IPH Institut für Integrierte Produktion Hannover

Gefördert durch: Bundesministerium für Wirtschaft und Technologie aufgrund eines Beschlusses des Deutschen Bundestages

# „Hydroforming of Titanium Tubes“

Development of a multi stage hydroforming process for titanium tubes

Hannover Messe | Hanover | April, 12th, 2013

| Produktion erforschen und entwickeln |

# Initial Situation

## Context

- Hydroforming is a cost effective way of shaping metals into lightweight and strong pieces
- Titanium has a high potential for lightweight constructions
- Due to its low proportional elongation titanium was not processed by hydroforming yet

## Intention

- Developing a hydroforming process for shaping titanium tubes

## Result

- cost-efficient and complex lightweight parts with unprecedented properties

# Project Objectives

## Overall Objective

- Developing a cost effective **process chain** for hydroforming **titanium tubes**

## Subtasks

- Subtask 1: Analyzing **material properties** of several titanium alloys and their hydroforming **process limits**
- Subtask 2: Investigating adequate **heat treatments to reestablish the formability** for several alloys and forming processes
- Subtask 3: Ascertain a suitable **lubricant**

# Experimental Studies

## Scheduled Workflow

- Pre-distension, heat treatment and **tensile test** as well as microstructure analysis of metal strips (UTS, PA)
- Boundless expansion, heat treatment and **burst testing** tube (UTS, PA)
- **Tribological examinations** (IPH, PA)
- **Process verification** on a demonstration part (IPH, if necessary PA)

## Expected Results

- Selection of a suitable **heat treatment**
- Analyze the **influence of the tube production** on the workability of titanium alloys
- Ascertain suitable **lubricants**
- Final outcome: **Guidelines for hydroforming titanium tubes**

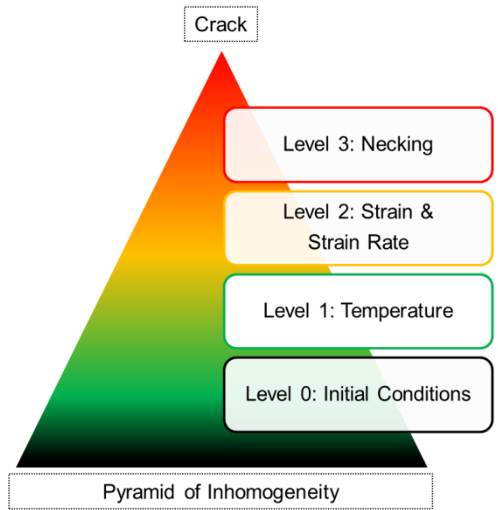
# Boundary conditions

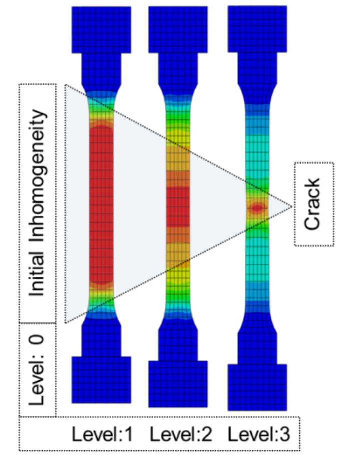


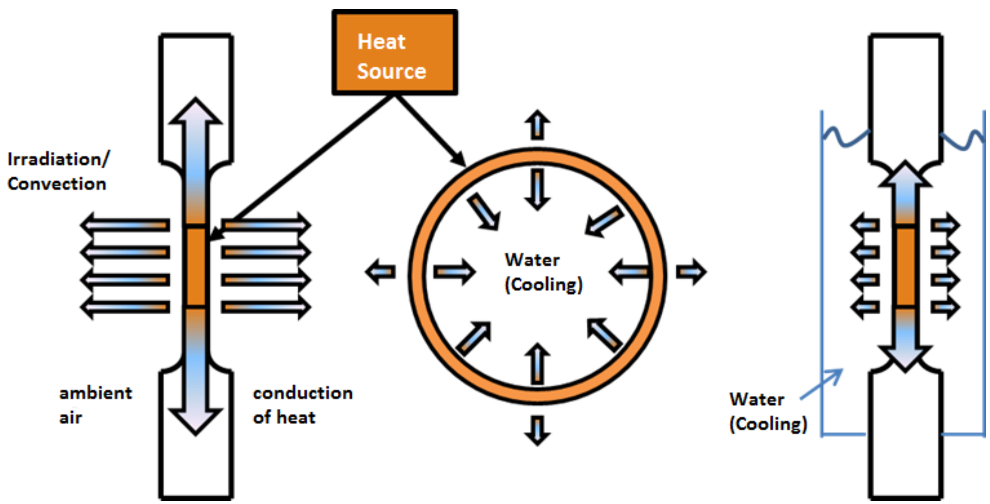
## Assimilation of tensile strength test

