

ionicLife Cast Technology – High Performance Copper Coolers

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This article describes a new innovative technology for manufacturing of copper coolers. With the so-called ionicLife cast process the cooling tube, which is made of copper, is actively cooled during the casting process. The result is an excellent connection between copper matrix and copper tube, which leads to highest thermal conductivity and also lifetime. Cooling by means of a non-explosive ionic liquid

makes it possible to dispense with expensive monel tubes, which in turn leads to lower manufacturing costs.

Keywords:

Copper cooler – Copper casting – ILTEC – Ionic liquid – Launder – Cooling channel – Bonding

ionicLife cast Verfahren – Hochleistung-Kupferkühler

Dieser Artikel beschreibt eine neue innovative Technologie zur Herstellung von Kupferkühlern. Mit dem sogenannten ionicLife cast Verfahren wird das Kühlrohr, welches aus Kupfer besteht, aktiv während des Abgusses gekühlt. Das Ergebnis ist eine hervorragende Verbindung zwischen Kupfermatrix und Kupferrohr, was zu einer höchsten Wärmeleitfähigkeit und auch Lebensdauer führt. Das

Kühlen mittels einer nicht-explosiven ionischen Flüssigkeit ermöglicht den Verzicht auf teure Monel-Rohre, was wiederum zu günstigeren Herstellkosten führt.

Schlüsselwörter:

Kupferkühler – Ionische Flüssigkeit – Kupferrinnen – Kühlkanal – ILTEC – Verbindung

ionicLife Cast Technology – Refroidisseurs de cuivre de haute performance

Tecnología de fundición ionicLife - Enfriadores de cobre de alto rendimiento

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1 Introduction

Mettop (www.mettop.com) and WeCo (www.weldingcopper.es) have developed an innovative casting process that enables the casting of copper cooling elements with embedded copper tube. The copper tube is actively and safely cooled by a non-explosive ionic liquid during the casting process. The result is an excellent metallurgical connection between copper tube and copper casting, which leads to a long service life on the one hand and to better recyclability of the copper cooler on the other hand. With the know-how and mastery of the manufacturing process combined with the competence to design, simulate and optimise coolers for critical applications, Mettop and WeCo started the development towards the perfect cooler. In order to achieve a high cooling capacity and a long service life of these coolers, copper tubes are the most suitable for the cooling circuits. This brings with it the challenge of placing a thin

metal structure in an environment with a large amount of liquid metal, with a temperature higher than the melting point of the tube. The newly developed “ionicLife cast” method allows sufficient cooling of a copper cooling circuit during the casting process to prevent melting or deformation of the cooling tube. Since cooling with gases is not sufficient and the use of water in the presence of liquid metals is extremely dangerous, cooling with an ionic liquid is the only safe option. These ionic liquids can be adapted in their properties to the respective application. In this case, it is a cooling medium that can be used up to 250 °C and is safe to handle and in direct contact with liquid metal. Mettop holds the patent on the only non-corrosive and non-toxic ionic liquid specifically designed for metallurgical applications – the IL-B2001. Therefore, a collaboration between WeCo and Mettop has been formed to safely address the challenges of manufacturing large cooling elements made entirely of copper.

2 State-of-the-art technologies

In metallurgy, large cooling elements have been increasingly used in recent decades to increase the service life of important furnace systems through intensive cooling in conjunction with refractory lining [1]. These often have complex geometries and have internal cooling channels through which a cooling liquid flows. In order to meet these geometric challenges and at the same time ensure acceptable manufacturing costs, these elements are usually produced by compound casting. This is a process in which a solid body of defined dimensions is cast with a liquid metal. In cooler production, preformed pipe bends are encapsulated with a melt. The channels formed by the tubes serve in the finished product as cooling coils through which the cooling medium flows. By combining the sand casting process with the casting of pre-formed cooling coils, it is possible to produce complex geometries of the cooling circuit within the copper cooler. An example of a ceiling cooler of a metallurgical aggregate produced by copper compound casting is shown in Figure 1.

