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I²FG Workshop
Impulse Forming

May 7th, 2013
Gent, Belgium

Determination of suitable driver materials for electromagnetic sheet metal forming

Soeren Gies

Agenda

- **Introduction**
- **Effect of driver sheets**
- **State of the art**
- **Experimental setup and procedure**
- **Results**
- **Summary and Outlook**

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Introduction

- **Objective:** Electromagnetic forming of stainless steel 1.4301 and 1.4509

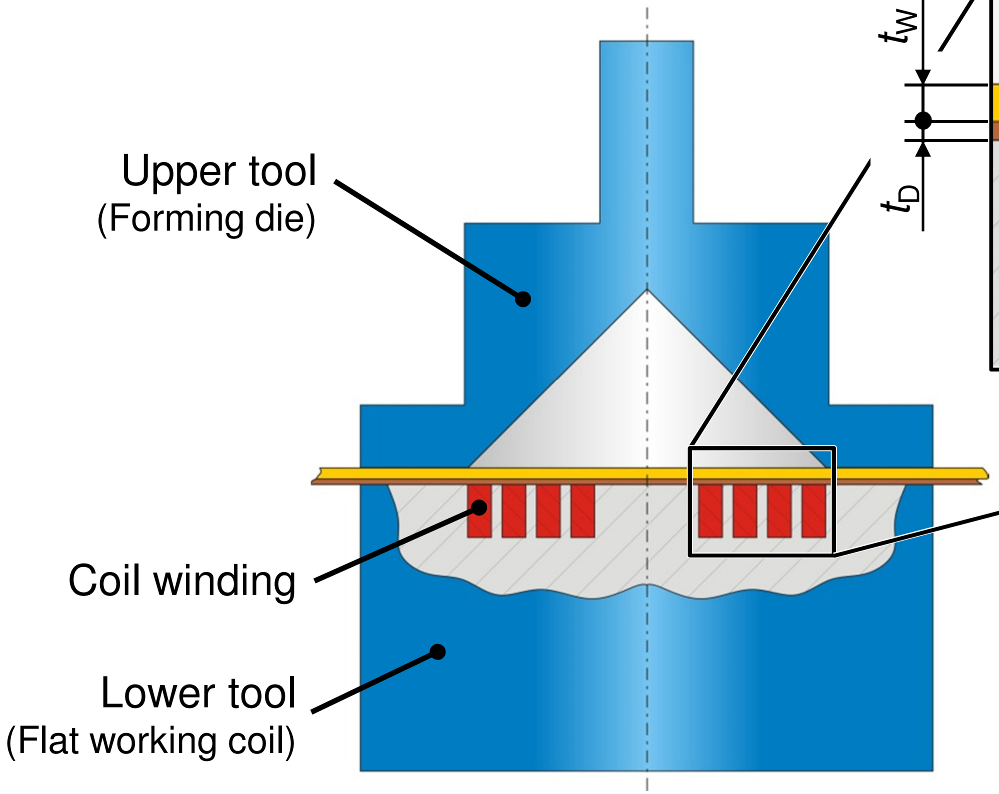
- **Challenge:** Low electrical conductivity of stainless steel

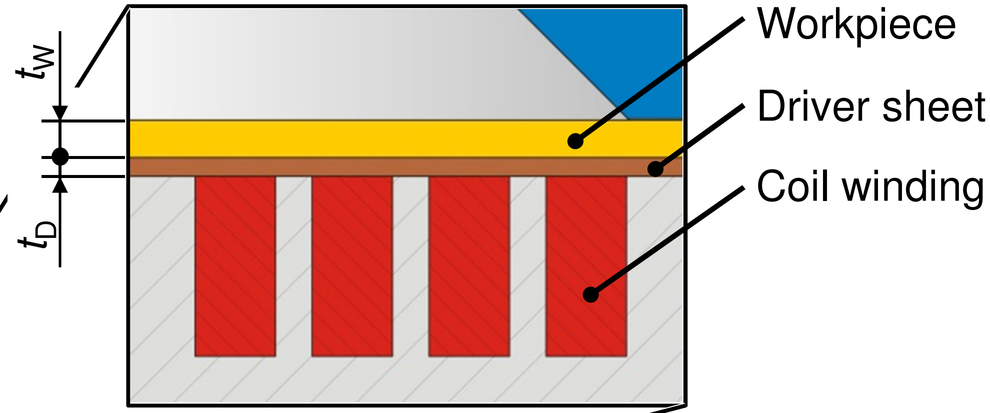
Copper		Aluminum		Steel	Stainless steel	
CU-ETP	CU-DHP	EN AW-1050A	EN AW-5083	DC06	1.4301	1.4509
57 MS/m	43 MS/m	34 MS/m	16 MS/m	8 MS/m	1.5 MS/m	
100%	75%	60%	28%	14%	**2,6%**	

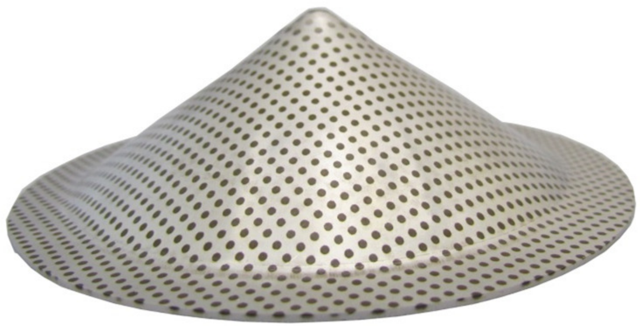
- **Solution:** Use of driver sheets

Introduction

- Working principle of driver sheets:







Workpiece: 1.4301, t_W = 0.8 mm
Driver: Aluminum, t_D=0.8 mm

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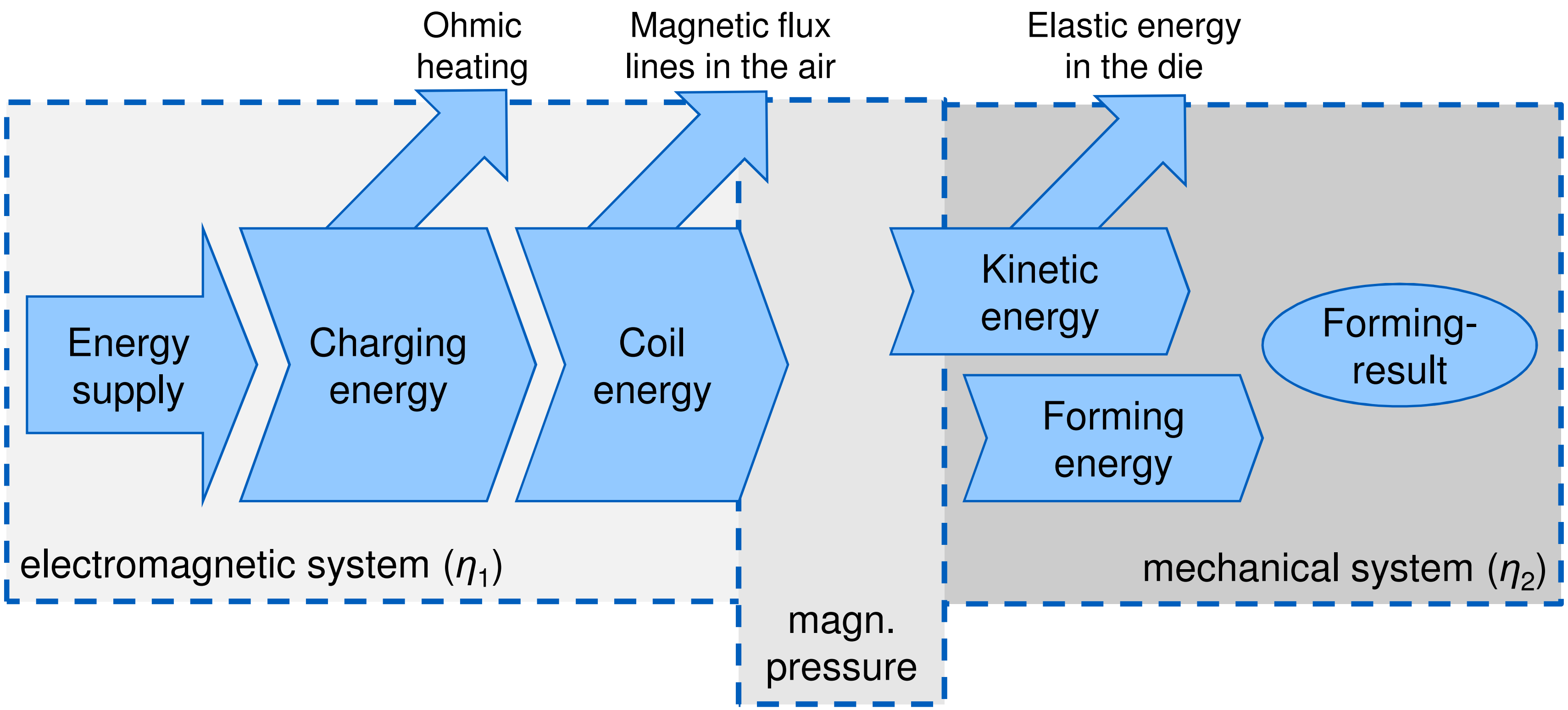
Effect of driver sheets

