Universität Stuttgart

AmagS –
Aktivmaterialien aus gepressten Spänen – Entwicklung eines neuen Verfahrens zur Herstellung eines Aktivmaterials für elektrische Maschinen aus recycelten Blechabfällen

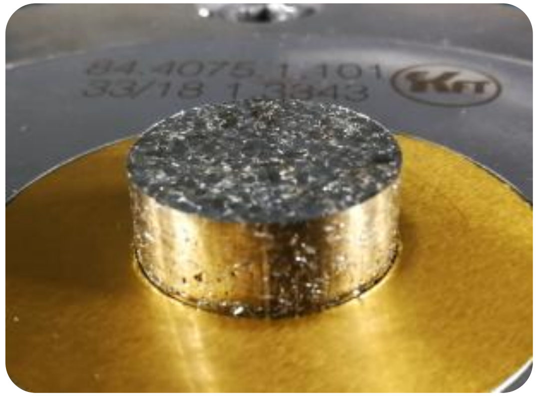
Institut für Umformtechnik

AmagS

Laufzeit: 08/2024 – 07/2026

DBU Projekt: Aktivmaterialien aus gepressten Spänen – Entwicklung eines neuen Verfahrens zur Herstellung eines Aktivmaterials für elektrische Maschinen aus recycelten Blechabfällen

Koordination:	Institut für Umformtechnik (IFU), Universität Stuttgart
Projektpartner:	Institut für elektrische Energiewandlung (IEW), Universität Stuttgart
	WEIMA Maschinenbau GmbH
	Stiefelmayer-Lasertechnik GmbH & Co. KG
	Fischer Elektromotoren GmbH
	BLOCK Transformatoren-Elektronik GmbH



State of the art

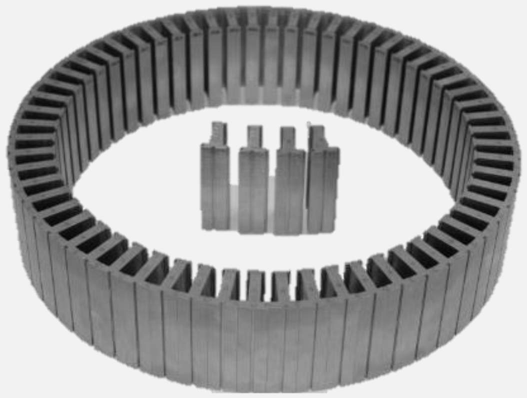
Source: ecomento.de; .domo-elektro; autobild.de, digikey.de, est-aegis.com, windenergie-gieboldehausen, sparesinmotion.com