Pyramid of Inhomogeneity

→ Isothermal tensile test



# Isothermal Tensile Test

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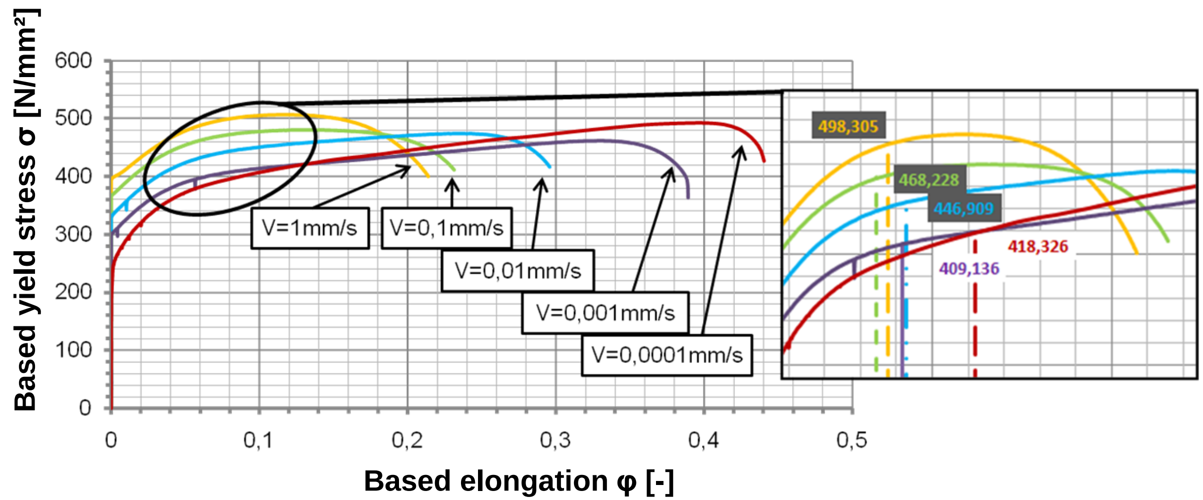
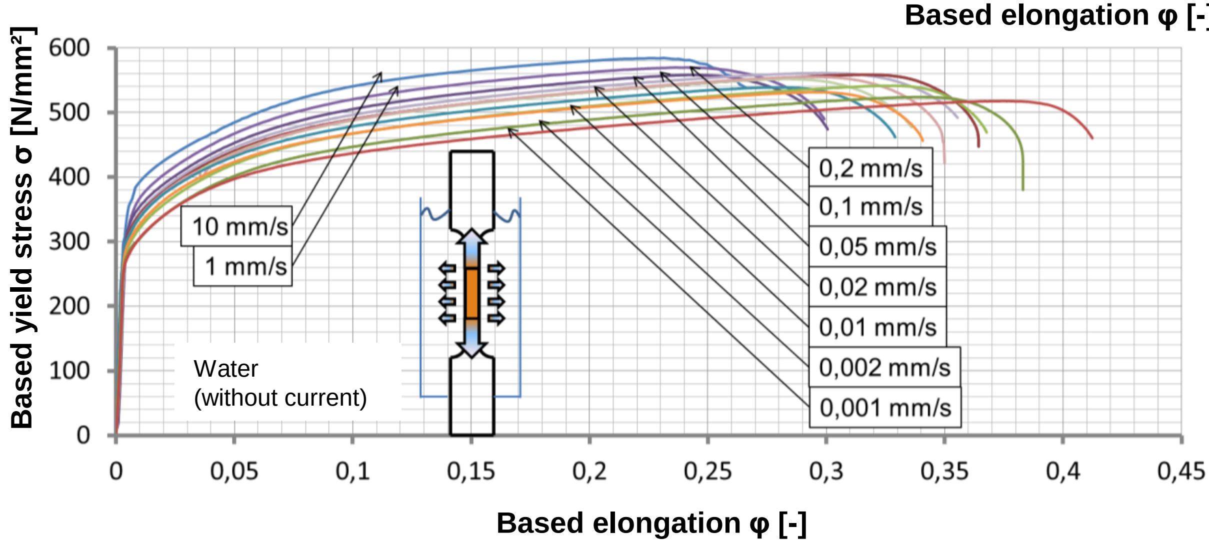
## Cooling Influence