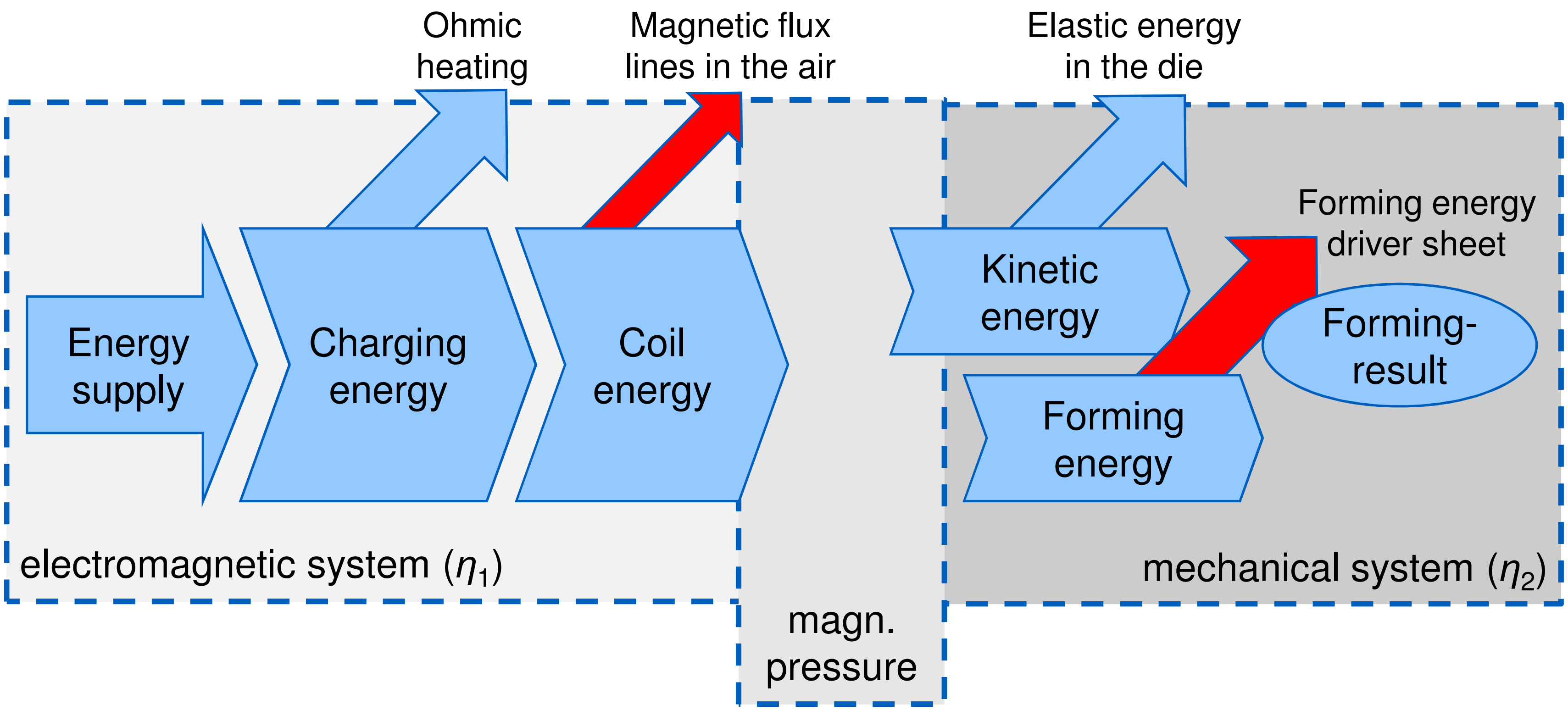
- Use of driver sheets causes **two opposing effects** in the energy conversion sequence



Energy conversion sequence: *Risch, 2009*

Effect of driver sheets

- Use of driver sheets causes **two opposing effects** in the energy conversion sequence



➡ **<u>Trade off:</u> higher magnetic pressure vs. additional forming energy**

Effect of driver sheets

- Use of driver sheets is beneficial if the following condition is fulfilled:

Additional kinetic energy > Additional forming energy for driver

Optimum ➡ $$\text{MAX}\left(\frac{\text{Additional kinetic energy } \boldsymbol{E_{kin}}}{\text{Additional forming energy for driver } \boldsymbol{E_{form}}}\right)$$

- **Self-evident consequences:**
  - High electrical conductivity → E_{kin} ↑
  - Low yield strength → E_{form} ↓

- **Question:** Which **driver material** and which **driver thickness** $\boldsymbol{t_D}$ maximize the energy ratio?

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State of the art

- **Scientific investigations using driver sheets:**
  - Seth et al. (2004)
    - Workpiece: Low-alloy carbon steel, t_W = 0.1 mm – 0.38 mm
    - Driver: Aluminium EN AW-6111 T4, t_D = 1 mm
  - Li et al. (2012)
    - Workpiece: Ti-6Al-4V, t_W = 0.5 mm
    - Driver: CU-DHP, t_D = 0.5 mm
  - Andersson and Syk (2008)
    - Workpiece: X5CrNiMo17-12-2, t_W = 0.25 mm / DP600, t_W = 0.7 mm
    - Driver: Copper, t_D = 0.6 mm
  - Srinivasan et al. (2010)
    - Workpiece: Titanium, t_W = 0.076 mm
    - Driver: Copper, t_D = 0.381 mm
  - Ishibashi et al. (2011)
    - Workpiece: X5CrNi18-10, t_W = 0.15 mm
    - Driver: EN AW-1050-H24, t_D = 0.3 mm

t_W ≙ Workpiece thickness
t_D ≙ Driver thickness
σ_s ≙ Skin depth

State of the art

- **Scientific investigations using driver sheets:**
  - Tillmann et al. (2008)
    - Workpiece: DC04, t_W = 0,8 mm
    - Driver: Copper (sputtered), t_D = 0,65 mm (optimum)
    - Recommendation: $t_D = \sigma_s$
  - Bely et al. (1977)
    - Recommendation: $t_D = 0{,}5 \cdot \sigma_s$
  - Desai et al. (2011)
    - Workpiece: Stainless steel
    - Driver: Aluminum, Copper
    - Recommendation: Aluminum → $t_D = 0{,}8 \cdot \sigma_s$ / Copper → $t_D = \sigma_s$

