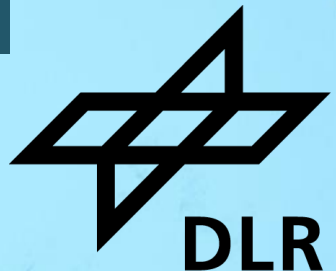
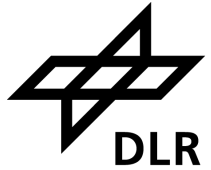


Blow-Moulded Mandrels for the Production of One-Piece Hollow Profiles with Undercuts

Dipl.-Ing. Fabian Neumann, Research Associate
DLR (German Aerospace Center), Institute of Lightweight Systems
Campus-Boulevard 79
52074 Aachen



About the Author: Fabian Neumann



- until 2019 **Dipl.-Ing. Mechanical Engineering – Aerospace Engineering**
TU Dresden, Linköpings Universitet
 - Member of Akaflieg Dresden e.V. (academic glider association)
 - Thesis: „Development of a range-extender for a hybrid-electric motorglider“
@ reinerstemme.Aero GmbH
- 2019-2022 **German Aerospace Center (DLR)**
Institute of Composite Structures and Adaptive Systems
Department of Production Technology, Brunswick
- since 08/2022 **German Aerospace Center (DLR)**
Institute of Lightweight Systems
Innovation Center for Small Aircraft Technologies, Aachen

Agenda



- 1 DLR at a glance
- 2 Introduction
- 3 State-of-the-Art
- 4 Blow-Moulded Mandrels
- 5 Conclusion and Outlook

DLR: German Aerospace Center at a glance



Research Center + Space Agency + Project Management Agency

AERONAUTICS



SPACE



ENERGY



TRANSPORT



SECURITY

Research on Civil & Military Security



DIGITALISATION

Quantum Technologies & Systems Modeling



- Europe's largest research center for aeronautics and space, i.a. covering the **entire air transport system**
- Close cooperation with science, business and industry
- 10,000+ employees in 55 research institutes and facilities at 30 locations and 4 offices abroad

1

2

3

4

5

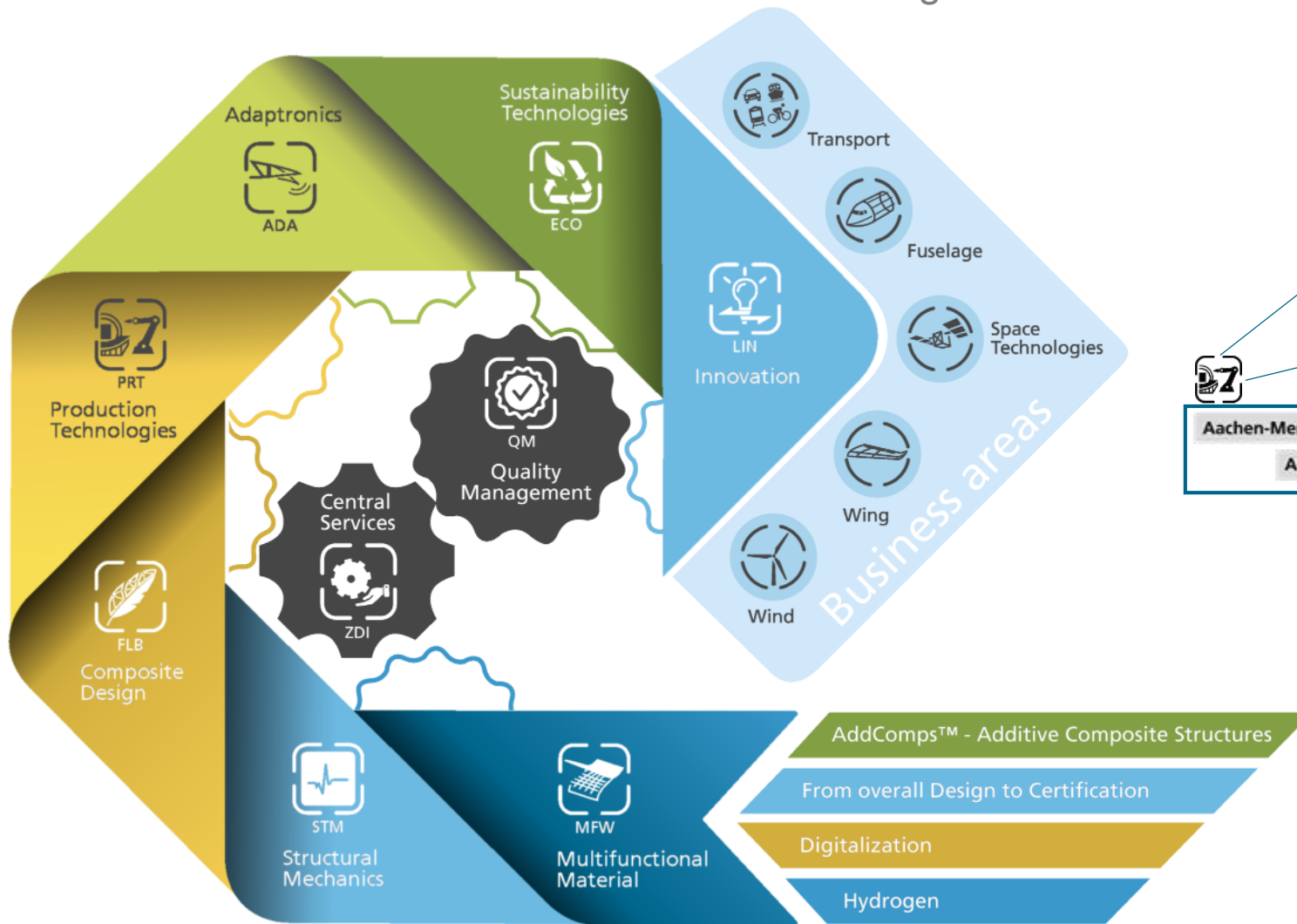
Institute of Lightweight Systems (SY)