Common tensile test

Isothermal tensile test

→ Isothermal tensile test



# Isotherme Zugversuche

## Mathematical description

— Nadai‘s approach:

$$k_f(T,v) = A(T,v) * \varphi_v{}^{n(T)}$$

$$k_f(T,v) = \begin{Bmatrix} v = [0{,}001 - 10]mm/s \\ T = [20 - 80]°\,C \end{Bmatrix}$$

$$A(T,v) \;= A_{Start} + \ln\left(\frac{V}{V_{ref}}\right)\left(0{,}0077\left(\frac{T}{T_{ref}}\right) + 20{,}804\right) - 1{,}7581\left(\frac{T}{T_{ref}}\right)$$

$$n(T) \;= n_{Start} - 0{,}00007\left(\frac{T}{T_{ref}}\right)$$

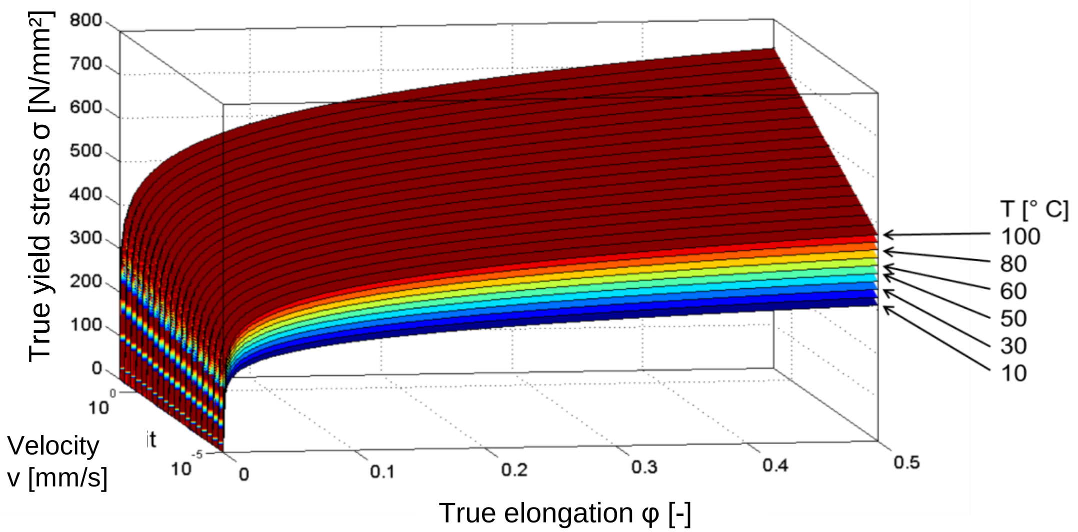
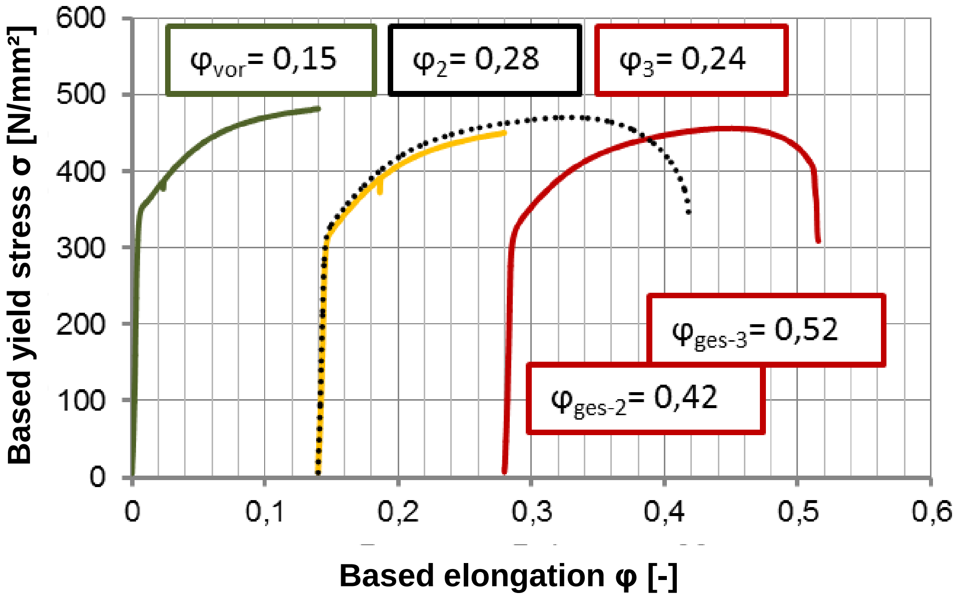