State of the art

Conventional production method

Sorce: https://vacuumschmelze.de

SMC manufacturing method



Sorce: swd-technology

State of the art

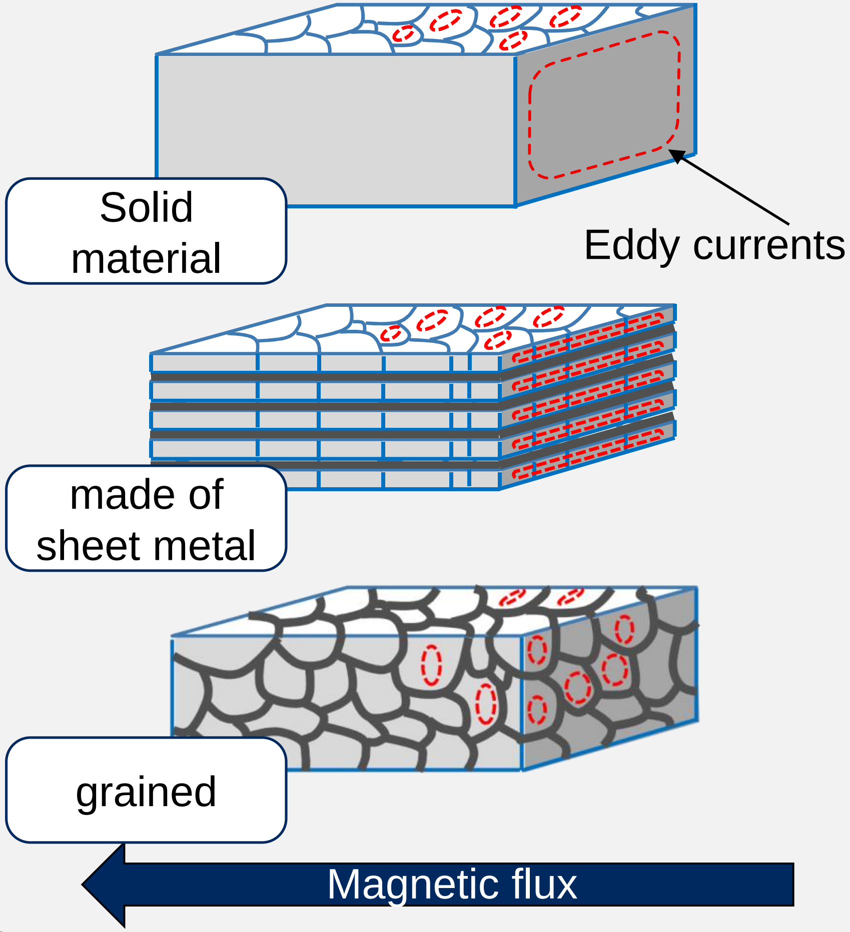
Eddy current losses

$$P_W = \frac{(\pi f d\, B)^2}{6\gamma\rho}$$

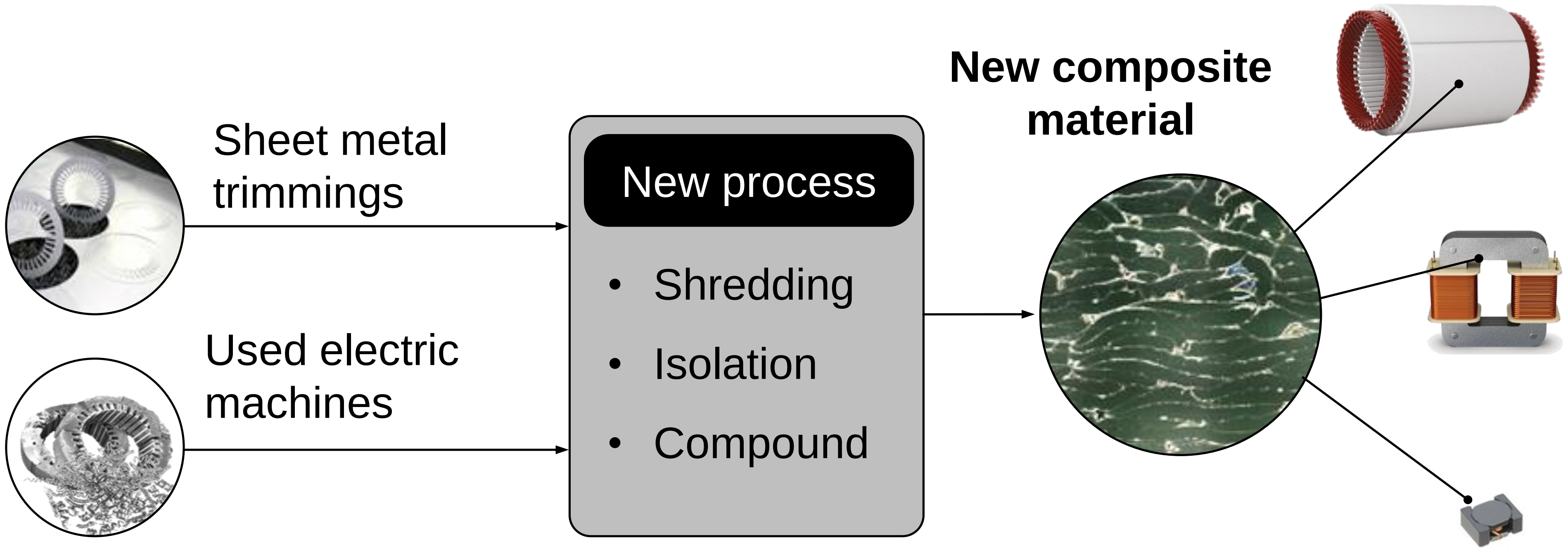
depending on the

- frequency f,
- thickness d,
- Field strength B

Eddy current losses in different materials

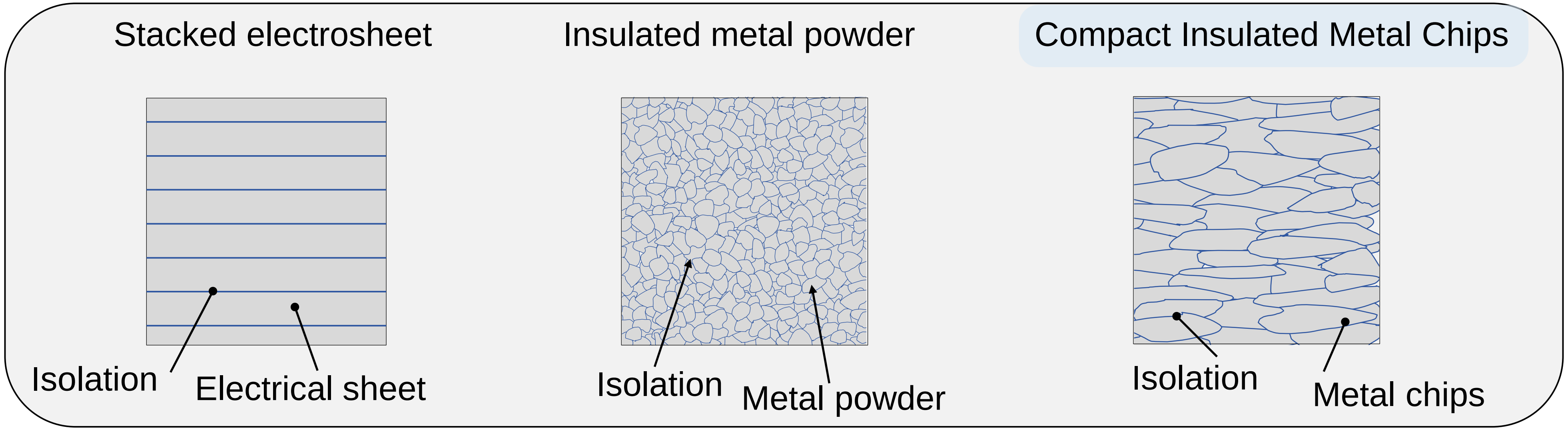


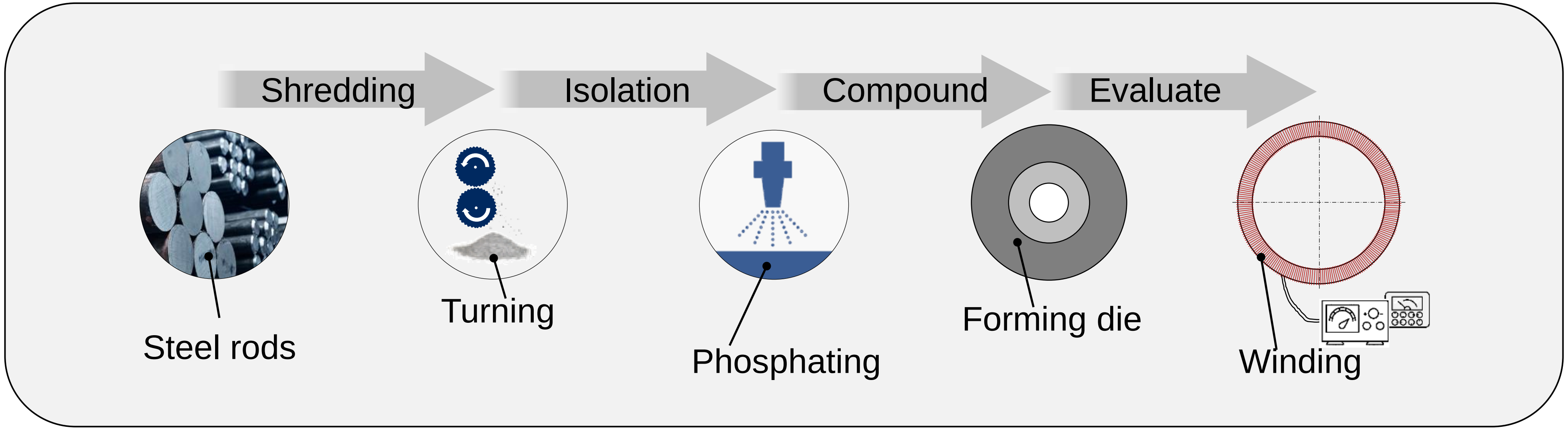
Motivation



Until now, stators for electric machines have been made from stapled insulated sheets. We designed a new method for the recycling of electric machines. The objective is to manufacture a stator from shredded electrical sheet or insulated chips.

Working principle of the method





Experimental results - Phosphating

Non-insulated chips

made out of the material
S355 / AISI A738

Container for phosphating the chips

Phosphate is an insulator which is commonly used for the insolation in conventional e-machines

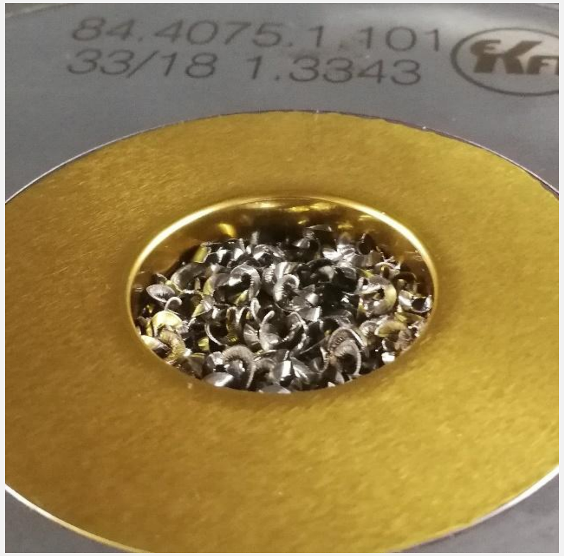
Phosphated metal chips

Layer thickness of the manganese phosphate coating
- Target 2.0 - 5.0 µm
- Actual 2.2 - 2.8 µm