Director:

Vice-Director:

Prof. Dr.-Ing. Martin Wiedemann

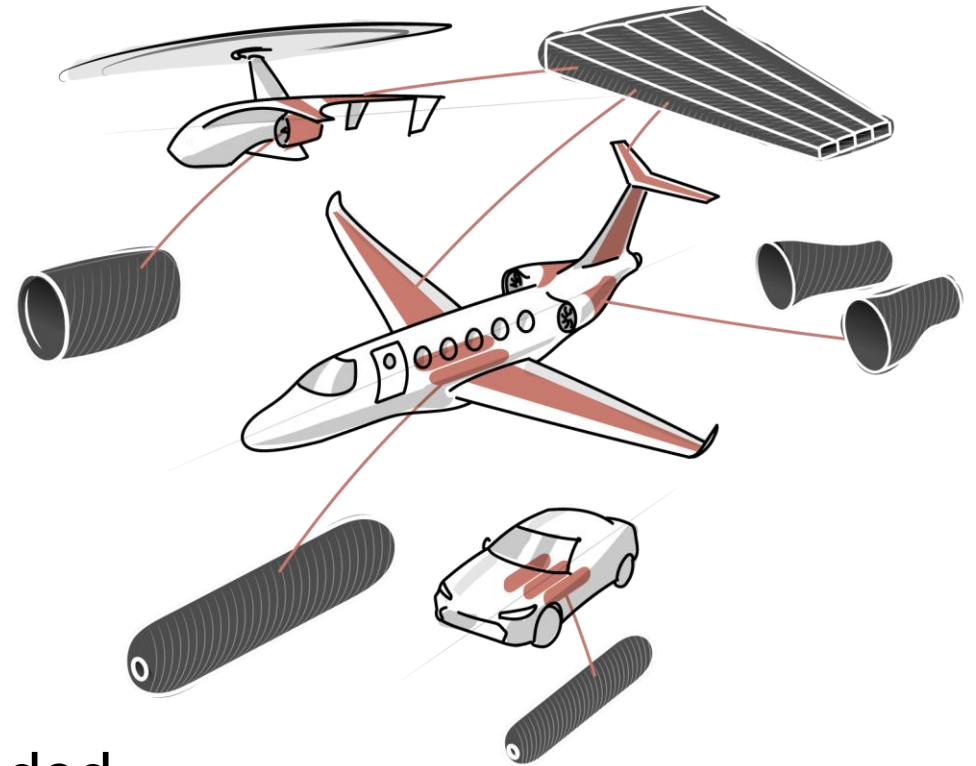
Prof. Dr.-Ing. Peter Wierach



Introduction

Motivation

- New Energy and New Mobility Solutions:
 - Small Aircraft, UAM, UAV
 - H²-powered transport
 - H²-storage
 - Production of hollow composite parts is expected to grow strongly over next decades:
 - Type V pressure vessels
 - Air inlet ducts
 - One-shot structural elements
 - Hollow Struts with variable cross-section
- High-rate production of hollow FRP parts needed

