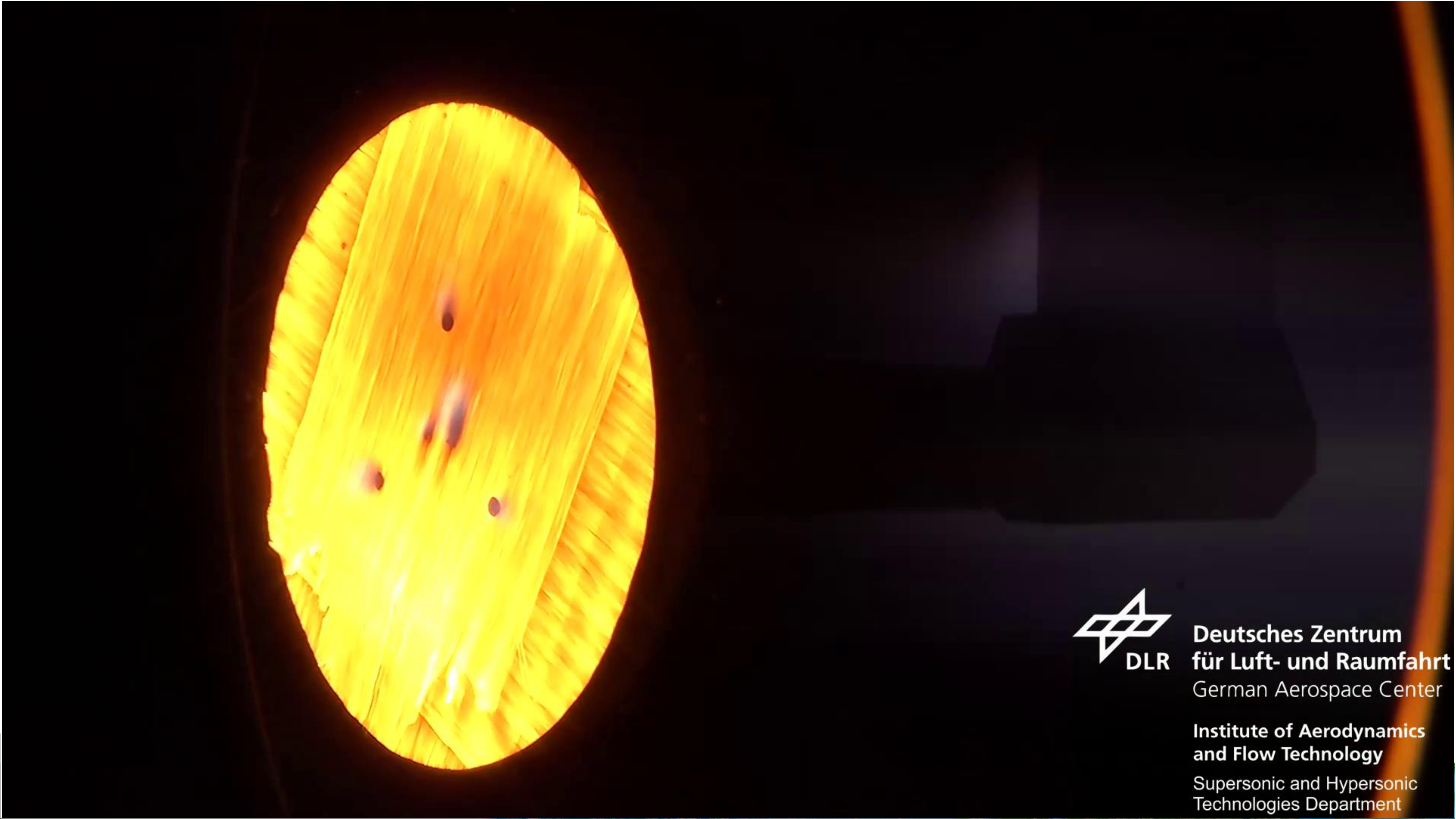
High char yield of the matrix, yielding solid C/C..

Demise through oxidization / melting of the fiber and oxidization of the char.

Can we demonstrate the two extremes?

Are we missing something?

