RECYCLING UND REUSE

VON TYPISCHEN FLUGZEUGBAU-ALUMINIUMLEGIERUNGEN

FORSCHUNGSERGEBNISSE UND WEITERFÜHRENDE ANSÄTZE

18.12.2023, FFG, Wien

Rudolf Gradinger, Dr. Carina Schlögl, Clemens Simson
LKR Leichtmetallkompetenzzentrum Ranshofen GmbH

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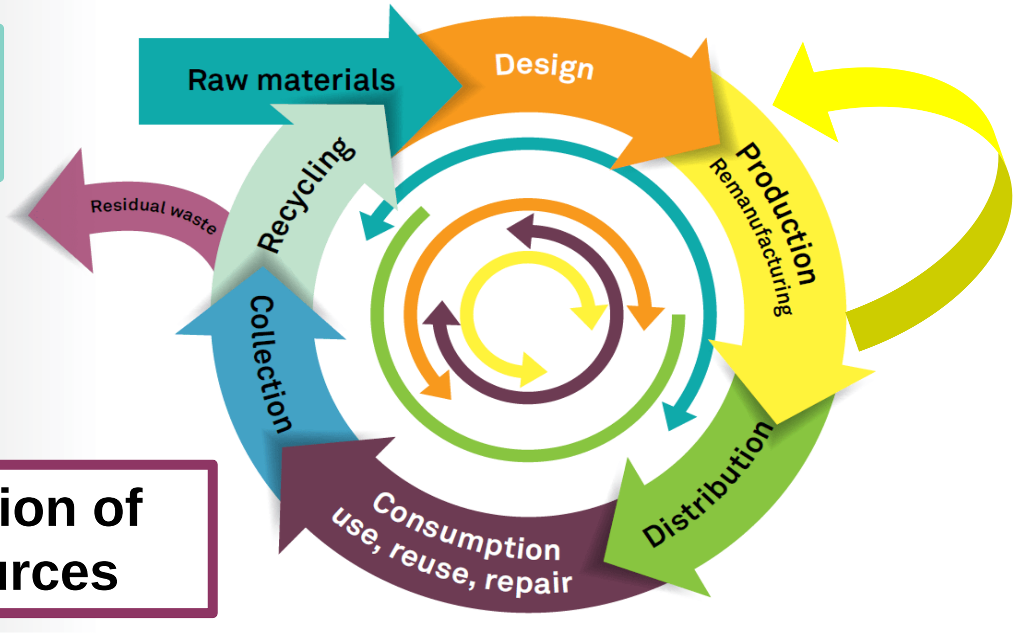
Agenda

Forschungsergebnisse und weiterführende Ansätze

MULTI-FUN: **New alloys & LCA**

SUSTAINair: **New alloys & dismantling**



KryoReIF: **Cyogenic cleaning of contaminated metal scrap**

RecAL: E**xploitation of secondary resources**

COMPASS & ProMetHeus: **"REFORMING"**

KryoReIF

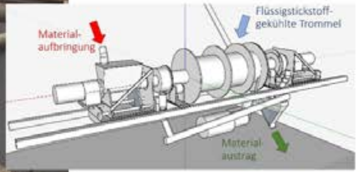
Kryogenes Recycling von wertvollen, industriell unzureichend genutzten Materialien als Industrielle Forschung

https://projekte.ffg.at/projekt/4141491

KryoRelF
Background knowledge and CRYOMILL infrastructure

- Cryomill combining cooling by liquid nitrogen and ball milling
- e.g. for micronizing of (plastic) rubber at cryogenic temperature

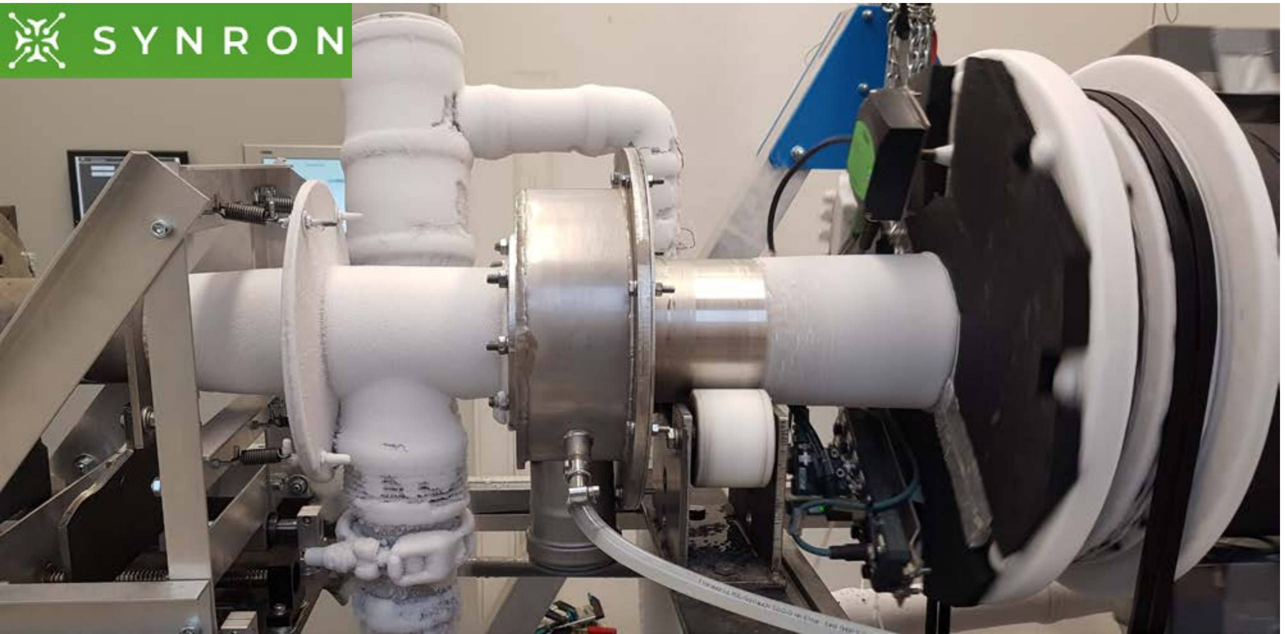




KryoRelF

Basic idea of LKR: applying SYNRONS‘s cryomilling for cryogenic cleaning

- Preliminary tests applying Cryomill positively confirmed that there was no significant change in chip geometry during cryo-cleaning.