Experimental results - Compaction

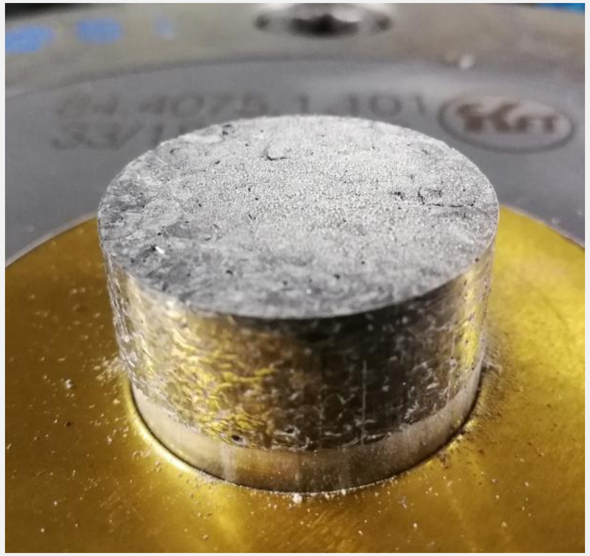
Weighing a defined amount of chips

For a constant part weight
By means of a precision scale



Inserted chips in forming die

Depth 55mm of die till ejector



Compacted metal chip part

The compacted parts are partly electrically conductive, depending on the areas measured

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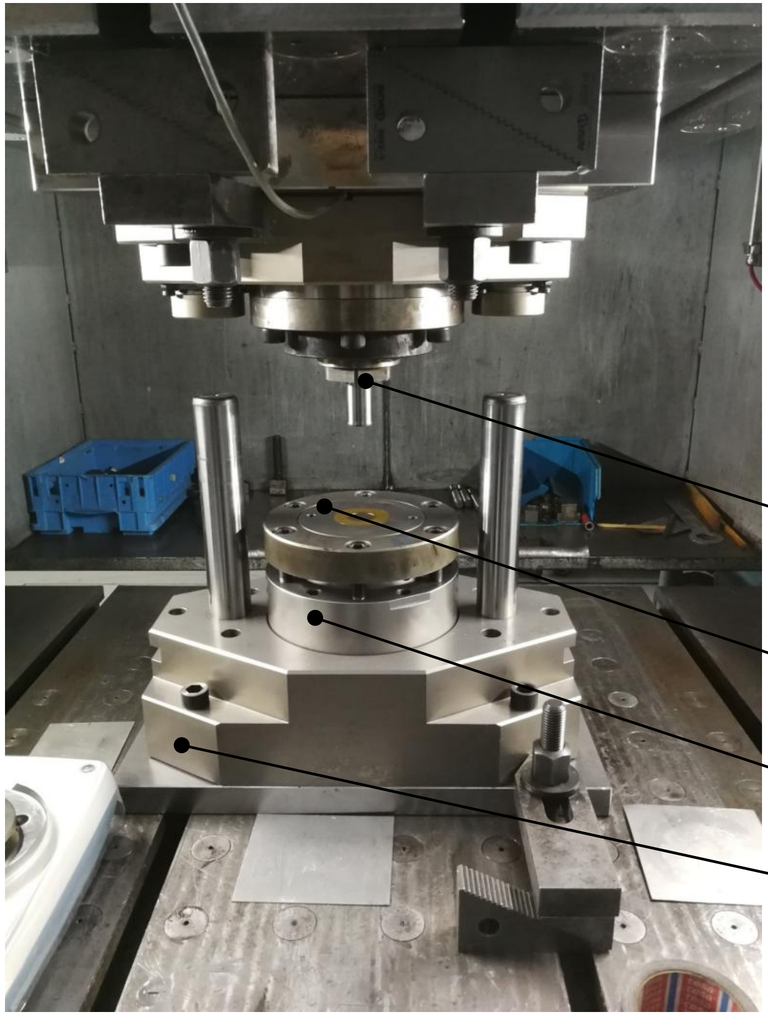
Experimental results - Compaction

