ADVANCED COPPER SOLUTIONS FOR REMELTING TECHNOLOGIES

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ABSTRACT

The transformation of the steel industry toward more sustainable and efficient production routes requires continuous innovation in remelting technologies such as Vacuum Arc Remelting (VAR) and Electroslag Remelting (ESR). High-performance copper components are essential in this context because they directly influence process stability, product quality, service life and resource efficiency. This contribution presents advanced copper solutions for remelting applications, focusing on forged crucibles, power rams, and alternative furnace concepts using short collar moulds and cold-hearth components. A central aspect is the comparison between forged, one-piece crucibles and longitudinally seam-welded designs. Forged crucibles manufactured from a single block provide a homogeneous structure and uniform material properties around the circumference, while eliminating longitudinal welding seams. CuCrZr material, represented by ELBRODUR® G, combines high thermal conductivity with substantially higher strength, hardness and recrystallisation temperature than conventional Cu-DHP copper. An important factor is a controlled production route for crucibles, including forging, machining, ultrasonic inspection, mechanical-property testing, X-ray examination ‘(for skull crucibles) and helium leak testing. Complementary developments include high-accuracy Cu-HCP power rams and reinforced slab moulds for ESR plants, as well as deep-drilled and slotted short collar mould concepts. The overall approach is aimed at reducing distortion, improving dimensional stability and supporting reliable remelting operations.

KEYWORDS: copper components – remelting – VAR – ESR – forged crucible – CuCrZr – ELBRODUR® G – power ram – cold hearth – skull crucible

INTRODUCTION

Remelting processes such as Vacuum Arc Remelting (VAR) and Electroslag Remelting (ESR) are used where control of solidification, chemical homogeneity and cleanliness is critical. Copper components are active process elements: crucibles and moulds define the heat-transfer boundary, while power rams influence electrical conditions. Their dimensional stability and thermal performance therefore affect process reliability.

The solutions discussed in this paper are based on three principles: selection of a copper alloy appropriate for the thermal and mechanical load, manufacturing from large starting sections with high deformation during forging or rolling, and quality assurance integrated into the production route. The resulting components include seamless forged crucibles for VAR and ESR, skull crucibles for vacuum melting of titanium, Cu-HCP power rams, and alternative mould concepts for electron-beam plants.

MATERIAL SELECTION FOR DEMANDING THERMAL SERVICE

The choice of copper alloy is a central design decision. The presentation compares Cu-DHP (C12200) with ELBRODUR® G (C18150, CuCrZr). Both materials offer high thermal conductivity, but the reported mechanical-property data show a pronounced advantage for the CuCrZr alloy at elevated temperature. The thermal conductivity values are close, whereas yield strength, tensile strength, hardness and recrystallisation temperature differ substantially.

Property	ELBRODUR® G (C18150)	Cu-DHP (C12200)
Thermal conductivity [W/mK]	350	340
Yield stress, 0.2%, at 20 °C [MPa]	280	265
Yield stress, 0.2%, at 200 °C [MPa]	260	235
Tensile strength at 20 °C [MPa]	390	275
Tensile strength at 200 °C [MPa]	340	240
Recrystallisation temperature [°C]	≥800	350
Hardness [HBV]	120	50

Tab. 1 - Material-property comparison

The data illustrate why CuCrZr is attractive for components exposed to demanding thermal cycles. At 200 °C, the yield stress of ELBRODUR® G is 260 MPa compared with 235 MPa for Cu-DHP, while tensile strength is 340 MPa compared with 240 MPa. The most pronounced difference is the recrystallisation temperature: ≥800 °C for ELBRODUR® G versus 350 °C for Cu-DHP. This higher thermal stability provides a larger margin against softening and loss of mechanical performance during operation.