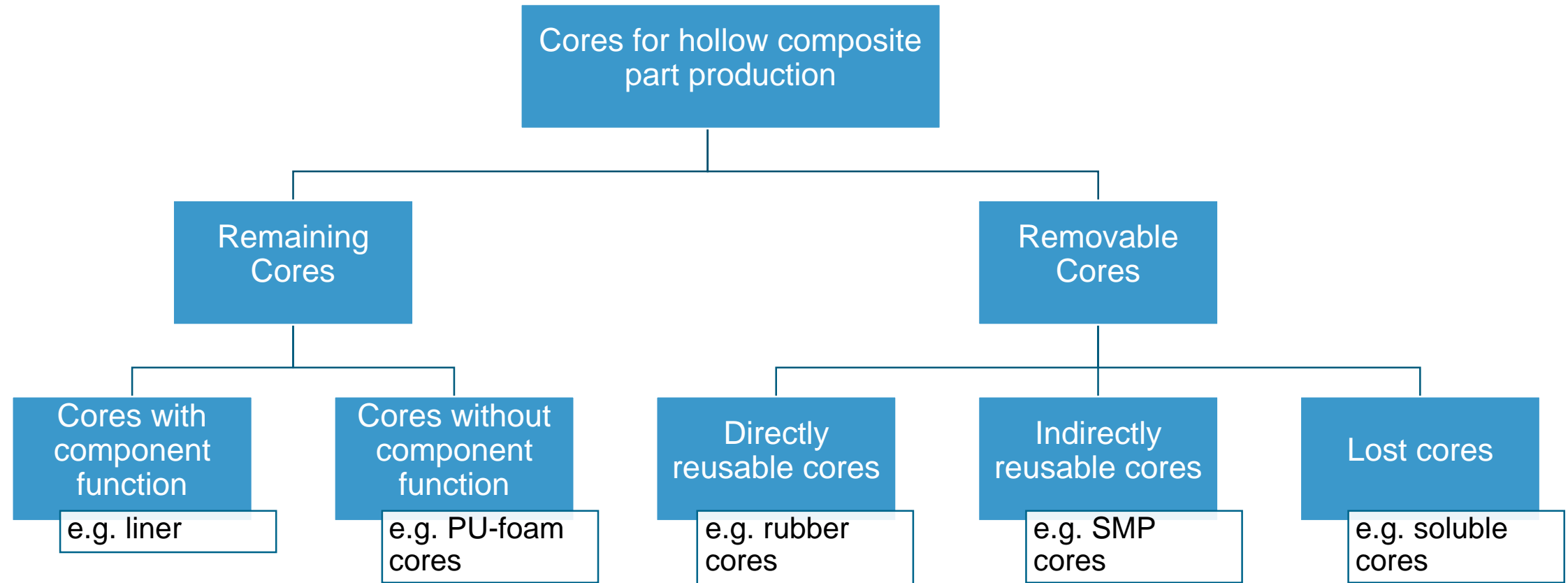


Introduction

Production of FRP hollow profiles



- Hand Lay-Up, Winding, Pultrusion, AFP → A rigid core/mandrel is always needed



1

2

3

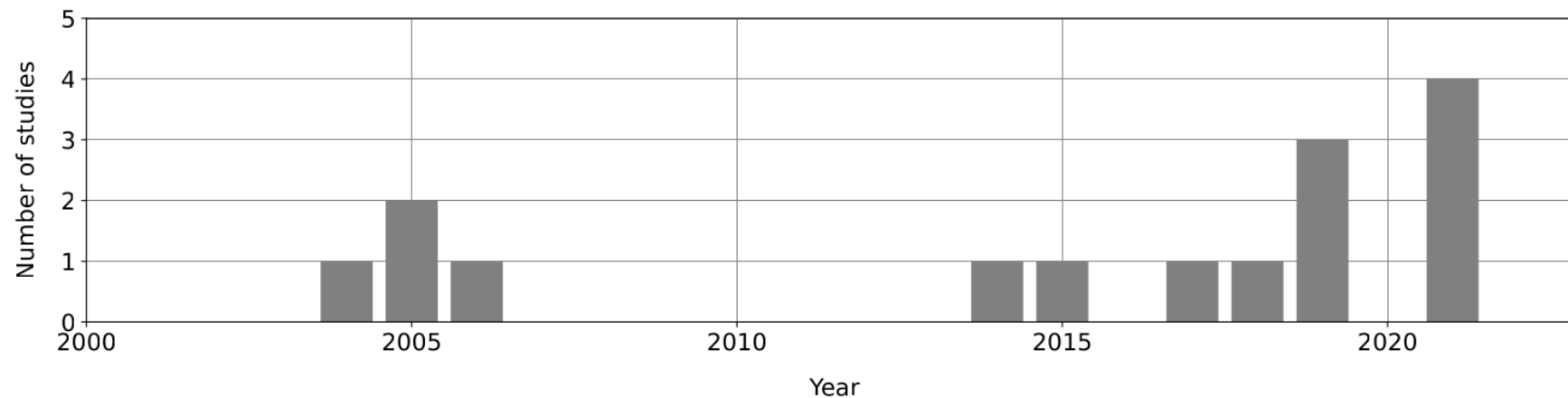
4

5

State-of-the-Art

Deformable Mandrels

	Thermoset	Thermoplastic
Softening-by-Heating	<ul style="list-style-type: none"> Spintech Holdings Inc. Everhart et al. (2005) – Cyanatester TS 	<ul style="list-style-type: none"> Miadowitz (2019) – PP Jing et al. (2021) – PMMA/CF
Shape-Memory	<ul style="list-style-type: none"> Du et al. (2015, 2018) – Styrene-based TS Zhang et al. (2013) – Styrene-based TS 	<ul style="list-style-type: none"> Neumann, Rings (2023) – PET, PA66, PA6



State-of-the-Art Research Gaps



1. Thorough ecological and economical assessment of shape variable mandrels in comparison with conventional tooling
2. Thermoplastic shape memory polymer mandrels
3. Further investigation of simulation capabilities for shape memory mandrels

Full SotA-review will be presented
@ SAMPE Europe Conference Oct. 23

SAMPE Europe Conference 2023 Madrid - Spain

1. VARIABLE SHAPE TOOLING FOR COMPOSITE MANUFACTURING: A SYSTEMATIC REVIEW

Fabian Neumann
German Aerospace Center (DLR), Institute of Lightweight Systems
Campus-Boulevard 79
52074 Aachen, Germany

ABSTRACT

Context: The choice of material, manufacturing process, and moulding tool significantly affects the quality, environmental impact, and cost efficiency of composite components. Producing one-piece hollow profiles with smooth inner surfaces and undercuts presents major challenges for conventional mould concepts.

Objectives: This paper provides an overview of research on shape memory polymers and other shape variable materials used in tooling applications for composite manufacturing. This work covers shape memory, heat shrinkable and other deformable tooling concepts.

Methods: A systematic literature review (SLR) in combination with a state-of-the-art open-source active learning tool *ASReview* is conducted. 15 relevant studies were identified.

Results: Research on shape variable tooling is mainly conducted by three research groups in the USA and PRC. The tooling is mostly made of unreinforced thermosets, especially styrene-based. Thermoplastic resins are less common and reinforcements limit the usable elongation in the temporary shape. The shape variability is either a shape memory and/or a softening process which in all studies is activated by heating. Release agents are widely used to ease demoulding. No ecological or economical assessment of the manufacturing methods was conducted in the reviewed studies.

