

Device and method for producing an investment casting component

The present invention relates to a device and a method for producing an investment casting component by use of a ceramic-free continuous melt jet. In other words, the invention relates to a device and a method for investment casting of molded parts.

Background of the invention

Investment casting plants and investment casting processes carried out therewith are used to produce cast components made of metal alloys with comparatively high surface quality and dimensional accuracy. In particular, investment casting plants and processes can be used to produce components for the aerospace industry, the power generation industry, the automotive industry, the medical technology, the chemical industry and/or the electrical industry. Components manufactured by use of investment casting processes require minimal post-processing. In addition, investment casting processes can be used to produce components with complex structures.

In known investment casting plants, material to be melted is melted in a crucible and then poured into a prepared melt mold. However, in known investment casting plants, undesirable impurities can occur in the molten material, which negatively affects the quality of the cast component produced.

It is therefore an object of the invention to provide a device and a method which overcome the disadvantages of the prior art.

In particular, it is an object of the invention to provide a device and a method that enable the production of investment casting components with improved quality. Improved quality here can mean, for example, a higher material purity and/or a higher surface quality of the component.

This object is achieved by the subject-matter of the independent claims. Further developments and embodiments of the device and the method are subject-matter of the dependent claims and the following description.

Description of the invention

One aspect of the invention relates to a device or plant for producing investment casting components, in particular complex cast parts. The device includes a melting chamber comprising an induction coil assembly disposed in the melting chamber. The induction coil assembly is adapted to melt an electrode received at least in part therein to produce a ceramic-free continuous melt jet with a melt flow rate (MFR) of at least 2.5 kg/min. The device further comprises a casting chamber downstream of and connected to the melting chamber and comprising an investment casting mold received or receivable therein and adapted to be filled by means of the ceramic-free continuous melt jet.

The generation and use of a ceramic-free, continuous melt jet can prevent contamination of the melt during the process, which serves both to improve the mold filling process and to improve the metallurgical properties of the cast part produced.

By generating and using a continuous melt jet, a less turbulent mold filling process can be realized. This reduces the occurrence of ceramic impurities in the melt material and thus in the investment casting due to particles dislodged from the mold wall. In addition, a continuous and uniform filling of the mold allows possible contaminating particles to be carried upward during the casting process, where they are less likely to affect the quality of the cast part.

The induction coil assembly can be designed to melt the electrode received at least partially therein in such a way that it generates a ceramic-free, continuous melt jet with a melt flow rate MFR of at least 4 kg/min, preferably at least 5 kg/min, more preferably at least 6 kg/min, still preferably at least 8 kg/min.

The induction coil assembly can be designed to melt the electrode received therein at least partially in such a way that it generates a ceramic-free, continuous melt jet with a melt flow rate MFR of at most 15 kg/min, preferably at most 12 kg/min, more preferably at most 10 kg/min.

In particular, the induction coil assembly can be designed to melt the electrode received therein at least partially in such a way that it generates a ceramic-free, continuous melt jet with a melt flow rate MFR of between 2.5 kg/min and 10 kg/min.

The melt flow rate MFR of at least 2.5 kg/min, in particular in the range between 2.5 kg/min and 10 kg/min, as determined by the inventors, represents a melt flow rate suitable for investment casting applications, which represents an optimal balance between ensuring sufficient superheating of the melt jet, achieving an appropriate mold filling time and an energy consumption acceptable in practice.

In particular, the inventors of the present invention have recognized that sufficient superheating of the melt jet can be realized at a melt flow rate MFR of at least 2.5 kg/min. Such a surprising relationship between the melt flow rate MFR and superheating was not expected based on the prior art known from practice. Rather, it would have been expected that only a very low superheating could be achieved due to a relatively short dwell time of the melted material within the coil arrangement resulting from an increased melt flow rate. However, sufficiently high superheating of a melt is required for investment casting applications in order to prevent solidification and clumping of the melt before it is introduced into the mold. At the same time, in investment casting, complete filling within a reasonable mold filling time must be ensured in order to produce an investment casting component with the required quality and grade.

Due to the melt flow rate of at least 2.5 kg/min, in particular in the range between 2.5 kg/min and 10 kg/min, of the continuous melt jet generated by means of the device, it can be achieved that the investment casting mold is completely filled in a reasonable time. In other words, the minimum melt flow rate provided by the inventors can reduce the mold filling time to an optimum level. At lower melt flow rates, such as those known from conventional continuous melting processes, it would not be possible to ensure adequate mold filling and thus production of an investment casting component of sufficient quality. In particular, the adequate mold filling time may refer to a mold filling time for common investment casting components in the aerospace industry - for example turbine blades, the power generation industry - for example turbine blades, the automotive industry - for example turbocharger wheels, the medical technology, the chemical and/or electrical industry. The minimum melt flow rate envisaged by the inventors may thus be particularly

suitable for the production of such investment casting components of high quality, without being limited thereto.

The investment casting mold is a lost mold. The material of the investment casting mold may be, for example, ceramic or graphite.

In particular, the meltable electrode may be a rotating electrode suspended vertically in the melting chamber and continuously melted off under vacuum or under an inert gas atmosphere by means of a controlled motion at a lower end by means of the induction coil assembly. The controlled motion may include, in addition to the rotational motion for uniform melting, continuous feeding the electrode toward the casting chamber. The induction coil assembly may comprise a tapered shape tapering toward the lower end of the electrode. The induction coil assembly and the electrode are arranged coaxially with respect to each other.

In one embodiment, the casting chamber may include a mold heater configured to heat the investment casting mold during casting or during the production process. This can prevent premature and undesired cooling and thus solidification of the melt jet introduced into the investment casting mold. This can contribute to ensure that the investment casting mold is completely filled and the quality of the produced investment casting component is further increased.