**Illustration of a multi-stage process chain with sheet specimens**

— tensile test with optimized heat treatment parameters:

- Pre-distension: $\varepsilon_{pre}$ = 15 %, ($\varepsilon_{min}$ = 5 %)
- Annealing temperature: $T_{heat}$ = 750° C
- Annealing time: $t_{heat}$ = 20 min
- Cooling: k = 750° C / 5 h

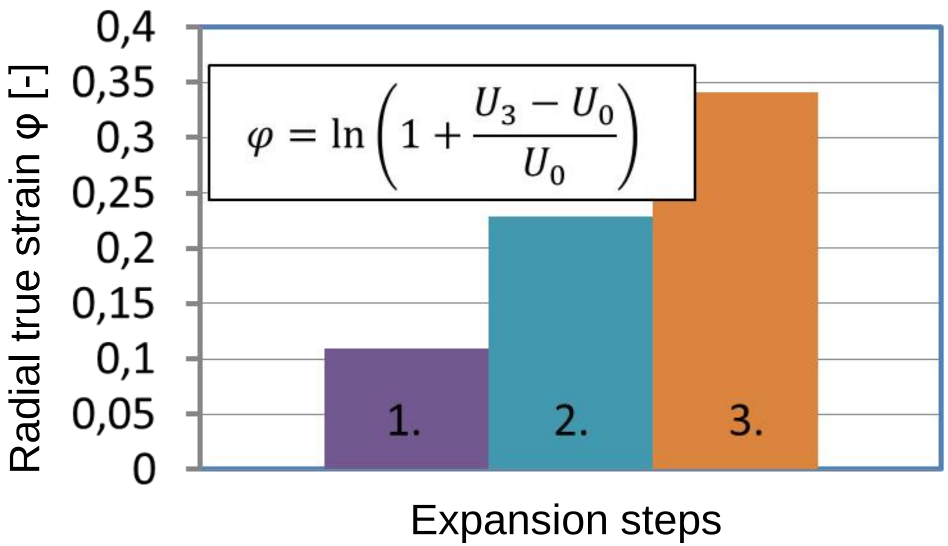


# Multi-Stage Process chain

**Illustration of a multi-stage process chain with tubes**

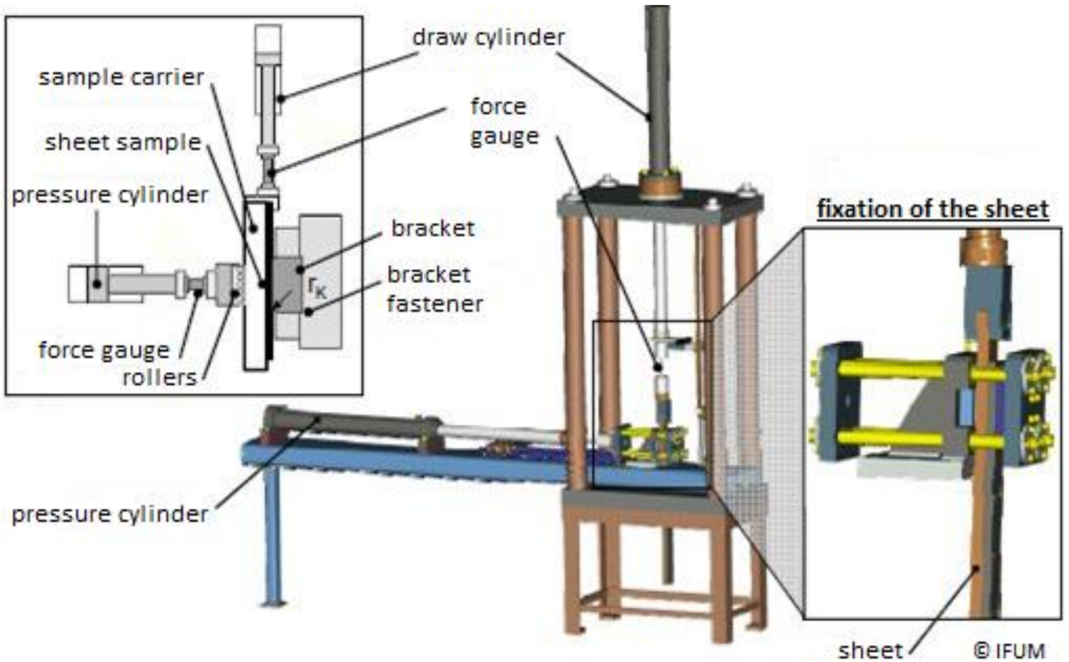
— Burst test with free ends

- Pre-distension: $\varepsilon_{pre}$ = 12 %, ($\varepsilon_{min}$ = 5 %)
- After the third forming stage there was a maximum strain of φ = 0,35