Conclusion: Three fields for further research could be identified: 1) Thorough ecological and economical assessment of shape variable mandrels in comparison with conventional tooling; 2) Thermoplastic shape memory polymer mandrels; 3) Further investigation of simulation capabilities for shape memory mandrels.

NOMENCLATURE

AFP	Automated Fibre Placement	RQ	Research Question
DLR	German Aerospace Center	RTM	Resin Transfer Moulding
EC	Exclusion Criterion	SLR	Systematic Literature Review
FRP	Fibre-Reinforced Polymer	SMP	Shape Memory Polymer

2. INTRODUCTION

Fibre-reinforced polymer (FRP) composites are one of the dominant materials in aerospace applications. They offer good fatigue behaviour, excellent material properties, and the possibility to tailor them by varying the fibre angles. Therefore, the percentage of FRP in the structural mass of current civil aircraft like Airbus A350 or Boeing 787 is at about 50%. In the General Aviation and in Unmanned Aerial Vehicles FRP accounting for more than 90% of the structural mass [1]. Besides that, there is a strongly growing market in Urban Air Mobility forecasted, expecting 160,000 passenger drones until 2050, even if there are some

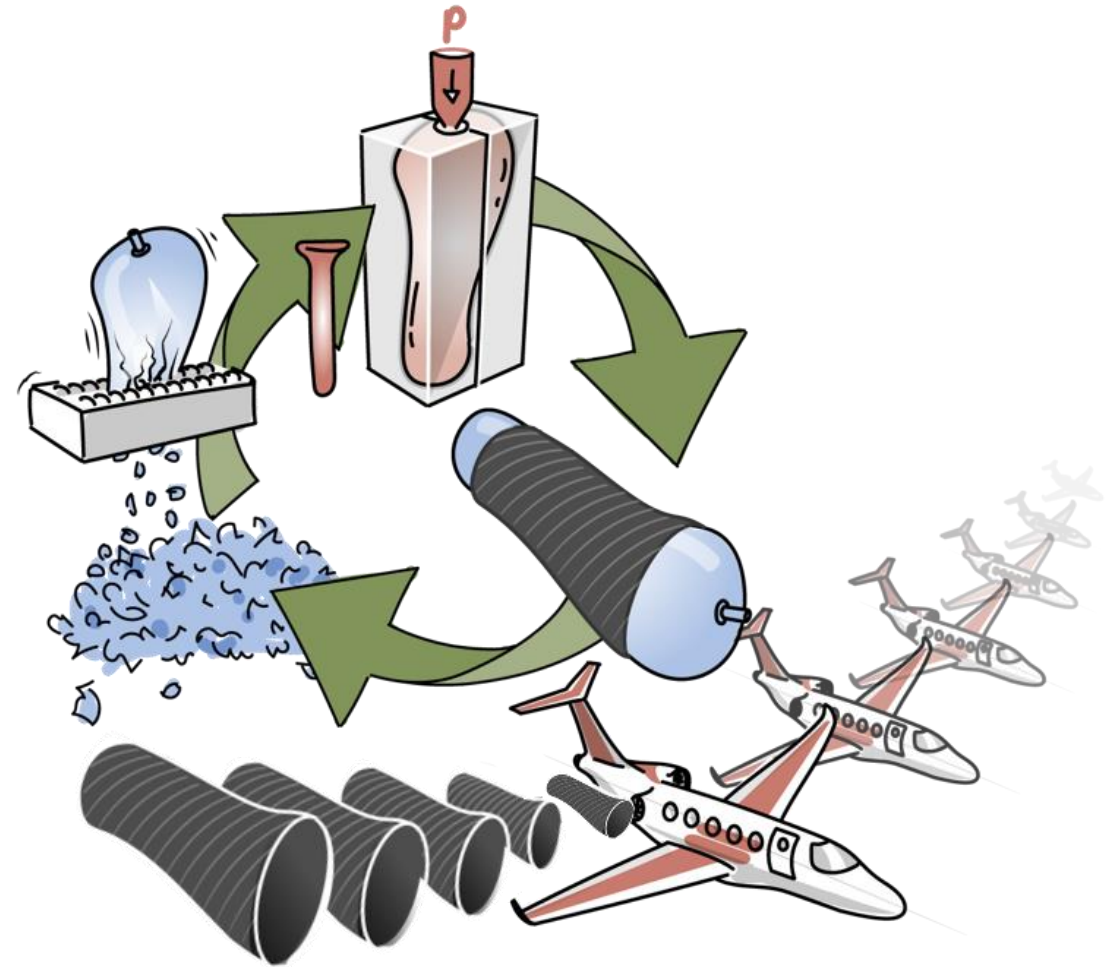
www.sampe-europe.org

1

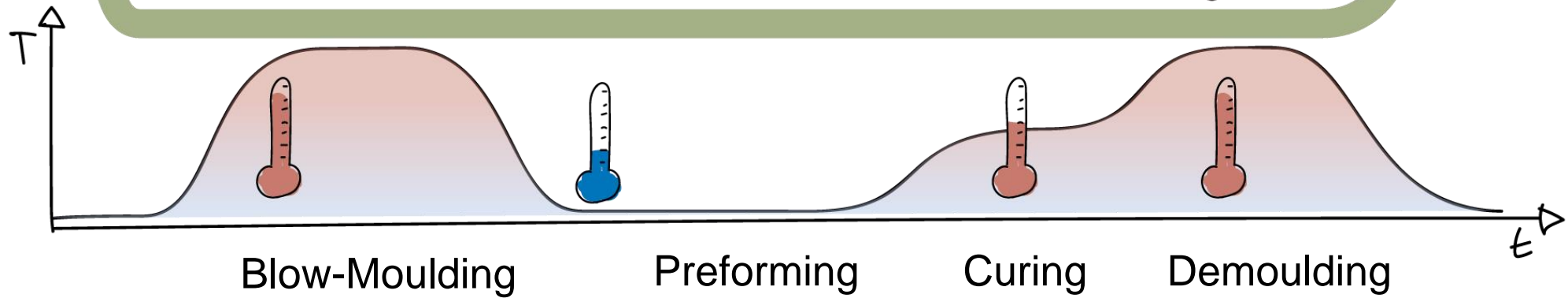
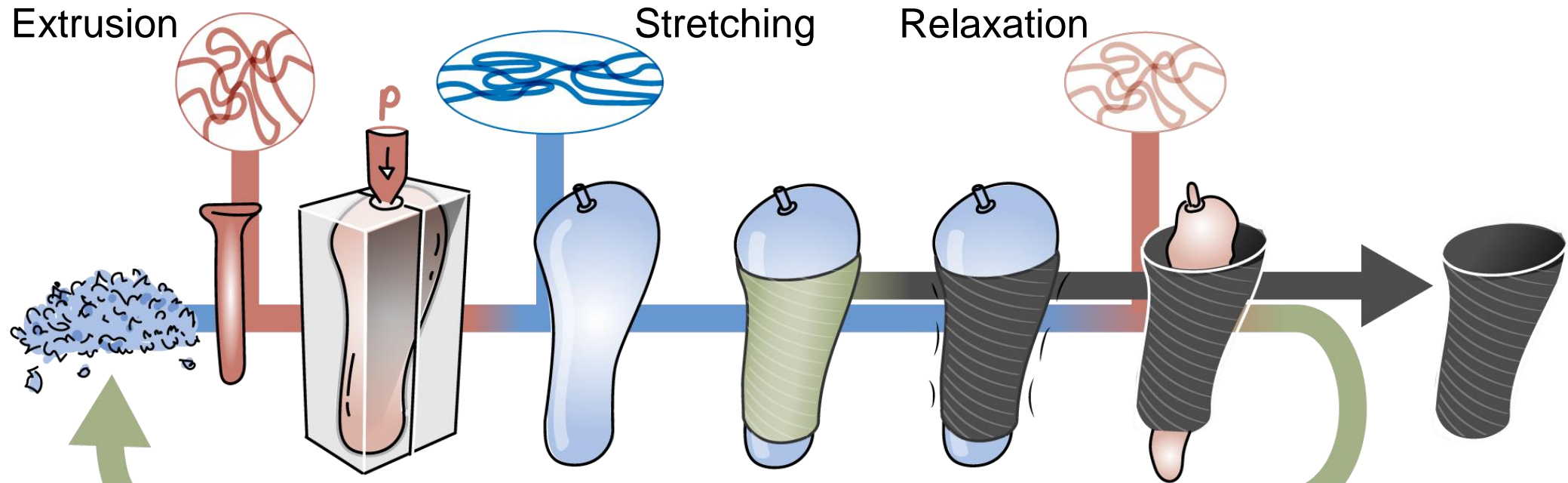
Blow-Moulded Mandrels