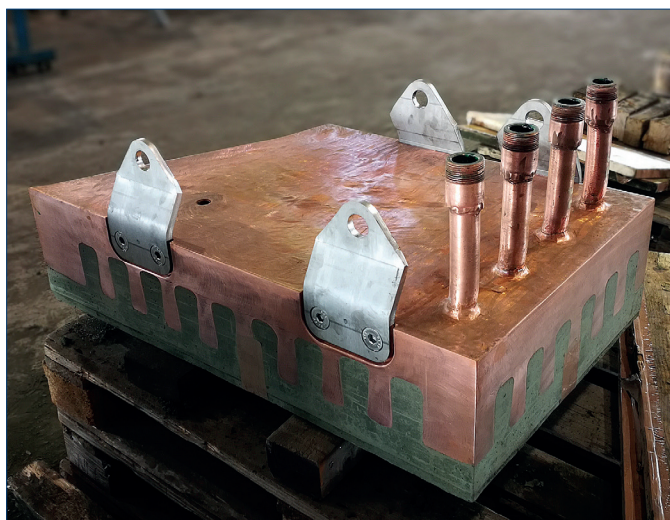


Fig. 1: Copper cooling element with cast-in tube coils and combined refractory lining

As users demand the highest thermal conductivity and service life of the cooling elements, pure copper is often used as the casting metal. In order to achieve the best possible heat conductivity, it would be advantageous if the tube was also made of pure copper. However, this results in the difficulty that the object to be cast in has the same melting point as the liquid metal with which it is to form a bond. Therefore, local melting of the substrate (tube) can easily occur if it is not cooled from the inside. This will result in the casting becoming a reject, as the cooling channels will be damaged and the cooling effect will be reduced. The factors influencing the production parameters on the heat conductivity of such copper coolers with copper tubes inside are discussed below:

2.1 Field of application and environment

In metallurgical plants, more and more areas are being equipped with intensive cooling systems in the zones of

greatest stress. By cooling the copper behind the refractory material, the temperature gradient between the melt in the furnace interior, the refractory lining and the steel shell becomes steeper. This enables the freezing of a slag layer or the reduction of the penetration depth into the pores of the refractory material. This allows a more even wear of the overall lining to be achieved, thus extending the service life of the entire furnace. These coolings are implemented by means of cooling elements made of steel or copper and the use of different cooling media. Currently, most copper coolers consist of cast pure copper with cast-in cooling loops (Figure 2) made of stainless steel, monel or copper.

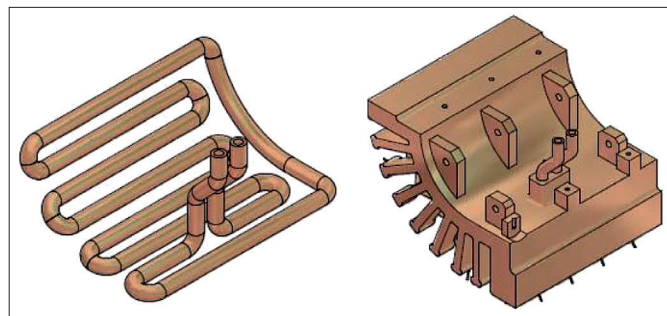


Fig. 2: Typical construction of a copper cooler: on the left the pipe loops before casting; on the right the finished cooler (source: Mettop GmbH)

If the hot-side cooling surface of a copper cooler is worn out, it must be replaced completely. Until now, the copper cooler has had to be recycled in the first process steps of copper production. The mechanical separation of the tubes from the copper castings is usually not feasible with reasonable effort, which is why the remaining parts of the elements are usually molten down in the primary unit or converter of a copper smelter. The reason for this is that the contaminating elements from the tube alloys or coatings can only be separated in these aggregates.

When a cooling element consists entirely of pure copper, recycling is much easier. Such a cooling element can simply be remelted in a melting furnace of a copper foundry and cast into a new cooler. The product would have a higher residual value at the end of its lifetime than before. Compared to currently available coolers, this would provide the customer with cost savings over the entire life cycle of the product.

However, the use of monel or steel tubes does not only affect the refurbishment of old cooling elements. Due to the different coefficients of thermal expansion of the tube metals and the cast copper, stresses arise during operation which often lead to the formation of gaps. If the tube separates from the rest of the copper block and a fine air gap is formed, the heat is only insufficiently dissipated and the element wears out more quickly due to the greater local thermal load. This is a particular problem in furnaces that are subject to cyclical temperature fluctuations, such as the electric arc furnace. If only copper is used as a material, the tube and matrix have the same expansion characteristics and no resulting stresses occur [2].

2.2 Existing processes and patents

2.2.1 Drilling of copper blocks

This is a simple and cost-effective process that has been in use for a long time and is well suited for simple geometries [3] (Figure 3). However, the problems here are that more complex, round or curved geometries of the cooling channels cannot be realized and that the open ends of the drilling channels must be closed again. These welded joints are weak points, since they repeatedly lead to leakages during operation. Such a malfunction represents a major safety risk in the case of water cooling. A steam explosion can occur if the cooling water comes into direct contact with a molten metal. Subsequently, the water escaping from small leaks can severely impair the service life of the surrounding refractory materials by absorbing moisture [4].