The device may include a mold extractor by means of which the investment casting mold can be extracted in a direction away from the melting chamber. The mold extractor may be located in or at or below the casting chamber. For example, the mold extractor may be mounted in a load/unload chamber. By means of the mold extractor, controlled solidification of the cast part can be achieved. Hereby, a feeding or refilling of liquid metal from an upper part of the mold, to which the melt jet is fed, to areas of the mold that become free due to solidification shrinkage can be enabled. Moreover, directionally solidified castings can be produced by means of the mold extractor and the controlled solidification.

The device may include a load/unload chamber for loading/unloading the investment casting mold. The load/unload chamber is located downstream of the casting chamber.

The induction coil assembly may be operated with a power P for which the following conditions are satisfied:

$$\begin{aligned} P \text{ [kW]} &\geq 5 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ \text{preferably } P \text{ [kW]} &\geq 15 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ \text{more preferably } P \text{ [kW]} &\geq 50 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ \text{still preferably } P \text{ [kW]} &\geq 125 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}. \end{aligned}$$

The induction coil assembly may be operated with a power P for which the following conditions are satisfied:

$$\begin{aligned} P \text{ [kW]} &\leq 600 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ \text{preferably } P \text{ [kW]} &\leq 300 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ \text{more preferably } P \text{ [kW]} &\leq 100 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ \text{still preferably } P \text{ [kW]} &\leq 35 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}. \end{aligned}$$

The induction coil assembly can be operated with a power P for which the following conditions are satisfied:

$$\begin{aligned} 5 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR} &\leq P \text{ [kW]} \leq 600 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ \text{preferably } 15 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR} &\leq P \text{ [kW]} \leq 125 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ \text{more preferably } 17,5 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR} &\leq P \text{ [kW]} \leq 90 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ \text{still preferably } 20 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR} &\leq P \text{ [kW]} \leq 30 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}. \end{aligned}$$

The power P can be set as a function of a diameter of the electrode to be melted off according to the above conditions.

The induction coil assembly can, in particular for melting off an electrode with a diameter of 150 mm, be operated with a power P for which the following conditions are satisfied:

$$\begin{aligned} P \text{ [kW]} &\geq 15 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ \text{preferably } P \text{ [kW]} &\geq 17,5 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \end{aligned}$$

$$\begin{aligned} &\text{more preferably } P \text{ [kW]} \geq 20 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ &\text{still preferably } P \text{ [kW]} \geq 22,5 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}. \end{aligned}$$

The induction coil assembly can, in particular for melting off an electrode with a diameter of 150 mm, be operated with a power P for which the following conditions are satisfied:

$$\begin{aligned} &P \text{ [kW]} \leq 50 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ &\text{preferably } P \text{ [kW]} \leq 40 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ &\text{more preferably } P \text{ [kW]} \leq 35 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ &\text{still preferably } P \text{ [kW]} \leq 30 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}. \end{aligned}$$

The induction coil assembly may be operated with a power P of 400 kW or less, in particular 350 kW or less, preferably 300 kW or less.

The aforementioned powers P with which the induction coil assembly or induction coil may be supplied or operated can contribute to optimize the power consumption and voltage of the device, while ensuring the balance with an appropriate mold filling time and the optimal superheating.

The induction coil assembly may be set up to superheat the melt jet as a function of the melt flow rate MFR such that the superheating temperature T_{sup} satisfies the following conditions:

$$\begin{aligned} &T_{\text{sup}} \text{ [}^\circ\text{C]} \geq 5 \left[^\circ\text{C} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ &\text{preferably } T_{\text{sup}} \text{ [}^\circ\text{C]} \geq 45 \left[^\circ\text{C} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ &\text{more preferably } T_{\text{sup}} \text{ [}^\circ\text{C]} \geq 100 \left[^\circ\text{C} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ &\text{still preferably } T_{\text{sup}} \text{ [}^\circ\text{C]} \geq 270 \left[^\circ\text{C} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}. \end{aligned}$$

The induction coil assembly may be set up to superheat the melt jet as a function of the melt flow rate MFR such that the superheating temperature T_{sup} satisfies the following conditions:

$$\begin{aligned}
T_{\text{sup}} [^{\circ}\text{C}] &\leq 600 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR}, \\
\text{preferably } T_{\text{sup}} [^{\circ}\text{C}] &\leq 400 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR}, \\
\text{more preferably } T_{\text{sup}} [^{\circ}\text{C}] &\leq 250 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR}, \\
\text{still preferably } T_{\text{sup}} [^{\circ}\text{C}] &\leq 100 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR}.
\end{aligned}$$

The induction coil assembly can be set up to superheat the melting jet as a function of the melt flow rate MFR in such a way that the superheating temperature T_{sup} satisfies the following conditions:

$$\begin{aligned}
5 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR} &\leq T_{\text{sup}} [^{\circ}\text{C}] \leq 600 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR}, \\
\text{preferably } 7 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR} &\leq T_{\text{sup}} [^{\circ}\text{C}] \leq 400 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR}, \\
\text{more preferably } 25 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR} &\leq T_{\text{sup}} [^{\circ}\text{C}] \leq 250 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR}, \\
\text{still preferably } 10 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR} &\leq T_{\text{sup}} [^{\circ}\text{C}] \leq 100 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR}.
\end{aligned}$$

The superheating temperature T_{sup} can be set as a function of a diameter of the electrode to be melted off according to the above conditions.

The induction coil assembly can be set up, in particular for melting off an electrode with a diameter of 150 mm, to superheat the melt jet as a function of the melt flow rate MFR in such a way that the superheating temperature T_{sup} satisfies the following conditions:

$$\begin{aligned}
T_{\text{sup}} [^{\circ}\text{C}] &\geq 5 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR}, \\
\text{preferably } T_{\text{sup}} [^{\circ}\text{C}] &\geq 6,5 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR}, \\
\text{more preferably } T_{\text{sup}} [^{\circ}\text{C}] &\geq 7,9 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR}.
\end{aligned}$$

The induction coil assembly can be set up to superheat the melt jet by at least 10°C, preferably by at least 20°C, preferably by at least 40°C, more preferably by at least 60°C, still more preferably by at least 80°C. Superheating of more than 100°C can also be achieved.