Advantages / Disadvantages

- Decoupling of expensive tooling and production rate
 - Rigid @ RT, Soft @ higher T
 - No need for release agents
 - Cheap & recyclable mandrel material
 - In-House recycling of mandrel material possible
-
- Not suitable for 180°C – Epoxy FRP



Blow-Moulded Mandrels Production Cycle



1

2

3

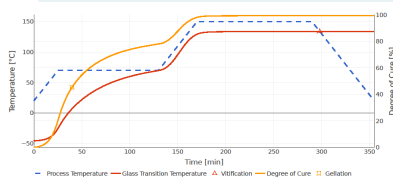
4

5

Blow-Moulded Mandrels Research Overview



- Semi-finished
- Manufacturing Methods
- Process Parameters
- Process Adjustment



- Pre-Selection
- Coupon-Tests
- Selection



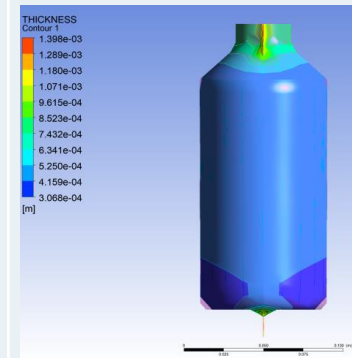
- Process Development
- Tooling
- Blow-Moulding @IKV Aachen



- Coupon-Tests
- Simulation
- Validation



- Coupon-Tests
- Simulation
- Manufacturing Trials



- Process assessment
- Scenario Comparison



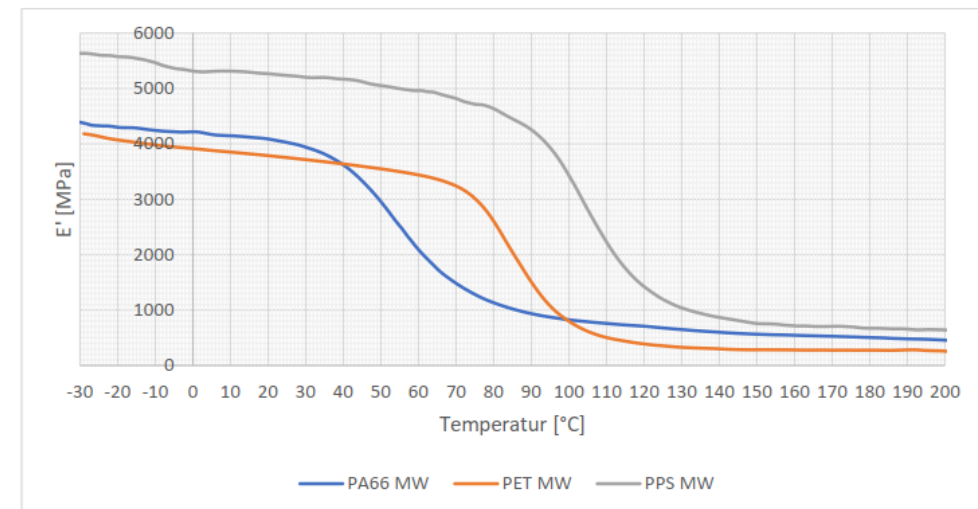
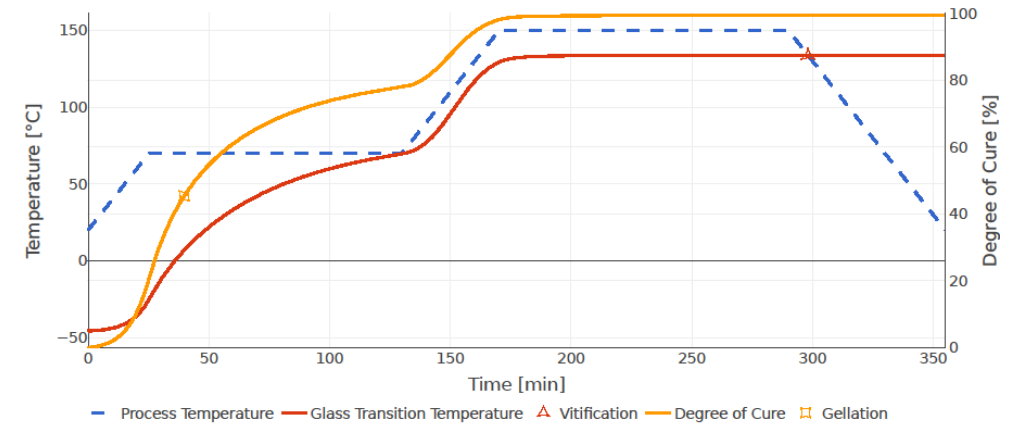
Blow-Moulded Mandrels Research Overview

