

# Copper staves for blast furnaces

KME Germany GmbH & Co. KG  
Copper staves  
[GB]



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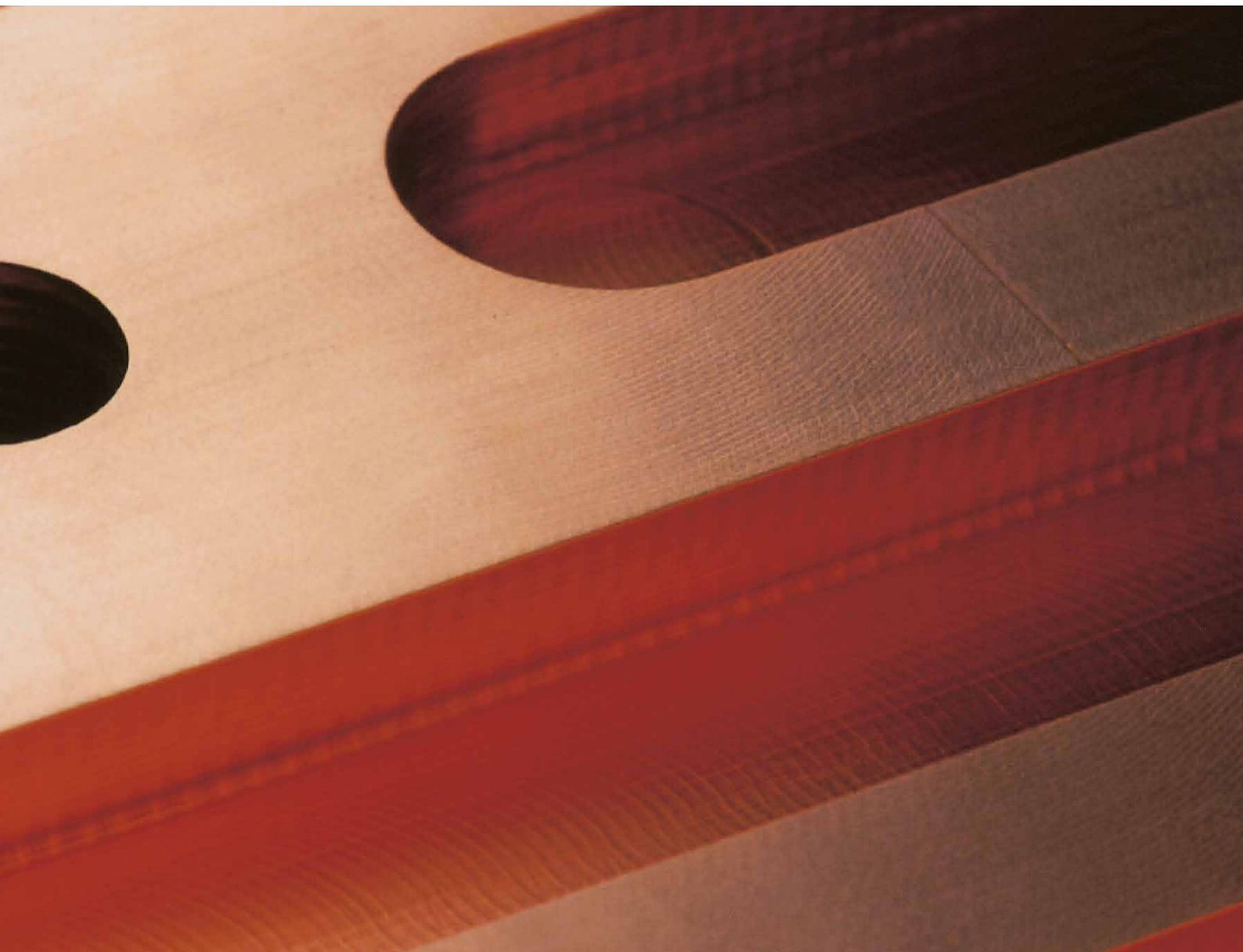
*KME offers a unique combination of know-how and experience in all key technologies for the production of high-performance copper staves for blast furnaces.*