The induction coil assembly can be set up, in particular for melting off an electrode with a diameter of 150 mm, to superheat the melt jet as a function of the melt flow rate MFR in such a way that the superheating temperature T_{sup} satisfies the following conditions:

$$T_{\text{sup}} [^{\circ}\text{C}] \leq 25 \left[^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR},$$

$$\text{preferably } T_{\text{sup}} [^{\circ}\text{C}] \leq 20 \left[^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR},$$

$$\text{more preferably } T_{\text{sup}} [^{\circ}\text{C}] \leq 15 \left[^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}.$$

The superheating here may be a superheating of the melt jet averaged over time and volume.

The induction coil assembly may be set up to superheat the melt jet by 250°C or less, preferably 200°C or less, more preferably 150°C or less. The superheating can be adjusted depending on the material (with respect to the electrode).

Said superheating of the melt jet can ensure an optimization of the balance between the energy consumption and voltage of the device, the appropriate mold filling time and the optimal superheating. In particular, the specified superheating as a function of melt flow rate can provide a measure by means of which the quality of the investment casting components can be further improved.

The induction coil assembly may be operated with a voltage of 1200 V or less, preferably 1000 V or less. The voltage may be at least 100 V, preferably at least 200 V, more preferably at least 450 V. This upper voltage limit of 1000 V allows the plant to be operated in the low-voltage range. Also, at such a voltage, for example, any insulation between the windings of the induction coil can be dispensed with.

In alternative embodiments, however, higher voltages are also possible for energizing the induction coil assembly. In particular, a higher voltage, for example of 1500 V or more, may be provided when the plant is operated under elevated pressure.

The induction coil assembly may be operated at a frequency between 10 kHz and 300 kHz, preferably between 50 kHz and 200 kHz, still preferably between 75 kHz and 125 kHz. In particular, a frequency may be 100 kHz.

At least the melting chamber may be pressurized with an absolute pressure so that the melt jet is generated under this absolute pressure. The absolute pressure may be at least 30 mbar, preferably at least 1 bar, still preferably at least 5 bar. The absolute pressure

may be less than 10 bar. The absolute pressure may be between 30 mbar and 10 bar, preferably between 1 bar and 10 bar. In particular, in such an embodiment, the induction coil assembly may be operated at a voltage of 1000 V or more, preferably 1200 V or more, still preferably 1500 V or more. The induction coil assembly may comprise at least one induction coil having four serial windings or less, preferably three serial windings or less, still preferably two serial windings or less (i.e. having only one winding).

An induction coil having four windings may also be referred to as a four-windings induction coil. Here, it describes an induction coil with four serially interconnected windings. An induction coil with three windings can also be called a three-windings induction coil. It describes here an induction coil with three serially interconnected windings. An induction coil with two windings can also be called a two-windings induction coil. It describes here an induction coil with two serially linked windings. An induction coil with one winding may also be referred to as a single-winding induction coil.

The induction coil assembly may comprise at least one induction coil having at least two parallel windings with a common current draw. Preferably, the induction coil assembly may comprise an induction coil having exactly two parallel windings with a common current draw. In this case, the induction coil assembly comprises a single winding induction coil having two parallel windings.

Accordingly, the above-described embodiments of the induction coil may be combined. For example, the induction coil assembly may comprise an $n \times m$ -windings induction coil, where m indicates the number of serial windings of the induction coil and n indicates the number of parallel m -winding winding arrangements. In one embodiment, the induction coil assembly may comprise a 2×2 -windings induction coil, i.e., an induction coil with a total of four windings, of which two serially interconnected windings are connected in parallel with two other serially interconnected windings and have a common current draw therewith. In particular, in such an arrangement, the first and the last, i.e. the uppermost and the lowermost or outer, windings are serially interconnected and the second and the third, i.e. the two intermediate or inner, windings are serially interconnected. The two outer windings are interconnected in parallel with the two inner windings. In one embodiment, the induction coil assembly may comprise a 2×1 -windings induction coil, i.e., an induction coil having two parallel windings in total. In one embodiment, the induction coil assembly

may comprise a 1×2-windings induction coil, in other words a two-winding induction coil, i.e. an induction coil with a total of two serial windings.

An induction coil assembly of the type described above can contribute to achieve the desired optimal balance between ensuring a sufficient superheating of the melt jet, achieving a reasonable mold filling time and an energy consumption acceptable in practice. Thus, an induction coil assembly of the type described above, in particular a 2×2-windings induction coil, can contribute to ensure a uniform power input into the electrode tip of an electrode with a large electrode diameter (e.g. 150 mm or more), while at the same time avoiding that the voltage of an upper limit of, for instance, 1000 V is exceeded.

The use of an induction coil with a smaller number of windings - compared to a coil of the same dimension and a larger number of windings - enables to generate a larger superheating when operated at a lower voltage. Here, in particular, a two-windings (1×2-windings) induction coil or a 2×2-windings induction coil may be provided, for example.

The induction coil assembly may comprise a first induction coil and at least one second induction coil. The two induction coils are separate from each other and each has its own current draw. The first induction coil, the at least second induction coil, or the first and the at least second induction coils may be formed with the features described above. The first induction coil may be supplied or operated with a power P_1 , a frequency f_1 and a voltage U_1 (preferably $U_1 \leq 1000 \text{ V}$). The at least second induction coil can be supplied or operated with a power P_2 , a frequency f_2 and a voltage U_2 (preferably $U_2 \leq 1000 \text{ V}$).

In one embodiment, the first induction coil and the at least second induction coil can be arranged in such a way that both induction coils serve to melt off the electrode. For this purpose, the two induction coils may be arranged side by side and aligned along an imaginary cylinder or an imaginary cone. In other words, in a cross-sectional view, adjacent winding cross-sections of both induction coils may be aligned along a common axis. The common axis may be arranged substantially parallel to an inclined surface of a melted off end portion of the electrode. Both induction coils may have a conical shape. The two induction coils may be embedded in a soft magnetic yoke, thereby preventing an unwanted coil interaction. By means of such an embodiment, the generated melt flow rate can be increased, i.e., $P_1 + P_2$ leads to an increase in the melt flow rate MFR.