Fig. 3: Drilled copper coolers

2.2.2 Casting of steel pipes in sand casting molds

Instead of making the cooling channels through holes, this process uses steel tubes to map the cooling channels. They are processed into tube bundles which are positioned in the sand mold. These tubes (low and high alloyed) are relatively easy to handle and inexpensive to process. They can be cast-in without any problems, as their melting point is significantly higher than that of copper. However, the lack of metallic bonding between the cast-in tube and the copper matrix and the significantly different coefficients of thermal expansion are problematic. These lead to low boundary layer strength and poor heat transfer. This can cause separation of the tube from the copper matrix. The resulting gaps have a large negative effect on the heat transfer even at very small widths. The overall efficiency of the cooling blocks is additionally reduced by the low thermal conductivity of steel [6].

2.2.3 Casting of monel tubes into sand casting molds

Monel alloys are Cu-Ni alloys with a higher melting point than pure copper. They can therefore, similar to steel tubes, be cast in without cooling or supports and, especially in combination with coatings, show a significantly better metallic bond to the surrounding copper than steel. However, Monel tubes are very expensive due to their high nickel content and can hardly be bent due to their high strength. Instead, prefabricated pipe bends must be used, which are then welded. In addition to the increased manufacturing costs due to the additional manufacturing effort required, each weld seam is also a potential defect. The frequently

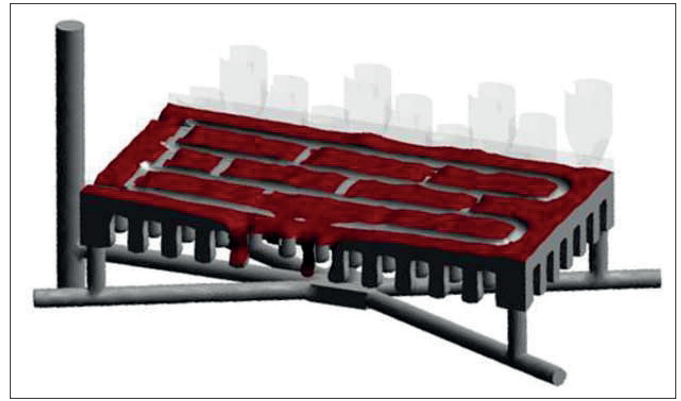


Fig. 4: Filling simulation of a copper cooler: at this point in time the cooling coils are already enclosed by the cast metal up to half their height (source: Click2Cast simulation by the manufacturer solidThinking)

used material Monel 400 has a similarly low heat conduction coefficient to stainless steel (1.4301: 15 [W/(m·K)], monel: ~22 [W/(m·K)], copper: 380 [W/(m·K)]), which means that here too, despite a significantly better bond to copper, the efficiency of the coolers is reduced [1].

2.2.4 Casting of sand filled copper pipes in sand casting

In this process, the tube is also made of copper so that the heat can be dissipated better and no bottleneck occurs in the heat dissipation. This means, however, that the material of the tube has the same melting point as the melt. As a result, the tube softens or even melts and the cooling channels cannot be reproduced true to shape. For this reason, the pipes are often packed tightly with sand beforehand, which makes them more dimensionally stable during the casting process. However, this results in the problem that sand residues remain in the pipe, which are washed out during use and enter the cooling circuit. There they cause problems with pumps and filters. Furthermore, this process is severely limited in the maximum size of the copper coolers. With large castings the pipe melts or gets cracks. Such faulty castings then fail the usual test methods of quality control and can therefore not be used and usually cannot be repaired. Such rejects represent a corresponding financial loss for the foundry. The most common quality checks are a pressure test at 8 to 10 bar with water to check the tightness of the system and the ball test, in which a spherical test piece of defined diameter is blown through the pipes to ensure that the inner pipe diameter is sufficiently large throughout [1].

2.2.5 Casting with the help of sand cores

Similar to the way entire engine blocks are produced in the automotive industry using sand casting and sand cores, these cores can also be used to create cooling channels in cooling elements. However, the relatively low strength of the molding materials limits the possible geometries and the sand cores often have to be supported. Otherwise they would break off due to their own weight or due to the buoyancy in the melt. The limited mold freedom, the effort required to remove the sand from the inside of the

finished casting and the remaining sand residues in the cooling channels pose the greatest problems here. Supporting structures lead to holes which have to be closed by welding or other methods and therefore again represent an increased risk of leakage. Therefore, this manufacturing process is constantly replaced by pipe-cooled elements where possible, after conducting the relevant studies, to ensure that the quantity, speed and direction of water in the tube cooling circuit can replace and improve the surely greater volume of water present in the piece made with sand cores.