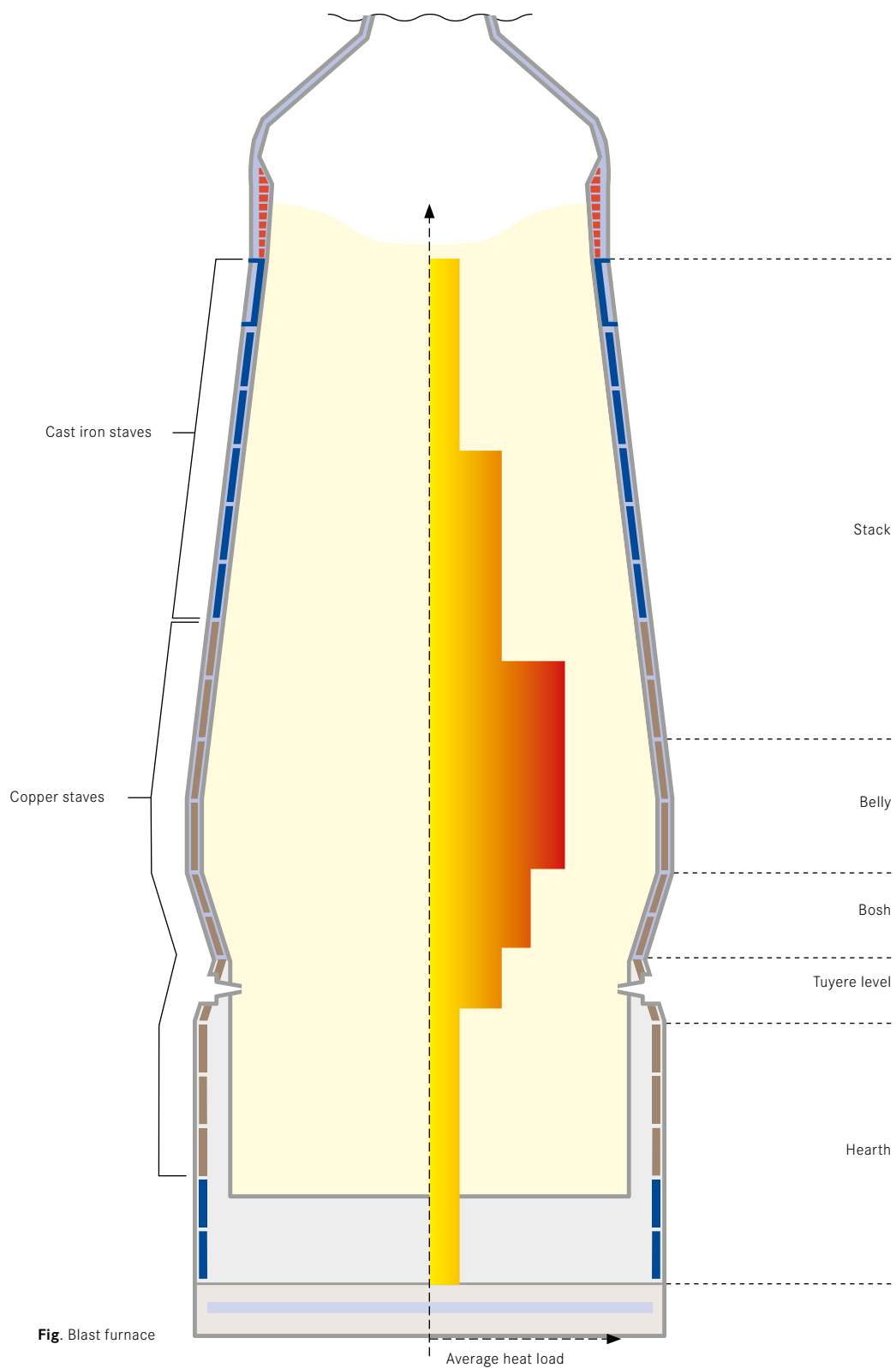
## *KME*

*KME's corporate goal is to develop and manufacture products that meet customer demands, supporting them in finding solutions for their specific applications, and providing services as a long-term partner.*

*KME's strategy for accomplishing this goal is based on a highly skilled and experienced workforce. KME has the capacity for inventing and developing new materials and innovative production processes, which KME sustains by ongoing advancement and training of its employees as well as the continual improvement of its organisational structures.*



# Copper staves – advanced cooling technology





Integrated steelworks use blast furnaces as a means of supplying pig iron. For high productivity levels to be achieved it is crucial that the downstream casting plants and rolling mills are continuously supplied with iron. Throughout the world, KME copper staves play a vital role in ensuring that blast furnaces are readily available and consequently achieve a high level of productivity.

Copper staves were first utilised in blast furnaces in the late 1970s as the best high heat-load wall-cooling element. As blast furnace productivity intensified and desired campaign life goals increased to beyond 15 years it became apparent that copper staves had the best potential to meet or exceed these demands.

KME was involved in the development of copper staves from the very beginning and is also the owner of the basic patent. Copper stave cooling is today the method utilised in leading blast furnaces worldwide.

The engineered products division was founded with the aim of reacting even more flexibly to market demands and improving the customer orientation of our business. Our customers are plant/blast furnace builders, steel-making companies as well as engineering and maintenance companies throughout the world.

## Blast furnace cooling

*Stave coolers first began to be developed in the late 1960s. The rise in furnace-productivity was accompanied by a greater demand for efficient cooling systems. Modern-day copper stave coolers insulate the outer shell from the process heat generated in highly stressed furnaces. Yet, depending on where they are positioned within the blast furnace, they will be subjected to differing levels of thermal load.*