In one embodiment, the first induction coil may be arranged to serve to melt off the electrode, while the at least second induction coil may be arranged downstream of the first induction coil and can be arranged to serve to heat the melt jet. For this purpose, the winding(s) of the first induction coil can be arranged substantially parallel to an inclined surface of a melted off end portion of the electrode. The first induction coil may have a conical shape. The downstream at least second induction coil may be coaxial with the melt jet generated by the first induction coil and may have a cylindrical shape. The at least second induction coil may be embedded in a soft magnetic yoke. By means of such an embodiment, the superheating of the generated melt jet can be further increased, i.e. P2 serves to enhance the superheating.

In one embodiment, the first induction coil may be arranged to serve for melting off the electrode, while the second induction coil may be located upstream of the first induction coil and arranged to serve for preheating the electrode to be melted off. For this purpose, the winding(s) of the first induction coil may be arranged substantially parallel to an inclined surface of a melted off end portion of the electrode. The first induction coil may have a conical shape. The upstream at least second induction coil may be coaxial with the electrode and may have a cylindrical shape. The at least second induction coil may be embedded in a soft magnetic yoke. By means of such an embodiment, the superheating of the generated melt jet can be further increased, i.e. P2 serves to enhance the superheating. In addition, the upstream second induction coil may also contribute at least slightly to the generation of the melt jet, so that P1 + P2 contribute to an increase in the melt flow rate MFR.

In one embodiment, the induction coil assembly may have an average coil diameter of 50 mm or more, preferably 150 mm or more. In particular, the induction coil assembly may be configured to be able to receive at least partially an electrode having a diameter of 50 mm or more, preferably of 150 mm or more. The use of an electrode with a diameter of 150 mm or more may contribute to provide sufficient material for filling an investment casting mold, since the length of the electrodes may be limited due to the system.

Another aspect of the invention relates to a system for producing an investment casting component, comprising a device of the type described above and the electrode at least partially received therein.

The electrode may be a cast electrode. Alternatively, the electrode may be a compacted electrode comprising a plurality of particles or sections. The particles or sections can be of undefined shape, i.e. they can have different and almost arbitrary shapes. Such an electrode may be less expensive to manufacture. The electrode may consist of or comprise a metal alloy. The electrode may comprise or consist of titanium or a titanium alloy, for example Ti64. The electrode may comprise or consist of a nickel-chromium alloy, for example IN718. It is to be understood that the electrode may also comprise or consist of other metals or metal alloys.

Another aspect of the invention relates to a method for producing an investment casting component, that is, an investment casting method. The method comprises the steps of:

- providing an electrode in a melting chamber;
- inserting the electrode, at least in sections, into an induction coil assembly disposed in the melting chamber;
- generating a ceramic-free, continuous melt jet with a melt flow rate of at least 2.5 kg/min by melting off the electrode by means of the induction coil assembly;
- providing an investment casting mold in a casting chamber downstream of and connected to the melting chamber;
- continuously filling the investment casting mold with the melt jet.

The investment casting mold may be heated during the production process by means of a mold heater of the casting chamber.

The investment casting mold may be extracted during continuous filling in a direction away from the melting chamber by means of a mold extractor.

In the method, the induction coil assembly can be operated at a power P for which the following conditions are satisfied:

$$\begin{aligned}
 P \text{ [kW]} &\geq 5 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\
 \text{preferably } P \text{ [kW]} &\geq 15 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\
 \text{more preferably } P \text{ [kW]} &\geq 50 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\
 \text{still preferably } P \text{ [kW]} &\geq 125 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}.
 \end{aligned}$$

In the method, the induction coil assembly can be operated at a power P for which the following conditions are satisfied:

$$\begin{aligned} P \text{ [kW]} &\leq 600 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ \text{preferably } P \text{ [kW]} &\leq 300 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ \text{more preferably } P \text{ [kW]} &\leq 100 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ \text{still preferably } P \text{ [kW]} &\leq 35 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}. \end{aligned}$$

In the method, the induction coil assembly can be operated at a power P for which the following conditions are satisfied:

$$\begin{aligned} 5 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR} &\leq P \text{ [kW]} \leq 600 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ \text{preferably } 15 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR} &\leq P \text{ [kW]} \leq 125 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ \text{more preferably } 17,5 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR} &\leq P \text{ [kW]} \leq 90 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ \text{still preferably } 20 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR} &\leq P \text{ [kW]} \leq 30 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}. \end{aligned}$$

The power P can be set as a function of a diameter of the electrode to be melted off in accordance with the above conditions.

In the method, the induction coil assembly, in particular when using an electrode with a diameter of 150 mm, can be operated with a power P for which the following conditions are satisfied:

$$\begin{aligned} P \text{ [kW]} &\geq 15 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ \text{preferably } P \text{ [kW]} &\geq 17,5 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ \text{more preferably } P \text{ [kW]} &\geq 20 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ \text{still preferably } P \text{ [kW]} &\geq 22,5 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}. \end{aligned}$$

In the method, the induction coil assembly can be used to superheat the melt jet as a function of the melt flow rate MFR in such a way that the superheating temperature T_{sup} satisfies the following conditions:

$$\begin{aligned}
T_{\text{sup}} [^{\circ}\text{C}] &\geq 5 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR}, \\
\text{preferably } T_{\text{sup}} [^{\circ}\text{C}] &\geq 45 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR}, \\
\text{more preferably } T_{\text{sup}} [^{\circ}\text{C}] &\geq 100 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR}, \\
\text{still preferably } T_{\text{sup}} [^{\circ}\text{C}] &\geq 270 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR}.
\end{aligned}$$

In the method, the induction coil assembly can be used to superheat the melt jet as a function of the melt flow rate MFR in such a way that the superheating temperature T_{sup} satisfies the following conditions:

$$\begin{aligned}
T_{\text{sup}} [^{\circ}\text{C}] &\leq 600 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR}, \\
\text{preferably } T_{\text{sup}} [^{\circ}\text{C}] &\leq 400 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR}, \\
\text{more preferably } T_{\text{sup}} [^{\circ}\text{C}] &\leq 250 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR}, \\
\text{still preferably } T_{\text{sup}} [^{\circ}\text{C}] &\leq 100 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR}.
\end{aligned}$$