– Contradicting recommendations
– No recommendation regarding optimal driver material
– No consideration of mechanical workpiece parameters

t_W ≙ Workpiece thickness
t_D ≙ Driver thickness
σ_s ≙ Skin depth

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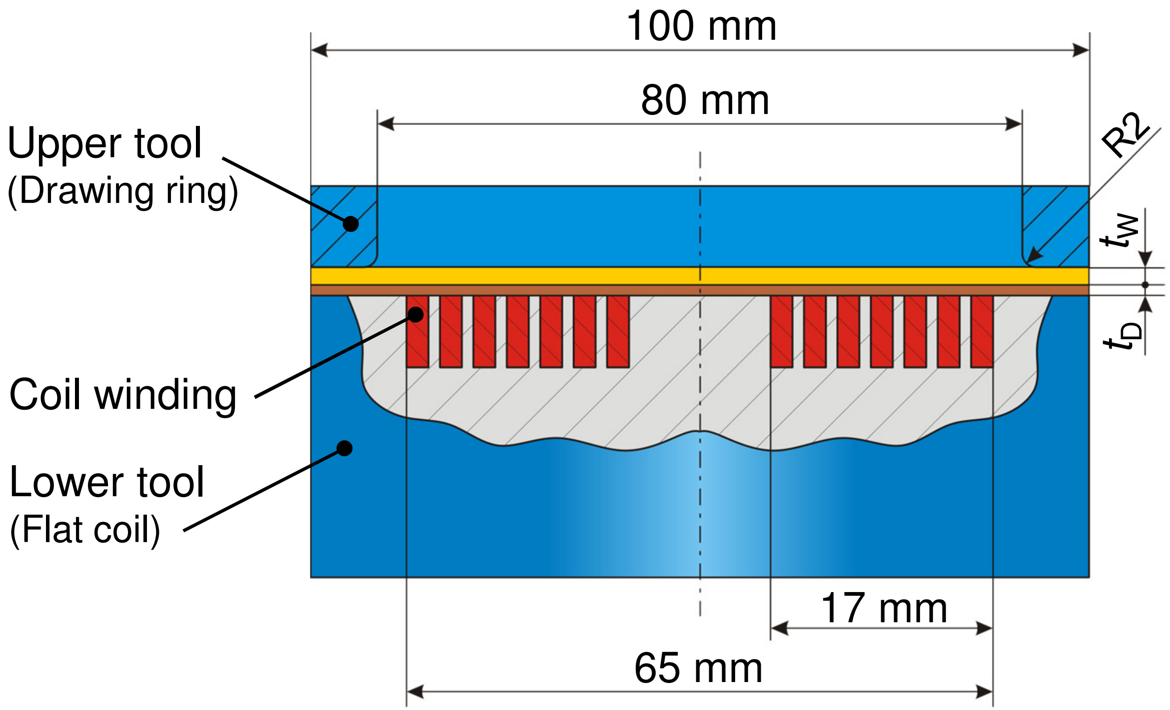
Experimental Setup and Procedure

1 Free forming of workpiece and driver



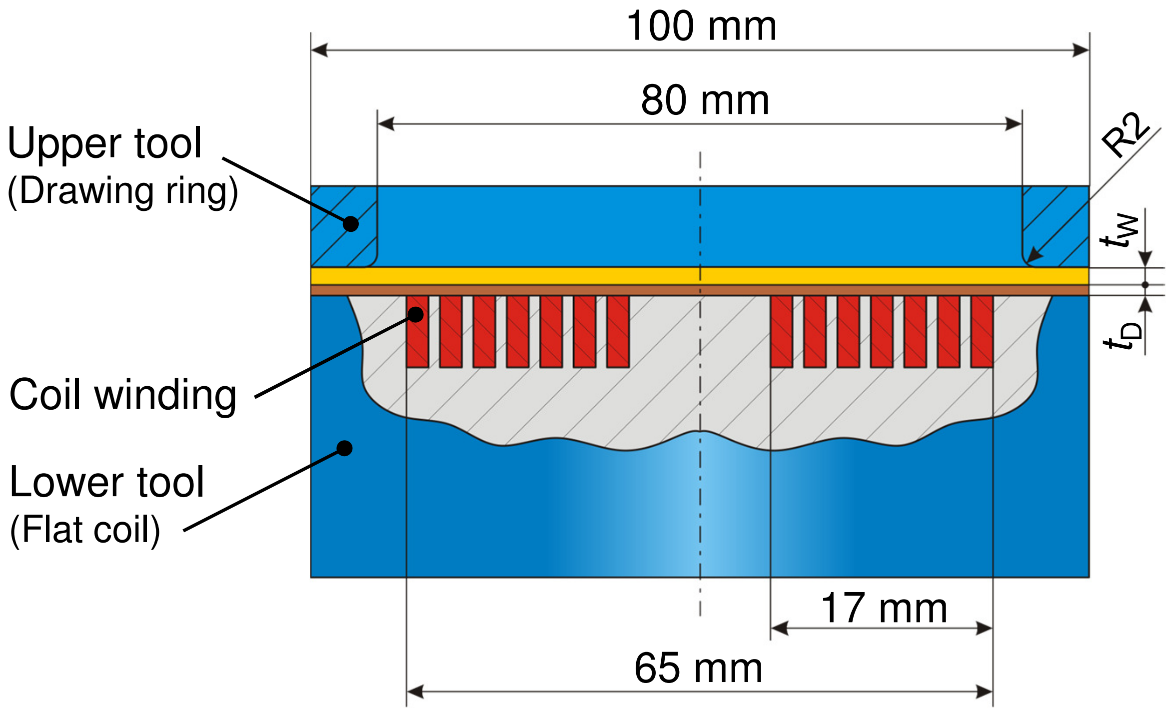
Pulse generator used: Maxwell Magneform 7000

Max. charging energy E_C = 20 kJ
Short circuit frequency f^* = 25 kHz

Inner resistance R_i = 4.2 mΩ
Inner inductance L_i = 60 nH

Experimental Setup and Procedure

① Free forming of workpiece and driver



Pulse generator used: Maxwell Magneform 7000

Max. charging energy E_C = 20 kJ
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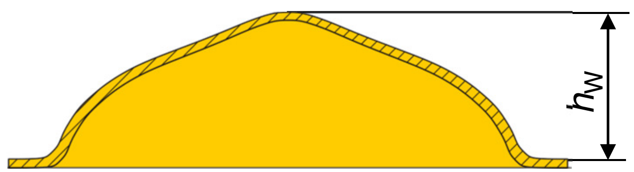
② Measuring of workpiece height h_w



h_w = Workpiece forming height
t_w = Workpiece thickness
t_D = Driver thickness

Experimental Setup and Procedure

- **Scope of investigations:**
  - Workpiece material
    - **1.4301**, t_W = 0.5 / 0.8 / 1.0 mm
    - **1.4509**, t_W = 0.5 / 0.8 / 1.0 mm
    - **DC04**, t_W = 0.5 / 0.8 / 1.0 mm
    - **EN AW-5083**, t_W = 1.0 mm
  - Driver material
    - **CU-ETP**, t_D = 0.3 / 0.5 / 0.7 / 0.8 / 1.0 / 2.0 mm
    - **EN AW-1050A**, t_D = 0.3 / 0.5 / 0.7 / 0.8 / 1.0 / 2.0 mm
  - Charging Energy E_C
    - E_C = 1.0 / 1.8 / 2.4 kJ