What influence does the shear load have?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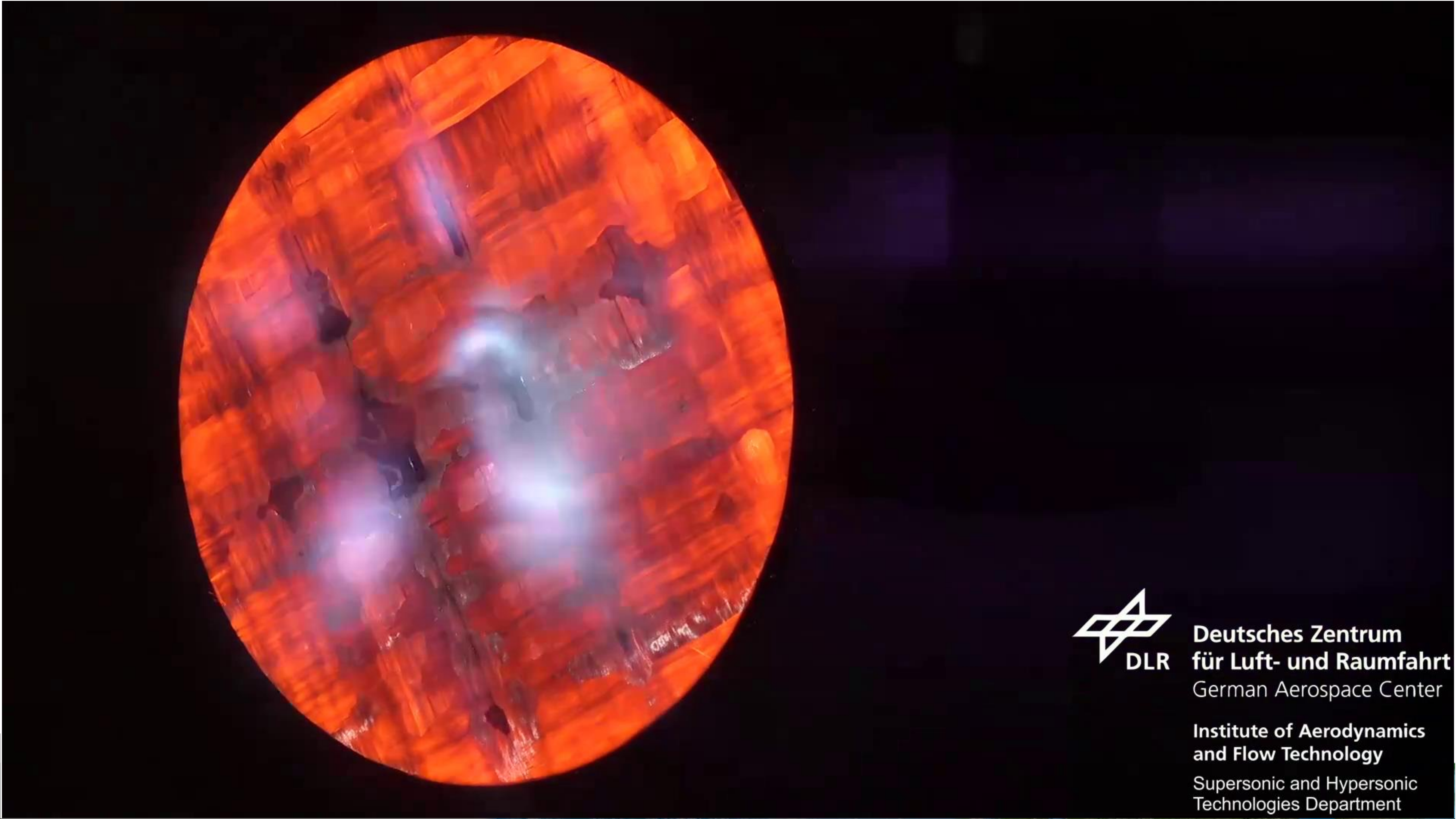
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Baseline Composite C01

The baseline material shows intermediate behavior with ablation of fiber strands or full fabric layers when matrix decomposition reaches the layer boundary.

But: demise behavior and thus demisability depend on heating rate / incident heat flux!