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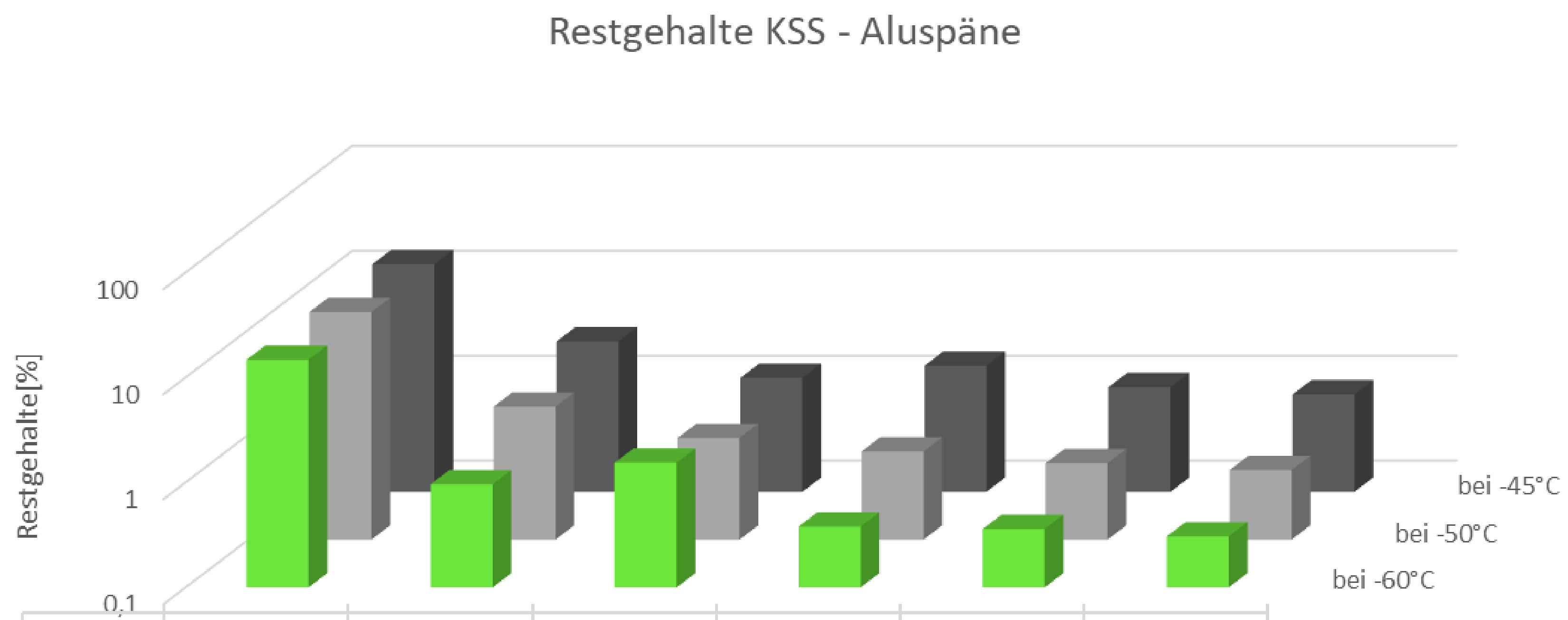
KryoRelF

Cryogenic cleaning success for contaminated metal chips

- Remaining contamination on the chips w/o and after 1-5 runs (Fraction of contamination in [%] of current total mass)



bei -60°C	14,75	0,96	1,54	0,38	0,36	0,31
bei -50°C	14,75	1,85	0,93	0,69	0,53	0,46
bei -45°C	14,75	2,71	1,22	1,59	1,00	0,85

Anzahl der Maschinendurchläufe

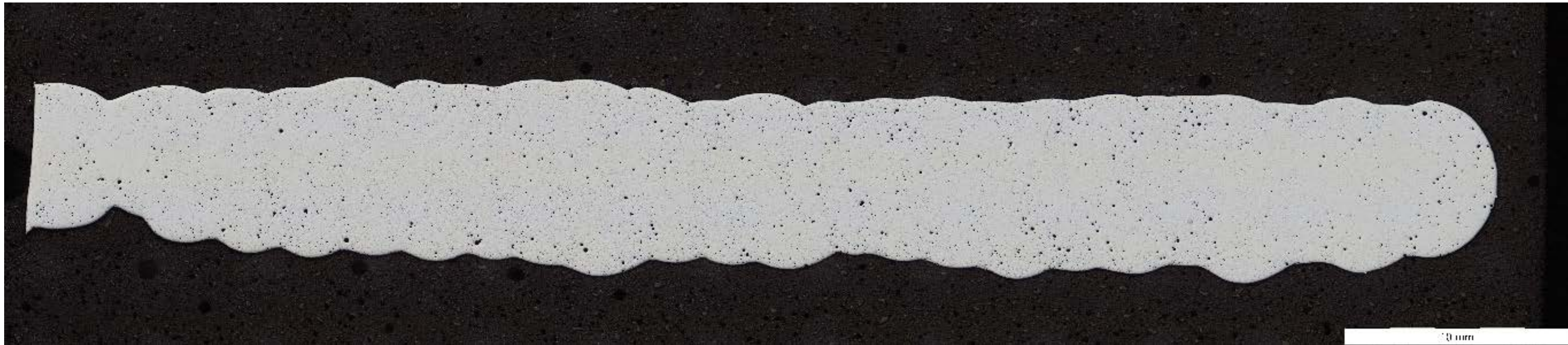
KryoRelF
Cleaned metal chips recycling

LKR's manufacturing route for small batches of filler wires

Billet casting	• Manufacturing of pre-material via Gravity / Pressure / Continuous casting
Wire extrusion	• Hot Extrusion of billets of different sizes down to extrusion billets, wire filaments or endless wires
Spooling Finishing	• Joining of single wire filaments • Cleaning, finishing, spooling

S. Frank, S. Ucsnik, M. Hartmann, R.Gradinger "Smart process chain for the development of additive manufacturing specific Aluminium powders and filler wires", proceedings of Aluminium Conference Düsseldorf 2018

- Wire in sufficient quality (but in low amount of a few kg)
- WAAM samples built
- Porosity of ~1% in the layered structure



KryoRelF
Acknowledgement to AMAG for their support

- AMAG supplying large volumes of 7075 chips (lubricated & pyrolysis-cleaned chips of aerospace grade 7075 composition)
- AMAG as a frontrunner in closed loop recycling:

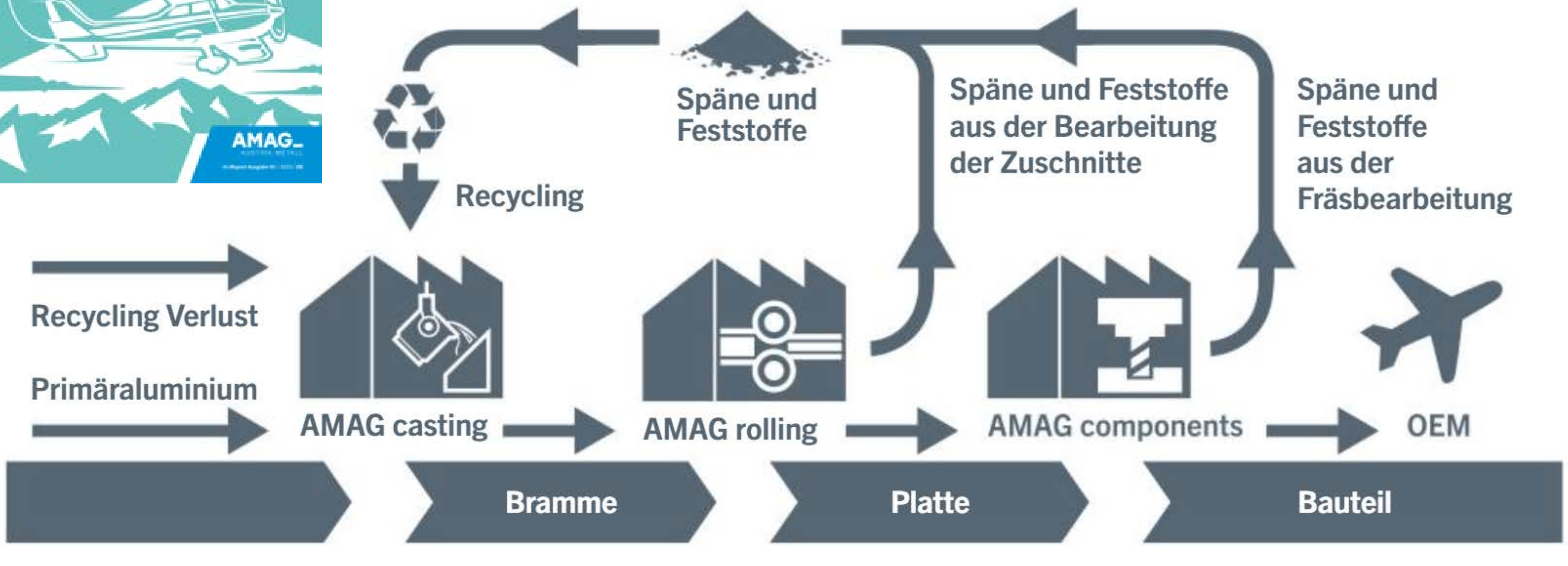
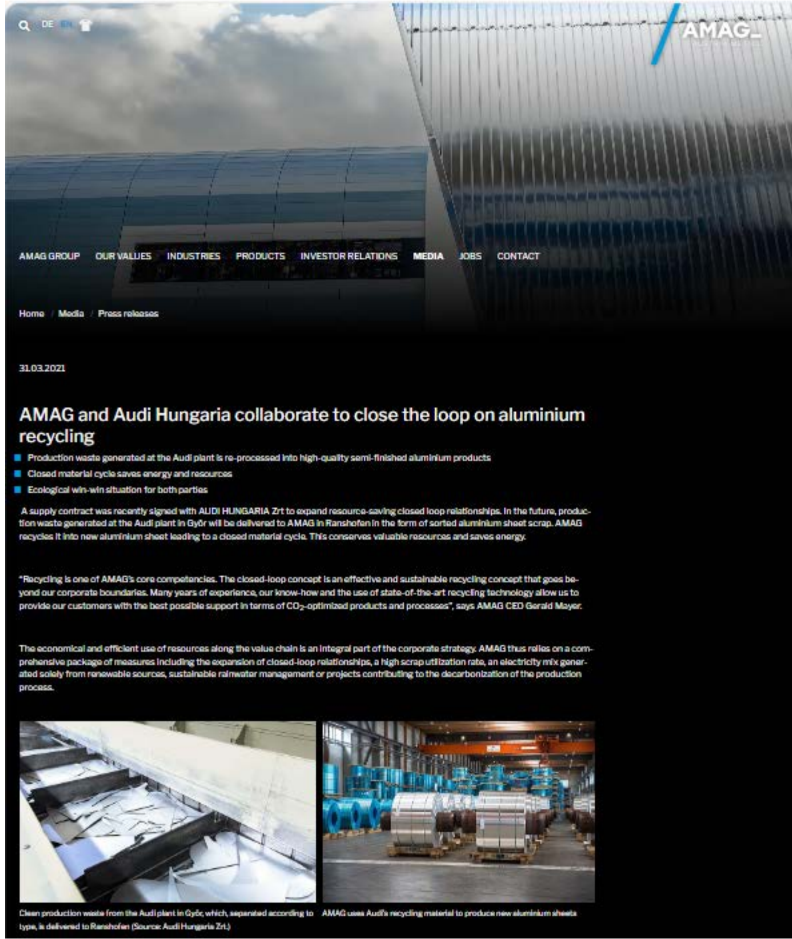


Bild 2: Closed-Loop-Materialprozess



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31.03.2021

AMAG and Audi Hungaria collaborate to close the loop on aluminium recycling

- Production waste generated at the Audi plant is re-processed into high-quality semi-finished aluminium products
- Closed material cycle saves energy and resources
- Ecological win-win situation for both parties

A supply contract was recently signed with AUDI HUNGARIA Zrt to expand resource-saving closed loop relationships. In the future, production waste generated at the Audi plant in Győr will be delivered to AMAG in Ranshofen in the form of sorted aluminium sheet scrap. AMAG recycles it into new aluminium sheet leading to a closed material cycle. This conserves valuable resources and saves energy.

"Recycling is one of AMAG's core competencies. The closed-loop concept is an effective and sustainable recycling concept that goes beyond our corporate boundaries. Many years of experience, our know-how and the use of state-of-the-art recycling technology allow us to provide our customers with the best possible support in terms of CO_2-optimized products and processes", says AMAG CEO Gerald Mayer.

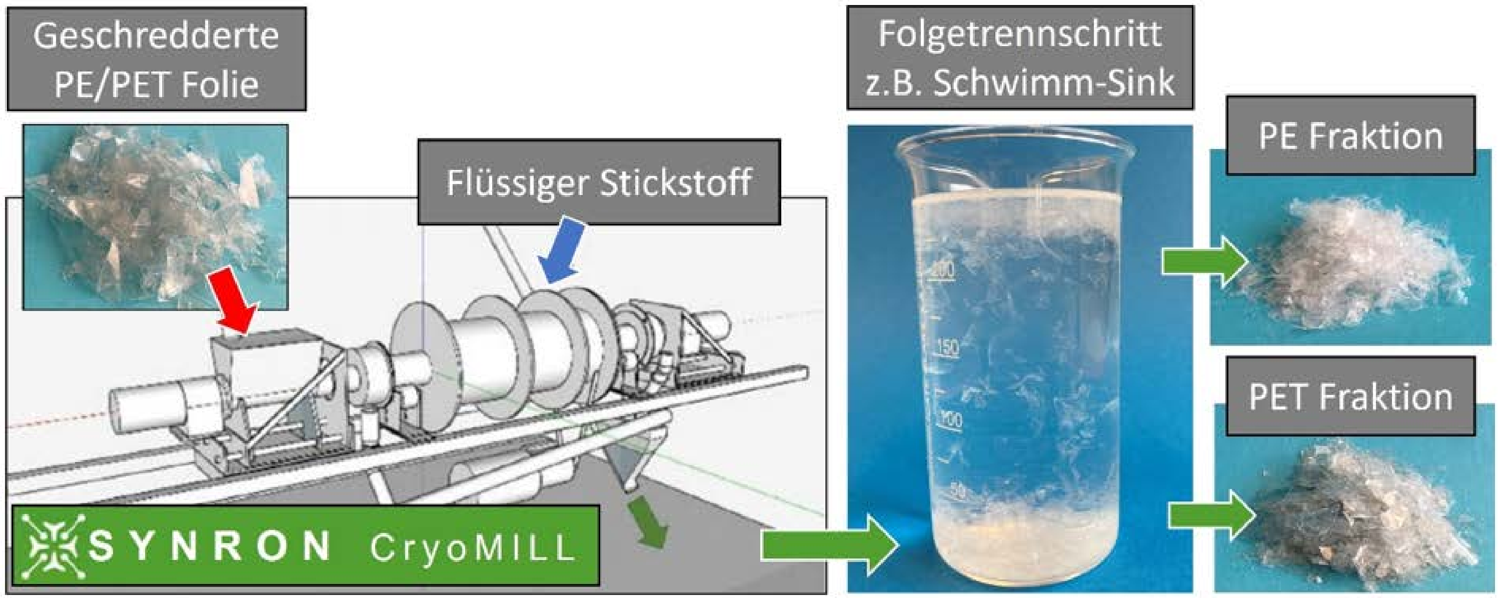
The economical and efficient use of resources along the value chain is an integral part of the corporate strategy. AMAG thus relies on a comprehensive package of measures including the expansion of closed-loop relationships, a high scrap utilization rate, an electricity mix generated solely from renewable sources, sustainable rainwater management or projects contributing to the decarbonization of the production process.