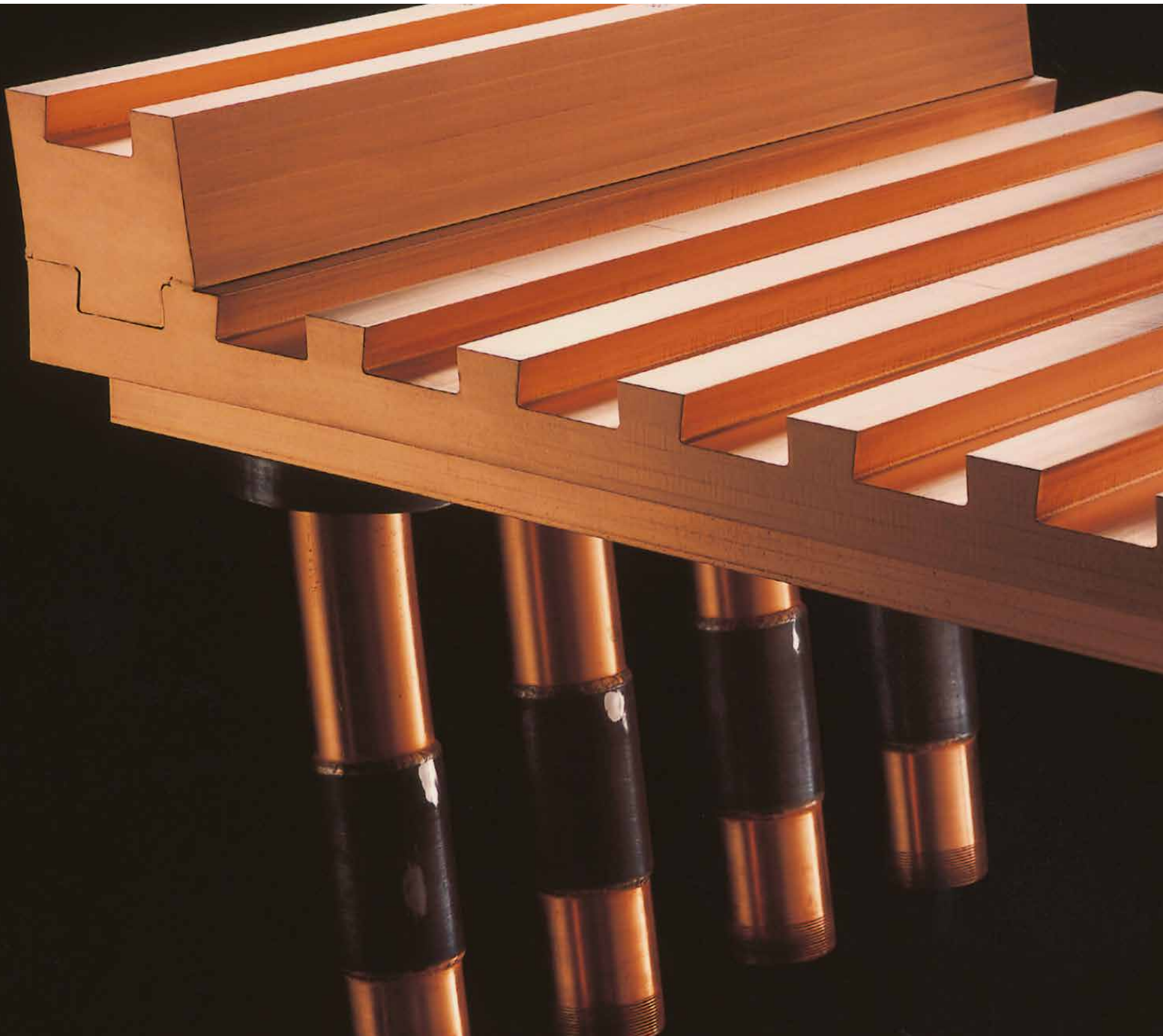
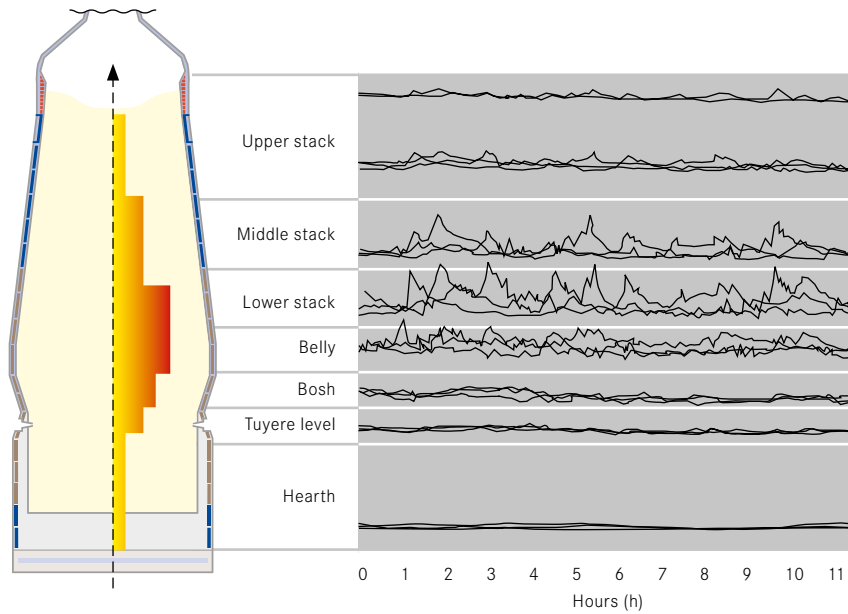


Fig. Typical heat load fluctuations in blast furnaces.



With modern blast furnaces, production rates greater than 3.0 tonnes of hot metal per cubic metre of working volume per day can now be reached. This is achieved by using improved burden materials, burden distribution techniques, process control, high hot blast temperatures, oxygen enrichment and pulverised coal injection or natural gas enrichment.

However, these high productivity practices result in high heat loads and heat load fluctuations to act on the walls of the blast furnace.

Although the specific zone and the magnitude of peak heat loads can vary significantly between furnaces, the belly and lower stack region usually encounter the highest heat fluctuations [see Fig. shown above]. The area in which the highest heat load is experienced is closely related to the position and shape of the cohesive zone and specific charging pattern of the furnace. The main cause of high heat fluctuations is irregular high velocity gas jets venting toward the furnace walls through coke slits in the burden. High-performance cooling systems are needed to ensure that the operational process runs smoothly even when under such stress.

With more than 11,000 units produced, KME copper staves have proven to be a reliable and effective solution also in the high loaded zones of the blast furnaces.

The theory that the high thermal conductivity of copper would lead to an increased dissipation of process heat has been disproved. The high conductivity of copper results in low surface temperatures and a rapid formation of a thin layer that reduces the heat removal from the furnace. Recent results have shown that the level of heat removed from the furnace is even lower than experienced with cast iron staves.

## Cooling elements

*High and fluctuating temperatures are the main loads cooling elements in blast furnaces have to cope with.*

Burden composition and quality have been observed to significantly affect heat loads and heat fluctuations. Blast furnace burden with more than 70 % sinter can result in peak loads of 100,000 to 200,000 W/m<sup>2</sup>. While burden with a high percentage of pellets or lump can generate peak heat loads of over 400,000 W/m<sup>2</sup>. Depending on the expected heat load, different cooling elements have to be applied (see table below).

*Failure mechanism of cast iron staves under high fluctuating heat loads*

Cast iron staves have a lower cooling efficiency compared to copper staves due to the relatively low conductivity of cast iron and the presence of an insulating layer. This layer results in a thermal barrier between the water-cooled tube and cast iron stove body reducing the heat transfer.