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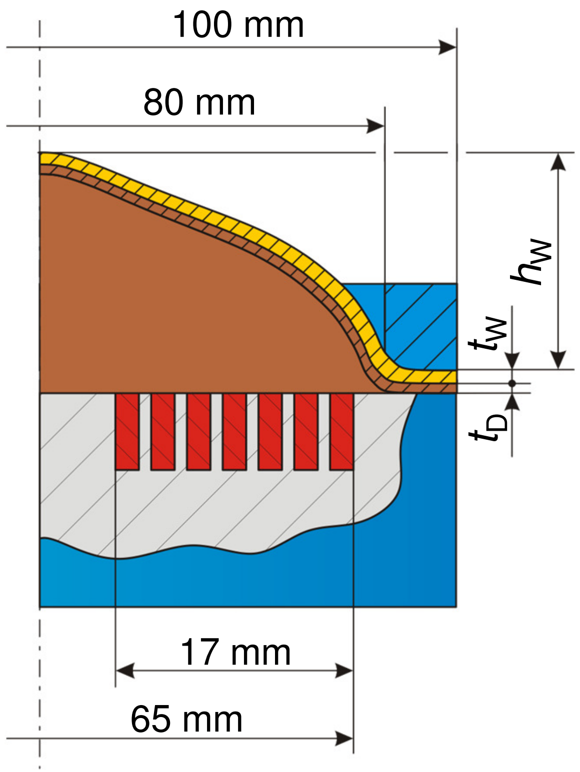
Results

Workpiece:

Material 1.4509

Thickness t_W = 0.8 mm



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t_w = Workpiece thickness
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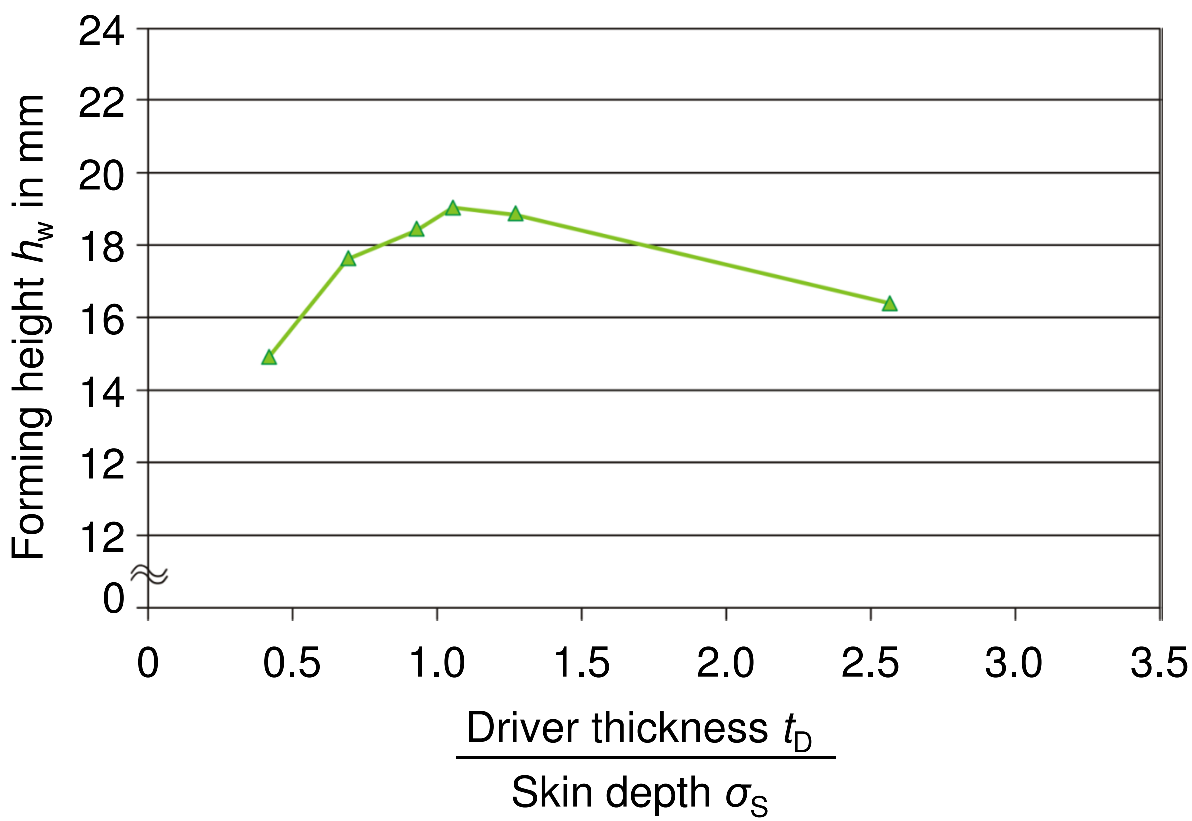

Results

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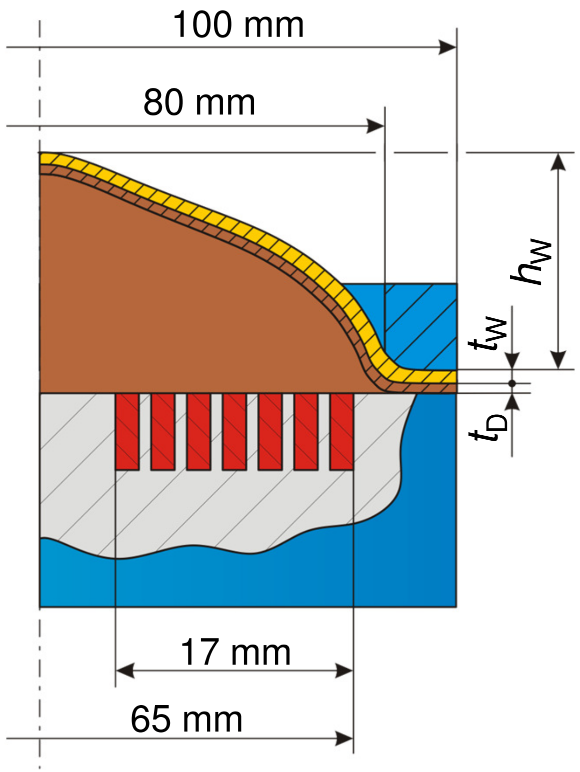