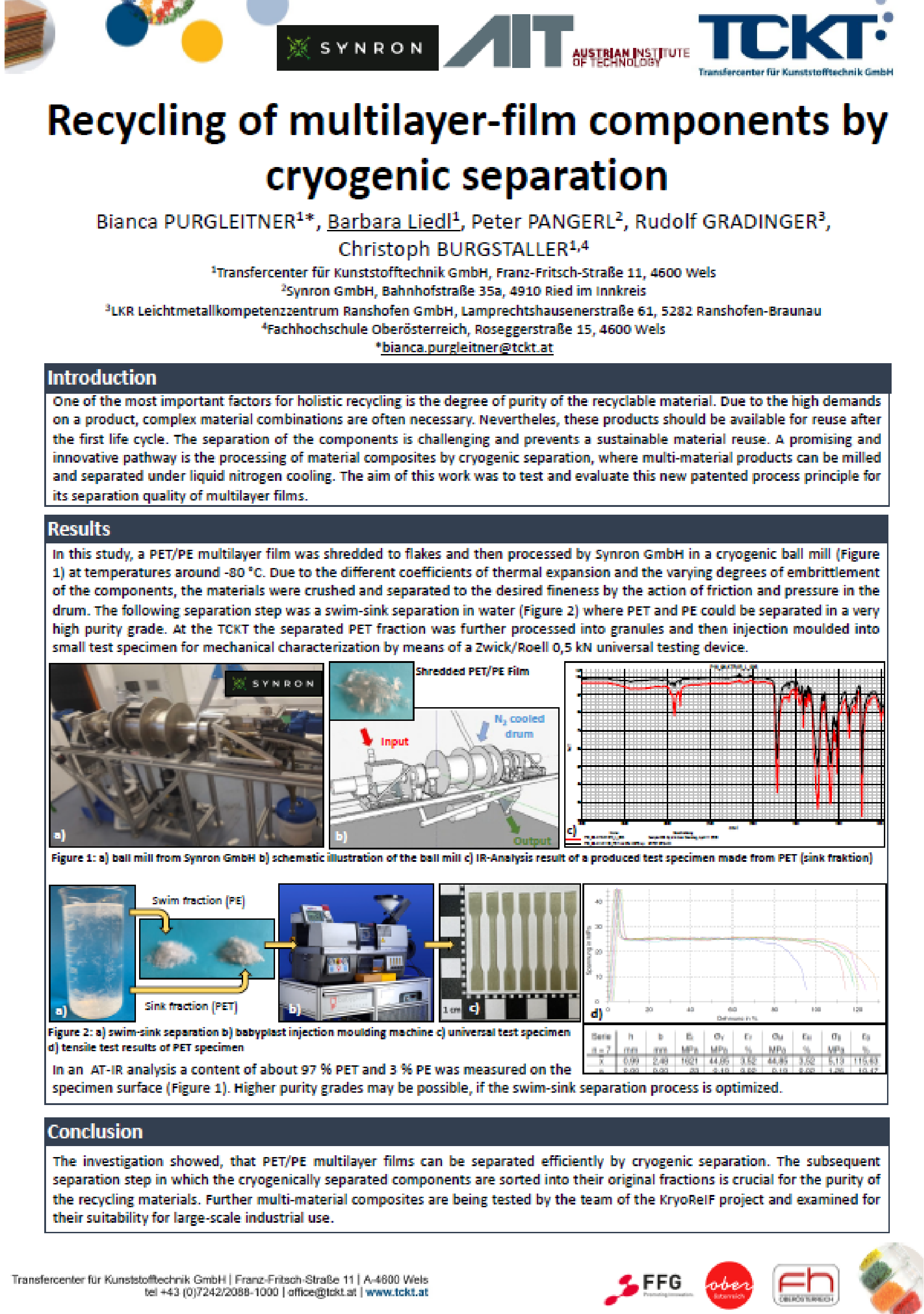
Clean production waste from the Audi plant in Győr, which, separated according to type, is delivered to Ranshofen (Source: Audi Hungaria Zrt.)

AMAG uses Audi's recycling material to produce new aluminium sheets

KryoRelF
Successful cryogenic separation of polymer compounds

- Recycling of multilayer-film (polymer) components by cryogenic separation by SYNRON and TCKT





Recycling of multilayer-film components by cryogenic separation

Bianca PURGLEITNER[1]*, Barbara Liedl[1], Peter PANGERL[2], Rudolf GRADINGER[3], Christoph BURGSTALLER[1,4]

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Introduction

One of the most important factors for holistic recycling is the degree of purity of the recyclable material. Due to the high demands on a product, complex material combinations are often necessary. Nevertheles, these products should be available for reuse after the first life cycle. The separation of the components is challenging and prevents a sustainable material reuse. A promising and innovative pathway is the processing of material composites by cryogenic separation, where multi-material products can be milled and separated under liquid nitrogen cooling. The aim of this work was to test and evaluate this new patented process principle for its separation quality of multilayer films.

Results

In this study, a PET/PE multilayer film was shredded to flakes and then processed by Synron GmbH in a cryogenic ball mill (Figure 1) at temperatures around -80 °C. Due to the different coefficients of thermal expansion and the varying degrees of embrittlement of the components, the materials were crushed and separated to the desired fineness by the action of friction and pressure in the drum. The following separation step was a swim-sink separation in water (Figure 2) where PET and PE could be separated in a very high purity grade. At the TCKT the separated PET fraction was further processed into granules and then injection moulded into small test specimen for mechanical characterization by means of a Zwick/Roell 0,5 kN universal testing device.

Figure 1: a) ball mill from Synron GmbH b) schematic illustration of the ball mill c) IR-Analysis result of a produced test specimen made from PET (sink fraktion)

Figure 2: a) swim-sink separation b) babyplast injection moulding machine c) universal test specimen d) tensile test results of PET specimen

In an AT-IR analysis a content of about 97 % PET and 3 % PE was measured on the specimen surface (Figure 1). Higher purity grades may be possible, if the swim-sink separation process is optimized.

Conclusion

The investigation showed, that PET/PE multilayer films can be separated efficiently by cryogenic separation. The subsequent separation step in which the cryogenically separated components are sorted into their original fractions is crucial for the purity of the recycling materials. Further multi-material composites are being tested by the team of the KryoRelF project and examined for their suitability for large-scale industrial use.