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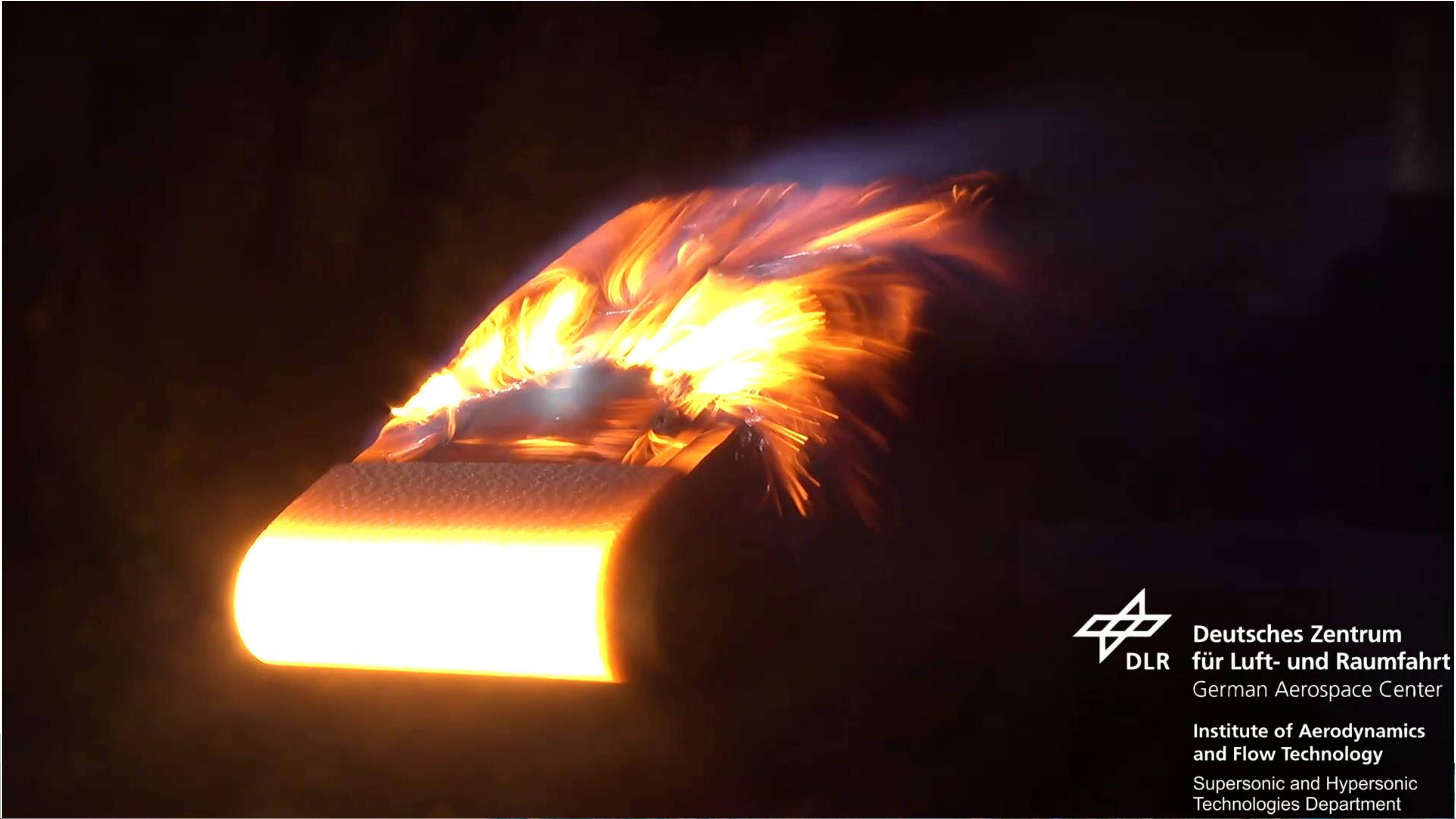

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Composite C02

The composite with L20 / EPH960 matrix system shows extreme behavior on the demisable side of the spectrum – almost complete matrix decomposition and mechanical ablation of the dry fibers.