Inefficient heat transfer results in a significantly higher hot face temperature of the cast iron stove (over 700 °C) and subsequent thermal deformation of the cast iron stove. The cast iron body also experiences phase volume transformation at elevated temperatures, resulting in fatigue cracking, loss of stove body material and exposure of steel cooling pipes directly to the furnace heat.



**Table:** Overview of different cooling and refractory designs with their maximum peak heat load capabilities

Design	Peak heat load
Plate coolers with alumina refractories	50,000 W/m <sup>2</sup>
Cast iron staves 1 <sup>st</sup> generation	100,000 W/m <sup>2</sup>
Thicker cast iron staves with multiple cooling water circuits	200,000 W/m <sup>2</sup>
Plate cooler (closer spacing 300 mm), closer spacing with special refractories	400,000 W/m <sup>2</sup>
High-performance copper staves	500,000 W/m <sup>2</sup>

It must be emphasised that these peak thermal load is the primary determining factor for the long-term survival of the furnace lining or cooling staves.



## Skull formation

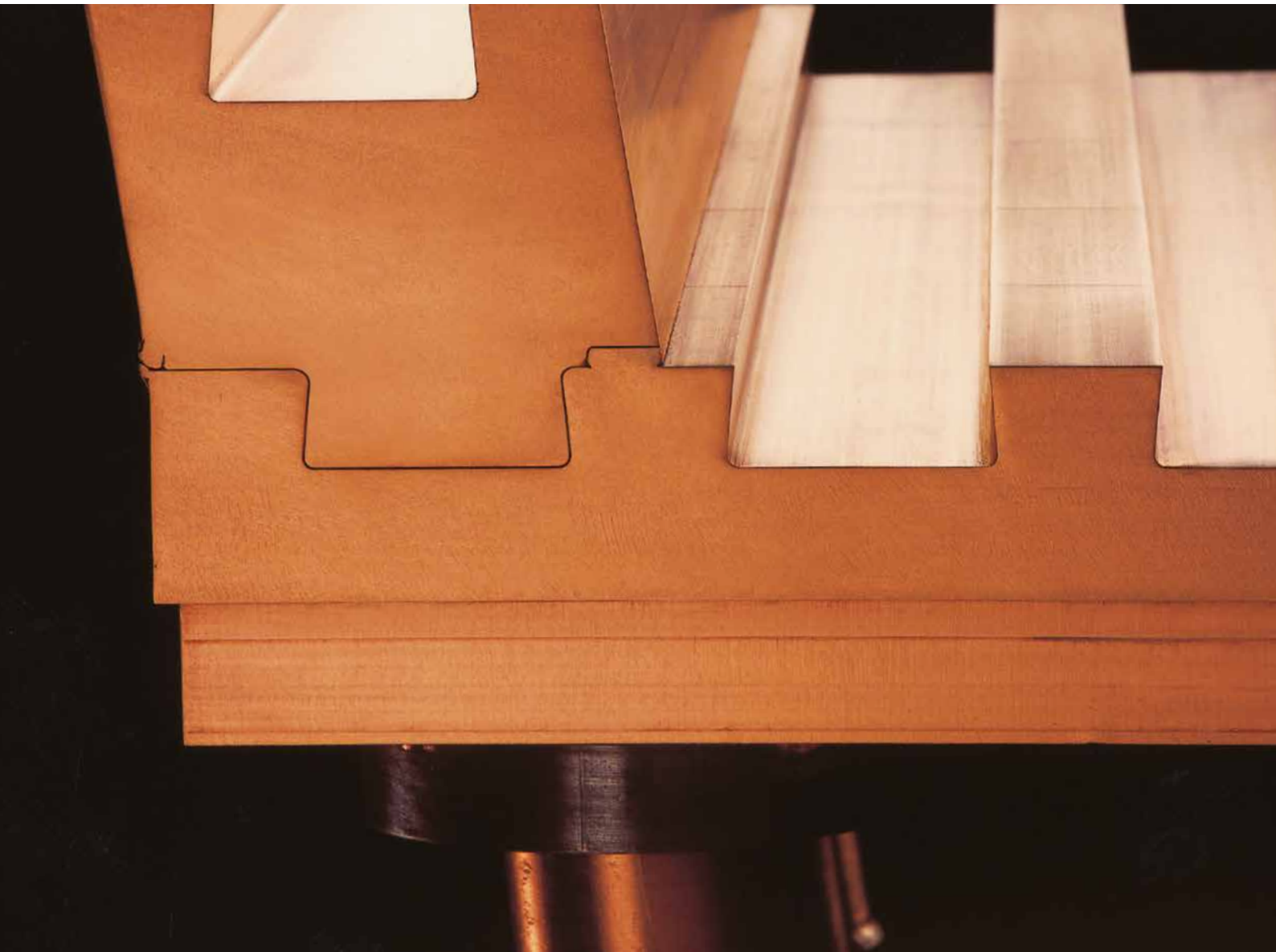
*The key to successful operation of a cooling system in a high heat load metallurgical furnaces is the formation of a skull on the hot face of the cooling element.*

This skull is composed of condensed vapours, solidified slag and metal that attaches the cooling element surface by splashing, dripping and freezing onto it. The thickness can vary by up to 20 mm. The stability of the skull mainly depends on the cooling capacity and mechanical adherence ability of the cooling element to which it adheres. The severity of gas streaming at the wall will also affect skull retention. The skull is a natural insulator if metallic content is low.

During periods of extreme heat load (i.e. high temperature gas jets or process upsets) the skull may spall off, then build up again afterwards. The falling and building up of skulls causes significant fluctuations in heat loads on the furnace wall with peak loads in the range of 300,000 to 500,000 W/m<sup>2</sup>.

Thus the lining and cooling design should ideally be able to handle such heat loads to avoid premature failures. Detailed investigations have revealed that the higher the cooling efficiency of the cooling element, the more stable the skull and the longer it will adhere to the cooling element and retain its insulating and protective properties.