In the method, the induction coil assembly can be used to superheat the melt jet as a function of the melt flow rate MFR in such a way that the superheating temperature T_{sup} satisfies the following conditions:

$$\begin{aligned}
5 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR} &\leq T_{\text{sup}} [^{\circ}\text{C}] \leq 600 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR}, \\
\text{preferably } 7 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR} &\leq T_{\text{sup}} [^{\circ}\text{C}] \leq 400 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR}, \\
\text{more preferably } 25 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR} &\leq T_{\text{sup}} [^{\circ}\text{C}] \leq 250 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR}, \\
\text{still preferably } 10 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR} &\leq T_{\text{sup}} [^{\circ}\text{C}] \leq 100 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR}.
\end{aligned}$$

The superheating temperature T_{sup} can be set in dependence on a diameter of the electrode to be melted off according to the above conditions.

In the method, the induction coil assembly can be used to superheat the melt jet as a function of the melt flow rate MFR, in particular for melting off an electrode with a diameter of 150 mm, in such a way that the superheating temperature T_{sup} satisfies the following conditions:

$$\begin{aligned}
T_{\text{sup}} [^{\circ}\text{C}] &\geq 5 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR}, \\
\text{preferably } T_{\text{sup}} [^{\circ}\text{C}] &\geq 6,5 [^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}}] \cdot \text{MFR},
\end{aligned}$$

more preferably $T_{\text{sup}} [^{\circ}\text{C}] \geq 7,9 \left[^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}$.

The melt jet can be superheated by the induction coil assembly by at least 10°C, preferably by at least 20°C, preferably by at least 40°C, more preferably by at least 60°C, still more preferably by at least 80°C.

The induction coil assembly may be operated at a voltage of 1200 V or less, preferably 1000 V or less. The induction coil assembly can be operated at a frequency between 10 kHz and 300 kHz, preferably between 50 kHz and 200 kHz, more preferably between 75 kHz and 125 kHz.

At least the melting chamber can be pressurized with an absolute pressure, so that the melt jet is generated under this absolute pressure. The absolute pressure can be at least 30 mbar, preferably at least 1 bar, more preferably at least 5 bar. The absolute pressure may be less than 10 bar. The absolute pressure may be between 30 mbar and 10 bar, preferably between 1 bar and 10 bar.

A further aspect relates to the structural design of the induction coil assembly. This aspect may be independent of the described embodiment of the overall device and may form a separate subject matter. The induction coil assembly may comprise at least one induction coil comprising four serial windings or less, preferably comprising three serial windings or less, more preferably comprising two serial windings or less (i.e. having only one winding). An induction coil comprising four windings may also be referred to as a four-windings induction coil. Here, it describes an induction coil with four serially interconnected windings. An induction coil with three windings can also be denoted as a three-windings induction coil. Here, it describes an induction coil with three serially interconnected windings. An induction coil with two windings can also be denoted as a two-windings induction coil. Here, it describes an induction coil with two serially interconnected windings. An induction coil with one winding may also be referred to as a single-winding induction coil.

The induction coil assembly may comprise at least one induction coil comprising at least two parallel windings with a common current draw. Preferably, the induction coil assembly may comprise an induction coil comprising exactly two parallel windings with a common

current draw. In this case, the induction coil assembly comprises a single-winding induction coil comprising two parallel windings.

Accordingly, the above-described embodiments of the induction coil assembly may be combined. Thus, the induction coil assembly may comprise an $n \times m$ -windings induction coil, where m indicates the number of serial windings of the induction coil and n indicates the number of parallel m -windings winding arrangements. In one embodiment, the induction coil assembly may comprise a 2×2 -windings induction coil, i.e., an induction coil with a total of four windings, of which two serially interconnected windings are connected in parallel with two other serially interconnected windings and have a common current draw therewith. In particular, in such an arrangement, the first and the last, i.e. the uppermost and the lowermost or outer, windings are serially interconnected and the second and the third, i.e. the two intermediate or inner, windings are serially interconnected. The two outer windings are interconnected in parallel with the two inner windings. In one embodiment, the induction coil assembly may comprise a 2×1 -windings induction coil, i.e., an induction coil comprising two parallel windings in total. In one embodiment, the induction coil assembly may comprise a 1×2 -windings induction coil, in other words a two-windings induction coil, i.e. an induction coil with a total of two serial windings.

The use of an induction coil with a smaller number of windings - compared to a coil of the same dimension and a larger number of windings - enables to generate greater superheating when operated at a lower voltage. In particular, a two-windings (1×2 -windings) induction coil or a 2×2 -windings induction coil may be provided here, for example.

Although some features, advantages, functions, modes of operation, embodiments and further developments have been described above only with respect to the device, they may correspondingly also apply to the method and vice versa.

Brief description of the figures

Exemplary embodiments of the present invention are explained in more detail below with reference to the accompanying schematic drawing. In the drawing:

Fig. 1 is a schematic sectional view of a device according to one embodiment of the invention;

Fig. 2A is a schematic representation of an embodiment of an induction coil according to the invention for the device of Fig. 1;

Fig. 2B is a schematic sectional view of the induction coil of Fig. 2A in operation;

Fig. 3 is a schematic representation of a first embodiment of an induction coil assembly according to the invention in operation;

Fig. 4 is a schematic representation of a second embodiment of an induction coil assembly according to the invention in operation;

Fig. 5 is a schematic representation of a third embodiment of an induction coil assembly according to the invention in operation;

Fig. 6 is a diagram showing the relationship between superheating temperature and melt flow rate in a device according to the invention for different electrode materials;

Fig. 7 is a diagram showing the relationship between voltage and melt flow rate in a device according to the invention for different electrode materials;

Fig. 8 is a diagram showing the relationship between power and melt flow rate in a device according to the invention for different electrode materials;

Fig. 9 is a diagram showing the relationship between superheating temperature and melt flow rate in devices according to the invention with different induction coil designs;

Fig. 10 is a diagram showing the relationship between voltage and melt flow rate in devices according to the invention with different induction coil designs; and

Fig. 11 is a diagram showing the relationship between power and melt flow rate in devices according to the invention with different induction coil designs.