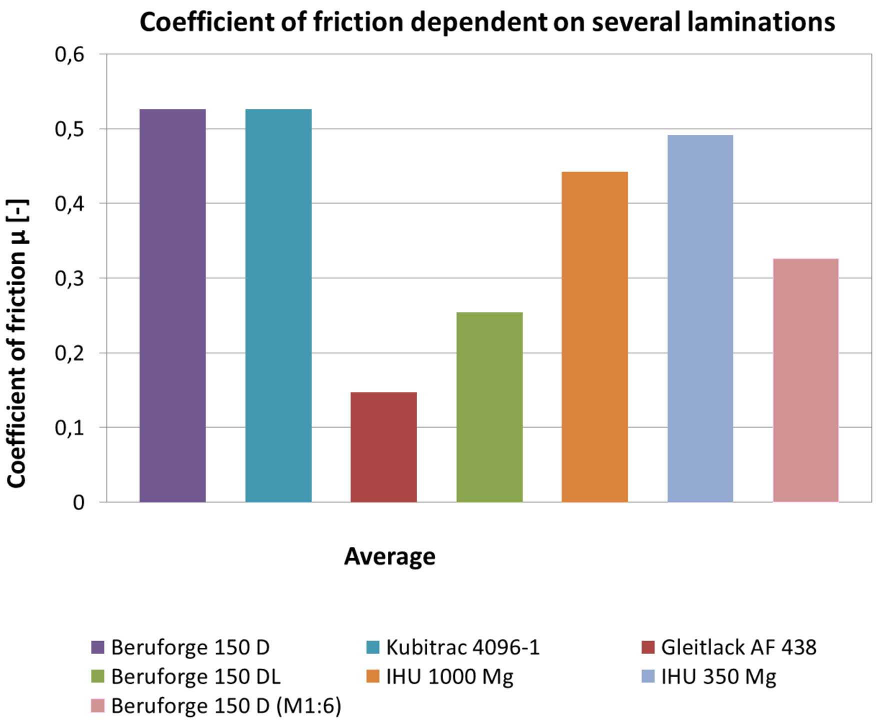


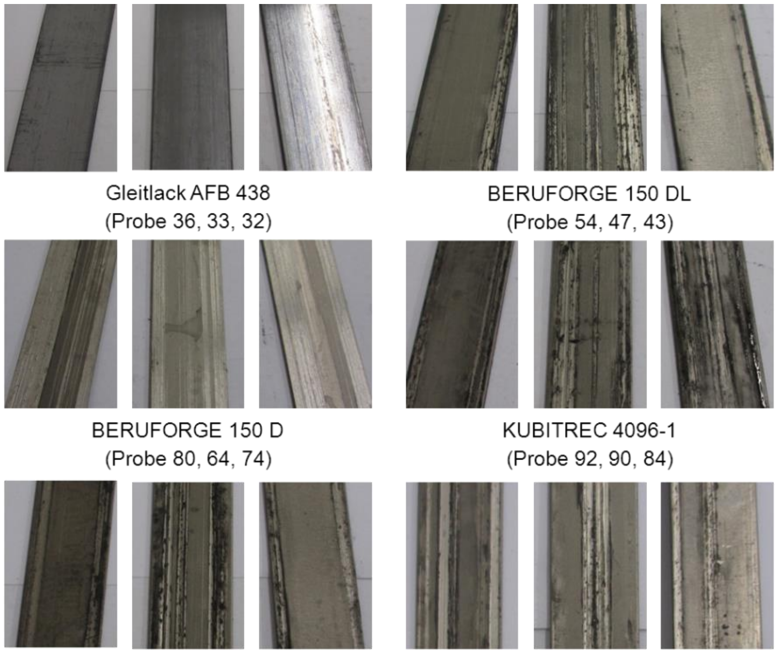

## Provided lubricants

- Berucoat AF 438 (air-hardening inorganic $MoS_2$/Graphite – sliding lacquer) [B]
- Beruforge 150 DL (water-soluble drawing paste) [B]
- Beruforge 150 D (water-soluble drawing paste) [B]
- Kubibrac 4096-1 (fully synthetic high performance drawing oil) [B]
- Raziol IHU 350 Mg [R]
- Raziol IHU 1000 Mg [R]



## Results of the strip drawing test



Gleitlack AFB 438 (Probe 36, 33, 32)