The outcome is that highly efficient cooling systems will usually result in lower overall heat losses from the furnace.



# Furnace revamping

As most modern integrated steel plants have a minimum number of large blast furnaces in operation, blast furnace availability has become an important factor for achieving production targets. Consequently, intermediate repair and revamping times must be kept to a minimum.

KME staves achieve very high life-times due to their good thermal and crystallisation properties. Experience to date has shown that it is possible to achieve a campaign life of over 15 years. This means that the costs related to furnace downtimes and maintenance work can be reduced significantly compared to conventional coolers.

## Revamping strategies

When determining the most suitable relining program, downtime and reline costs must be considered along with the consequences for the lining and cooling design.

There are a number of possibilities available for converting existing furnaces to copper stave technology. They need to be adapted to the specific needs of the individual customer's project. Some of the typical procedures involved in replacing the cooling elements are:

## 1. Partial replacement of cast iron staves

Copper staves are used in high heat load zones where cast iron staves do not reach the desired life-time. The existing shell can be used because the staves can be engineered to match the existing openings in the shell. If the design of the furnace is to be changed, copper staves can be designed with larger dimensions so as to reduce the number of cooling water openings.

## 2. Replacing plate-cooler design with copper staves

The main reason for this replacement strategy is a reduction of downtime due to the improved lifetime of copper staves. Furthermore, an increase in the working volume can be achieved. Project costs may increase but the refractory costs for copper stave design compared to plate cooler design are substantially less.

Copper stave installation will save as a result significant downtime and field labour which results in future savings.





## Increased working volume

When copper staves are installed, an increase of working volume of up to 20 % can be achieved using the existing shell, due to the reduced lining thickness. The working volume increase will contribute to

- increased production
- lower wall stresses
- increased campaign life

Design	Lining thickness (mm)
Plate coolers with alumina refractories	700 – 800
Cast iron staves 1 <sup>st</sup> generation	300
Thicker cast iron staves with multiple cooling water circuits	450 – 600
Plate cooler (closer spacing 300 mm, with special refractories)	450 – 550
High-performance copper staves	100 – 150

# Advanced stave engineering

To help our customers determine the right type of stave design for them, KME also provides services in the concept and project settlement phases as part of KME's advanced stave engineering.

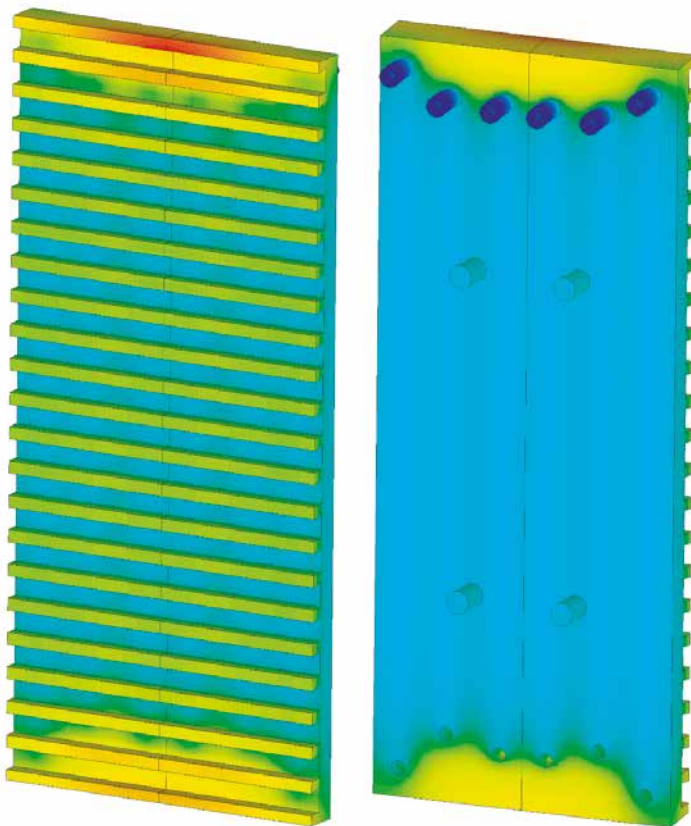
Since the copper staves supplied by KME are so varied and extensive in number, a customised solution can be found for each individual application.

Having established the basic engineering of the staves, FEM calculation programs are then used to determine the number and progression of the cooling bores in KME's copper staves. In this way, it is possible to apply simulation calculations to compute the impact of various cooling scenarios on the emerging temperature load of the staves and deduce the deformations arising from this. As a result, it is possible to pinpoint the ideal cooling effect for each individual application.

The services that are available for determining the most appropriate cooling ducts and the matching cooling effects of the staves are especially suited to converting cast iron staves to copper staves in the blast furnace.

As part of its service package, KME also helps to determine the losses of pressure that will occur in the cooling system of the staves. Moreover, KME will also assist customers in selecting the right compensators for installing the copper staves in the blast furnace.

KME engineers and technicians provide their services as part of KME's customer service.

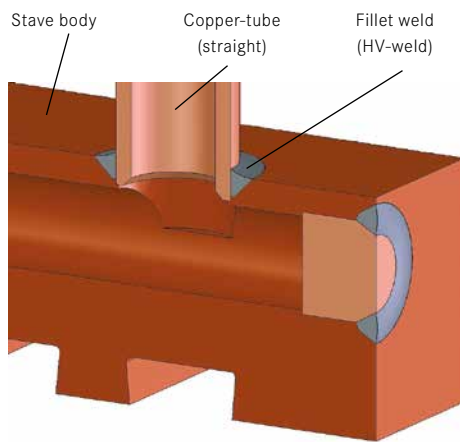


FEM calculation of the temperature distribution of copper staves under heat load.