Description of the figures

Figure 1 shows a device or plant 10 for producing investment casting components. The device 10 comprises a melting chamber 12 comprising an induction coil assembly 14 mounted in the melting chamber 12. A vacuum is applied to the melting chamber 12. Alternatively, the melting chamber 12 may be pressurized with an inert gas atmosphere.

Above the melting chamber 12, i.e. upstream thereof, an electrode charger 16 is disposed. This comprises an electrode 18 that can be displaced along its longitudinal axis in the direction of the induction coil assembly 14 and can be rotated about its longitudinal axis by means of the electrode charger 16. In this embodiment, the electrode 18 is an electrode made of a titanium alloy. It is understood that electrodes of other metals or metal alloys may likewise be provided. The electrode 18 is inserted into the induction coil assembly 14 at least in sections, more specifically with a lower end portion, during operation of the plant.

The induction coil assembly 14 is adapted to melt the electrode 18 off in order to produce a ceramic-free continuous melt jet (not shown in Fig. 1, but see, for example, Fig. 2B). Feeding the electrode 18, as well as rotating the electrode 18 by means of the electrode charger 16, can ensure uniform melting of the electrode 18 and a generation of a substantially uninterrupted, continuous melt jet.

The induction coil assembly 14 is operated or controlled to melt off the electrode 18 and to generate a continuous melt jet with a melt flow rate MFR of at least 2.5 kg/min, in particular between 2.5 kg/min and 10 kg/min.

The device 10 further comprises a casting chamber 20 which is disposed downstream of the melting chamber 12, i.e. arranged below the latter, and is connected to the melting chamber 12 in a pressure-tight manner. The casting chamber 20 is adapted to receive an investment casting mold (not shown here) that is filled with the melt jet during operation.

The investment casting mold may have any shape, depending on the investment casting to be produced. In particular, the investment casting mold may be a ceramic mold.

The casting chamber 20 includes a mold heater 22. The mold heater 22 is used to heat an investment casting mold provided in the casting chamber 20 prior to the start of the melting process or a melting sequence. In addition, the mold heater 22 can be used to further heat the investment casting mold during melting and filling. This can prevent the melt from solidifying too early and upon contact with the wall of the investment casting mold, which would negatively affect the quality of the investment casting component.

Below the casting chamber 20, an loading/unloading chamber 24 of the device 10 is formed, which is connected to the casting chamber 20. The loading/unloading chamber 24 is used for inserting the investment casting mold and removing the cast investment casting component.

A mold extractor 26 is formed in the loading/unloading chamber 24, by means of which the investment casting mold can be extracted in a direction away from the melting chamber 12.

Figure 1 also shows a maintenance platform 28 formed at the device 10 and an operating platform 29 formed at the apparatus 10.

Figures 2A and 2B show an embodiment of an induction coil 30 of the induction coil assembly 14 of Fig. 1. As can be seen in the perspective view of Fig. 2A, the induction coil 30 in this embodiment is formed as a 2×2-windings induction coil. That is, the induction coil 30 comprises two parallel two-windings winding arrangements. The windings 32 to 38 have a common current draw (not shown). The current flow through the induction coil 30, or more precisely its equal division due to the parallel connection, is shown in Figure 2A by lines 40 and 42. Moreover, the uniform distribution of the current is indicated in Figure 2B by the different patterns of the cross-sections of the windings 32 to 38. As can be seen from Figures 2A and 2B, windings 32 and 38 are connected in series and in parallel with windings 34 and 36, which (i.e. windings 34 and 36) in turn are connected in series.

By use of the 2×2-windings coil configuration shown in Figures 2A and 2B, a uniform power input to the electrode 18 to be melted off can be achieved. It is understood that in other embodiments of the invention other coil configurations may be provided. In particular, two-windings, three-windings or four-windings coil configurations without parallel windings may be provided. Alternatively, single-winding coil configurations with or without parallel connection of windings may be provided (an induction coil with two or more parallel single-winding winding arrangements may nevertheless be referred to herein as a single-winding coil).

In addition to the coil configuration, Figure 2B also shows the electrode 18 inserted into the induction coil 30 in sections and melted off at a lower end by means of the induction coil 30, thereby producing a continuous melt jet 40.

Different induction coil assemblies 114, 214 and 314 are shown in Figures 3 to 5. Each of these induction coil assemblies 114, 214, 314 comprises in the embodiments shown, in addition to the induction coil 30, a further induction coil 50, which are only schematically indicated in Figs. 3 to 5. They can each be a single- or multi-windings configuration and have the same or a different number of windings. The two induction coils 30, 50 are formed and controlled separately from each other in the induction coil assemblies 114, 214, 314 shown. They each have their own power supply. In the embodiments shown, the induction coil 30 is operated at a power P_1 , a frequency f_1 , and a voltage U_1 (here, for example, $U_1 \leq 1000 \text{ V}$, $P_1 \leq 500 \text{ kW}$, $f_1 \leq 350 \text{ kHz}$). The second induction coil 50 is operated at a power P_2 , a frequency f_2 and a voltage U_2 (here, for example, $U_2 \leq 1000 \text{ V}$, $P_2 \leq 500 \text{ kW}$, $f_2 \leq 350 \text{ kHz}$).

In the embodiment shown in Figure 3, both induction coils 30, 50 are arranged such that they both serve to melt off the electrode 18. The induction coils 30, 50 are arranged side by side. In the cross-sectional view shown, the adjacent winding cross-sections of both induction coils are arranged substantially parallel to an inclined surface of the melted off end portion of the electrode 18. Both induction coils 30, 50 have a conical shape in Figure 3. The two induction coils 30, 50 are here embedded in a soft magnetic yoke 52, whereby an undesired coil interaction is prevented. By means of such an embodiment, the generated melt flow rate MFR can be increased by increasing the powers P_1 and P_2 of the two induction coils 30, 50.