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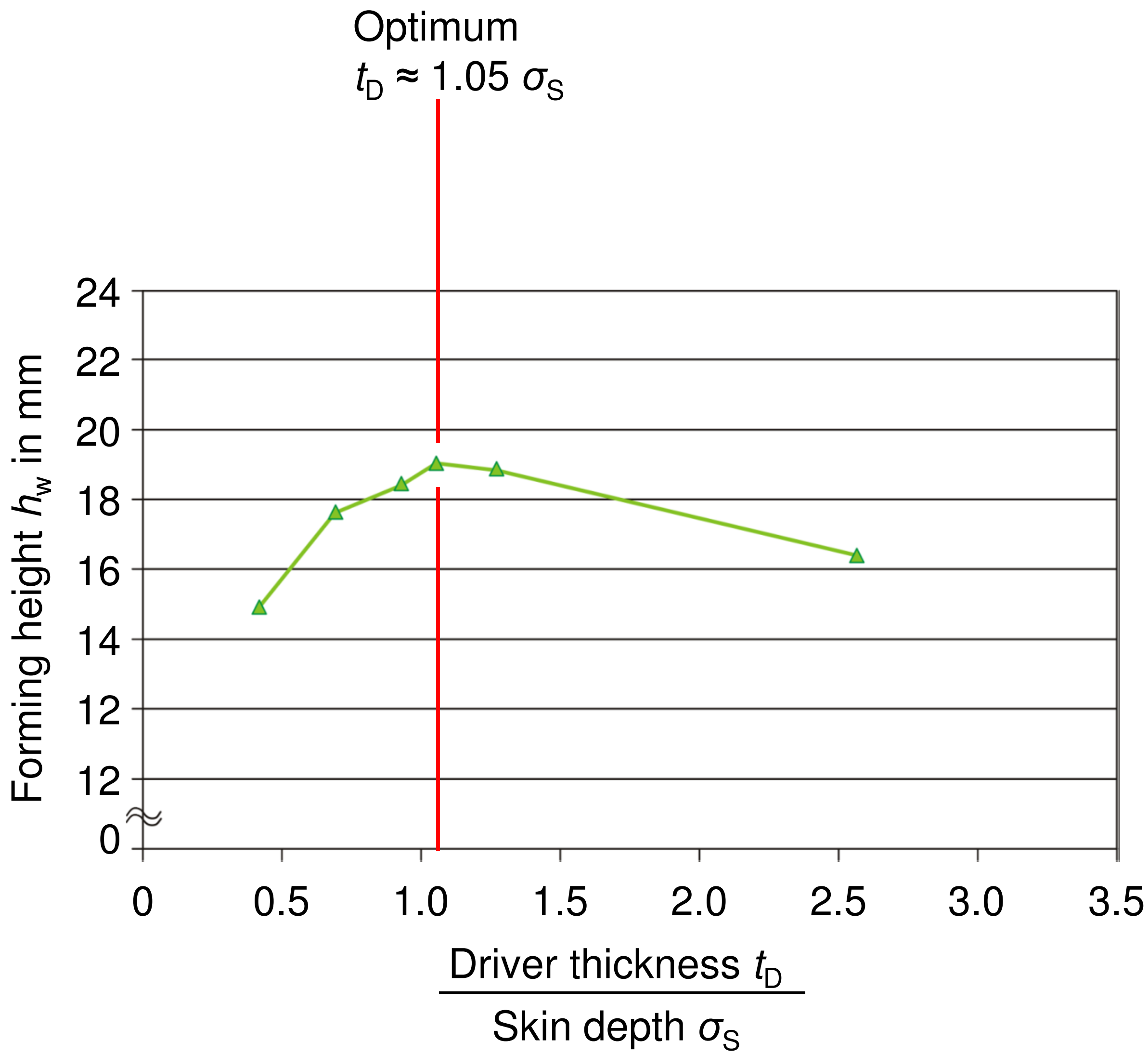

Results

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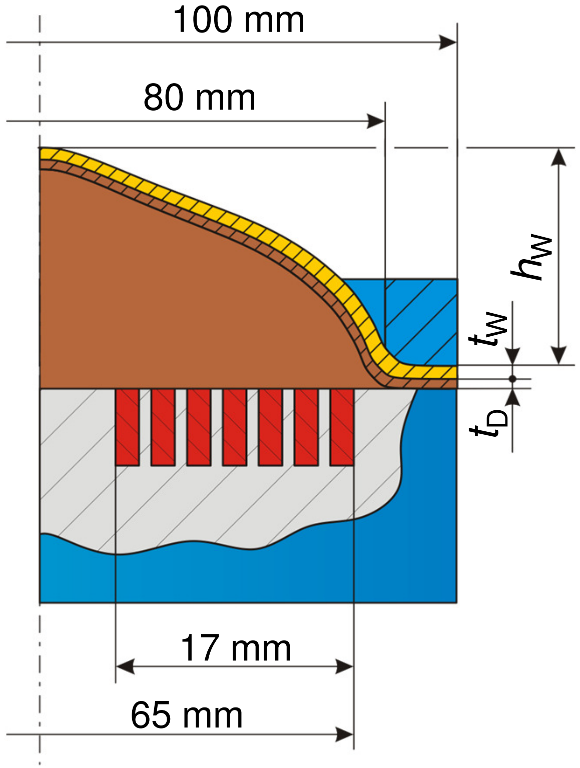
Thickness t_W = 0.8 mm



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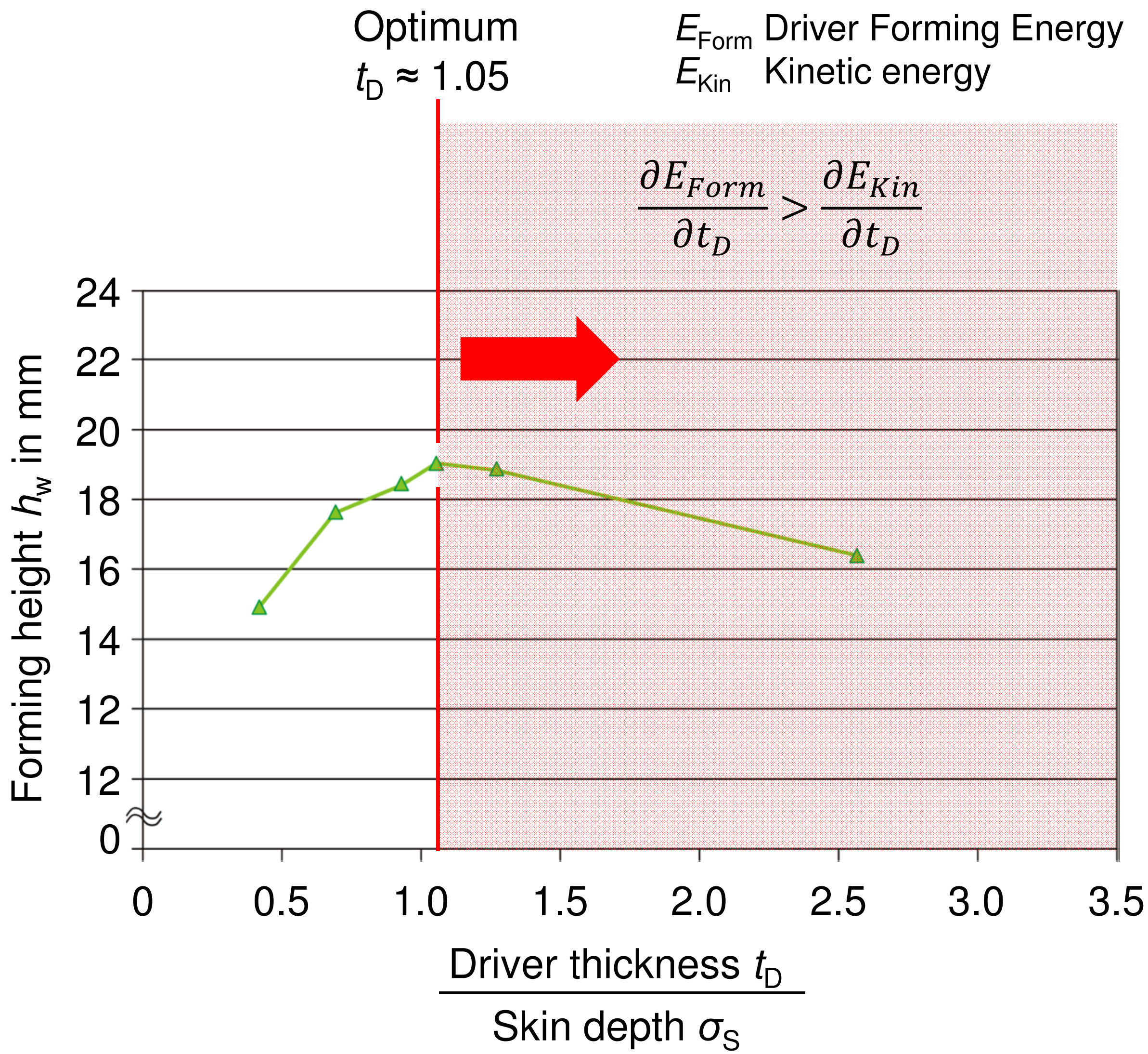
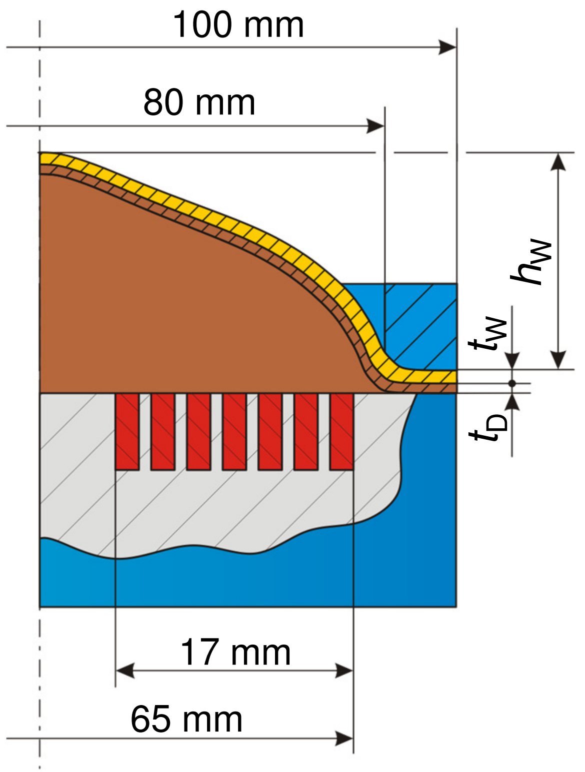