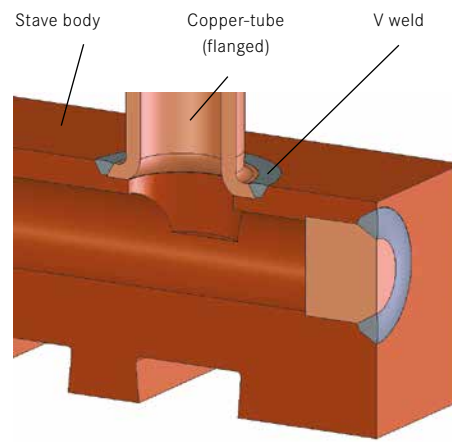
# Improved "flanged" joint design

The properties of the new design were assessed by an endurance test of the assembly in comparison to the standard design. An independent institute simulated the thermally induced deformations of copper staves under operating conditions. The new design has proven that the number of cycles to fracture significantly increases. To be derived from this is a higher degree of safety against leaks at the cooling tube - to stave joint during service and a higher safety against thermal overloads which may cause early fatigue cracks.

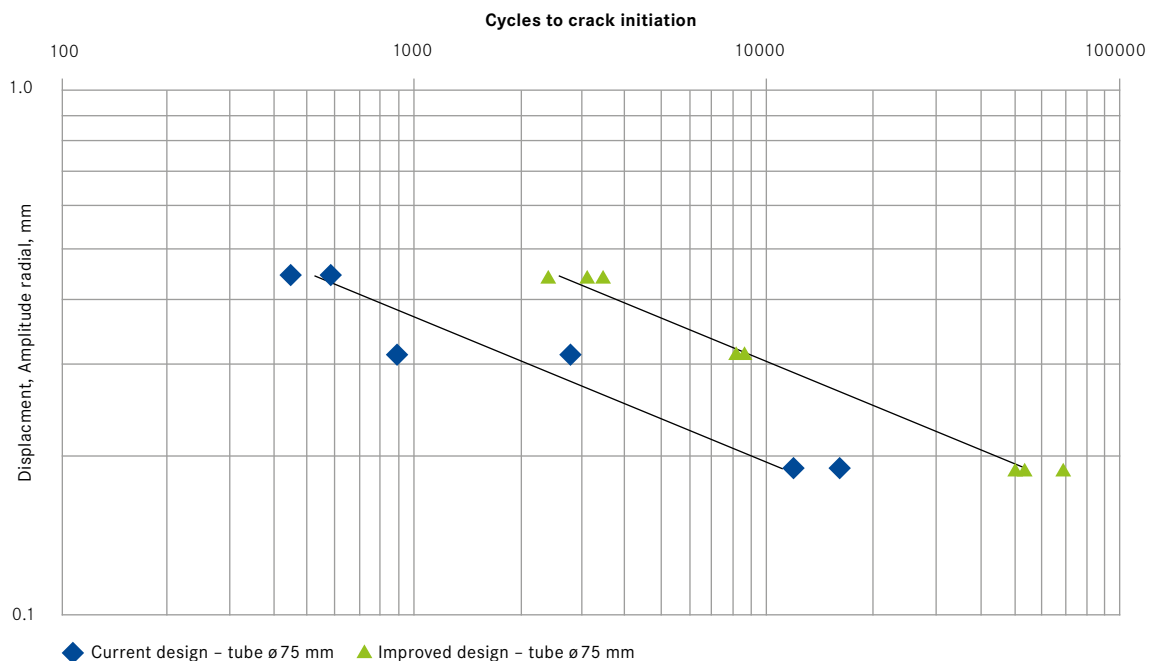
Keeping in mind the proven reliability of the current stave design it was a clear goal not to design a new stave, but to improve the current design. In the course of this systematic analysis of the optimization potentials an improved type of welded joint between the stave body and cooling pipe has been developed and extensively fatigue life tested. The advantage of this improvement is a stronger weld connection which would be more durable. The improved stave is assembled to the furnace shell in the same manner as the current stave.



Standard joint design



Improved joint design (KME Patent)



# Copper stave manufacturing

## Melting and casting

In KME's melting and casting facilities, copper and copper alloys are produced on state-of-the-art systems. Cathodic, high-purity copper is mainly used for producing copper staves. The composition of the melt is monitored by an analysis system. Billets and slabs can be cast on various casting systems in different geometries, so that the dimensions of the starting material offer favourable properties for subsequent downstream production stages.

## Forming

Close coordination between the casting process and the subsequent forming process is crucial for ensuring optimal material properties and tight tolerances in production.

KME has hot and cold rolling systems for forming the material in addition to systems for forging and heat treating the material. Special procedures and process sequences developed by KME make it possible to produce various geometries while maintaining the highest level of quality.

## Welding

KME has different welding processes at its disposal, including robot-supported, automated processes. Depending on the product requirements, either Metal Inert Gas (MIG) or Tungsten Inert Gas (TIG) processes can be used.

KME's highly skilled welding specialists possess all the necessary certifications and approvals required to perform this type of work.

## Machining

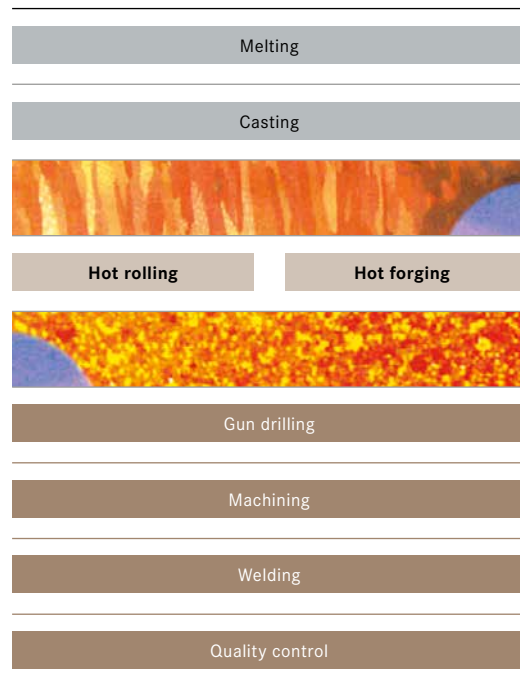
Modern, precise CNC-driven machine tools are available for the final machining of staves. The construction data of components used to produce the desired work-piece geometry is acquired via integrated CAD/CAM systems.