2.2.6 Immersion of tube bundles in liquid copper after casting

There are also approaches that the tube bundle is only immersed in the melt after casting. This is intended to avoid melting of the tubes. However, the possible geometries are very limited and the positioning accuracy is lower [7]. The use of feeders and closed sand molds is not possible, which is why this manufacturing method is not used.

2.2.7 Casting of copper tubes, which are cooled during casting

In the course of this approach, an attempt was made to cool the tube bundles with the aid of a commercial ionic liquid (low-melting, organic salt melts). The cooling with the chlorine-containing liquid described in the patent caused major problems due to the highly corrosive effect of this liquid [4]. Although costly precautions were taken to protect the inside of the copper pipe against corrosion, the entire pump and piping system, including heat exchangers and valves, was also damaged by the strong corrosive attack [8]. Therefore, the technical feasibility of this process has not yet been established [7].

3 ionicLife cast process

The driving force behind the development of the ionicLife cast process was the aim to provide a safe manufacturing process enabling best possible heat transfer and recyclability of copper cooling elements.

In order to achieve optimum cooling efficiency, the use of copper tubes is generally considered the optimum, as copper conducts heat best of all the technology metals.

In the case of larger castings, long tube lengths, thinner tube wall thicknesses and high casting modules, active internal cooling is required, as otherwise the copper tubes will melt through due to the high thermal load during casting. Water cannot be used as a coolant because there is an acute risk of explosion if it comes into contact with molten metal [3]. The spontaneous multiplication of the volume of the liquid water to water vapor creates enormous, explosive forces. Based on these safety considerations, ionic liquids offer themselves as alternative cooling media for such applications. These can be used within a wider temperature window. Due to their extremely low vapor pressure, they do not pose a safety risk in case of damage at high temperatures, as they only decompose and no explosive



Fig. 5: Water-free cooling solution – ionic liquid IL-B2001 (source: Met-top GmbH)

deflagration occurs. However, many ionic liquids on the market are highly corrosive, which is why the patented non-corrosive ionic liquid IL-B2001 (Figure 5) is used in the ionicLife cast process [9].

3.1 Function and design of the ILTEC system

In principle an ILTEC system consists of a tank in which the cooling liquid is stored, a pump for delivery as well as a heat exchanger and a flow heater for temperature control of the liquid. Furthermore, these systems are equipped with sensors for flow and temperature measurement (Figure 6). Since the temperature at the interface between the pipe and the cast copper in production cannot be measured, but only that of the coolant, conclusions are drawn about the conditions based on the trends prevailing there. The relevant measuring point for this is located when the liquid re-enters the machine after it has been pumped through the copper tubes to be cast in. The temperature of the ionic liquid measured here during pouring is used to analyze the thermal load on the liquid and for process control, and reflects the heat extracted from the coolers over time.



Fig. 6: ILTEC system for active cooling of high temperature applications

3.2 Results

The heat dissipated from the cooling circuit leads to accelerated and controlled solidification. As a result, the coolers solidify from the inside out, which leads to a simplification of the complete mold filling and a more favourable casting structure (Figure 7). Due to the cooling, the solidification process takes place in a fraction of the normal time and much smaller directional grains are formed in the solidified copper block. This in turn has a positive influence on the mechanical properties of the product, improving strength, hardness and toughness compared to conventional castings [2, 10].

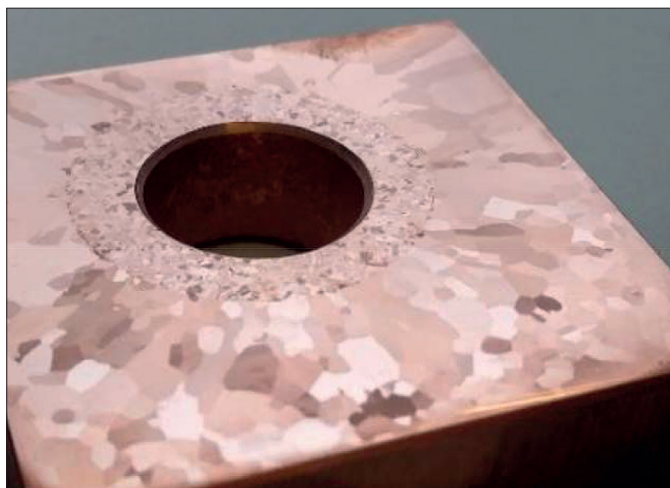


Fig. 7: Etched microsection of a radiator

4 Summary and outlook

The ionicLife cast process enables the production of coolers with an excellent metallurgical bond between copper tube and copper casting. On the one hand, this enables a long service life and, on the other hand, leads to better recyclability of the copper cooler.

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