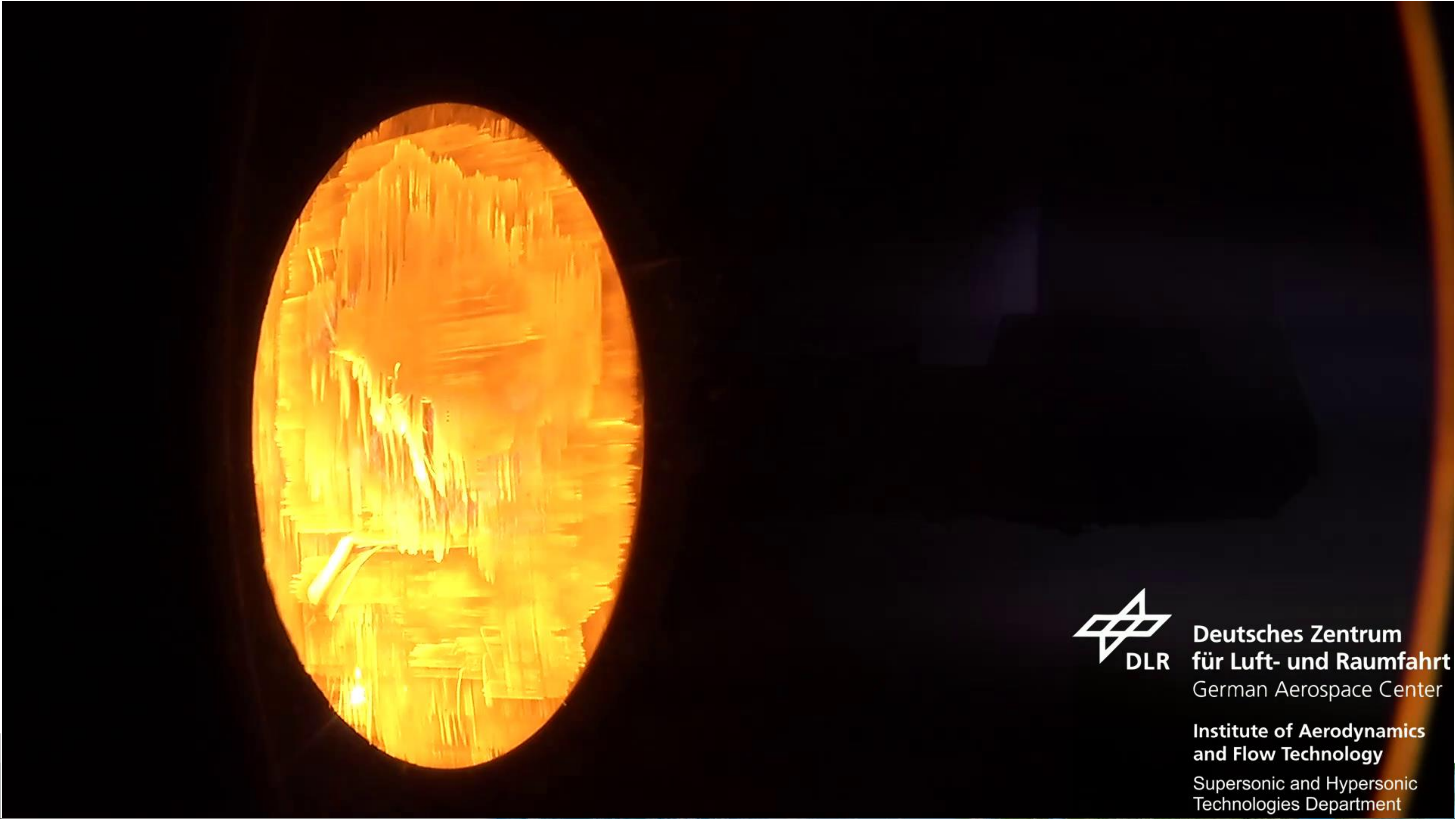
-> Demise behavior reflects the low char yield in the TGA of matrix M02.

Shear load can reduce demisability through shielding by still-attached fibers. It is unknown whether this is only the case in an arbitrarily constrained wind tunnel environment with fixed orientation.