Not only does KME possess comprehensive experience in milling and drilling copper, we also have many years of know-how in the field of deep hole drilling. This technique ensures optimum cooling conditions for copper staves. Due to our know-how and experience we at KME have the ability to produce deep-hole drillings in lengths of more than 6,000 mm.

## Quality assurance

Supplying high-quality components is an essential prerequisite of our business that assures our customers smooth, trouble free plant operation. To ensure that our customers only receive high-quality components, all processes and operational procedures at KME are certified in accordance with the DIN ISO 9000 series.

In addition to the analysis of materials, KME has a wide range of test procedures.



# Product range and materials

## Stave dimensions\*

Max. width (mm)	up to 1,300
Max. length (mm)	3,800 (6,000)
Max. piece weight (kg)	4,000

\*Stave dimensions realised; other dimensions possible on request

## Stave accessories

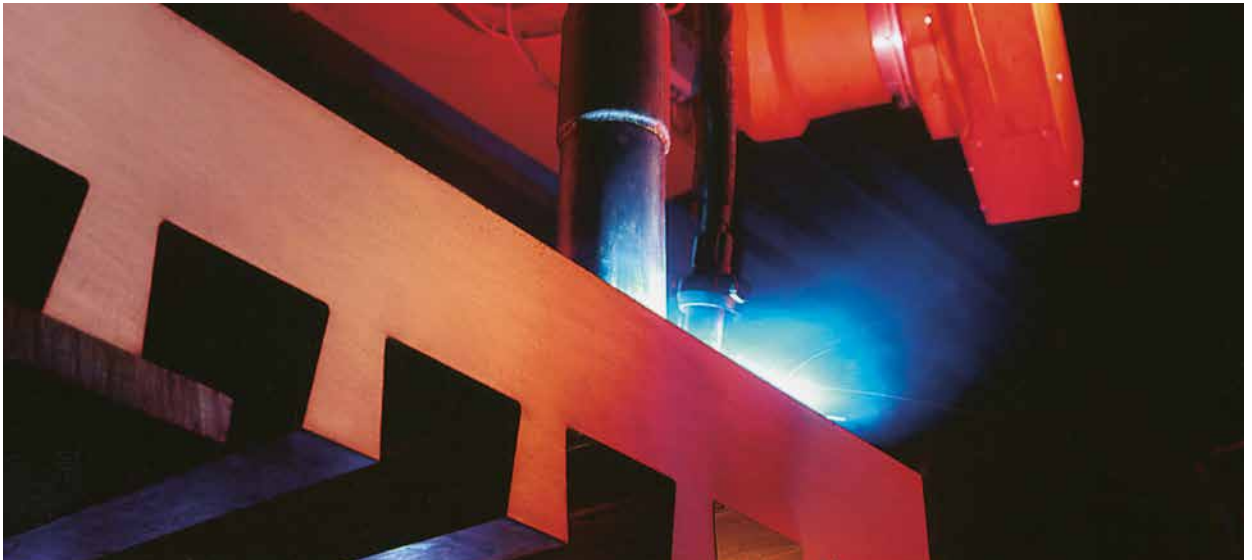
Fastening	Guide pins, sealings, sleeves, caps washers, bolts, lifting eye bolts
Compensators	Compensator for inlet/outlet tubes Compensator for thermocouples