BERUFORGE 150 DL (Probe 54, 47, 43)

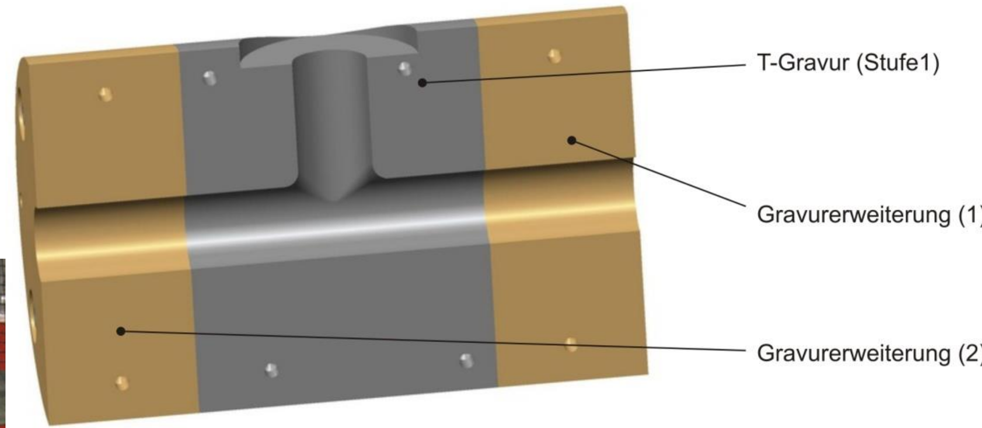
BERUFORGE 150 D (Probe 80, 64, 74)

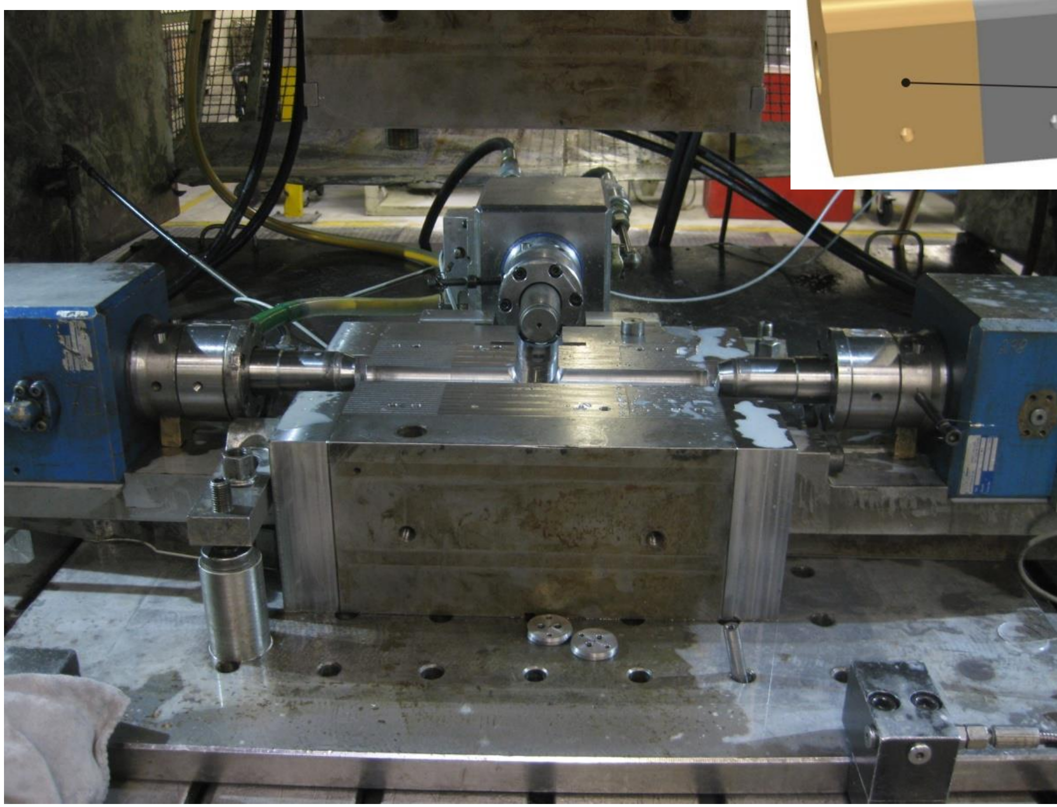
KUBITREC 4096-1 (Probe 92, 90, 84)

IHU 350 Mg / 1000 Mg (Probe 119, 112, 103)