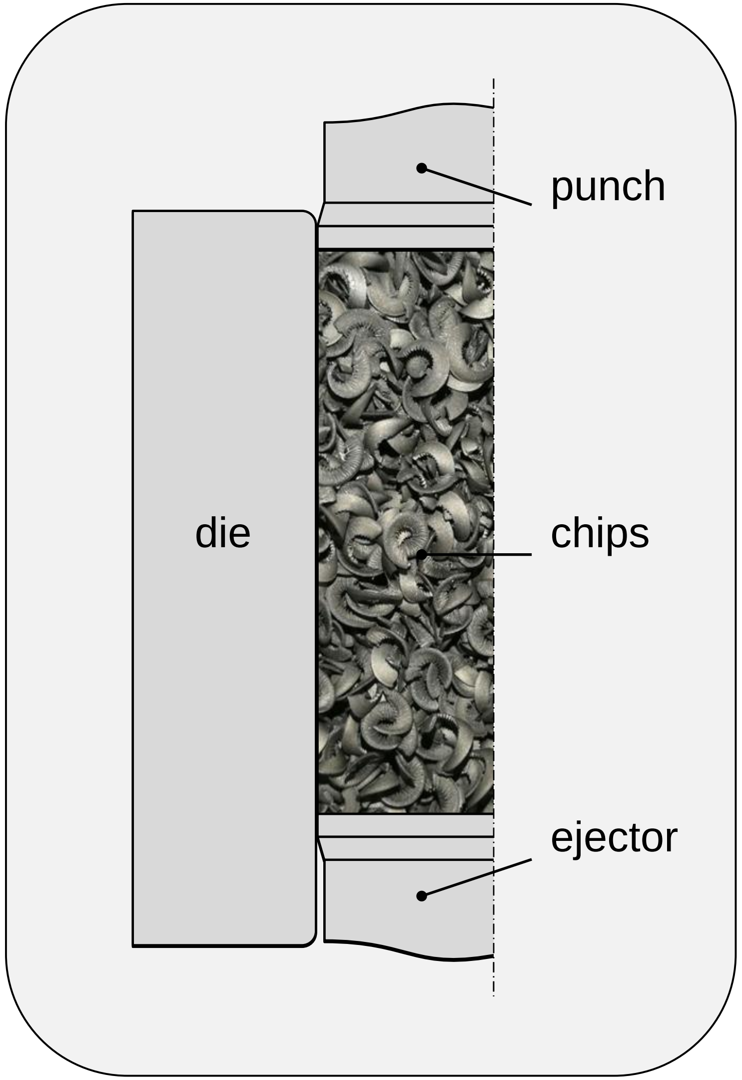


VVFP punch Ø 30 mm

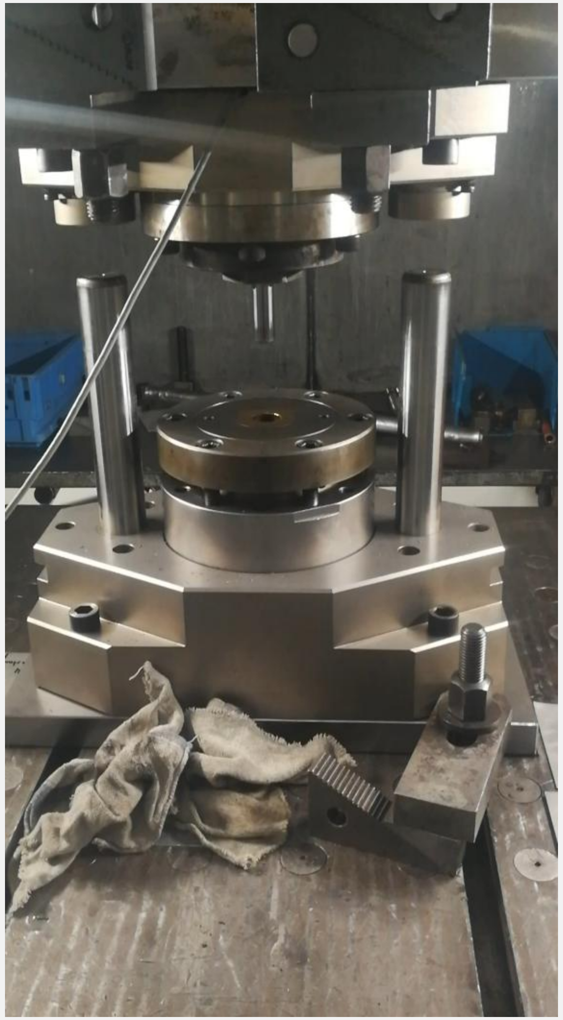
Die Ø 30,3 mm

High alignment ring

Rack to mount a
Ø 160 mm die



Experimental results - Compaction



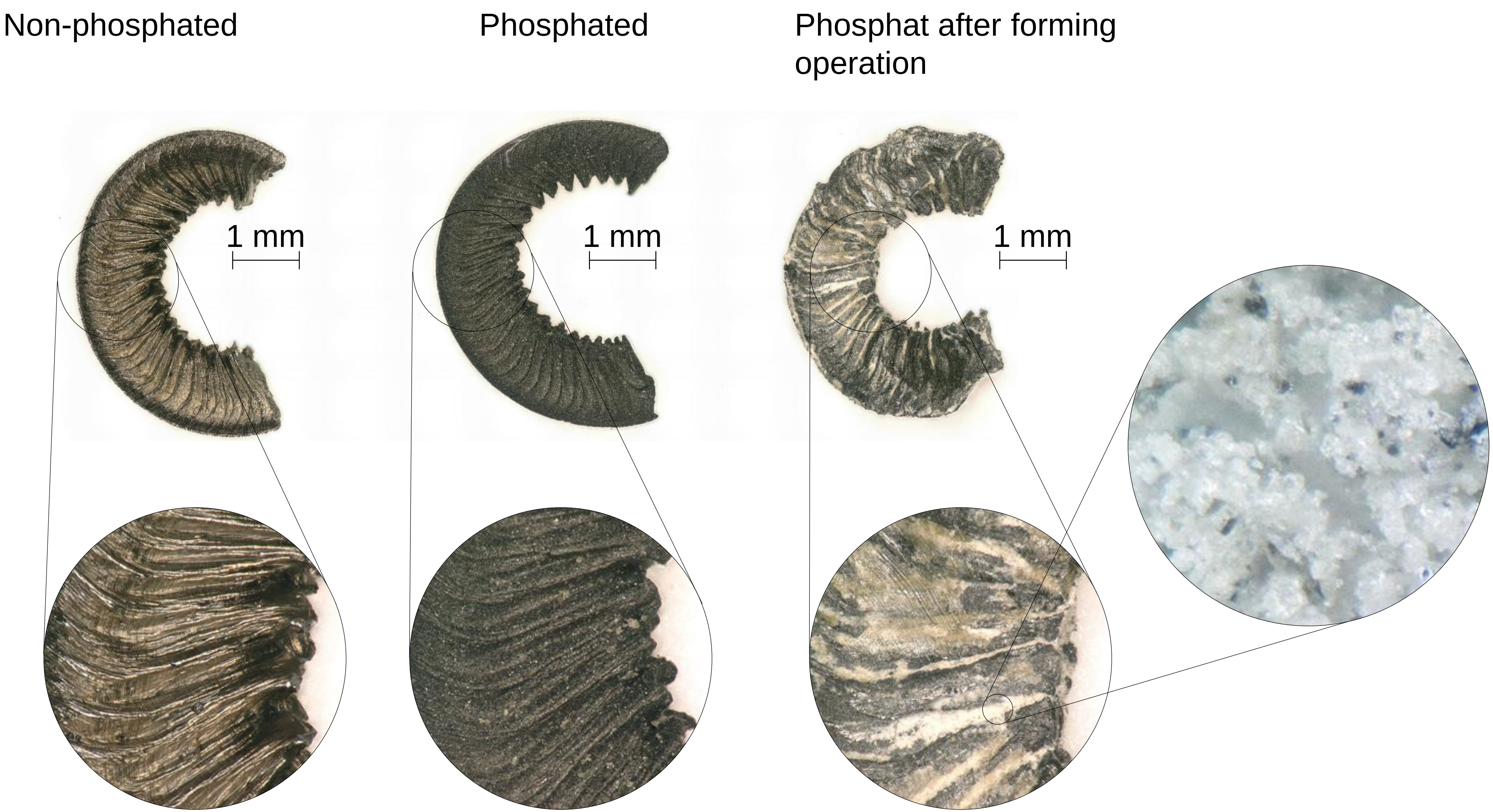
Non-phosphated

Phosphated

Experimental results - Compaction

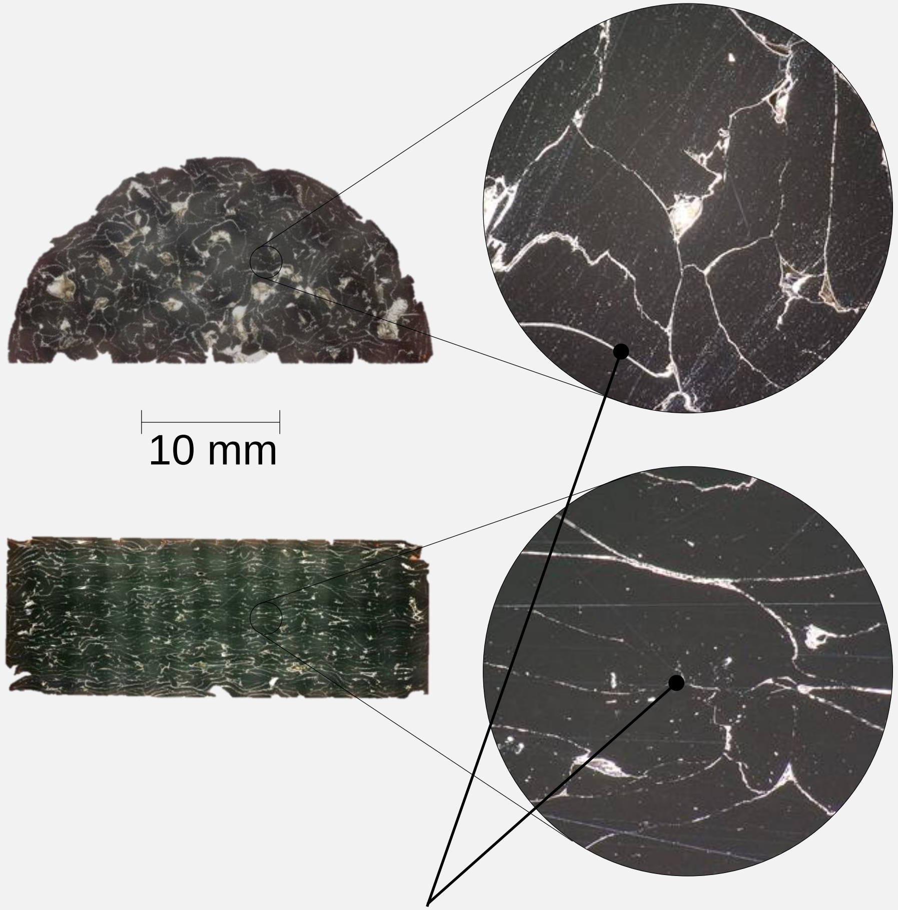
	1. Attempt	2. Attempt	3. Attempt	4. Attempt
				
Height of loose chips in die [mm]	50	55	55	55
Weight of chips [g]	57,797	60,000	60,173	60,057
Rel. initial density at 7,8g/cm³ [%]	20,6	19,4	19,5	19,4
Max. press force [kN]	490	1.640	1.810	1.770
Ram stroke (adjusted) [mm]	1148,4	1141,9	1141,4	1141,4
Actual height of pressed part [mm]	13,35	11,50	11,20	11,30
Rel. final density to 7,8g/cm³ [%]	77,0	92,8	95,5	94,5

Experimental results – Close-up of chips



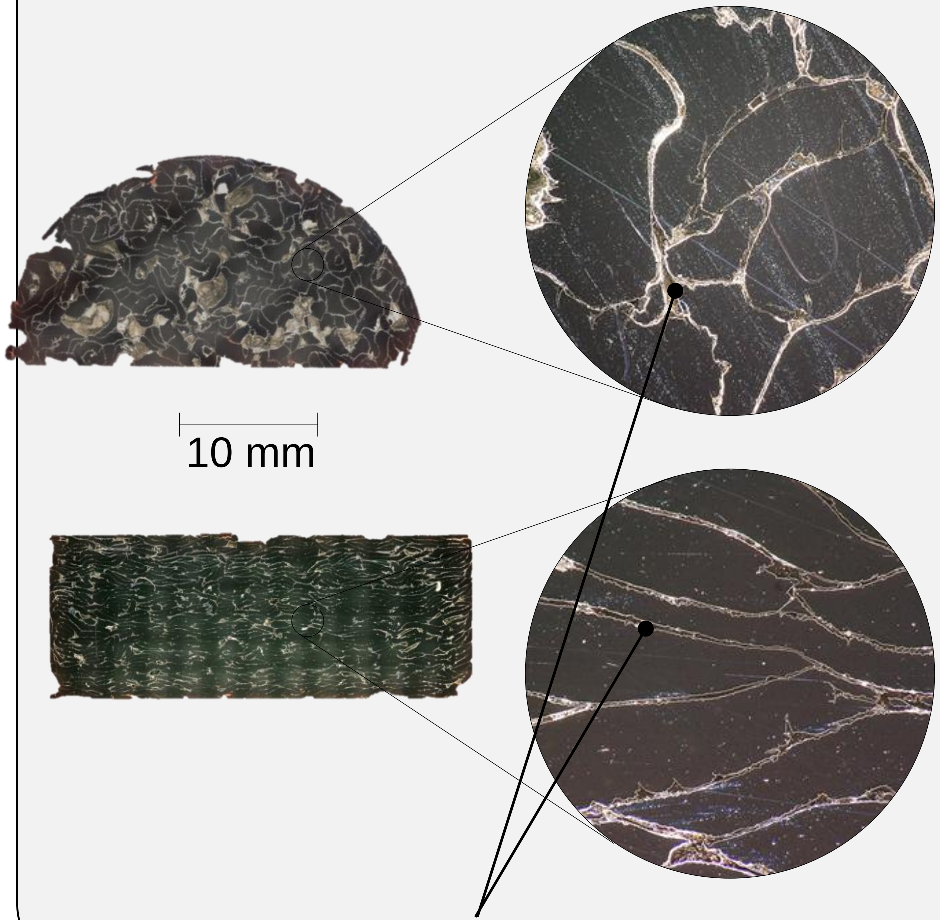