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MULTI-FUN

Enabling MULTI-FUNctional performance through multi-material additive manufacturing

https://cordis.europa.eu/project/id/862617

www.MULTI-FUN.eu

MULTI-FUN
ENABLING MULTI-FUNCTIONAL PERFORMANCE THROUGH MULTI-MATERIAL ADDITIVE MANUFACTURING

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 862617 – MULTI-FUN

MULTI-FUN

applying the KryoReIF approach used for LKR's alloy development in MULTI-FUN

Al-5.4 Mg-3.8Zn-0.3Cu-0.2Ag

- Offering high strength
- Reacting to air quenching
- LCA trade-off studies ongoing: Ag vs. lightweighting

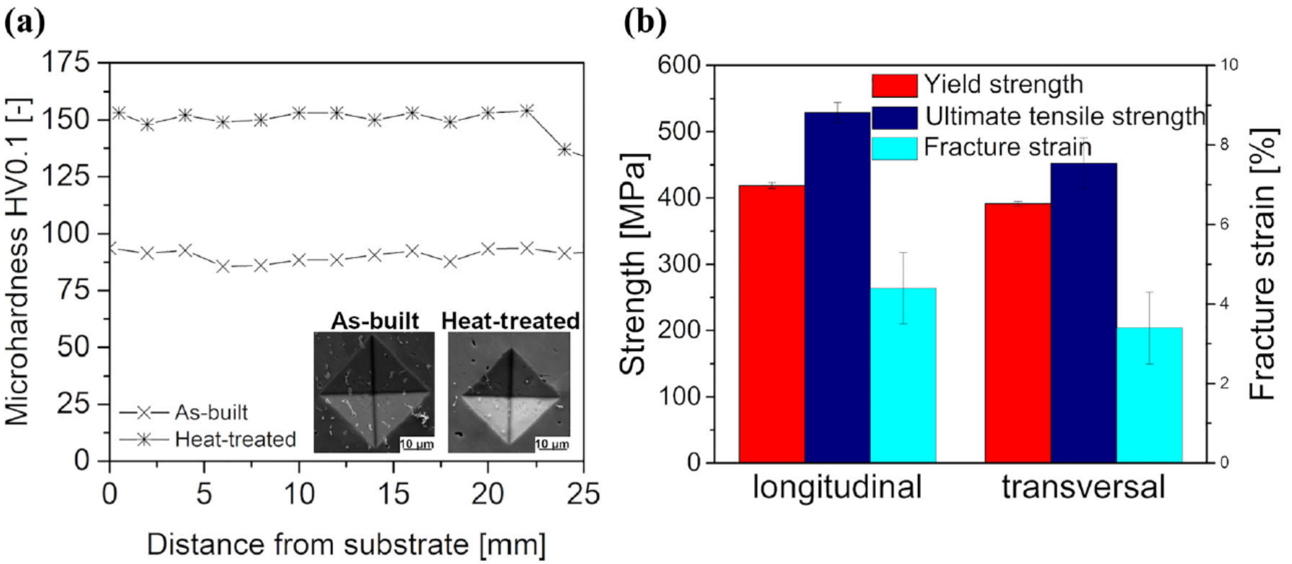

Fig. 7. (a) Hardness profiles along the as-built and heat-treated specimens' height in its lower portion. The hardness values are homogeneous and raised from approximately 95 HV to approximately 155 HV because of the AA. For comparison the microhardness indents are depicted as insets. (b) Characteristic mechanical properties of the heat-treated material condition from tensile testing with respect to specimen direction.

Primary alloying elements used here:

JOM
https://doi.org/10.1007/s11837-023-05838-y

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ADVANCED MATERIALS FOR ADDITIVE MANUFACTURING

Microstructure and Mechanical Properties of an Advanced Ag-Microalloyed Aluminum Crossover Alloy Tailored for Wire-Arc Directed Energy Deposition

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The implementation of wire-arc directed energy deposition requires the development of novel, process-adapted, high-performance aluminum alloys. Conventional high-strength alloys are, however, difficult to process as they are prone to hot-cracking. Crossover alloys based on Al-Mg-Zn combine good processability with good mechanical properties following artificial aging. Here, we present an effort to further improve the mechanical properties of Al-Mg-Zn crossover alloys using Ag microalloying. No cracks and few porosities were observed in the samples. The microstructure is dominated by fine and globular grains with a grain size ≈ 26.6 μm. The grain structure is essentially free of texture and contains fine microsegregation zones with ≈ 3–5 μm thickness of segregation seams. Upon heat treatment these microsegregation zones are dissolved and T-phase precipitates are formed as clarified by diffraction experiments. This precipitation reaction results in a microhardness of ≈ 155 HV0.1, a yield strength of 391.3 MPa and 418.6 MPa, an ultimate tensile strength of 452.7 MPa and 529.4 MPa and a fracture strain of 3.4% and 4.4% in transversal and in longitudinal directions, respectively. The gained results suggest that highly loaded structures can be manufactured by wire-arc directed energy deposition using the newly developed aluminum crossover alloy.

INTRODUCTION

The ever-increasing demands on structural components with new functionalities used, for example, in aerospace industries, require the development of novel, process-specific metal materials. With the advent of additive manufacturing (AM), alloys are needed that show robust processability in addition to good mechanical performance.[1,2] High-strength aluminum alloys such as 2xxx[3] or 7xxx[4] series are, however, challenging to process via AM. These challenges mostly arise from their high hot-cracking susceptibility.[5]

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Wire arc directed energy deposition (waDED) uses metal feedstock wires, which are melted by an energy source such as an electric or plasma arc.[6,7] The droplet formed on the wire tip is then deposited according to a predefined path.[8] waDED is particularly suitable for large structures with medium complexities.[9] Together with high-performance aluminum alloys, the technology is envisaged to be used in future structural applications in aviation industry including fabrication of fuselage or wing structures,[10] whereby conventional manufacturing and AM could be combined in hybrid manufacturing in a highly flexible manner.[11]

As feedstock material, commercially available welding wires are mostly used.[7] The processing behavior and resultant properties of aluminum feedstock wires have

SUSTAINair

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006952

SUSTAINablility increase of lightweight, multifunctional and intelligent airframe and engine parts

https://cordis.europa.eu/project/id/101006952

www.SUSTAINair.eu

SUSTAINair
Remelting of random scrap

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- Shredded aluminium aircraft scrap consisting of mainly Aluminium 2024 (ISO AlCu4Mg1) and Aluminium 7075 (ISO Alum AlZn5.5MgCu) and their derivates
- Melt composition of remelted aluminium aircraft scrap (named “LKR 1181/22” and “LKR 1182/22”) in comparison to standard compositions of typical structural alloys

→ Limited chemical compatibility (due to limited element contents or toxic elements) of mixed scrap to create again aerospace grade alloys

→ End of ICE in 2030/2035 (pistons, crankcase, gearbox) → loss of sink for high alloyed scrap

Element [m%]	Al	Cu	Zn	Mg	Cr	Si	Mn	Fe	Ti	Zr	Ni	Other, each	Other, total
Samples:													
LKR 1181/22	90,9	3,01	3,47	1,80	0,072	0,16	0,25	0,23	0,039	0,059	0,021	-	-
LKR 1182/22	90,7	3,05	3,55	1,82	0,075	0,16	0,25	0,26	0,044	0,059	0,025	-	-
Standards:													
7075 min.	87,1	1,20	5,10	2,10	0,180	-	-	-	-	-	-	-	-
7075 max.	91,4	2,00	6,10	2,90	0,280	0,40	0,30	0,50	0,200	-	-	0,05	0,15
2024 min.	90,7	3,80	-	1,00	-	-	0,30	-	-	-	-	-	-
2024 max.	94,7	4,90	0,25	1,80	0,100	0,50	0,90	0,50	0,150	-	-	0,05	0,15