CRUCIBLES FOR VAR AND ESR FURNACES

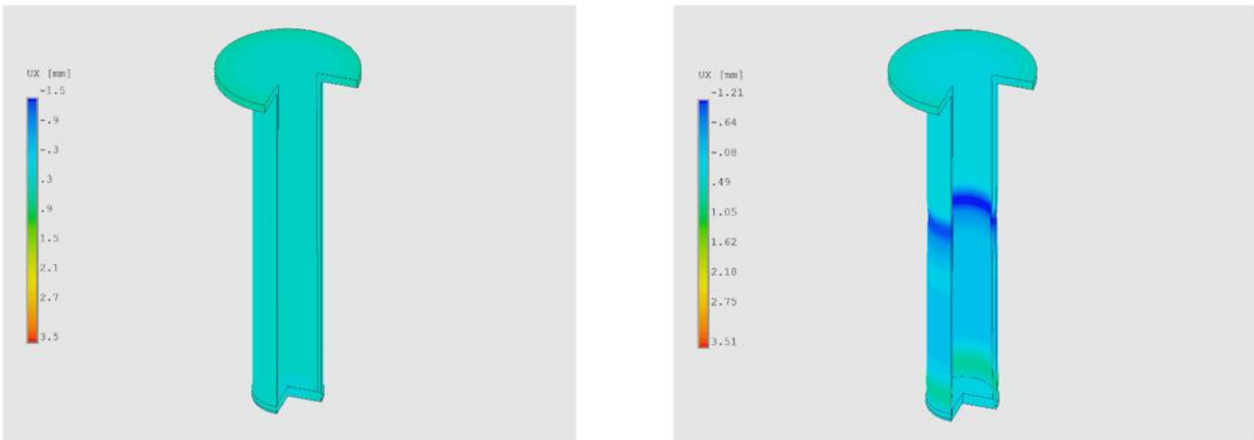
For VAR and ESR crucibles, the manufacturing concept combines large copper-alloy starting sections with controlled deformation and precision machining. For forged crucibles dimensions of up to approximately 1,200 mm in diameter and 5,600 mm in length are possible. To produce components of this scale, very large copper-alloy billets are casted, with diameters of approximately 900 to 1,000 mm and individual piece weights up to 20 t. The high deformation introduced in subsequent processing is a major advantage because it contributes to the microstructural quality of the finished component.

Fig. 1 - Large copper-alloy billet used as starting material for forged remelting components; billet diameter is approximately 900–1,000 mm and piece weight can reach 17 t

The same manufacturing philosophy is applied to large hot-rolled plates for components produced from plate when it comes to longitudinally welded crucibles. Plates up to approximately 3 m × 6 m × 50 mm with a weight of about 8 t. Here, too, the objective is to start from a section that permits substantial deformation before the final component geometry is established. The resulting manufacturing route is therefore not simply a machining operation; the condition and history of the starting material are part of the component design.

FORGED VERSUS LONGITUDINALLY WELDED DESIGN

A key comparison is the forged, one-piece crucible versus a conventional longitudinally seam-welded design. The forged route removes the longitudinal weld seam and creates a circumferentially homogeneous component. This results in equal material properties around the circumference, lower distortion in use – reduced “banana effect”, tighter manufacturing tolerances and increased lifetime. In the welded design, the plate-forming and welding operations introduce a different manufacturing history and a longitudinal seam with different chemical composition and material properties that becomes part of the component. Reduced distortion also reduces the tendency of the remelted material to stick to the crucible wall.



Elbrodur G Deformation after 10 heats Cu-DHP

Fig. 2 -FEM - Comparison of distortion of crucibles made if CucrZr and Cu-DHP

	FORGED	CONVENTIONAL WELD (MIG)
Material	ELBRODUR® (CuCrZr) (C18150)	Cu-DHP (C12200)
High softening / recrystallisation temperature	++	o
Welding seams	no	yes
Homogeneous structure	++	o
Equal material properties over the entire circumference	++	o
Distortion in use	++	-
Manufacturing tolerances	++	o
FORGED One-piece • homogeneous • no welding seams	ELBRODUR® G / CuCrZr — C18150	

Fig. 3 - Comparison of forged and conventional longitudinally welded crucible

POWER RAMS FOR VAR AND ESR FURNACES

Copper power rams provide both mechanical guidance and electrical current transfer in VAR and ESR furnaces. Their geometry and dimensional stability are therefore important for reliable process operation. A diameter tolerance of approximately ±0.5 mm is possible while taking utmost care of the process. The challenge of the production process is accurately inserting the steel core in the copper tube and avoid distortion during the welding process.