Experimental results - Micrographs

Non-phosphated



Almost no space between the chips

Phosphated

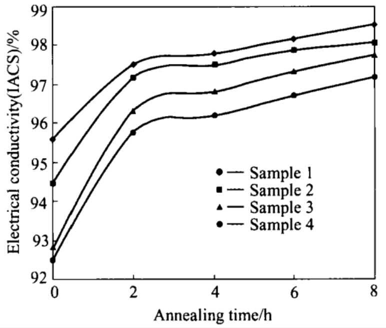


Distance between the chips

Experimental results – Annealing treatment

Why annealing?

- Higher dislocation density due to work-hardening leads to higher electric resistivity
  [2011, Dominguez, Sevostianov, Cross-Property Connection between Work-Hardening Coefficient and Electrical Resistivity of Stainless Steel During Plastic Deformation]
- Annealing of e.g. Cu-Materials shows improved electric conductivity
  [2006, Zhu et al., Effects of annealing process on electrical conductivity and mechanical property of Cu-Te alloys]

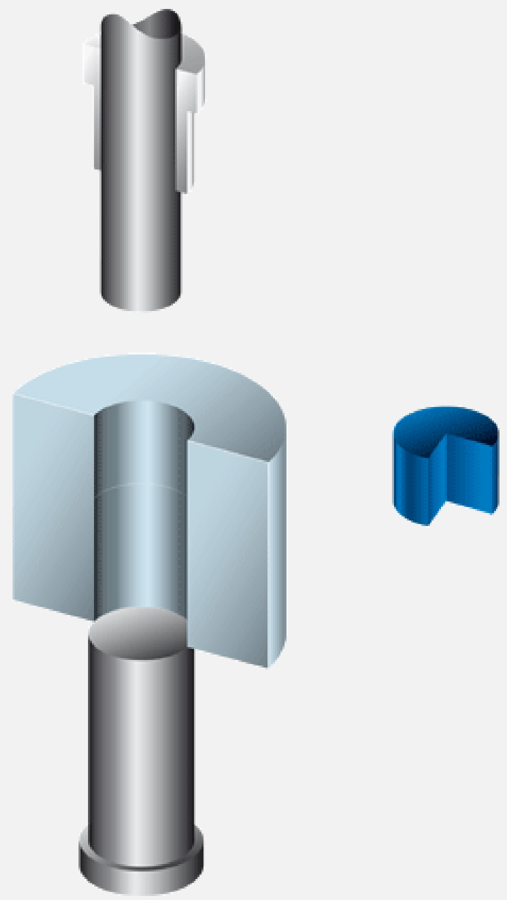


[2006, Zhu et al., Effects of annealing process on electrical conductivity and mechanical property of Cu-Te alloys]