SUSTAINair

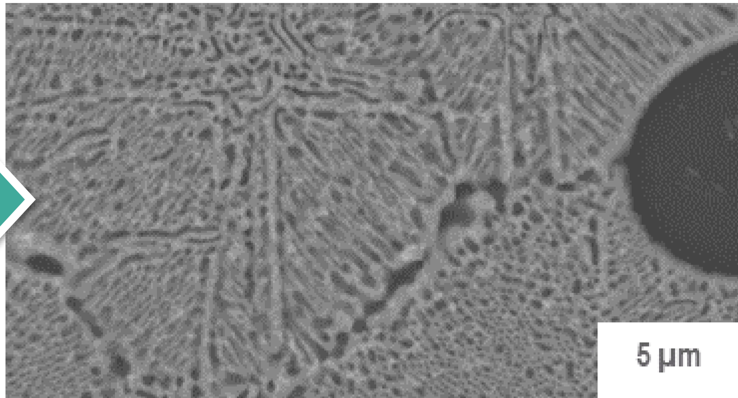
Random scrap leading to new alloys

- Aviation material flows are not suited for closed-loop recycling
- Aviation allows have limited intrinsic and zero extrinsic recyclability
- Very low buy-to-fly ratios in SoA aircraft manufacturing (<<80%)

→ Introduce “new”, material efficient processing routes

→ Align new aviation alloy designs with larger ones (automotive, construction)

→ Complex (pseudo)eutectics → intrinsic refinement



SUSTAINair

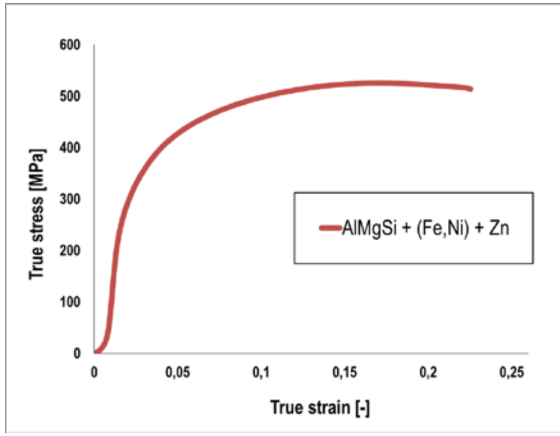
Random scrap leading to new alloys

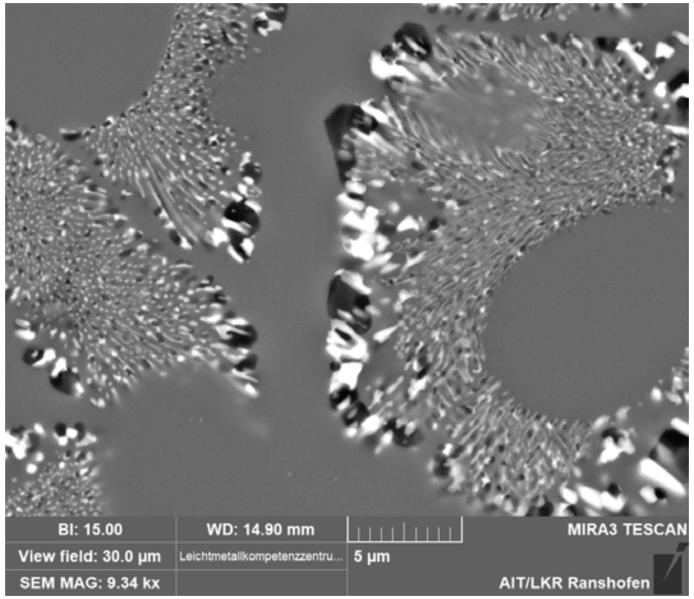
Lab scale SUSair_14.9 (AlMgSiFeNi+Zn)
- High compressive properties
- Easy processing

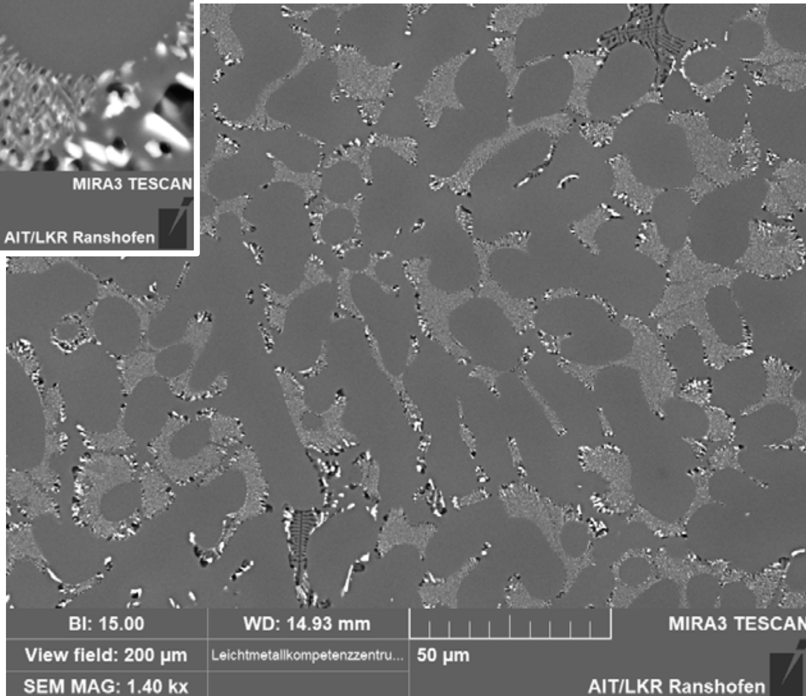
Challenges
- Beyond CALPHAD predictability
- Elaborate (5D) screening

Wt.-%	*Si*	*Mg*	*Cu*	*Mn*	*Fe*	*Ni*	*Zn*	$R_{p0,2}$ [MPa]	R_m [MPa]	A [%]
Magsimal-59 (AlMg5Si2)	1,8-2,6	5,0-6,0	0,2	0,5-0,8	0,2	-	0,07	160-220	310-340	12-18
SUSAIR_14.9	1,6	5,4	-	-	0,7	0,8	2,4	-	504	22

Transfer to wrought 6xxx
- Cross alloying "light"
- Cu/Zn introduce 7xxx mechanisms
- (nano)eutectics enhance properties and composition + HAZ improvement anticipated







SUSTAINair

SUSTAINablility increase of lightweight, multifunctional and intelligent airframe and engine parts

- CFRP industrial scrap recycling

- Aluminium full value chain approach towards recycling → Projects ReCAL
- Aluminium EoL scrap recycling → REFORMING → Projects COMPASS & ProMetHeus

RecAL

Recycling technologies for circular Aluminium

https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/how-to-participate/org-details/999999999/project/101138747/program/43108390/details