Process
Development

Material
Selection



- Production Cycle developed for GA-Epoxy systems
 - 80% Curing + Postcuring/Activation step
 - Thermoplastic Material assessment
 - Literature
 - DMA / DSC
 - Coupon-Tests
- PET-C, PPS, PA66, PA6



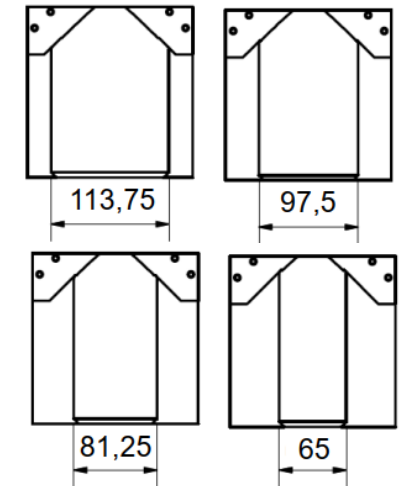
Blow-Moulded Mandrels Research Overview

Manufacturing

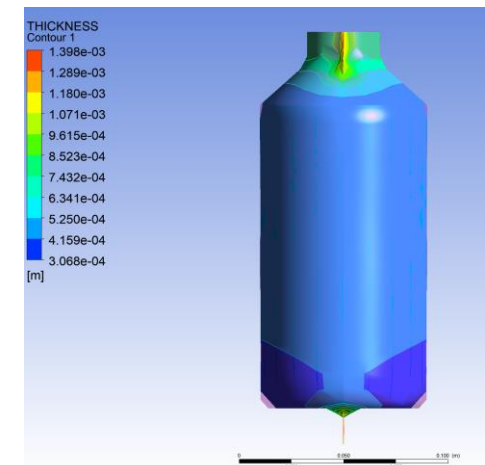
Activation



- Blow-Moulding Trials @ IKV Aachen (RWTH)
 - Process development
 - Test specimen production



- Simulation
 - Material model development
 - Production process sim.
 - Activation & Shrinking process sim.



1

2

3

4

5

Conclusion & Outlook

- Stretched Thermoplastics are suitable for demouldable mandrels / cores
- Scalable production of mould and FRP possible
- Established recycling processes available

- DLRK 2023 – Stuttgart
“Investigation of thermoplastic polymers with regard to their suitability as mould material in the FRP manufacturing process”

- SAMPE Europe Conference 23 – Madrid
“Variable Shape Tooling for Composite Manufacturing: A Systematic Review”



Contact:

DLR | Innovation Center for
Small Aircraft Technologies

Campus-Boulevard 79 • 52074 Aachen • GER

Dipl.-Ing. Fabian Neumann

+49 241-160578888

Fabian.Neumann@dlr.de

www.dlr.de/sy



Thank You!