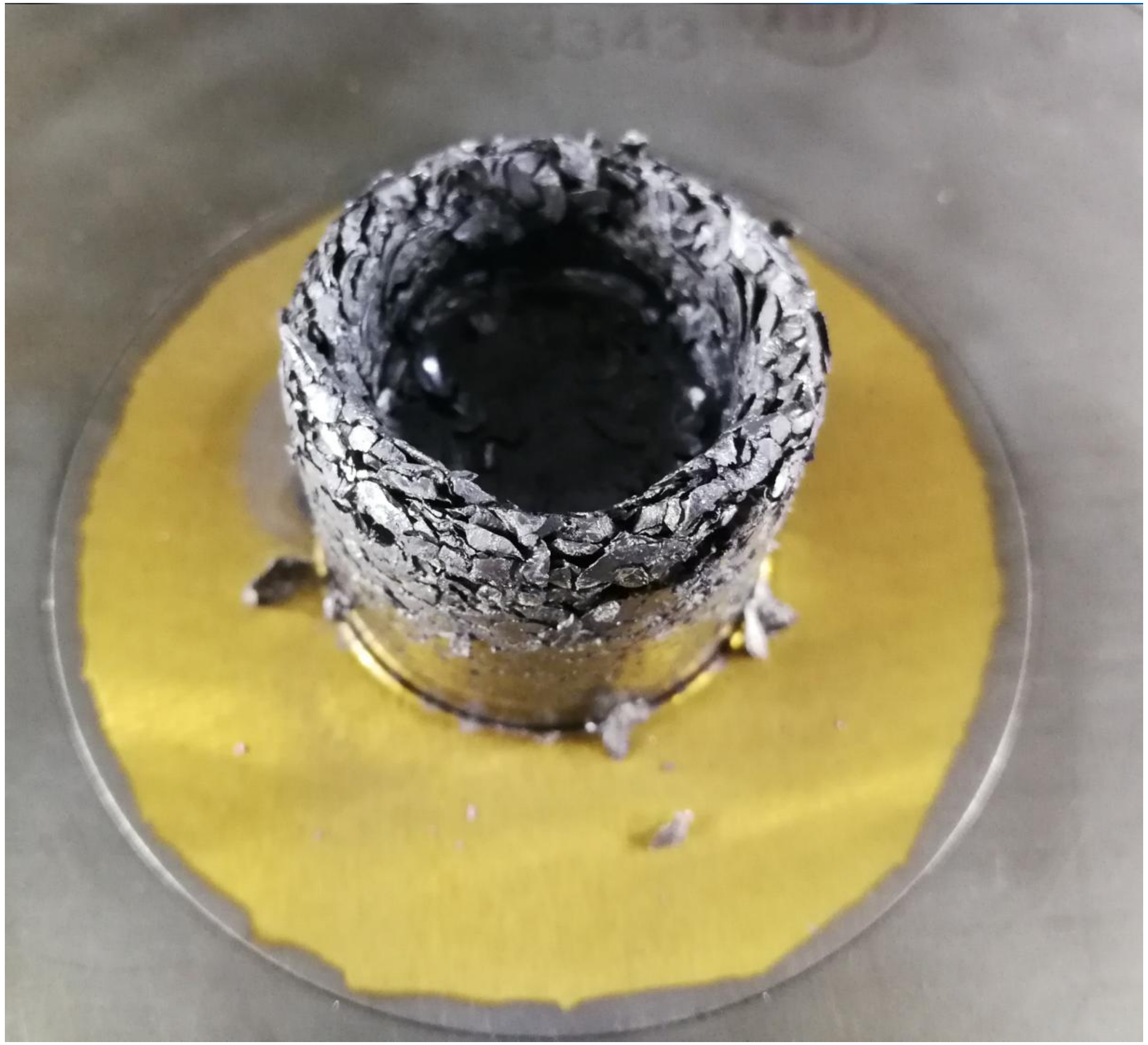
Heat quickly to 690°C, maintain at 690°C for 2h, cool down with a cooling rate of 300°C/h

non-phosphated sample	phosphated sample	annealed phosphated sample	Reference sample out of solid material
			