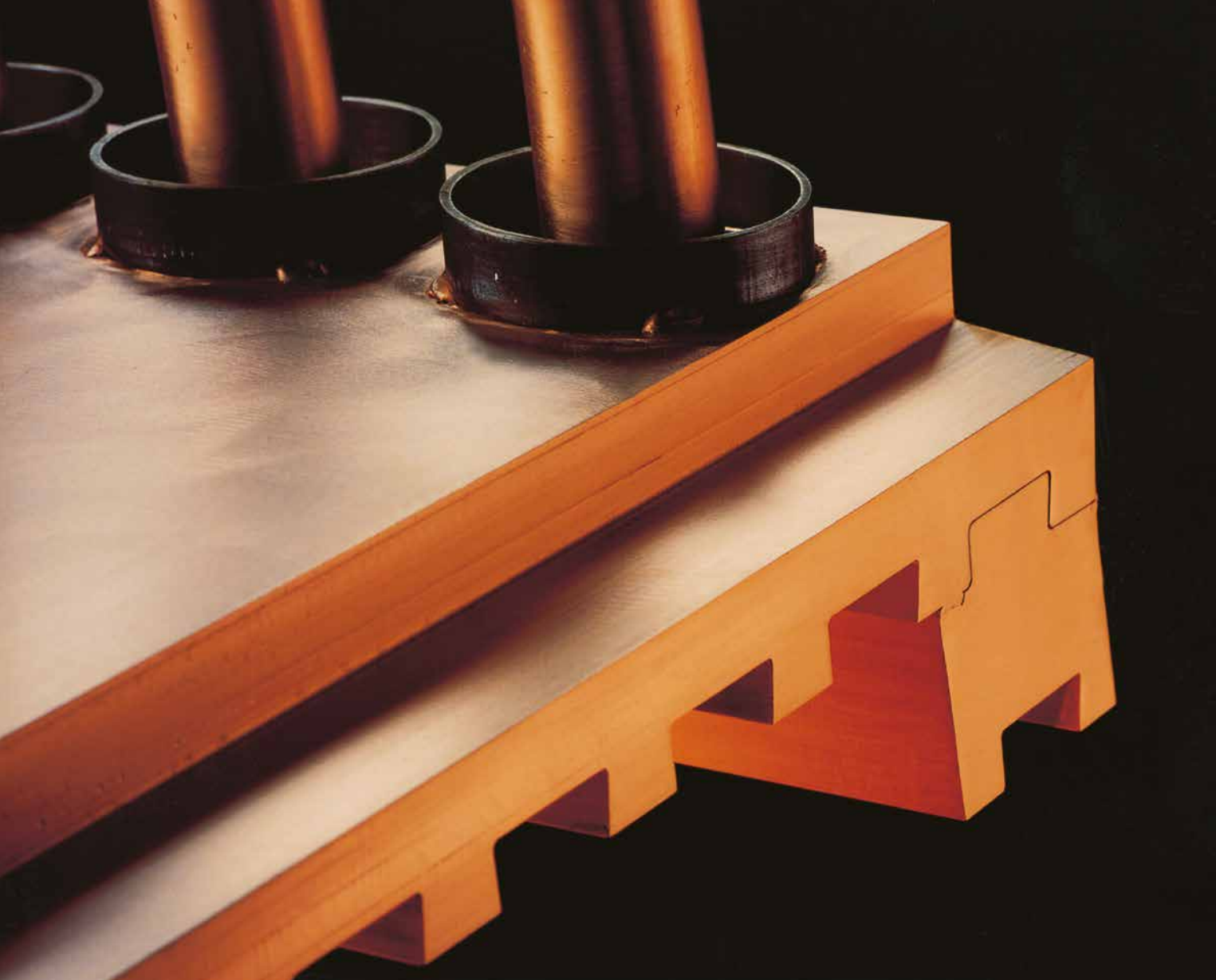
## Stave types

Shape	Parallel	Conical
	Bent horizontal	
	Bent vertical	
With ledge	Uncooled	Cooled
	Bolted	Bolted
	Inserted/spot welded	

## Connecting tubes

Protection tubes and spacer/ protection tubes – Mild steel tubes	SF-Cu/Cu-DHP according to DIN CEN/TS 13388 – Steel, steel/copper
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#### Stave accessories

Analysis	Cu	≥ 99.9	%
	P	≤ 0.008	%
	O	≤ 0.005	%

Structure	hot wrought fine grained
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#### Physical Properties

Electrical conductivity	≥ 55	S·m/Ω mm <sup>2</sup>
	≈ 95	% IACS
Melting point	1083	°C
Coeff. of linear thermal expansion	16.8	10 <sup>-6</sup> /K
Density	8.9	g/cm <sup>3</sup>

#### Mechanical Properties\*

- Proof stress R <sub>p0.2</sub>	40	MPa
- Tensile strength R <sub>m</sub>	200	MPa
- Elongation after fracture A <sub>5</sub>	45	%
- Hardness	40	HBW 2.5/62.5

\* Values may change with varying thermal and mechanical treatment due to geometry and manufacturing procedure.

#### Stave material

To achieve life time cycles of more than 15 years, the copper base material that is used must display exceptional properties and a first-rate, homogeneous crystallisation structure. At KME therefore, only top-grade SE-Cu/Cu-HCP is used in copper staves as it maintains its hot wrought structure exactly as a result of the specifically designed metal forming stages. Only when the structure takes on this state it can be tested to ultrasonic standard.



# Advantages of hot wrought structure copper stave

## KME - Fine grained structure

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### Material structure

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- Hot worked material with wrought homogenous grain structure
  - Equiaxed grains
  - Fine grained 1...5 mm
- 

### Technological data

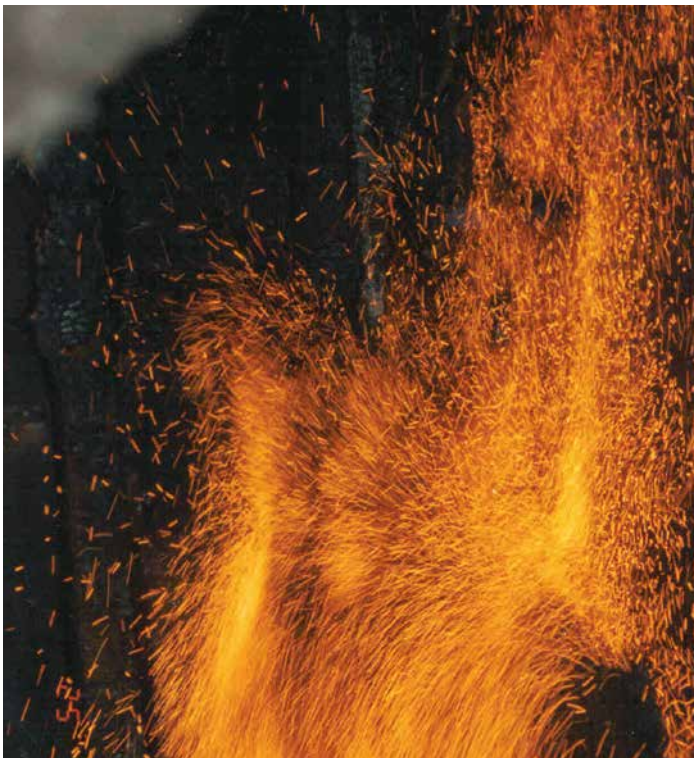
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- Good mechanical properties  $R_{p0.2}$ ,  $R_m$ ,  $A_5$
  - Good thermal conductivity
  - Good low-cycle fatigue resistance
- 

### Reliability of processing/quality of staves

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- Best homogeneity of material
- Ultrasonic tests as standard procedure micro-defects or local porosity are detectable
- Fine grain structure in weld areas (cold face)
- Safety in a longer life time:
  - ▶ No risk of cracking
  - ▶ No risk of water leakage
- even with temporary increases in temperature/stresses
- right from the start



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