-> Dynamic testing required.

Behavior al low heating rates and the demisable matrix with glass fiber reinforcement have not been tested.

-> Further testing on composite C02 required.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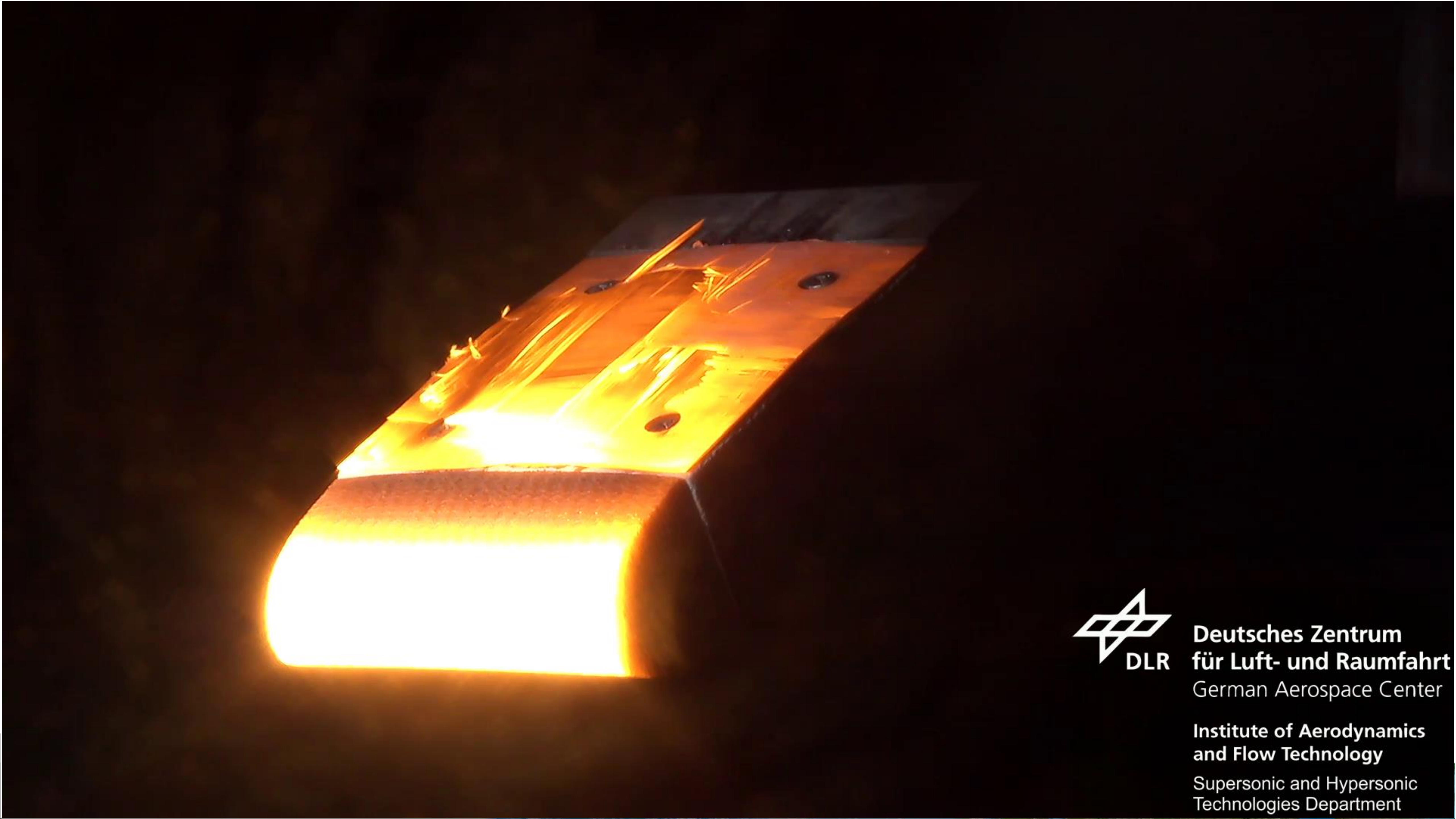
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Composite C10

Composite 10 shows the other extreme – high char yield means creation of solid charred piece and demise being driven by oxidation; behavior similar to high-density ablators.