RecAL
Recycling technologies for circular Aluminium

Abstract

Recycling aluminium from existing End of Life (EoL) and production scraps uses only 5% of energy compared to primary material production, making it mandatory for exploiting its global decarbonisation potential and meeting the demands of the European Green Deal. However, once aluminium is alloyed with other metals, it is virtually impossible to remove these elements again. Extensive mixing of different EoL alloys therefore inevitably leads to downcycling. This practice has been a successful strategy due to high demand for cast aluminium alloys in combustion engines, a universal recycling "sink" that will dry up in the coming years. **Europe possesses a rich potential of secondary aluminium resources with an expected share of 49% of total aluminium production by 2050. The RecAL project (Recycling technologies for circular ALuminium) provides a balanced approach to fully exploit this valuable resource.** It synergistically addresses all stages of circular production and tackles problems of the entire value chain: - Increase impurity tolerance in alloy design at level or superior performance - Exploit the benefits of digitization and robotic assistance in sorting and dismantling - Create recyclate streams with vastly enhanced purities - Adapt production paradigms to unfold the full potential of secondary resources - Harmonise communication between all sectors of the aluminium industry The project will mature an envelope of 14 crucial technological solutions towards these goals up to TRL6 and embed them into a digital, "socio-technical ecosystems": the Aluminium HUB for circularity. This interactive platform will directly link stakeholders along the value chain for full scale industrial and technological symbiosis and circular economy closing energy, resource and data loops at regional and European scale.

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REFORMING

COMPASS

A data-driven remanufacturing process for sheet metal and thermoplastic composites

https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/how-to-participate/org-details/999999999/project/101136940/program/43108390/details

ProMetHeus

PROduction and processing of METals for High-performance, Energy Efficiency, environmental protection a. Sustainability

https://www.ffg.at/presse/ffg-kraeftiger-schub-fuer-die-spitzenforschung-oesterreich

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REFORMING

ReForming instead of ReMelting …

… between ReCycling and ReUse

REFORMING
WHAT IS THE POINT?

ReForming instead of *ReMelting* in the second and third life cycle:

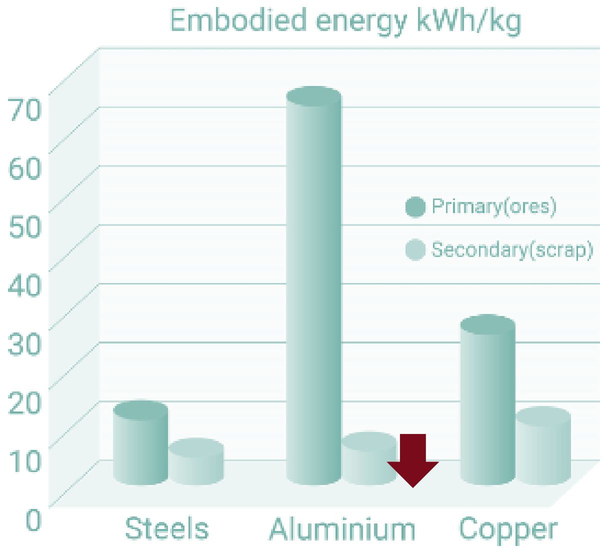
... no shredding, no sorting, no melting down, no hot and cold rolling …

... no solution annealing if necessary

Different expansion stages in the project:

(1) Production scrap (from different resources)
(2) EoL scrap
(3) ReForming Ecosystem

> 99 % of energy/CO_2 savings compared to primary production



[1]

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REFORMING
WHAT IS THE POINT?

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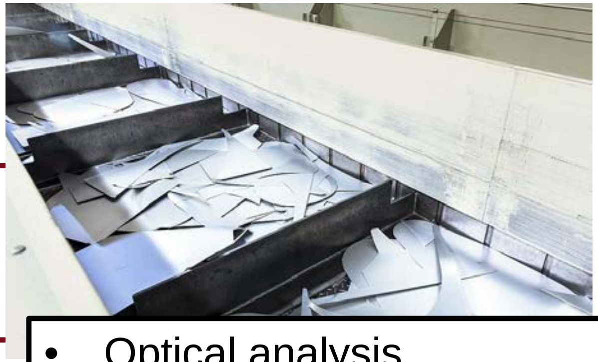
In House — A

- Optical analysis
- Defect detection
- Mechanical properties
- Heat treatment and forming recommendations



EoL Scrap — B

- Optical analysis
- Defect detection
- Mechanical properties
- Cleaning & Paint stripping
- Specific heat treatment & forming operations

Specific ReForming Products — C

- Digital ReForming Passport
- ReForming alloy (fine recrystallising, healing)
- ReForming operations
- Formable, healing lacquers

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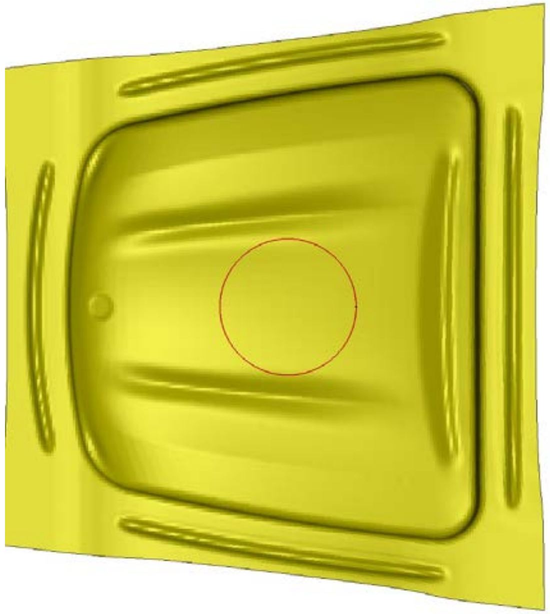
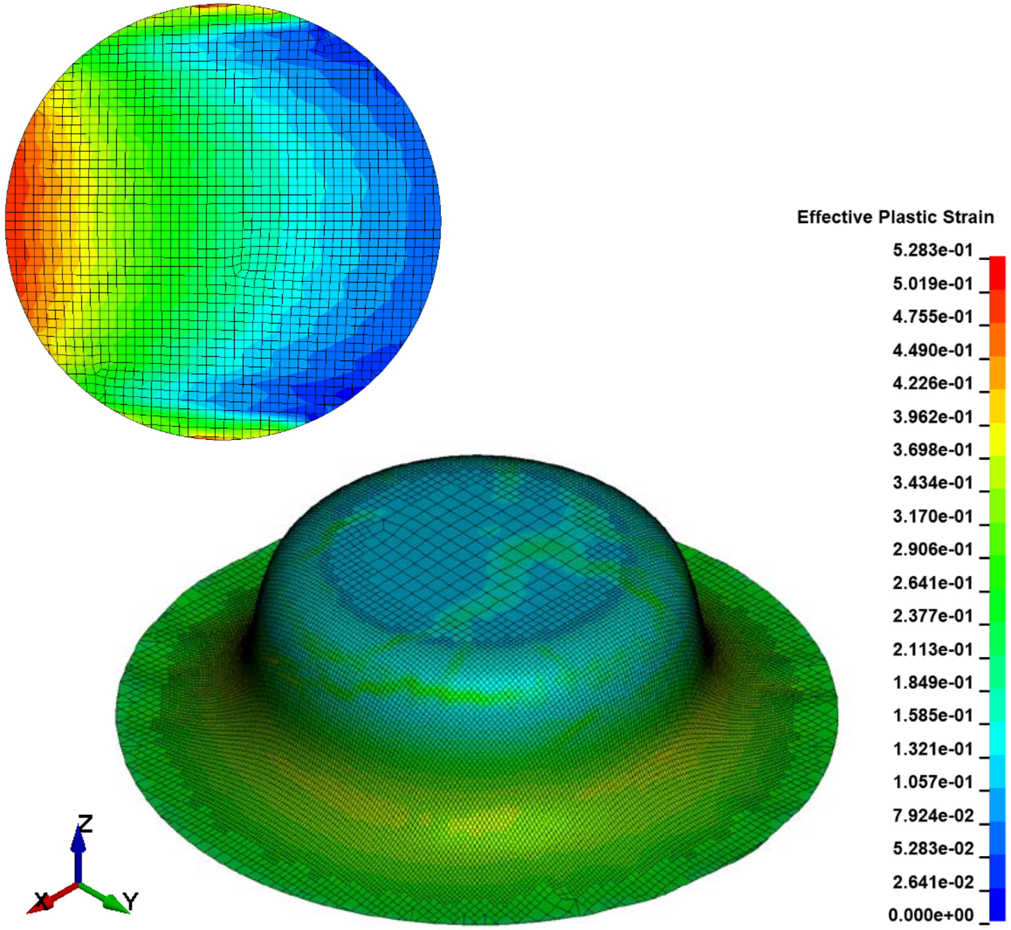
WHAT IS THE POINT?