Results

Workpiece:
Material 1.4509
Thickness t_W = 0.8 mm



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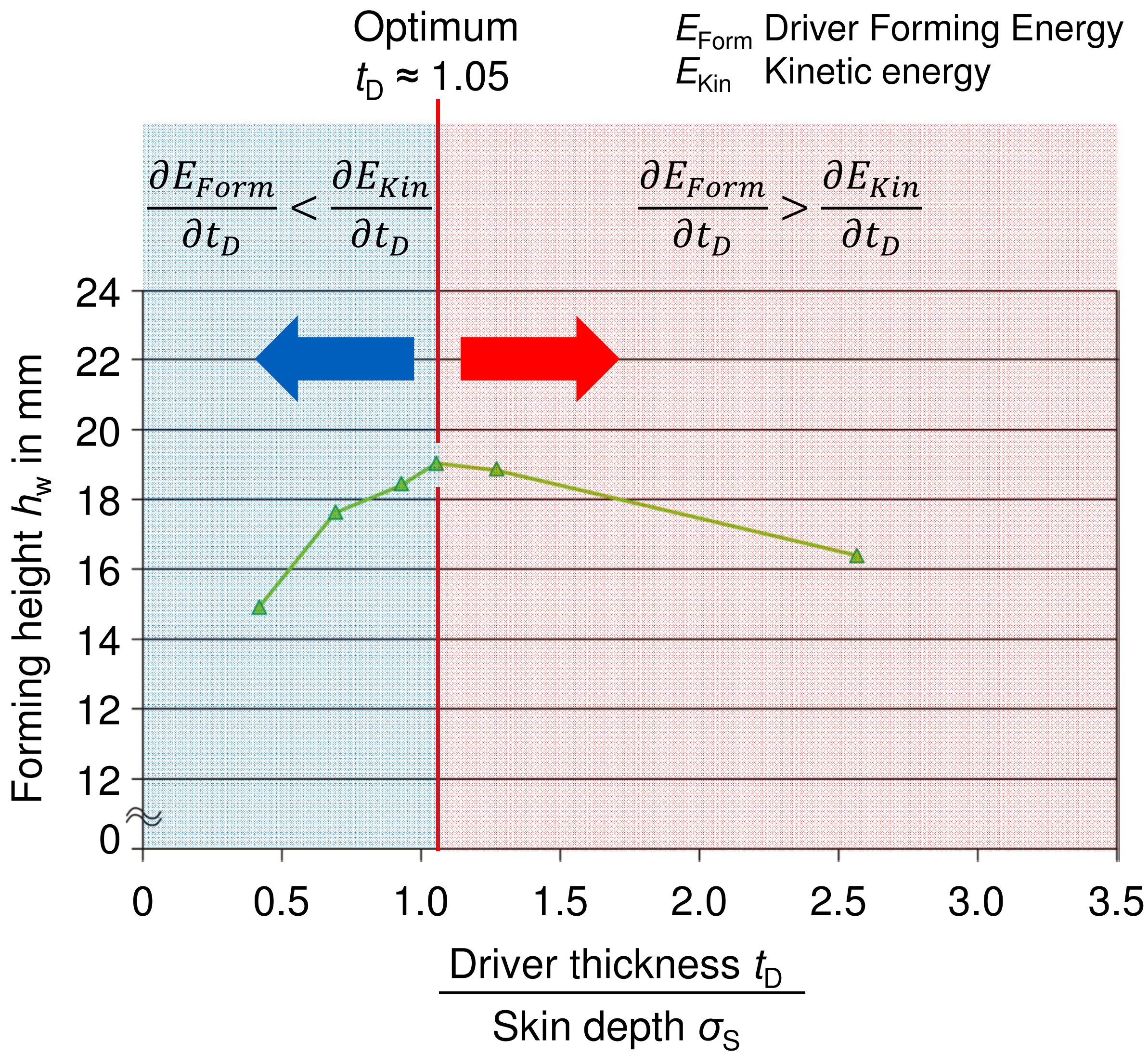

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Material 1.4509

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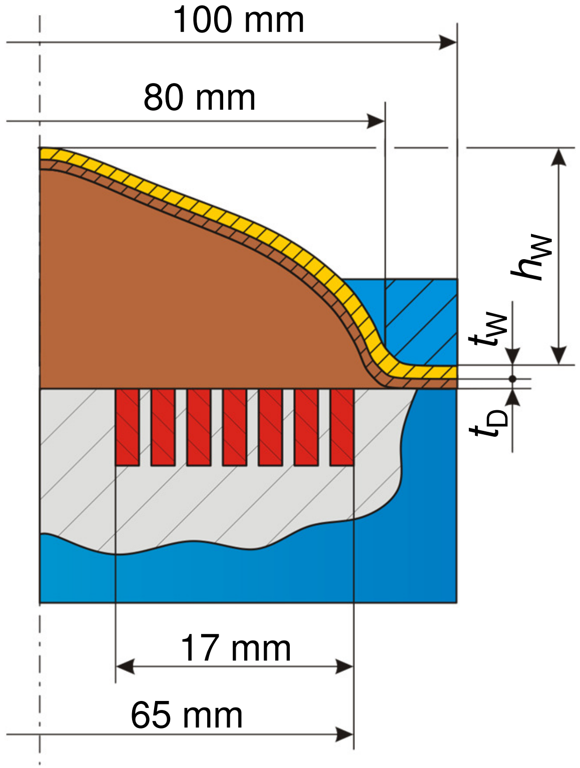