Shear loads seem to have small impact on the demise behavior.

Conclusions

- Fiber precursor, diameter and sizing, weave, layup, fiber volume fraction etc. all have an impact on the demise behavior (tests and results not shown here), but the matrix and its char yield seem to be dominating.

  -> Every detail can change the behavior and any FRP (even if same composition) must be tested.

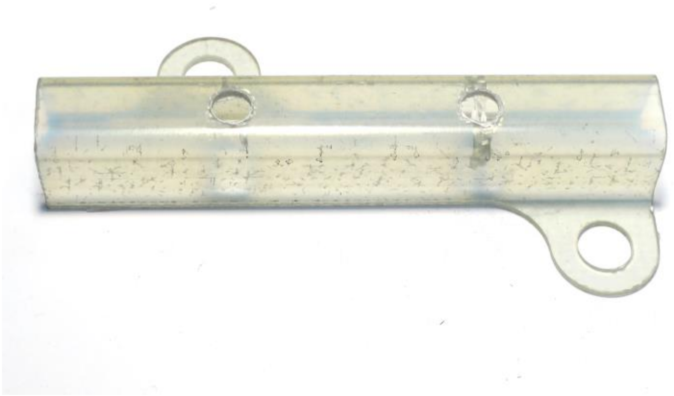
- Heating rate is important and can drastically change the demise behavior. High heating rates seem very favorable.
  - Is early exposure bad for FRP demise?
  - Material specific critical heating rate that determines macroscopic demise behavior?
  - Demisability testing at one heat flux is insufficient for judging the demisability!
- Future activities need to include dynamic testing of both material samples and complex objects.
- Test setup shall not interfere with the demise of the test samples.