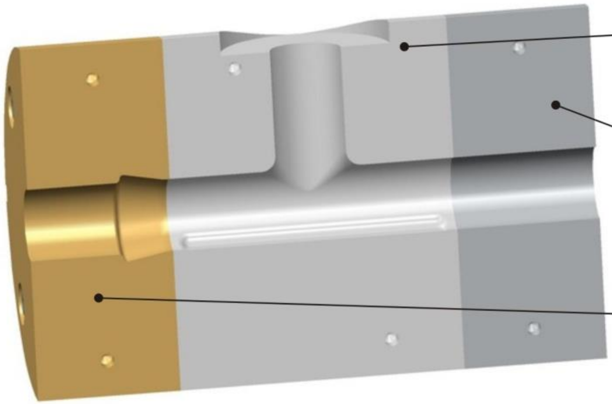
BERUFORGE 150 D (M1:6) (Probe 125, 124, 122)

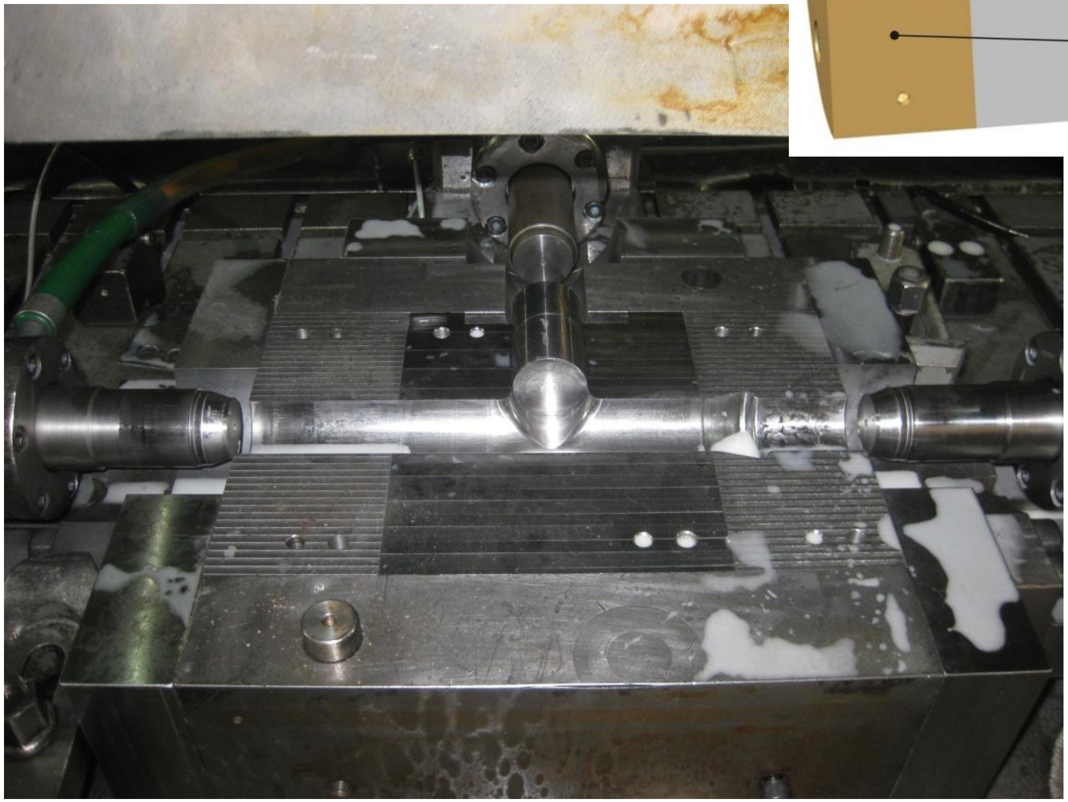
# Dies of the First Forming Stage



# Dies of the Second Forming Stage



# Results of the Hydroforming Experiments


| Sample 44 | Stage 1 | Stage 2 |
|---|---|---|
| (Strut-) Height | 62,52 (~23 %) | 70,56 (~38,9 % [~12,9 %]) |
| Length | 341,5 | 319 |
| Circumference | 199 | 214 |
| Diameter | ~ 51 | 51,09 |