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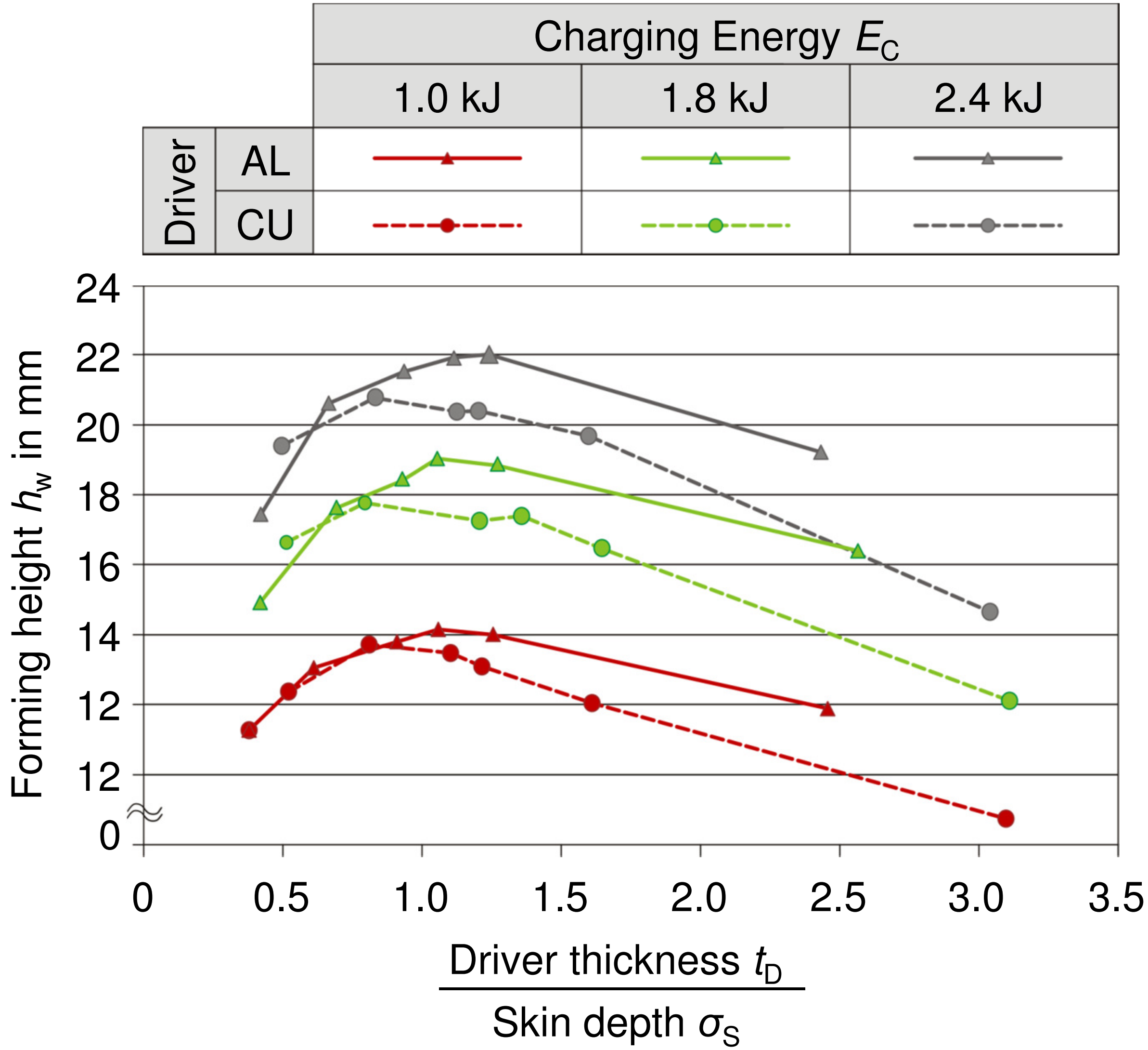
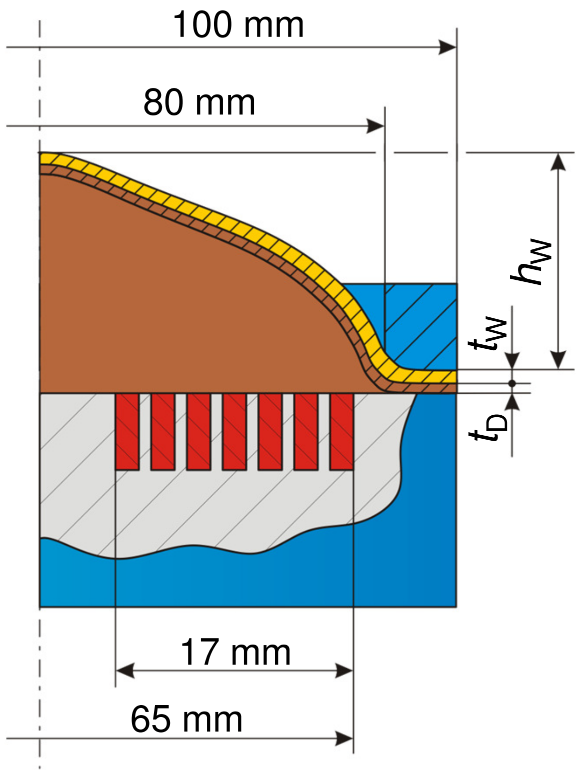


Results

Workpiece:

Material 1.4301

Thickness t_W = 0.8 mm



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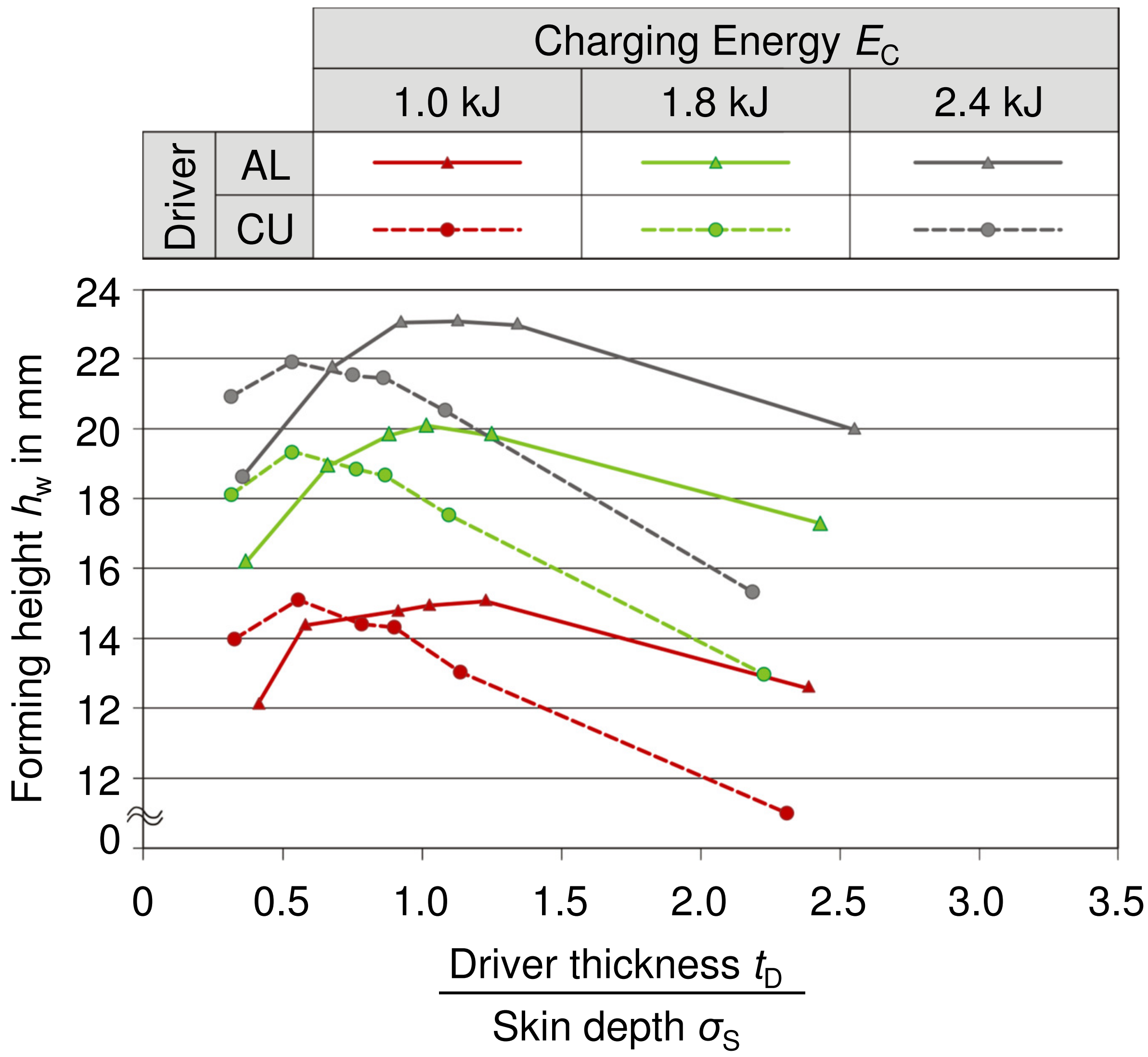
t_w = Workpiece thickness