In the embodiment shown in Figure 4, the first induction coil 30 is arranged such that it serves to melt off the electrode 18. The second induction coil 50 is arranged downstream of the first induction coil and is arranged such that it serves to heat the already melted melt jet 40. The winding/s of the first induction coil 30 are arranged substantially parallel to the inclined surface of the melted off end portion of the electrode 18. The first induction coil 30 has a conical shape. The downstream second induction coil 50 has a cylindrical shape and encloses the melt jet 40 in sections. The second induction coil 50 is embedded in a soft magnetic yoke 52. By means of such an embodiment, the superheating of the generated melt jet can be further increased by increasing the power P2 of the second induction coil 50.

In the embodiment shown in Figure 5, the first induction coil 30 is arranged such that it serves to melt off the electrode 18. The second induction coil 50 is located upstream of the first induction coil 30 and is arranged such that it serves to preheat the electrode 18 to be melted. For this purpose, the windings of the first induction coil 30 are arranged substantially parallel to the inclined surface of the melted end portion of the electrode 18. Here, too, the first induction coil 30 has a conical shape. The upstream second induction coil 50 has a cylindrical shape and encloses the electrode 18 in sections, more precisely a part of the electrode 18 which has not yet been melted off. The second induction coil 50 is embedded in a soft magnetic yoke 52. By means of such an embodiment, the superheating of the generated melt jet can be further increased by increasing the power P2 of the second induction coil 50. In addition, the upstream second induction coil 50 may also contribute at least slightly to the generation of the melt jet, so that an increase in P1 and P2 may contribute to an increase in the melt flow rate MFR.

Figure 6 shows a diagram illustrating a determined relationship between the superheating temperature T_{sup} [°C] of the melt jet and the melt flow rate MFR [kg/min] in a device 10 according to the invention comprising a two-windings induction coil. Line A1 shows the relationship for an electrode 18 made of Ti64. Line A2 shows the relationship for an electrode 18 made of IN718. As can be seen, sufficient superheating can be achieved at a melt flow rate of at least 2.5 kg/min.

Figure 7 shows a diagram illustrating a determined relationship between the voltage U [V] at which the induction coil is operated and the melt flow rate MFR [kg/min] in a device 10 according to the invention comprising a two-windings induction coil. Line B1 shows

the relationship for an electrode 18 made of Ti64. Line B2 shows the relationship for an electrode 18 made of IN718.

Figure 8 shows a diagram illustrating a determined relationship between the power P [kW] at which the induction coil is operated and the melt flow rate MFR [kg/min] in a device 10 according to the invention comprising a two-windings induction coil. Line C1 shows the relationship for an electrode 18 made of Ti64. Line C2 shows the relationship for an electrode 18 made of IN718.

Figure 9 shows a diagram illustrating a determined relationship between the superheating temperature T_{sup} [°C] of the melt jet and the melt flow rate MFR [kg/min] in devices 10 according to the invention comprising different induction coil designs. More specifically, the relationship is shown here for induction coil designs with different numbers of windings. Line D1 shows the relationship for a two-windings induction coil for generating the melt jet (without windings connected in parallel). Line D2 shows the relationship for a three-windings induction coil for generating the melt jet (without windings connected in parallel). Line D3 shows the relationship for a four-windings induction coil for generating the melt jet (without windings connected in parallel). As can be seen, a larger superheating temperature T_{sup} can be achieved with the same melt flow rate MFR by using a smaller number of windings in the induction coil.

Figure 10 shows a diagram illustrating a determined relationship between the voltage U [V] with which the induction coil is operated and the melt flow rate MFR [kg/min] in devices 10 according to the invention with different induction coil designs. More precisely, the relationship is shown here for induction coil designs with different numbers of windings. Line E1 shows the relationship for a two-windings induction coil for generating the melt jet (without windings connected in parallel). Line E2 shows the relationship for a three-windings induction coil for generating the melt jet (without windings connected in parallel). Line E3 shows the relationship for a four-windings induction coil for generating the melt jet (without windings connected in parallel). As can be seen, with a lower number of windings in the induction coil, a lower voltage U is required for generating the same melt flow rate MFR.

Figure 11 shows a diagram illustrating a determined relationship between the power P [kW] with which the induction coil is operated and the melt flow rate MFR [kg/min] in

devices 10 according to the invention with different induction coil designs. More precisely, the relationship is shown here for induction coil designs with different numbers of windings. Line F1 shows the relationship for a two-windings induction coil for generating the melt jet (without windings connected in parallel). Line F2 shows the relationship for a three-windings induction coil for generating the melt jet (without windings connected in parallel). Line F3 shows the relationship for a four-winding induction coil for generating the melting beam (without windings connected in parallel). As can be seen, the different number of windings of the induction coil has no significant effect on the power P required to be applied to generate a given melt flow rate MFR.

The diagrams in Figures 9 to 11 refer to an electrode used made of IN718 with an electrode diameter of 150 mm.

The frequency of the induction coil set for Figures 6 to 11 is 100 kHz.