Experimental results – Ring Probe Manufacturing

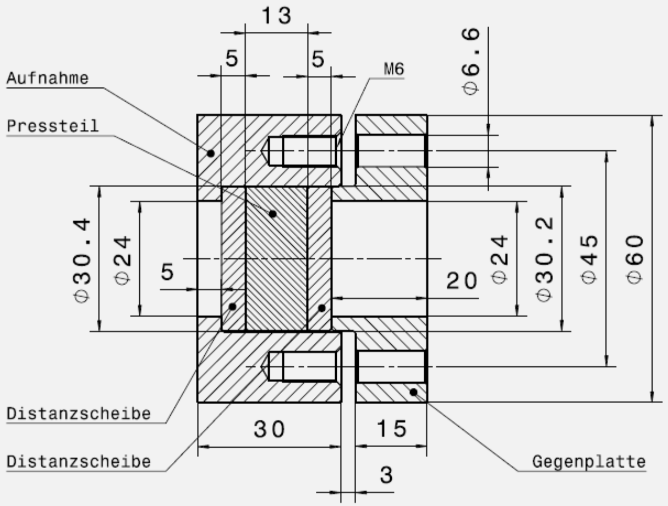


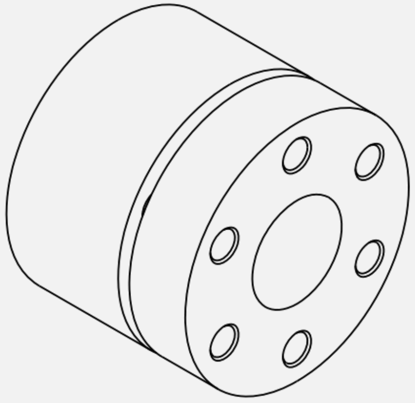
Quelle: Schneider-Umformen

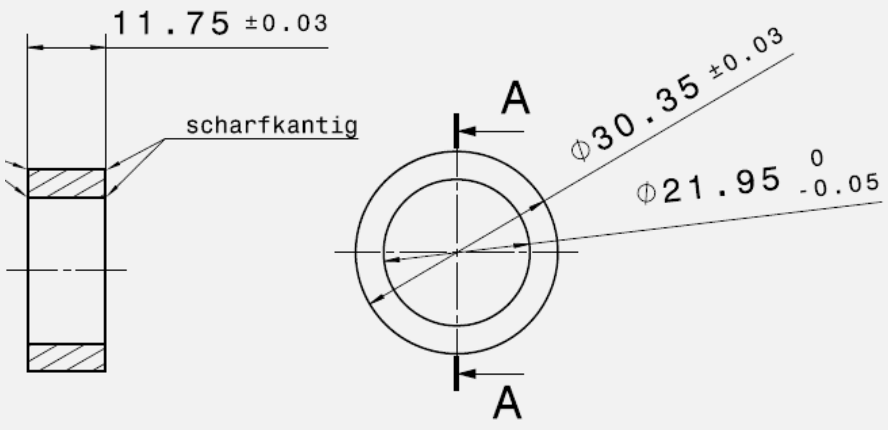


Experimental results – Rin Probe Manufacturing

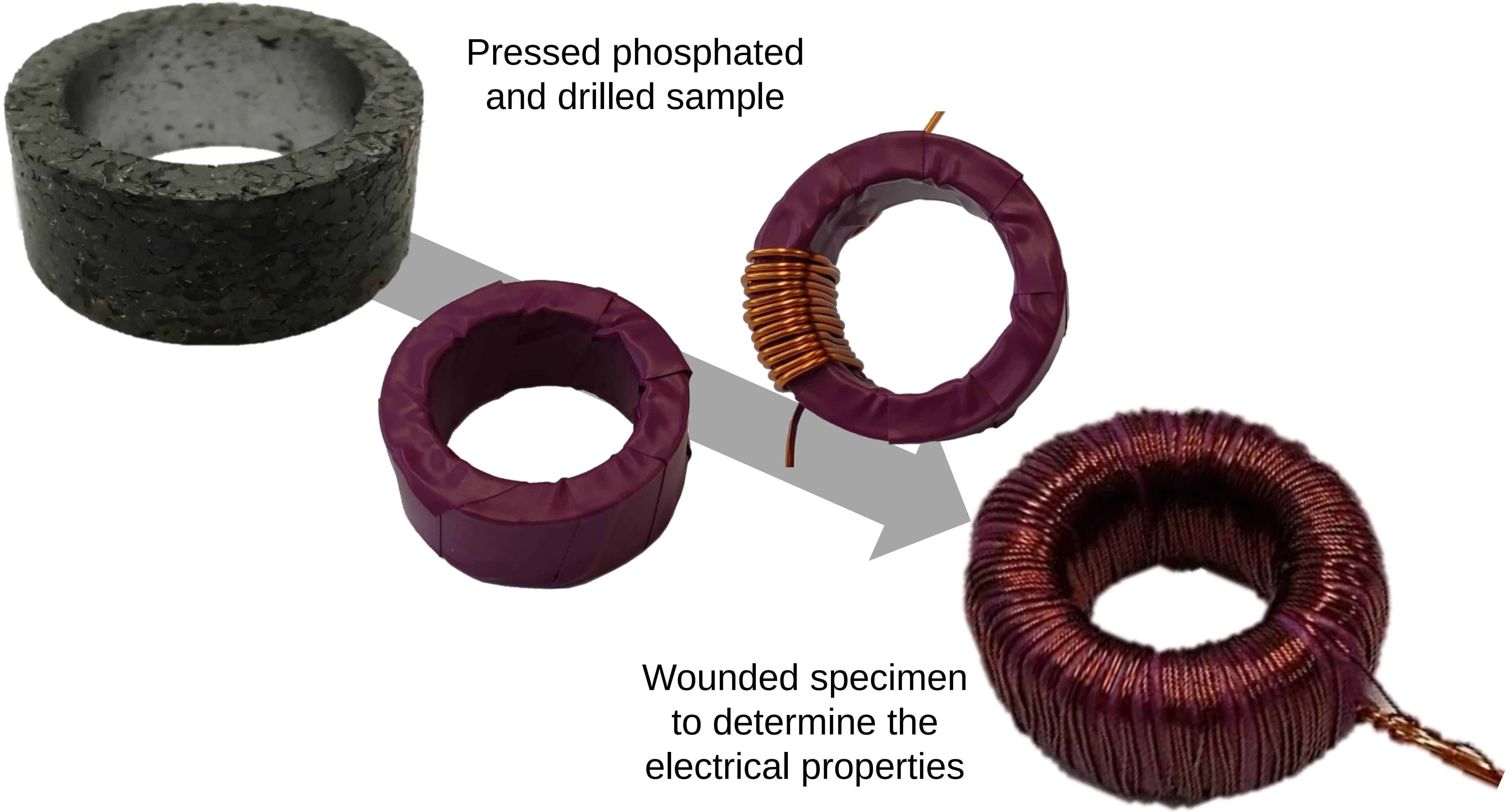
Experimental results – Rin Probe Manufacturing



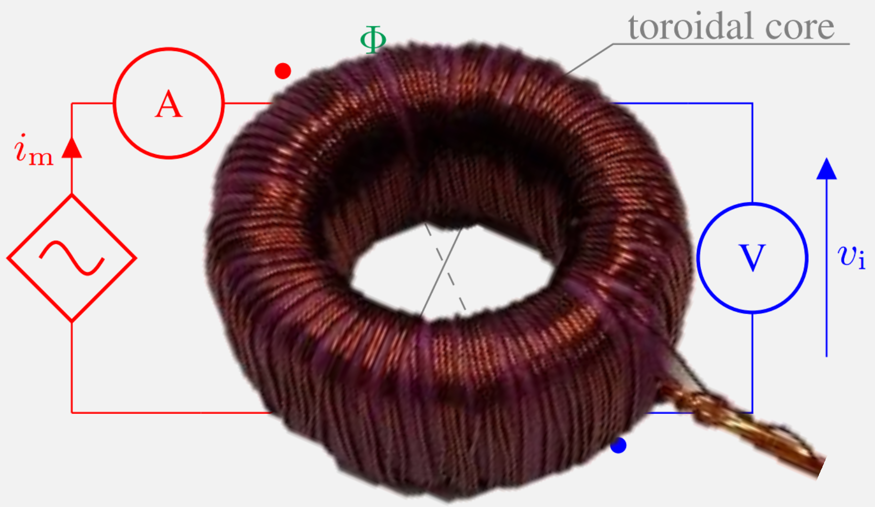




Experimental results - Electromagnetic investigations



Experimental results - Electromagnetic investigations



Description	Symbol	Value
Four quadrant amplifier		
output voltage	$\hat{v}_{out}$	$\pm75\,V$
output current	$\hat{i}_{out}$	$\pm28\,A$
frequency range	f	$0 - 200\,kHz$
Current measurement		
measuring range	$\hat{i}_{meas}$	$\pm30\,A$
measuring accuracy		$\pm5\,\%$
Voltage measurement		
measuring range	$\hat{v}_{meas}$	$\pm10\,V$
measuring accuracy		$\pm5\,\%$
measuring frequency	f_{meas}	$\geq 50\,kHz$

Magnetization measurement:

$$H(t) = H_m \cdot \sin^2(2\pi \cdot f \cdot t) \quad 0 \leq t \leq \frac{1}{4f}$$

$$H(t) = H_m \cdot \sin(2\pi \cdot f \cdot t) \quad \frac{1}{4f} \leq t \leq \frac{5}{4f}$$