t_D = Driver thickness



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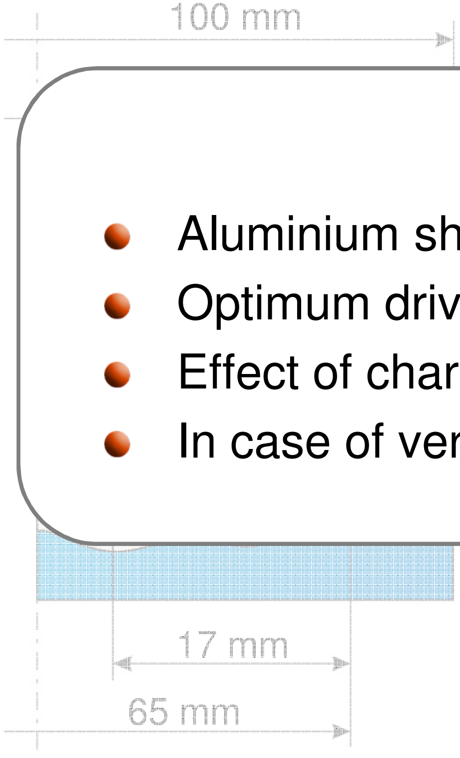
Workpiece:
Material 1.4301
Thickness t_W = 0.8 mm



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t_w = Workpiece thickness
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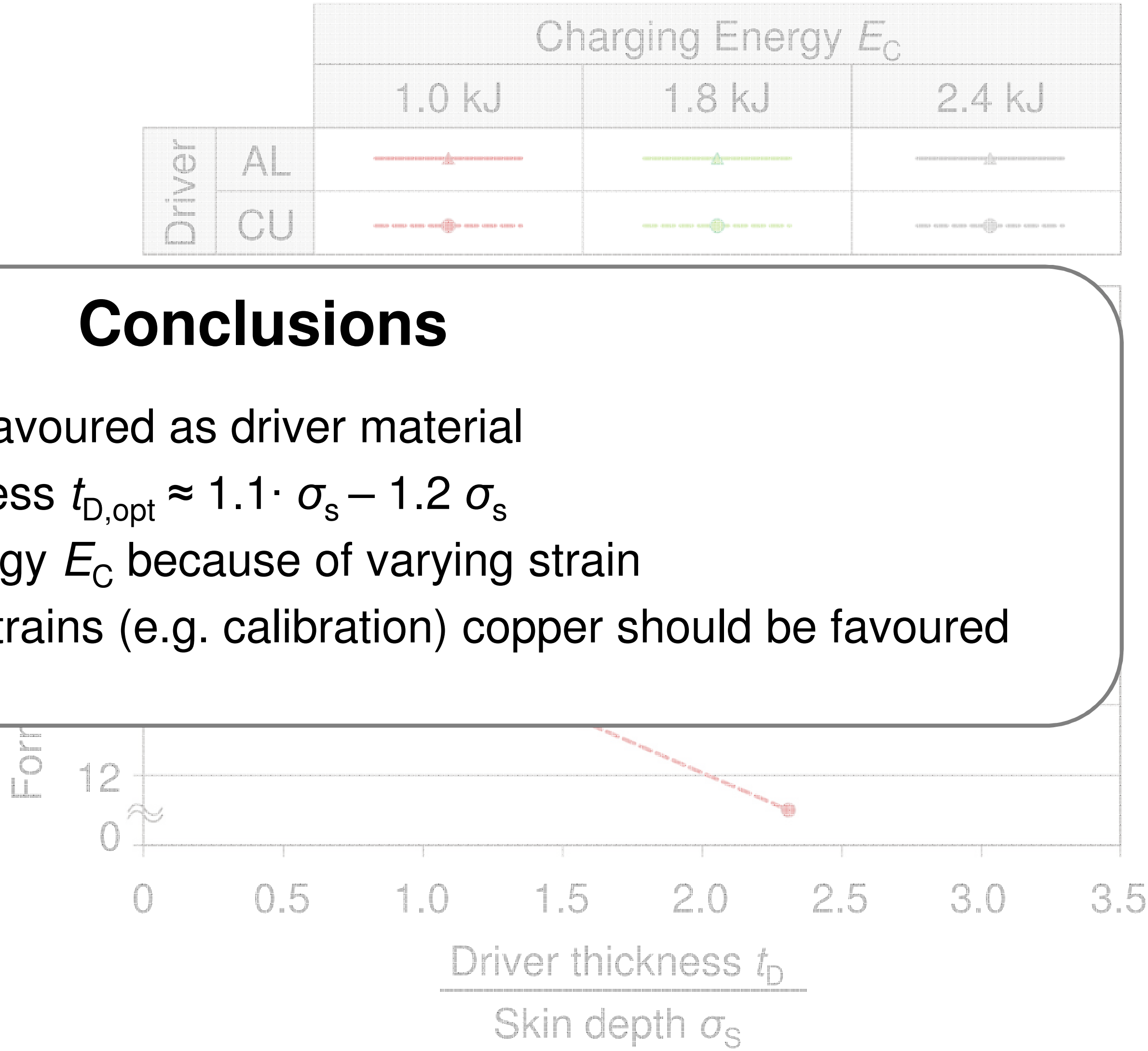

Conclusions

- Aluminium should be favoured as driver material
- Optimum driver thickness $t_{D,opt} \approx 1.1 \cdot \sigma_s - 1.2\ \sigma_s$
- Effect of charging energy E_C because of varying strain
- In case of very small strains (e.g. calibration) copper should be favoured

Results

- Comparision of optimum driver thicknesses $t_{D,opt}$
  (Driver material: AL)

	Workpiece thickness t_W		
Workpiece material	0.5 mm	0.8 mm	1.0 mm
1.4301	$0.95 \cdot \sigma_s$	$1.0 \cdot \sigma_s$	$1.27 \cdot \sigma_s$
1.4509	$1.0 \cdot \sigma_s$	$1.05 \cdot \sigma_s$	$1.29 \cdot \sigma_s$

- Conclusions:
  - Increasing workpiece thickness t_W → Increasing optimum driver thickness $t_{D,opt}$
  - Rule of thumb: Optimum driver thickness ≈ σ_s (AL)

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Summary and Outlook

- **Summary:**
  - Aluminum should be favoured as driver material
  - Positive correlation between workpiece thickness t_W and optimum driver thickness $t_{D,opt}$
  - Rule of thumb: Optimum driver thickness ≈ σ_s (AL)

- **Outlook:**
  - EMF of stainless steel into a conical die using the optimum driver material und thickness
  - Analytical calculation of the optimum driver thickness $t_{D,opt}$

Questions?