Fig. 4 - Example of a copper power ram for VAR/ESR applications

SKULL CRUCIBLES – ONE-PIECE MANUFACTURING

The skull crucible is a particularly demanding application because it is used for vacuum melting of reactive materials such as titanium. The concept is seamless and forged-and-machined from one single block. Design verification is supported by finite-element method (FEM) calculations, while the manufacturing route combines high deformation, controlled machining and several inspection stages.

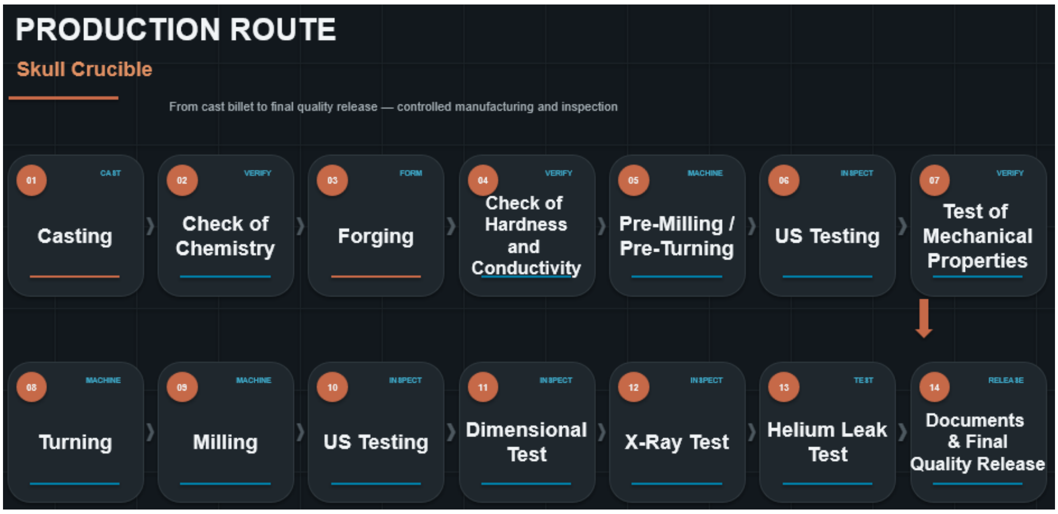
Fig. 5 -Single piece forged skull crucible ready for machining.

The one-piece construction is intended to avoid the asymmetric behaviour associated with a longitudinal seam. Under thermal cycling, the crucible body undergoes contraction and deformation. A homogeneous material structure and uniform properties around the circumference are therefore important for maintaining geometry. Reduced distortion also reduces the tendency of the remelted material to stick to the crucible wall.

PRODUCTION ROUTE FOR A SKULL CRUCIBLE

The production route is deliberately structured so that material verification and non-destructive testing are integrated between major manufacturing operations. The sequence used for the skull crucible is:

After casting and chemistry verification, the billet is forged and checked for hardness and conductivity. Pre-milling/pre-turning is followed by US-testing and mechanical-property testing. Final turning and milling establish the geometry, followed by a second US inspection, dimensional testing, X-ray examination, helium leak testing and final quality release.



Tab. 2 - Production route of the skull crucible, from casting to final quality release.

QUALITY ASSURANCE

The inspection sequence addresses complementary failure modes: material identity and condition, internal integrity, final geometry and leak-tightness. The combination of US-testing, mechanical-property testing, dimensional inspection, X-ray examination and helium leak testing is particularly relevant to vacuum skull crucibles.

ALTERNATIVE MELTING FURNACE CONCEPTS

The development of advanced copper solutions is not limited to conventional VAR and ESR crucibles. The presentation also covers components for electron-beam melting and alternative ESR mould concepts. These applications use different geometries and load cases, but the same basic requirements remain: efficient heat extraction, dimensional stability, structural integrity and the possibility of refurbishment or remachining where appropriate.