# Process Parameters

**Sample 44**

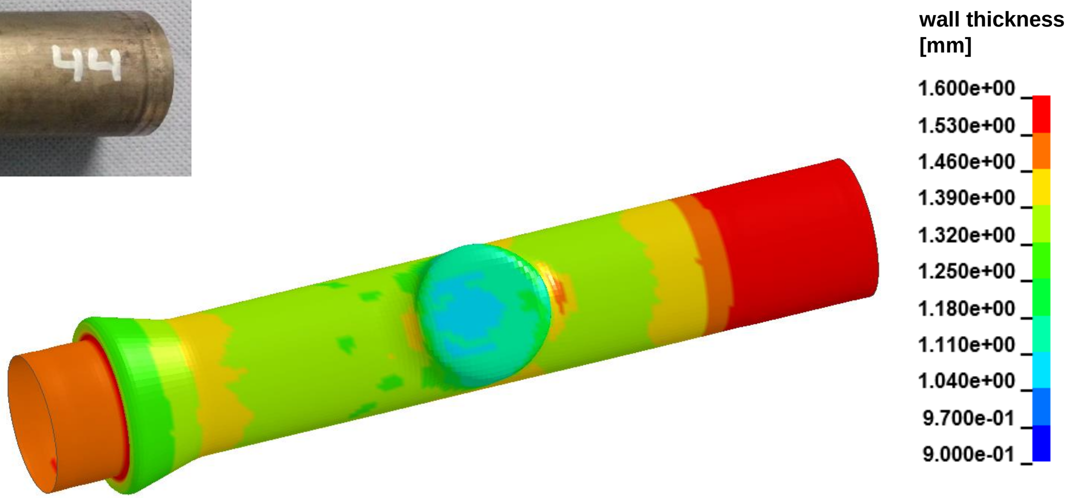
- Stage 1

| Time [s] | 0,2 | 2 | 4 | 10,6 | 11,6 | 12,6 |
|---|---|---|---|---|---|---|
| Pressure [bar] | 180 | 250 | 330 | 380 | 390 | 585 (620) |
| Punch 1&2 [mm] | 0,3 | 1,7 | 8 | 15 | 17 | 26 (27) |
| Strut [mm] | 0 | 0 | 0 | 5 | 7 | 1 |

- Stage 2

| Time [s] | 0,2 | 2 | 4 | 10,6 | 11,6 | 12,6 |
|---|---|---|---|---|---|---|
| Pressure [bar] | 180 | 250 | 330 | 380 | 390 | 620 |
| Punch 1 [mm] | 0,3 | 1,7 | 8 | 15 | 17 | 22 |
| Punch 2 (T) [mm] | 0,3 | 1,7 | 6 | 8 | 9 | 10 |
| Strut [mm] | 0 | 0 | 0 | 4 | 5 | 6 |

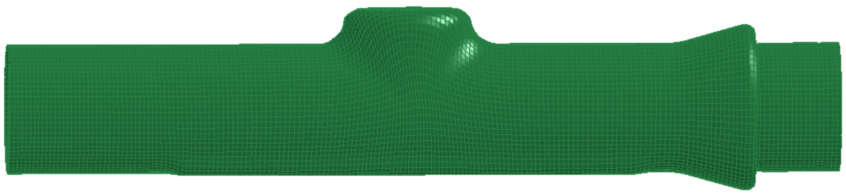
# Simulations

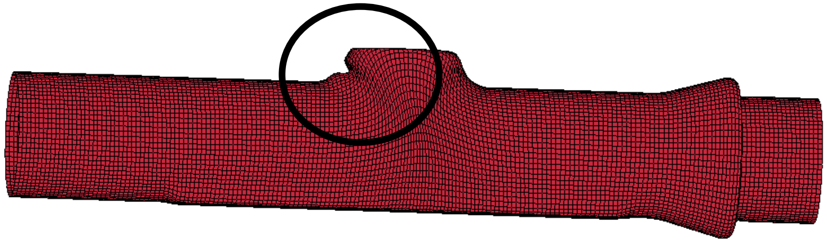

| Sample 44 | Simulation | Reality |
|---|---|---|
| (Strut-)Height | 64,74 | 70,56 (~38,9 %) |
| Length | 307,26 | 319 |
| Failure | No | No |

## Component failure when considering anisotropy

| Boundary conditions | |
|---|---|
| Element type | 16 |
| Material Model | 037 Transversely Anisotropy |
| Anitsotropy | 1 |



| Boundary conditions | |
|---|---|
| Element type | 16 |
| Material Model | 037 Transversely Anisotropy |
| Anitsotropy | 4 |



## Wall thickness distribution in its dependencies of the anisotropy

# Abstract and Forecast

## Abstract

- Basic studies on hydroforming of titanium alloys have been successfully completed
- Multi-stage process chain has been successfully designed for shaping titanium tubes
- Demonstration parts have been successfully created

## Forecast

- Improving the simulation results
- Defining an universal range of parameters

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