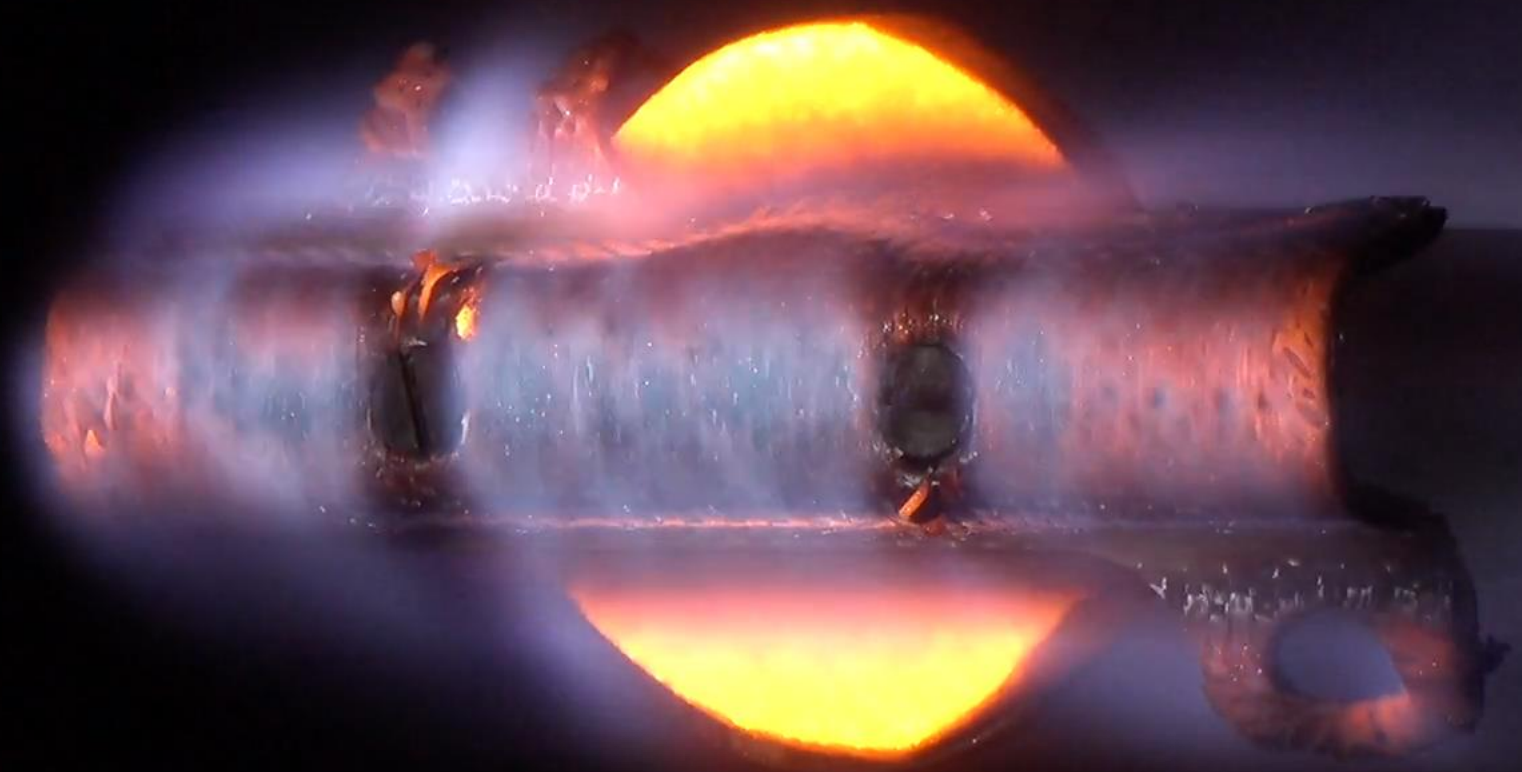
Structure Samples

Structure Samples Selection

Four different samples were chosen:

- A tube rod consisting of the baseline composite.
- A reinforcing corner made from a very similar composite.
- A plate with ribs, that was chosen for its complexity.
- And a GFRP rib that was made with the demisable matrix system.





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GFRP Rib

Unfortunately, a “demisable” matrix system (=low char residue) seems not to be sufficient to make a composite demisable. Or was it the shape of the sample?

-> GFRP with L20 / EPH960 should be further investigated.

Upcoming Test Campaign

Upcoming Test Campaign

Knowledge gained from previous test campaigns is limited.

-> Design of demisable composites not possible yet.

Focus of the final test campaign will closing the most relevant gaps.

Interesting Material Options

Option	Description	Expected demise behaviour	Prob. of high dem.	Scientific interest	Procurement / manufacturing	Score
A	T300 with L20/ EPH 960 matrix	Full decomposition of matrix, ablation of dry fibres	High	Very high	Samples available	14
B	Composite with L20/ EPH 960 matrix and different carbon fibre	Full decomposition of matrix, ablation of dry fibres	High	Moderate	Easy	11
C	Composite with L20/ EPH 960 matrix and glass fibre	Full decomposition of matrix, but molten layer may prevent ablation	Moderate	Very high	Easy	12
D	Carbon fibre composite with epoxy resin with low Tg	Potentially favourable or ablator like demise behaviour.	Moderate	Very high	Moderate	11
E	Composite with baseline matrix and aramid fibres	Unknown impact on demise behaviour	Moderate	Moderate	Easy	10
F	Composite with baseline matrix and PBO fibres	Unknown impact on demise behaviour	Moderate	Very high	Tough	10
G	Composite with increased thermal conductivity	Unknown impact on demise behaviour	Moderate	Very high	Very tough	9

Actual Material Selection

Option	Description	Thermophysical characterization	Wind tunnel testing
A	T300 with L20/ EPH 960 matrix	No	Stagnation and tangential setup, both at low heat flux conditions
C	Composite with L20/ EPH 960 matrix and glass fibre	Yes, composite	Stagnation and tangential setup, both at low and high heat flux conditions
D	Baseline carbon fibre composite with epoxy resin with low Tg	Yes, composite and matrix	Stagnation and tangential setup, both at low and high heat flux conditions
E	Composite with baseline matrix and aramid fibres	Yes, composite and fibre	Stagnation and tangential setup, both at low and high heat flux conditions
*	Bonus: composite consisting of EPDM matrix and aramid fibres (very low char yield)	No	Stagnation setup, tested at high heat flux conditions