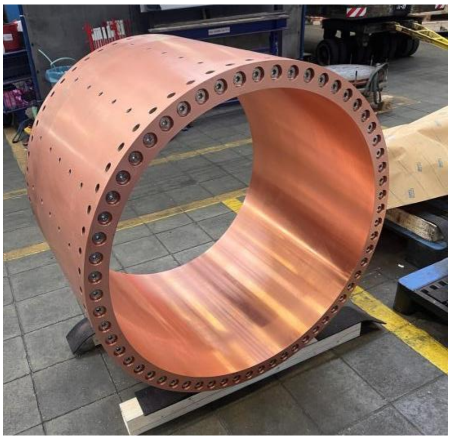
Cold hearth and pouring ring

Electron-beam cold-hearth melting is used for vacuum remelting of titanium and other reactive alloys. The copper cooling bed, cast mould and pouring-ring components form the heat-transfer boundary around the melt. The copper component can be adapted to the individual furnace and process requirements. The cooling bed and cast mould are therefore considered as part of an integrated copper solution rather than as isolated standard parts.

Fig. 6 - Copper cold-hearth

SHORT COLLAR MOULDS FOR ESR FURNACES

For ESR furnaces, short collar moulds—also referred to as sliding crucibles—can be designed with different cooling-channel concepts. Deep-drilled and slotted configurations are available on the market. Both concepts aim to provide effective heat removal while maintaining sufficient structural integrity and dimensional stability. The appropriate configuration depends on the required cooling performance, geometry, manufacturability and operating conditions.



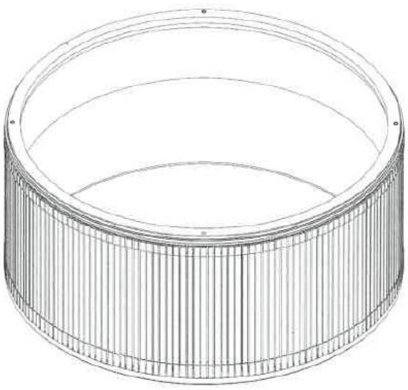


Fig. 7 - Short collar mould concept for ESR applications; deep-drilled and slotted cooling configurations.

SLAB MOULD

An alternative concept is a four-piece, deep-drilled and screwed slab mould. Its reinforced steel frame provides greater structural stability, while the presentation highlights lower distortion and good remachining capability.

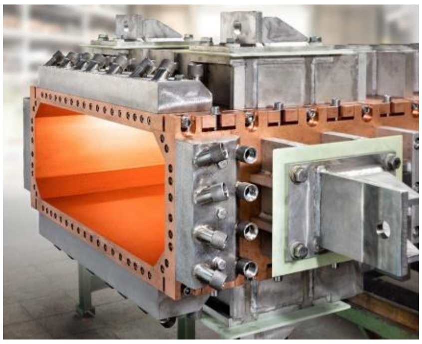


Fig. 8 - Four-piece, deep-drilled and screwed slab mould; the reinforced steel frame is intended to limit distortion

RESULTS AND PRACTICAL BENEFITS

The solutions combine material selection and manufacturing route to address the principal failure mechanisms of copper components. The forged one-piece crucible eliminates a longitudinal seam, supports homogeneous circumferential properties and is intended to reduce distortion. ELBRODUR® G combines high thermal conductivity with higher strength, hardness and recrystallisation temperature than Cu-DHP

For skull crucibles, inspection is distributed across the manufacturing sequence. Ultrasonic testing, mechanical-property testing, dimensional inspection, X-ray examination and helium leak testing provide complementary evidence of integrity, followed by documented final quality release.

SUSTAINABILITY AND RESOURCE EFFICIENCY

Sustainability in remelting is not limited to the energy consumed by the furnace. Component lifetime, machining efficiency, repairability and process downtime also influence the resource footprint of a production route. Increasing pre-material efficiency with respect to the input/output ratio, reducing manufacturing tolerances and increasing component dimensions have been identified as future work. For forged components, the starting billet can be very large—up to 20 t in the presented crucible route—so improving material utilization has significant potential value.

CONCLUSIONS AND FUTURE WORK

Advanced copper solutions for VAR, ESR and vacuum melting require an integrated view of alloy selection, manufacturing and quality assurance. The forged crucible concept combines large billets, high deformation, precision machining and multi-stage inspection. ELBRODUR® G offers higher strength and temperature resistance than Cu-DHP, while the one-piece construction eliminates longitudinal welding seams and is intended to reduce distortion [1].

Future development will focus on material efficiency, lower manufacturing tolerances, larger special crucibles and further cold-hearth improvements. The objective is higher process reliability with lower resource consumption.

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