Using a magnetic field with strength H (t), frequency f and the maximum field strength H_m

Magnetic field strength measurement:

$$P_{V,Fe} = f \cdot \frac{N_1}{N_2} \int_{t=\frac{1}{4f}}^{\frac{5}{4f}} i_m(t) \cdot v_i \, dt$$

Thereby the losses of the resulting hysteresis loop are determined

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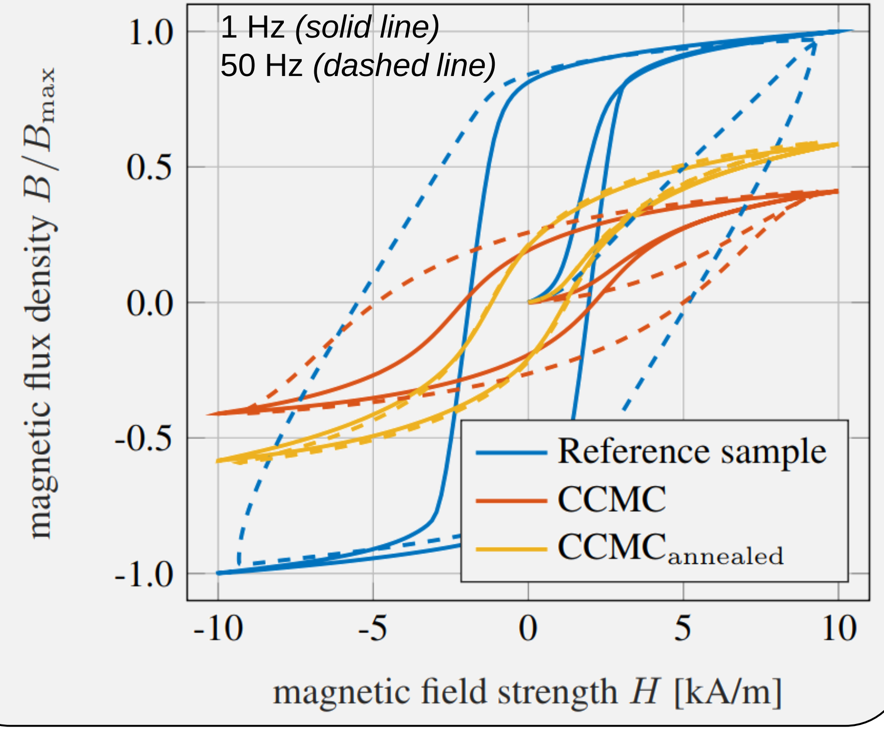
Experimental results - Electromagnetic investigations

Sample	Frequency f	Sp. iron losses $p_{V,Fe}$
Reference sample	1 Hz	1.6 W/kg
CCMC	1 Hz	0.6 W/kg
$CCMC_{annealed}$	1 Hz	0.6 W/kg
Reference sample	50 Hz	217.1 W/kg
CCMC	50 Hz	70.9 W/kg
$CCMC_{annealed}$	50 Hz	29.9 W/kg

Increase of specific losses by a factor of

- 135.7 with reference sample
- 118.2 with CCMC sample
- 49.8 annealed CCMC sample



The lower increase factor of the iron losses as well as the small broadening of the hysteresis curve of the annealed CCMC sample demonstrate the potential of the reduction of iron losses for the annealed CCMC material.

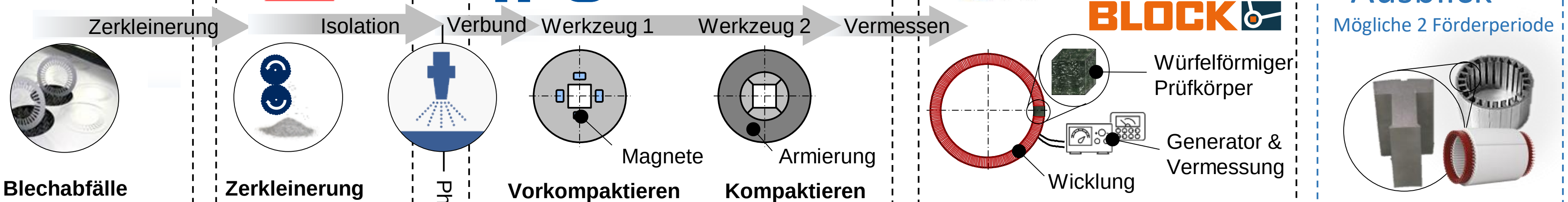
Summary and DBU-Project

Summary

DBU-Project

DBU

STIEFELMAYER lasertechnik | IFU | iew | FISCHER Elektromotoren | BLOCK



Blechabfälle
- Elektrobleche
- Stahlblech
- Unterschiedliche Blechdicke

Zerkleinerung
- Einstellung der Spangröße
- Homogenität der Spangröße
- Späne reinigen

Vorkompaktieren
- geringe Kräfte
- Matrize hoch
- Späne orientieren → Magnete

Kompaktieren
- Hohe Kräfte → armiert
- geringere Höhe

Vermessung
- Richtungs-abhängige el. mag. Eigenschaften

Bewertung
- Eignung des CCMC als Aktivmaterial

- Testen des Materials in E-Maschine
- Leistungsfähigkeit als Aktivmaterial

Aktueller Stand im Projekt - Zerkleinerungsversuche bei WEIMA

Zerkleinerungsmaschine WLK4

Metallspäne

Alte Transformatoren

Platinenbeschnitt

Ausschuss

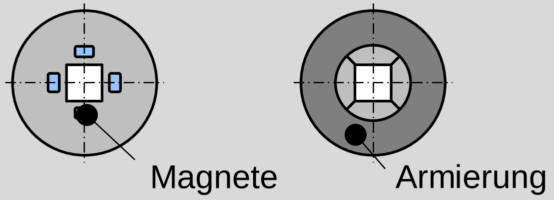
Aktuelles Stand im Projekt - Zerkleinerungsversuche bei WEIMA

Mehrfache Zerkleinerung unter Verwendung von verschiedenen Siebeinsätzen

Material	Lochdurchmesser der Siebe in mm
Elektroblech N020	1. Sieb: 15-20mm 2. Sieb: 8-10mm 3. Sieb: 6mm
Elektroblech M800/50c	1. Sieb: 8-10mm 2. Sieb: 6mm
Elektroblech M350/50BL	1. Sieb: 8-10mm 2. Sieb: 6mm
Transformator-bleche	1. Sieb: 8-10mm 2. Sieb: 6mm
Späne	1. Sieb: 6mm

Aktuelles Stand im Projekt - Nächste Schritte

- Vorsortierung der Späne
- Durchführung von Kompaktierversuchen
- Vergleich der aus unterschiedlichen Spänen (u. a. aus unterschiedlichen Blechdicken gewonnen) kompaktierten Butzen
- Werkzeugauslegung für Würfelgeometrie



Vorkompaktieren
- geringe Kräfte
- Matrize hoch
- Späne orientieren → Magnete

Kompaktieren
- Hohe Kräfte → armiert
- geringere Höhe