We need a lot of information ... to make the ReForming economically and ecologically reasonable.

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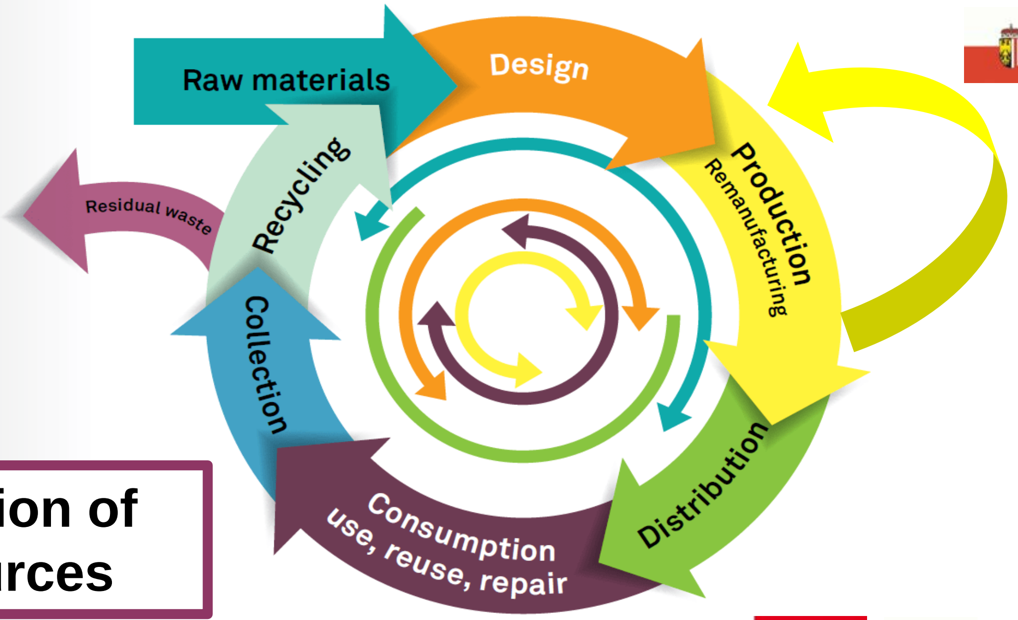
Motivation
Horizon 2020 & Horizon Europe funding

MULTI-FUN: **New alloys & LCA**

SUSTAINair: **New alloys & dismantling**



KryoReIF: **Cyogenic cleaning of contaminated metal scrap**

RecAL: E**xploitation of secondary resources**

COMPASS & ProMetHeus: **"REFORMING"**

Austrian Footprint

MULTI-FUN consortium

(1) LKR LEICHTMETALLKOMPETENZZENTRUM RANSHOFEN GMBH
(2) VOESTALPINE METAL FORMING GMBH
(3) DEUTSCHES ZENTRUM FUR LUFT - UND RAUMFAHRT EV
(4) FUNDACION BCMATERIALS - BASQUE CENTRE FOR MATERIALS, APPLICATIONS AND NANOSTRUCTURES
(5) INOCON TECHNOLOGIE GMBH
(6) FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV
(7) LORTEK S COOP
(8) INPHOTECH SP ZOO
(9) INSTITUTO DE SOLDADURA E QUALIDADE
(10) MIGAL.CO GMBH
(11) EUROPEAN FEDERATION FOR WELDING JOINING AND CUTTING
(12) RHP TECHNOLOGY GMBH
(13) CRANFIELD UNIVERSITY
(14) WAAM3D LIMITED
(15) AEROTECNIC METALLIC SL
(16) EDAG ENGINEERING GMBH
(17) PEAK TECHNOLOGY GMBH
(18) ALPEX TECHNOLOGIES GMBH
(19) BEYOND GRAVITY AUSTRIA GMBH
(20) ALUWAG AG
(21) AVL LIST GMBH

SUSTAINair consortium

(1) LKR LEICHTMETALL-KOMPETENZZENTRUM RANSHOFEN GmbH
(2) STICHTING KONINKLIJK NEDERLANDS LUCHT - EN RUIMTEVAARTCENTRUM
(3) DEUTSCHES ZENTRUM FUR LUFT - UND RAUMFAHRT EV
(4) JOANNEUM RESEARCH FORSCHUNGSGESELLSCHAFT MBH
(5) UNIVERSITAT LINZ JKU
(6) TECHNISCHE UNIVERSITEIT DELFT
(7) AIRCRAFT END-OF-LIFE SOLUTIONS (AELS) BV
(8) INOCON TECHNOLOGIE GMBH
(9) INVENT INNOVATIVE VERBUNDWERKSTOFFEREALISATION UND VERMARKTUNG NEUERTECHNOLOGIEN GMBH
(10) DUTCH THERMOPLASTIC COMPONENTS BV
(11) RTDS - VEREIN ZUR FORDERUNG DER KOMMUNIKATION UND VERMITTLUNG VON FORSCHUNG, TECHNOLOGIE UND INNOVATION (RTDS VEREIN,

RecALconsortium

(1) LKR LEICHTMETALLKOMPETENZZENTRUM RANSHOFEN GMBH
(2) RTDS - VEREIN ZUR FORDERUNG DER KOMMUNIKATION UND VERMITTLUNG VON FORSCHUNG, TECHNOLOGIE UND INNOVATION
(3) AIRCRAFT END-OF-LIFE SOLUTIONS (AELS) BV
(4) ALOUMYL, BIOMICHANIA ALOUMINIOY ANONIMI ETAIRIA - ALUMIL ALUMNINIUM INDUSTRY
(5) BENTELER AUTOMOBILTECHNIK GMBH
(6) FERIMET SL
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(9) FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV
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