List of reference symbols

10	device
12	melting chamber
14, 114, 214, 314	induction coil assemblies
16	electrode charger
18	electrode
20	casting chamber
22	mold heater
24	loading/unloading chamber
26	mold extractor
28	maintenance platform
29	operating platform
30	induction coil
32, 34, 36, 38	windings
40, 42	melt jet
50	second induction coil
52	soft magnetic yoke

Claims

1. Device (10) for producing an investment casting component, comprising:
 - a melting chamber (12) comprising an induction coil assembly (14, 114, 214, 314) disposed in the melting chamber (12) and adapted to melt off an electrode (18) at least partially received therein to produce a ceramic-free continuous melt jet (40) with a melt flow rate MFR of at least 2.5 kg/min; and
 - a casting chamber (20) downstream of the melting chamber (12) and connected thereto and comprising an investment casting mold received or receivable therein for being filled by means of the ceramics-free continuous melt jet (40).
2. Device (10) according to claim 1, wherein the casting chamber (20) comprises a mold heater (22) adapted to heat the investment casting mold.
3. Device (10) according to at least one of the preceding claims, wherein the induction coil assembly (14, 114, 214, 314) is operated with a power P for which the following conditions are satisfied:

$$\begin{aligned}
 P \text{ [kW]} &\geq 5 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\
 \text{preferably } P \text{ [kW]} &\geq 15 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\
 \text{more preferably } P \text{ [kW]} &\geq 50 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\
 \text{still preferably } P \text{ [kW]} &\geq 125 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}.
 \end{aligned}$$

4. Device (10) according to at least one of the preceding claims, wherein the induction coil assembly (14, 114, 214, 314) is arranged to superheat the melt jet (40) in dependence on the melt flow rate MFR such that the superheat temperature T_{sup} satisfies the following condition:

$$\begin{aligned}
 T_{\text{sup}} \text{ [}^{\circ}\text{C]} &\geq 5 \left[^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\
 \text{preferably } T_{\text{sup}} \text{ [}^{\circ}\text{C]} &\geq 45 \left[^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\
 \text{more preferably } T_{\text{sup}} \text{ [}^{\circ}\text{C]} &\geq 100 \left[^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\
 \text{still preferably } T_{\text{sup}} \text{ [}^{\circ}\text{C]} &\geq 270 \left[^{\circ}\text{C} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}.
 \end{aligned}$$

5. Device (10) according to at least one of the preceding claims, wherein the induction coil assembly (14, 114, 214, 314) is operated with a voltage of 1200 V or less,

preferably 1000 V or less, at a frequency between 10 kHz and 300 kHz, preferably between 50 kHz and 200 kHz, more preferably between 75 kHz and 125 kHz.

6. Device (10) according to at least one of the preceding claims, wherein the induction coil arrangement (14, 114, 214, 314) comprises at least one induction coil (30, 50) comprising four windings or less, preferably three windings or less, more preferably two windings or less.
7. Device (10) according to at least one of the preceding claims, wherein the induction coil assembly (14, 114, 214, 314) comprises at least one induction coil (30, 50) comprising two parallel windings with a common current draw.
8. Device (10) according to at least one of the preceding claims, wherein the induction coil assembly (14, 114, 214, 314) comprises a first induction coil (30) and at least one second induction coil (50), wherein preferably
the first induction coil (30) and the second induction coil (50) are arranged such that both induction coils serve to melt off the electrode (18); or
the first induction coil (30) is arranged such that it serves to melt off the electrode (18), and the second induction coil (50) is arranged downstream of the first induction coil (30) and is arranged such that it serves to heat the melt jet (40);
or
the first induction coil (30) is arranged such that it serves to melt off the electrode (18), and the second induction coil (50) is arranged upstream of the first induction coil (30) and is arranged such that it serves to preheat the electrode (18) to be melted off.
9. Device (10) according to at least one of the preceding claims, wherein the induction coil assembly (14, 114, 214, 314) has an average coil diameter of 50 mm or more.
10. Method for producing an investment casting component, comprising the steps of
providing an electrode (18) in a melting chamber (12);
inserting the electrode (18), at least in sections, into an induction coil assembly (14, 114, 214, 314) disposed in the melting chamber (12);

generating a ceramic-free, continuous melt jet (40) with a melt flow rate of at least 2.5 kg/min by melting off the electrode (18) by means of the induction coil assembly (14, 114, 214, 314);

providing an investment casting mold in a casting chamber (20) downstream of and connected to the melting chamber (12); and

continuously filling the investment casting mold with the melt jet (40).

11. Method according to claim 10, wherein the induction coil assembly (14, 114, 214, 314) is operated at a power P for which the following conditions are satisfied:

$$\begin{aligned} P \text{ [kW]} &\geq 5 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ \text{preferably } P \text{ [kW]} &\geq 15 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ \text{more preferably } P \text{ [kW]} &\geq 50 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ \text{still preferably } P \text{ [kW]} &\geq 125 \left[\text{kW} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}. \end{aligned}$$

12. Method according to claim 10 or 11, wherein by means of the induction coil assembly (14, 114, 214, 314) the melt jet (40) is superheated as a function of the melt flow rate MFR such that the superheating temperature T_{sup} satisfies the following conditions:

$$\begin{aligned} T_{\text{sup}} \text{ [}^\circ\text{C]} &\geq 5 \left[^\circ\text{C} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ \text{preferably } T_{\text{sup}} \text{ [}^\circ\text{C]} &\geq 45 \left[^\circ\text{C} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ \text{more preferably } T_{\text{sup}} \text{ [}^\circ\text{C]} &\geq 100 \left[^\circ\text{C} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}, \\ \text{more preferably } T_{\text{sup}} \text{ [}^\circ\text{C]} &\geq 270 \left[^\circ\text{C} \cdot \frac{\text{min}}{\text{kg}} \right] \cdot \text{MFR}. \end{aligned}$$

13. Method according to at least one of claims 10 to 12, wherein the melt jet (40) is superheated by means of the induction coil assembly (14, 114, 214, 314) by at least 10°C, preferably by at least 20°C, still preferably by at least 40°C, more preferably by at least 60°C, still more preferably by at least 80°C.
14. Method according to at least one of claims 10 to 13, wherein the induction coil assembly (14, 114, 214, 314) is operated at a voltage of 1200 V or less, preferably 1000 V or less, at a frequency between 10 kHz and 300 kHz, preferably between 50 kHz and 200 kHz, more preferably between 75 kHz and 125 kHz.

15. Method according to at least one of claims 10 to 14, wherein at least the melting chamber (12) is pressurized with an absolute pressure of at least 30 mbar, preferably at least 1 bar, more preferably at least 5 bar, and further preferably less than 10 bar, so that the melt jet (40) is generated under this absolute pressure.